AEM13920 Evaluation Kit User Guide

Description

The AEM13920 evaluation kit (EVK) is a printed circuit board (PCB) featuring all the required components to operate the AEM13920 integrated circuit (IC) in QFN 40-pin package.

The AEM13920 evaluation board allows users to test the e-peas IC and analyze its performances in a laboratory-like setting or in product mock-ups.

It allows easy connections to one or two energy harvesters (e.g. an indoor PV cell and an outdoor PV cell), an optional 5 V power source, a storage element and an application circuit. It also provides all the configuration accesses to set the device in any of the modes described in the datasheet. The control and status signals are available on standard pin headers or through an I²C bus communication, allowing users to over-ride preconfigured board settings through host MCU and evaluate the IC performances.

The AEM13920 EVK is a plug and play, intuitive and efficient tool to optimize the AEM13920 configuration, allowing users to design a highly efficient subsystem for the desired target application. Component replacement and operating mode switching is convenient and easy.

More detailed information about AEM13920 features can be found in the datasheet.

Applications

Remote Controls	eReader
PC Peripherals	Electronic Shelf Labels
Asset Tracking	Indoor Sensors

Features and Benefits

Two-way screw terminals
- Two DC sources of energy (SRCx).
- ZMPP configuration.
- Energy storage element (STO).
- Application circuit (LOAD).
- 5 V DC power input (5V_IN).

3-pin headers
- Sources voltage regulation mode configuration.
- Storage element voltage thresholds configuration.
- Load voltage regulation configuration.
- I²C enable/disable.
- Thermal monitoring enable/disable.
- Shipping mode enable/disable.

2-pin headers
- 5 V power input max. current presets.

6-pin header
- I²C communication with application circuit.

USB connector
- 5 V DC power input (max. 5.5 V peak).

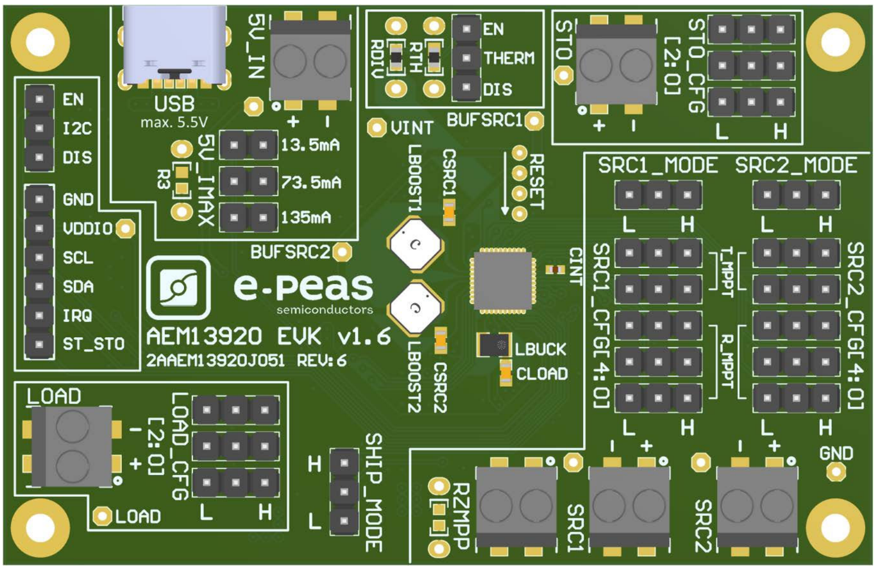
Evaluation Kit Information

Part number	Dimensions
2AAEM13920J051	76 mm x 49 mm

Device Information

Part Number	Package	Body size
10AEM13920J0000	QFN 40-pin	5x5mm

Appearance



1. EVK Connection Diagram

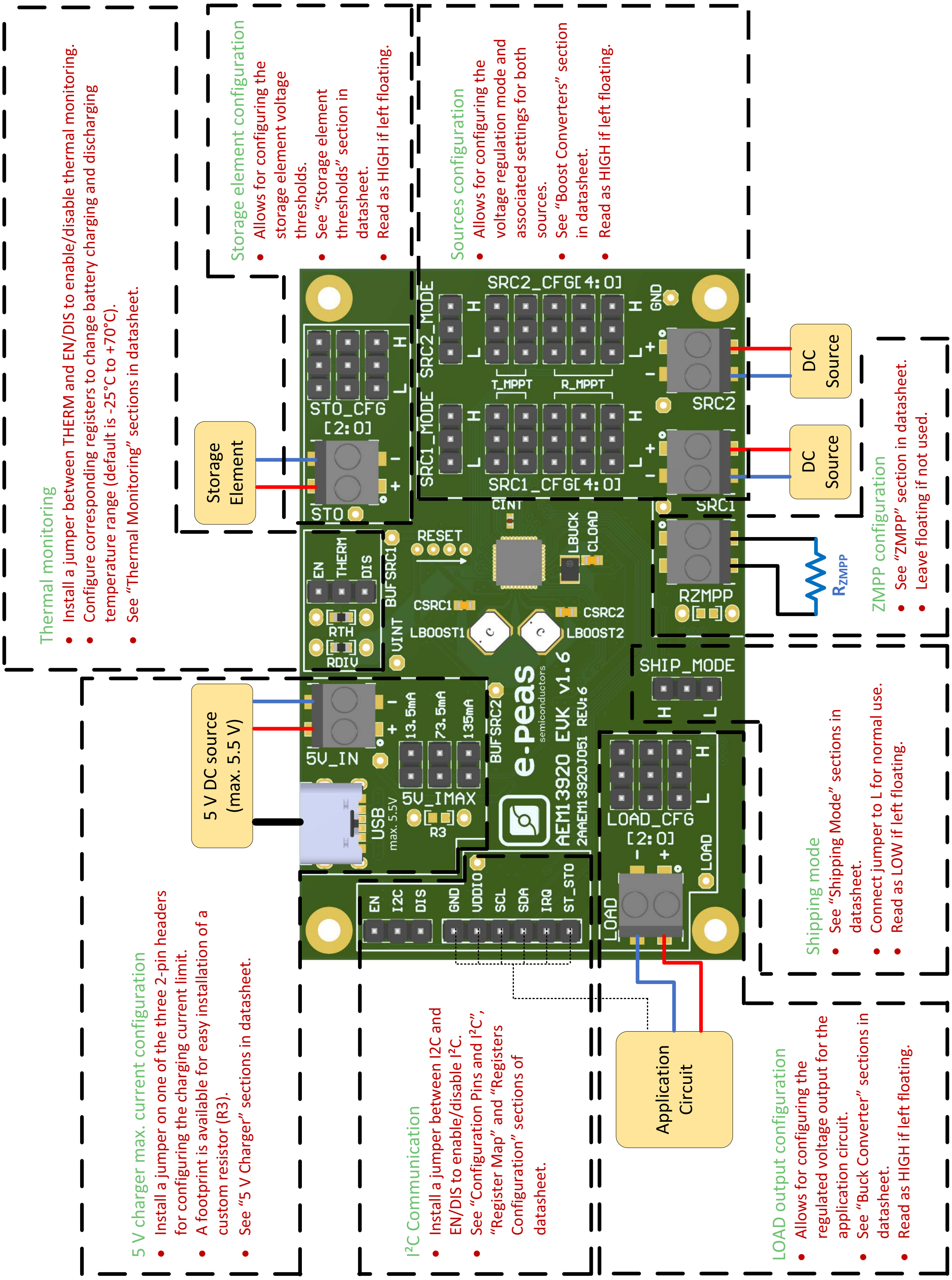


Figure 1: AEM13920 EVK connection diagram

2. Pin Configuration and Functions

NAME	FUNCTION	CONNECTION	
		If used	If not used
Power Pins			
SRC1 SRC2	Connection to the energy source harvested by the boost converter #1 and #2 respectively.	Connect to the source element.	Can be left floating or connected to GND.
ZMPP	Connection for R_{ZMPP}.	Connect R_{ZMPP} resistor.	Leave floating.
STO	Connection to the energy storage element (rechargeable battery or LiC).	Connect the storage element.	Leave floating. If left floating, storage element is on-board capacitor C_{STO}, which may be too small for most applications.
LOAD	Output voltage of the buck converter to supply an application circuit.	Connect the application circuit.	Disable buck converter through LOAD_CFG[2:0] pins or BUCKCFG.VOUT register field and leave the LOAD pin floating.
5V_IN	Input of the 5 V DC power supply.	Connect a 5 V DC power source.	Leave floating.
VDDIO	Supply and voltage reference for the I²C interface, as well as for the IRQ and ST_STO pins.	Connect to a DC power supply.	Connect to GND by placing a jumper between “VDDIO” and “GND” on J2 header.
Control Pin			
SHIP_MODE	Logic input. When HIGH: - Minimum consumption from the storage element. - Storage element charge is disabled (Boost converters are disabled). - Buck (LOAD) is disabled. - Only VINT is charged if energy is available on SRC1 or SRC2.	Connect a jumper to H.	Connect a jumper to L or leave floating. Read as LOW if left floating.

Table 1: Signals description (part 1)

<table>
<tr><th rowspan="2">NAME</th><th rowspan="2">FUNCTION</th><th colspan="2">CONNECTION</th></tr>
<tr><th>If used</th><th>If not used</th></tr>
<tr><td colspan="4">Configuration Pins</td></tr>
<tr><td>SRCx_MODE</td><td>Sets SRCx voltage regulation strategy:
- LOW: constant voltage mode.
- HIGH: MPPT mode (ratio or ZMPP).</td><td>Connect jumper.</td><td>Read as HIGH is left floating.</td></tr>
<tr><td>SRCx_CFG[4:0]</td><td>Used for the configuration of SRCx regulation voltage.
SRCx_MODE = LOW (constant voltage mode):
- SRCx_CFG[4:0] are used to set SRCx constant regulation voltage.
SRCx_MODE = HIGH (MPPT ratio mode):
- SRCx_CFG[2:0] are used to set SRCx MPPT ratio.
- SRCx_CFG[4:3] are used to set SRCx MPPT timings.</td><td>Connect jumpers.</td><td>Read as HIGH is left floating.</td></tr>
<tr><td>STO_CFG[2:0]</td><td>Used to configure the storage element voltage thresholds.</td><td>Connect jumpers.</td><td>Read as HIGH is left floating.</td></tr>
<tr><td>LOAD_CFG[2:0]</td><td>Used to configure the LOAD output regulation voltage.</td><td>Connect jumpers.</td><td>Read as HIGH is left floating.</td></tr>
<tr><td>5V_IMAX</td><td>Connection to an external resistor to set the charging current from the 5V_IN supply to STO.</td><td>Connect jumper on one of the three 2-pin headers or place a resistor on R3.</td><td>Leave floating if 5V_IN is not used.</td></tr>
<tr><td>TH_MON</td><td>Connection for thermistor voltage divider mid-point.</td><td>Connect jumper between THERM and EN.</td><td>Connect jumper between THERM and DIS.</td></tr>
<tr><td colspan="4">I²C Pins</td></tr>
<tr><td>SDA
SCL</td><td>Unidirectional serial data/clock for I²C communication.</td><td>Pull-up to VDDIO by installing a jumper between I2C and EN.
Connect application circuit MCU.</td><td>Connect to GND by installing a jumper between I2C and DIS.</td></tr>
<tr><td colspan="4">Status Pin</td></tr>
<tr><td>ST_STO</td><td>Logic output.
- HIGH when in SUPPLY STATE or in SLEEP STATE.
- LOW otherwise.</td><td>Connect to application circuit.
Works only if VDDIO is supplied.</td><td>Leave floating.</td></tr>
</table>

Table 1: Signals description (part 2)

3. General Considerations

3.1. Safety Information

Always perform the following steps in the correct order:

1. Reset the board by temporally connecting the “RESET” pads to GND, from top to bottom (as shown on PCB) silkscreen.
2. Completely configure the PCB (jumpers/resistors):
   - Sources voltage regulation mode (SRCx_CFG[4:0] and SRCx_MODE).
   - Storage element voltage thresholds (STO_CFG[2:0]).
   - Load output regulation voltage (LOAD_CFG[2:0]).
   - Thermal monitoring.
   - 5 V charger maximum current.
   - I²C enable/disable.
3. Connect a power supply VDDIO if I²C bus / IRQ pin / ST_STO pin is used.
4. Connect a storage element on the STO screw connector.
5. Connect the application circuit on the LOAD screw connector.
6. Connect the harvester(s) to the source(s).

3.2. AEM13920 Reset

The following procedure must be followed to properly reset the AEM13920:

- Connect a wire to GND.
- Use it to short the “Reset” pads to GND from top to bottom, as indicated on the EVK silkscreen.

3.3. Basic Configurations

3.3.1. Source Configuration

3.3.1.1. MPPT Mode (SRCx_MODE = H)

Configuration pins		Sampling Duration [ms]	Period [ms]
SRCx_CFG[4:3]		$T_{MPPT,SAMPLING}$	$T_{MPPT,PERIOD}$
L	L	2	128
L	H	8	512
H	L	32	2048
H	H	256	16384

Configuration pins			MPPT Ratio [%]
SRCx_CFG[2:0]			R_{MPPT}
L	L	L	35%
L	L	H	50%
L	H	L	65%
L	H	H	70%
H	L	L	75%
H	L	H	80%
H	H	L	85%
H	H	H	ZMPP (SRC1) / 100% (SRC2)

Table 2: MPPT ratio and timings configuration with SRCx_CFG[4:0] pins

3.3.1.2. Constant Voltage Mode (SRCx_MODE = L)

Configuration pins					Voltage [V]
SRCx_CFG[4:0]					$V_{SRCx,REG}$
L	L	L	L	L	0.14
L	L	L	L	H	0.30
L	L	L	H	L	0.36
L	L	L	H	H	0.42
L	L	H	L	L	0.48
L	L	H	L	H	0.51
L	L	H	H	L	0.525
L	L	H	H	H	0.54
L	H	L	L	L	0.555
L	H	L	L	H	0.57
L	H	L	H	L	0.60
L	H	L	H	H	0.66
L	H	H	L	L	0.72
L	H	H	L	H	0.735
L	H	H	H	L	0.75
L	H	H	H	H	0.765

Configuration pins					Voltage [V]
SRCx_CFG[4:0]					$V_{SRCx,REG}$
H	L	L	L	L	0.78
H	L	L	L	H	0.81
H	L	L	H	L	0.87
H	L	L	H	H	0.93
H	L	H	L	L	0.99
H	L	H	L	H	1.10
H	L	H	H	L	1.20
H	L	H	H	H	1.31
H	H	L	L	L	1.40
H	H	L	L	H	1.50
H	H	L	H	L	1.61
H	H	L	H	H	1.70
H	H	H	L	L	1.79
H	H	H	L	H	1.90
H	H	H	H	L	1.99
H	H	H	H	H	2.10

Table 3: Configuration of the source constant regulation voltage with SRCx_CFG[4:0] pins

3.3.2. Storage Element Configuration

Configuration pins			Overdischarge voltage [V]	Charge ready voltage [V]	Overcharge voltage [V]	Storage element type
STO_CFG[2:0]			V_{OVDIS}	V_{CHRDY}	V_{OVCH}	
L	L	L	2.50	2.55	3.80	Lithium-ion Super Capacitor (LiC)
L	L	H	2.50	2.55	3.50	Lithium-ion Super Capacitor 85 °C (LiC)
L	H	L	3.00	3.30	4.12	Lithium-ion
L	H	H	3.00	3.30	3.90	Lithium-ion (long life)
H	L	L	3.50	3.55	3.90	Lithium-ion (super long life)
H	L	H	3.00	3.30	4.12	Lithium Polymer (LiPo)
H	H	L	2.80	3.10	3.63	Lithium Iron Phosphate (LiFePO4)
H	H	H	2.60	2.80	3.80	Tadiran HLC1020

Table 4: Storage element configuration with STO_CFG[2:0] pins

3.3.3. Load Configuration

Configuration pins			LOAD voltage [V]
LOAD_CFG[2:0]			V_{LOAD}
L	L	L	Buck disabled
L	L	H	0.6
L	H	L	0.9
L	H	H	1.2
H	L	L	1.5
H	L	H	1.8
H	H	L	2.2
H	H	H	2.5[1]

Table 5: Configuration of LOAD voltage with LOAD_CFG[2:0] pins

1. This configuration is only available if $V_{OVDIS} \geq 2.5$ V.

3.3.4. 5 V Charger Configuration

Resistor [Ω]	Maximum Charging Current [mA]
R_{5V_IMAX}	$I_{5V,CC}$
370	135.0
680	73.5
1500[1]	33.3
3700	13.5

Table 6: Typical resistor values for setting 5 V charger max. current

1. Could be obtained by installing a 1.5 kΩ resistor on R3 and leaving all 3 headers open.

Three 2-pin headers corresponding to three current presets are available on the EVK. Install a jumper on the corresponding header to enable a preset.

Furthermore, R3 allows users for an easy installation of a custom resistor, either in through-hole or in SMD 0603 package. In that case, do not install any jumper on the three preset headers and install a resistor on R3 footprint.

3.4. I²C Configuration

3.4.1. I²C Communication

The device address on the I²C bus is 0x41. All information about the I²C communication is available in the AEM13920 datasheet "System configuration" Section.

VDDIO must be connected to an external power supply which voltage is within the 1.5 V to 5.0 V range. On the evaluation board, 1 kΩ pull-up resistors on SDA and SCL (RSDA and RSCL) to VDDIO are provided.

In case the AEM13920 configurations are set by I²C communication, the configuration pins will not be taken into account anymore.

3.4.2. Register Map

Please note that the AEM13920 device address is 0x41.

All the register descriptions are provided in the AEM13920 datasheet.

Address	Name	Bit	Field Name	Access	Reset	Description
0x00	VERSION	[3:0]	MINOR	R	-	Minor version number.
		[7:4]	MAJOR	R	-	Major version number.
0x01	SRC1REGU0	[0:0]	MODE	R/W	0x01	SRC1 regulation mode.
		[3:1]	CFG0	R/W	0x00	SRC1 regulation mechanism configuration.
0x02	SRC1REGU1	[2:0]	CFG1	R/W	0x00	
		[5:3]	CFG2	R/W	0x00	
0x03	SRC2REGU0	[0:0]	MODE	R/W	0x01	SRC2 regulation mode.
		[3:1]	CFG0	R/W	0x00	SRC2 regulation mechanism configuration.
0x04	SRC2REGU1	[2:0]	CFG1	R/W	0x00	
		[5:3]	CFG2	R/W	0x00	
0x05	VOVDIS	[5:0]	THRESH	R/W	0x06	Storage element overdischarge threshold.
0x06	VCHRDY	[5:0]	THRESH	R/W	0x05	Storage element charge ready threshold.
0x07	VOVCH	[6:0]	THRESH	R/W	0x3A	Storage element overcharge threshold.
0x08	BST1CFG	[0:0]	EN	R/W	0x01	Boost SRC1 enable.
		[1:1]	HPEN	R/W	0x01	Boost SRC1 high-power mode enable.
		[4:2]	TMULT	R/W	0x01	Boost SRC1 current configuration.
0x09	BST2CFG	[0:0]	EN	R/W	0x01	Boost SRC2 enable.
		[1:1]	HPEN	R/W	0x01	Boost SRC2 high-power mode enable.
		[4:2]	TMULT	R/W	0x01	Boost SRC2 current configuration.
0x0A	BUCKCFG	[2:0]	VOUT	R/W	0x00	Buck voltage configuration.
		[5:3]	TMULT	R/W	0x03	Buck current configuration.
0x0B	TEMPCOLDCH	[7:0]	THRESH	R/W	0xD1	Cold temperature threshold for storage element charging.
0x0C	TEMPHOTCH	[7:0]	THRESH	R/W	0x18	Hot temperature threshold for storage element charging.
0x0D	TEMPCOLDDIS	[7:0]	THRESH	R/W	0xD1	Cold temperature threshold for storage element discharging.
0x0E	TEMPHOTDIS	[7:0]	THRESH	R/W	0x18	Hot temperature threshold for storage element discharging.
0x0F	TMON	[0:0]	EN	R/W	0x01	Temperature monitoring enable.

Table 7: Register map (part 1)

Address	Name	Bit	Field Name	Access	Reset	Description
0x10	SRCLOW	[2:0]	SRC1THRESH	R/W	0x00	V_{SRCLOW} threshold for SRC1.
		[5:3]	SRC2THRESH	R/W	0x00	V_{SRCLOW} threshold for SRC2.
0x11	APM	[0:0]	SRC1EN	R/W	0x00	APM SRC1 enable.
		[1:1]	SRC2EN	R/W	0x00	APM SRC2 enable.
		[2:2]	BUCKEN	R/W	0x00	APM LOAD enable.
		[3:3]	RSVD1	R/W	0x00	APM reserved 1.
		[4:4]	RSVD2	R/W	0x00	APM reserved 2.
0x12	IRQEN0	[0:0]	I2CRDY	R/W	0x01	IRQ serial interface ready enable.
		[1:1]	VOVDIS	R/W	0x00	IRQ VOVDIS enable.
		[2:2]	VCHRDY	R/W	0x00	IRQ VCHRDY enable.
		[3:3]	VOVCH	R/W	0x00	IRQ VOVCH enable.
		[4:4]	SRCLOW	R/W	0x00	IRQ source low threshold (SRCx) enable.
		[5:5]	TEMPCH	R/W	0x00	IRQ temperature (charge) enable.
		[6:6]	TEMPDIS	R/W	0x00	IRQ temperature (discharge) enable.
0x13	IRQEN1	[0:0]	SRC1MPPTSTART	R/W	0x00	IRQ MPPT start (SRC1) enable.
		[1:1]	SRC1MPPTDONE	R/W	0x00	IRQ MPPT done (SRC1) enable.
		[2:2]	SRC2MPPTSTART	R/W	0x00	IRQ MPPT start (SRC2) enable.
		[3:3]	SRC2MPPTDONE	R/W	0x00	IRQ MPPT done (SRC2) enable.
		[4:4]	STODONE	R/W	0x00	IRQ STO ADC done enable.
		[5:5]	TEMPDONE	R/W	0x00	IRQ temperature ADC done enable.
		[6:6]	APMDONE	R/W	0x00	IRQ APM done enable.
		[7:7]	APMERR	R/W	0x00	IRQ APM error enable.
0x14	CTRL	[0:0]	UPDATE	R/W	0x00	Load I²C registers configurations.
		[2:2]	SYNCBUSY	R/W	0x00	Synchronization busy flag.
0x15	IRQFLG0	[0:0]	I2CRDY	R	0x00	IRQ serial interface ready flag.
		[1:1]	VOVDIS	R	0x00	IRQ VOVDIS flag.
		[2:2]	VCHRDY	R	0x00	IRQ VCHRDY flag.
		[3:3]	VOVCH	R	0x00	IRQ VOVCHH flag.
		[4:4]	SRCLOW	R	0x00	IRQ source low threshold (SRCx) flag.
		[5:5]	TEMPCH	R	0x00	IRQ temperature (charge) flag.
		[6:6]	TEMPDIS	R	0x00	IRQ temperature (discharge) flag.
0x16	IRQFLG1	[0:0]	SRC1MPPTSTART	R	0x00	IRQ MPPT start (SRC1) flag.
		[1:1]	SRC1MPPTDONE	R	0x00	IRQ MPPT done (SRC1) flag.
		[2:2]	SRC2MPPTSTART	R	0x00	IRQ MPPT start (SRC2) flag.
		[3:3]	SRC2MPPTDONE	R	0x00	IRQ MPPT done (SRC2) flag.
		[4:4]	STODONE	R	0x00	IRQ STO ADC done flag.
		[5:5]	TEMPDONE	R	0x00	IRQ temperature ADC done flag.
		[6:6]	APMDONE	R	0x00	IRQ APM done flag.
		[7:7]	APMERR	R	0x00	IRQ APM error flag.
0x17	STATUS0	[0:0]	VOVDIS	R	0x00	Status VOVIDS.
		[1:1]	VCHRDY	R	0x00	Status VCHRDY.
		[2:2]	VOVCH	R	0x00	Status VOVCH.
		[3:3]	SRC1SRCLOW	R	0x00	Status source low threshold (SRC1).
		[4:4]	SRC2SRCLOW	R	0x00	Status source low threshold (SRC2).

Table 7: Register map (part 2)

Address	Name	Bit	Field Name	Access	Reset	Description
0x18	STATUS1	[0:0]	TEMPCOLDCH	R	0x00	Status cold temperature (charge).
		[1:1]	TEMPHOTCH	R	0x00	Status hot temperature (charge).
		[2:2]	TEMPCOLDDIS	R	0x00	Status cold temperature (discharge).
		[3:3]	TEMPHOTDIS	R	0x00	Status hot temperature (discharge).
0x19	APM0SRC1	[7:0]	DATA	R	0x00	APM data 0 (SRC1).
0x1A	APM1SRC1	[7:0]	DATA	R	0x00	APM data 1 (SRC1).
0x1B	APM2SRC1	[7:0]	DATA	R	0x00	APM data 2 (SRC1).
0x1C	APM0SRC2	[7:0]	DATA	R	0x00	APM data 0 (SRC2).
0x1D	APM1SRC2	[7:0]	DATA	R	0x00	APM data 1 (SRC2).
0x1E	APM2SRC2	[7:0]	DATA	R	0x00	APM data 2 (SRC2).
0x1F	APM0BUCK	[7:0]	DATA	R	0x00	APM data 0 (BUCK).
0x20	APM1BUCK	[7:0]	DATA	R	0x00	APM data 1 (BUCK).
0x21	APM2BUCK	[7:0]	DATA	R	0x00	APM data 2 (BUCK).
0x22	APMERR	[0:0]	SRC1ERR	R	0x00	APM SRC1 error.
		[1:1]	SRC1NVLD	R	0x00	APM corrupted SRC1.
		[2:2]	SRC2ERR	R	0x00	APM SRC2 error.
		[3:3]	SRC2NVLD	R	0x00	APM corrupted SRC2.
		[4:4]	BUCKERR	R	0x00	APM BUCK error.
		[5:5]	BUCKNVLD	R	0x00	APM corrupted BUCK.
0x23	TEMP	[7:0]	DATA	R	0x00	Temperature monitoring value.
0x24	STO	[7:0]	DATA	R	0x00	Storage monitoring value.
0x25	SRC1	[7:0]	DATA	R	0x00	SRC1 monitoring value.
0x26	SRC2	[7:0]	DATA	R	0x00	SRC2 monitoring value.

Table 7: Register map (part 3)

3.5. Advanced Configurations

A complete description of the system constraints and configurations is available in Section “System configuration” of the AEM13920 datasheet.

3.5.1. Shipping Mode

The shipping mode feature allows for forcing the AEM13920 in RESET STATE (see datasheet), thus, disabling all AEM13920 functionalities including both boost converters, the buck converter and the 5 V charger. Only VINT is charged from SRCx if energy is available from it. The battery is no longer charged or discharged.

Shipping mode is enabled by installing a jumper to HIGH on the EVK dedicated header. It is disabled if a jumper is connected to LOW or if SHIP_MODE pin is left floating.

3.5.2. ZMPP Configuration

In ZMPP mode, the AEM13920 regulates the input resistance of SRC1 to match the resistance R_{ZMPP} connected to the ZMPP pin. See the “Theory of Operations” section from the AEM13920 datasheet for more information about the ZMPP mode.

R_{ZMPP} must comply with the following formula:

$$33\ \Omega < R_{ZMPP} < 100\ \text{k}\Omega$$

R_{ZMPP} can be connected either on the dedicated screw connector or soldered on the RZMPP footprint next to it.

If unused, leave the resistor footprint RZMPP empty and do not connect a resistor to the screw connector.

3.5.3. Thermal Monitoring

The thermal monitoring feature protects the storage element by disabling its charge when the ambient temperature is outside a specified range. The higher and lower thresholds are configurable using the I²C communication (see datasheet).

- Place a jumper between THERM and EN to enable the feature.
- Place a jumper between THERM and DIS to disable the feature.

4. Functional Tests

This section presents a few simple tests that allow users to understand the functional behavior of the AEM13920. To avoid damaging the board, follow the procedure found in Section 3.1. If a test has to be restarted, make sure to properly reset the system to obtain reproducible results.

Users can adapt the setup to match the use case system as long as the source limitations are respected, as well as the minimum storage voltage and cold-start constraints (see “Typical Electrical Characteristics at 25 °C” Section of AEM13920 datasheet).

In the following sections, when a “power supply” is required, it can be either a standard one quadrant positive voltage / positive current laboratory power supply with regulated voltage, or an SMU set as voltage source with current compliance.

4.1. Start up

4.1.1. Description

The following example allows users to observe the start-up behavior of the AEM13920. The energy source can be connected either on SRC1 or SRC2 (named SRCx).

4.1.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: VINT (may be probed on H pin on SRC2_CFG[0] header for example).
- SRCx (2 alternatives, initially disconnected):
  - 1 V / 10 mA power supply with a 100 Ω resistor in series (I_{SRCx} = 2.5 mA with R_{MPPT} = 75%).
  - SMU set as 2.5 mA current source with 1 V voltage compliance.
- SRCx_MODE = H.
  - MPPT mode.
- SRCx_CFG[2:0] = HLL.
  - R_{MPPT} = 75%.
- $I_{SRCx} = \frac{1V - 0.75V}{100\Omega} = 2.5mA$ (PSU)
- $I_{SRCx} = 2.5mA$ (SMU)
- SRCx_CFG[4:3] = LH.
  - $T_{MPPT,PERIOD}$ = 512 ms.
  - $T_{MPPT,SAMPLING}$ = 8 ms.
- 1000 µF capacitor connected to STO as storage element.
- 3 V power supply or SMU connected to STO beforehand.
- STO_CFG[2:0] = LHL.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.30 V.
  - V_{OVCH} = 4.12 V.
- LOAD_CFG[2:0] = LLL.
  - LOAD disabled.
- LOAD is floating.
- 5V_IN left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.
- Nothing connected to R_{ZMPP} screw terminal.

4.1.3. Measurements

- Reset the AEM13920 as described in Section 3.2.
- Start with:
  - 3 V power supply connected to STO so that C_{STO} is charged to 3.0 V beforehand.
  - No source connected to SRCx.
- Disconnect the power supply from STO.
- Connect the power supply or the SMU to SRCx.
- Observe V_{INT} rise up to 2.2 V and be regulated at that voltage.
- Energy is transferred from SRCx to STO: V_{STO} rises from its initial 3.0 V voltage to V_{OVCH} (4.12 V).
- V_{STO} is regulated to V_{OVCH} (4.12 V) as the AEM13920 prevents the storage element to be charged any further.

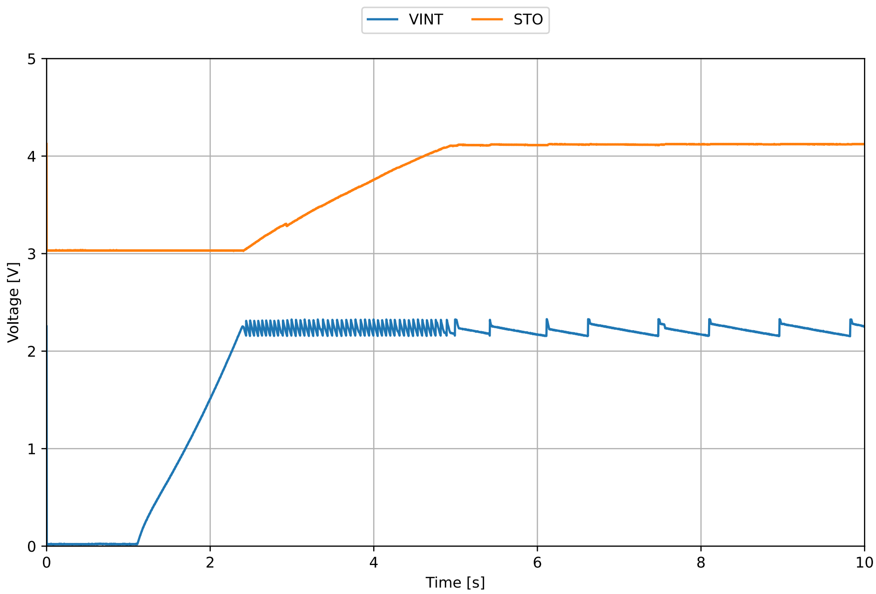


Figure 2: AEM13920 start-up behavior

4.2. Cold start

4.2.1. Description

The following example allows users to observe the cold-start behavior of the AEM13920. The energy source can be connected either on SRC1 or SRC2 (named SRCx).

4.2.2. Setup

- Oscilloscope:
  - Channel 1: SRCx.
  - Channel 2: VINT (may be probed on H pin on SRC2_CFG[0] header for example).
- SRCx (2 alternatives, initially disconnected):
  - 1 V / 10 mA power supply with a 68 kΩ resistor in series (I_{SRCx} = 10 µA with source voltage clamped to 0.3 V during cold start). Please note that using a standard power supply allows for validating the minimum cold-start voltage but does not allow for validating the minimum cold-start power.
  - SMU set as 10 µA current source with 1 V voltage compliance. Using an SMU allows for validating the minimum cold-start power as well as the minimum cold-start voltage.
- SRCx_MODE = H.
  - MPPT mode.
- SRCx_CFG[2:0] = HLL.
  - R_{MPPT} = 75%.
- $I_{SRCx} = \frac{1V - 0.3V}{68k\Omega} = 10\mu A$ (PSU)
- $I_{SRCx} = 10\mu A$ (SMU)
- SRCx_CFG[4:3] = LH.
  - $T_{MPPT,PERIOD}$ = 512 ms
  - $T_{MPPT,SAMPLING}$ = 8 ms.
- 1000 µF capacitor connected to STO as storage element.
- 3 V power supply connected to STO beforehand.
- STO_CFG[2:0] = LHL.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.30 V.
  - V_{OVCH} = 4.12 V.
- LOAD_CFG[2:0] = LLL.
  - LOAD disabled.
- LOAD is floating.
- 5V_IN left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.
- Nothing connected to R_{ZMPP} screw terminal.

4.2.3. Measurements

- Reset the AEM13920 as described in Section 3.2.
- Start with:
  - 3 V power supply connected to STO so that C_{STO} is charged to 3.0 V beforehand.
  - No source connected to SRCx.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRCx.
- Cold-start phase:
  - Observe V_{SRCx} clamped to 0.3 V.
  - Observe V_{INT} rise up to 2.2 V and be regulated at that voltage.
- Once V_{INT} has reached its 2.2 V regulation voltage, the AEM13920 performs a first V_{OC} evaluation on SRCx.
- Then, the AEM13920 extracts energy from SRCx, regulating V_{SRCx} to 75% of V_{OC} (about 750 mV).
- V_{OC} is re-evaluated every 512 ms.

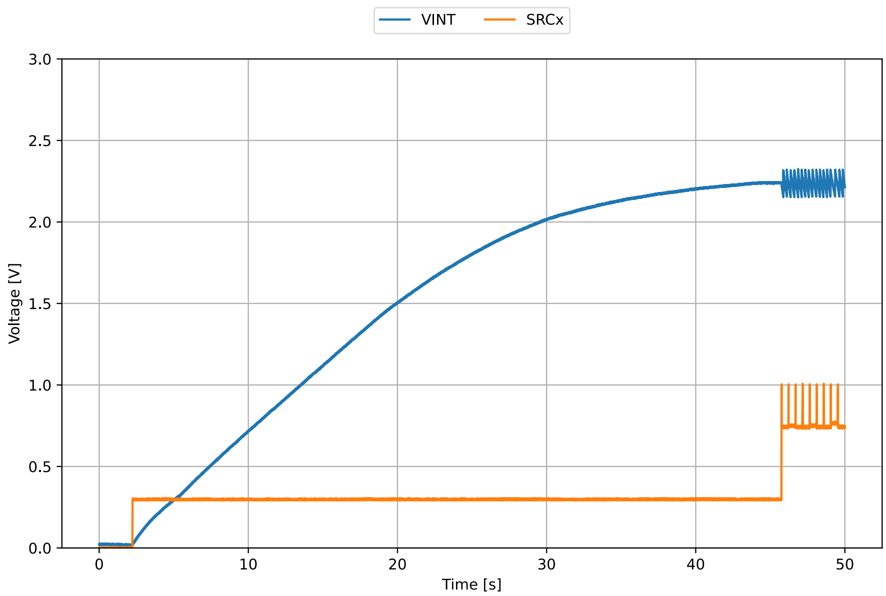


Figure 3: AEM13920 cold-start behavior

4.3. Load

4.3.1. Description

The following example allows users to observe how the AEM13920 switches ON and OFF the buck converter supplying the LOAD pin. The energy source can be connected either on SRC1 or SRC2 (named SRCx).

4.3.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: LOAD.
- SRCx (2 alternatives, initially disconnected):
  - 1 V / 10 mA power supply with a 100 Ω resistor in series (I_{SRCx} = 2.5 mA with R_{MPPT} = 75%).
  - SMU set as 2.5 mA current source with 1.0 V voltage compliance.
- SRCx_MODE = H.
  - MPPT mode.
- SRCx_CFG[2:0] = HLL.
  - R_{MPPT} = 75%.
- $I_{SRCx} = \frac{1V - 0.75V}{100\Omega} = 2.5mA$ (PSU)
- $I_{SRCx} = 2.5mA$ (SMU)
- SRCx_CFG[4:3] = LH.
  - $T_{MPPT,PERIOD}$ = 512 ms
  - $T_{MPPT,SAMPLING}$ = 8 ms.
- 1000 µF capacitor connected to STO as storage element.
- 2.8 V power supply connected to STO beforehand.
- STO_CFG[2:0] = LHL.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.30 V.
  - V_{OVCH} = 4.12 V.
- LOAD_CFG[2:0] = HLH.
  - LOAD is regulated at 1.8 V.
- LOAD: 5 kΩ resistor connected between LOAD and GND.
  - I_{LOAD} = 360 µA.
- 5V_IN left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.
- Nothing connected to R_{ZMPP} screw terminal.

4.3.3. Measurements

- Reset the AEM13920 as described in Section 3.2.
- Start with:
  - 2.8 V power supply connected to STO so that C_{STO} is charged to 2.8 V beforehand.
  - No source connected to SRCx.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRCx.
- After cold start, observe the storage element charging.
- When $V_{STO} > V_{CHRDY}$, LOAD starts being regulated to 1.8 V, thus, providing current to the 5 kΩ resistor. There is more energy harvested than consumed (positive power budget), so the storage element keeps being charged.
- Disconnect the power supply or SMU from SRCx (done at about 9 s on Figure 4).
- The current drawn by the 5 kΩ is now discharging the storage element, as no more energy is harvested to compensate for the load.
- When $V_{STO} < V_{OVDIS}$, the AEM13920 waits for T_{CRIT} (2.5 s) and then switches OFF the buck converter. LOAD is no longer regulated and drops down to 0 V.

Please note that, in a real application, the storage element would be a battery or a supercapacitor, with much higher stored energy, so that V_{STO} would not drop as low as on Figure 4 during T_{CRIT}.

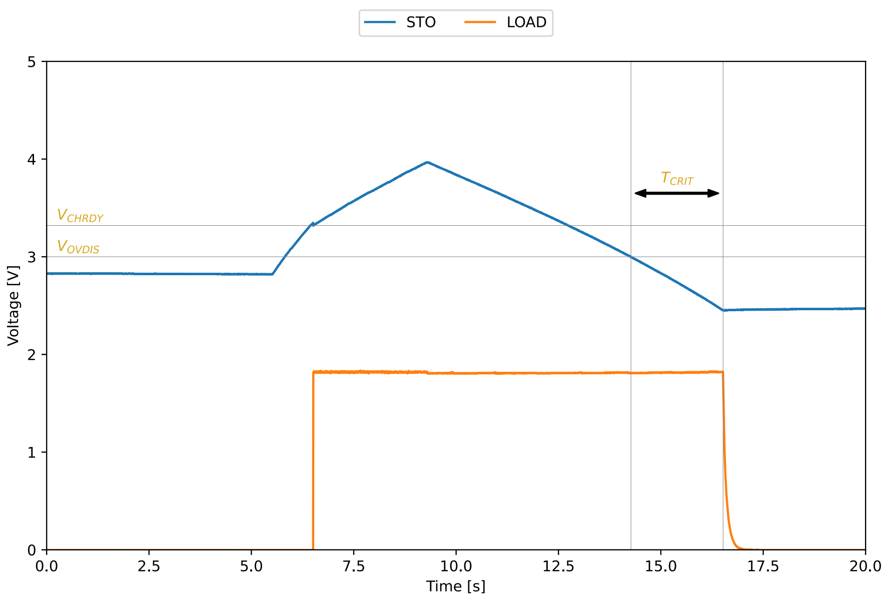


Figure 4: AEM13920 LOAD output behavior

4.4. 5 V Charger

4.4.1. Description

The following example allows users to observe how the AEM13920 coldstarts and charges the storage element from the 5 V charger.

4.4.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: 5V_IN.
- SRCx left floating.
- 5V_IN: 5.0 V / 200 mA power supply or SMU (initially disconnected).
- 5V_IN constant current set to 13.5 mA by installing a jumper on the corresponding header.
- 10 mF capacitor connected to STO as storage element (1000 µF will also work but STO charging slope will be even steeper).
- 2.8 V power supply connected to STO beforehand.
- STO_CFG[2:0] = LHL.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.30 V.
  - V_{OVCH} = 4.12 V.
- LOAD_CFG[2:0] = LLL.
  - LOAD is disabled.
- LOAD left floating.
- Jumper between I2C and DIS.
  - I^2C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.
- Nothing connected to R_{ZMPP} screw terminal.

4.4.3. Measurements

- Reset the AEM13920 as described in Section 3.2.
- Start with:
  - 2.8 V power supply connected to STO so that C_{STO} is charged to 2.8 V beforehand.
  - No source connected to 5V_IN.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to 5V_IN.
- After cold start, observe the storage element charging up to V_{OVCH} (4.12 V).

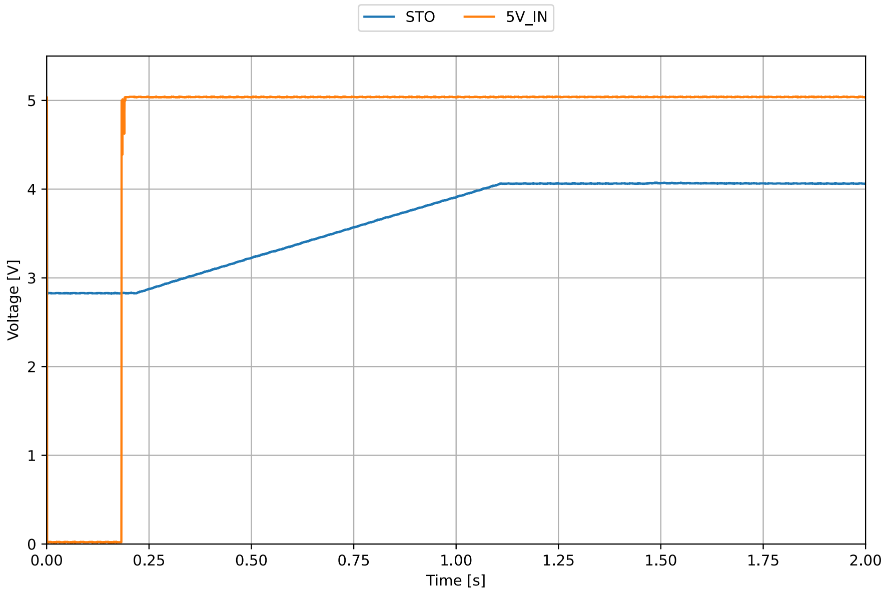


Figure 5: AEM13920 cold start and storage element charge from 5V_IN

4.5. Thermal Monitoring

4.5.1. Description

The following test allows users to observe the thermal monitoring functionality.

4.5.2. Setup

- Use a heat source to increase the thermistor R_{TH} temperature. In the following example, an SMD hot air rework station has been used, with temperature set to +100°C with moderate air flow.
- Oscilloscope:
  - Channel 1: SRCx.
  - Channel 2: STO.
- SRCx: 1 V / 10 mA power supply with a 3 kΩ resistor in series (I_{SRCx} = 83 µA with R_{MPPT} = 75%).
- SRCx_MODE = H.
  - MPPT mode.
- SRCx_CFG[2:0] = HLL.
  - R_{MPPT} = 75%.
- $I_{SRCx} = \frac{1V - 0.75V}{3k\Omega} = 83\mu A$
- SRCx_CFG[4:3] = HL.
  - $T_{MPPT,PERIOD}$ = 2048 ms.
  - $T_{MPPT,SAMPLING}$ = 32 ms.
- 1000 µF capacitor connected to STO as storage element.
- 2.8 V power supply connected to STO beforehand.
- STO_CFG[2:0] = LHL.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.30 V.
  - V_{OVCH} = 4.12 V.
- LOAD_CFG[2:0] = LLL.
  - LOAD is disabled.
- LOAD left floating.
- 5V_IN left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and EN.
  - Thermal monitoring enabled.
  - 10 kΩ NTC thermistor with β = 3380 on R_{TH} (default on EVK).
  - 22 kΩ pullup resistor on R_{DIV} (default on EVK).
  - Storage element charging and discharging enabled above -25°C.
  - Storage element charging and discharging enabled below +70°C.
- Nothing connected to R_{ZMPP} screw terminal.

4.5.3. Measurements

- Reset the AEM13920 as described in Section 3.2.
- Start with:
  - 2.8 V power supply connected to STO so that C_{STO} is charged to 2.8 V beforehand.
  - SRCx left floating.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRCx.
- After cold start, observe the storage element charging.
- Start flowing hot air on the thermistor R_{TH}.
- When R_{TH} is hot enough (above 70°C, near 7 s on Figure 6), the boost converter stops:
  - No more energy is extracted from the source connected on SRCx, which rises to its open circuit voltage V_{OC}.
  - The storage element is no longer charged (V_{STO} stops rising) even though V_{STO} is below V_{OVCH}, and thus, is protected.
  - VINT is still supplied.

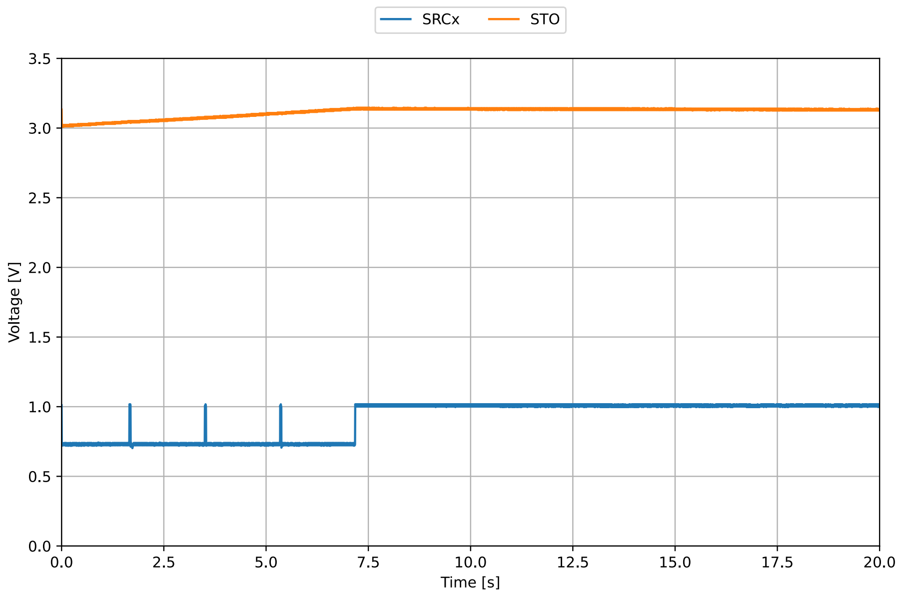


Figure 6: AEM13920 thermal monitoring protecting the storage element

5. Performance Tests

This section presents the tests to reproduce the performance graphs found in the AEM13920 datasheet. To be able to reproduce those tests, you will need the following:

- 2 source measure units (SMU, typically Keithley 2450). Those must be set with longest integration time.
- 1 voltage source (only for coldstarting the AEM13920 when performing buck efficiency measurement).

To avoid damaging the board, follow the procedure found in Section 3.1 “Safety information”. If a test has to be restarted, make sure to properly reset the system to obtain reproducible results, as shown in Section 3.2.

5.1. Boost Converters Efficiency

5.1.1. Description

The boost converter efficiency is determined for a fixed set point of the AEM13920:

- Fixed SRCx voltage V_{SRCx}.
- Fixed SRCx current I_{SRCx}.
- Fixed STO voltage V_{STO}.
- Fixed inductor value L_{BOOSTx}. Please note that the inductor model has a subsequent influence on the efficiency.
- Fixed boost timing, as set in the BST1CFG and BST2CFG I²C registers. Default is x2.

Boost efficiency measurement is about measuring the current provided to STO for all other parameters fixed.

The following apply for both SRC1 and SRC2 (noted SRCx).

Please note that, to avoid any leakage that would affect the measurement, no probe or voltmeter should be connected to the AEM13920 pins while measuring the boost efficiency.

5.1.2. Setup

- SRCx_MODE = L.
  - Constant voltage mode.
- SRC1_CFG[4:0] set according to the desired V_{SRCx} set point (see Table 3).
- SRCx: SMU set as current source.
  - Current source set to the desired I_{SRCx}.
  - Voltage compliance set to 0.5 V above the desired V_{SRCx} set point.
- STO: SMU set as voltage source:
  - Voltage set to the desired V_{STO} set point.
  - Current compliance set so that the power on STO (V_{STO} x I_{STO}) is at least higher that the power of the SMU connected to SRCx (V_{SRCx} x I_{SRCx}). Do not lower the current compliance lower than 100 µA.
- Optional: a device able to act as an I²C master and send I²C commands to the AEM13920. Only useful when testing settings that are not accessible through the configuration pins, such as boost timings. Please note that, the results shown on Figure 7 are with x3 boost timing, which has to be set to this value through I²C communication.

5.1.3. Measurements

Cold start and initialization

This part must only be done for the first efficiency data point measurement. To avoid having to do it between two subsequent set points, users must make sure that V_{STO} does not drop below V_{OVDIS} between measurements.

- Start with both SMU switched OFF.
- Reset the AEM13920.
- STO SMU: set the voltage to 5.0 V and switch ON, to make sure that V_{STO} is above V_{OVCH}.
- SRCx SMU: set the current source to 1 mA with the voltage compliance to 1.0 V to trigger the AEM13920 cold start.
- Wait for V_{INT} to rise to its 2.2 V regulation voltage.
- The AEM13920 is now ready to perform an efficiency measurement. Do not lower V_{STO} below V_{OVDIS} from that point to avoid the AEM13920 going to OVDIS STATE. Keep STO SMU current compliance at least 100 µA.

Efficiency measurement

The following needs to be done for all desired set points:

- Set SRCx SMU to the desired voltage and current set point.
- Set STO SMU to the desired voltage and current set point.
- Clear both SMU buffers.
- Wait for the number of measures of both SMU to be sufficient (the lower the current the higher the necessary number of measures).
- Determine the average currents and voltages from both SMU buffers.
- Determine the boost efficiency with the following formula:

$$\eta[\%] = \frac{V_{STO} \cdot I_{STO}}{V_{SRCx} \cdot I_{SRCx}} \cdot 100$$

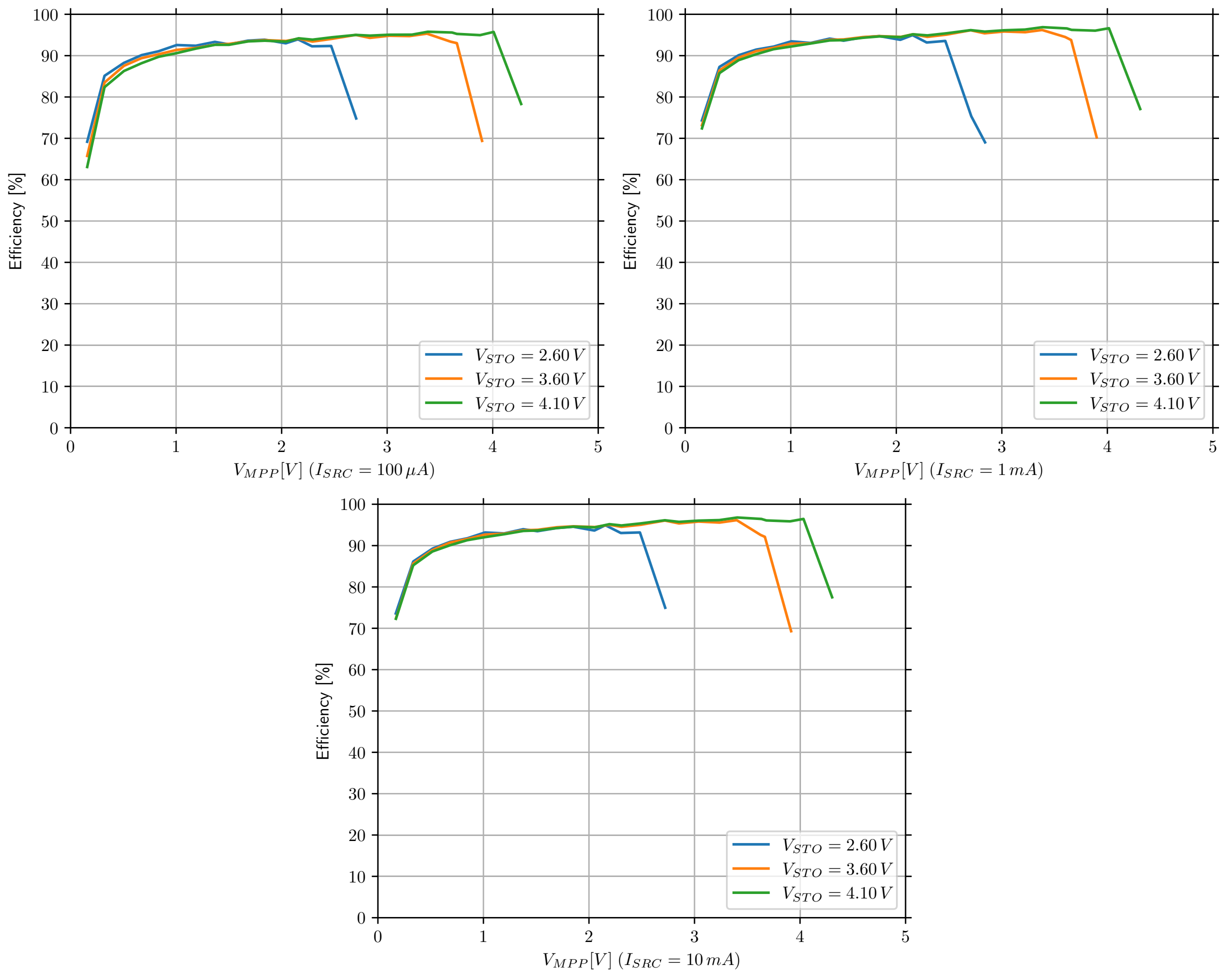


Figure 7: Boost converter efficiency with L_{BOOSTx} = 33 µH (Coilcraft LPS4018-333MRB), BSTxCFG.TMULT = 0x02 (x3)

5.2. Buck Converters Efficiency

5.2.1. Description

The buck converter efficiency is determined on a fixed set point of the AEM13920:

- Fixed STO voltage V_{STO}.
- Fixed LOAD voltage V_{LOAD}.
- Fixed LOAD current I_{LOAD}.
- Fixed inductor value L_{BUCK}. Please note that the inductor model has a subsequent influence on the efficiency.
- Fixed buck timing, as set in the BUCKCFG I²C register. Default is x4.

Buck efficiency measurement is about measuring the current that needs to be pulled from STO at a given V_{STO}, to provide a given current/voltage on LOAD, with all other parameters fixed.

Please note that, to avoid any leakage that would affect the measurement, no probe or voltmeter should be connected to the AEM13920 pins while measuring the buck efficiency.

5.2.2. Setup

- STO: SMU set as voltage source:
  - Voltage set to the desired V_{STO} set point.
  - Current compliance set so that the power on STO (V_{STO} x I_{STO}) is at least higher that the power of the SMU connected to LOAD (V_{LOAD} x I_{LOAD}).
- LOAD: SMU set as voltage source.
  - Voltage set to 0.5 V below the desired V_{LOAD} set point, forcing the SMU to pull the compliance current when the buck converter is regulating its output voltage.
  - Current compliance set to the desired I_{LOAD}.
- SRCx: any power supply with voltage higher than $V_{SRCx,CS}$ and lower than 5.0 V (1 V / 1 mA is typically fine).
- Optional: a device able to act as an I²C master and send I²C commands to the AEM13920. Only useful when testing settings that are not accessible through the configuration pins, such as buck timings. Please note that the results shown on Figure 8 are with x2 buck timing, which has to be set to this value through I²C communication.

5.2.3. Measurements

Cold start and initialization

This part must only be done for the first efficiency data point measurement. To avoid having to do it between two subsequent set points, users must make sure that STO voltage doesn't drop below V_{OVDIS} between measurements, with at least 100 µA current compliance.

- Start with both SMU switched OFF.
- Reset the AEM13920.
- STO SMU: set the voltage to 5.0 V and switch ON, to make sure that the V_{STO} is above V_{OVCH}.
- Switch ON SRCx power supply.
- Wait for V_{INT} to be regulated at 2.2 V.
- Switch OFF SRCx power supply.
- The AEM13920 is now ready to perform an efficiency measurement. Do not lower V_{STO} below V_{OVDIS} from that point to avoid the AEM13920 going to OVDIS STATE. Keep the STO SMU current compliance at least 100 µA.

Efficiency measurement

The following needs to be done for all desired set points:

- Set STO SMU to the desired voltage and current set point.
- Set LOAD SMU to the desired voltage and current set point.
- Clear both SMU buffers.
- Wait for the number of measures of both SMU to be sufficient (the lower the current the higher the necessary number of measures).
- Determine the average currents and voltages from both SMU buffers.
- Determine the buck efficiency with the following formula:

$$\eta[\%] = \frac{V_{LOAD} \cdot I_{LOAD}}{V_{STO} \cdot I_{STO}} \cdot 100$$

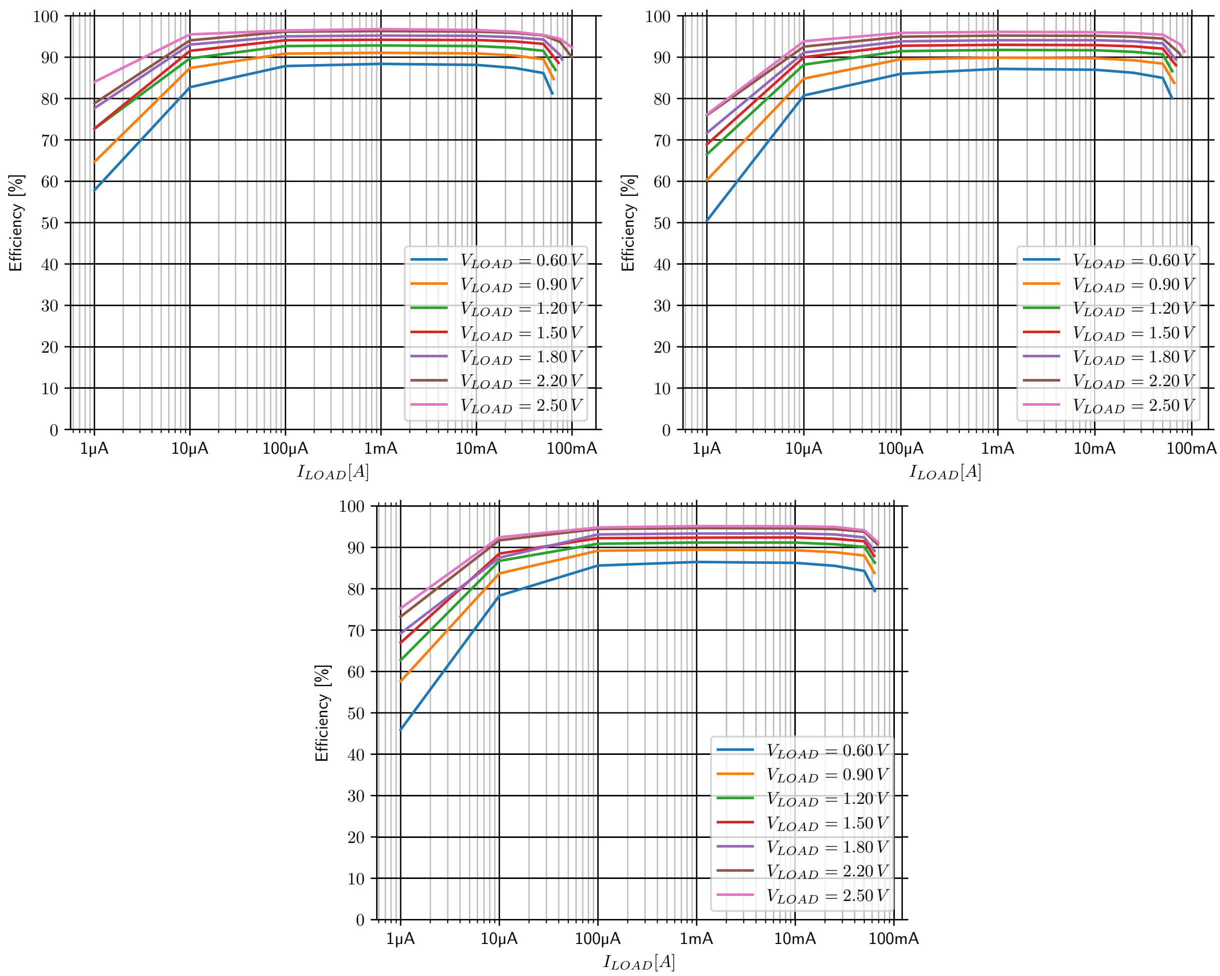


Figure 8: Buck (LOAD) converter efficiency with L_{BUCK} = 10 µH (Coilcraft LPS4018-103MRB), BUCKCFG.TMULT = 0x01 (x2)

6. EVK Schematic

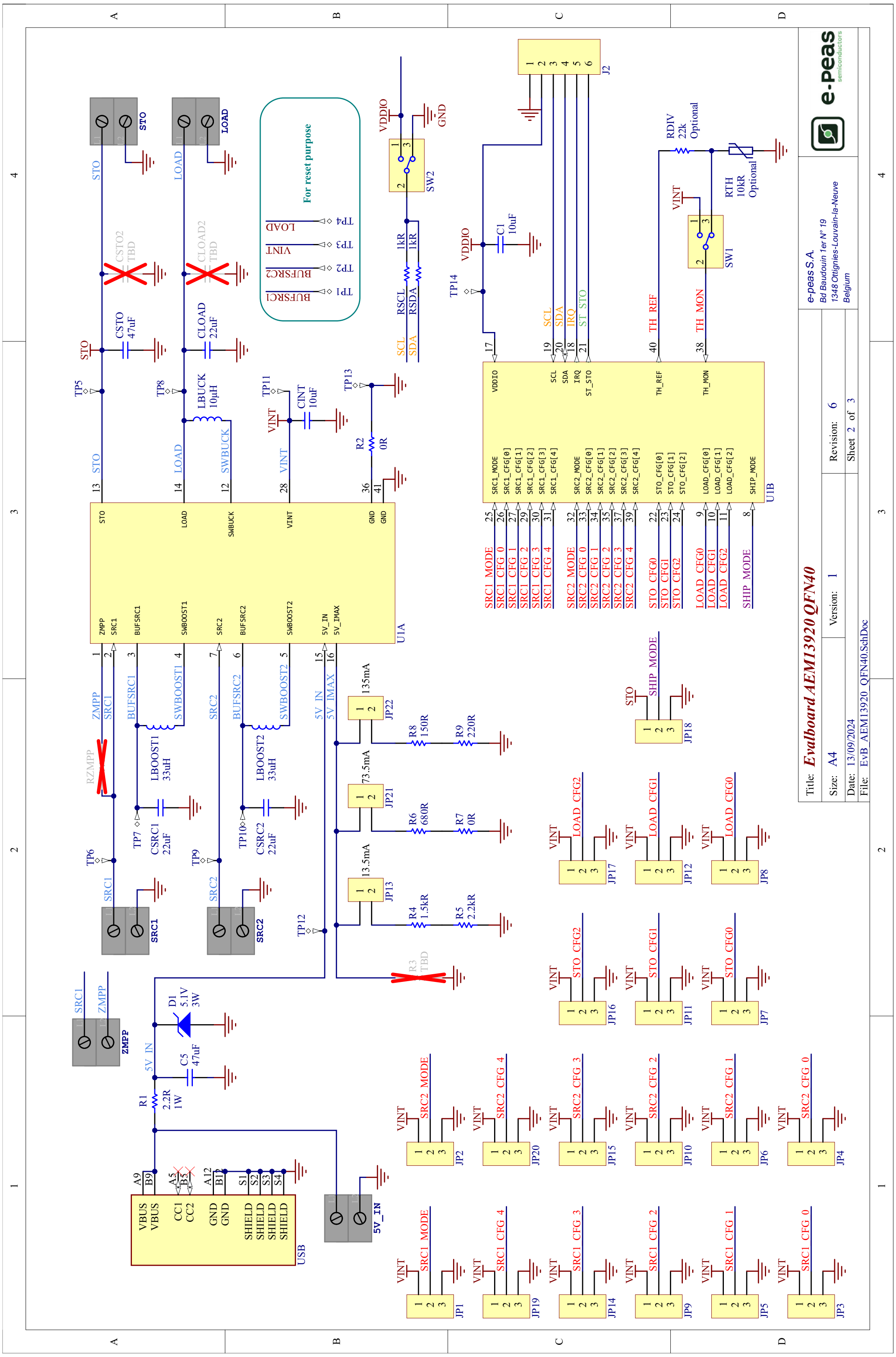


Figure 9: EVK schematic

7. Revision History

EVK Version	User Guide Revision	Date	Description
1.2	1.0	December, 2023	Creation of the document.
1.5	1.0	August, 2024	- Update figures to EVK v1.5. - Corrected EVK dimensions on first page. - Corrected error in “Advanced Configurations”, “Thermal Monitoring” section. - Renamed “sleep threshold” to “source low threshold” in Register map table. - Corrected inconsistencies in “Functional Test” section. - Modified cold start functional test setup and results for Voc = 1 V instead of 0.3 V.
1.6	1.0	September, 2024	Update to EVK v1.6.
1.6	1.1	November, 2024	Corrected typos throughout the document.

Table 8: Revision history

