User manual SiPM-FE-Rev1-A

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Specification

Power requirements

Symbol	Parameter	MIN	TYP	MAX	UNITS
Vin	Supply voltage	11	12	13	VDC
Pin	Input Power at 12V		10	15*	W
T_A	Ambient operating temperature	10		35	°C

* Peak power depends on single board computer (Nanopi) load – rate power supply for at least 1.2 A
Force airflow around the unit if you read CPU or ADC temperature above 50C (see commands)

Amplifiers

Symbol	Parameter	MIN	TYP	MAX	UNITS
A	Voltage gain on 50R system		60		V/V
Bw	Bandwidth	200			MHz
Vn	Output noise with open inputs		620		uVrms
Vout	Output voltage swing range		+/- 2		V

Amplifiers inputs and outputs are AC coupled, 50R terminated

Channel inputs handling

Channel inputs are sensitive!
Turn off HV source before connecting/disconnecting SiPM to amp input – see commands.
Discharge cables before plugging them to input connectors.
Do not measure voltage on input connector using a multi meter leads to avoid destroying amp.

Bias voltage and current

Symbol	Parameter	MIN	TYP	MAX	UNITS
+QP	SW Controlled positive charge pump output	40		90	V
-QP	Fixed Negative charge pump output	-8 at +QPmin		-20 at QPmax	V
HVout	Common HV range	-QP + 1V		70 or +QP – 1V	V
Rtotal (R1+Rs+R2)	HV source output impedance		59984.9		Ohm

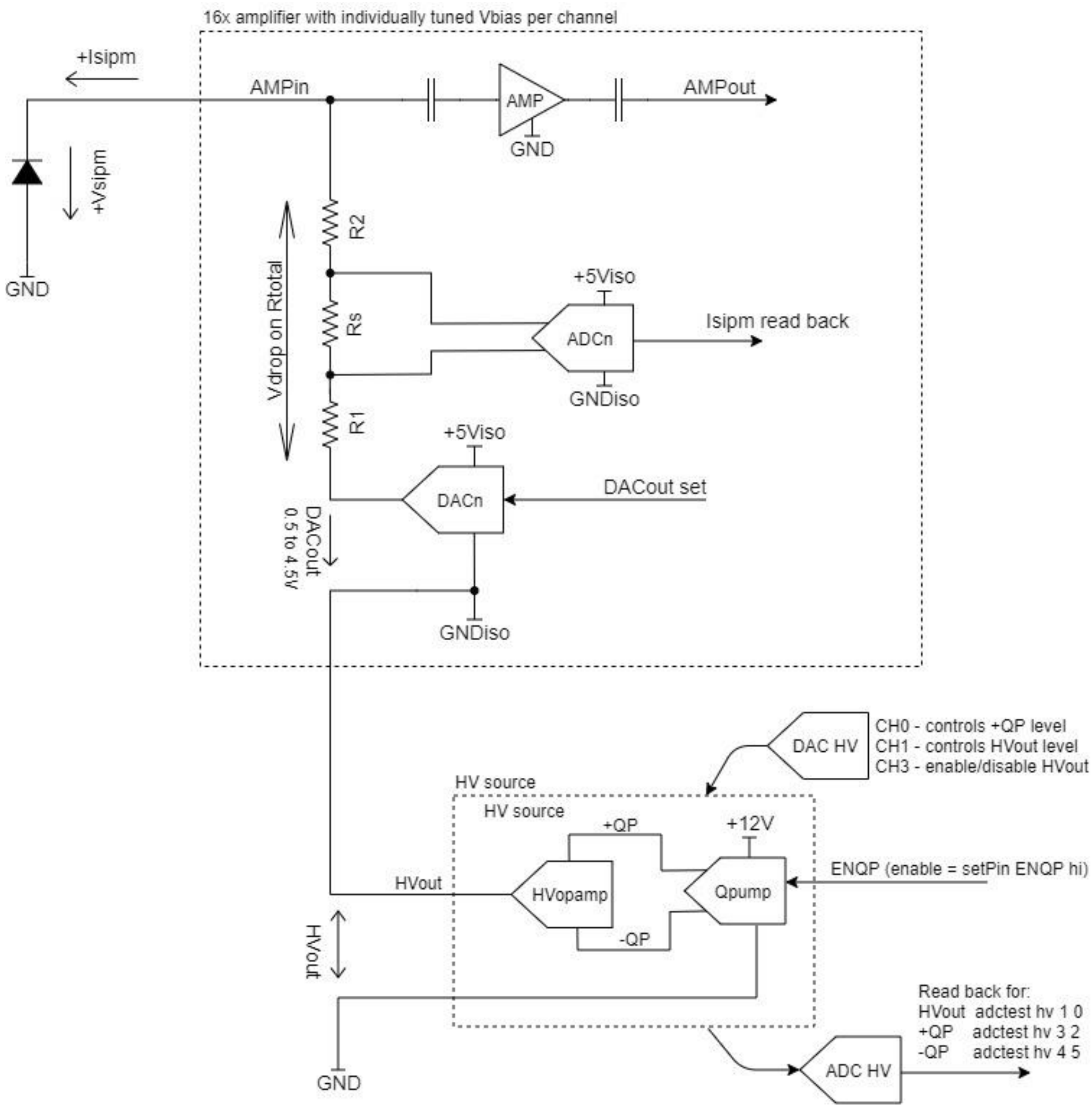
R1			10004.9		Ohm
Rs	ADC sense resistor		30000		Ohm
R2			19980		Ohm
HVnoise	Low freq. Noise/stability <10Hz at HVout max		10		mV
HVerr	HVout read back uncertainty at HVout max		10	30	mV
Thv	HVout settling time		1		s
DACnrange	Channel DAC output range	0.5		4.5	V
Irbmax	Vref/Rs =max measurable bias current at ADC gain 1 ("-g 0")		+/- 83		uA
DACn(+Irbmax)	Output range for correct max. reverse current read back	3.8		4.5	V
DACn(-Irbmax)	Output range for correct max. forward current read back	0.5		1.2	V
Insipm	Isipm read back noise open input		0.2		nArms

Used ADCs and DACS

Symbol	**Part number**	**Configuration**
DAC HV	AD5686ARUZ	16bit, Ext Vref 2.5V, LSB = 2.5V/2^16
ADC HV	ADS1248IPW	24bit, Ext Vref 2.5V, LSB = 5V/2^24
DACn	AD5676ARUZ	16bit, Vref 5V, LSB = 5V/2^16
ADCn	ADS1248IPW	24bit, Ext Vref 2.5V, LSB = 5V/2^24

ADC drivers support to configure ADCs programmable gain. This user manual is valid for default gain 1 (option " -g 0 " which can be omitted in command as ADC reset/power up gain is always set to 1).
Please refer to devices datasheets for more information.
Default DACn output is 0V, please set it correctly after power up or reset.

Simplified schematic



Given biasing concept and ADCs inputs mapping we work with:

- positive Vsipm and Isipm for reverse biased Sipm
- negative Vsipm and Isipm for forward biased Sipm

HV source

Key components are Charge pump (QP) with positive and negative output and High voltage op amp.
QP provides power supply rails to HVopamp. There is option to adjust +QP level and turn OFF QP by stopping its input clock. -QP is fixed.
HVopamp provides HVout once enabled by DACHV – this is safety feature to always power up with HVout disabled.
Due to HVout low freq. noise acquire HVout read back for longer to improve measurement repeatability.
Taking 1000 samples at 1ksps rate is recommended with command "adctest -l 1000 -r 8 hv 1 0".

HV source DAC and ADC mapping

	DAC address	DAC channel	function
DAC HV	hv	0	+QPout
	hv	1	HVout
	hv	2	Not used
	hv	3	Enable HVout

	ADC address	channel 0 (ADCinPos)	channel 1 (ADCinNEG)	function
ADC HV	hv	1	0	HVout read back
	hv	3	2	+QPout read back
	hv	4	5	-QPout read back

Channel DACs

There are 2 DACs with 8 channels each to provide individual offset from common HVout for each input channel.
There is no physical output voltage read back. Only DAC's output register can be read back. See spec for converting register value to voltage.

Channel DACs mapping

	Input Channel	DAC address	DAC channel
DAC mapping for tuning Vsipm per channel	1	5	0
	2	5	1
	3	5	2
	4	5	3
	5	5	4
	6	5	5
	7	5	6
	8	5	7

	9	2	0
	10	2	1
	11	2	2
	12	2	3
	13	2	4
	14	2	5
	15	2	6
	16	2	7

Current read back ADCs

There are 4 ADC for 4 groups of input channels. Current is measured as differential voltage on Rs resistor. ADCs are configurable with gain and sampling rate.

Current read back ADCs mapping

	Input Channel	ADC address	channel 0 (ADCinPos)	channel 1 (ADCinNEG)
ADC mapping for Isipm read back	1	6	0	1
	2	6	4	5
	3	6	6	7
	4	6	2	3
	5	4	0	1
	6	4	4	5
	7	4	6	7
	8	4	2	3
	9	3	0	1
	10	3	4	5
	11	3	6	7
	12	3	2	3
	13	1	0	1
	14	1	4	5
	15	1	6	7
	16	1	2	3

Reversed biased SiPMs

The easy way to setup all channels for normal operation with reversed biased SiPMs is setting up all channel DAC output to middle of output range and apply common mode HVout.
Then an offset can be applied to individual channel by changing DACn out value.

Measuring IV curve

The simplest way to cycle through multiple voltage set points while reading Isipm is setting all DACn to same proper voltage (as described in following text) and stepping HVout.

Measuring Isipm

Current read back ADCs and channel DACs are floating. Their inputs and outputs are referenced to GNDiso which is at the same potential as HVout.

To make correct measurements potentials on Rs resistor must stay within ADC common mode voltages compliance with respect to GNDiso. Directional Isipm creates voltage on R1 which can offset voltage on Rs terminal out of common mode ADC range with respect to GNDiso.

Setting up correct channel DAC output voltage for given direction and magnitude of Isipm will keep voltages on Rs within ADC spec.

Please see spec for range of possible channel DAC outputs value to get correct current measurement or calculate range for different current using following formulas:

For Reverse +Isipm:

DACnmin + |Isipm |* (R1+Rs) < DACn out < DACnmax

For Forward –Isipm:

DACnmin < DACn out < DACnmax – |Isipm |* (R1+Rs)

Please note that even for close to zero currents DACn out must be set within <DACnmin,DACnmax> range.

Measuring Vsipm

Vsipm is voltage on the center wire of input channel connector. It needs to be recalculated for every present Isipm because Isipm creates Vdrop in internal HV source resistance:

Vsipm for channel n:

Vsipm(n) = HVout + DACout(n) – Vdrop(n) //take signs of reported currents and voltages in account

where Vdrop(n) = Isipm(n) * Rtotal

Commands

Following table describes commands to control HW components. Sending command without parameters will print out short help with options and examples.

Command	Description
dactest [-vr] <cselect> <channel> [vset]	Set/Read vset for selected address and channel cselect = address in mapping tables -v vset value is in Volts, otherwise Counts -1 for channel to set value for all channels at once -r read back DAC output register
adctest [options] <cselect> <channel 0> <channel 1>	Configure/Read ADC value Use mapping tables for cselect and channel 0,1 Options: -g <gain> gain setting from 0-7, see manual -r <rate> rate setting from 0-9, see manual -l <N> acquire N samples, output mean and stdev -p print N results –t <N> <address> reads ADC temperature diode See ADS1248 datasheet for more detais
setPin <pinID> <hi|lo>	pin IDs: ENQP (hi = QP enable) START (lo = power down current read back ADCs)
enhv <enable/disable/query> enhv command is user friendly alias for dactest hv 3 <vset>	enable HVout disable HVout query HVout status
cat /sys/class/thermal/thermal_zone0/temp	Reads Nanopi CPU temperature in mCelsius

Known issues and command bugs

dactest –r <address>
Reading back set points for all channels for selected DAC sometimes fails, typically just one read is corrupted. Read multiple times – reading is valid if you see the same values

adctest –t N <address>
Reading ADC case temperature sometimes return not realistic temperature. Read multiple times.

Even with HVout disabled (HVopamp output in HiZ) there is about 1.3V present on HVout with additional 100kohm output impedance due to buffer op amp Vcm is back powering HVout via feedback resistor.

The first amplifiers stage is very sensitive with high bandwidth - to be on the safe side eliminate possible digital noise coupling to analog signals:

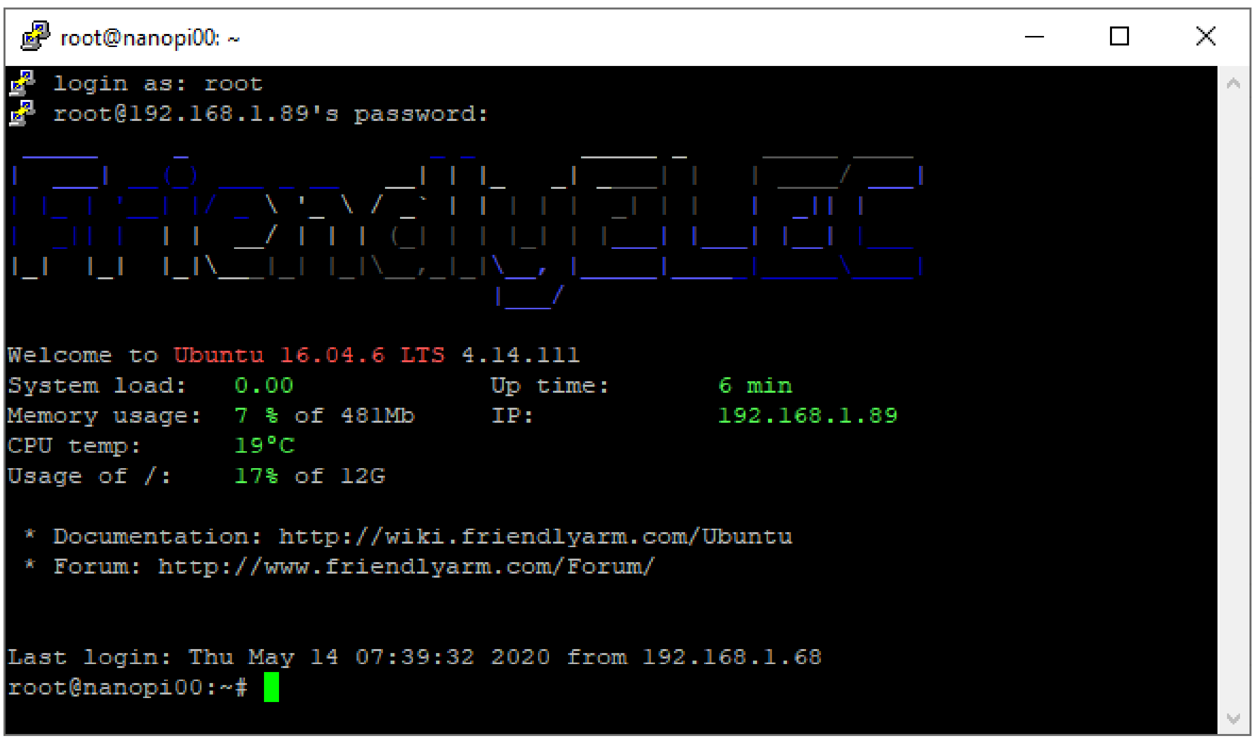
- stop sampling of Isipm read back ADCs with keep them in power down mode - asserting setPin START lo
- stop sending commands to avoid noise from SPI transactions

Examples

Please note HVout voltages used in following examples might damage your device – set them with respect of actual device connected to input.

Connecting to the unit

Find the unit on network, then open ssh connection (e.g. with putty from windows pc)
Log in as root, Password is: nexo_daq2020



Another useful tool witch comes with putty is psftp – you can ftp to Nanopi SD card from windows pc.

Setting the same HVout for all channels

root@nanopi00:~# dactest -v hv 1 0 //pre-setting HVout close to 0V
Closest voltage set point to 0V is -0.0007789V, i.e. vset 50731
channel 1 vset 50731 status 1
root@nanopi00:~# setPin ENQP hi // enabling charge pump
root@nanopi00:~# dactest -v hv 0 70 // pre-setting +QP close to 70V
Closest voltage set point to 70V is 69.9998V, i.e. vset 28239

```
 channel 0 vset 28239 status 1
root@nanopi00:~# enhv enable                               // enabling HVout
root@nanopi00:~# adctest -l 1000 -r 8 hv 3 2               //reading back +QP
Gain = 1
Rate = 1000 samples/second
Measuring between channels 3 and 2
Skipped 1 reads
Results:
TimeDiff (us):  mean: 1051.42, stdev: 111.4
ADCValue:       mean: 4.74427e+06, stdev: 208.671
Converted:      mean: 70.6951 V, stdev: 3.10944mV
root@nanopi00:~# adctest -l 1000 -r 8 hv 1 0               //reading back HVout
Gain = 1
Rate = 1000 samples/second
Measuring between channels 1 and 0
Skipped 1 reads
Results:
TimeDiff (us):  mean: 1056.05, stdev: 120.225
ADCValue:       mean: -2349.07, stdev: 119.758
Converted:      mean: -0.0350039 V, stdev: 1.78454mV
root@nanopi00:~# dactest -v hv 1 40                        //setting HVout close to 40V
Closest voltage set point to 40V is 40.0004V, i.e. vset 25053
 channel 1 vset 25053 status 1
root@nanopi00:~# adctest -l 1000 -r 8 hv 1 0               //reading back HVout
Gain = 1
Rate = 1000 samples/second
Measuring between channels 1 and 0
Skipped 4 reads
Results:
TimeDiff (us):  mean: 1071.2, stdev: 130.716
ADCValue:       mean: 2.69809e+06, stdev: 155.974
Converted:      mean: 40.2046 V, stdev: 2.32419mV
```

At this point all Sipms are reverse biased with 39.62V
We are going to add 2.5V to each channel using channel DAC:

```
root@nanopi00:~# dactest -v 2 -1 2.5                       // “2 -1” = all channels 9-16
Closest voltage set point to 2.5V is 2.5V, i.e. vset 32768
 channel 0 vset 32768 status 1
 channel 1 vset 32768 status 1
 channel 2 vset 32768 status 1
 channel 3 vset 32768 status 1
 channel 4 vset 32768 status 1
 channel 5 vset 32768 status 1
 channel 6 vset 32768 status 1
 channel 7 vset 32768 status 1
root@nanopi00:~# dactest -v 5 -1 2.5                 // “5 -1” = all channels 1-8
Closest voltage set point to 2.5V is 2.5V, i.e. vset 32768
```

```
 channel 0 vset 32768 status 1
 channel 1 vset 32768 status 1
 channel 2 vset 32768 status 1
 channel 3 vset 32768 status 1
 channel 4 vset 32768 status 1
 channel 5 vset 32768 status 1
 channel 6 vset 32768 status 1
 channel 7 vset 32768 status 1
```

At this point all Sipms are reverse biased with 40.2046V + 2.5V
Connected sipms for this example have break down voltage around 50V at room temp. We need to increase bias to about 53V to see dark noise.

```
root@nanopi00:~# dactest -v hv 1 51.5
Closest voltage set point to 51.5V is 51.5001V, i.e. vset 17671
 channel 1 vset 17671 status 1
```

At this point all Sipms are reverse biased with 51.17V + 2V, some pulses should be visible on amplifiers outputs.

Adjusting reverse bias for selected channel

So let's say we want to increase reverse bias by 0.5V for SiPM connected to channel 9 while keeping others in same conditions.

```
root@nanopi00:~# dactest -v 2 0  3                    // address = 2, DAC channel = 0, voltage = 3V
Closest voltage set point to 3V is 3.00003V, i.e. vset 39322
 channel 0 vset 39322 status 1

root@nanopi00:~# dactest -r 2                         // reading back DAC
Readback values for DAC on cselect 2
V[0] = 39322
V[1] = 32768
V[2] = 32768
V[3] = 32768
V[4] = 32768
V[5] = 32768
V[6] = 32768
V[7] = 32768
```

Measuring SiPM current

Note – please make sure you apply correct channel DAC voltage for your application. See "Measuring Isipm" for details.

```
root@nanopi00:~# adctest -l 6 -r 4 3 0 1              // read input 9 Isipm 6 samples at rate 4
Gain = 1
Rate = 80 samples/second
Measuring between channels 0 and 1
```

Results:
TimeDiff (us): mean: 12533.4, stdev: 17.7606
ADCValue: mean: 87287.2, stdev: 290.387
Converted: mean: 0.86712uA, stdev: 2.88473nA

Measuring IV point (Isipm, Vsipm)

Here is an example how to take a forward I-V point on input channel 9:
We need to create negative voltage on the input channel connector.

```
root@nanopi00:~# enhv disable                         // disable HVout
root@nanopi00:~# dactest -v hv 1 0                    // set HVout close to 0V
Closest voltage set point to 0V is -0.0007789V, i.e. vset 50731
 channel 1 vset 50731 status 1
root@nanopi00:~# dactest -v 2 0 0.5                   // set channel 9 DACout to 0.5V
Closest voltage set point to 0.5V is 0.500031V, i.e. vset 6554
 channel 0 vset 6554 status 1
root@nanopi00:~# enhv enable                          // enable HVout
root@nanopi00:~# dactest -v hv 1 -3                   // set HVout close to -3V
Closest voltage set point to -3V is -2.99954V, i.e. vset 52656
 channel 1 vset 52656 status 1
root@nanopi00:~# adctest -l 1000 -r 8 hv 1 0          // read back HVout
Gain = 1
Rate = 1000 samples/second
Measuring between channels 1 and 0
Skipped 3 reads
Results:
TimeDiff (us):  mean: 1080.76, stdev: 138.865
ADCValue:       mean: -204884, stdev: 139.889
Converted:      mean: -3.05301 V, stdev: 2.08451mV
root@nanopi00:~# adctest -l 6 -r 4 3 0 1              // read input 9 Isipm 6 samples at rate 4
Gain = 1
Rate = 80 samples/second
Measuring between channels 0 and 1
Results:
TimeDiff (us):  mean: 12528.8, stdev: 15.0519
ADCValue:       mean: -3.46917e+06, stdev: 186.552
Converted:      mean: -3.44631e-05 A, stdev: 1.85323nA    // Isipm(9) = - 34.463uA
```

Recaltulating Vsipm for channel 9:
Vsipm(9) = -3.053 + 0.5 - (-34.463uA) * 59984.9ohm = -0.486V

Python script for taking IV curve

There is iv_cmd.py script in directory 'nanopi' with following options:

--start <value>	HVout start voltage
--stop <value>	HVout stop voltage
--step <value>	HVout step voltage
--adc_rate <0-9>	ADS1248 sample rate 5sps to 2ksps
--num_readings <n>	number of readings to average
--only_chans <list>	skip this option to acquire all channels
--file <filename.csv>	output file name; file will be stored in 'nanopi' directory

Please note HVout voltages used in following example might damage your device – set them with respect of actual device connected to input.

Example for **forward IV** curve:
iv_cmd.py --start_v -6.1 --stop_v -1 --step_v 0.3 --adc_rate 4 --num_readings 6 --file test.csv

Example for **reverse IV** curve on selected channels only:
iv_cmd.py --start_v 47 --stop_v 57 --step_v 0.5 --only_chans 1,2,3,4,5,6,7,8 --adc_rate 4 --num_readings 6 --file test.csv

There is the same additional voltage applied to all channels with DACs channel outputs depending on HVout to stay within Isipm ADC input voltages range:
DACs outs = **0.5V** when HVout < 0V
DACs outs = **2V** when HVout > 0V

Notes:

- DACs at **2V** are good only to measure current up to about 40uA
- In a rare occasion a read back error can occur causing a python script runtime error. HVout stays enabled in such case, disable it manually after error.