



## Joulescope™ JS110 User's Guide

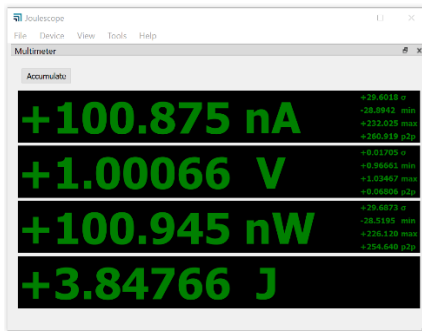
### Precision DC Energy Analyzer

Revision 0.6 - PRELIMINARY

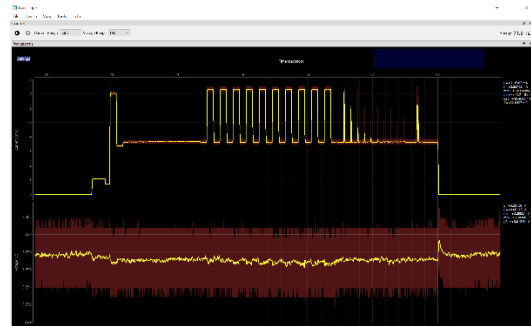
Last revised 2019 Oct 16



Affordable, easy-to-use, accurate and precise



Multimeter view



Oscilloscope view

Applications include:

- Microprocessor and microcontroller power profiling and optimization
- Hardware power optimization
- Sleep current optimization
- Hardware and software troubleshooting
- Software characterization and interrupt service routine profiling
- USB 2.0 inrush and suspend current pre-compliance testing
- General purpose current, voltage, power, and energy measurement

The Joulescope™ JS110 is the most affordable and easy-to-use precision DC energy analyzer. It measures current and voltage, then computes power and energy. Many modern battery powered devices and IoT devices have a high dynamic current range which makes accurate measurement difficult. When “sleeping” the devices consume nanoamps (nA) or microamps ( $\mu$ A), but when active, they consume milliamps (mA) or amps (A). Joulescope combines high-speed sampling and rapid dynamic current range switching to provide accurate and seamless energy measurements, even for devices with rapidly varying current consumption. The unprecedented accuracy and low-cost of Joulescope allows every engineer on the team to measure the energy consumed by the target device during development. Joulescope provides rapid feedback on how changes affect the overall product battery life.

Joulescope displays instantaneous voltage, current, power, and energy, like a multimeter. The multimeter provides a quick and easy summary of the present state of your device.

Joulescope displays waveforms of voltage and current over time, like an oscilloscope. This oscilloscope view allows you to identify and to troubleshoot dynamic behavior and short events including inrush current, event handlers, and tasks.

## Key benefits

- **Dynamic range:** Joulescope accurately measures electrical current over nine orders of magnitude from amps down to nanoamps. This wide range allows accurate and precise current measurement for modern devices. Sleep modes are often just nanoamps (nA) or microamps ( $\mu$ A). Active modes are often milliamps (mA) or amps (A).
- **Low voltage drop:** Most multimeters and current meters have a significant voltage drop (sometimes called burden voltage or insertion loss) which affects the actual voltage delivered to the device under test. Joulescope has a total voltage drop of 25 mV at 1 A, which keeps your target device running correctly. Joulescope's extremely fast current range switching maintains low voltage drop even under rapidly varying current demands.
- **Makes the invisible visible:** Joulescope measures current and voltage 2 million times per second with 250 kHz bandwidth. This high sampling rate makes the power consumption of interrupt service routines, inrush currents, and other short events visible.
- **Easy to use:** Joulescope reports cumulative energy consumption along with real-time current, voltage, and power. The multimeter view clearly shows the most recent value while the oscilloscope view allows you to explore changes over time. Much simpler and more accurate than anything in its class!
- **Customizable:** The Joulescope host software is open source on GitHub. You can also swap the banana jack front panel with front panels that have other connector types! The front panels are open source on GitHub.
- **Portable:** Joulescope fits in your backpack and only needs a small part of your desk. Take Joulescope wherever you want to use it!
- **Affordable:** Joulescope is affordable and priced so that every developer on the team can have one at their desk. With such convenient access, Joulescope allows developers to see the impact of their changes on energy consumption immediately. Developers can make informed choices to account for battery life during design. Eliminate power consumption surprises during final product testing!

## Key features

- -1V to 15V voltage range
- -1A to 3A current range, continuous
- Up to 10A current pulses (<10 ms, < 3A average per second)
- Down to 1.5 nA resolution, equivalent to 32-bits of dynamic range
- Synchronously measures voltage and current at 2 million samples per second, 14-bit
- 250 kHz bandwidth
- Rapid 1  $\mu$ s switching between shunt resistors for seamless dynamic current measurement
- Computes power and total energy
- Operates with minimal voltage disturbance between IN and OUT ports
- Up to  $\pm 48$ V common mode voltage between USB ground and IN-, IN+, OUT+, and OUT-
- 2 general purpose inputs and 2 general purpose outputs
- Programmable on/off for power cycling the target device and measuring inrush currents
- USB 2.0 high-speed host connectivity with full-rate data streaming
- Host software support for Microsoft® Windows®, Apple® Mac® OS X®, and Linux®
- Host software provides real-time graphs of current and voltage over time
- Host software is open source and available on GitHub
- Swappable front panel with open source designs on GitHub
- Firmware upgradable

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## What comes in the box

Your Joulescope JS110 purchase includes:

- Joulescope JS110 instrument
- Banana Jack Front Panel, already installed
- 6' USB 2.0 A to B cable
- T15 Torx screwdriver
- Quick Start Guide
- Joulescope sticker

You will need to provide:

- A host computer which must be running Microsoft® Windows® 10, Window 7, Apple® Mac® OS/X® or Linux®. Most computers manufactured within the last five years should work. The computer requires an available USB 2.0 port, at least 500 MB of hard drive / solid state drive storage space, and 1 GB of available RAM.
- Suitable cable(s) to connect Joulescope to your power source
- Suitable cable(s) to connect Joulescope to your target device.

You need an internet connection to download the free software for your computer.

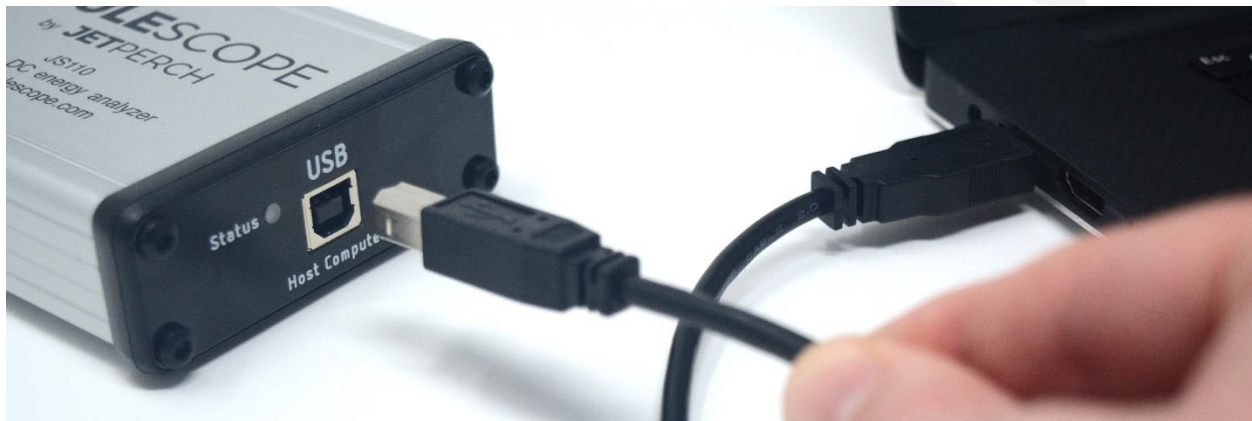
## Quick start

Download the host software from <http://www.joulescope.com/download>. Follow the instructions on the download page to install the software for your platform.

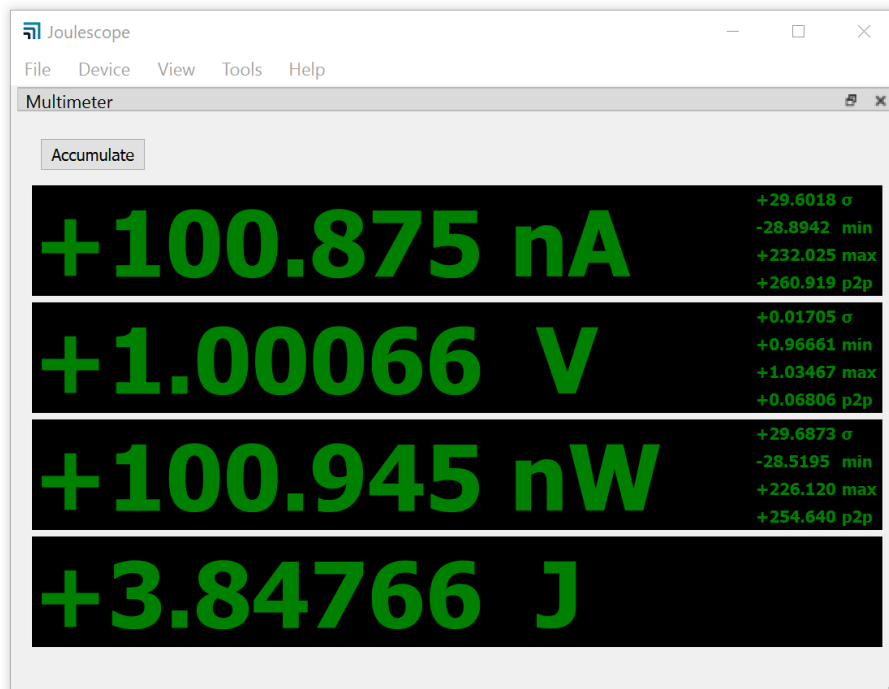
Start the Joulescope host software.



Connect the Joulescope USB port to the host computer using the provided USB cable.



The host software will automatically detect the connected Joulescope and start displaying data.

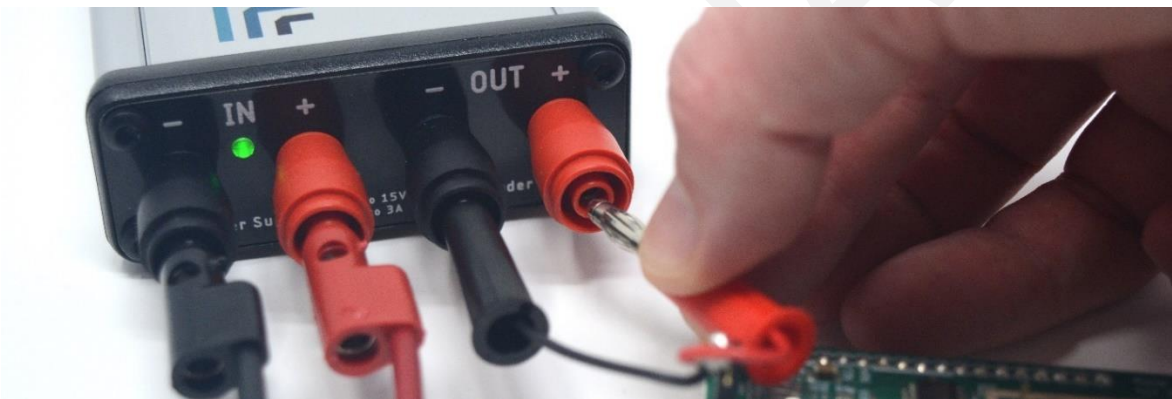




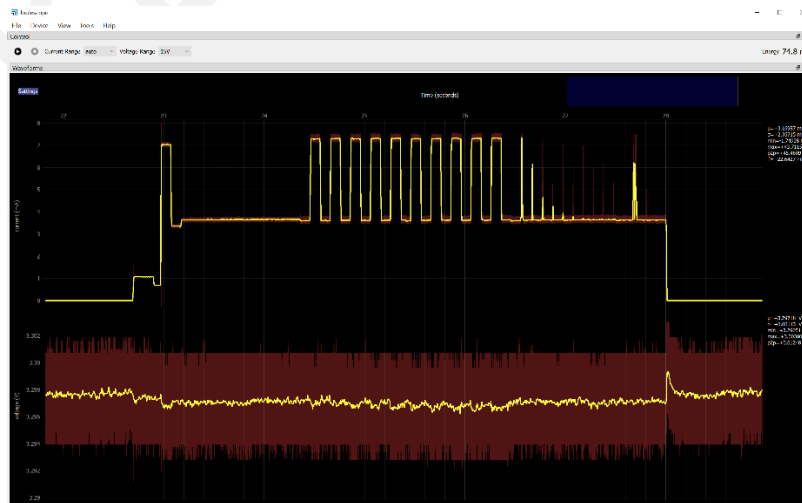
Connect the Joulescope **IN** port to your power source. If using a configurable power supply, set the voltage and current suitable for your device under test. The maximum voltage between **IN+** and **IN-** should never exceed  $\pm 15V$ . **IN** and **OUT** are electrically isolated from USB, but the voltage between any port and US ground should never exceed  $\pm 48V$ .



Connect the Joulescope “OUT” port to the power input for your device under test.



Operate your device under test. Use the Joulescope host software to measure the current, voltage, power and total energy consumption. If desired, dive into more detail with the oscilloscope view **View** → **Oscilloscope Default** to display waveforms of voltage, current, and power over time.



## Specifications

### Absolute maximum ratings

	Min	Max	Unit
USB voltage	-0.3	6	V
Max voltage applied between IN+ to IN-	-20	20	V
Max voltage applied between OUT+ to OUT-	-20	20	V
Max voltage to USB ground (IN+, IN-, OUT+, OUT-)	-48	48	V
Input current (powered, burst)	-10	10	A
Input current (powered, sustained)	-3	3	A
Input current (unpowered)	-0.5	N/A (off)	A
Storage temperature	-40	80	°C
Operating temperature	0	50	°C
Relative humidity (non-condensing)	0	95	%
Altitude from sea level	-100	2500	m
Max voltage applied to GPI relative to USB ground	-10	10	V

### Mechanical

	Typical	Unit
Weight	217	grams
Width	81	mm
Length (including banana jack front panel)	150	mm
Height	33	mm

### Recommended operating conditions

	Test condition	Min	Typical	Max	Unit
Operating temperature		10		40	°C
USB supply voltage		4.5	5.0	5.5	V
USB supply current				500	mA
Voltage applied to IN		-1.0		15	V
Input current	continuous	-1.5		3	A
Input current pulse	< 10 milliseconds, < 3A average			10*	A
Input current pulse	< 100 milliseconds < 3A average			5*	A

\* Suitable for handling inrush currents when connecting capacitive loads.

### Specification conditions

Temperature	23 °C ± 10 °C
Humidity	20% to 80% RH, non-condensing
Calibration interval	1 year*

\* Recommended to comply with industry standard practices, but Joulescope is designed not to need recalibration.

## Current measurement specifications

Range	Accuracy	Resolution	Impedance	Bandwidth
10 A*	$\pm 0.3\% \pm 7 \text{ mA}$	1 mA	0.01 $\Omega$	250 kHz
2 A	$\pm 0.3\% \pm 1.50 \text{ mA}$	175 $\mu\text{A}$	0.01 $\Omega$	250 kHz
180 mA	$\pm 0.3\% \pm 150 \mu\text{A}$	15 $\mu\text{A}$	0.11 $\Omega$	250 kHz
18 mA	$\pm 0.25\% \pm 15 \mu\text{A}$	1.5 $\mu\text{A}$	1.11 $\Omega$	250 kHz
1.8 mA	$\pm 0.25\% \pm 1.5 \mu\text{A}$	150 nA	11.1 $\Omega$	180 kHz
180 $\mu\text{A}$	$\pm 0.25\% \pm 150 \text{ nA}$	15 nA	111 $\Omega$	70 kHz
18 $\mu\text{A}$	$\pm 0.25\% \pm 30 \text{ nA}$	1.5 nA	1111 $\Omega$	15 kHz

\* Joulescope is designed for 3 A sustained. See the recommend operation conditions for maximum durations for higher currents.

Test current measurement bandwidth by varying the effective load impedance. Due to load capacitance, varying the source voltage is not a valid method of testing current bandwidth.

## Voltage measurement specifications

Range	Accuracy	Resolution	Impedance	Bandwidth
15 V	$\pm 0.1\% \pm 11 \text{ mV}$	1.2 mV	-	250 kHz
5V	$\pm 0.1\% \pm 3.5 \text{ mV}$	400 $\mu\text{V}$	-	250 kHz

## General specifications

	Test condition	Min	Typical	Max	Unit
Sampling frequency	25 °C		2000000		sps
Sampling frequency	25 °C	-20		20	ppm
Front panel insertions				100	

## Parasitic effects specifications

	Test condition	Min	Typical	Max	Unit
Current leakage (IN+ to IN-)	25 °C, +3.3V		2		nA
Current leakage (IN+ to IN-)	25 °C, +5V		2		nA
Current leakage (IN+ to IN-)	25 °C, +15V		3		nA
Shunt resistor voltage, max	0 to 2 A, static		20	21	mV
Burden voltage (IN+ to OUT+)	< 1 A, banana jacks	0	25	30	mV
Burden voltage (OUT- to IN-)	< 1 A, banana jacks	0	3	8	mV
Shunt switching time	Over-range < 100 ns rise time	0	0.8	1.2	$\mu\text{s}$
Over-range settling time		0	2	5	$\mu\text{s}$
Under-range settling time		0	2	5	$\mu\text{s}$

## Software-controlled fuse specifications

	Test condition	Min	Typical	Max	Unit
Current leakage (IN+ to OUT+)	25 °C, 3.3V		5		nA
Current leakage (IN+ to OUT+)	25 °C, 5V		7		nA
Current leakage (IN+ to OUT+)	25 °C, 15V		28	5000	nA

## General Purpose Inputs & Outputs

	Test condition	Min	Typical	Max	Unit
Programmable logic level voltage		1.8		VUSB - 0.2	V
Input leakage per pin	25 °C			±1	µA
Input leakage per pin				±2	µA
Output voltage high	-100 µA	Vcco-0.1			V
Output voltage high	-4 mA @ 1.65 V	1.2			V
Output voltage high	-8 mA @ 1.65 V	1.9			V
Output voltage high	-24 mA @ 1.65 V	2.4			V
Output voltage high	-32 mA @ 1.65 V	3.8			V
Output voltage low	100 µA			0.1	V
Output voltage low	4 mA @ 1.65 V			0.45	V
Output voltage low	8 mA @ 2.3 V			0.3	V
Output voltage low	24 mA @ 3 V			0.55	V
Output voltage low	32 mA @ 4.5 V			0.55	V
Output impedance	10 mA	90	100	110	Ω
GPI sample rate			2		MSPS
Continuous output current	Per pin			±50	mA
Total power dissipation	Over output impedance			0.25	W

The Joulescope uses the TI SN74LVC2T45 for both the GPIs and GPOs. See the [SN74LVC2T45 datasheet](#) for more information. Both the GPIs and GPOs are protected with the [Vishay VEMI45AA-HNH](#) which is an EMI filter with ESD protection. The filter is a pi filter with 100 Ohm resistance and capacitance between 29 pF and 60 pF.

### GPIO Supply

	Min	Typical	Max	Unit
+5V output	4.4V	VBUS – 0.1	5.5	V
Current			100	mA
Output impedance		1		Ω

## Host software

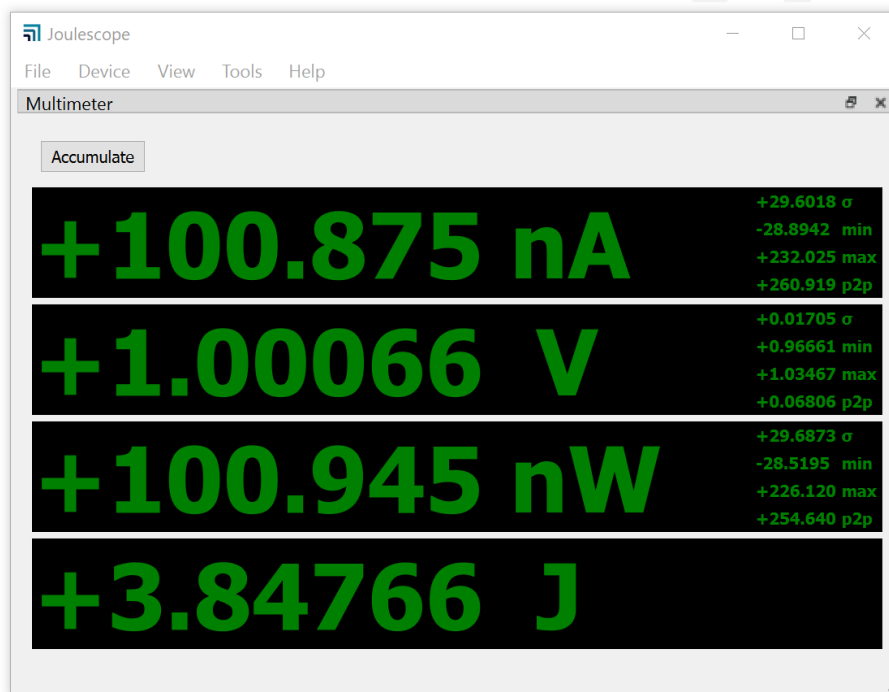
The Joulescope host software runs on a host computer and communicates with the Joulescope unit over USB 2.0. The Joulescope software is available to download at

[www.joulescope.com/download/](http://www.joulescope.com/download/)

The software works with Microsoft® Windows® 10, Windows® 7, Apple® Mac® OS/X® and Linux®. For Linux, only Ubuntu 18.04.1 LTS is tested. Joulescopes software only supports 64-bit operating systems with 64-bit python.

## Multimeter view

Upon launching the host software, you see the multimeter view:



You can return to this view at any time using **View** → **Multimeter**.

The multimeter view provides the present operating state at a glance. The multimeter view displays several quantities:

- Electrical current in amperes (A)
- Electrical voltage in volts (V)
- Power in watts (W)
- Energy in joules (J)

This display, along with all other value displays in the Joulescope software, the SI standard prefixes for orders of magnitude:

Prefix	Power	Name
G	$10^9$	giga-
M	$10^6$	mega-
k	$10^3$	kilo-
m	$10^{-3}$	milli-
$\mu$	$10^{-6}$	micro-
n	$10^{-9}$	nano-
p	$10^{-12}$	pico-

The multimeter view updates every half second (0.5 seconds). The software computes and displays the statistics over each half-second time window. The large numbers are the mean (also called average) value of that quantity over the window. The software also displays:

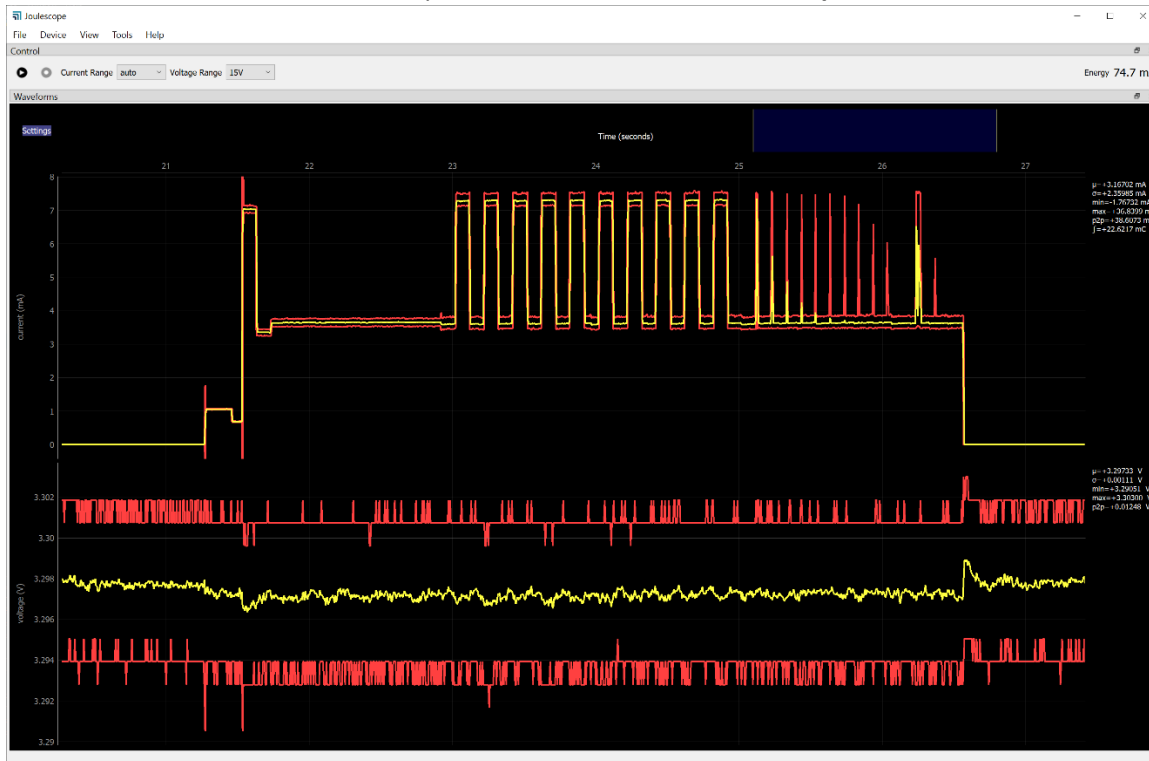
- $\sigma$ : The standard deviation
- min: The minimum value
- max: The maximum value
- p2p: The peak-to-peak value, which is equal to (max – min)



Note that energy does not display these additional statistics since they are not meaningful.

Every update normally represents only the data recorded over the last half second. If you click on the “Accumulate” button to activate it, then the software extends the statistics to combine each new half-second window without discarding results from previous windows.

## Oscilloscope view

The software includes an oscilloscope view. Click **View** → **Oscilloscope**.



The first view allows you to control the connected Joulescope. Press  to pause or resume capturing live data. Press  to start and stop recording data to a file. This feature is only available when the device is capturing live data.

**Current Range** allows you to select Joulescope's active shunt resistor. Most applications use **auto**, where Joulescope automatically selects the best range. However, you can manually force the range.

**Voltage Range** allows you to select the voltage range. Joulescope includes a **15V** range and a more sensitive **5V** range.

The oscilloscope view also displays the energy consumed since the Joulescope software started. Use **Tools** → **Clear Energy** to reset the energy to zero.

The software displays two different waveforms by default. The top waveform is electrical current, and the bottom waveform is electrical voltage. The x-axis is time. If you have a Joulescope connected, it will automatically add the most recent data to the right of the waveform and shift existing data to the left. The y-axis data is the value measured at that point in time. Joulescope captures data 2 million times per second. When zoomed out, each x-axis pixel may represent many, many samples, which are that pixel's sample window. The plot displays the statistics over each pixel. The yellow line is the mean (average). The red lines are the minimum and maximum. Power glitches, such as interrupt service routines, are very interesting for energy optimization. The minimum and maximum ensure that you do not miss these events, even when zoomed out. When you eventually zoom in far enough, the red lines disappear because 1 pixel becomes 1 sample, and the minimum and the maximum are the same as the average.

You can use **File → Preferences → Waveform → show\_min\_max** to disable these lines or display the minimum to maximum region as a fill instead.

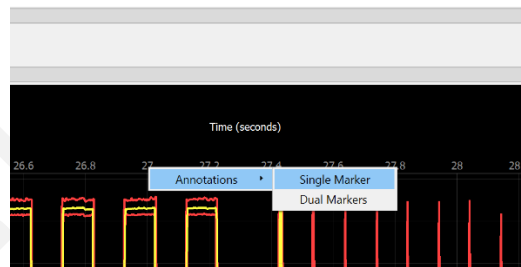
The software computes statistics quantities over the full time window shown in the present view for each waveform. The software displays the statistics on the right edge of the window. The statistical quantities are:

- $\mu$ : The mean (also called average) value
- $\sigma$ : The standard deviation
- p2p: The peak-to-peak value (max - --in)
- min: The minimum value
- max: The maximum value
- $\int$ : The integral over the time window

The waveform view supports **Annotations** to present additional information, which include:

- A **Single Marker** that display information at a single point. Names used by other equipment for this feature include marker and cursor.
- **Dual Markers** that display information over a time window. Names used by other equipment for this feature include cursors, timing markers, window, and range selection.

To display statistics at a single point, move the mouse to the x-axis time labels near the top. Then right click (control click on Mac OS) to bring up the context menu. Select **Annotations → Single Marker**.



Left click the marker to move it with the mouse. As you move the mouse over the waveforms, the vertical marker follows along. The line displays statistics about that location:

- t: The sample time for the displayed sample or window
- $\mu$ : The mean (also called average) value

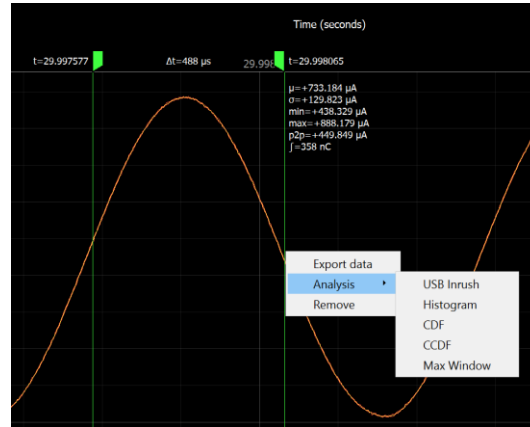
When the location contains more than one sample per displayed pixel, the line displays statistics over that single pixel's sample window:

- $\sigma$ : The standard deviation
- p2p: The peak-to-peak value (max - --in)
- min: The minimum value
- max: The maximum value

Left click again to keep the marker in position.



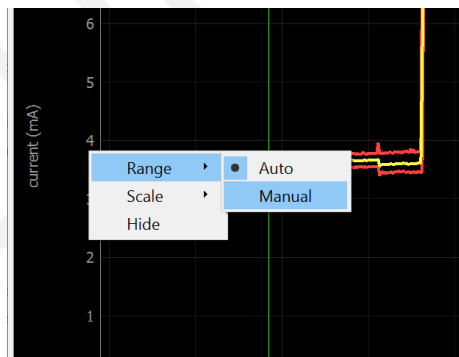
To display statistics over a selectable range, right click on the x-axis time labels and select **Annotations** → **Dual Markers**. Left click a marker to move it with the mouse, then left click again to stop moving the marker. Right click (control click on Mac OS) on one of the dual markers to export data or perform analysis over the selected range.



Use the scroll wheel to zoom in and zoom out. The zoom operation keeps the point under the mouse cursor at the same location after the zoom operation. However, when the maximum extents are reached on zoom out, that point may move. When viewing live data, the zoom operation always keeps the most recent data in view at the right.

Press the left mouse button and drag the cursor left or right to pan in time. Pan is not supported when viewing live data from a Joulescope.

The software displays on a linear scale with automatic y-axis ranging by default. The y-axis context menu has additional options. Right click (control click on Mac OS) on a y-axis to display the menu.



When manual ranging is activated, hover over the y-axis and use the scroll wheel to zoom in and out. Left click and drag up and down to pan the y-axis.

Use the y-axis context menu to change the y-axis scale mode. The y-axis displays in linear coordinates by default, but also supports a logarithmic scale. A logarithmic scale is very useful to display wide dynamic ranges for current and power.

Use the y-axis context menu to hide the signal. Click **Settings** at the top left to display the settings menu. Select **Add** → **[Signal Name]** to display a signal not already shown.

## Energy

A Joulescope measures current and voltage two million times per second. It then multiplies current by voltage to compute power. Joulescope then integrates power over time to compute energy. Joulescope displays energy in both the Multimeter view and Oscilloscope view. This value starts accumulating when the software starts. Use **Tools** → **Clear Energy** to reset it to zero at any time.

The energy value provides a simple tool to observe changes, especially for software. You can baseline the performance of an operation by recording the measured energy value. You can then make changes, repeat the test, and observe the new energy value. The oscilloscope view enables you to investigate in further detail.

The Joulescope software is under active development, and new features are being added. Future features will make analyzing and comparing energy consumption even easier.

## Open source

The host software is open source and written in Python 3.6+. The host software consists of two layers:

Repo name	Python package name	Description
<a href="https://github.com/jetperch/pyjoulescope_ui">pyjoulescope_ui</a>	<code>joulescope_ui</code>	The Joulescope User Interface written in QT/PySide2
<a href="https://github.com/jetperch/pyjoulescope">pyjoulescope</a>	<code>joulescope</code>	The Joulescope “driver” which enables scripting

The `joulescope` package was designed so that you can script custom Joulescope actions and integrate Joulescope into your applications. See the GitHub repositories for the latest details.

[https://github.com/jetperch/pyjoulescope\\_ui](https://github.com/jetperch/pyjoulescope_ui)

<https://github.com/jetperch/pyjoulescope>

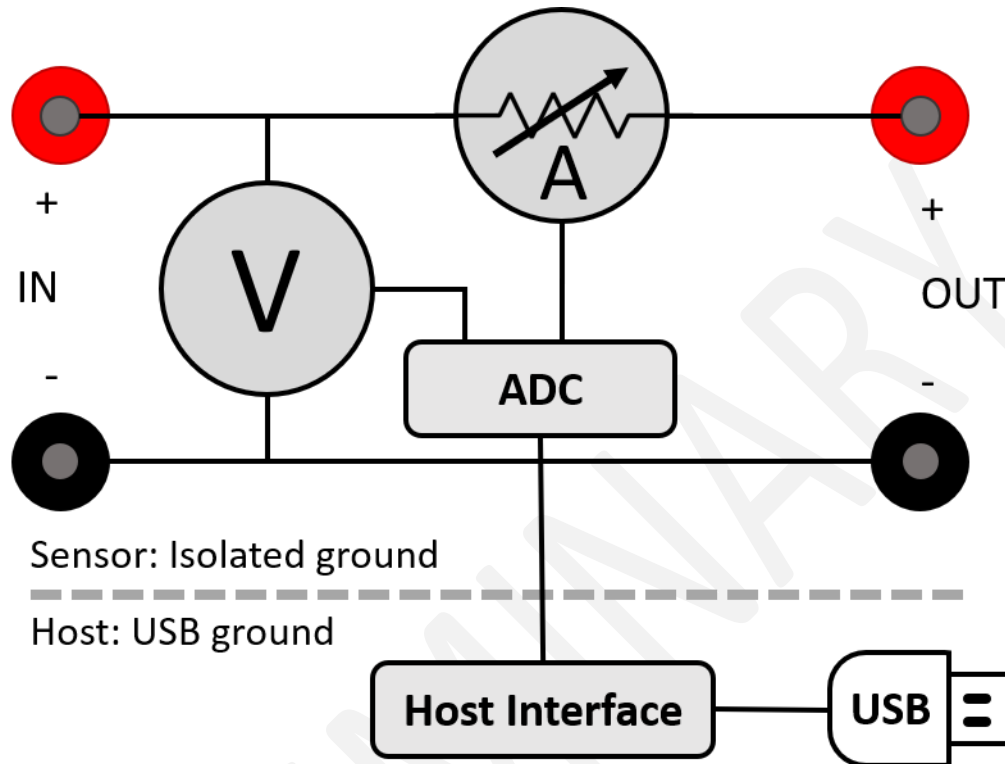
You can find examples for how to use Joulescope in your Python application at:

[https://github.com/jetperch/pyjoulescope\\_examples](https://github.com/jetperch/pyjoulescope_examples)

The Joulescope software depends upon other software and libraries. See `CREDITS.html` for [pyjoulescope\\_ui](https://github.com/jetperch/pyjoulescope_ui) and [pyjoulescope](https://github.com/jetperch/pyjoulescope).

## Theory of operation

Joulescope simultaneously measures current and voltage, and then computes power and energy. Joulescope combines a voltmeter and a fast auto-range current shunt ammeter.



### Ammeter

The ammeter consists of multiple shunt resistor values. Joulescope actively adapts to keep the maximum voltage across the shunt resistor to 20 mV. This low voltage drop minimizes the impact on the device under test. Other equipment, including standard multimeters, have a much larger burden voltage that can cause the target device to behave unusually.

As the current changes, the ammeter selects the optimal shunt resistor value. Joulescope uses dedicated hardware to quickly select the appropriate shunt resistor to avoid impacting the device under test. The shunt value selection uses the ADC output, dedicated over-range comparators, and a unique algorithm that runs in an FPGA. The FPGA selects the active shunt resistors using MOSFETs, which were carefully qualified to meet Joulescope's demanding performance characteristics.

The shunt resistor selection does take some time. How fast does the shunt resistor need to change to have minimal impact? The linearized equation is:

$$t = C * \Delta V / \Delta I$$

Let's take a typical example. The target device takes 3.3V and can tolerate a temporary 3% (0.03) voltage glitch on a 1 amp change. If the target device has 10  $\mu$ F of capacitance, the required shunt resistor switching time is approximately:

$$10 \mu\text{F} * 3.3 \text{ V} * 0.03 / 1 \text{ A} = 1 \mu\text{s}$$

Joulescope was designed to achieve 1  $\mu$ s switching speed to meet this demanding case. Most target systems have larger capacitance and less dramatic step current changes. In all cases, the shunt resistor selection is always make-before-break to ensure uninterrupted connectivity to the target device.

### Voltmeter

Both the voltage and current are sampled 2 million times per second, and the sample data is sent to the computer. Unlike traditional oscilloscopes, a Joulescope is always capturing data. The terms “trigger” and “sample buffer” do not apply to the Joulescope device, and all sample data is sent to the host computer. The Joulescope User Interface temporarily stores capture data in a circular buffer. However, Joulescope can also record to a file, and the capture size is only limited by your computer’s available disk space.

### High impedance / low leakage

Joulescope measures currents at nanoamp resolutions and accuracies. Many contemporary devices have input impedances of 1 M $\Omega$  to 10 M $\Omega$ , which is not good enough. At 3.3V, a 10 M $\Omega$  load draws:

$$3.3V / 10 M\Omega = 330 \text{ nA}$$

Joulescope features a combined input impedance and leakage current of approximately 1 G $\Omega$ . This high input impedance allows Joulescope to make accurate and precise low current measurements.

### Electrical isolation

The sensor side of Joulescope is electrically isolated from the host computer. This isolation allows you to insert Joulescope into your test system without worrying about ground issues including ground loops and ground noise.

## How to swap the front panel

Joulescope comes standard with a banana jack front panel. However, Joulescope is designed to be flexible and can support other connector types.



The front panel design is open source, and available on GitHub:

[https://github.com/jetperch/joulescope\\_front\\_panels](https://github.com/jetperch/joulescope_front_panels)

To swap the front panel, you will need:

- T15 Torx screwdriver
- The new front panel

Swapping the panel is easy, but you do need to take proper precautions to avoid damaging your Joulescope. Joulescope can be damaged by static electricity that you don't even notice. When you expose the Joulescope main board, be sure only to handle it by the board edges. Follow these steps carefully:

- Completely disconnect the Joulescope, including **IN**, **OUT** and **USB** ports.
- Use the Torx screwdriver to remove the four screws at the corners of the existing front panel.
- Gently push the Joulescope's USB connector into the Joulescope body. This action will push the front panel out. Expose about ½" or 1 cm.
- Grab the sides of the main board in one hand, being careful not to touch any other part of the board.
- Grab the existing front panel by the sides and carefully pull it directly out.
- Grab the new front panel by the sides, align the pins, and carefully push it in.
- Fully seat the front panel in the black plastic bezel. You may need to gently guide the board to ensure that the USB connector fits in the back panel.
- Use the Torx screwdriver to install the four screws at the corners of the existing front panel.

## GPI & GPO

The Joulescope contains two (2) general purpose inputs (GPI) and two (2) general purpose outputs (GPO). These signals enable time-synchronization with the device under test and other external equipment. The user interface can display GPIs time-synchronized with current, voltage, and power in the oscilloscope view.

One intended application for the GPIs is to allow the target microcontroller firmware to identify areas of interest. The microcontroller can toggle bits so that you can easily see the energy consumption in the marked time windows.

When the GPI feature is activated, the voltage and current samples will only be 13 bits (the GPI will be in the LSB), not the full 14-bits. The GPI may also be configured to trigger a Joulescope capture.

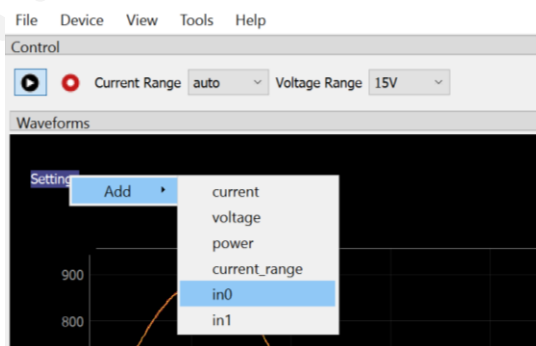
GPO1 emits a pulse on Joulescope capture start, which allows Joulescope to trigger other equipment. GPO2 is under software control.

Both GPI and GPO are referenced to USB ground. The GPI and GPO will support a 3.3V logic level at minimum, but programmable support for signal levels from 1.8V to 5.0V is planned.

Many applications using Joulescope will want isolated GPI/GPO for improved performance. We do plan to recommend and perhaps offer a separate isolation module that supports electrical isolation along with all the great features you would expect to make quality, low-power measurements including:

- Electrical isolation
- Self-powered target interface with very low power from target device – leakage currents only
- Variable voltage technology levels with external reference voltage
- ESD protection
- Overvoltage protection (GPO)
- Short circuit protection (GPO)
- Very high ( $G\Omega$ ) input impedance (GPI)

The GPI data collection is supported in the Joulescope production hardware and firmware. The Joulescope User Interface 0.6.6+ supports GPI display. To display either IN0 or IN1, select **Settings** → **Add**, then select either in0 or in1.



## Electrical Isolation

The Joulescope is electrically isolated between the USB interface and the IN/OUT sensor. Joulescope is rated to  $\pm 48V$  between USB ground and any of IN+, IN-, OUT+, and OUT-. The individual component ratings far exceed this specification. The components are:

Part #	Mfgr	Description	Isolation working	Isolation 60s	Isolation 1 s
760390014	Würth	Transformer	400 VRMS	2500 VAC	3125 VAC
Si8661BB-B-IS1	Silicon Labs	Digital isolator	445 VRMS		4500 VRMS
TLP2361(TPL,E	Toshiba	Opto isolator	500 VRMS	3750 VRMS	

The printed circuit board (PCB) clearance between the isolated sensor side and the USB host side is 1 mm. The use of an aluminum enclosure effectively limits the isolation voltage and requires that USB chassis ground surrounds the sensor edges. If you use Joulescope in a custom application without the standard enclosure, the four chassis ground rails (2 top & 2 bottom) can be cut around the isolation line to give a 4 mm PCB clearance between the USB host side and the sensor side.

## Typical Behavior

This section contains information regarding typical Joulescope behavior.

### Step Response

Joulescope is a shunt ammeter with incredibly fast autoranging. This section contains typical autoranging measurements.

The test setup includes a Joulescope, a custom load board, a power supply, a computer and some cables. A custom load board is the Joulescope target. The load board was specifically designed for the sole purpose of creating very fast, repeatable edges. It has a 1 M $\Omega$  resistor in parallel with a 1 $\Omega$  resistor. The board contains a momentary pushbutton and debouncer which is the input to the MCP1416 MOSFET driver. The MCP1416 drives the FDMC7678 MOSFET which enables or disables the 1 $\Omega$  resistor. The entire circuit is powered by a 9V battery and connected to the Joulescope OUT.

The power supply is a Siglent SPD3303X-E bench supply configured for 1.00V and 2.9A. The supply is connected to Joulescope IN. Any bench supply with reasonable transient performance should do.

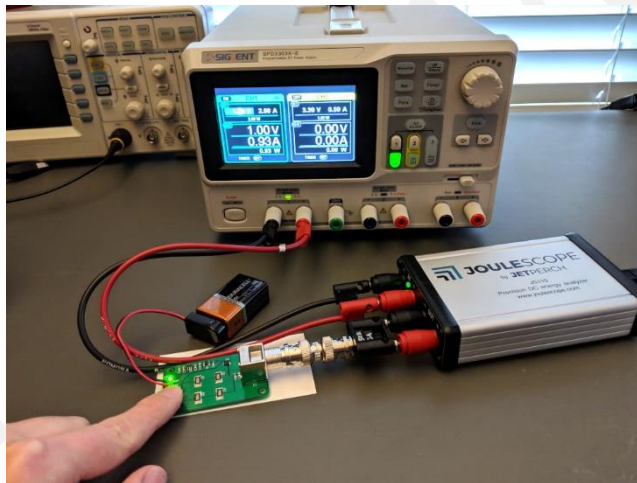


Figure 1: The step response test setup

The normal Joulescope user interface software captures data while pressing the target board's switch to toggle the MOSFET & 1 $\Omega$  resistor. A custom Python script reads the data, processes the data, and creates plots. The python script finds each edge and aligns them so that they can be plotted together. The plots show rising edges in the left column and falling edges in the right column.

The first capture "step\_2A.png" is the baseline with Joulescope autoranging disabled and set to a fixed 2A range. The rise time you see is due to the Joulescope bandwidth. The actual edge is much, much faster.



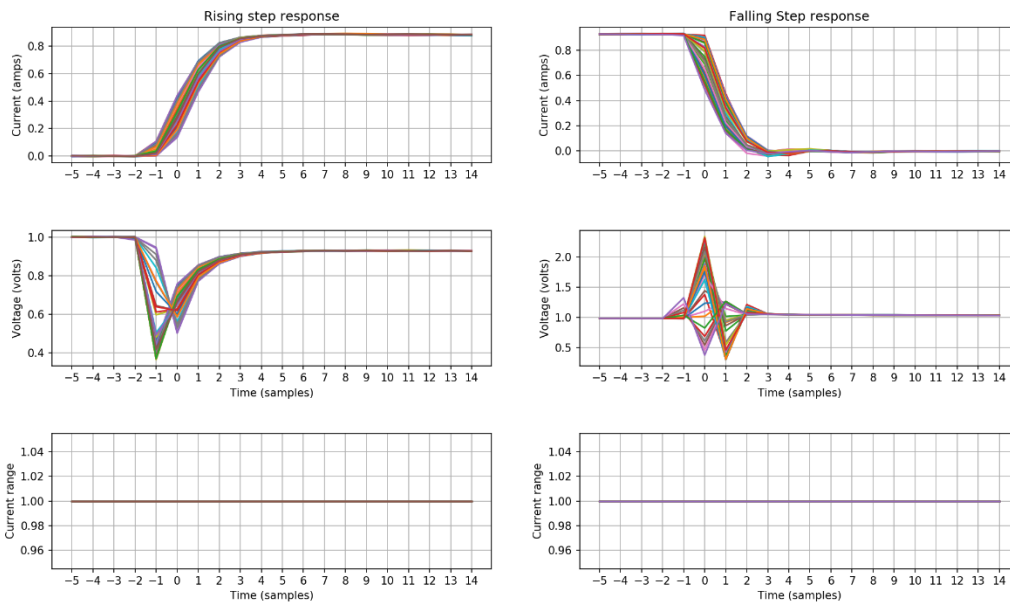


Figure 2: Step response with fixed 2A range

The second capture “step\_autorange.png” is with autoranging. The two samples after over-range tend to contain “garbage” data that messes up the y-axis range, so they are omitted. These samples are captured at 2 MSPS (500 ns). Joulescope’s stated bandwidth is 250 kHz ( $4 \mu s = 8$  samples).

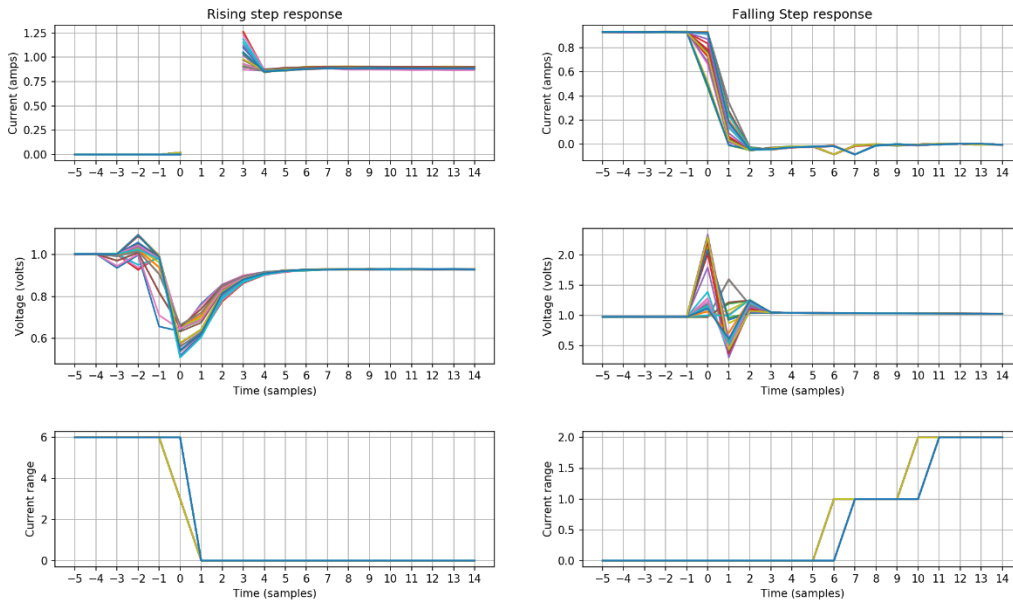


Figure 3: Step response with autoranging

The Joulescope specification states that range switching occurs within 1.2  $\mu\text{s}$  max. This specification determines how much (or in the case of Joulescope, how little) voltage drop happens when the target changes current demands. The Joulescope specification gives over-range settling time is 2  $\mu\text{s}$  typical with 5  $\mu\text{s}$  max. This specification determines how well Joulescope can measure data through the transition. Any autoranging ammeter needs to be VERY fast to limit voltage variations at the target device, and Joulescope was designed to meet these demanding requirements.

PRELIMINARY

## Compliance

For additional compliance information, see

<https://www.joulescope.com/compliance/JS110>

### United States

#### FCC Notice

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.


Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

### Europe

**Warning** – This is a Class A product. In a domestic environment this product may cause radio interference, in which case the user may be required to take adequate measures.

	In accordance with the European Waste Electrical and Electronic Equipment Directive (WEEE), this device needs to be recycled in accordance with local regulations.
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### Safety

Joulescope is an Extra-Low Voltage device as per IEC 60038. Joulescope is intended for INDOOR USE only.

### RoHS Directive 2011/65/EU, 2015/863/EU

This product is CE marked and complies with the European Union's Directive 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

EU Directive 2015/863 of 31 March 2015 amends Annex II to Directive 2011/65/EU of the European Parliament and of the Council as regards the list of restricted substances.

Country of origin

United States of America

Made in Maryland, USA.

PRELIMINARY

## Maintenance

Joulescope is designed for minimal maintenance. To clean your Joulescope, disconnect all wires from the unit. You can gently wipe the unit with a damp cloth using water only. Using rubbing alcohol or other cleaning agents may damage your Joulescope. Do not submerge.

Joulescope is factory calibrated and should continue to function within specifications over its operating life. For critical or demanding applications, you may choose to follow industry-standard practices and have your Joulescope recalibrated annually. Visit <http://www.joulescope.com> or contact [support@jetperch.com](mailto:support@jetperch.com) for details. Recalibrating Joulescope requires custom equipment and trained personnel. Only Jetperch LLC is authorized to perform recalibration.

PRELIMINARY

## Warranty

The Joulescope JS110 is warranted to be free from defects in materials and workmanship for a period of one year from the date of purchase. If your Joulescope becomes inoperative from such a defect within the warranty period, Jetperch will either repair or replace your unit, at Jetperch's discretion.

This warranty covers normal use. The warranty does not cover damage which occurs during shipment. The warranty does not cover damage from improper use, misuse, abuse, tampering, alteration, accident, software hacking, or recalibration other than by an authorized recalibration provider.

Jetperch LLC makes no other representations or warranties, express or implied, of any kind including, but not limited to, any implied warranty of merchantability or fitness for a particular purpose. Jetperch shall not be liable for loss of use of Joulescope. Jetperch will not be liable for any other incidental or consequential damages, expenses, or financial losses, nor will Jetperch be liable for claims of such damages.

To submit a warranty claim, contact [support@jetperch.com](mailto:support@jetperch.com). You will need to provide your name, address, phone number, and email. You will also need to provide proof of purchase, such as a purchase receipt, that contains the original date of sale.

## Contact

To purchase this product, visit:

<https://www.joulescope.com>

To submit a warranty claim, first review the warranty section above. You can submit warranty claims to:

[support@jetperch.com](mailto:support@jetperch.com)

If you have questions regarding operation of Joulescope, search the website at:

<https://www.joulescope.com/>

And visit the forum:

<https://forum.joulescope.com/>

For compliance information, see

<https://www.joulescope.com/compliance/JS110>

If you wish to contact Jetperch regarding the operation of your Joulescope, contact us through email at:

[support@jetperch.com](mailto:support@jetperch.com)

### Location

Jetperch LLC  
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Olney, MD 20832-1734  
USA

## Glossary

### **Accuracy**

The average variation in the bias between measurements and truth. Good measurements are both accurate and precise.

### **Ammeter**

A device that measures electrical current.

### **Burden Voltage**

The voltage drop that occurs through the test equipment device. For shunt ammeters, the burden voltage includes the voltage across the shunt resistor, connectors, fuses, and any additional resistance in the device.

### **Current**

The flow of electric charge per time from positive voltage to negative voltage, measured in amperes (A), often called amps. One amp is one coulomb of charge flowing per second. One coulomb is approximately  $6.242 \times 10^{18}$  electrons, but electric current is defined opposite to the electron flow.

### **Energy**

The total power exerted over time, measured in joules (J). Energy is the time integral of power.

### **Insertion Loss**

The loss in signal power due to a device in the signal path, most commonly used in reference to radio frequency (RF) or telecommunications. See **Burden Voltage**.

### **Multimeter**

A multifunction device that usually incorporates a voltmeter and shunt ammeter, at a minimum. A standard multimeter supports only one measurement quantity at a time.

### **Ohm's Law**

The equation that relates voltage, current and resistance:  $V = I * R$

### **Oscilloscope**

A device that graphically displays a one or more signals, usually voltages, varying over time as a two-dimensional plot with time on the x-axis and the signal on the y-axis.

### **Power**

The time-rate of doing work, measured in watts (W). Power is voltage multiplied by current.

### **Precision**

The amount of variation between measurements of the same value relative to each other. Good measurements are both accurate and precise.

### **Resistance**

The quantity of opposition to the flow of electric current.

### **Shunt Ammeter**

An ammeter that measures the voltage across a resistor, and then uses Ohm's Law to compute current.



**Shunt Resistor**

The resistor used by “Shunt Ammeters” to detect current using Ohm’s Law:  $I = V / R$ . Given a known R and a measured V, the ammeter computes I.

**Universal Serial Bus (USB)**

The now ubiquitous standard for connecting computers and peripherals. Joulescope connects to the host computer using USB 2.0.

**Voltage**

The electric potential difference, measured in volts (V).

**Voltmeter**

A device that measures electrical voltage.

PRELIMINARY

## User's guide information

This section contains information regarding this document. See the other sections of this document for information regarding the Joulescope product.

### Copyright notice

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### Warranty

The Joulescope JS110 User's Guide is provided AS-IS with no other representations or warranties, expressed or implied, of any kind including, but not limited to, any implied warranty of merchantability of fitness for a particular purpose. Jetperch LLC does make reasonable effort to present accurate and reliable information in this Joulescope JS110 User's Guide.

The information in this User's Guide is subject to change. The most up-to-date version of this User's Guide can be retrieved from <http://www.joulescope.com/>.

### Why is this document preliminary?

The performance specifications in this document are derived from error analysis on the design. The performance specifications were validated on 25 beta units, which have confirmed these specifications. Full performance qualification over the first production units is still pending. The specifications herein are conservative, but final performance specifications may change.

## Change log

Revision	Date	Description
0.6	2019 Oct 16	Added GPO current and power specifications. Added GPI information. Clarified annotations, markers and cursors. Increased over-range settling time from 3 $\mu$ s to 5 $\mu$ s. Updated directions for UI 0.6.
0.5	2019 Jun 20	Added table of contents to table of contents. Updated GPI/O section for production rev H. Added statement about software support. Fixed typos and grammar. Updated compliance information. Updated for 0.4.x software. Updated "Why is the document preliminary".
0.4	2019 Mar 11	Updated electrical isolation section for rev E
0.3	2019 Mar 1	Added electrical isolation section Added GPI/GPO Added Typical Behavior section with step response Fixed SI unit capitalization: See the definitive <a href="#">SI Brochure</a>
0.2	2019 Feb 12	First public release
0.1	2018 Dec 17	Initial draft