Fermilab-TM-2749

April 15, 2021

A Low Cost SIPM Evaluation and Control Prototyping System including accurate bias voltage generation, leakage current measurement, and temperature control using Peltier cooling.

Sergey Los*, Jim Freeman* (Fermilab)

Sam Atac (UI-Urbana)

We describe an electronics system to operate SIPMs in the laboratory. The system is comprised of a single channel amplifier board (SIPM Amp) and a 4-channel control board to which up to 4 SIPM Amp boards can be connected. The control board supplies a common low voltage power for the amplifiers. All channels feature individually regulated bias and Peltier power voltages, along with Pt10K RTD readout.

A graphical user interface allows control of the bias voltages, amplifier voltage, Peltier voltages, and also provides for readback of leakage currents and other voltages. The GUI app has a feedback loop to measure the SIPM temperature (with the PT10K) and generate correction voltages to the Peltier to regulate the temperature. The temperatures, which can be achieved by Peltier cooling depend on the thermal design of the setup, the practical limit being about 50C below ambient.

The SIPM Amp. board is a small (3x5cm) PCB that has a single SIPM readout channel. The SIPMs can be surface mounted on the pcb or connected to a 2-pin 0.100" socket. The area around the SIPM footprint is thermally isolated by perforations in the PCB. The RTD is located inside the thermal break. Onboard is BV and LV filtering.

The 10X amplifier is based on MiniCircuits' GALI-S66+ integrated circuit, tweaked for a 6V power. The amplifier was selected for a combination of high bandwidth, low noise, and low power. An ac-coupled amplifier output is connected to an SMA connector. For best operation of this inverting amplifier the output signal should be in the range of 0 to -1V.

The Amplifier board is connected to the Control board with a 10-conductor 0.025" pitch ribbon cable, carrying all the services. Peltier power for currents more than 1A should use a separate 2-contact connector.

Contents

* los@fnal.gov freeman@fnal.gov

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

1. SIPM Amp BOARD

Description

The SIPM AMP board is a small (3x5cm) PCB that accommodates a single SIPM. The SIPM can be surface mounted for several size footprints. Also sockets can be added to mount SIPMs on pins. The area around the SIPM is thermally isolated by perforations in the PCB. Onboard is BV and amplifier filtering. There is a ~10X ~2GHz inverting amplifier accepting positive voltages in the range 0 to 0.1V (for best operation.) Close to the SIPM mount is a PT10K platinum resistor to read out temperature. The BV, LV are supplied by a ribbon cable (mating to the Control board). The PT10K is connected across 2 conductors of the ribbon cable so temperatures can be read out remotely. Power to an optional Peltier is provided on 2 conductors of the ribbon cable.

Specs of the SIPM AMP board:

+6V power @ 16mA is required for onboard amplifier.

10K PtRTD for temperature readback

Services connector type: CNC Tech 3221-10-0200-00

Signal connector: SMA

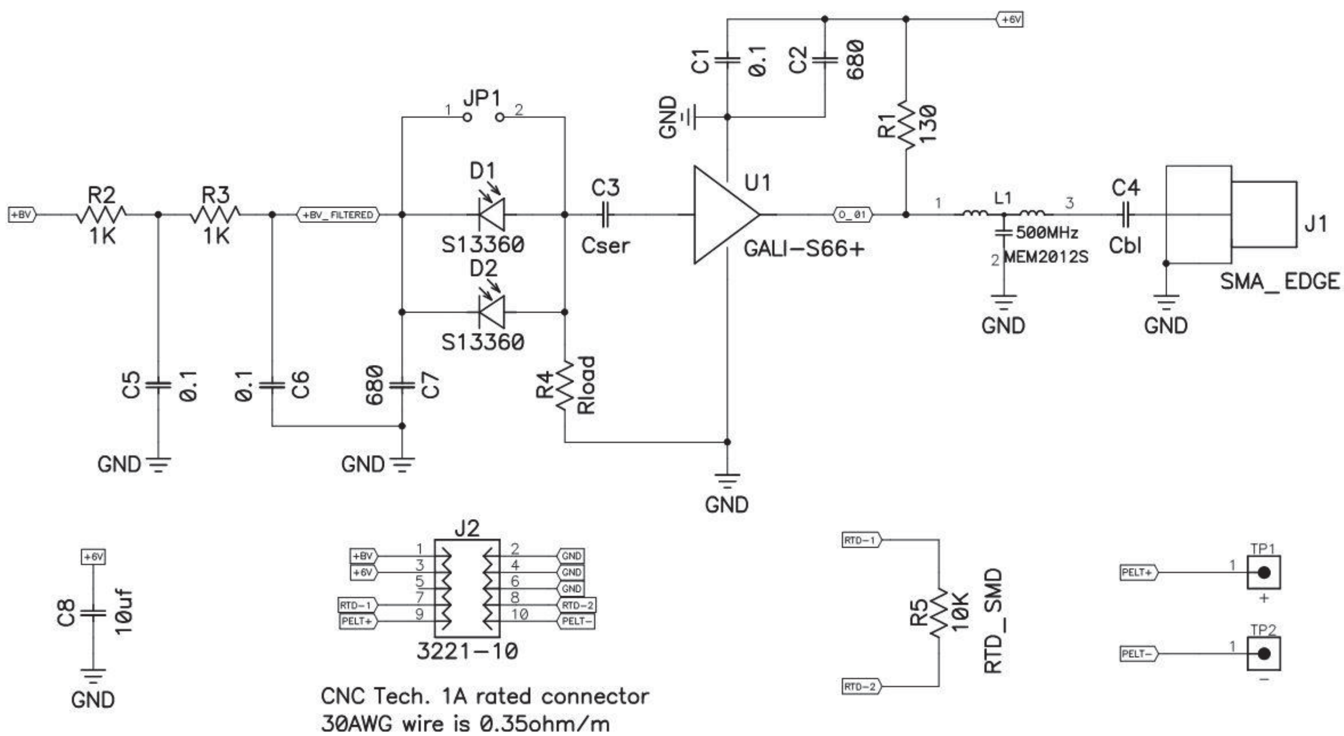
SIPM footprint: S13360-2050VE/3050VE/6050VE and a 0.100" socket.

Gain ~ 10X

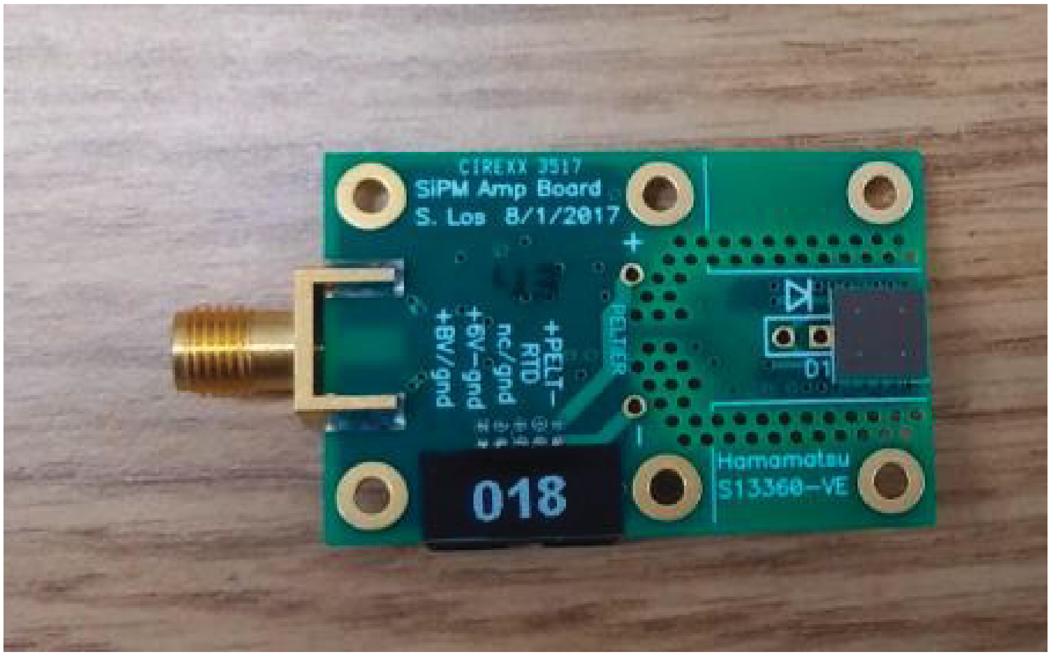
Amplifier bandwidth ~2.4GHz

Maximum output voltage (for linear operation) -1.0V. It is important to note that the SIPM AMP is a more linear amplifier for charge than for voltage.

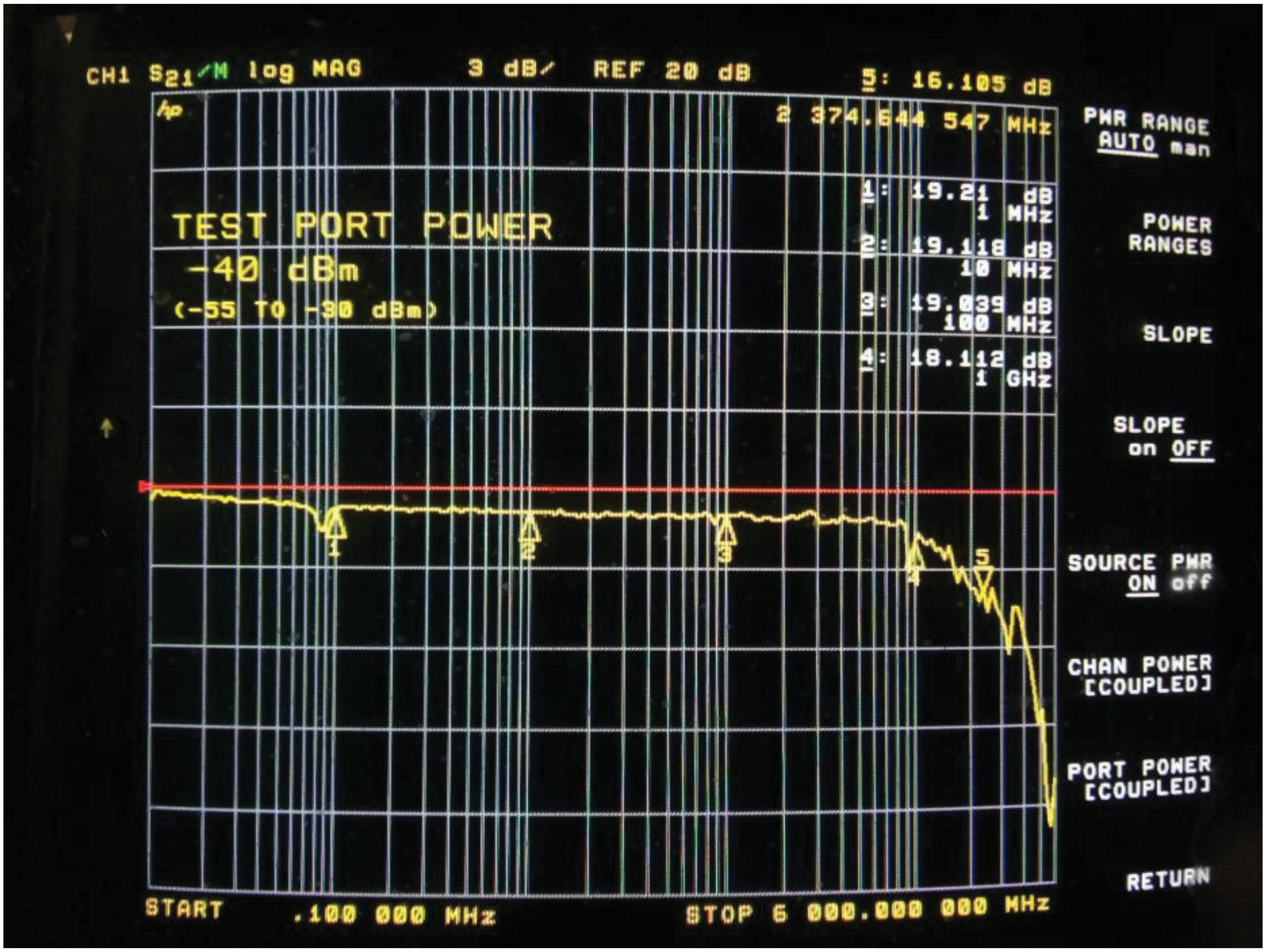
SiPM Amp Circuit Diagram



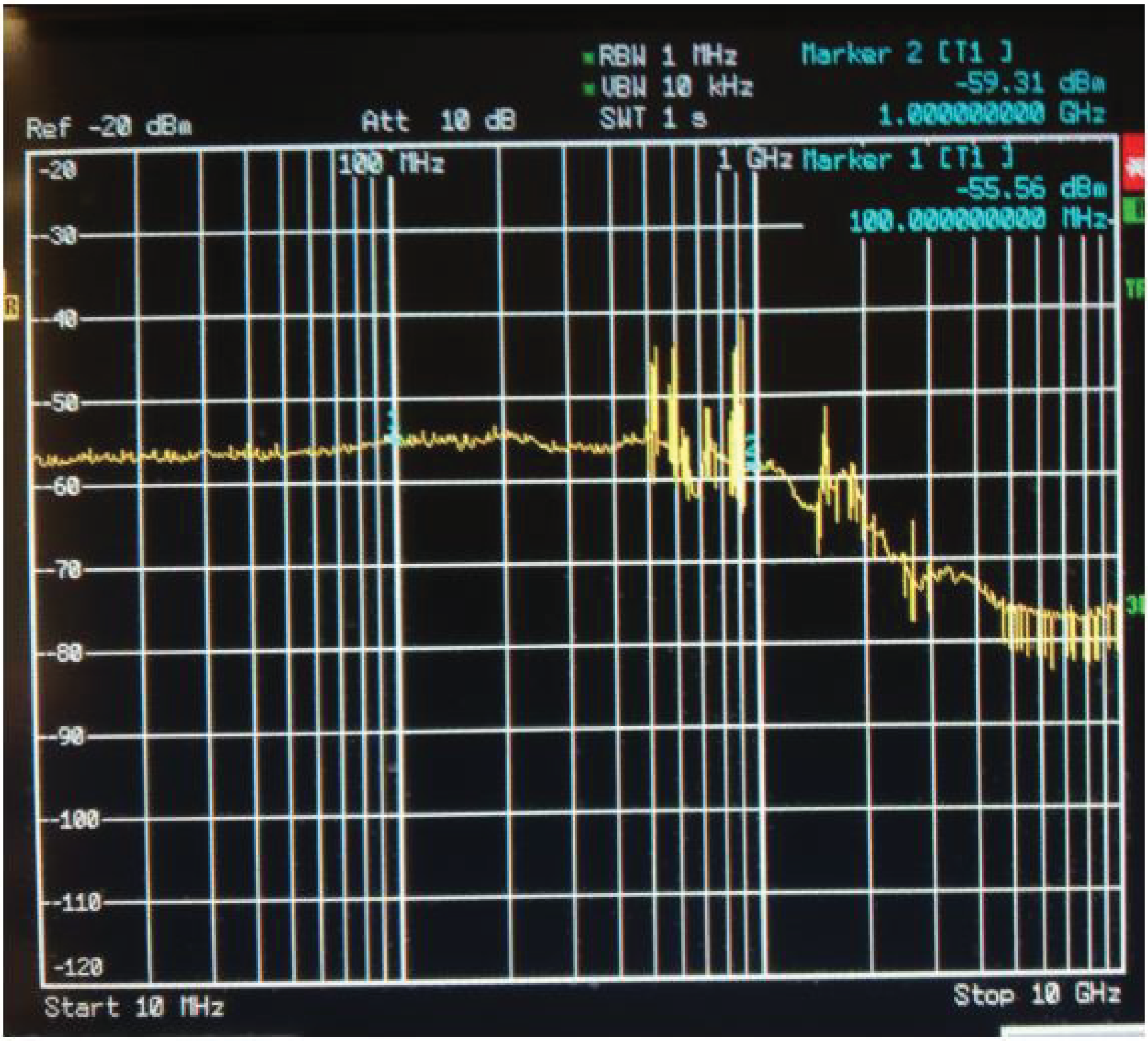
SIPM AMP Board Photos



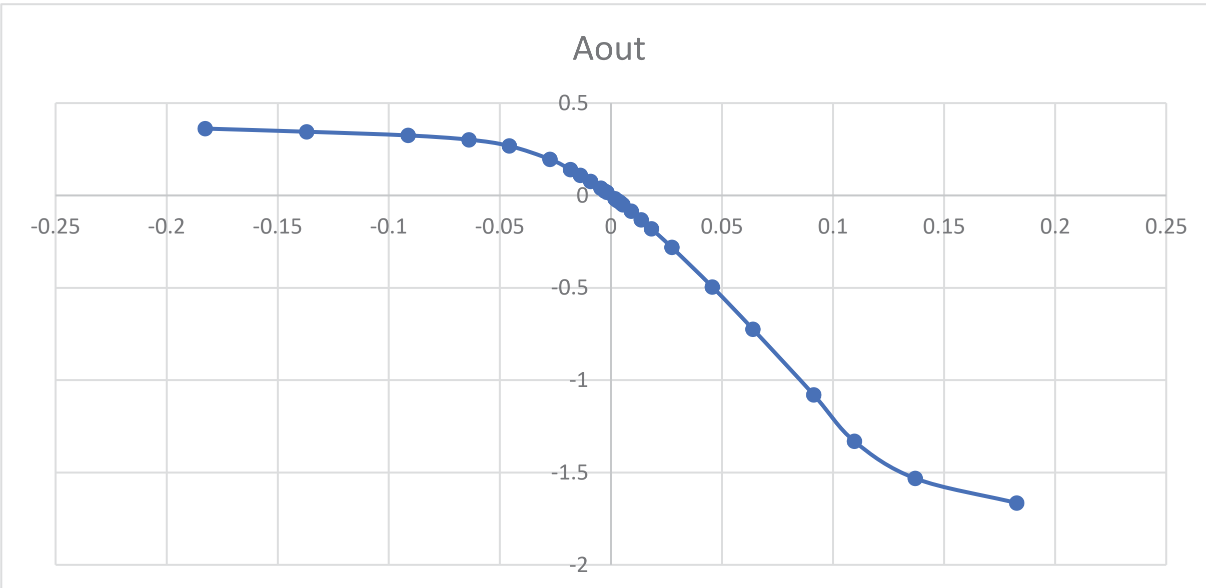
Frequency response plot. SIPM AMP-Gain-40db-Input.jpg a gain plot vs. frequency without a low-pass filter. BW(-3db)=2.37GHz, Gain(100MHz)=19db (x8.9)



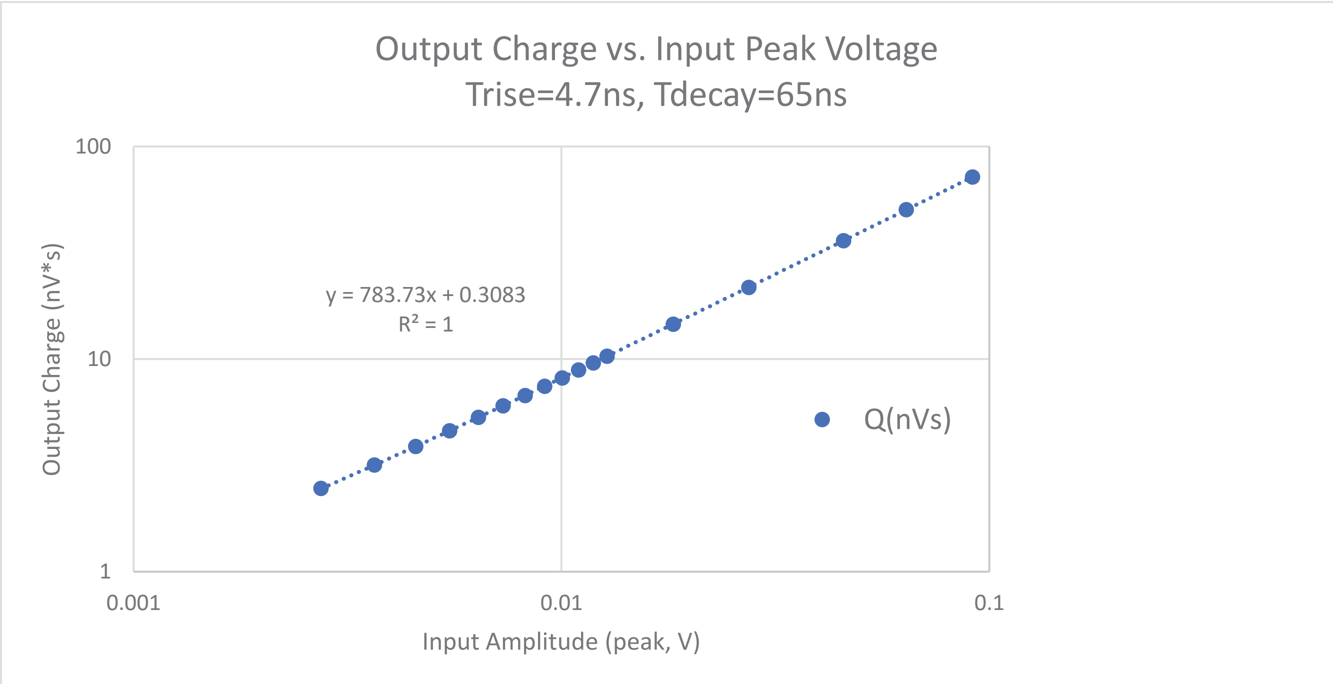
Noise. output noise spectrum measured (in dbm per 1MHz) with an additional external gain of x96.6 and BW=1.16GHz), an equivalent input noise of 0.73nV/sqrt(Hz), 16.3uV rms for BW=500MHz, 145uV rms output noise.



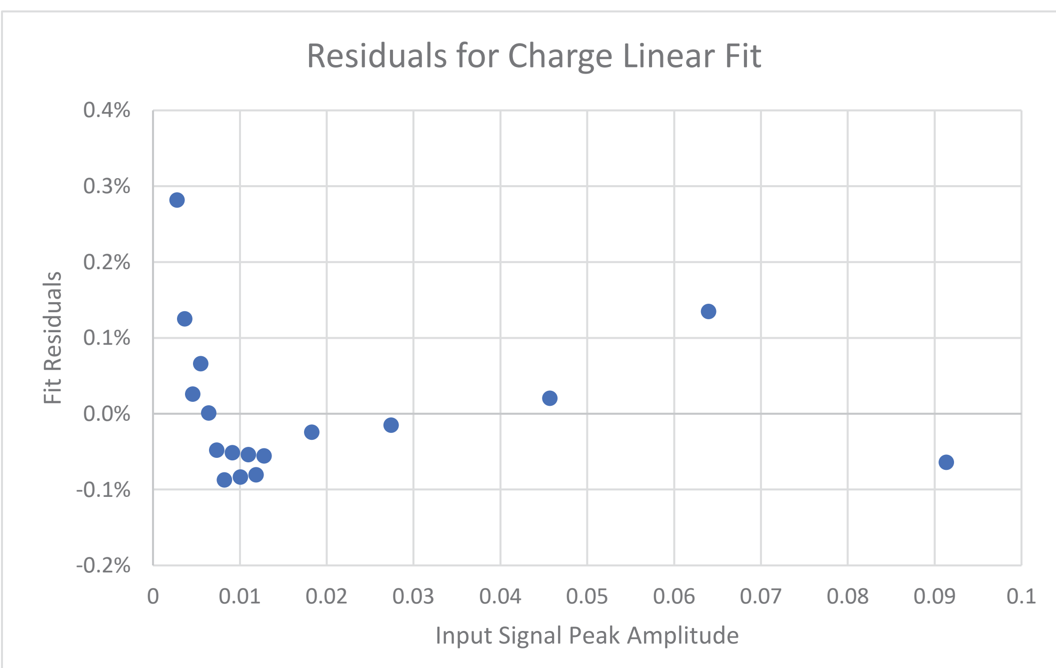
Voltage Linearity (non-linearity) plot. Horizontal and vertical scale volts. Normal operation is input signals less than +0.1V



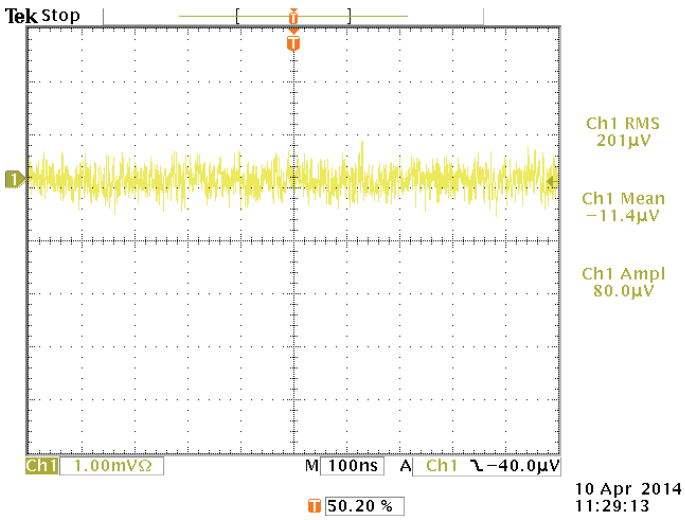
Charge linearity vs input pulse voltage. Pulse generator with a 40db attenuator, 4.7ns rise time, 65ns decay time. The SiPM board amplifier is very linear for input signals with voltage up to 0.1V.



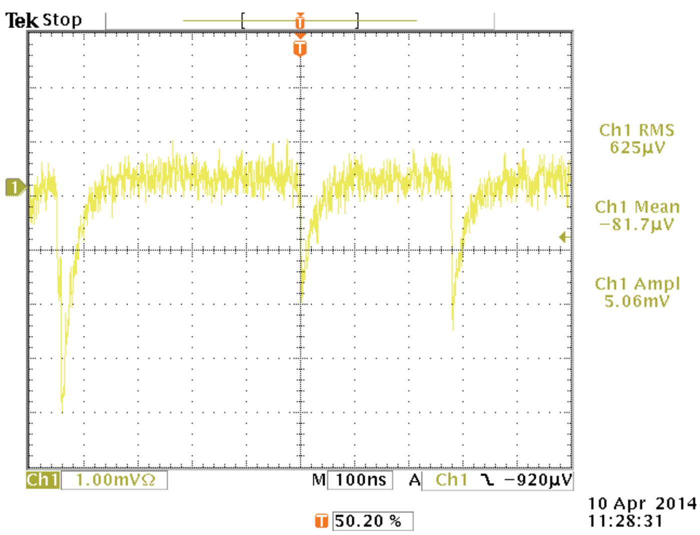
Residuals for charge linear fit in percent.



Oscilloscope waveforms for the SiPM AMP board. 500MHz oscilloscope



Noise. 1mV/division 100ns/division



Dark counts from SiPM. 1mV/division. 100ns/division.

2. Control Board

Description

The Control board controls 4 channels of SIPM AMP boards. It has 4 ribbon cable connectors to mate with cables to the SIPM AMP. For each SIPM AMP it supplies

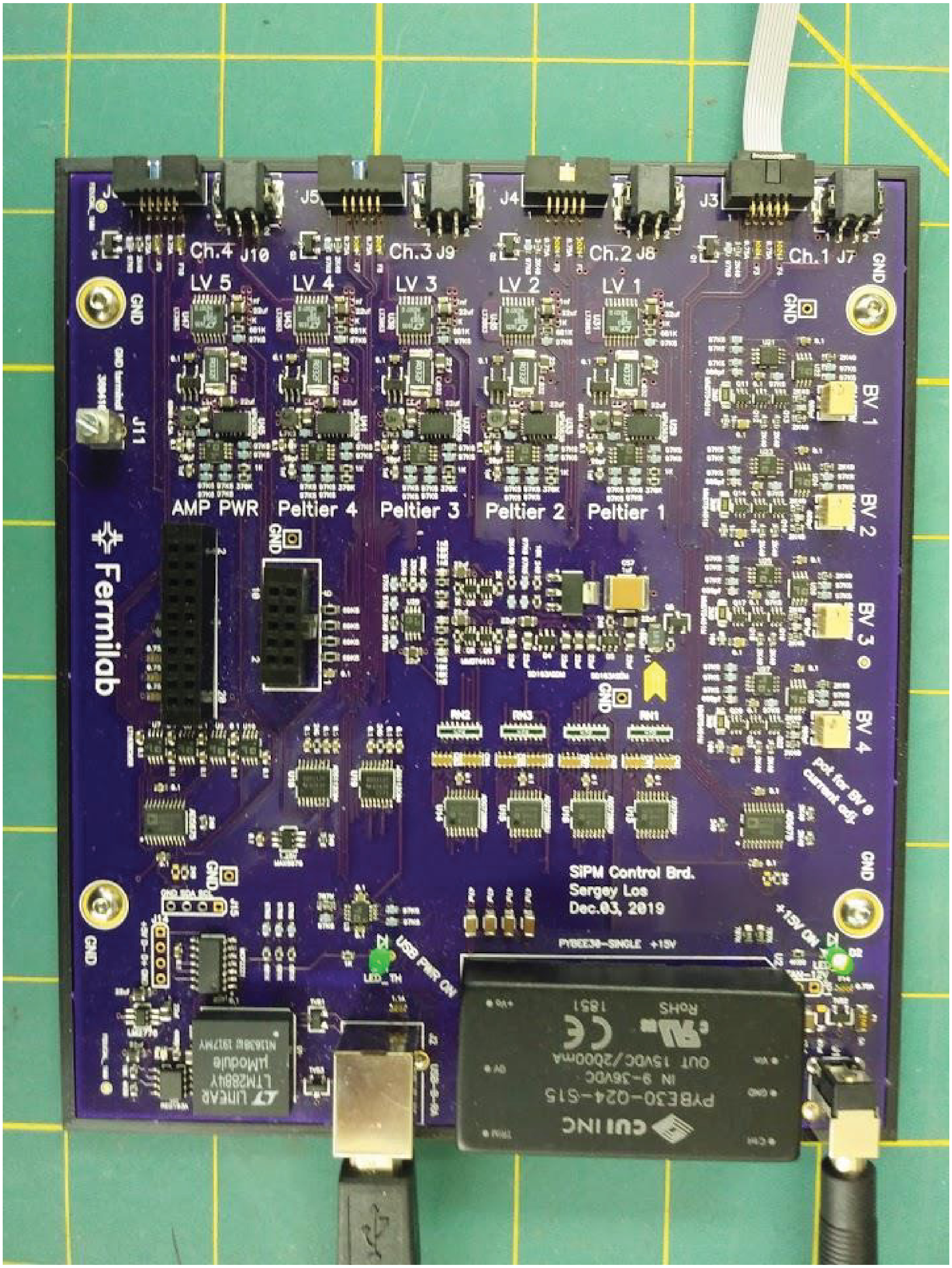
- Low voltage for the amplifier (All 4 channels share the same voltage.) 0V– 12V @ 2A. The set voltage is read back.
- SIPM bias voltage 20V – 100V @ 2mA. The set voltage is read back.
- Readback of leakage current of the SIPM with resolution 5nA
- Readback of PT10K on the SIPM AMP board
- Power to an optional Peltier cooler 0-12V@2A, fused at 0.75A for the ribbon cable, full power at an additional 2-contact connector

The control board implements full galvanic isolation for both the USB and external power connection, which minimizes EMI to the sensitive FE electronics.
The control board uses a USB interface to communicate with the slow control hardware. The whole system is powered by a wall-brick DC power supply, 12V, 4A or equivalent

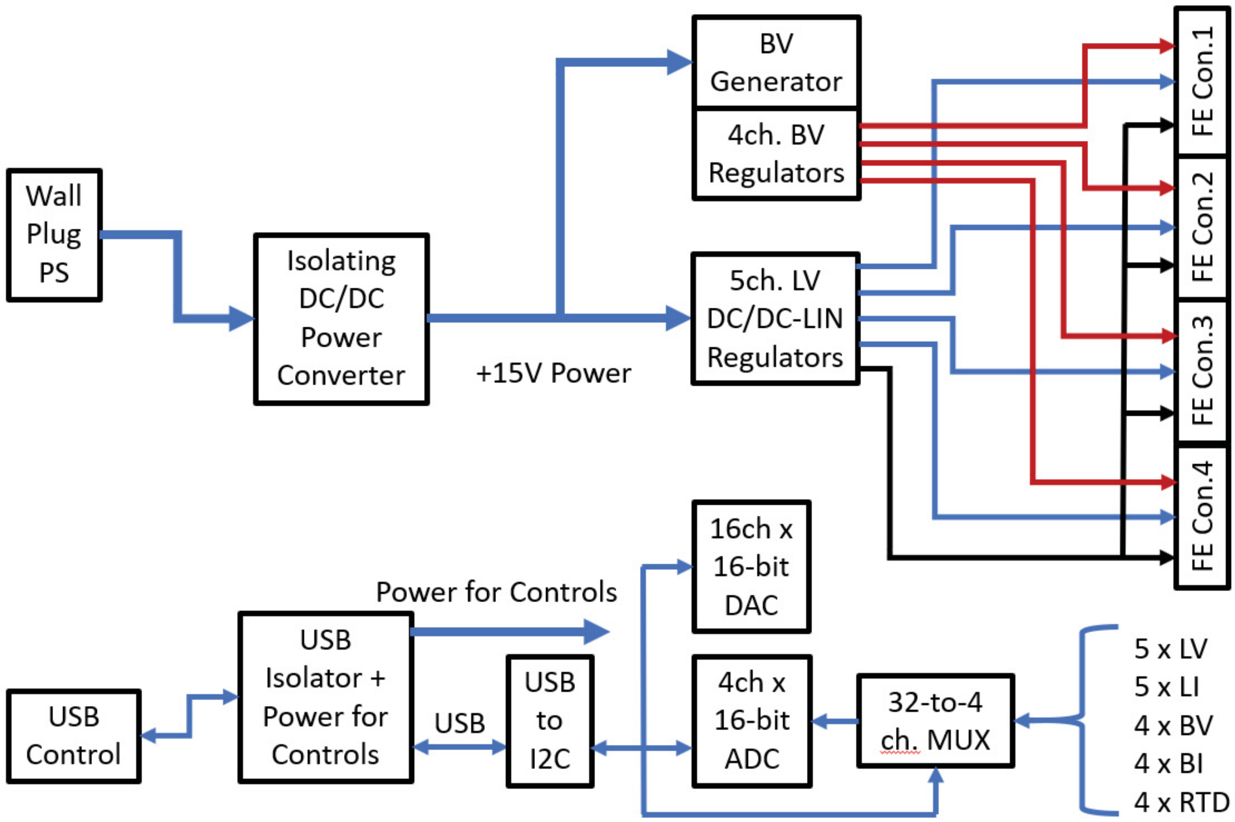
Control Board Specs table

SIPM AMP Control Card		Feb.19, 2021
		Sergey L.
Component description	**Spec**	**Comment**
Linear LTM2884 USB isolator	Output power <200mA@5V is used for ICs	
Microchip MCP2221 is a USB-to-I2C protocol converter	3-5.5V @ 15mA	
Power		
External PS (say 12V/48W adapter L6R48-120400)	1x 12V @ 4A	
+12V DC to +15V DC isolated Power converter	+15V @ 2A	
Cockcroft-Walton 15V to 120V convertor	1x 120V @ 10mA, 2.5W consumption	
Peltier/Amp power - combination of switching/linear regulator	5x 0-12V/2A, 10W max	
DAC settings (9 channels)		
BV voltage	4x 100V @ 2mA	(1)
Peltier/Amp voltage	5x 12V @ 2A	
ADC measurements (18 channels)		(2)
BV voltage	4x 100V	Of primary User interest
Peltier/Amp voltage	5x 20V	
Peltier/Amp current	5x 2.5A	
RTD readout	4x 0-10V	
Other ADC measurements (5 channels)		
External PS voltage	0-20V	For debugging only
Isolated +15V voltage	0-20V	
MCP2221 generated 5V power	0-10V	
3.9V generated from the MCP2221 5V	0-10V, also used for RTD temp. calculation	
Cockcroft-Walton output voltage	0-200V	
(1) These have to be manually calibrated, also the BV measurements (pedestal and slope)		
Everything else is 1% or better by design		
(2) Reserve 2 channels for voltage and current of possible negative power rail for Amp		

Control Board Photo



Control Board Block Diagram



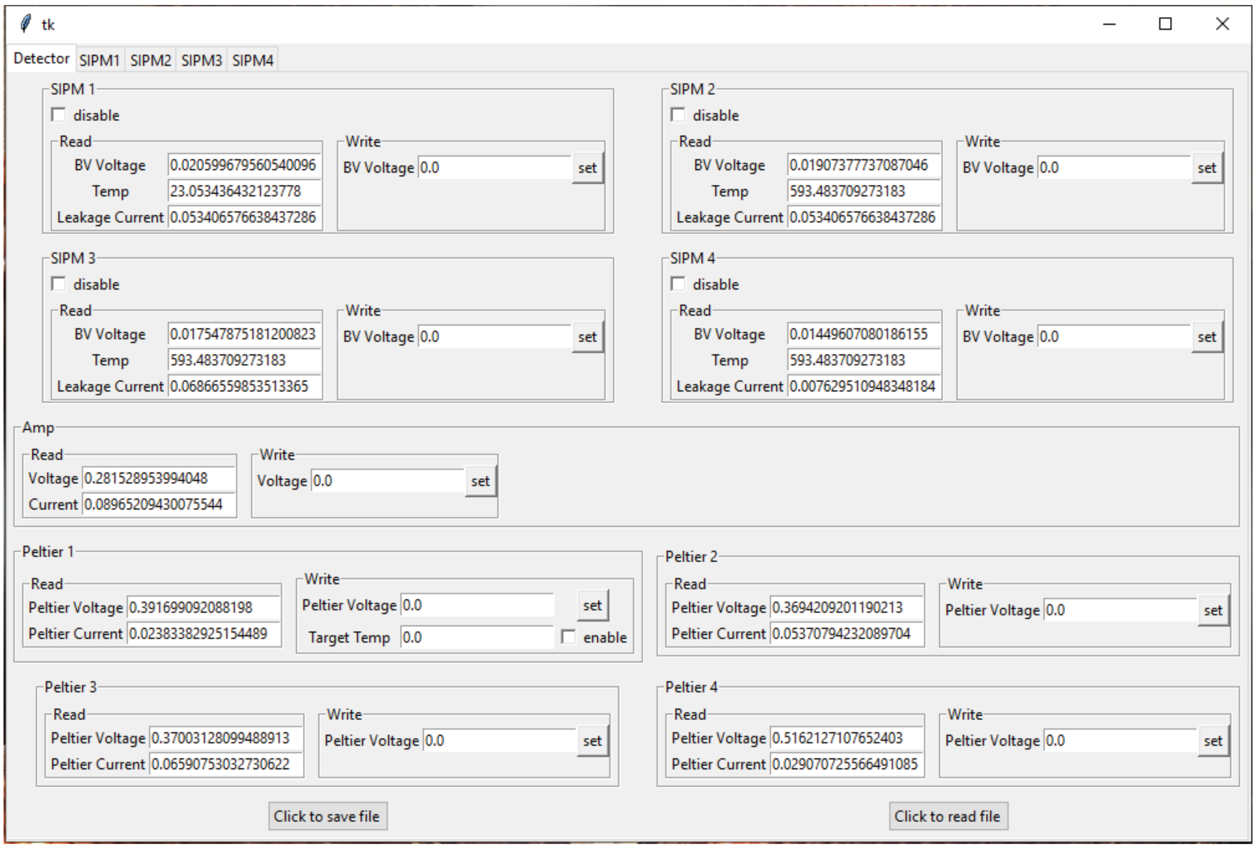
3. GUI / software control interface

Description of program

A graphical user interface program has been written in Python. It allows for control of SiPM bias and amplifier voltages, control of Peltier voltages, read-back of these voltages as well as temperature and SiPM leakage current.

The GUI is composed of 5 tabs, the main tab and 4 tabs. One for each SiPM.

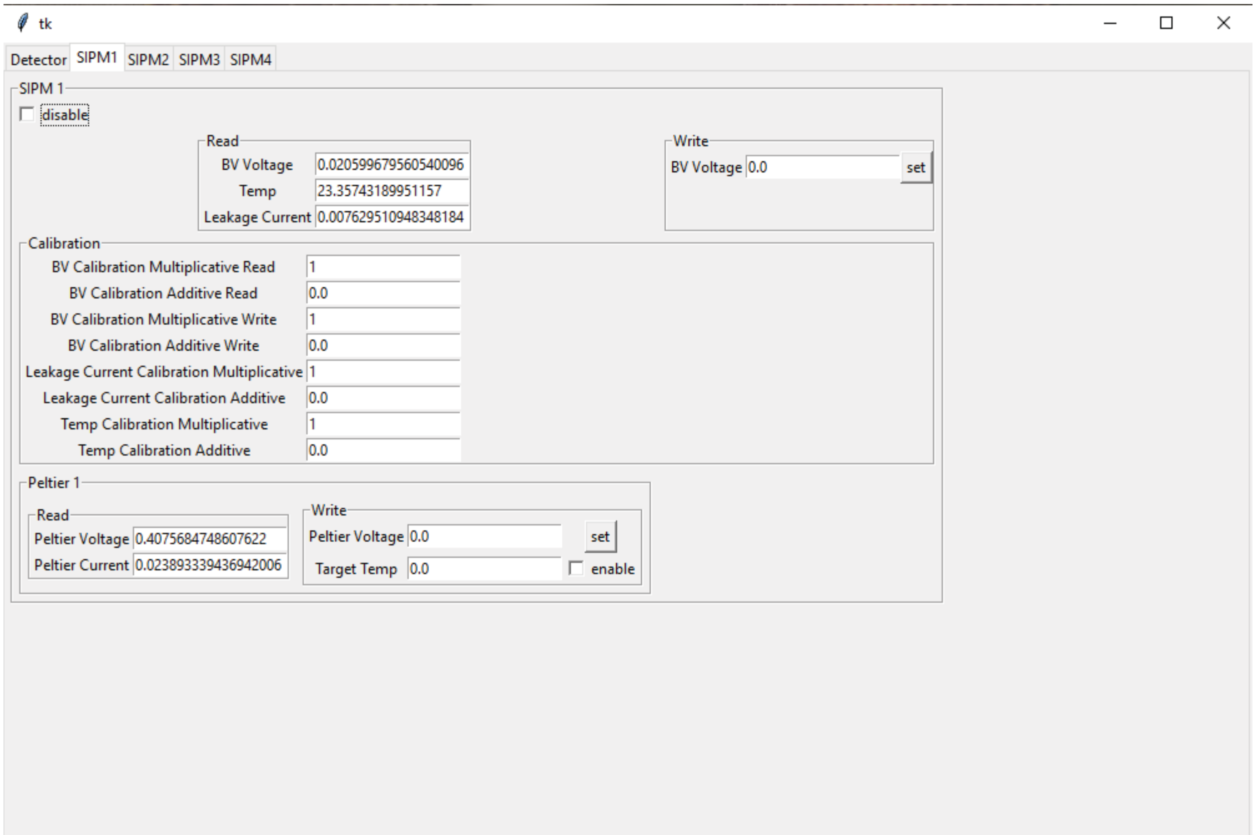
The GUI main tab screenshot:



Voltages are displayed in Volts. Temperatures are in degrees C. The leakage currents are displayed in µV. Note there is a "disable" button for each SiPM. To operate a SiPM, the SiPM must be enabled. Then a desired bias voltage is entered and "set".

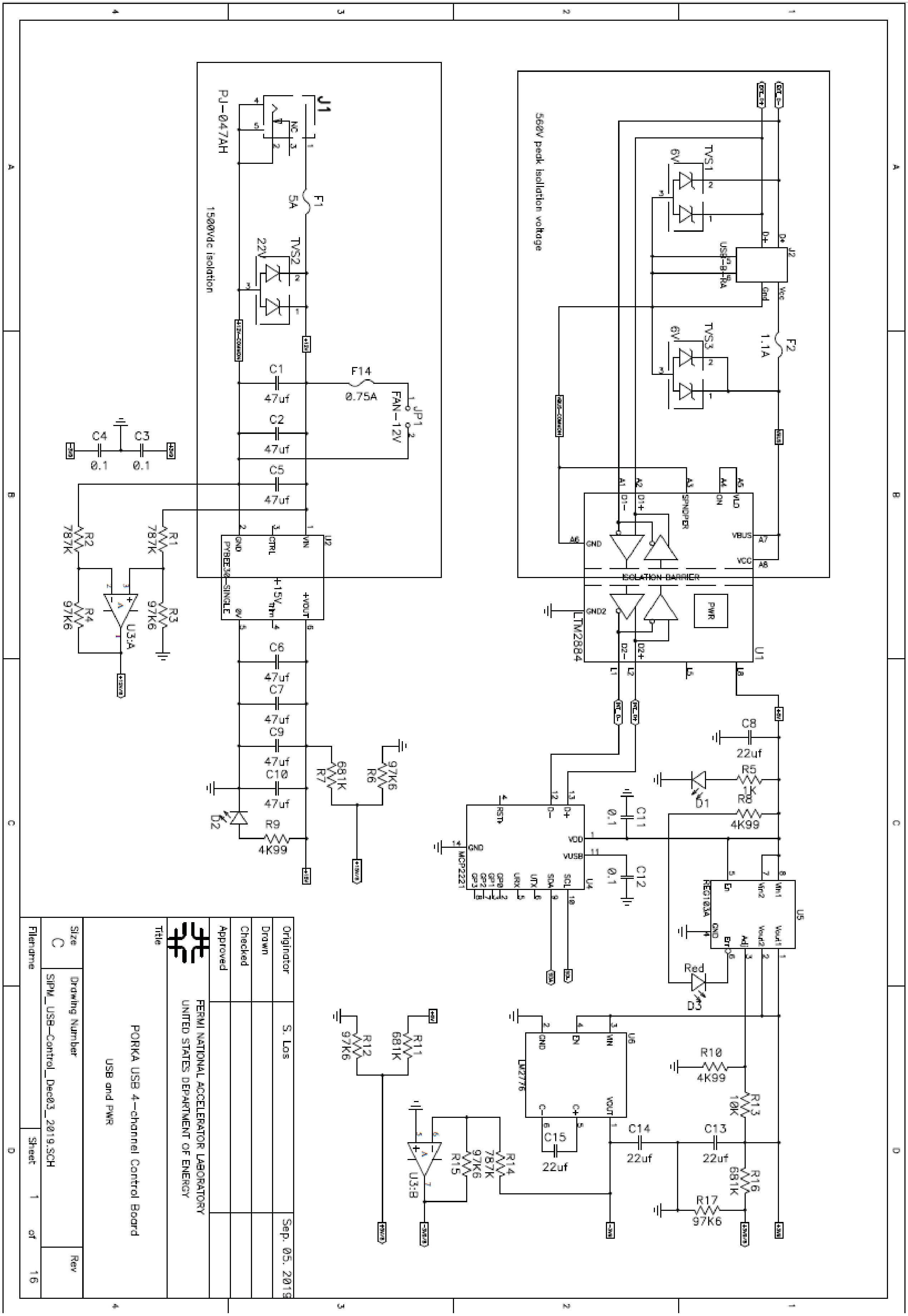
A single voltage for all connected SiPM AMP board amplifiers is settable and should normally be +6V. The current drawn for this power should be about 16mA per connected SiPM AMP board.

Screen shot of a dedicated SIPM tab of the GUI.

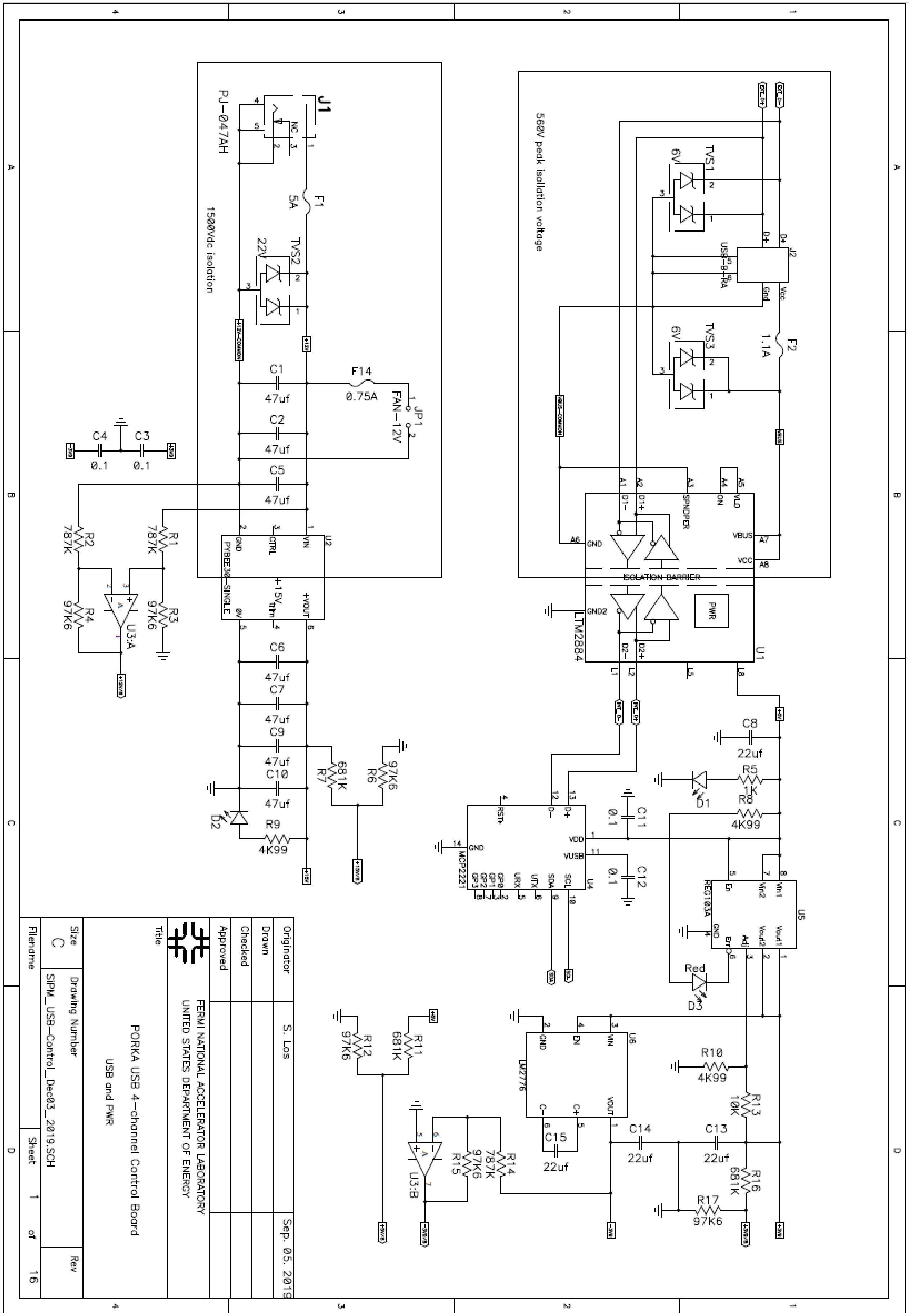


Controls from the main tab are duplicated on this screen. Additionally there are independent fields for calibration of the bias voltage read and write. Also there are fields to calibrate the readback temperature.

Appendix 1.
Control Board Circuit Diagram



Originator S. Los Sep. 05, 2019
Drawn
Checked
Approved
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
Title
PORKA USB 4-channel Control Board
USB and PWR
Size C
Drawing Number
SiPM_USB-Control_Dec03_2019.SCH
Rev
Filename
Sheet 1 of 16
1500Vdc isolation
560V peak isolation voltage
ISOLATION BARRIER
LTM2884
PYBEE30-SINGLE
MCP2221
REG103A
LM2776
PJ-047AH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UNITED STATES DEPARTMENT OF ENERGY
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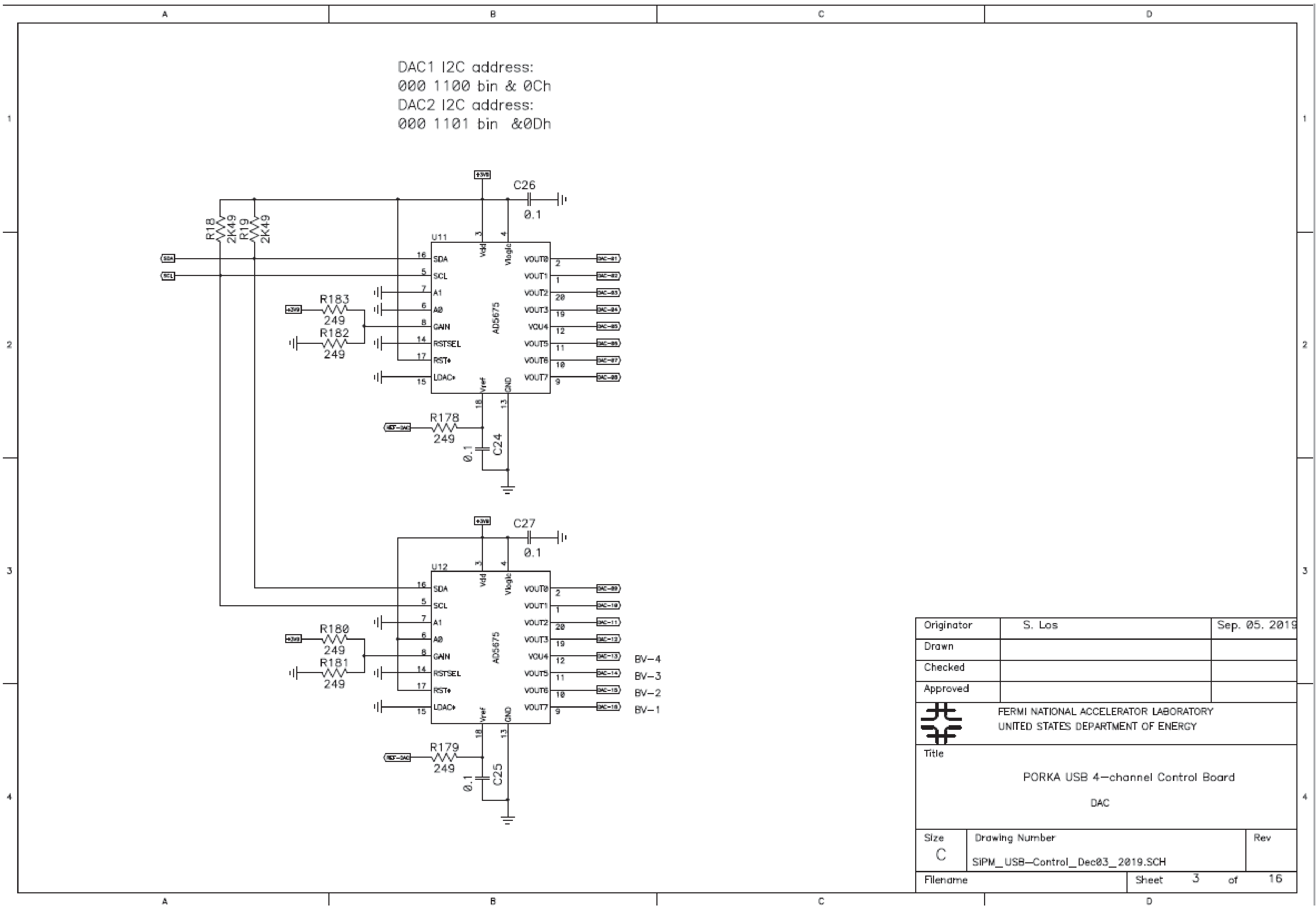
PORKA USB 4-channel Control Board
USB and PWR
Originator
S. Los
Drawn
Checked
Approved
Sep. 05. 2019
Size
C
Drawing Number
SIPM_USB-Control_Dec03_2019.SCH
Rev
Sheet 1 of 16
Filename
1500Vdc isolation
560V peak isolation voltage
J1
PJ-047AH
F1
5A
TVS2
22V
C1
47uf
F14
0.75A
JP1
FAN-12V
C2
47uf
C5
47uf
C4
0.1
C3
0.1
R2
787K
R1
787K
R4
97K6
R3
97K6
U3:A
U2
PYBE30-SINGLE
+15V
C6
47uf
C7
47uf
C9
47uf
C10
47uf
R7
681K
R6
97K6
D2
R9
4K99
TVS1
6V
J2
USB-B-RA
F2
1.1A
TVS3
6V
U1
LTM2884
ISOLATION BARRIER
PWR
C8
22uf
R5
1K
D1
R8
4K99
U4
MCP2221
C11
0.1
C12
0.1
U5
REG103A
Red
D3
U6
LM2776
R10
4K99
R13
10K
R12
97K6
R11
681K
C15
22uf
C14
22uf
C13
22uf
R14
787K
R15
97K6
U3:B
R16
681K
R17
97K6


DAC1 I2C address:
000 1100 bin & 0Ch
DAC2 I2C address:
000 1101 bin &0Dh
R18
2K49
R19
2K49
C26
0.1
U11
AD5675
SDA
SCL
A1
A0
GAIN
RSTSEL
RST
LDAC
Vdd
Vlogic
Vref
GND
VOUT0
VOUT1
VOUT2
VOUT3
VOU4
VOUT5
VOUT6
VOUT7
R183
249
R182
249
R178
249
C24
0.1
C27
0.1
U12
AD5675
R180
249
R181
249
R179
249
C25
0.1
BV-4
BV-3
BV-2
BV-1
Originator
S. Los
Sep. 05. 2019
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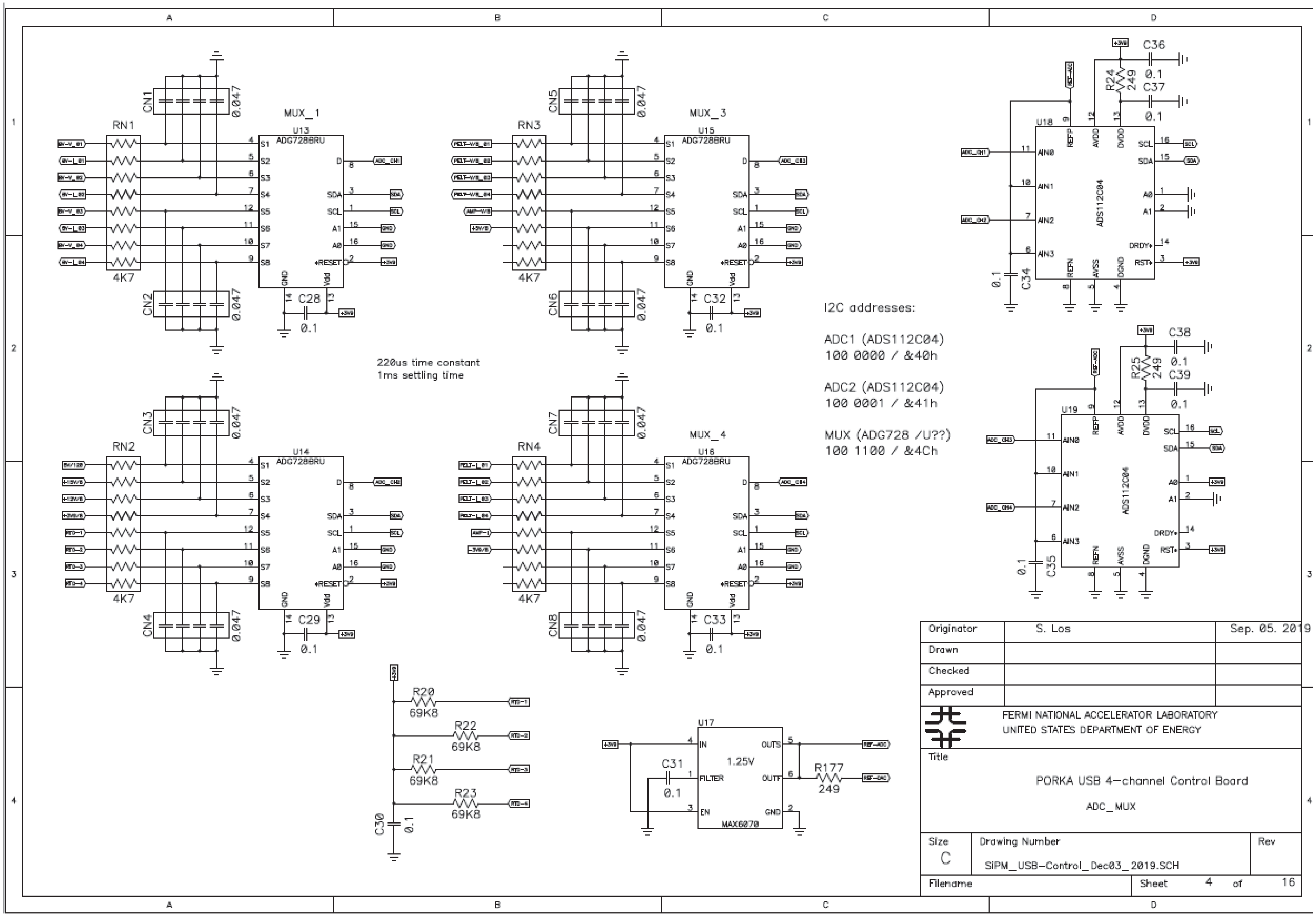
PORKA USB 4-channel Control Board
DAC
Size
C
Drawing Number
SIPM_USB-Control_Dec03_2019.SCH
Rev
Filename
Sheet 3 of 16



MUX_1
U13
ADG728BRU
MUX_3
U15
U14
MUX_4
U16
RN1
RN2
RN3
RN4
4K7
CN1
CN2
CN3
CN4
CN5
CN6
CN7
CN8
0.047
C28
C29
C32
C33
0.1
220us time constant
1ms settling time
I2C addresses:
ADC1 (ADS112C04)
100 0000 / &40h
ADC2 (ADS112C04)
100 0001 / &41h
MUX (ADG728 /U??)
100 1100 / &4Ch
U18
U19
ADS112C04
R24
R25
249
C34
C35
C36
C37
C38
C39
R20
R21
R22
R23
69K8
C30
U17
1.25V
MAX6070
C31
R177
Originator
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PORKA USB 4-channel Control Board
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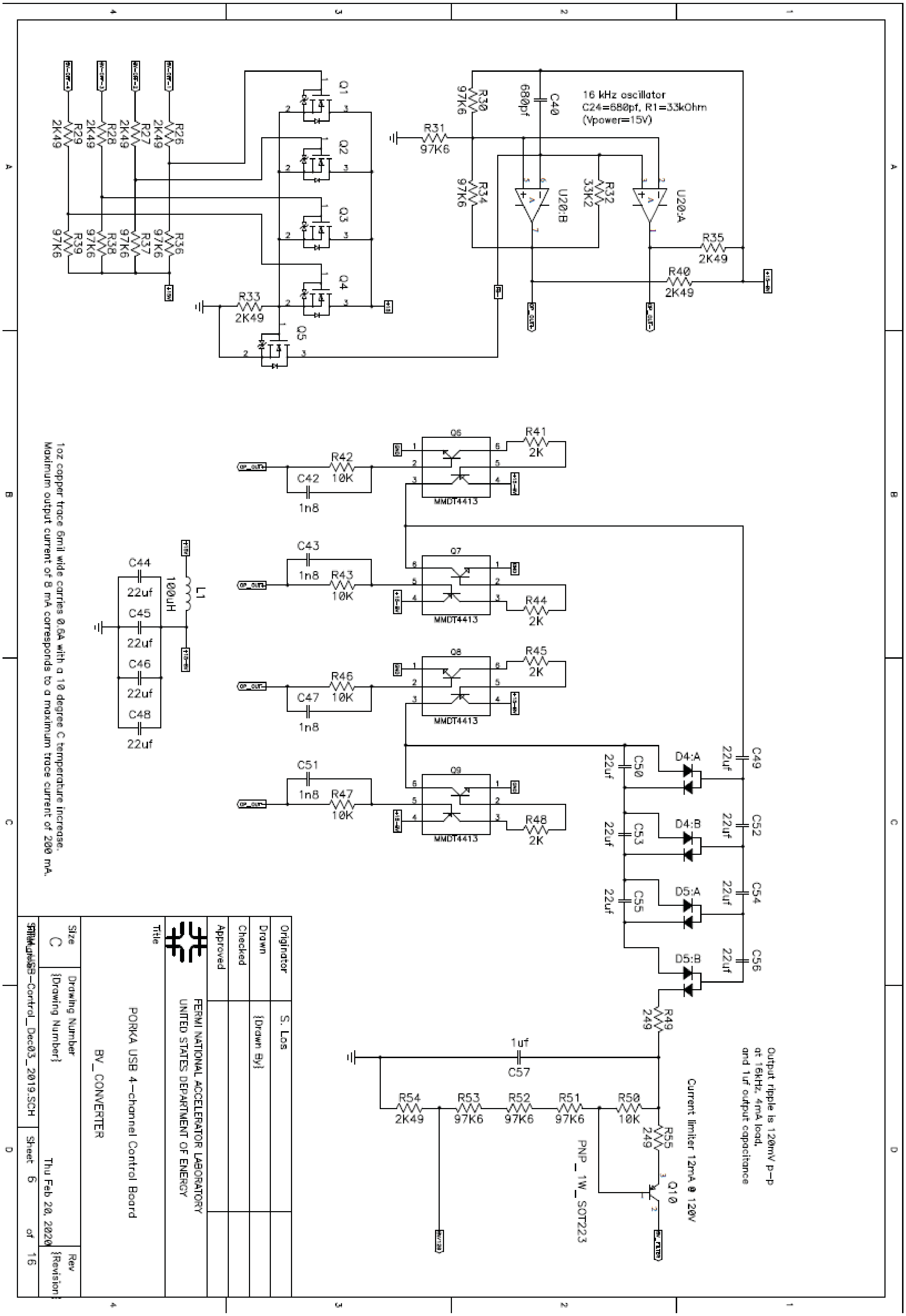
Size
C
Drawing Number
SIPM_USB-Control_Dec03_2019.SCH
Rev
Filename
Sheet 4 of 16


16 kHz oscillator
C24=680pf, R1=33kOhm
(Vpower=15V)
Output ripple is 120mV p-p
at 16kHz, 4mA load,
and 1uf output capacitance
Current limiter 12mA @ 120V
PNP_1W_SOT223
1oz copper trace 6mil wide carries 0.6A with a 10 degree C temperature increase.
Maximum output current of 8 mA corresponds to a maximum trace current of 200 mA.
MMDT4413
Originator
S. Los
Drawn
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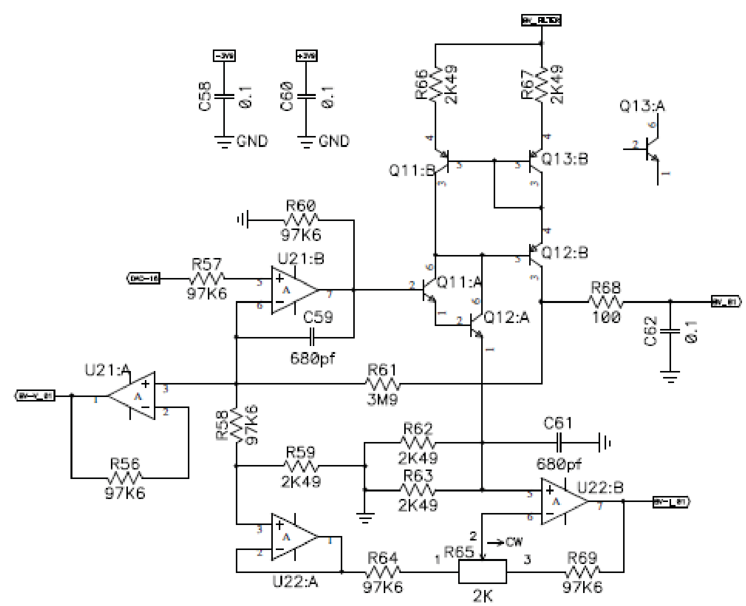
Checked
Approved
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
Title
PORKA USB 4-channel Control Board
BV_CONVERTER
Size
C
Drawing Number
{Drawing Number}
Rev
{Revision}
Thu Feb 20, 2020
Sheet 6 of 16



For R=3.9M, BVmax=100V (1.526mV/LSB)
Maximum measured output current is 1000uA, out of which up to 25uA go into feedback loop. Automatically subtracts feedback loop current, needs adjustment. Output current hardware limited to 2mA

Originator	S. Los
Drawn	{Drawn By}
Checked	
Approved	

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UNITED STATES DEPARTMENT OF ENERGY

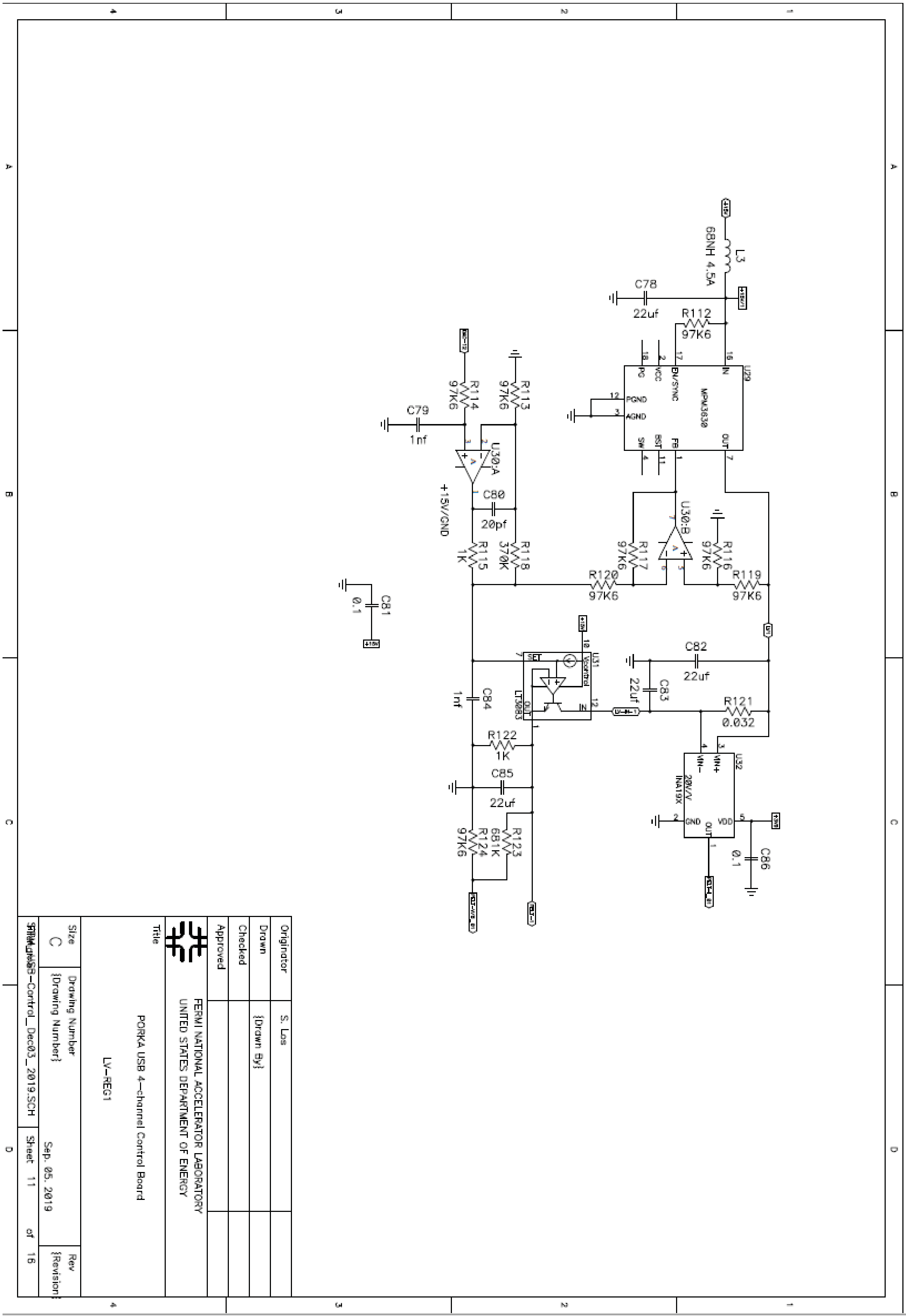
Title

PORKA USB 4-channel Control Board

BV_REGUL1

Size	Drawing Number	Rev
C	{Drawing Number} Thu Feb 20, 2020	{Revision}

Filename: PORKA_USB-Control_Dec03_2019.SCH — Sheet 7 of 16



Originator S. Los
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Approved
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UNITED STATES DEPARTMENT OF ENERGY
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LV-REG1
Size C
Drawing Number {Drawing Number}
Rev {Revision}
Control_Dec03_2019.SCH
Sep. 05, 2019
Sheet 11 of 16
L3
68NH 4.5A
C78
22uf
R112
97K6
U29
MPM3630
PGND
AGND
PG
VCC
EN/SYNC
IN
SW
BST
FB
OUT
R114
97K6
R113
97K6
C79
1nf
U30:A
+15V/GND
C80
20pf
R115
1K
R118
370K
R117
97K6
U30:B
R116
97K6
R120
97K6
R119
97K6
C81
0.1
C82
22uf
C83
22uf
R121
0.032
U31
LT3083
SET
OUT
IN
C84
1nf
R122
1K
C85
22uf
R123
681K
R124
97K6
U32
INA19X
20V/V
VIN-
VIN+
GND
OUT
VDD
C86
0.1

I2C addresses:– HAS to be CORRECTED !!!!

1001000 &48h ADC1 (ADS7828, U5)
Ch.1 – MUX1
Ch.2 – MUX2
Ch.3 – MUX3
Ch.4 – MUX4
Ch.5 – MUX5
Ch.6 – MUX6
1001001 &49h ADC2 (ADS7828, U8)
Ch.1 – Vin/6 (input power voltage)
Ch.2 – Vdd/2 (regulated power voltage)
Ch.3 – BV–IN/65 (BV from voltage converter)
Ch.4 – V_Peltier/6 (measured Peltier voltage)
Ch.5 – I_Peltier (Peltier current 2.5V=2.5A)
Ch.6 – *T/RH–1 (temperature or humidity signal from sensor 1)
Ch.7 – *T/RH–2 (emperature or humidity signal from sensor 2)
if SHT21S sensor installed Ch.6/7 read Temperature when DAC63 is LOW and Humidity when HIGH,
T(C)=–46.85+175.72 x "T/RH"/Vdd, RH=–6+125 x "T/RH"/Vdd)
Ch.8 – DAC_MON (readout MON voltage from DAC1 and DAC2, allows to monitor DAC set values)
1001100 &4Ch MUX1–6 (same adress) (ADG728, U3, U6, U9, U4, U7, U10)
MUX1 – leakage currents Ch.1–8
MUX2 – leakage currents Ch.9–16
MUX3 – leakage currents Ch.17–24
MUX4 – leakage currents Ch.25–32
MUX5 – leakage currents Ch.33–40
MUX6 – leakage currents Ch.41–48
Leakage current
1010100 &54h DAC1 (AD5383BST–3, U1)
Ch.1–32 / BV1–32
1010101 &55h DAC2 (AD5383BST–3, U2)
Ch.33–48 / BV33–48
BVout=DAC x 32.5 (81.25V max)
Ch.63 – selects T/RH function
Ch.64 – sets Peltier Voltage Vpelt=Vdac x 3 (7.5V max)

Originator	S. Los	
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Approved		

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Title: PORKA USB 4–channel Control Board
Addresses_Mapping

Size	Drawing Number		Rev
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Filename: ...USB–Control_Dec03_2019.SCH		Sheet 16 of 16	