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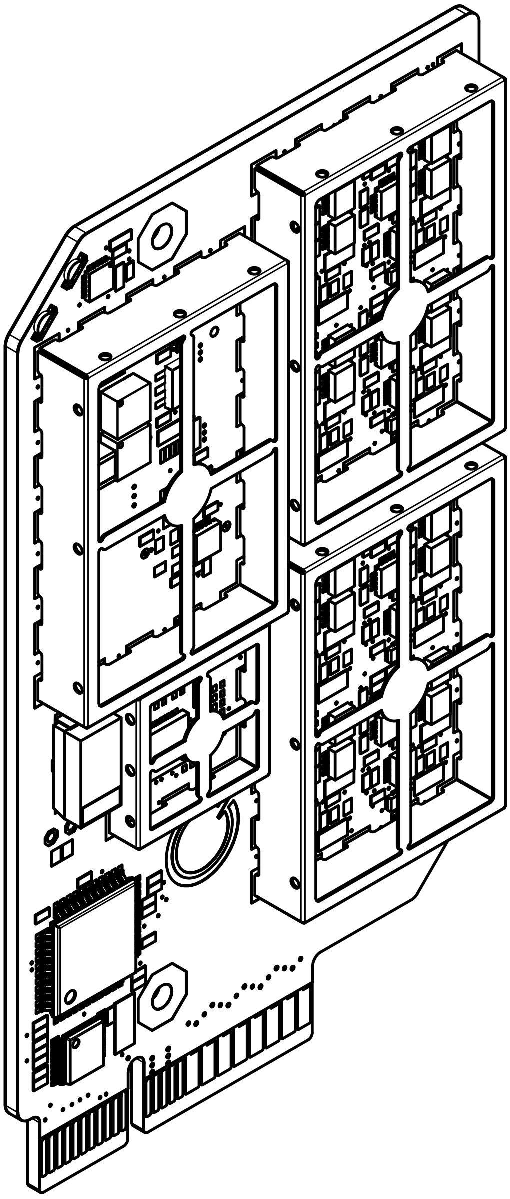
Q8a User Manual



The Q8a is a precise current- and voltage-output driver module with hardware limits. It is designed to drive thermo-optic phase modulators in silicon, silicon nitride, silicon oxynitride, and silica planar lightwave circuits. It integrates 8 channels with a per-channel current-limit and voltage-limit analog architecture, and current and voltage readout. Each channel can be programmatically switched to ground.

Qontrol modules are interoperable, and can be chained together in Qontrol backplanes to form larger control systems. A range of compatible accessories can be found at www.qontrol.co.uk.

Contents of this document

Module characteristics

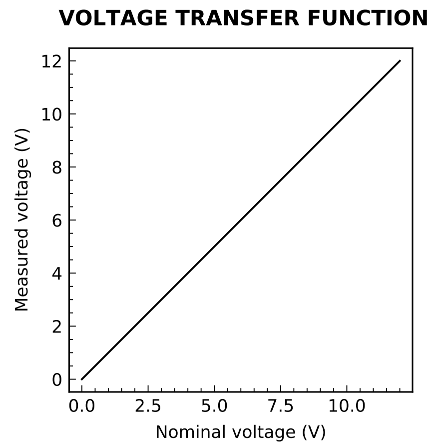
Parameter	Min.	Typ.	Max.	Units	Note
Size		103×62×12		mm³	
Weight		100		g	
Supply voltage	15	24	28	V	supply less than 18V will limit output
Supply current[1]	50		850	mA	per module
Serial parameters		8N1			
Serial baud rate		115200		baud	
Maximum reconfiguration rate			1000	Hz	
Voltage output range	0		12	V	hardware range 12.5 V
Voltage output resolution		180		μV	
Voltage output precision		40		μV	
Voltage mode crosstalk		40		μV	
Current output (sourcing)	0		100	mA	current controlled
Current output (sinking)			800	mA	uncontrolled sinking to ground (V = 0)
Current output resolution		1.6		μA	
Current output precision		500		nA	
Current mode crosstalk		5		μA	
Voltage measure range	−1.5		13.7	V	
Voltage measure precision		15		μV	
Current measure	−250		+250	mA	
Current measure precision		1.9		μA	
Power delivered to load			1.2	W	for 120 Ω load
Hardware voltage limit overshoot energy			1.8	μJ	for 120 Ω load [2]
Hardware current limit overshoot energy			27	μJ	for 120 Ω load [3]

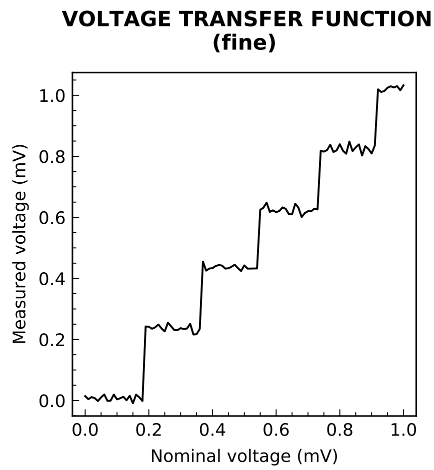
[1] To be confirmed in future revisions of this document.
[2] Take care to limit sinking current.
[3] See line transient (LC to HV) in performance data. (Current output reaches voltage limit)

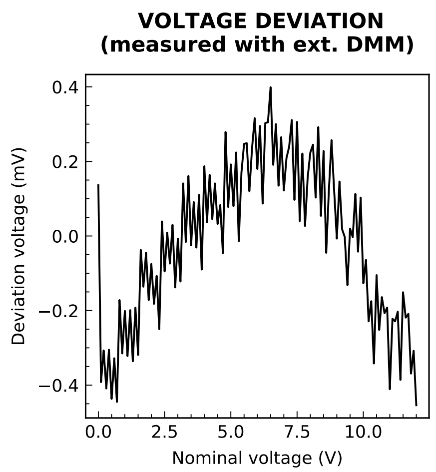
Performance data

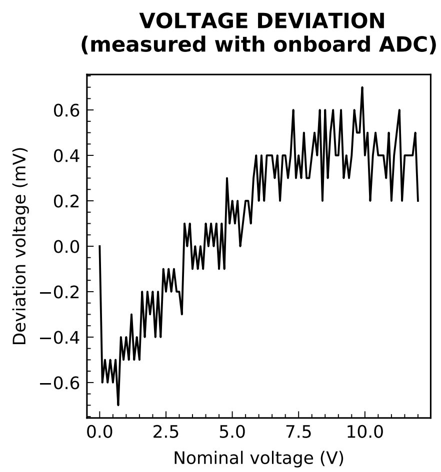
Representative performance data is presented below. Additional data may be available. Contact us at support@qontrol.co.uk to discuss your requirements. Unless stated otherwise, load conditions are: 1.0 kΩ for voltage-drive data, and 100 Ω for current-drive data.

DC data

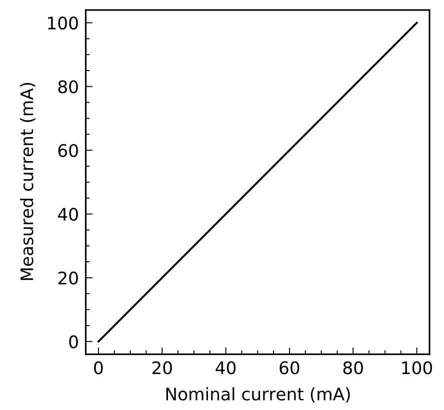




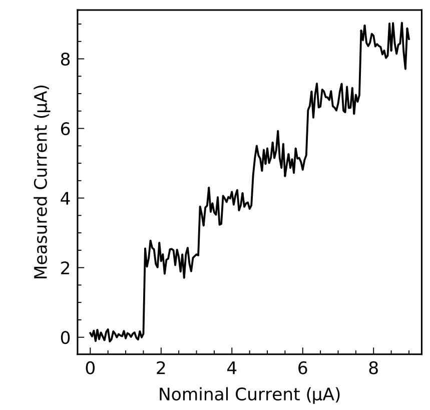




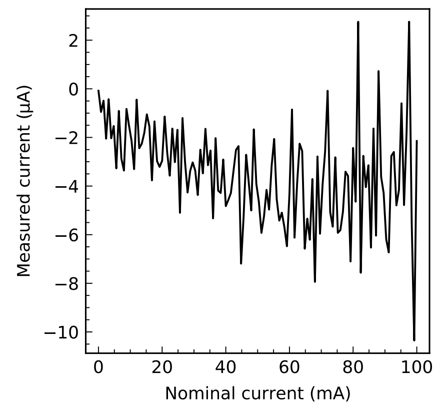
CURRENT TRANSFER FUNCTION



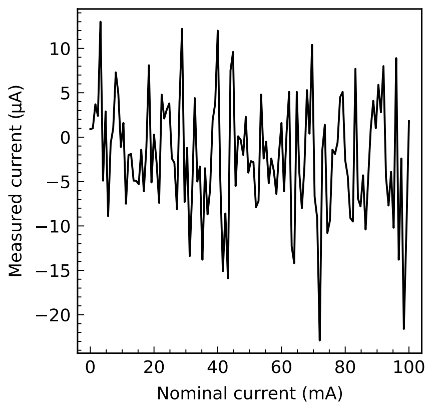
CURRENT TRANSFER FUNCTION (fine)



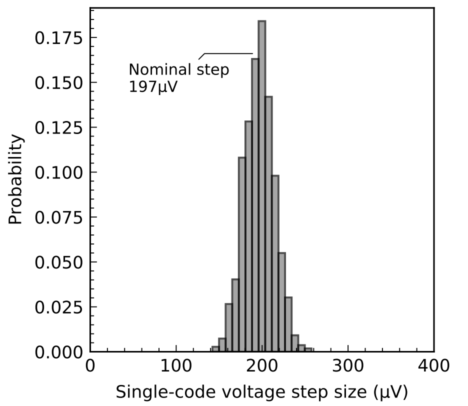
CURRENT DEVIATION (measured with ext. DMM)



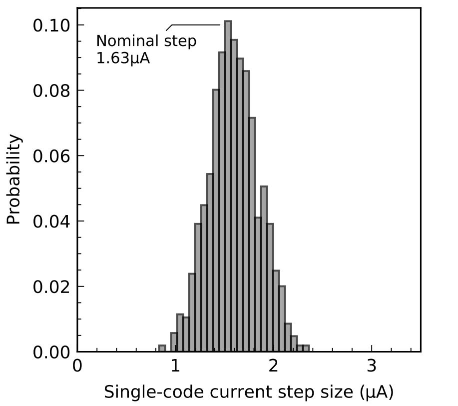
CURRENT DEVIATION (measured with onboard ADC)



VOLTAGE SINGLE-CODE STEP SIZE



CURRENT SINGLE-CODE STEP SIZE



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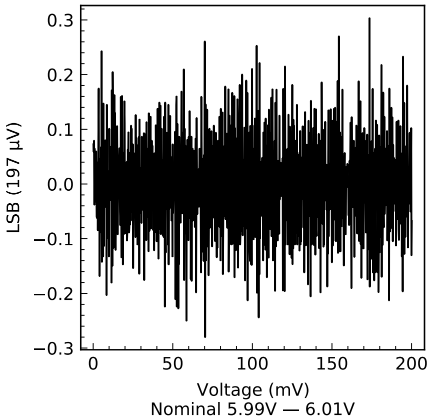
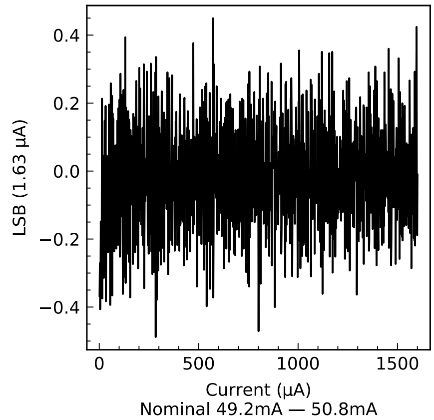
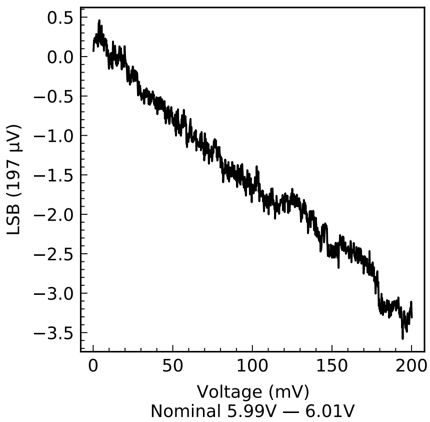
VOLTAGE-MODE DNL
(differential nonlinearity)



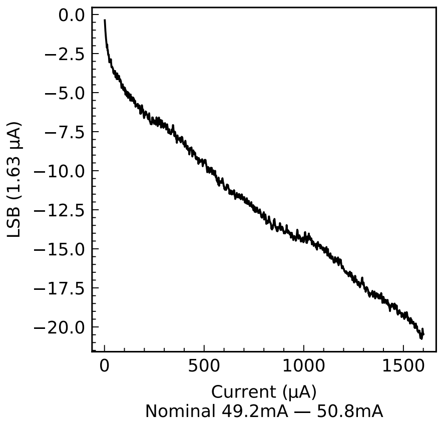
CURRENT-MODE DNL
(differential nonlinearity)



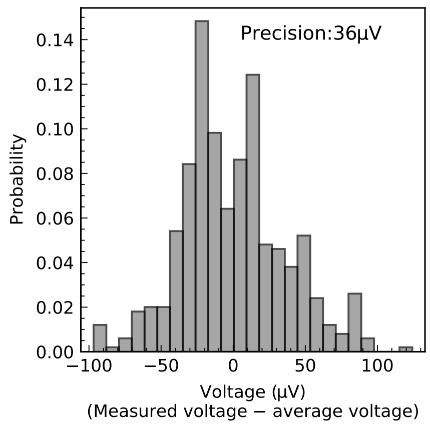
VOLTAGE-MODE INL
(integral nonlinearity)



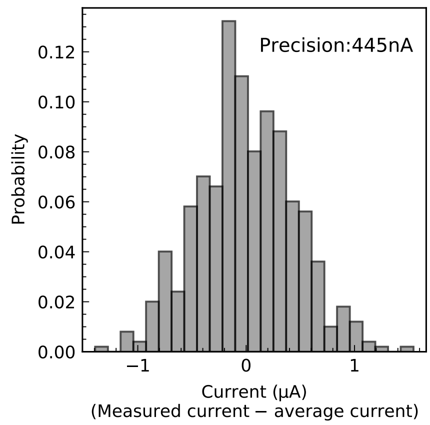
CURRENT-MODE INL
(integral nonlinearity)



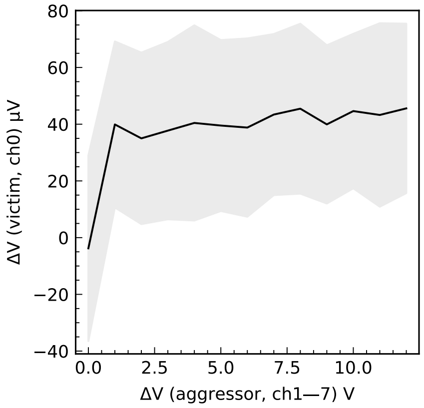
VOLTAGE Standard Deviation
(at 6 V)



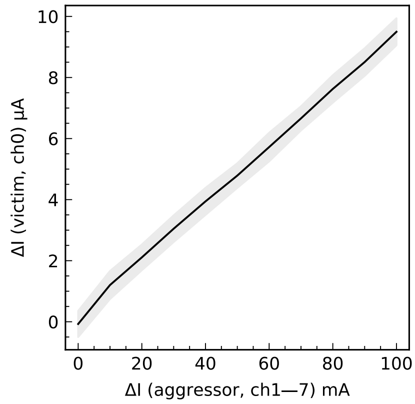
CURRENT Standard Deviation
(at 50 mA)



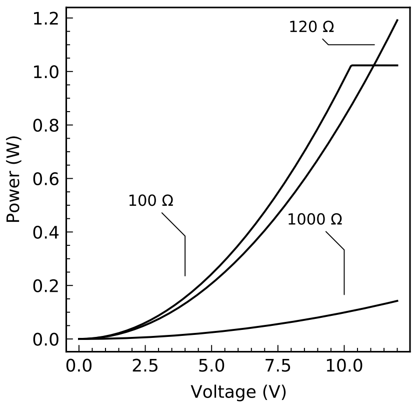
VOLTAGE-MODE CROSSTALK



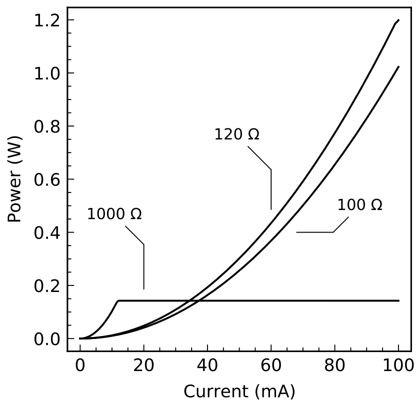
CURRENT-MODE CROSSTALK



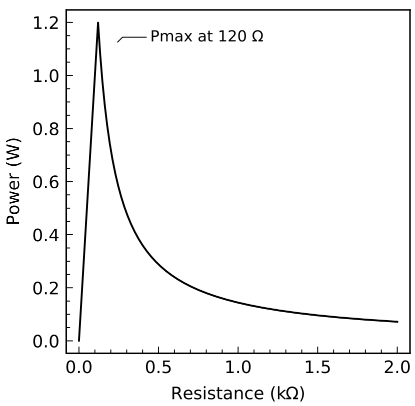
VOLTAGE-MODE POWER INTO LOAD



CURRENT-MODE POWER INTO LOAD

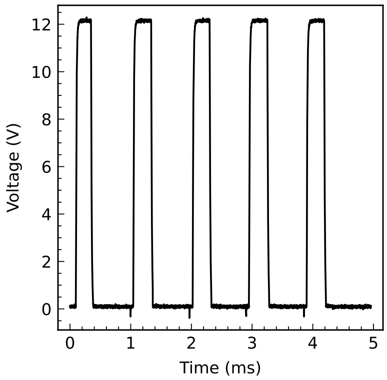


NOMINAL MAXIMUM POWER INTO LOAD

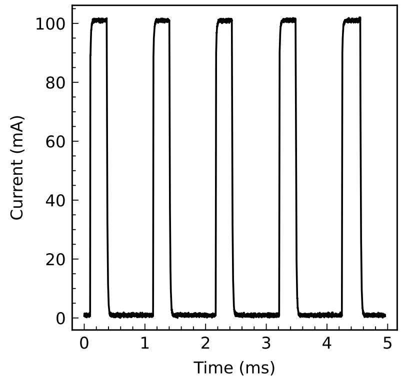


Transient data

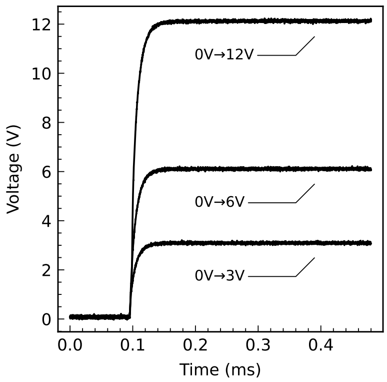
MAXIMUM RECONFIGURATION RATE
(voltage mode)



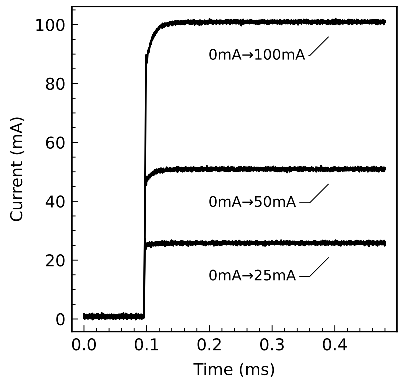
MAXIMUM RECONFIGURATION RATE
(current mode)



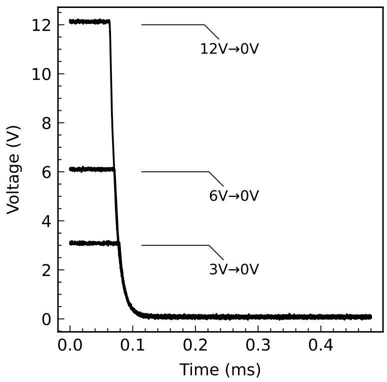
RISING EDGE TRANSIENTS
(voltage mode)



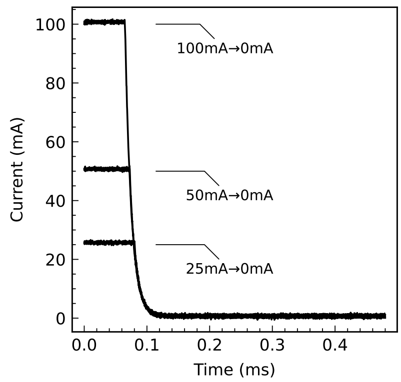
RISING EDGE TRANSIENTS
(current mode)



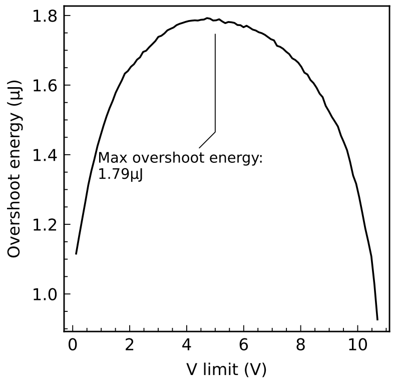
FALLING EDGE TRANSIENTS
(voltage mode)



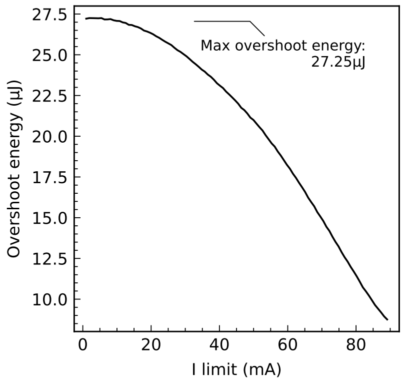
FALLING EDGE TRANSIENTS
(current mode)



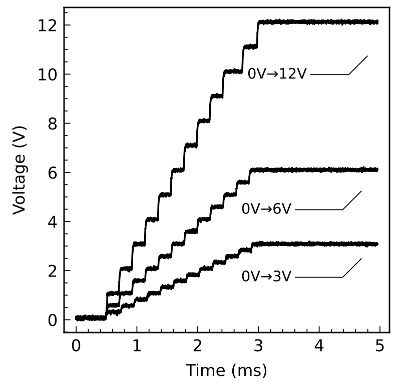
LINE TRANSIENT (LC to HV)
Load=120Ω



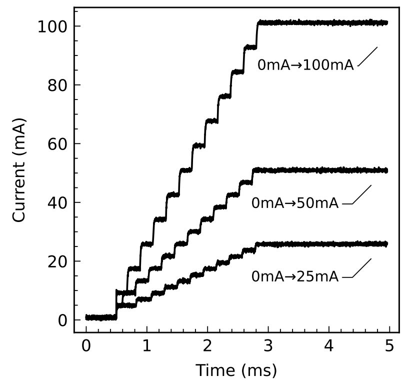
LINE TRANSIENT (LV to HC)
Load=120Ω



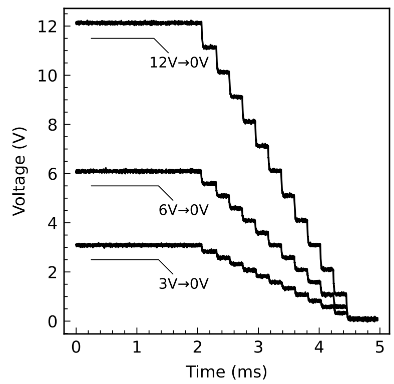
RISING EDGE TRANSIENTS
(voltage mode, MODE=1)



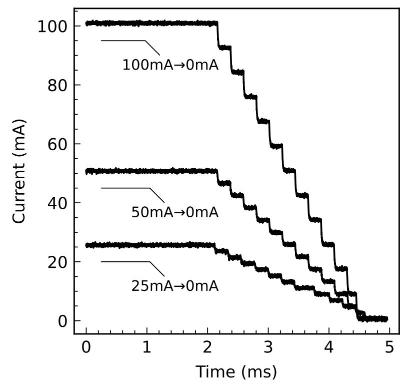
RISING EDGE TRANSIENTS
(current mode, MODE=1)

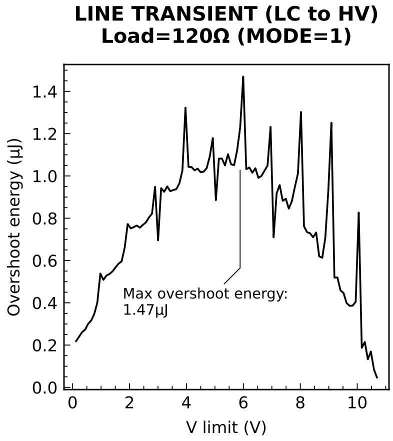


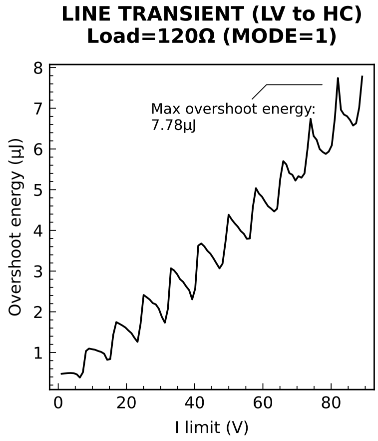
FALLING EDGE TRANSIENTS
(voltage mode, MODE=1)



FALLING EDGE TRANSIENTS
(current mode, MODE=1)




LINE TRANSIENT (LC to HV)
Load=120Ω (MODE=1)
Overshoot energy (µJ)
V limit (V)
Max overshoot energy:
1.47µJ
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10


LINE TRANSIENT (LV to HC)
Load=120Ω (MODE=1)
Overshoot energy (µJ)
I limit (V)
Max overshoot energy:
7.78µJ
1
2
3
4
5
6
7
8
0
20
40
60
80

Safety information

Hot swapping

The Q8a does not support hot swapping. Remove backplane power before inserting or removing modules.

Power supply overvoltage/undervoltage protection

After each power-on, when the user sets the output voltage or current, the Q8a will automatically detect the power supply voltage. If the power supply voltage is greater than 28V or less than 14V, the outputs will be locked, and error `E03:00` will be returned. This feature only applies on start-up and will not detect changes in the power supply voltage during operation.

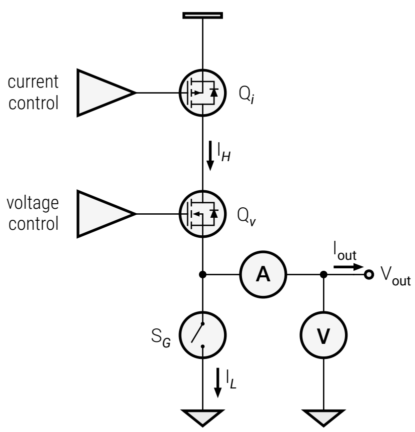
This feature can be disabled by deactivating safety features with the `SAFE` command.

Application information

Theory of operation

The Q8a functions differently to previous Qontrol models, like the Q8iv, Q8b, and Q8. Each output channel is controlled in *both voltage and current, simultaneously*, with the stricter of the two controls determining the output. This is analogous to a typical bench-top power supply, with CV (constant voltage) and CC (constant current) modes. The power supply outputs the maximum voltage permitted by its CC setting, and the maximum current permitted by its CV setting, depending on the load.

A schematic of the Q8a output is shown below. The output current and voltage are simultaneously controlled, with only one or the other controlling the output at any given moment.



High-side current and output voltage are controlled, but low-side current is not. This means that when the channel voltage (V) is set to zero (i.e. the channel ground switch S_G is activated) then no limit is placed on the amount of current that can be sunk.

Warning: Take care not to sink more than the maximum permissible current (see Module characteristics) into a single channel pin.

System set up

You will need:

- at least one Q8a module
- a suitable backplane, such as Qontrol's BP8 or BP12
- a USB Mini-B cable (supplied with the backplane)
- a power supply capable of supplying voltage and current according to Module characteristics.
- a computer running Python 3

Then proceed as follows.

1. Ensure the computer has Python 3 installed.
2. Install the Qontrol API on the computer.
   - The simplest way to do this is by using `pip`, running `pip install qontrol`.
   - You may alternately choose to use the latest version by cloning from our Github[4] and ensuring the `qontrol` module is included in your `PYTHONPATH` environment variable.
3. Set the backplane on a flat surface.
   - If using a metal surface, such as an optical table, ensure the contacts on the bottom of the backplane cannot touch the metal surface. If your backplane was supplied with stand-offs or feet, use these.
4. Insert the module(s) into the backplane, starting from the slot marked '0'.
   - Insert subsequent modules into the lowest-index slot. Qontrol BLANK8 dummy modules can be used to skip slots and ground the corresponding outputs should you not wish to fill every slot from 0.
5. Connect the backplane to your computer using the USB cable.
6. Open a terminal or command prompt and launch the Qontrol Interactive Shell by entering the command `python -m qontrol` into the computer's terminal. Enter the number corresponds to the target backplane and press Enter or Return.
   - You may need to work out which USB device is the backplane if more than one device shows up when prompted.
   - No messages will show for now, as the modules are not yet powered.
7. When you are happy with the physical connections, plug the power supply into the wall, then insert the barrel connector into the backplane power socket labelled 'Analog'.
   - The module indicator lights should illuminate, and a welcome message should be received in the computer's interactive shell.
8. Test the connection by typing IDALL? into the interactive shell, and press Enter or Return. All connected modules should respond with their device ID.

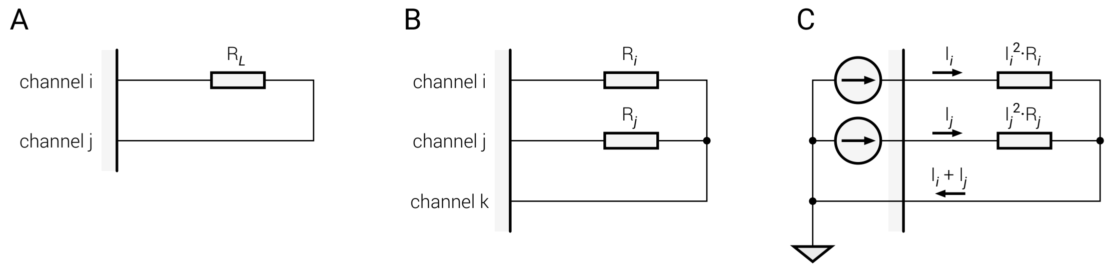
If the above steps all went smoothly, you are ready to start controlling devices. Before connecting to your application, you may wish to experiment to confirm your understanding of how the system works. For information on programming, see our Programming Manual. For a listing of unique Q8a commands, see the Progamming section, below. For an example Python script, see `example.py` included with the API code.

If you need help getting started, please contact us at support@qontrol.co.uk.

[4] https://github.com/takeqontrol/api

Load examples

Pictured below are circuit diagrams of several common load configurations.



In **A**, two channels are connected to a load, but everything else is unspecified. We will explore a few different configurations for channels *i* and *j* to understand how the module behaves more generally. Three current-driving scenarios are listed below.

1. Controlling current across an optimal load. Given R_L = 120 Ω, and releasing voltage control by setting V_i = 12 V, we vary the current on channel *i* up to I_i = 100 mA, and set V_j = 0 (grounded). This load is perfectly matched to the output driver, and the maximum 1.2 W can be delivered. The voltage derived at pin *i* will be 12 V, and the current flowing back into pin *j* will be 100 mA.
2. Controlling current across a low-resistance load. Given R_L = 60 Ω, V_i = 12 V, I_i = 100 mA, and V_j = 0 (grounded). This load is not perfectly matched to the output driver, but the output voltage will not get clipped as the current is varied over the full output range; 0.6 W can be delivered. The voltage derived at pin *i* will be 6 V, and the current flowing back into pin *j* will be 100 mA.
3. Controlling current across a high-resistance load. Given R_L = 500 Ω, I_i = 100 mA, and V_j = 0 (grounded). The requested output current is unreachable within the module's maximum supply voltage (12 V), and voltage clipping will occur above 24 mA. The voltage derived at pin *i* will be 12 V, the current flowing out of pin *i* will be 24 mA and the current flowing back into pin *j* will be 24 mA.
4. Controlling voltage across a high-resistance load. Given R_L = 500 Ω, remove the current limit on channel *i* by setting I_i = 100 mA, and controlling V_i up to 12 V, and V_j = 0 (grounded). The requested output voltage leads to output currents that are within the module's output capability, so no clipping will occur. The current derived at pin *i* will be 24 mA, the current flowing out of pin *i* will be 41.7 mA and the current flowing back into pin *j* will be 41.7 mA.

In **B**, three channels are connected to a load, but everything else is unspecified. The recommended configuration of the Q8a is shown in **C**.

5. If channels *i* and *j* are both configured to source current (I_i, I_j), and channel *k* is configured as ground (V_k = 0 V), the result is as shown in part **C** of the figure. The current flowing into channel *k* will be $I_k = I_i + I_j$; care must be taken to limit this to the maximum per-channel sink current of 800 mA.

Programming

The Q8a is fully compatible with our Python software, available on Github[5] and the Python Package Index (PyPI/PIP)[6]. For direct serial programming, debugging, and application-code development, details of direct programming are available here.

Command reference

The Q8a uses Qontrol's standard human readable command syntax. Each command has three possible variants:

1	`COMMAND[CHANNEL] = VALUE`	Set
2	`COMMAND[CHANNEL]?`	Read
3	`COMMAND[CHANNEL]`	Action

Variant 1 is a set, optionally on a given channel (e.g. `I0=50` will set channel 0 to 50 mA drive current). Variant 2 is a read, optionally on a given channel (e.g. `I0?` will measure the current flowing out of channel 0). Variant 3 is an action, which only applies to a small set of commands (e.g. `RESET` causes the module to reset, provided the safety lock has been turned off).

The optional `[CHANNEL]` parameter may or may not apply or be required for each command. If the command should apply to all channels, it can be substituted with `ALL` (e.g. `VMAXALL=6` will set the voltage limit for all channels to 6 V). Some commands may not have all three command variants available.

Commands shared with other modules with meanings specific to the Q8a:

Command	Read/Write	Units	Description
`I`	R/W	mA	Constant current setting (W) or current measurement (R).
`V`	R/W	V	Constant voltage setting (W) or voltage measurement (R).
`IMAX`	R/W	mA	Max constant current setting and dynamic limit on channel current.
`VMAX`	R/W	V	Max constant voltage setting and dynamic limit on channel voltage.
`VFULL`	R	V	Full-scale voltage.
`IFULL`	R	mA	Full-scale current.

[5] https://github.com/takeqontrol/api
[6] https://pypi.org/project/qontrol/

Command	Read/Write	Units	Description
NCHAN	R	integer	Number of channels per module.
FIRMWARE	R	–	Firmware revision.
ID	R	–	Unique device identifier.
LIFETIME	R	–	Time since module was first powered.
HELP	R	–	Basic command reference.
ECHO	R/W	{0,1}	Serial echo enable.
LED	R/W	[0,1]	Indicator brightness; 0 turns LEDs off, 1 is full brightness.
NUP	R/W	–	Number of upstream modules in daisy chain. Can be overridden. Use NUP=0 to reinitialise daisy chain. NUPALL? gives a chain manifest.
OK	R/W	{0,1}	Respond to non-read commands with "OK".
NVM	R/W	–	Read module NVM[7].
LOG	R	–	Read module internal log.
QUIET	R/W	{0,1}	Suppress serial error messages.
SAFE	R/W	{0,1}	Module safety lock state.[8]
MODE	R/W	{0,1}	DAC mode[9]
TEMP	R	°C	Read temperature from the onboard temperature sensor.
RESET	A	–	Reset module.

Error reference

Errors unique to the Q8a are listed below. Errors are transmitted upstream when they occur, and are stored in the nonvolatile log onboard each module. In the Python API, errors can be caught or ignored using the `log_handler` method; see `example.py` for an example implementation.

Error code	Description
E00:NN	Uncategorised error.

[7] See line transient (LV to HC) in performance data. (Voltage output reaches current limit)
[8] Non-volatile memory. Data survives when powered off.
[9] Only for Q8a, 'Safe on' enables supply voltage check.

Error code	Description
`E01:NN`	Over-voltage detected or requested on channel `NN`.[10] Affected channel will be reset to `V[NN]=0`.
`E02:NN`	Over-current detected or requested on channel `NN`. Affected channel will be reset to `V[NN]=0`.
`E03:NN`	Module power error.
`E04:NN`	Error in calibration routine.
`E05:NN`	General output error on channel `NN`.
`E10:NN`	Unrecognised command. `NN = 1`: bad command. `NN=2`: command not found. `NN=3`: bad operator.
`E11:NN`	Unrecognised parameter.
`E12:NN`	Unrecognised channel.
`E13:NN`	Operation forbidden or access denied. See `SAFE` in Command reference.
`E14:NN`	Buffer overflow.
`E15:NN`	UART error.
`E16:NN`	Timed out waiting for end of command.
`E17:NN`	SPI error.
`E18:NN`	ADC error.
`E19:NN`	I2C error.
`E30:NN`	Too many errors; some have been suppressed.
`E31:NN`	Fatal error; module will reboot.
`E90:NN`	Log power-on event (not an error).

Non-volatile memory layout

The Q8a non-volatile memory (NVM) is composed of 16-bit words, and is 256 (`0xFF`) words long. This memory persists even when the module is unpowered, and is guaranteed to 40-years retention, and at least 10^5 erase/re-write cycles. The layout of the NVM is detailed in the table below.

First address	Last address	Contents
`0x00`	`0x00`	Device ID number.
`0x01`	`0x01`	Lock byte.

[10] When it is enabled, any current or voltage setting will be divided into 12 steps, which will reduce the overshoot in overvoltage or overcurrent protection.

First address	Last address	Contents
`0x02`	`0x03`	Device lifetime.
`0x04`	`0x04`	Pointer to next log location.
`0x06`	`0x06`	ADC integration time.
`0x07`	`0x07`	ADC number of averages ($\log_2$).
`0x10`	`0x17`	VMAX values (8 channels, 16b).
`0x18`	`0x1F`	IMAX values (8 channels, 16b).
`0x40`	`0x4F`	Voltage input calibration (offset, gain).
`0x50`	`0x5F`	Voltage output calibration (offset, gain).
`0x60`	`0x6F`	Current input calibration (offset, gain).
`0x70`	`0x7F`	Current output calibration (offset, gain).
`0x80`	`0xFF`	Log entries. Error codes and channels (2x8b).

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Calibration[11]

When you query `VCALn?` or `ICALn?` (where `n` is the channel number), you receive four integers. In order, they are: input gain, input offset, output gain, output offset. The 'input' values calibrate the measurement (which require an external calibrated source to calibrate properly) and the 'output' values calibrate the setting (which require an external calibrated meter to calibrate properly). The 'gain' values adjust the slope of the measurement or setting, while the 'offset' values adjust the value at zero measurement or setting. Each integer is on the range [–32,768, +32,767] (signed 16-bit), where a gain or offset of zero corresponds to no-change on the measurement or setting value. For a parameter `z` (which could be current `i`, voltage `v`) the calibration values are: $z_{in,gain}, z_{in,offset}, z_{out,gain}, z_{out,offset}$

The uncalibrated output `z` is: $z = z_{int}\left(\frac{z_{full}}{(2^{16}-1)}\right)$

When calibrated, this becomes (with all integers being 16-bit, `g` for gain, `o` for offset):

$$z_{int,cal} = z_{int}\left(1 + \frac{g}{2^{16}}\right) + o$$

$$z_{cal} = z_{int,cal}\left(\frac{z_{full}}{(2^{16}-1)}\right)$$

$$z_{cal,gmax} = z_{int}(1 + \frac{2^{15}}{2^{16}})\left(\frac{z_{full}}{(2^{16}-1)}\right) = \frac{3z}{2}$$

$$z_{cal,gmin} = z_{int}(1 - \frac{2^{15}}{2^{16}})\left(\frac{z_{full}}{(2^{16}-1)}\right) = \frac{z}{2}$$

$$z_{cal,omax} = (z_{int} + 2^{15})\left(\frac{z_{full}}{(2^{16}-1)}\right) = z + \frac{z_{full}}{2}$$

$$z_{cal,omin} = (z_{int} + 2^{15})\left(\frac{z_{full}}{(2^{16}-1)}\right) = z - \frac{z_{full}}{2}$$

For Q8a HW02: v_full_out = 12.87 V; i_full_out = 106.2 mA; v_full_in = 13.76 V; i_full_in = 500 mA.

[11] The Q8a has been calibrated by a multimeter before leaving the factory. This section only explains how users can calibrate it themselves.

Physical details

Wiring and Pin Map

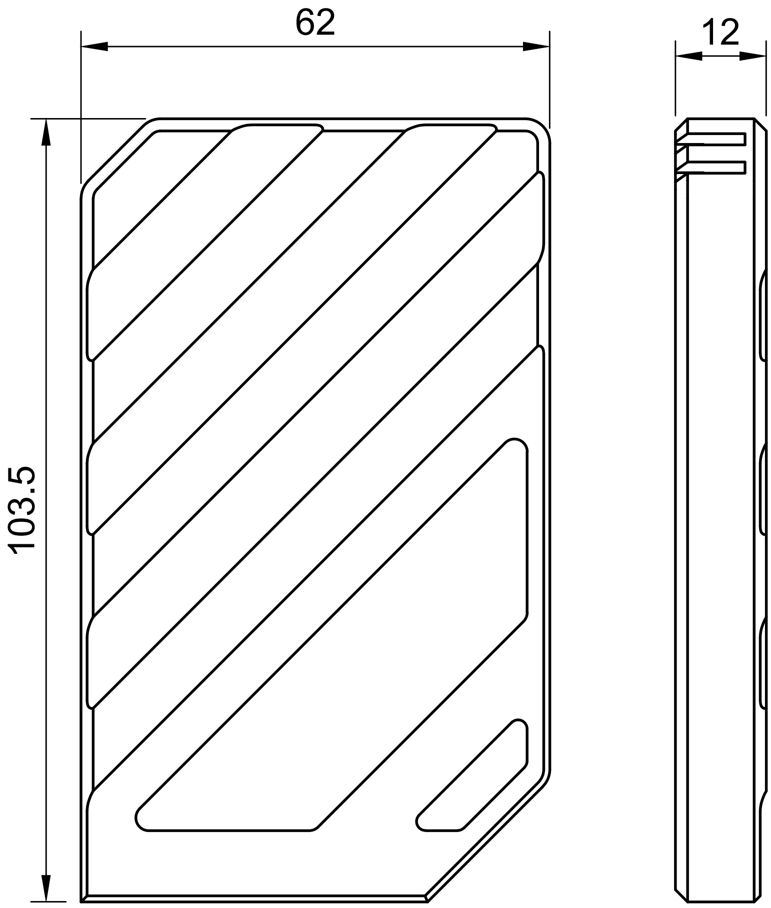
The Q8a connects to a BP8 or BP12 backplane via a card-edge connector[12]. Qontrol's backplanes conveniently handle the power and communications connections, as well as breaking out the module's analog channels to a shielded CAB8 or CAB12 connector. In the table below, side A refers to the bottom or back side of the module, which is thinner, and side B refers to the top or front side. The keying gap is between pins 11 and 12.

Side	Pin Number	Function
A	1	UART downstream receive
B	1	UART upstream transmit
A	2	UART downstream transmit
B	2	UART upstream receive
B	3	Reset
A	3	Flash programming clock
A	4	Flash programming data
A	8	Downstream RTR (output)
B	8	Upstream CTS (input)
A,B	10,11	Digital ground reference
A,B	12,13	Power supply input
A,B	14,15	Power supply return
B	17,18	Channel 0
B	19,20	Channel 1
B	21,22	Channel 2
B	23,24	Channel 3
B	25,26	Channel 4
B	27,28	Channel 5
B	29,30	Channel 6
B	31,32	Channel 7
A	17–32	Ground and shield

[12] These connectors use the PCI-e 4x mechanical specification. Despite using mechanically compatible connectors, the Q8a is not a conforming PCI-e device. Do not attempt to connect the Q8a to another PCI-e device as damage will result.

Mechanical

All dimensions are in millimetres.



Notes and disclaimer

If you find an error in this document, or have suggestions for how we could make it better, please do get in touch with us at support@qontrol.co.uk with your ideas and feedback.

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1.1	2023/08/22
1.0	2023/08/11