AEM00940 Evaluation Board User Guide

Description

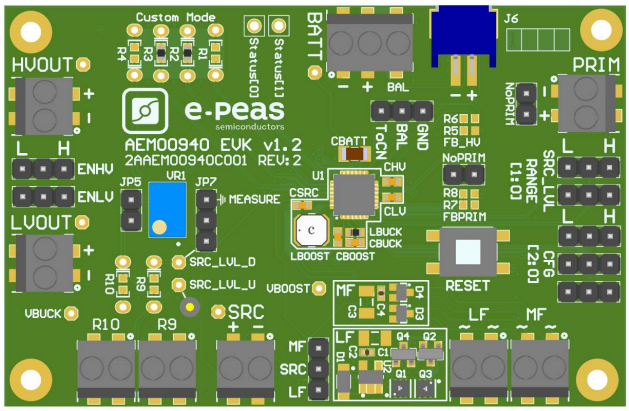
The AEM00940 evaluation board is a printed circuit board (PCB) featuring all the needed components to operate the AEM00940 integrated circuit (IC). Please refer to the datasheet for all the useful details about the AEM00940 (Document DS_AEM00940).

The AEM00940 evaluation board allows users to test the e-peas IC and analyze its performances in a laboratory-like setting.

It allows easy connections to the energy harvester (DC or AC source), the storage element, the low-voltage and the high-voltage loads. This evaluation board includes two rectifiers for the low and medium frequency AC sources. It also provides all the configuration access to set the device in any one of the modes described in the datasheet. The control and status signals are available on standard pin headers, allowing users to wire for any usage scenario and evaluate the relevant performance.

The AEM00940 evaluation board is a plug and play, intuitive and efficient tool for making the appropriate decisions (component selection, operating modes…) for the design of a highly efficient subsystem powered by energy harvesting in your target application.

Appearance



Features

Two-way screw terminals

- Source of energy (DC).
- Source of energy (low frequency AC).
- Source of energy (medium frequency AC).
- Low-voltage load.
- High-voltage load.
- Primary energy storage element.
- Resistors for source level setting.

Three-way screw terminals

- Energy storage element (Battery or (super)capacitor).

2-pin “Shrouded Header”

- Alternative connection for the storage element.

3-pin headers

- Source level range configuration.
- Low drop-out regulators (LDOs) enabling.
- Energy storage elements and LDOs configuration.
- Dual-cell supercapacitor configuration.
- AC rectifier selection.
- Source level measurement enabling.

2-pin headers

- Primary battery configuration.
- Connection of the on-board potentiometer for source level setting.

Provision for resistors

- Source level configuration.
- Custom mode configuration.
- Primary battery configuration.

1-pin headers

- Access to status pins.

EvB Information

Part Number	Dimensions
2AAEM00940C001 REV:2	76 mm x 49 mm

Device Information

Part Number	Dimensions
10AEM00940C0000	5 mm x 5 mm

1. Connections Diagram

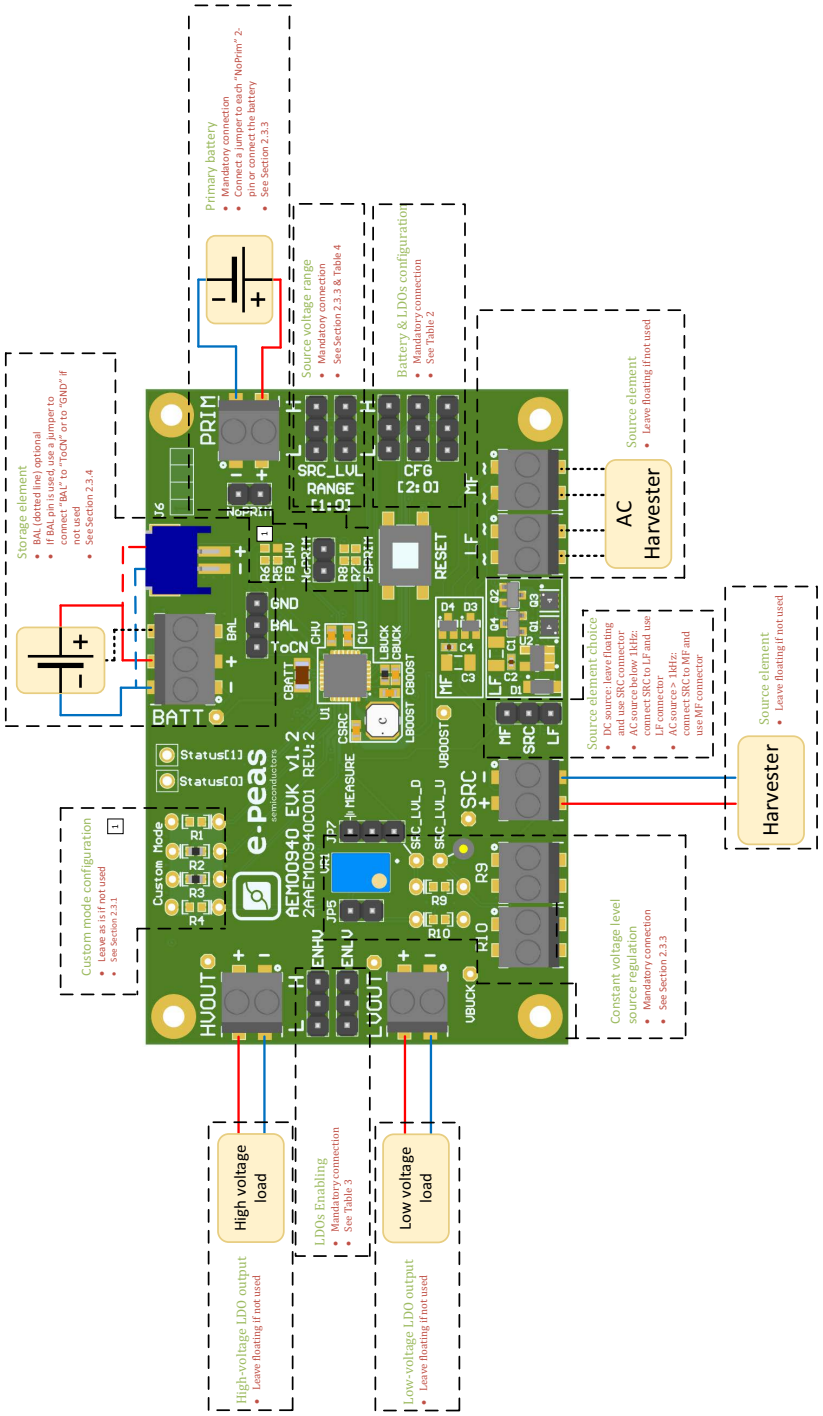


Figure 1: Connection Diagram

NOTE: if R1, R2, R3, R4 and R20 are not mounted (and thus SET_OVDIS, SET_OVCH and SET_CHRDY are floating), make sure that no power source is connected to SRC or to PRIM when CFG[2:0] is LLL (custom mode) or floating. This would lead to damaging the AEM00940. Having SET_OVDIS, SET_OVCH and SET_CHRDY tied to BUCK by installing 0 Ω on R2, R3 and R20 prevents this behavior.

1.1. Signals Description

		If used	If not used
NAME	**FUNCTION**	**CONNECTION**	
Power signals			
SRC	Connection to the harvested energy source.	Connect the source element.	
BATT	Connection to the energy storage element.	Connect the storage element in addition to CBATT (220 µF).	Do not remove CBATT.
BAL	Connection to mid-point of a dual-cell supercapacitor.	Connect mid-point of supercapacitor and a jumper from "BAL" to "ToCN".	Use a jumper to connect "BAL" to "GND".
PRIM	Connection to the primary battery.	Connect primary battery and remove the "NoPRIM" jumpers.	Connect a jumper to each "NoPRIM" 2-pin.
LVOUT	Output of the low-voltage LDO regulator.	Connect a load.	Leave floating
HVOUT	Output of the high-voltage LDO regulator.	Connect a load.	Leave floating
LF	Connection to the AC harvested energy source (low frequency).	Connect to the source element.	Leave floating.
MF	Connection to the AC harvested energy source (medium frequency).	Connect to the source element.	Leave floating.
Debug signals			
VBOOST	Output of the boost converter.		
VBUCK	Output of the buck converter.		
BUFSRC	Connection to an external capacitor buffering the boost converter input.		
Configuration signals			
CFG[2:0]	Configuration of the threshold voltages for the energy storage element.	Connect jumpers (see Table 2).	Cannot be left floating (see Table 2).
SRC_LVL_RANGE[1:0]	Constant voltage harvesting range multiplier.	Connect jumpers (see Table 4).	Cannot be left floating (see Table 4).
SRC_LVL_D SRC_LVL_U	Constant voltage harvesting range.	Three alternatives (see Section 2.3.2): - Use the potentiometer VR1 by placing a jumper on JP5, and another jumper between the middle pin and the pin below it on JP7. - Connect resistors on R9-R10 connectors. - Solder resistors on R9-R10 footprints.	Cannot be left floating (see Section 2.3.2).
FB_PRIM_D FB_PRIM_U	Configuration of the primary battery.	Use resistors R7-R8 (see Section 2.3.3).	Connect a jumper to each "NoPRIM" 2-pin.
FB_HV	Configuration of the high-voltage LDO in the custom mode.	Use resistor R5-R6 (see Section 2.3.1).	Leave floating.
Control signals			
ENHV	Enabling pin for the high-voltage LDO.	Connect jumper (see Table 3).	Cannot be left floating (see Table 3).
ENLV	Enabling pin for the low-voltage LDO.	Connect jumper (see Table 3).	Cannot be left floating (see Table 3).
Status signals			
STATUS[1]	Logic output. Asserted if the battery voltage falls under Vovdis or if the AEM is taking energy from the primary battery.		
STATUS[0]	Logic output. Asserted when the LDOs can be enabled.		

Table 1: Pin Description

2. General Considerations

2.1. Safety Information

Always connect the elements in the following order:

1. Reset the board - see “How to reset the AEM00940 evaluation board” on Figure 2.
2. Completely configure the PCB (jumpers/resistors):
   - Source level configuration (SRC_LVL_RANGE[1:0]) -Table 4.
   - Battery and LDOs configuration (CFG[2:0] and, if needed, R1 to R6) - see Table 2.
   - Primary battery configuration (“NoPRIM” or R7-R8) - see Section 2.3.3.
   - LDOs enabling (ENHV and ENLV) - see Table 3.
   - Balancing circuit connection (BAL) - see Section 2.3.4.
3. Connect the storage elements on BATT and optionally the primary battery on PRIM.
4. Connect the high and/or low voltage loads on HVOUT/LVOUT (optional).
5. Connect the Low or High frequency source on AC or DC SRC. Do not use both simultaneously.

To avoid damage to the board, users are urged to follow this procedure.

How to reset the AEM00940 evaluation board:

To reset the board, simply disconnect the storage element and the optional primary battery and press the reset button in order to discharge the internal nodes of the system.

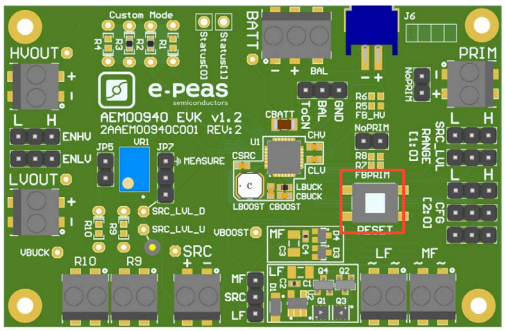


Figure 2: Board Reset

2.2. Basic Configurations

Configuration pins			Storage element threshold voltages			LDOs output voltages		Typical use
CFG[2]	CFG[1]	CFG[0]	V_{OVCH}	V_{CHRDY}	V_{OVDIS}	V_{HV}	V_{LV}	
H	H	H	4.12 V	3.67 V	3.60 V	3.3 V	1.8 V	Li-ion battery
H	H	L	4.12 V	4.04 V	3.60 V	3.3 V	1.8 V	Solid state battery
H	L	H	4.12 V	3.67 V	3.01 V	2.5 V	1.8 V	Li-ion/NiMH battery
H	L	L	2.70 V	2.30 V	2.20 V	1.8 V	1.2 V	Single-cell (super) capacitor
L	H	H	4.50 V	3.67 V	2.80 V	2.5 V	1.8 V	Dual-cell supercapacitor
L	H	L	4.50 V	3.92 V	3.60 V	3.3 V	1.8 V	Dual-cell supercapacitor
L	L	H	3.63 V	3.10 V	2.80 V	2.5 V	1.8 V	LiFePO4 battery
L	L	L	Custom mode - see Section 2.3.1.				1.8 V	

Table 2: Usage of CFG[2:0]

ENLV	ENHV	LV output	HV output
H	H	Enabled	Enabled
H	L	Enabled	Disabled
L	H	Disabled	Enabled
L	L	Disabled	Disabled

Table 3: LDOs enabling

Configuration pins		
SRC_LVL_RANGE[1:0]	Gain	V_{SRC_REG} range
LL	x1	V_{SRC_REG} < 1.35 V
LH	x2	1.35 V < V_{SRC_REG} < 2.70 V
HL	x4	2.70 V < V_{SRC_REG} < 4.47 V
HH		

Table 4: SRC_LVL_RANGE[1:0] Configuration

2.3. Advanced Configurations

A complete description of the system constraints and configurations is available in the AEM00940 datasheet "System configuration" Section.

A reminder on how to calculate the configuration resistors value is provided below. Calculation can be made with the help of the spreadsheet found on e-peas website.

2.3.1. Custom Mode

In addition to the pre-defined storage element protection levels, the custom mode allows users to define their own levels via resistors R1 to R4 and to tune the output of the high voltage LDO HVOUT via resistors R5-R6.

Here is how to determine the values of R1-R4 to set the desired storage element protection levels:

- $R_T = R1 + R2 + R3 + R4$
- $1M\Omega \leq R_T \leq 100M\Omega$
- $R1 = R_T \cdot \frac{1V}{V_{OVCH}}$
- $R2 = R_T \cdot \left(\frac{1V}{V_{CHRDY}} - \frac{1V}{V_{OVCH}}\right)$
- $R3 = R_T \cdot \left(\frac{1V}{V_{OVDIS}} - \frac{1V}{V_{CHRDY}}\right)$
- $R4 = R_T \cdot \left(1 - \frac{1V}{V_{OVDIS}}\right)$

Here is how to determine the values of R5-R6 to set the desired HVOUT voltages:

- $R_V = R5 + R6$
- $1M\Omega \leq R_V \leq 40M\Omega$
- $R5 = R_V \cdot \frac{1V}{V_{HV}}$
- $R6 = R_V \cdot \left(1 - \frac{1V}{V_{HV}}\right)$

Make sure the protection levels satisfy the following conditions:

- $V_{CHRDY} + 0.05V \leq V_{OVCH} \leq 4.5V$
- $V_{OVDIS} + 0.05V \leq V_{CHRDY} \leq V_{OVCH} - 0.5V$
- $2.2V \leq V_{OVDIS}$
- $V_{HV} \leq V_{OVDIS} - 0.3V$

If custom mode used:

- Remove R2, R3 and R20 zero ohm resistors.
- Set resistors R1 to R6 to configure the custom mode.

If custom mode unused:

- Leave the resistor footprints of R1 to R6 empty.
- Place 0 ohm resistors on R20.
- Do not set CFG[2:0] to LLL.

2.3.2. Constant Voltage Configuration

The regulated harvesting voltage $V_{SRC,REG}$ can be defined by the use of the resistors R9 and R10.

SRC_LVL_RANGE[1:0] must be set according to the range of $V_{SRC,REG}$ as shown in Table 4 by using the following formulas:

- $R_S = R9 + R10$
- $100k\Omega \leq R_S \leq 1M\Omega$
- $R9 = \frac{V_{SRC,REG}}{Gain} \cdot R_S \cdot \frac{1}{2.2V}$
- $R10 = R_S - R9$

R9 and R10 must either be set by:

- Soldering SMD/through-hole resistors on the R9-R10 footprints.
- Inserting through-hole resistors in the R9-R10 connectors.
- Using the EVK 200 kΩ potentiometer VR1 which is connected to VBUCK through R19 (100 kΩ).

The procedure of setting $V_{SRC,REG}$ through VR1 is the following:

- Ensure that neither of R9 and R10 are installed on either the footprints or the screw connectors.
- Place a jumper on JP5.

- Make sure the AEM00940 has coldstarted and that VBUCK is 2.2 V. The power available on SRC must be larger than 100 µW.
- Connect a jumper on JP7 between the middle pin and the pin above it to ensure that the resistive divider (VR1 and R19) is always grounded.
- Connect a voltmeter between GND and SRC_LVL_U using the dedicated test point below VR1.
- Set VR1 using a screwdriver until SRC_LVL_U reaches the desired voltage considering the above formulas.
- Move the jumper on JP7 to connect the middle pin and the pin below it.
- Remove the voltmeter and test with a source connected on SRC.

NOTE: If the potentiometer VR1 is not used to configure the source constant voltage, please leave JP5 and JP7 without jumpers.

2.3.3. Primary Battery Configuration

If a primary storage is used, it is mandatory to determine $V_{PRIM,MIN}$, the voltage at which the primary battery is considered fully depleted. To do so, use resistors R7 - R8.

These resistors are calculated as follows:

- $R_P = R7 + R8$
- $100k\Omega \leq R_P \leq 500k\Omega$
- $R7 = \frac{V_{PRIM\_MIN}}{4} \cdot R_P \cdot \frac{1}{2.2V}$
- $R8 = R_P - R7$

If unused, use a jumper to short each “NoPRIM” 2-pin headers.

2.3.4. Balancing Circuit Configuration

When using a dual-cell supercapacitor (that does not already include a balancing circuit), enable the balancing circuit configuration to ensure equal voltage on both cells. To do so:

- Connect the node between the two supercapacitor cells to BAL (on BATT connector).
- Use a jumper to connect “BAL” to “ToCN”.

If unused, use a jumper to connect “BAL” to “GND”.

3. Functional Tests

This section presents a few simple tests that allow the user to understand the functional behavior of the AEM00940. To avoid damaging the board, follow the procedure found in Section 2.1 “Safety Information”. If a test has to be restarted make sure to properly reset the system to obtain reproducible results.

Those functional tests were made using the following setup:

- Configurations:
  - SRC_LVL_RANGE[1:0] = LL
  - CFG[2:0] = HLL, ENHV = H, ENLV = H.
- Storage element: Capacitor (4.7 mF + CBATT).
- Loads: 10 kΩ on HVOUT. LVOUT left floating.
- SRC: current source (1 mA or 100 µA) with voltage compliance (4V).

Feel free to adapt the setup to match your system as long as the input and cold-start constraints are respected (see the AEM00940 datasheet “Introduction” Section).

3.1. Start-up

The following example allows users to observe the behavior of the AEM00940 in the wake-up mode.

Setup

- Place the probes on the nodes to be observed.
- Referring to Figure 1, follow steps 1 to 5 explained in Section 2.1 “Safety Information”.

Observations and Measurements

- BATT: Voltage rises as the power provided by the source is transferred to the storage element (see Figure 3).
- SRC: Regulated at V_{SRC_REG}.
- HVOUT/LVOUT: Regulated when voltage on BATT first rises above V_{CHRDY} (see Figure 3).
- STATUS[0]: Asserted when the LDOs are ready to be enabled (refer to the AEM00940 datasheet “Normal Mode” section) (see Figure 3).

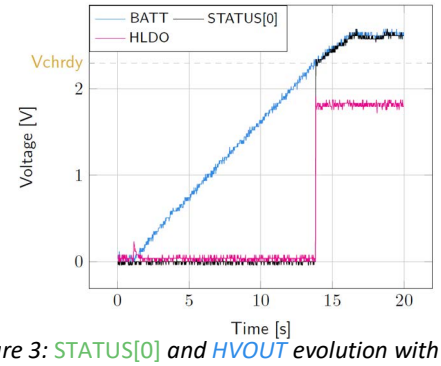


Figure 3: STATUS[0] and HVOUT evolution with BATT

3.2. Shutdown

This test allows users to observe the behavior of the AEM00940 when the system is running out of energy.

Setup

- Place the probes on the nodes to be observed.
- Referring to Figure 1, follow steps 1 to 5 explained in Section 2.1 “Safety Information”. Configure the board in the desired state and start the system (see Section 3.1). Do not use a primary battery.
- Let the system reach a steady state (i.e. voltage on BATT between V_{CHRDY} and V_{OVCH} and STATUS[0] asserted).
- Remove the PV cell and let the system discharge through quiescent current and HVOUT/LVOUT load(s).

Observations and Measurements

- BATT: Voltage decreases as the system consumes the power accumulated in the storage element. The voltage remains stable after crossing V_{OVDIS} (see Figure 4).
- STATUS[0]: De-asserted when the LDOs are no longer available as the storage element is running out of energy. This happens 600 ms after STATUS[1] assertion (see Figure 4).
- STATUS[1]: Asserted for 600ms when the storage element voltage (BATT) falls below V_{OVDIS} (see Figure 4).

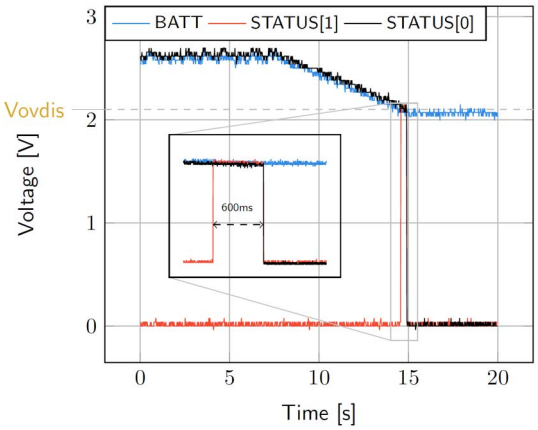


Figure 4: LDOs disabled around 600 ms after BATT reaches V_{OVDIS}

3.3. Switching on Primary Battery

This example allows users to observe switching from the main storage element to the primary battery when the system is running out of energy.

Setup

- Place the probes on the nodes to be observed.
- Referring to Figure 1, follow steps 1 to 5 explained in Section 2.1 “Safety Information”. Configure the board in the desired state and start the system (see Section 3.1). Connect a primary battery (example: 3.1 V coin cell with protection level at 2.4 V, R7 = 68 kΩ and R8 = 180 kΩ).
- Let the system reach a steady state (i.e. voltage on BATT between V_{CHRDY} and V_{OVDIS} and STATUS[0] asserted).
- Remove the PV cell and let the system discharge through quiescent current and HVOUT/LVOUT load(s).

Observations and Measurements

- BATT: Voltage decreases as the system consumes the power accumulated in the storage element. The voltage reaches V_{OVDIS} and than rises again to V_{CHRDY} as it is recharged from the primary battery (see Figure 5).
- STATUS[0]: Never de-asserted as the LDOs are still functional (see Figure 5).
- HVOUT: Stable and not affected by switching on the primary battery (see Figure 5).

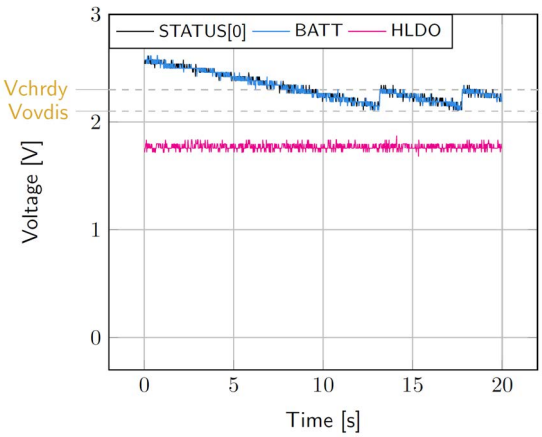


Figure 5: Switching from SRC to the primary battery

3.4. Cold Start

The following test allows the user to observe the minimum voltage required to coldstart the AEM00940. To prevent leakage current induced by the probe, the user should avoid probing any unnecessary node. Make sure to properly reset the board to observe the cold-start behavior.

Setup

- Place the probes on the nodes to be observed.
- Referring Figure 1, follow steps 1 and 2 explained in Section 2.1. Configure the board in the desired state. Do not plug any storage element in addition to CBATT.
- SRC: Connect your source element.

Observations and Measurements

- SRC: Equal to the cold-start voltage during the cold-start phase. Regulated at the selected voltage when cold start is over. (See Figure 6). Be careful that the cold-start phase time will shorten with the input power. Limit it to ease the observation.
- BATT: Starts to charge when the cold-start phase is over (see Figure 6).

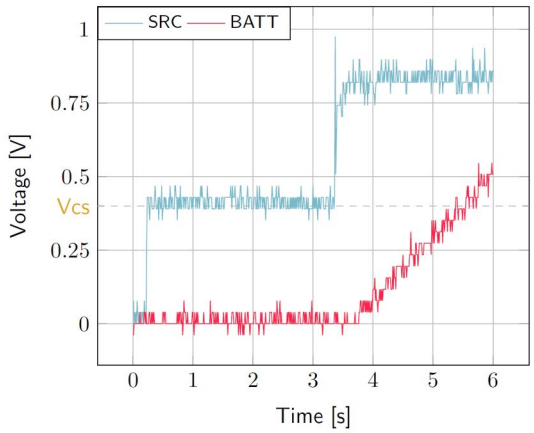


Figure 6: AEM00940 behavior during cold start

3.5. Dual-cell Supercapacitor Balancing Circuit

The following test allows the user to observe the balancing circuit behavior that balances the voltage on both side of the BAL pin.

Setup

- Following steps 1 and 2 explained in Section 2.1 and referring to Figure 1, configure the board in the desired state. Plug the jumper linking "BAL" to "ToCN".
- BATT: Plug a capacitor C1 between the positive (+) pin and the BAL pin, and a capacitor C2 between the BAL pin and the negative (-) pin.
  - C1 & C2 > 1 mF.
  - (C2 x V_{CHRDY}) / C1 ≥ 0.9 V.
- SRC: Connect your source element to power up the system.

Observations and Measurements

- BAL voltage equals half of the BATT voltage.

Warning regarding measurements:

Any item connected to the PCB (load, probe, storage device, etc.) involves a leakage current. This can negatively impact the measurements. Whenever possible, disconnect unused items to limit this effect.

4. Performance Tests

This section presents the tests to reproduce the performance graphs found in the AEM00940 datasheet and to understand the functionalities of the AEM00940. To be able to reproduce those tests, the following equipment is required:

- 1 voltage source.
- 2 source measure units (SMUs).
- 1 oscilloscope.

To avoid damaging the board, follow the procedure in Section 2.1 “Safety Information”. If a test has to be restarted, make sure to properly reset the system to obtain reproducible results (see “How to reset the AEM00940 evaluation board” in Section 2.1).

4.1. LDOs

The following example instructs users on how to measure the output voltage stability of the LDOs (Low-voltage and High-voltage LDO regulation Sections of the AEM00940 datasheet).

Setup

- Referring to Figure 1, follow steps 1 and 2 explained in the Section 2.1. Configure the board in the desired state and connect your storage element(s).
- VBOOST: Connect SMU1. Configure it to Voltage Source with a Current Compliance of 200 mA.
- HVOUT / LVOUT: Connect SMU2 to the LDO you want to measure. Configure it to sink current with a Voltage Compliance of 5 V for HVOUT or 2.5 V for LVOUT.

Manipulations

- Impose a voltage between V_{OVCH} and 5 V on SMU1 to force the AEM to start.
- Sweep voltage on SMU1 from V_{OVDIS} + 50 mV to 4.5 V.
- Repeat with different current levels on SMU2 (from 10 µA to 80 mA for HVOUT and from 10 µA to 20 mA for LVOUT). Please make sure to set negative current values on SMU2 to simulate the load.

Measurements

- HVOUT/LVOUT: Measure the voltage.

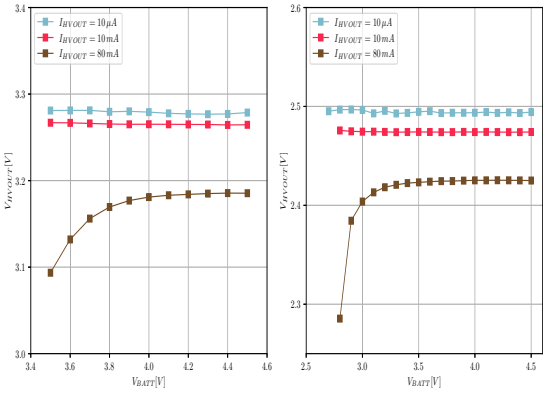


Figure 7: HVOUT at 3.3 V and 2.5 V

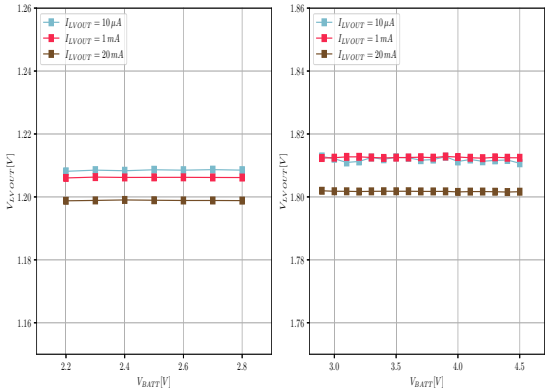


Figure 8: LVOUT at 1.2 V and 1.8 V

4.2. BOOST Efficiency

This test allows users to reproduce the efficiency graphs of the AEM00940 boost converter (Boost Conversion Efficiency Sections of the AEM00940 datasheet).

Setup

- Following steps 1 and 2 explained in the Section 2.1 and referring to Figure 1, configure the board in the desired state.
- VBUCK: Connect a 2.3 V Voltage Source to prevent VBUCK to sink current from VBOOST.
- SRC: Connect SMU1. Configure it to Current Source with a Voltage Compliance of 0 V.
- VBOOST: Connect SMU2 and configure it to Voltage Source with a Current Compliance of 200 mV.

Manipulations

- Impose a voltage between V_{OVCH} and 5 V on SMU2 to force the AEM to start. When done, impose a voltage between V_{OVDIS} + 50 mV and V_{OVCH}.
- Sweep voltage compliance on SMU1 from V_{OVDIS} + 50 mV to 4.5 V.
- Repeat with different current levels on SMU1 (from 100 µA to 100 mA) and with different voltage levels on SMU2 (from V_{OVDIS} + 50 mV to V_{OVCH}).

Measurements

- SRC: Measure the current and the voltage.
- VBOOST: Measure the current and the voltage. Repeat the measurement a copious number of times to be sure to capture the current peaks. Figure 9 has been obtained by averaging over 100 measurements configured with a 100 ms integration time.
- Deduce input and output power (P = U x I) and efficiency (η = Pout/Pin).

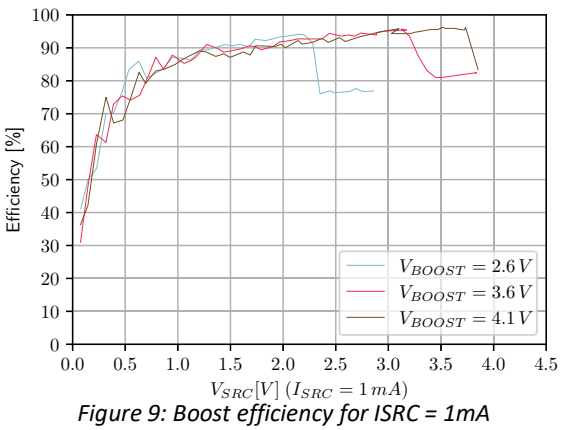


Figure 9: Boost efficiency for ISRC = 1mA

4.3. Custom Mode Configuration

This test allows users to measure the custom protection levels of the storage element set by resistors R1 to R6.

Setup

- Referring to Section 1, follow steps 1 and 2 explained in Section 2.1.
- To select custom mode:
  - Set CFG[2:0] = LLL.
  - Remove R2, R3 and R20.
  - Choose R1 to R6 to configure the battery protection levels and HVOUT output voltage.
- Place the probes on the nodes to be observed.
- SRC: connect your source element to power up the system.

Manipulations

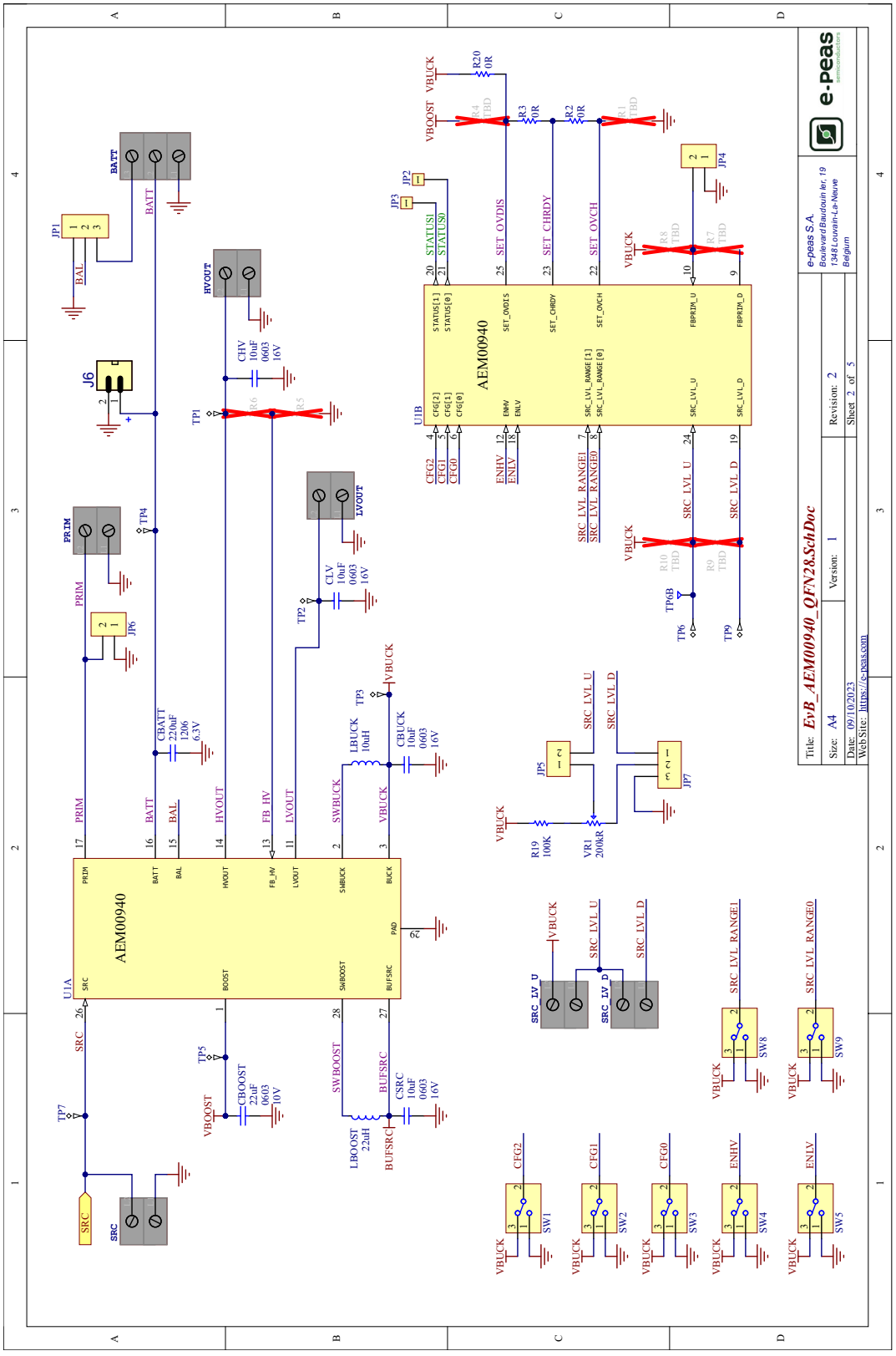
- Remove the source element after the voltage on BATT has reached steady state (between V_{CHRDY} and V_{OVCH}).

Measurements

Measure the following nodes to ensure the correct behavior of the AEM00940 with respect to the custom configuration:

- STATUS[0]: Asserted when the LDOs can be enabled (i.e. when BATT first rises above V_{CHRDY}).
- STATUS[1]: Asserted when BATT falls below V_{OVDIS}.
- BATT: Rise up and oscillate around V_{OVCH} as long as the source element has not been removed.
- HVOUT: Equal to the value set by R5-R6.

5. Schematic



6. Revision History

EVK Version	User Guide Revision	Date	Description
1.0	1.0	March, 2022	Creation of the document
1.1	1.1	August, 2023	- Update to EvK v1.1. - Functional tests section added. - Performance tests section added. - AEM00940 evaluation board schematic added.
1.2	1.0	October, 2023	Update to EvK 1.2

Table 5: Revision history

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