AEM11921 QFN-20 Evaluation Board

Description

The AEM11921 evaluation kit (EVK) is a printed circuit board (PCB) featuring all the required components to operate the AEM11921 integrated circuit (IC) in QFN 20-pin package.

The AEM11921 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 connection to an energy harvester (e.g. a 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 any I²C master device and evaluate the IC performances. Furthermore, the on-board USB-to-I²C converter and e-peas' "I²C Configuration Tool" simplify I²C communication.

The AEM11921 EVK is a plug and play, intuitive and efficient tool to optimize the AEM11921 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 AEM11921 features can be found in the datasheet.

Features

2-way screw terminals

- DC source of energy (SRC).
- Energy storage element (STO).
- Application circuit (LOAD).
- 5 V DC power input (5V_EXT).

3-pin headers

- Storage element protection thresholds configuration.
- Load voltage regulation configuration.
- I²C enable/disable.
- Thermal monitoring enable/disable.
- Shipping mode enable/disable.
- Overvoltage protection (OVP) enable/disable.

6-pin header

- I²C communication with application circuit.

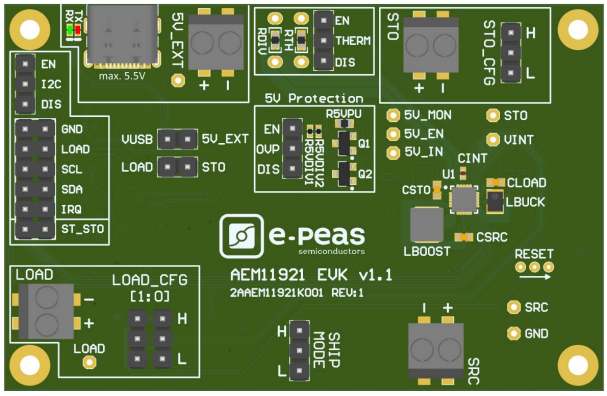
USB connector

- 5 V DC power input (max. 5.50 V peak).
- Connection to the on-board USB to I²C converter.

Device Information

Description	Part number
AEM11921 - Evaluation board 76 x 49 mm	2AAEM11920K001 REV:1
AEM11921 - QFN 20-pin 3 x 3 mm	10AEM11921K0000

Appearance



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1. EVK Connection Diagram

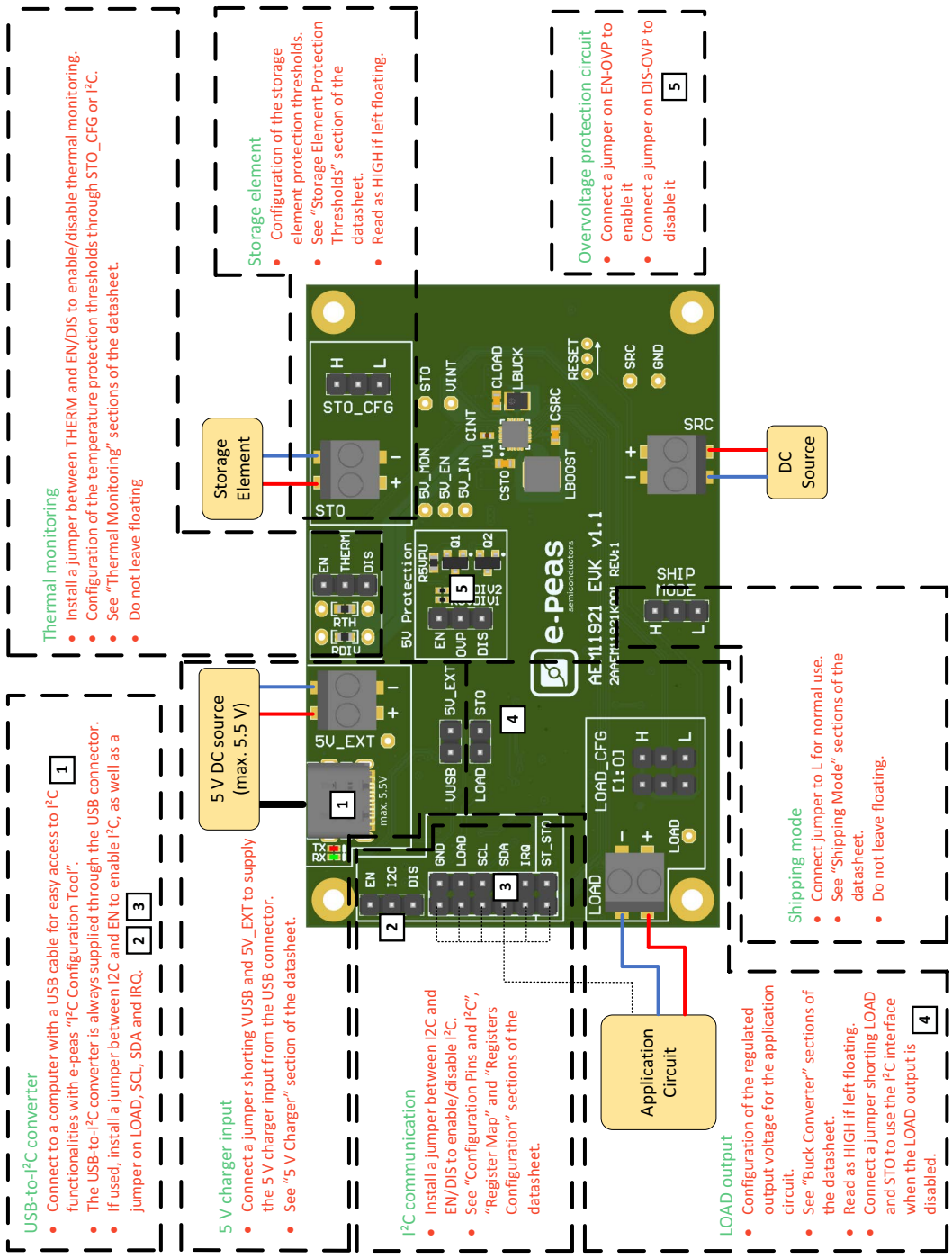


Figure 1: Connection diagram

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2. Pin Configuration and Functions

Name	Function
Power pins	
SRC	Connection to the harvested energy source. **If used:** Connect the source element. **If not used:** Leave floating.
STO	Connection to the energy storage element, battery or capacitor. **If used:** Connect the storage element in addition to C_{STO}. **If not used:** Do not remove C_{STO}.
LOAD	Output of the buck converter. **If used:** Connect a load. **If not used:** Leave floating.
5V_EXT	Connection to a 5 V power supply. **If used:** Connect a power supply. **If not used:** Leave floating.
Others	
USB connector	Supplies 5V_EXT from the USB connector, to do so, place a jumper on "5V_EXT-VUSB". Allows to use the on-board USB to I²C converter for easy access to the I²C functionalities of the AEM11921. **If used:** Connect a USB cable to a computer (I²C and 5V_EXT) or a USB charger (5V_EXT only). **If not used:** Do not connect.
Overvoltage protection circuit	Protects the AEM11921 from voltages higher than 5.50 V coming from 5V_EXT. **If used:** Place a jumper connecting OVP to EN. **If not used:** Place a jumper connecting OVP do DIS.

Table 1: Pins description (part 1)

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Name	Logic Level		Function
	LOW	HIGH	
Configuration pins			
STO_CFG	GND	VINT	Used to configure the storage element protection thresholds. **If used:** Connect jumper. **If not used:** Read as HIGH if left floating.
LOAD_CFG[1:0]	GND	VINT	Used to configure the LOAD output regulation voltage. **If used:** Connect jumpers. **If not used:** Read as HIGH if left floating.
Control pin			
SHIP_MODE	GND	STO	Used to enable/disable the shipping mode. **If used:** Connect jumper to "H". **If not used:** Connect a jumper to "L".
Status pin			
ST_STO	GND	STO	Logic output. Asserted when in SUPPLY STATE. LOW otherwise. **If used:** Connect high impedance circuit. **If not used:** Leave floating.
I²C pins			
SDA SCL	GND	LOAD	Serial data/clock for I²C communication. **If used:** Pull-up to LOAD by installing a jumper between I2C and EN. Connect to I²C master device. **If not used:** Connect to GND by installing a jumper between I2C and DIS.

Table 2: Pins description (part 2)

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3. General Considerations

3.1. Safety Information

Before using the AEM11921 EVK, always perform these steps in the correct order:

1. Reset the board - see Section 3.2.
2. Completely configure the PCB (jumpers):
   - Storage element configuration (STO_CFG) - see Table 4.
   - Load configuration (LOAD_CFG[1:0]) - see Table 8.
3. Connect the storage element on STO.
4. Connect the load circuit on LOAD (optional).
5. Connect the harvester on SRC.

3.2. AEM11921 Reset

The following procedure must be followed to properly reset the AEM11921:

- Connect a wire to GND.
- Use it to short the “RESET” pads to GND following the arrow direction, as indicated on the EVK silkscreen.

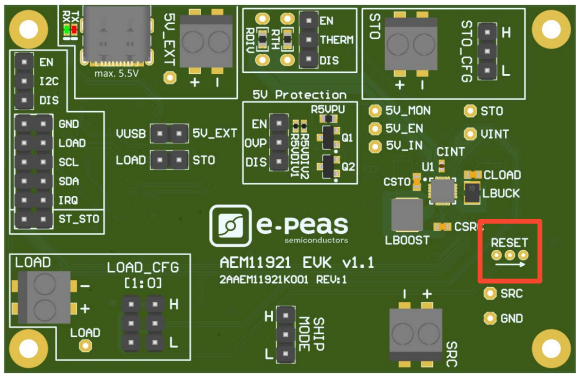


Figure 2: AEM11921 reset procedure

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4. Basic Configurations

4.1. Source Regulation

The source regulation can be configured for MPP tracking or constant voltage through I²C (see section "Source Regulation (SRCREGU)" of the datasheet. The default regulation is the following:

Configuration		Value
R_{MPPT}	MPPT ratio	80 %
$T_{MPPT,WAIT}$	MPPT wait time[1]	465 ms
$T_{MPPT,PERIOD}$	MPPT period	29.79 s

Table 3: Default source regulation of the AEM11921.

1.The total time spent in open-circuit is the sum of $T_{MPPT,WAIT}$ (configurable via I²C only) and $T_{MPPT,MEASURE}$ (1.36 ms)

4.2. Storage Element Protection Thresholds

The storage element protection thresholds, hysteresis voltage, and temperature thresholds (explained in "Storage Element Protections" section of the datasheet) are configurable to match various storage element types.

If the GPIO configuration is used, the STO_CFG pin allows configuring between two sets of thresholds (see Tables 4, 5, 6 and 7).

Configuration pin	Overdischarge voltage [V]	Charge-ready voltage [V]	Overcharge voltage [V]	Storage element type
STO_CFG	V_{OVDIS}	V_{CHRDY}	V_{OVCH}	
L	2.50	2.60	3.80	Lithium-ion Super Capacitor (LiC)
H	3.00	3.20	4.15	Lithium-ion Battery

Table 4: Storage element thresholds configuration with STO_CFG pin

Configuration pin	Buck charge-ready voltage [V]			Storage element type
STO_CFG	$V_{CHRDY,BUCK}$ for V_{LOAD} = 2.20 V	$V_{CHRDY,BUCK}$ for V_{LOAD} = 2.80 V	$V_{CHRDY,BUCK}$ for V_{LOAD} = 3.30 V	
L	2.60	2.90	3.40	Lithium-ion Super Capacitor (LiC)
H	3.20	3.20	3.50	Lithium-ion Battery

Table 5: Buck charge-ready threshold configuration with STO_CFG pin

Configuration pin	Overcharge hysteresis [mV]	Storage element type
STO_CFG	V_{HYST}	
L	0	Lithium-ion Super Capacitor (LiC)
H	37.5	Lithium-ion Battery

Table 6: Storage element overcharge hysteresis configuration with STO_CFG pin

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Configuration pin	Minimum charging temperature [°C]	Maximum charging temperature [°C]	Minimum discharging temperature [°C]	Maximum discharging temperature [°C]
STO_CFG	TEMPCOLDCH	TEMPHOTCH	TEMPCOLDDIS	TEMPHOTDIS
L	-15	60	-15	60
H	0	45	0	45

Table 7: Temperature thresholds configuration with STO_CFG pin with the recommended R_{DIV} and R_{TH}

DISCLAIMER: Storage element protection thresholds and temperature thresholds provided for each storage element type in the tables above are indicative. They are provided as is to the best knowledge of e-peas's application laboratory. They should not replace the actual values provided in the storage element manufacturer's specifications and datasheet.

4.3. Load Voltage

The regulated voltage on LOAD output can be configured with the LOAD_CFG[1:0] pins (see Table 8), or through the BUCKCFG register (see Section ”Buck Converter (BUCKCFG)” of the datasheet).

Configuration pins		LOAD voltage [V]
LOAD_CFG[1:0]		V_{LOAD}
L	L	LOAD disabled
L	H	2.20
H	L	2.80
H	H	3.30

Table 8: LOAD voltage configuration with LOAD_CFG[1:0] pins

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5. Advanced Configurations

A complete description of the system constraints and configurations is available in Section “System configuration” of the AEM11921 datasheet.

5.1. Thermal Monitoring

When the thermal monitoring is enabled by connecting R_{DIV} and R_{TH} as shown in Figure 3, the AEM11921 monitors the temperature periodically every $T_{TEMP,MON}$.

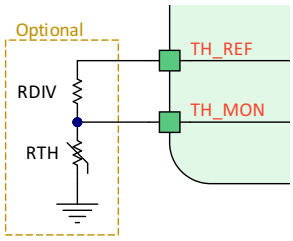


Figure 3: TH_REF and TH_MON connections

With the thermal monitoring enabled, the thermal protection can be used based on the temperature protection thresholds (see Table 7). If the thermal protection is not needed, it can be disabled through TEMPPROTECT register (see Section “Thermal Protection (TEMPPROTECT)” of the datasheet). In that case, if R_{DIV} and R_{TH} remain connected, the temperature will continue to be measured periodically every $T_{TEMP,MON}$ but the protection thresholds will be ignored. The temperature data remains available through the TEMP register.

If TH_MON is connected to VINT and TH_REF left floating, the thermal monitoring and thermal protections will be disabled. This is done by placing the jumper connecting THERM to EN or DIS on the EVK.

5.1.1. Temperature Protection Thresholds

Once the thermal monitoring is enabled, the thermal protection can be used based on the configured temperature thresholds for charge and discharge (except if disabled by the TEMPPROTECT.EN field through I^2C) to cut-off the charge and discharge of the storage element when outside of the temperature range.

5.2. Shipping Mode

The shipping mode feature allows forcing the AEM11921 in RESET STATE (see datasheet), thus, disabling all AEM11921 functionalities including the boost converter, the buck converter and the 5 V charger. Only VINT is charged from SRC or 5V_EXT if energy is available from it. The storage element is no longer charged or discharged.

Shipping mode is enabled by installing a jumper in HIGH position on the EVK dedicated header. It is disabled if a jumper is connected to LOW. Do not leave the SHIP_MODE pin floating.

5.3. 5 V Input Overvoltage Protection (OVP) Circuit

The AEM11921 EVK has an on-board overvoltage protection circuit controlled by the AEM11921. The OVP circuit, when enabled, protects the AEM11921 against voltages over 5.50 V on the 5V_EXT input. To enable the OVP circuit, place a jumper between the pins EN and OVP. To disable it, place a jumper on the pins OVP and DIS. See section “Overoltage Protection (OVP) Circuit” of the AEM11921 datasheet for further information.

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6. I²C Configurations

6.1. I²C Communication

The device address on the I²C bus is 0x31. All information about the I²C communication is available in the AEM11921 datasheet “Register Map” and “Registers Configuration” Sections.

In case the AEM11921 configurations are set by I²C communication, the configuration pins will not be taken into account anymore (except the SHIP_MODE pin).

The AEM11921 evaluation board provides a 12-pin, 2x6 header that supports two methods for accessing the I²C interface:

- Direct I²C access: The left row of the header (closest to the board edge) is directly connected to the AEM11921 I²C signals (LOAD, SCL, SDA, and IRQ). Note that the pull-up resistors on the board are disabled in direct access. If there is no pull-ups on the master side, use a cable to connect the middle point of the I2C enable header to any LOAD pin on the board.
- On-board USB-to-I²C converter: The right row of the header is connected to the integrated USB-to-I²C converter on the evaluation board. To communicate with the AEM11921 through USB, four jumpers must be installed, each linking the corresponding left-side pin to right-side pin for LOAD, SCL, SDA, and IRQ.

If the buck converter is disabled, LOAD must be supplied externally with a voltage lower or equal to V_{STO} or directly shorted to STO with the dedicated header to be able to use the I²C.

6.2. USB-to-I²C Converter

The AEM11921 EVK has an on-board USB-to-I²C converter. When a computer is connected to the USB connector and the four jumpers for LOAD, SCL, SDA, and IRQ are placed, it is recognized as a serial (COM) port.

DISCLAIMER: Place the jumpers on the 2x6 header only if you want to use the USB-to-I²C interface. Otherwise it will cause excessive current leakage altering the performances of the AEM11921.

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6.3. Register Map

Please note that the AEM11921 device address is 0x31.

Address	Name	Bit	Field Name	Access	Reset	Description
0x01	SRCREGU	[0:0]	MODE	R/W	0x01	SRC regulation mode.
		[2:1]	CFG0	R/W	0x02	SRC regulation mechanism configuration.
		[4:3]	CFG1	R/W	0x02	
		[6:5]	CFG2	R/W	0x02	
		[7:7]	CFG3	R/W	0x00	
0x02	VOVDIS	[4:0]	THRESH	R/W	0x04	STO overdischarge threshold.
0x03	VCHRDY	[4:0]	THRESH	R/W	0x04	STO charge-ready threshold.
0x04	VOVCH	[5:0]	THRESH	R/W	0x16	STO overcharge threshold.
0x05	STOHYST	[1:0]	VHYST	R/W	0x00	STO hysteresis configuration.
0x06	BSTCFG	[0:0]	EN	R/W	0x01	Boost converter enable.
		[1:1]	SRCBLEEDEN	R/W	0x00	Source bleed enable.
0x07	BUCKCFG	[0:0]	EN	R/W	0x00	Buck converter enable.
		[2:1]	VLOAD	R/W	0x00	LOAD voltage configuration.
		[3:3]	BYPASSEN	R/W	0x00	Buck converter bypass mode enable.
0x08	VCHRDYBUCK	[4:0]	THRESH	R/W	0x04	STO charge-ready buck threshold.
0x09	CHG5V	[0:0]	EN	R/W	0x01	5 V charger enable.
0x0A	TEMPCOLDCH	[7:0]	THRESH	R/W	0xB9	Cold temperature threshold for storage element charging.
0x0B	TEMPHOTCH	[7:0]	THRESH	R/W	0x1F	Hot temperature threshold for storage element charging.
0x0C	TEMPCOLDDIS	[7:0]	THRESH	R/W	0xB9	Cold temperature threshold for storage element discharging.
0x0D	TEMPHOTDIS	[7:0]	THRESH	R/W	0x1F	Hot temperature threshold for storage element discharging.
0x0E	TEMPPROTECT	[0:0]	EN	R/W	0x01	Thermal protection enable.
		[3:1]	HYST	R/W	0x05	Thermal protection hysteresis configuration.
0x0F	APM	[0:0]	SRCEN	R/W	0x00	APM SRC enable.
		[1:1]	LOADEN	R/W	0x00	APM LOAD enable.
0x10	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 enable.
		[5:5]	TEMPCH	R/W	0x00	IRQ temperature charge enable.
		[6:6]	TEMPDIS	R/W	0x00	IRQ temperature discharge enable.
		[7:7]	LOADSHTDWN	R/W	0x00	IRQ LOAD shutdown enable.

Table 9: Register map (part 1)

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Address	Name	Bit	Field Name	Access	Reset	Description
0x11	IRQEN1	[0:0]	MPPTSTART	R/W	0x00	IRQ MPPT start enable.
		[1:1]	MPPTDONE	R/W	0x00	IRQ MPPT done enable.
		[2:2]	STODONE	R/W	0x00	IRQ STO measurement done enable.
		[3:3]	TEMPDONE	R/W	0x00	IRQ temperature measurement done enable.
		[4:4]	APMDONE	R/W	0x00	IRQ APM done enable.
		[5:5]	APMERR	R/W	0x00	IRQ APM error enable.
		[6:6]	CHG5VCONN	R/W	0x00	IRQ 5 V charger connected enable.
		[7:7]	CHG5VON	R/W	0x00	IRQ 5 V charger ON enabled.
0x12	CTRL	[0:0]	UPDATE	R/W	0x00	Load I²C registers configuration.
		[1:1]	-	-	-	Reserved.
		[2:2]	SYNCBUSY	R	0x00	Synchronization busy flag.
0x13	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 VOVCH flag.
		[4:4]	SRCLOW	R	0x00	IRQ source low threshold flag.
		[5:5]	TEMPCH	R	0x00	IRQ temperature (charge) flag.
		[6:6]	TEMPDIS	R	0x00	IRQ temperature (discharge) flag.
		[7:7]	LOADSHTDWN	R	0x00	IRQ LOAD shutdown flag.
0x14	IRQFLG1	[0:0]	MPPTSTART	R	0x00	IRQ MPPT start flag.
		[1:1]	MPPTDONE	R	0x00	IRQ MPPT done flag.
		[2:2]	STODONE	R	0x00	IRQ STO measurement done flag.
		[3:3]	TEMPDONE	R	0x00	IRQ temperature measurement done flag.
		[4:4]	APMDONE	R	0x00	IRQ APM done flag.
		[5:5]	APMERR	R	0x00	IRQ APM error flag.
		[6:6]	CHG5VCONN	R	0x00	IRQ 5 V charger connected flag.
		[7:7]	CHG5VON	R	0x00	IRQ 5 V charger ON flag.
0x15	STATUS0	[0:0]	OVDIS	R	0x00	Status overdischarge.
		[1:1]	CHRDY	R	0x00	Status charge-ready.
		[2:2]	OVCH	R	0x00	Status overcharge.
		[3:3]	SRCLOW	R	0x00	Status source low threshold.
		[4:4]	CHG5VCONN	R	0x00	Status 5 V charger connected.
		[5:5]	CHG5VON	R	0x00	Status 5 V charger ON.
0x16	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).
0x17	APM0SRC	[7:0]	DATA	R	0x00	APM data 0 (SRC).
0x18	APM1SRC	[7:0]	DATA	R	0x00	APM data 1 (SRC).
0x19	APM2SRC	[7:0]	DATA	R	0x00	APM data 2 (SRC).
0x1A	APM0LOAD	[7:0]	DATA	R	0x00	APM data 0 (LOAD).
0x1B	APM1LOAD	[7:0]	DATA	R	0x00	APM data 1 (LOAD).
0x1C	APM2LOAD	[7:0]	DATA	R	0x00	APM data 2 (LOAD).

Table 9: Register map (part 2)

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Address	Name	Bit	Field Name	Access	Reset	Description
0x1D	APMERR	[0:0]	SRCERR	R	0x00	APM SRC counter corrupted.
		[1:1]	LOADERR	R	0x00	APM LOAD counter corrupted.
0x1E	TEMP	[7:0]	DATA	R	0x00	Temperature monitoring value.
0x1F	STO	[7:0]	DATA	R	0x00	STO monitoring value.
0x20	SRC	[7:0]	DATA	R	0x00	SRC monitoring value.

Table 9: Register map (part 3)

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7. Functional Tests

This section presents a few simple tests that allow the user to understand the functional behavior of the AEM11921. 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.

The user 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 "Electrical Characteristics at 25 °C" Section of AEM11921 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.

7.1. Startup

7.1.1. Description

The following example allows the user to observe the startup behavior of the AEM11921, showing that the AEM11921 starts charging the storage element as soon as VINT reaches its 2.20 V regulation voltage.

7.1.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: VINT (may be probed on H pin on LOAD_CFG[0] header for example).
- SRC (initially disconnected):
  - 1 V / 10 mA power supply with a 100 Ω resistor in series (I_{SRC} = 2 mA with R_{MPPT} = 80%).
  - SMU set as 2 mA current source with 1 V voltage compliance.
  - $I_{SRC} = \frac{1V - 0.8V}{100\Omega} = 2mA$ (PSU)
  - $I_{SRC} = 2mA$ (SMU)
- 1000 µF capacitor connected to STO as storage element.
- 3.0 V power supply or SMU connected to STO beforehand.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
- LOAD is floating.
- LOAD_CFG[1:0] = LL.
  - LOAD disabled.
- 5V_EXT left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.

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7.1.3. Measurements

- Reset the AEM11921 as described in Section 3.2.
- Start with:
  - 3.0 V power supply connected to STO so that C_{STO} is charged to 3.0 V beforehand.
  - No source connected to SRC.
- Disconnect the power supply from STO.
- Connect the power supply or the SMU to SRC.
- Observe V_{INT} rise up to 2.20 V and be regulated around that voltage.
- Energy is transferred from SRC to STO: V_{STO} rises from its initial 3 V voltage to V_{OVCH}.
- V_{STO} is maintained between V_{OVCH} and $V_{OVCH,LOW}$ as the AEM11921 prevents the storage element to be charged any further.

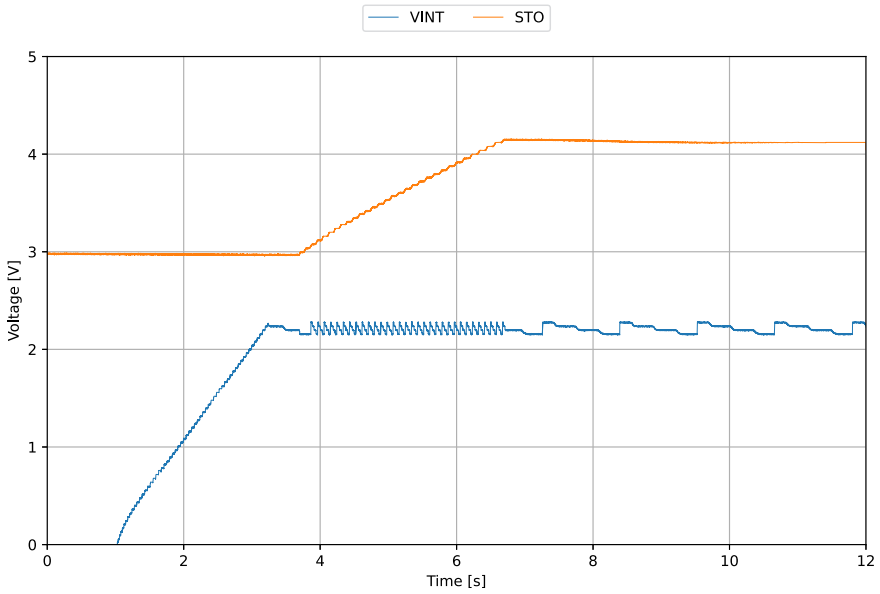


Figure 4: Startup behavior

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7.2. Cold start

7.2.1. Description

The following example allows the user to observe the cold-start behavior of the AEM11921, showing the behavior of SRC and VINT when the AEM11921 coldstarts.

7.2.2. Setup

- Oscilloscope:
  - Channel 1: SRC.
  - Channel 2: VINT (may be probed on H pin on LOAD_CFG[0] header for example).
  - Note than the oscilloscope probes will have an impact in the minimum input cold-start power due to their input impedance.
- SRC (initially disconnected):
  - 1 V / 10 mA power supply with a 68 kΩ resistor in series (I_{SRC} = 8.6 µA with source voltage clamped to 0.415 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.
  - Note that the AEM11921 is able to cold start at lower power than used in this example.
  - $I_{SRC} = \frac{1V - 0.415V}{68k\Omega} = 8.6\mu A$ (PSU)
  - $I_{SRC} = 8.6\mu A$ (SMU)
- 1000 µF capacitor connected to STO as storage element.
- 3 V power supply connected to STO beforehand.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
- LOAD is floating.
- LOAD_CFG[1:0] = LL.
  - LOAD disabled.
- 5V_IN left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.

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7.2.3. Measurements

- Reset the AEM11921 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 SRC.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRC.
- Cold-start phase:
  - Observe V_{SRC} clamped to 0.415 V.
  - Observe V_{INT} rise up to 2.20 V and be regulated around that voltage.
- Once V_{INT} has reached its 2.20 V regulation voltage, the AEM11921 performs a first V_{OC} evaluation on SRC.
- Note that during the first V_{OC} evaluation, the source current is insufficient to charge C_{SRC} up to the V_{OC} within $T_{MPPT,WAIT}$ resulting in a lower V_{MPP} compared to the target. This is solved in the next evaluations.
- V_{OC} is re-evaluated every 29.79 s.

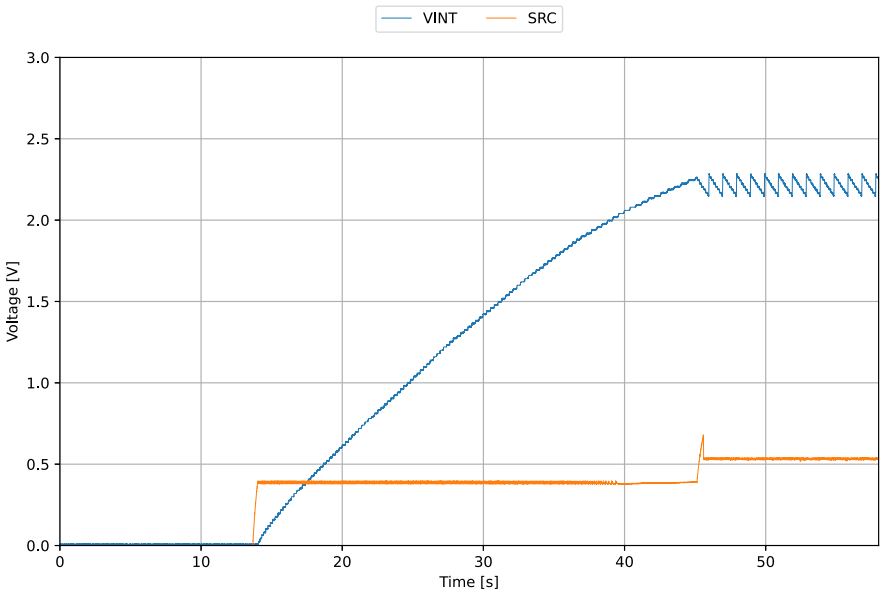


Figure 5: Cold-start behavior

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7.3. 5 V Charger

7.3.1. Description

The following example allows the user to observe how the AEM11921 coldstarts and charges the storage element from the 5 V charger.

7.3.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: 5V_EXT.
- SRC left floating.
- 5V_EXT: 5.0 V / 200 mA power supply or SMU (initially disconnected).
- 10 mF capacitor connected to STO as storage element.
- Power supply connected to STO beforehand with a voltage below V_{OVDIS}, 2.8 V in this example.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
- LOAD is floating.
- LOAD_CFG[1:0] = LL.
  - LOAD disabled.
- Jumper between I2C and DIS.
  - I^2C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.

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7.3.3. Measurements

- Reset the AEM11921 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 power supply connected to 5V_EXT.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to 5V_EXT.
- After the coldstart, STO is being charged at $I_{5V,OVDIS,CC}$ until it reaches V_{OVDIS}. After that, STO charges at 180 mA up to V_{OVCH}.

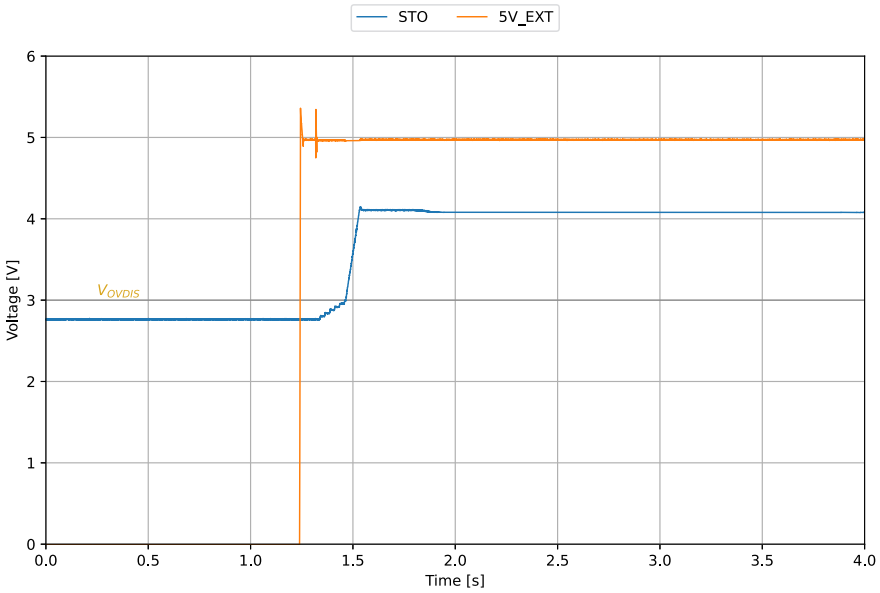


Figure 6: Cold-start and storage element charge from 5V_EXT behavior

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7.4. 5 V Charger Overvoltage Protection

7.4.1. Description

The following example allows the user to observe how the AEM11921 5 V charger overvoltage protection works.

7.4.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: 5V_EXT.
- SRC left floating.
- 5V_EXT: 5.0 V / 200 mA power supply or SMU (initially disconnected).
- 5 F supercapacitor connected to STO as storage element.
- Power supply connected to STO beforehand with a voltage below V_{OVDIS}, 3.0 V in this example.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
- LOAD is floating.
- LOAD_CFG[1:0] = LL.
  - LOAD disabled.
- Jumper between I2C and DIS.
  - I^2C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.

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7.4.3. Measurements

- Reset the AEM11921 as described in Section 3.2.
- Start with:
  - A supercapacitor charged at 3 V connected to STO beforehand.
  - No power supply connected to 5V_EXT.
- Connect the power supply on 5V_EXT and observe STO charging.
- Change the voltage on the power supply to a voltage above 5.50 V and observe STO not charging.
- Drop the power supply voltage below 5.50 V and observe STO charge resuming.

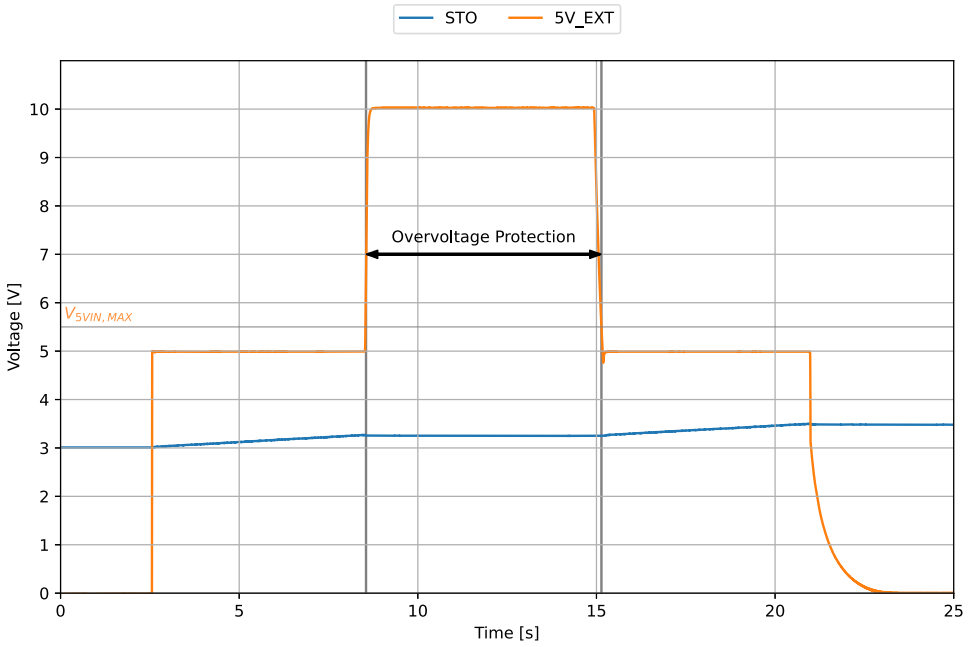


Figure 7: 5 V charger overvoltage protection behavior

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7.5. Load

7.5.1. Description

The following example allows the user to observe how the AEM11921 switches ON and OFF the buck converter supplying the LOAD pin.

7.5.2. Setup

- Oscilloscope:
  - Channel 1: STO.
  - Channel 2: LOAD.
- SRC (initially disconnected):
  - 1 V / 10 mA power supply with a 100 Ω resistor in series (I_{SRC} = 2 mA with R_{MPPT} = 80%).
  - SMU set as 2 mA current source with 1.0 V voltage compliance.
  - $I_{SRC} = \frac{1V - 0.8V}{100\Omega} = 2mA$ (PSU)
  - $I_{SRC} = 2mA$ (SMU)
- 1000 µF capacitor connected to STO as storage element.
- Power supply connected to STO beforehand with a voltage below V_{OVDIS}, 2.8 V in this example.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
  - $V_{OVDIS,BUCK}$ = V_{OVDIS}
  - $V_{CHRDY,BUCK}$ = 3.20 V.
- LOAD: 4.7 kΩ resistor connected between LOAD and GND.
- LOAD_CFG[1:0] = LH.
  - LOAD is regulated at 2.20 V.
  - I_{LOAD} = 468 µA.
- 5V_EXT left floating.
- Jumper between I2C and DIS.
  - I²C disabled.
- Jumper between THERM and DIS.
  - Thermal monitoring disabled.

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7.5.3. Measurements

- Reset the AEM11921 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 SRC.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRC.
- After cold start, observe the storage element charging.
- When $V_{STO} \geq V_{CHRDY,BUCK}$, the buck converter is enabled and the LOAD starts being regulated to 2.20 V, thus, providing current to the 4.7 kΩ resistor. There is more energy harvested than consumed (positive power budget), so the storage element keeps being charged.
- The current drawn by the 4.7 kΩ is now discharging the storage element, as no more energy is harvested to compensate for the load.
- When $V_{STO} < V_{OVDIS,BUCK}$ ($V_{OVDIS,BUCK} = V_{OVDIS}$ in this example), the AEM11921 waits for $T_{LOAD,DIS}$ (2.27 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 8 during $T_{LOAD,DIS}$.

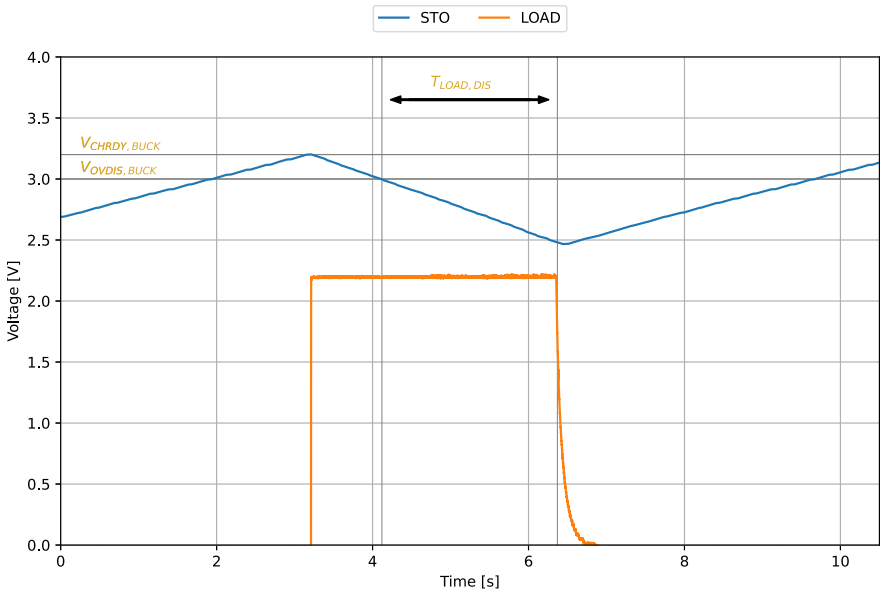


Figure 8: LOAD output behavior

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7.6. Thermal Protection

7.6.1. Description

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

7.6.2. 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: SRC.
  - Channel 2: STO.
- SRC: 1 V / 10 mA power supply with a 3 kΩ resistor in series (I_{SRC} = 67 µA with R_{MPPT} = 80%).
  - $I_{SRC} = \frac{1V - 0.80V}{3k\Omega} = 67\mu A$
- 1000 µF capacitor connected to STO as storage element.
- 3 V power supply connected to STO beforehand.
- STO_CFG = H.
  - V_{OVDIS} = 3.00 V.
  - V_{CHRDY} = 3.20 V.
  - V_{OVCH} = 4.15 V.
- LOAD is floating.
- LOAD_CFG[1:0] = LL.
  - LOAD disabled.
- 5V_EXT 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 disabled below 0°C.
  - Storage element charging and discharging disabled above +45°C.

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7.6.3. Measurements

- Reset the AEM11921 as described in Section 3.2.
- Start with:
  - 3 V power supply connected to STO so that C_{STO} is charged to 3 V beforehand.
  - No power supply connected to SRC.
- Disconnect the power supply from STO.
- Connect the power supply or SMU to SRC.
- After cold start, observe the storage element charging.
- Start flowing hot air on the thermistor R_{TH}.
- When R_{TH} is hot enough, above 45°C (near 6 s on Figure 9), the AEM11921 thermal protection is triggered:
  - No more energy is extracted from the source connected on SRC, which rises to its open circuit voltage V_{OC}.
  - The storage element is no longer charged (V_{STO} stops rising) and thus, is protected, even though V_{STO} is below V_{OVCH}.
  - The LOAD would stop being supplied if enabled.
  - VINT is still supplied from SRC.

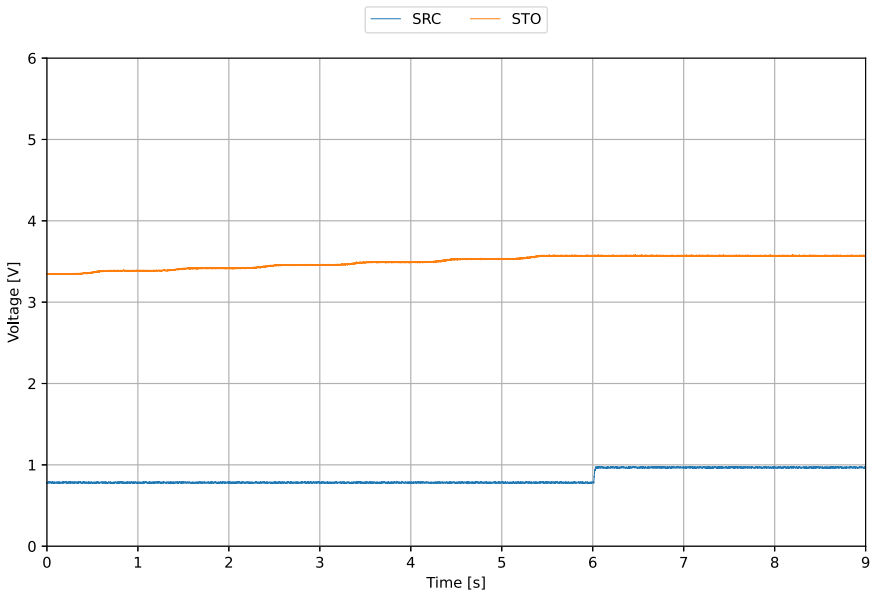


Figure 9: Storage element thermal protection behavior

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8. Performance Tests

This section presents the tests to reproduce the performance graphs found in the AEM11921 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 AEM11921 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.

8.1. Boost Converters Efficiency

8.1.1. Description

The boost converter efficiency is determined for a fixed set point of the AEM11921:

- Fixed SRC voltage V_{SRC}.
- Fixed SRC current I_{SRC}.
- Fixed STO voltage V_{STO}.
- Fixed inductor value L_{BOOST}. Please note that the inductor model has a subsequent influence on the efficiency.

Boost efficiency measurement is about measuring the current provided to STO for 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 AEM11921 pins while measuring the boost efficiency.

8.1.2. Setup

- SRC: SMU set as current source.
  - Current source set to the desired I_{SRC}.
  - Voltage compliance set to be 1.25 times the desired V_{MPP} set point as the default R_{MPPT} is 85 %.
- 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 than the power of the SMU connected to SRC (V_{SRC} x I_{SRC}). Do not lower the current compliance lower than 100 µA.
- Optional: a device able to act as an I^2C master and send I^2C commands to the AEM11921. Only useful when testing settings that are not accessible through the configuration pins, such as source configuration.

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8.1.3. 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, the user must make sure that V_{STO} does not drop below V_{OVDIS} between measurements.

- Start with both SMU switched OFF.
- Reset the AEM11921.
- STO SMU: set the voltage to 5.0 V and switch ON, to make sure that V_{STO} is above V_{OVCH}.
- SRC SMU: set the current source to 1 mA with the voltage compliance to 1.0 V to trigger the AEM11921 cold start.
- Wait for V_{INT} to rise to its 2.20 V regulation voltage.
- The AEM11921 is now ready to perform an efficiency measurement. Do not lower V_{STO} below V_{OVDIS} from that point to avoid the AEM11921 going to OVDIS STATE. Keep STO SMU current compliance to at least 100 µA.

Efficiency measurement

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

- Set SRC SMU to the desired voltage and current set point.
- Set STO SMU to the desired voltage and adapted current range.
- 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:

$$\eta[\%] = \frac{V_{STO} \times I_{STO}}{V_{SRC} \times I_{SRC}} \times 100$$

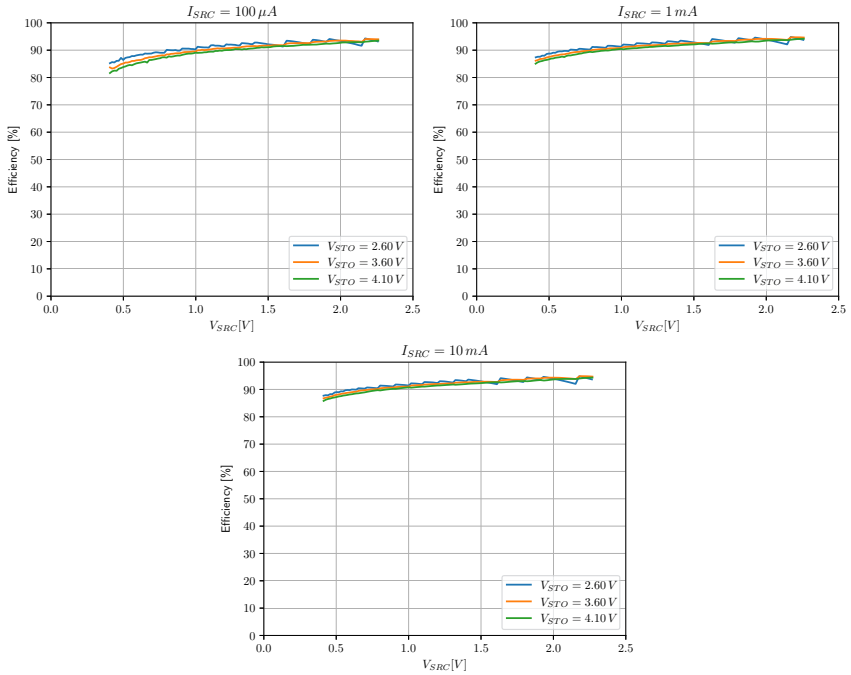


Figure 10: Boost converter efficiency with L_{BOOST} = 22 µH (Coilcraft LPS4018-223MRB)

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8.2. Buck Converter Efficiency

8.2.1. Description

The buck converter efficiency is determined on a fixed set point of the AEM11921:

- 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.

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 AEM11921 pins while measuring the buck efficiency.

8.2.2. 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}.
- SRC: any power supply with voltage higher than $V_{SRC,CS}$ and lower than V_{STO} (1 V / 1 mA is typically fine).
- Optional: a device able to act as an I²C master and send I²C commands to the AEM11921. Only useful when testing settings that are not accessible through the configuration pins.

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8.2.3. 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 AEM11921.
- 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 SRC power supply.
- Wait for V_{INT} to be regulated at 2.20 V.
- Switch OFF SRC power supply.
- The AEM11921 is now ready to perform an efficiency measurement. Do not lower V_{STO} below V_{OVDIS} from that point to avoid the AEM11921 going to OVDIS STATE. Keep the STO SMU current compliance to 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 adapted current range.
- 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:

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

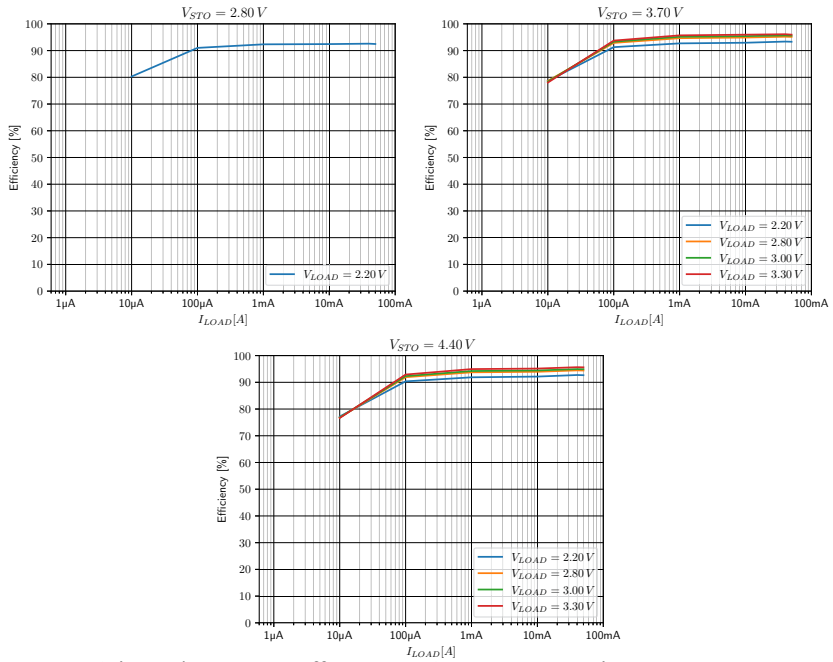


Figure 11: Buck (LOAD) converter efficiency with L_{BUCK} = 10 µH (TDK VLS252012CX-100M-1)

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9. EVK Schematic

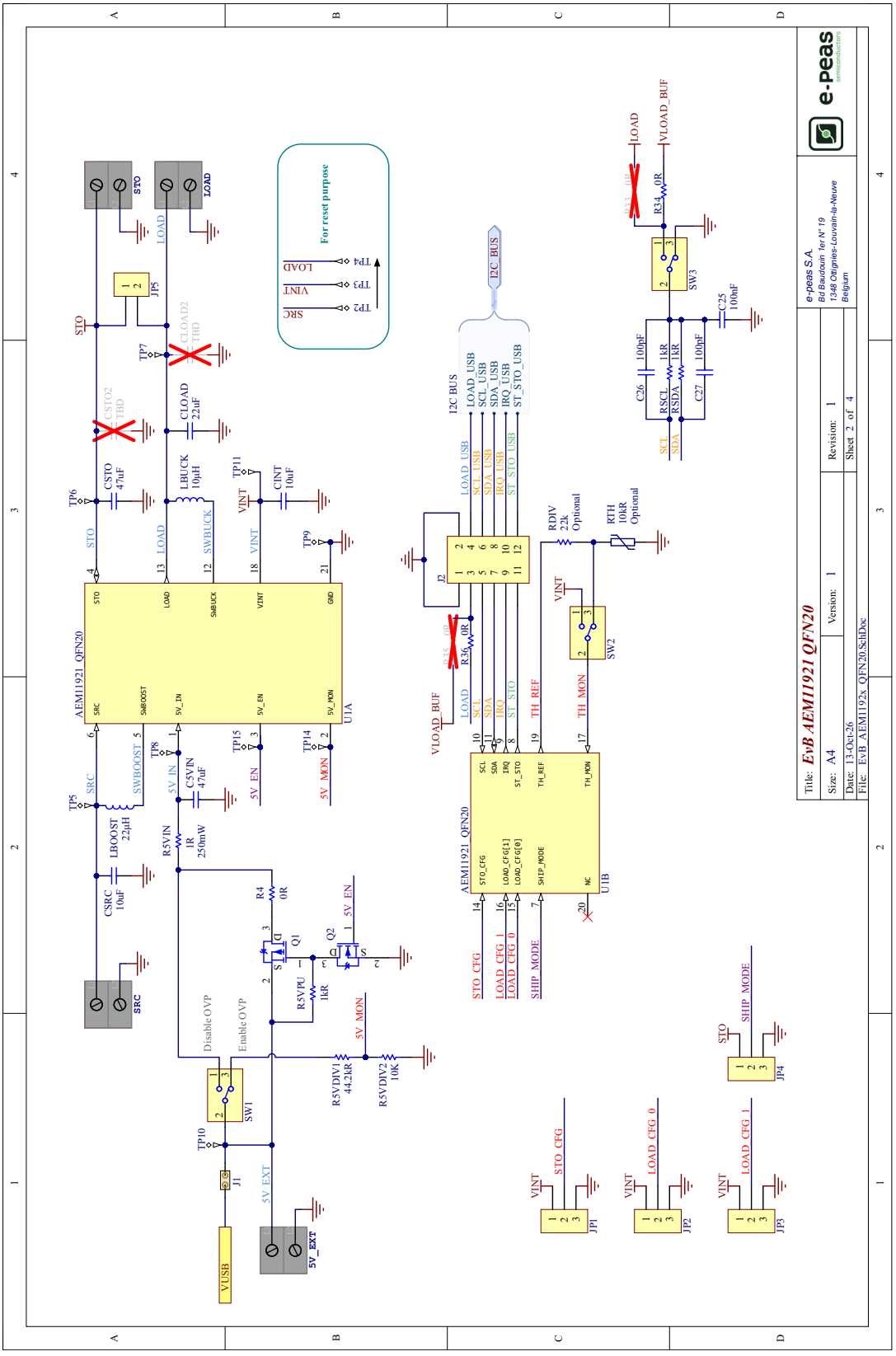


Figure 12: EVK schematic

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10. Revision History

EVK Version	User Guide Revision	Date	Description
1.1	1.0	November, 2026	Creation of the file.

Table 10: Revision history

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