

Highly-Efficient Regulated Dual-Output, Ambient Energy Manager for High-Frequency RF input with optional primary battery

Features

Ultra-low power start-up:

- RF input power from -18.5 dBm up to 10 dBm (typical)
- Cold start from the RF input or from the storage device

Ultra-low power boost regulator:

- Open-circuit voltage sensing for MPPT every 0.33 s
- Configurable MPPT with 2-pin programming
- Selectable Voc ratios of 60, 65 or 70 %
- Input voltage operation range from 50 mV to 2.5 V
- MPPT voltage operation range from 50 mV to 2.5 V
- Constant impedance matching (ZMPPT)

Integrated 1.2/1.8 V LDO regulator:

- Up to 20 mA load current
- Power gated dynamically by external control
- Selectable output voltage

Integrated 1.8 V-3.3 V LDO regulator:

- Up to 80 mA load current with 300 mV drop-out
- Power gated dynamically by external control
- Selectable output voltage

Flexible energy storage management:

- Selectable overcharge and overdischarge protection
- For any type of rechargeable battery or (super)capacitor
- Fast supercapacitor charging
- Warns the load when battery is running low
- Warns when output voltage regulators are available

Smallest footprint, smallest BOM:

- Only seven passive external components

Optional primary battery:

- Automatically switches to the primary battery when the secondary battery is exhausted

Integrated balun for dual-cell supercapacitor

Applications

- | | |
|-------------------------|-------------------------|
| • RF harvesting | • Home automation |
| • Industrial monitoring | • E-health monitoring |
| • Indoor geolocation | • Wireless sensor nodes |

Description

The AEM40940 is an integrated energy management subsystem that extracts AC power from high-frequency RF inputs to simultaneously store energy in a rechargeable element and supply the system with two independent regulated voltages. The AEM40940 allows to extend battery lifetime and ultimately eliminates the primary energy storage element in a large range of wireless applications, such as industrial monitoring, indoor geolocation, home automation, e-health monitoring and wireless sensor nodes.

The AEM40940 harvests the available input power up to 10dBm. It integrates an ultra-low power rectifier combined with a boost converter to charge a storage element, such as a Li-ion battery, a thin film battery, a supercapacitor or a conventional capacitor. With its unique cold-start circuit, it can start operating with empty storage elements at an input power as low as -18.5dBm.

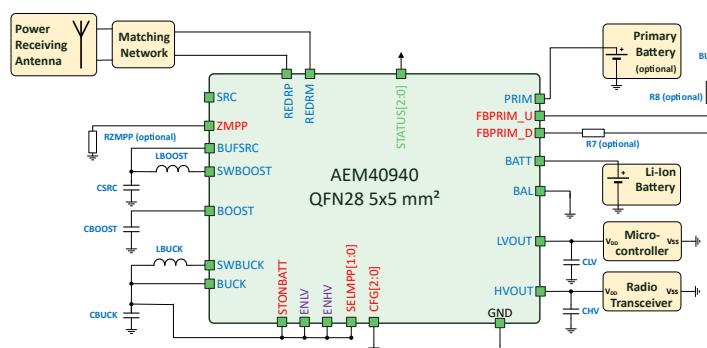
The low-voltage supply typically drives a microcontroller at 1.2 V or 1.8 V. The high-voltage supply may typically drive a radio transceiver at a configurable voltage between 1.8 V and 3.3 V. Both are driven by highly-efficient LDO (Low Drop-Out) regulators for low noise and high stability.

Configuration pins determine various operating modes by setting predefined conditions for the energy storage element (overcharge or overdischarge voltages), and by selecting the voltage of the high-voltage supply and the low-voltage supply. The chip integrates all the active elements for powering a typical wireless sensor. Five capacitors and two inductors are required, available respectively in the small 0402 and 0603 SMD formats.

With only seven external components excluding the matching network, integration is maximum, footprint and BOM are minimum, optimizing the time-to-market and the costs of WSN designs.

Device information

Part number	Package	Body size
AEM40940_a	QFN 28-pin	5 mm x 5 mm





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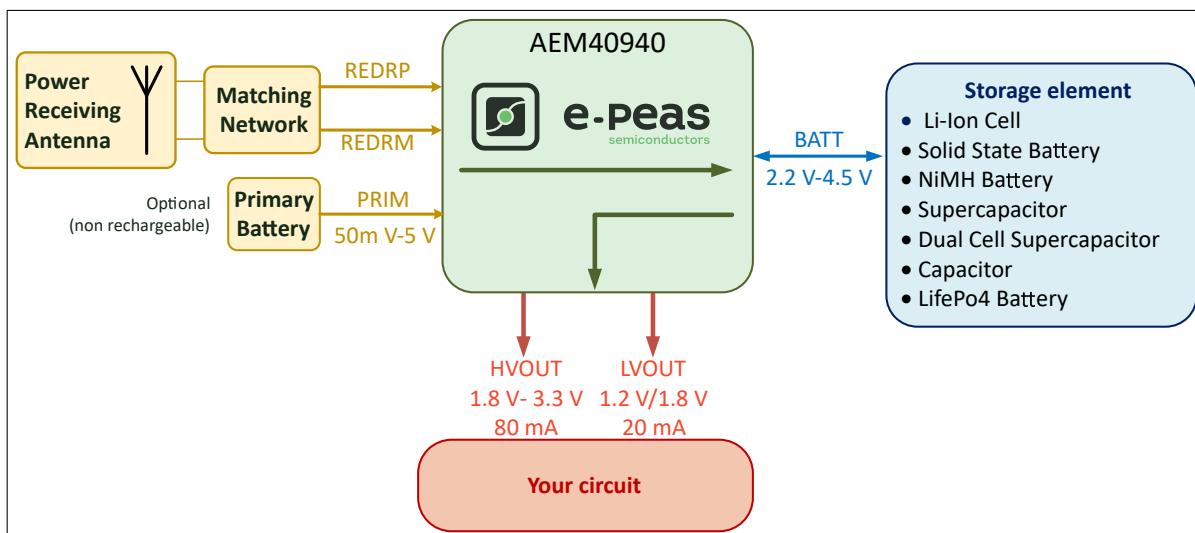


Figure 1: Simplified schematic view

1 Introduction

The AEM40940 is a full-featured energy efficient power management circuit able to charge a storage element (battery or supercapacitor, connected to **BATT**) from an energy source (connected to the rectifier) as well as to supply loads at different operating voltages through two power supplying LDO regulators (**LVOUT** and **HVOUT**).

The heart of the circuit is a cascade of a rectifier and two regulated switching converters, namely the boost converter and the buck converter with high-power conversion efficiencies, as shown in the performance data section (See page 18).

At first start-up, as soon as a required cold-start input power of -18.5 dBm is available from the harvested energy source, the AEM cold starts. Note that the **STONBATT** pin allows to bypass the cold start procedure using the pre-charged storage element to start the AEM40940 (see page 11).

Through three configuration pins (**CFG[2:0]**), the user can select a specific operating mode from a range of seven modes. Those operating modes define the LDO output voltages and the protection levels of the storage element.

The Maximum Power Point (MPP) ratio can be configured using two configuration pins (**SELMPP[1:0]**)(See page 11).

Moreover, if the storage element gets depleted and an optional primary battery is connected on **PRIM**, the chip automatically uses it as a source to recharge the storage element before switching back to the ambient source. This guarantees continuous operation even under the most adverse conditions (See page 10).

Two logic control pins are provided (**ENLV** and **ENHV**) to dynamically activate or deactivate the LDO regulators that supply the low- and high-voltage system load respectively. The status pin **STATUS[0]** warns the user that the LDOs are operational and can be enabled. This signal can also be used to enable an optional external regulator.

If the battery voltage gets depleted, the LDOs are power gated and the controller is no longer supplied by the storage element to protect it from further discharge. Around 600 ms before the shutdown of the AEM, the status pin (**STATUS[1]**) warns the user for a clean shutdown of the system.

Moreover, the status of the MPP controller is reported with one dedicated status pin (**STATUS[2]**). The status pin is asserted when a MPP calculation is being performed.

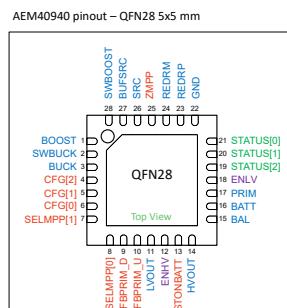


Figure 2: Pinout diagram QFN28

NAME	PIN NUMBER	FUNCTION
Power pins		
BOOST	1	Output of the boost converter.
SWBUCK	2	Switching node of the buck converter.
BUCK	3	Output of the buck converter.
LVOUT	11	Output of the low voltage LDO regulator.
HVOUT	14	Output of the high voltage LDO regulator.
BAL	15	Connection to mid-point of a dual-cell supercapacitor (optional). Must be connected to GND if not used.
BATT	16	Connection to the energy storage element, battery or capacitor. Cannot be left floating.
PRIM	17	Connection to the primary battery (optional). Must be connected to GND if not used.
REDRP	23	RF positive input voltage of the rectifier.
REDRM	24	RF negative input voltage of the rectifier.
SRC	26	Output of the rectifier. Must be left floating.
BUFSRC	27	Connection to an external capacitor buffering the boost converter input.
SWBOOST	28	Switching node of the boost converter.
Configuration pins		
CFG[2]	4	Used for the configuration of the threshold voltages for the energy storage element and the output voltage of the LDOs.
CFG[1]	5	
CFG[0]	6	
SELMPP[1]	7	Used for the configuration of the MPP ratio.
SELMPP[0]	8	
FB_PRIM_D	9	Used for the configuration of the primary battery (optional). Must be connected to GND if not used.
FB_PRIM_U	10	
STONBATT	13	Used for the configuration of the system cold start (optional). Must be connected to GND if not used.
ZMPPT	25	
Control pins		
ENHV	12	Enabling pin for the high-voltage LDO.
ENLV	18	Enabling pin for the low-voltage LDO.
Status pins		
STATUS[2]	19	Logic output. Asserted when the AEM performs the MPP evaluation.
STATUS[1]	20	Logic output. Asserted if the battery voltage falls under Vovdis .
STATUS[0]	21	Logic output. Asserted when the LDOs can be enabled.
Other pins		
GND	22, Exposed Pad	Ground connection, should be solidly tied to the PCB ground plane.

Table 1: Pins description

2 Absolute Maximum Ratings

Parameter	Rating
REDRP, REDRM	2.75 V
Operating junction temperature	-40 °C to +125 °C
Storage temperature	-65 °C to +150 °C

Table 2: Absolute maximum ratings

3 Thermal Resistance

Package	θ_{JA}	θ_{JC}	Unit
QFN28	38.3	2.183	°C/W

Table 3: Thermal data

ESD CAUTION

	ESD (ELECTROSTATIC DISCHARGE) SENSITIVE DEVICE These devices have limited built-in ESD protection and damage may thus occur on devices subjected to high-energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.
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4 Typical Electrical Characteristics at 25 °C

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Power conversion						
$P_{in,CS}$	Source power required for cold start.	During cold start	-18.5			dBm
P_{in}	Source power.	After cold start	-18.5		10	dBm
f_{in}	Source frequency.		865		2400	MHz
V_{src}	Output of the rectifier.	During cold start	0.38		2.5	V
		After cold start	0.05		2.5	
V_{boost}	Output of the boost converter.	During normal operation	2.2		4.5	V
V_{buck}	Output of the buck converter.	During normal operation	2	2.2	2.5	
Storage element						
V_{batt}	Voltage on the storage element.	Rechargeable battery	2.2		4.5	V
		Capacitor	0		4.5	V
T_{crit}	Time before shutdown after STA-TUS[1] has been asserted.		400	600	800	ms
V_{prim}	Voltage on the primary battery.		0.6		5	V
$V_{fb_prim_u}$	Feedback for the minimal voltage level on the primary battery.		0.15		1.1	V
V_{ovch}	Maximum voltage accepted on the storage element before disabling the boost converter.	see Table 7	2.7		4.5	V
V_{chrdy}	Minimum voltage required on the storage element before enabling the LDOs after a cold start.	see Table 7	2.3		4.04	V
V_{ovdiss}	Minimum voltage accepted on the storage element before switching to primary battery or entering into a shutdown.	see Table 7	2.2		3.6	V
Low-voltage LDO regulator						
V_{lv}	Output voltage of the low-voltage LDO.	see Table 7	1.2		1.8	V
I_{lv}	Load current from the low-voltage LDO.		0		20	mA
High-voltage LDO regulator						
V_{hv}	Output voltage of the high-voltage LDO.	see Table 7	1.8		3.3	V
I_{hv}	Load current from the high-voltage LDO.		0		80	mA
Logic output pins						
STATUS[2:0]	Logic output levels on the status pins.	Logic high (VOH)	1.98	V_{batt}		V
		Logic low (VOL)	-0.1		0.1	V

Table 4: Electrical characteristics



5 Recommended Operation Conditions

Symbol	Parameter	Min	Typ	Max	Unit
External components					
CSRC	Capacitance of the boost converter input.	8	10	22	μF
CBOOST	Capacitance of the boost converter.	10	22	25	μF
LBOOST	Inductance of the boost converter.	4	10	25	μH
CBUCK	Capacitance of the buck converter.	8	10	22	μF
LBUCK	Inductance of the buck converter.	4	10	25	μH
CLV	Capacitance decoupling the low-voltage LDO regulator.	8	10	14	μF
CHV	Capacitance decoupling the high-voltage LDO regulator.	8	10	14	μF
CBATT	Optional - Capacitance on BATT if no storage element is connected (see page 11).	150			μF
RZMPP	Optional - Resistance for the ZMPPT configuration. (see page 11).	10		1M	Ω
RP	Optional - Resistance to be used with a primary battery. Equal to R7 + R8 (see page 11).	100		500	$\text{k}\Omega$
Logic input pins					
ENHV	Enabling pin for the high-voltage LDO ¹ .	Logic high (VOH)	1.75	Vbuck	Vbuck
		Logic low (VOL)	-0.01	0	0.01
ENLV	Enabling pin for the low-voltage LDO ² .	Logic high (VOH)	1.75	Vbuck	Vboost
		Logic low (VOL)	-0.01	0	0.01
SELMPP[1:0]	Configuration pins for the MPP evaluation (see Table 8).	Logic high (VOH)	Connect to BUCK		
		Logic low (VOL)	Connect to GND		
CFG[2:0]	Configuration pins for the storage element (see Table 7).	Logic high (VOH)	Connect to BUCK		
		Logic low (VOL)	Connect to GND		
STONBATT	Configuration pin to select the energy source during the cold start.	Logic high (VOH)	Connect to BATT		
		Logic low (VOL)	Connect to GND		

Table 5: Recommended operating conditions

Note 1: ENHV can be dynamically driven by a logic signal from the LV domain. For a static usage, connect to BUCK (High) or GND (Low).

Note 2: ENLV can be dynamically driven by a logic signal from the HV domain. For a static usage, connect to BUCK or BOOST (High) or GND (Low).



6 Functional Block Diagram

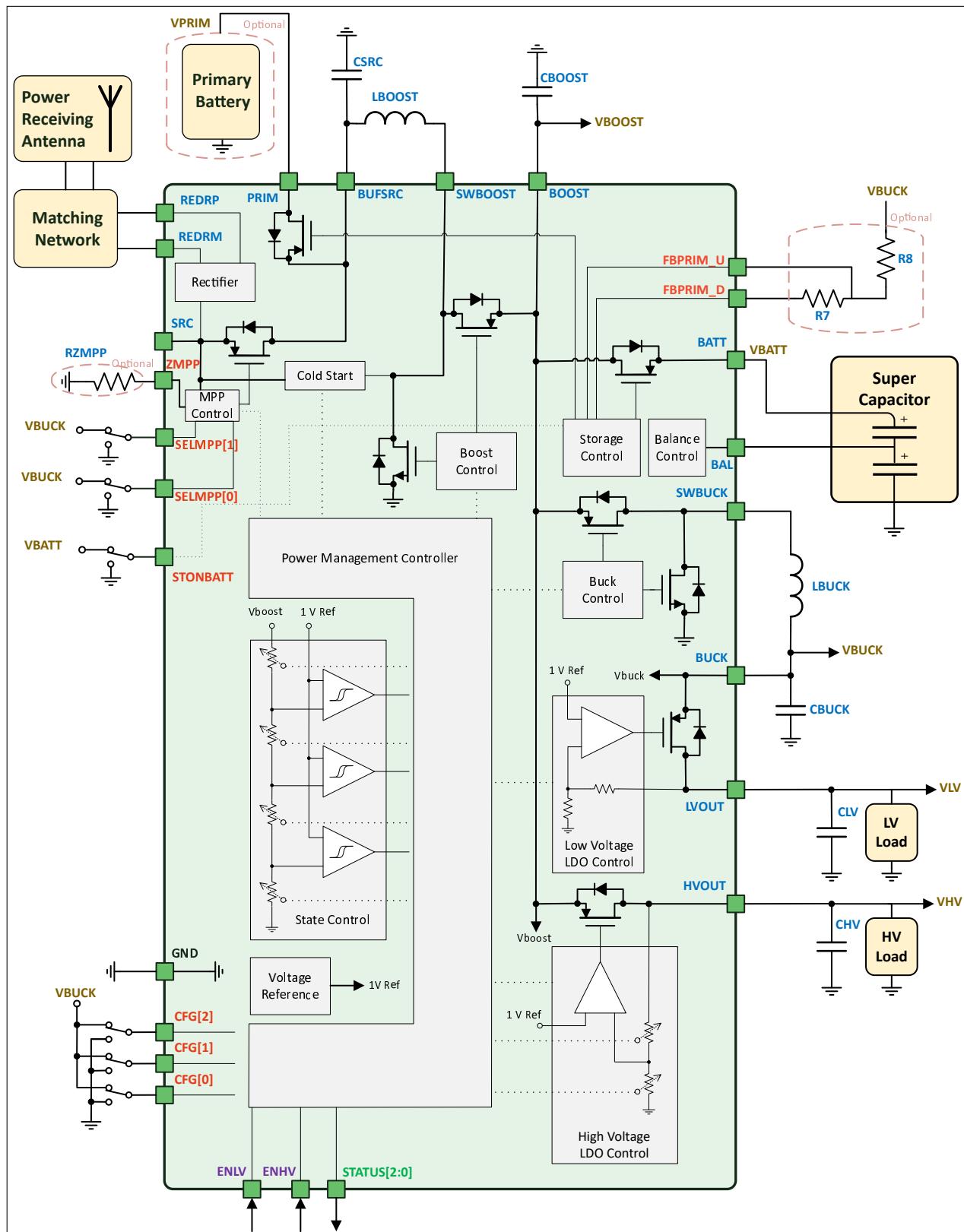


Figure 3: Functional block diagram

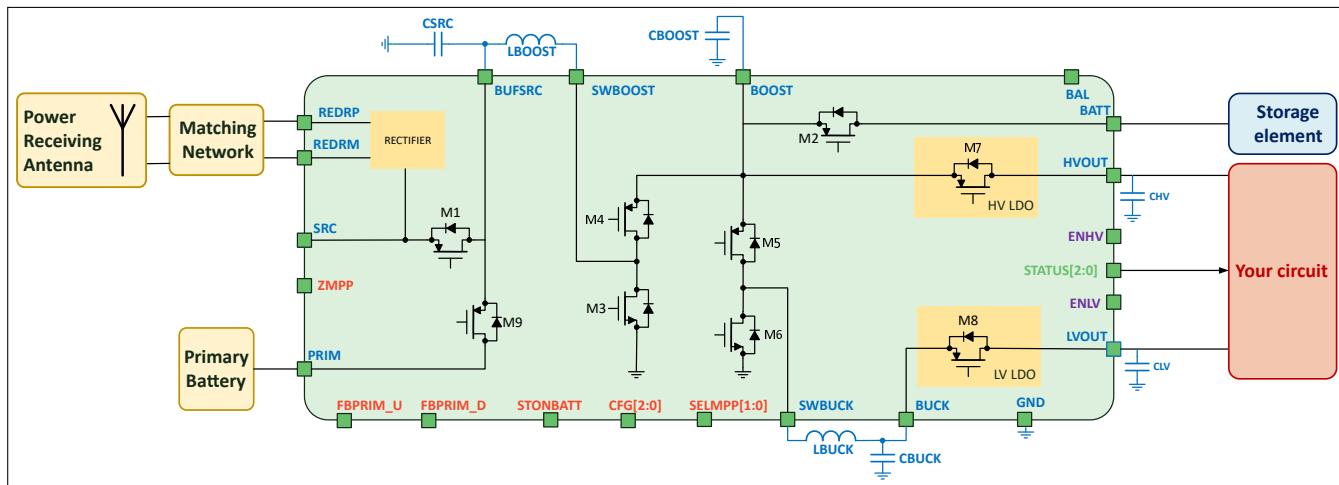


Figure 4: Simplified schematic view of the AEM40940

7 Theory of Operation

7.1 Deep sleep & Wake up modes

The **DEEP SLEEP MODE** is a state where all nodes are deeply discharged and there is no available energy to be harvested. As soon as a required cold start input power of -18.5 dBm is available at the input of the rectifier, the **WAKE UP MODE** is activated. **Vboost** and **Vbuck** rises up to a voltage of 2.2 V. **Vboost** then rises alone up to **Vovch**.

At that stage, both LDOs are internally deactivated. Therefore, **STATUS[0]** is equal to 0 as shown in Figure 8 and Figure 9.

When **Vboost** reaches **Vovch**, two scenarios are possible: in the first scenario, a super-capacitor or a capacitor having a voltage lower than **Vchrsty** is connected to the **BATT** node. In the second scenario, a battery charged is connected to the **BATT** node.

Supercapacitor as a storage element

If the storage element is a supercapacitor, the storage element may need to be charged from 0 V. The rectifier combined to the boost converter charges **BATT** from the input source and by modulating the conductance of M2. During the charge of the **BATT** node, both LDOs are deactivated and **STATUS[0]** is de-asserted. When **Vbatt** reaches **Vchrsty**, the circuit enters into the **NORMAL MODE**, **STATUS[0]** is asserted and the LDOs can be activated by the user using the **ENLV** and **ENHV** control pins as shown in Figure 8.

Battery as a storage element

If the storage element is a battery, but its voltage is lower than **Vchrsty**, then the storage element first needs to be charged until it reaches **Vchrsty**. Once **Vbatt** exceeds **Vchrsty**, or if the battery was initially charged above **Vchrsty** the circuit enters into the **NORMAL MODE**. **STATUS[0]** is asserted and the LDOs can be activated by the user thanks to **ENLV** and **ENHV** as shown in Figure 9.

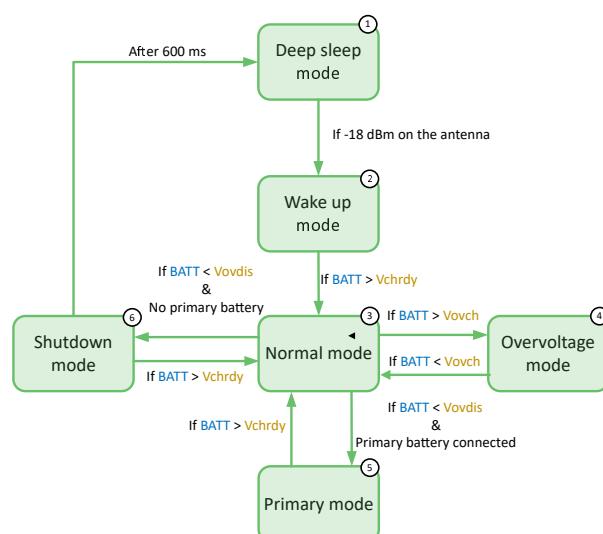


Figure 5: Diagram of the AEM40940 modes

7.2 Normal mode

Once the AEM enters into the **NORMAL MODE**, three scenarios are possible:

- There is enough energy provided by the source to maintain **Vbatt** above **Vovdis** but **Vbatt** is below **Vovch**. In that case, the circuit remains into the **NORMAL MODE**.
- The source provides more power than the load consumes, and **Vbatt** increases above **Vovch**. The circuit enters into the **OVERVOLTAGE MODE**, as explained in the **Over-voltage mode** section.
- Due to a lack of energy provided by the source, **Vbatt** decreases below **Vovdis**. In this case, either the circuit enters into the **SHUTDOWN MODE** as explained in **Shutdown mode** section or, if a charged primary battery is connected on **PRIM**, the circuit enters into the **PRIMARY MODE** as explained in the **Primary mode** section.

Rectifier

The AEM40940 offers the possibility to connect an RF antenna harvesting frequencies from 868MHz to 2.45GHz as input power supply throughout a dedicated matching network. The output of the rectifier is connected on **SRC** which is connected to the input of the boost converter (**BUFSRC**) through M1. The matching network is dedicated to a specific frequency and optimized for a range of input power. A support can be given from e-peas to develop a matching network according to each specifications.

Boost

The boost (or step-up) converter raises the voltage available at **BUFSRC** to a level suitable to charge the storage element, in the range of 2.2 V to 4.5 V, according to the system configuration. This voltage (**Vboost**) is available at the pin **BOOST**. The switching transistors of the boost converter are M3 and M4, with the switching node available externally at **SWBOOST**. The reactive power components of this converter are the external inductor and capacitor **LBOOST** and **CBOOST**.

Periodically, the MPP control circuit disconnects the rectifier from the **BUFSRC** pin with the transistor M1, in order to measure the open-circuit voltage of the rectifier on **SRC** and define the optimal level of voltage. **BUFSRC** is decoupled by the capacitor **CSRC**, which smooths the voltage against the current pulses induced by the boost converter.

The storage element is connected to the **BATT** pin, at a voltage **Vbatt**. This node is linked to **BOOST** through the transistor M2. In **NORMAL MODE**, this transistor effectively shorts the battery to the **BOOST** node (**Vbatt** = **Vboost**). When energy harvesting is occurring, the boost converter delivers a current that is shared between the battery and the loads. M2 is opened to disconnect the storage element when **Vbatt** reaches

the **Vovdis**. However, in such a scenario, the AEM40940 offers the possibility of connecting a primary battery to recharge **Vbatt** up to the **Vchrdy**. The transistor M9 connects **PRIM** to **BUFSRC** and the transistor M1 is opened to disconnect the rectifier as explained in the **Primary mode** section and shown in Figure 12.

Buck

The buck (or step-down) converter lowers the voltage from **Vboost** to a constant value **Vbuck** of 2.2 V. This voltage is available at the **BUCK** pin. The switching transistors of the buck converter are M5 and M6, with the switching node available externally at **SWBUCK**. The reactive power components of the buck converter are the external inductor **LBUCK** and the capacitor **CBUCK**.

LDO outputs

Two LDOs are available to supply loads at different operating voltages:

Through M7, **Vboost** feeds the high-voltage LDO that powers its load through **HVOUT**. This regulator delivers a clean voltage (**Vhv**) with a maximum current of 80 mA on **HVOUT**. An output voltage of 1.8 V, 2.5 V or 3.3 V can be selected. The high-voltage output can be dynamically enabled or disabled with the logic control pin **ENHV**. The output is decoupled by the external capacitor **CHV**.

Through M8, **Vbuck** feeds the low-voltage LDO that powers its load through **LVOUT**. This regulator delivers a clean voltage (**Vlv**) of 1.8 V or 1.2 V with a maximum current of 20 mA on **LVOUT**. The low-voltage output can be dynamically enabled or disabled with the logic control pin **ENLV**. The output is decoupled by the external capacitor **CLV**.

Status pin **STATUS[0]** warns the user when the LDOs can be enabled as explained in the **Deep sleep & Wake up modes** section and in the **Shutdown mode** section. The table below shows the four possible configurations:

ENLV	ENHV	LV output	HV output
1	1	Enabled	Enabled
1	0	Enabled	Disabled
0	1	Disabled	Enabled
0	0	Disabled	Disabled

Table 6: LDOs configurations

7.3 Overvoltage mode

When **Vbatt** reaches **Vovch**, the charge is complete and the internal logic maintains **Vbatt** around **Vovch** with a hysteresis of a few mV as shown in Figure 10 to prevent damage to the storage element and to the internal circuitry. In this configuration, the boost converter is periodically activated to maintain **Vbatt** and the LDOs are still available.



7.4 Primary mode

When V_{batt} drops below V_{ovdis} , the circuit compares the voltage on **PRIM** with the voltage on **FB_PRIM_U** to determine if a charged primary battery is connected on **PRIM**. The voltage on **FB_PRIM_U** is set thanks to two optional resistances as explained in the [Primary battery configuration](#) section. If the voltage on **PRIM** divided by 4 is higher than the voltage on **FB_PRIM_U**, the circuit considers the primary battery as available and the circuit enters into the **PRIMARY MODE** as shown in Figure 12.

In that mode, transistor M1 is opened and the primary battery is connected to **BUFSRC** through transistor M9 to become the source of energy for the AEM40940. The chip remains in this mode until V_{batt} reaches V_{chrdy} . When V_{batt} reaches V_{chrdy} , the circuit enters into **NORMAL MODE**.

If no primary battery is used in the application, **PRIM**, **FB_PRIM_U** and **FB_PRIM_D** must be tied to **GND**.

7.5 Shutdown mode

When V_{batt} drops below V_{ovdis} and no power is available from a primary battery, the circuit enters into the **SHUTDOWN MODE** as shown in Figure 11 to prevent deep discharge potentially leading to damage to the storage element and instability of the LDOs. The circuit asserts **STATUS[1]** to warn the system that a shutdown will occur. Both LDO regulators remain enabled. This allows the load, whether it is powered on **LVOUT** or **HVOUT**, to be interrupted by the low-to-high transition of **STATUS[1]**, and to take all appropriate actions before power shutdown.

If energy at the input source is available and V_{batt} recovers to V_{chrdy} within T_{crit} (~ 600 ms), the AEM returns in **NORMAL MODE**. But if, after T_{crit} , V_{batt} does not reach V_{chrdy} , the circuit enters into the **DEEP SLEEP MODE**. The LDOs are deactivated and **BATT** is disconnected from **BOOST** to avoid damaging the battery due to the overdischarge. From now, the AEM will have to go through the wake-up procedure described in the [Deep sleep & Wake up modes](#) section.

7.6 Maximum power point tracking

During **NORMAL MODE**, **SHUTDOWN MODE** and a part of the **WAKEUP MODE**, the boost converter is regulated thanks

to an internal MPPT (Maximum Power Point Tracking) module. V_{mpp} is the voltage level of the MPP, and depends on the input power available at the source. The MPPT module evaluates V_{mpp} as a given fraction of V_{oc} , the open-circuit voltage of the rectifier. By temporarily disconnecting the rectifier from **CSRC** as shown in Figure 4 during 5.12 ms, the MPPT module receives and maintains knowledge of V_{mpp} . This sampling occurs every 0.33 s approximatively.

Except during this sampling process, the voltage of the rectifier output, V_{src} , is continuously compared to V_{mpp} . When V_{src} exceeds V_{mpp} by a small hysteresis, the boost converter is switched on, extracting electrical charges from the source and lowering its voltage. When V_{src} falls below V_{mpp} by a small hysteresis, the boost converter is switched off, allowing the harvester to accumulate new electrical charges into **CSRC**, which restores its voltage. In this manner, the boost converter regulates its input voltage so that the electrical current (or flow of electrical charges) that enters the boost converter yields the best power transfer from the harvester in any ambient conditions. The AEM40940 supports any V_{mpp} level in the range from 0.05 V to 2.5 V. It provides a choice among three values for the V_{mpp}/V_{oc} fraction or to match the input impedance of the BOOST converter with an impedance connected to the ZMPP terminal through configuration pins **SELMPP[1:0]** as shown in Table 8. The status of the MPPT controller is reported through one dedicated status pins (**STATUS[2]**). The status pin is asserted when a MPP calculation is being performed.

7.7 Balun for dual-cell supercapacitor

The balun circuit allows for balancing the internal voltage in a dual cell supercapacitor in order to avoid damaging the supercapacitor because of excessive voltage on one cell. If **BAL** is tied to **GND**, the balun circuit is disabled. This configuration must be used if a battery, a capacitor or a single cell supercapacitor is connected on **BATT**. If **BAL** is connected to the node between the cells of a supercapacitor, the balun circuit allows for compensating mismatch of the two cells that could lead to over-charge of one of both cells. The balun circuit guarantees that **BAL** remains close to $V_{batt}/2$. This configuration must be used if a dual cell supercapacitor is connected on **BATT**.

8 System Configuration

Configuration pins			Storage element threshold voltages			LDOs output voltages		Typical use
CFG[2]	CFG[1]	CFG[0]	Vovch	Vchrny	Vovdis	Vhv	Vlv	
1	1	1	4.12 V	3.67 V	3.60 V	3.3 V	1.8 V	Li-ion battery
1	1	0	4.12 V	4.04 V	3.60 V	3.3 V	1.8 V	Solid state battery
1	0	1	4.12 V	3.67 V	3.01 V	2.5 V	1.8 V	Li-ion/NiMH battery
1	0	0	2.70 V	2.30 V	2.20 V	1.8 V	1.2 V	Single cell supercapacitor
0	1	1	4.50 V	3.67 V	2.80 V	2.5 V	1.8 V	Dual-cell supercapacitor
0	1	0	4.50 V	3.92 V	3.60 V	3.3 V	1.8 V	Dual-cell supercapacitor
0	0	1	3.63 V	3.10 V	2.80 V	2.5 V	1.8 V	LifePo4 battery
0	0	0	Reserved for future use					

Table 7: Usage of CFG[2:0]

8.1 Battery and LDOs configuration

Through three configuration pins (**CFG[2:0]**), the user can set a particular operating mode without any dedicated external component as shown in Table 7. The three threshold levels are defined as:

- **Vovch** : Maximum voltage accepted on the storage element before disabling the boost converter,
- **Vchrny** : Minimum voltage required on the storage element after a cold start before enabling the LDOs,
- **Vovdis** : Minimum voltage accepted on the storage element before considering the storage element as depleted.

See [Theory of Operation](#) section for more information about the purposes of these thresholds.

The two LDOs output voltages are called **Vhv** and **Vlv** for the high- and low-output voltages, respectively. Seven combinations of these voltage levels are hardwired and selectable through the **CFG[2:0]** configuration pins.

8.2 MPP configuration

Two dedicated configuration pins, **SELMPP[1:0]**, allow selecting the MPP tracking ratio based on the characteristic of the input power source.

SELMPP[1]	SELMPP[0]	Vmpp/Voc
0	0	60 %
0	1	65 %
1	0	70 %
1	1	ZMPP

Table 8: Usage of SELMPP[1:0]

8.3 Primary battery configuration

To use the primary battery, it is mandatory to determine **Vprim_min**, the voltage of the primary battery at which it has to be considered as empty. During the evaluation of **Vprim_min**, the circuit connects **FB_PRIM_D** to **GND**. The circuit uses a resistive divider between **BUCK** and **FB_PRIM_D** to define the voltage on **FB_PRIM_U** as **Vprim_min** divided by 4. When **Vprim_min** is not evaluated, **FB_PRIM_D** is left floating to avoid quiescent current on the resistive divider. If we define the total resistor ($R_7 + R_8$) as RP , R_7 and R_8 are calculated as:

- $100 \text{ k}\Omega \leq RP \leq 500 \text{ k}\Omega$

- $R_7 = (\frac{V_{PRIM_MIN}}{4} * RP) / 2.2 \text{ V}$

- $R_8 = RP - R_7$

Note that **FB_PRIM_U** and **FB_PRIM_D** must be tied to **GND** if no primary battery is used.

8.4 ZMPPT configuration

Instead of working at a ratio of the open-circuit voltage, the AEM40940 can regulate the input impedance of the BOOST converter so that it matches a constant impedance connected to the **ZMPP** pin (**RZMPP**). In this case, the AEM40940 regulates **Vsrc** at a voltage equals to the product of the **ZMPP** impedance and the current available at the source.

- $10 \Omega \leq RZMPP \leq 1 \text{ M}\Omega$

8.5 Start-on-battery configuration

Alternatively to the cold-start procedure described in [Deep sleep & Wake up modes](#) section, by connecting **STONBATT** to **BATT**, the circuit can also start with the energy provided by the storage element connected on **BATT** if its voltage is higher than **Vchrny**. Note the AEM40940 will not start if the voltage on **BATT** is lower than **Vchrny**.

8.6 No-battery configuration

If the harvested energy source is permanently available and covers the applications purposes or if the application does not need to store energy for the period during the harvested energy source is not available, the storage element may be replaced by an external capacitor **CBATT** of minimum 150 μF .

8.7 Storage element information

The energy storage element of the AEM40940 can be a rechargeable battery, a supercapacitor or a large capacitor (minimum 150 μF). It should be chosen so that its voltage does not fall below **Vovdis** even during occasional peaks in the load current. If the internal resistance of the storage element cannot sustain this voltage limit, it is advisable to buffer the battery with a capacitor.

The **BATT** pin that connects the storage element must never be left floating. If the application expects a disconnection of the battery (e.g. because of a user removable connector), the

PCB should include a capacitor of at least $150 \mu\text{F}$. The leakage current of the storage element should be small as leakage currents directly impact the quiescent current of the subsystem.

External inductors information

The AEM40940 operates with two standard miniature inductors of $10 \mu\text{H}$. Inductors must sustain a peak current of at least 250 mA and 50 mA and a switching frequency of at least 10MHz for the BOOST and BUCK inductor, respectively. Low equivalent series resistance (ESR) favors the power conversion efficiency of the boost and buck converters.

External capacitors information

The AEM40940 operates with four identical standard miniature ceramic capacitors of $10 \mu\text{F}$ and one miniature ceramic capacitor of $22 \mu\text{F}$. The leakage current of the capacitors should be small as leakage currents directly impact the quiescent current of the subsystem.

CSRC

This capacitor acts as an energy buffer at the input of the boost converter. It prevents large voltage fluctuations when the boost converter is switching. The recommended value is $10 \mu\text{F} +/- 20 \%$.

CBUCK

This capacitor acts as an energy buffer for the buck converter. It also reduces the voltage ripple induced by the current pulses inherent to the switched mode of the converter. The recommended value is $10 \mu\text{F} +/- 20 \%$.

CBOOST

This capacitor acts as an energy buffer for the boost converter. It also reduces the voltage ripple induced by the current pulses inherent to the switched mode of the converter. The recommended value is $22 \mu\text{F} +/- 20 \%$.

CHV and CLV

These capacitors ensure a high-efficiency load regulation of the high-voltage and low-voltage LDO regulators. Closed-loop stability requires the value to be in the range of $8 \mu\text{F}$ to $14 \mu\text{F}$.

9 Typical Application Circuits

9.1 Example circuit 1

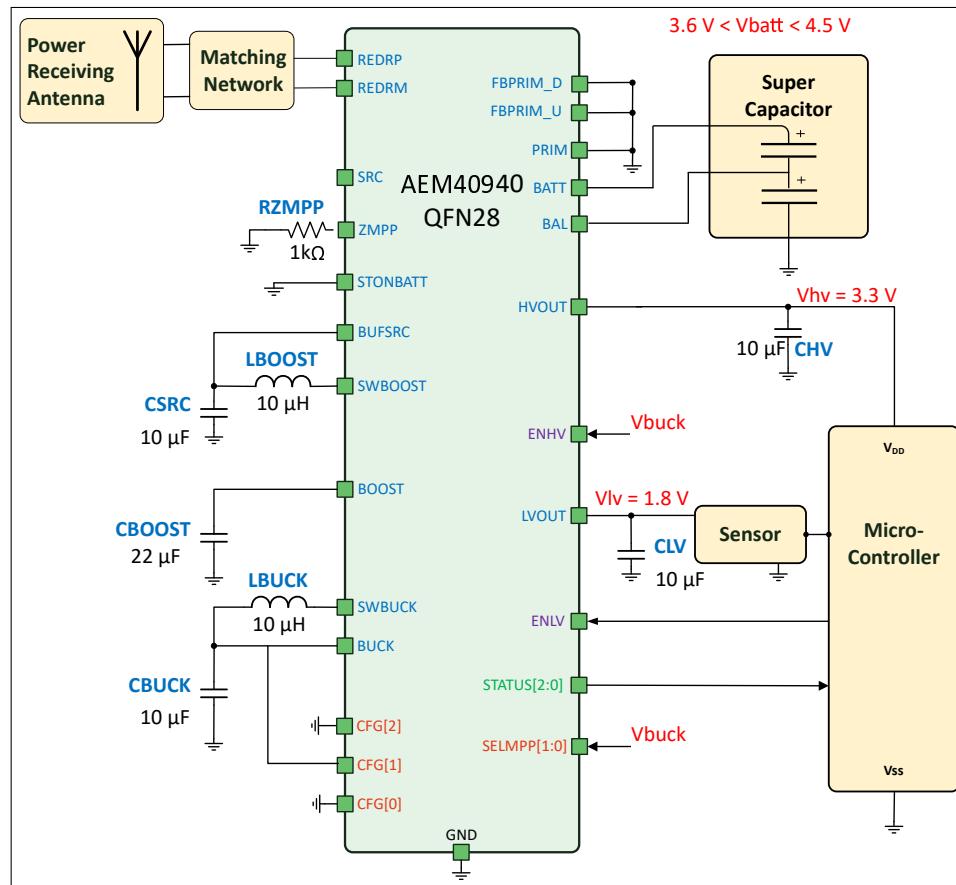


Figure 6: Typical application circuit 1

The energy source is a RF source, and the storage element is a standard Li-ion battery cell. The radio communication makes use of a transceiver that operates from a 3.3 V supply.

This circuit uses an operating mode, typical of systems that use standard components for radio and energy storage.

The operating mode pins are connected to:

- **CFG[2:0]**= 111

Following the Table 7, in this mode, the threshold voltages are:

- $V_{ovch} = 4.12 \text{ V}$
 - $V_{chrdf} = 3.67 \text{ V}$
 - $V_{ovdis} = 3.60 \text{ V}$
- Moreover, the LDOs output voltages are:
- $V_{hv} = 3.3 \text{ V}$
 - $V_{lv} = 1.8 \text{ V}$

STONBATT is tied to **BATT**, bypassing the cold start procedure to start thanks to the energy stored in the pre-charged Li-ion battery cell.

A primary battery is also connected as a back-up solution. The minimal level allowed on this battery is set at 3.5 V. Following equations on page 11:

- $R_P = 0.5 \text{ M}\Omega$
- $R_7 = (\frac{3.5 \text{ V}}{4} * 0.5 \text{ M}\Omega) / 2.2 \text{ V} = 200 \text{ k}\Omega$
- $R_8 = 0.5 \text{ M}\Omega - 200 \text{ k}\Omega = 300 \text{ k}\Omega$

The MPP configuration pins **SELMPP[1:0]** are tied to **GND** (logic low), selecting an MPP ratio of 60 %.

The **ENLV** enable pin for the low-voltage LDO is tied to **BUCK**. The microcontroller will be enabled after the system wake-up. The application software can enable or disable the radio transceiver with a GPIO connected to **ENHV**.



9.2 Example circuit 2

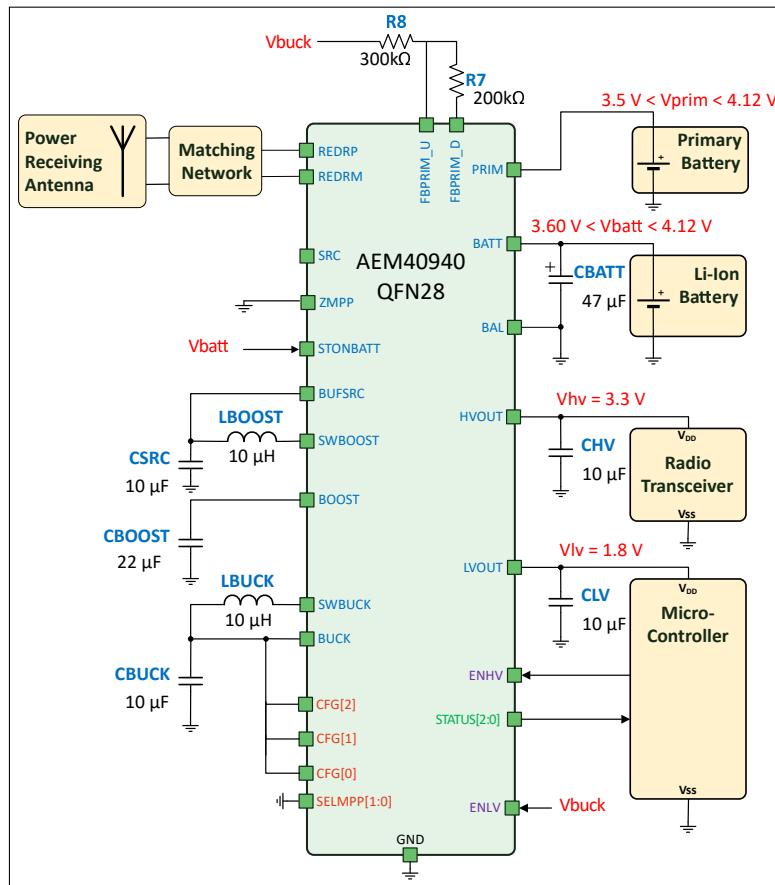


Figure 7: Typical application circuit 2

The energy source is an RF source, and the storage element is a dual-cell supercapacitor. The supercapacitor can be completely depleted during the cold start. In consequence, **STON-BATT** is tied to **GND** to use the RF input for the cold start. Moreover, **BAL** is connected to the dual-cell supercapacitor to compensate the mismatch between the two cells and thus, protect the supercapacitor. The operating mode pins are connected to:

- **CFG[2:0]** = 010

Following the Table 7, in this operation mode, the threshold voltages are:

- **Vovch** = 4.5 V
- **Vchrny** = 3.92 V

- **Vovdis** = 3.60 V

Moreover, the LDOs output voltages are:

- **Vhv** = 3.3 V
- **Vlv** = 1.8 V

The **ENHV** enable pin for the high-voltage LDO is tied to **BUCK**. The microcontroller is enabled when **Vbatt** and **Vboost** exceeds **Vchrny** as the high-voltage regulator supplies it.

The MPP configuration pins **SELMPP[1:0]** are tied to **BUCK** (logic high), selecting the ZMPPT configuration to match a 1 K Ω impedance.

No primary battery is connected and the **PRIM**, **FBPRIM_U** and **FBPRIM_D** pins are tied to **GND**.

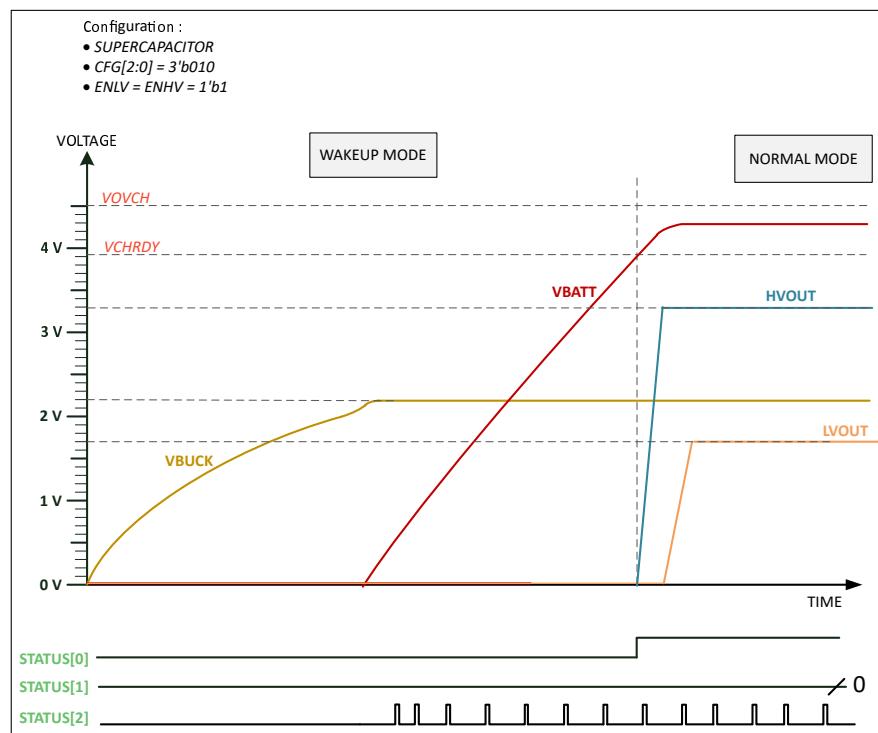


Figure 8: Cold start with a supercapacitor connected to BATT

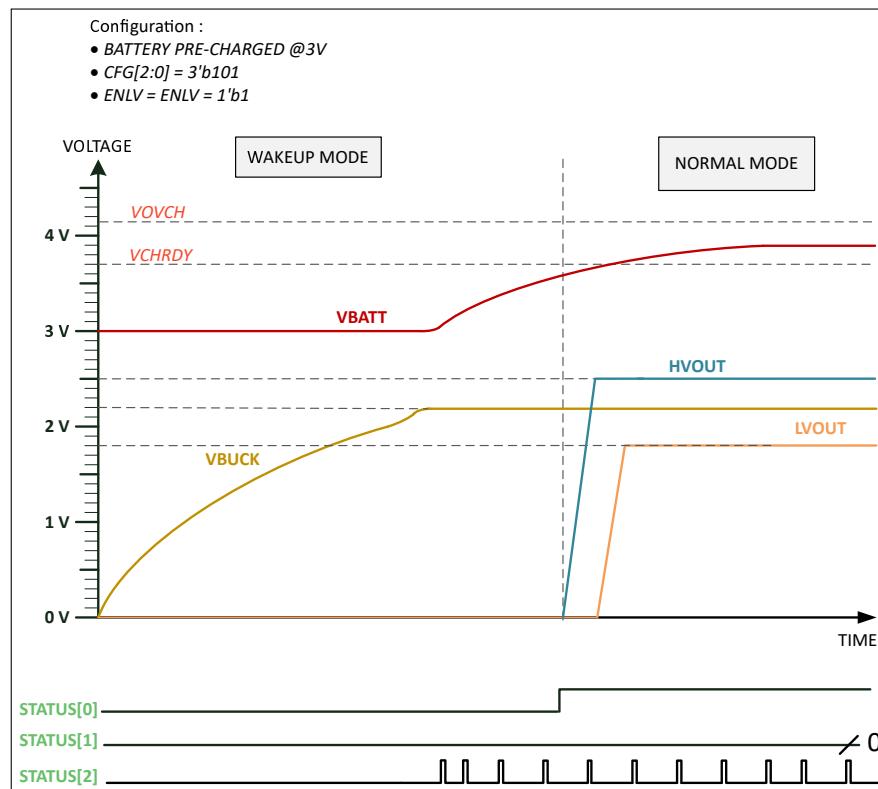


Figure 9: Cold start with a battery connected to BATT

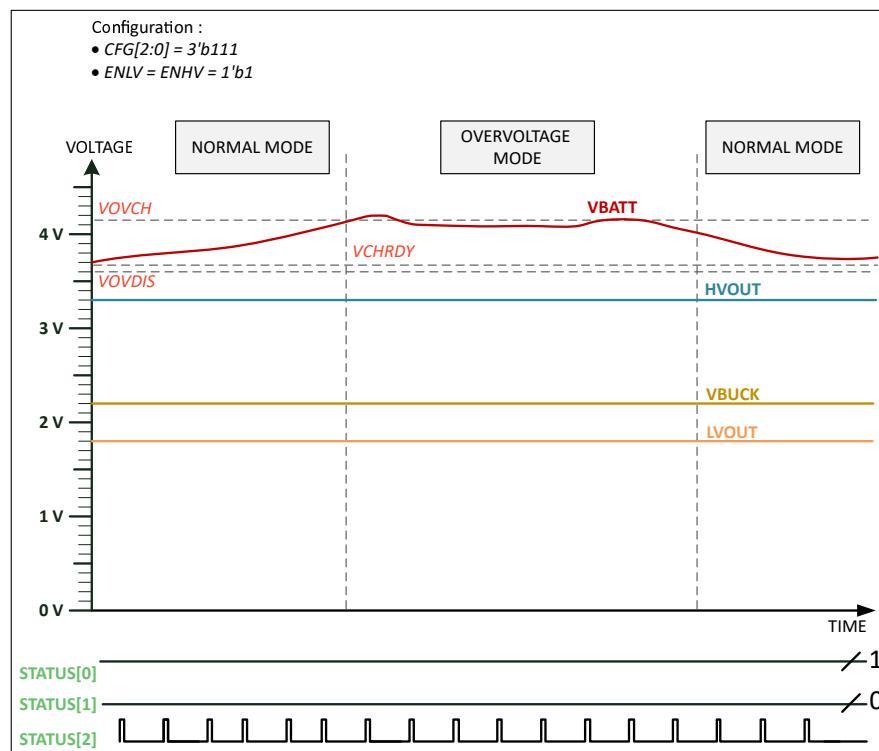


Figure 10: Overvoltage mode

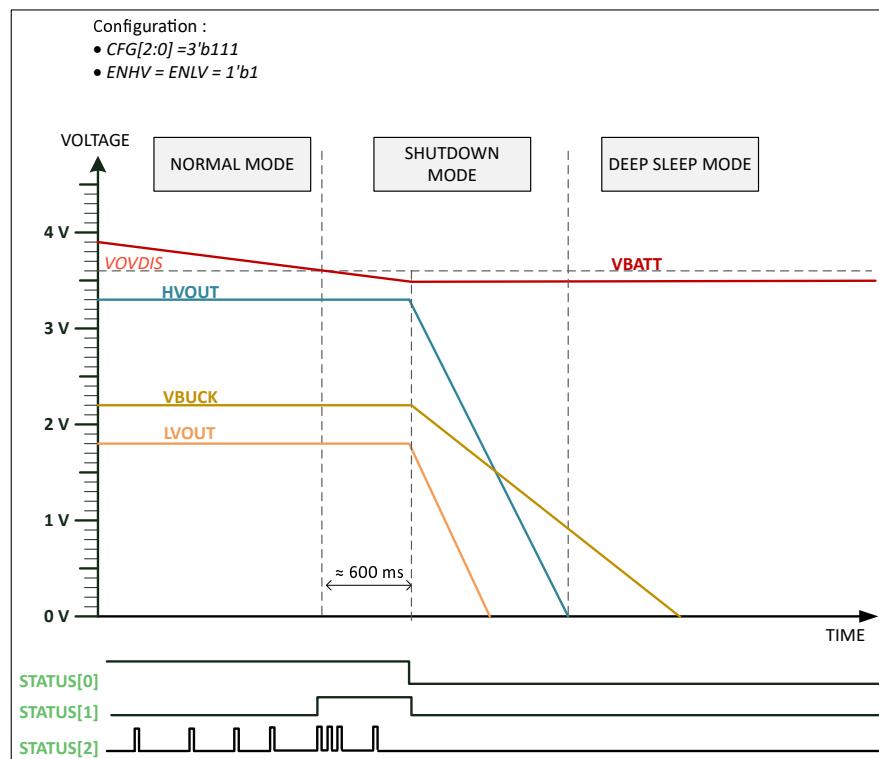


Figure 11: Shutdown mode (without primary battery)

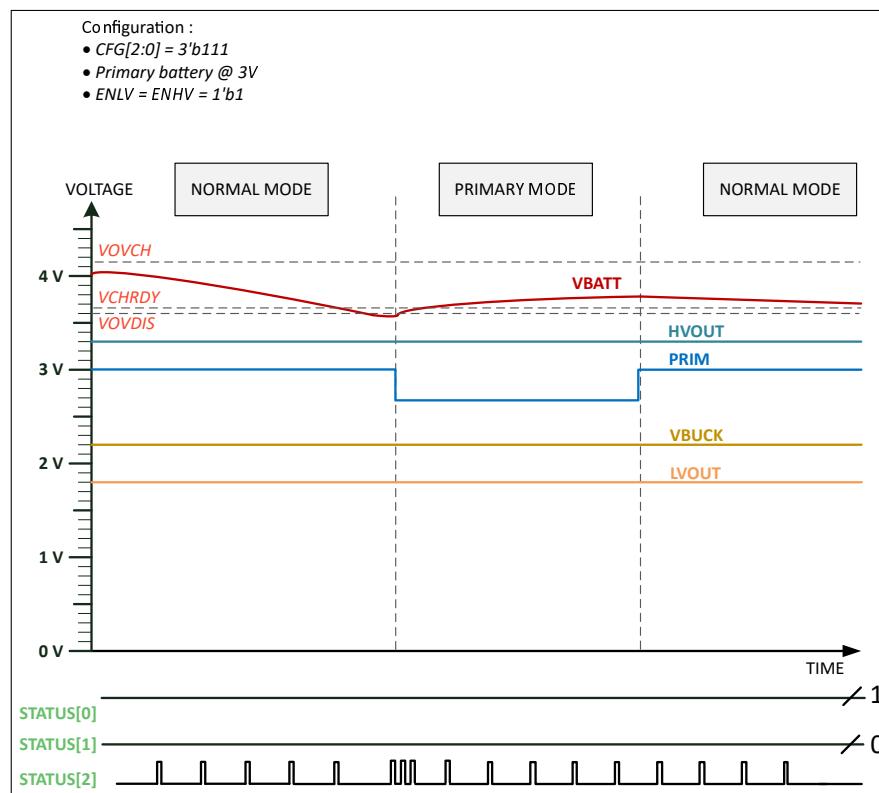


Figure 12: Switch to primary battery if the battery is overdischarged

10 Performance Data

10.1 BOOST conversion efficiency

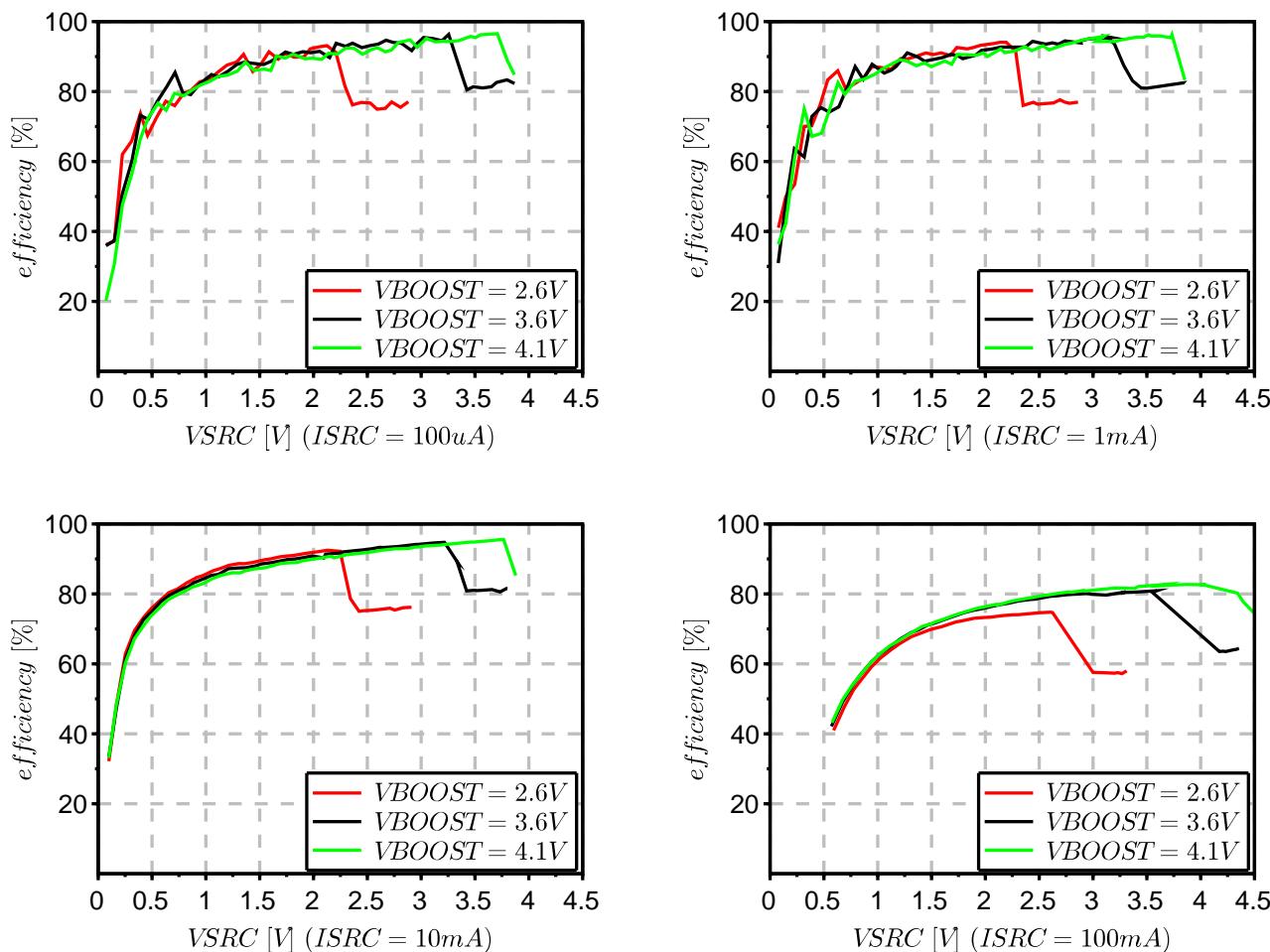


Figure 13: Boost efficiency for current delivered by the rectifier at $100 \mu A$, $1 mA$, $10 mA$ and $100 mA$

10.2 Quiescent current

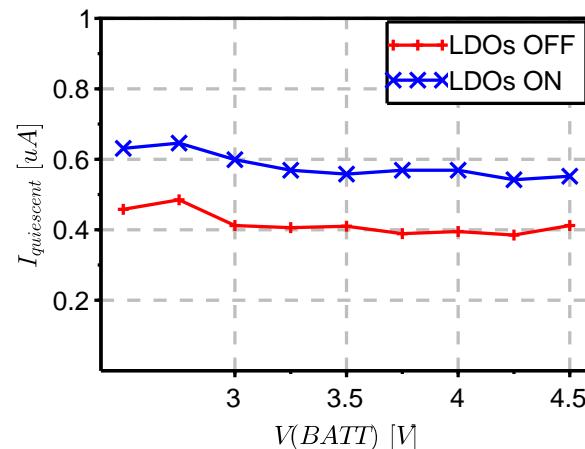


Figure 14: Quiescent current with LDO on and off



10.3 High-voltage LDO regulation

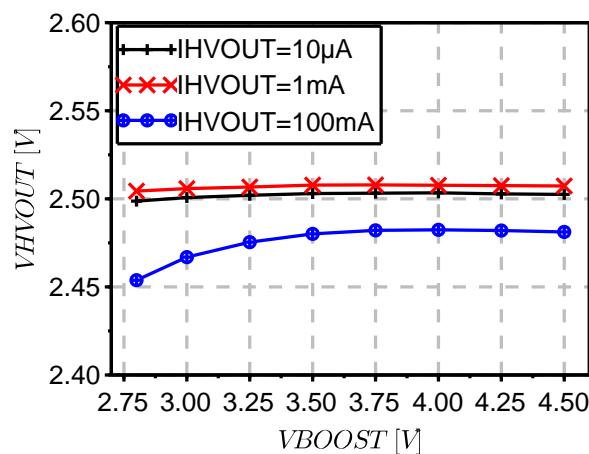
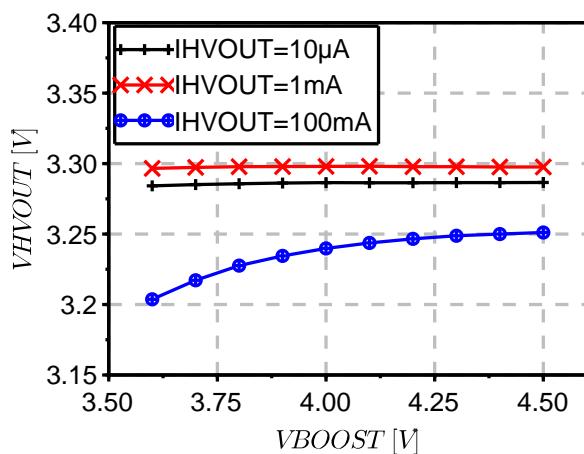


Figure 15: $HVOUT$ at 2.5 V and 3.3 V

10.4 Low-voltage LDO regulation

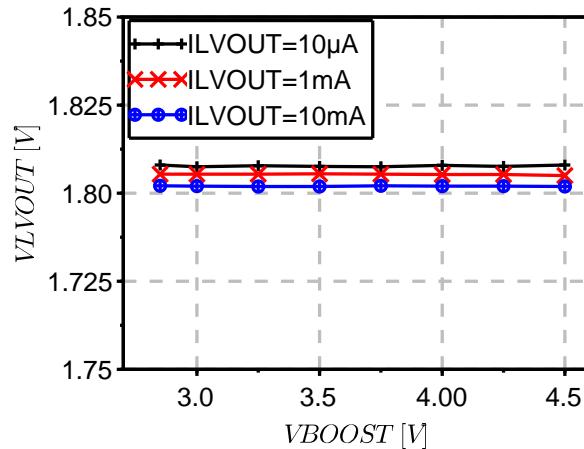
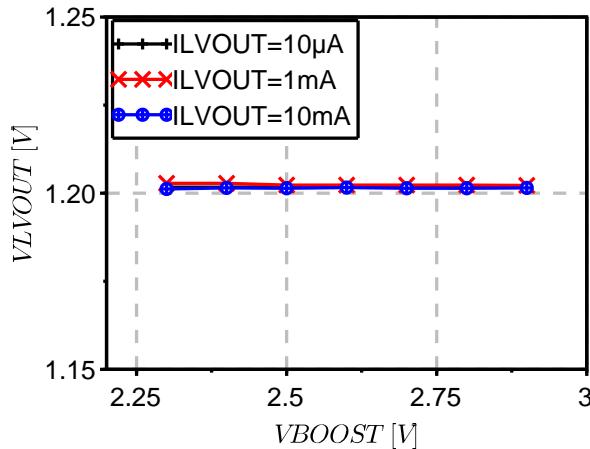


Figure 16: $LVOUT$ at 1.2 V and 1.8 V

10.5 Internal rectifier

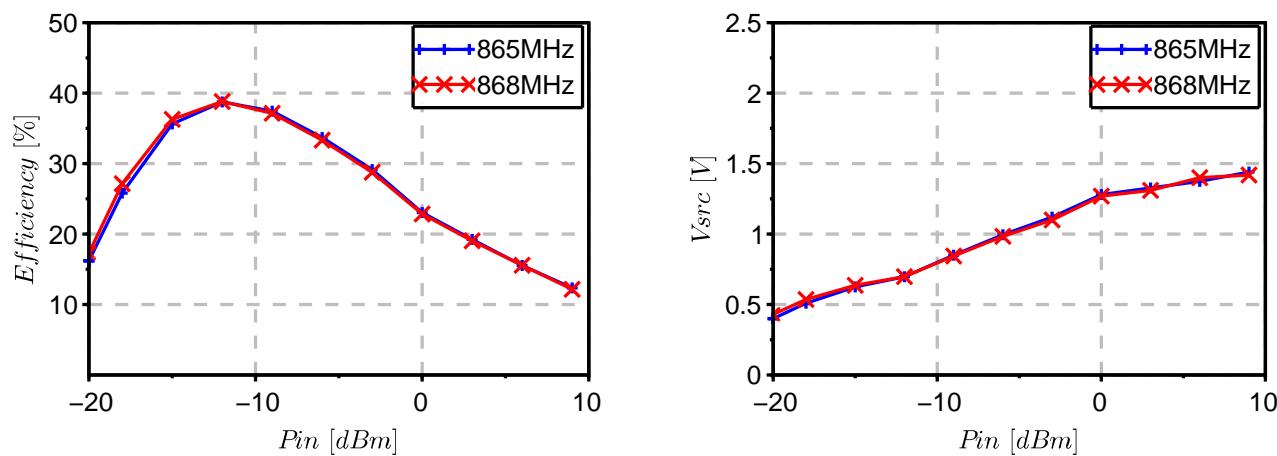


Figure 17: Efficiency and output voltage of the internal rectifier

10.6 Global efficiency

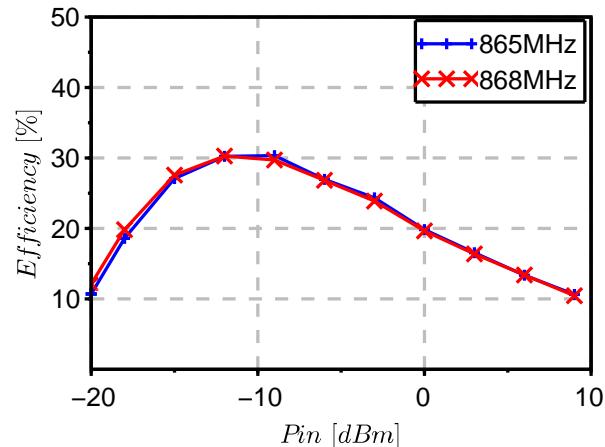


Figure 18: Global efficiency (rectifier and boost) of the AEM40940 in NORMAL MODE



11 Schematic

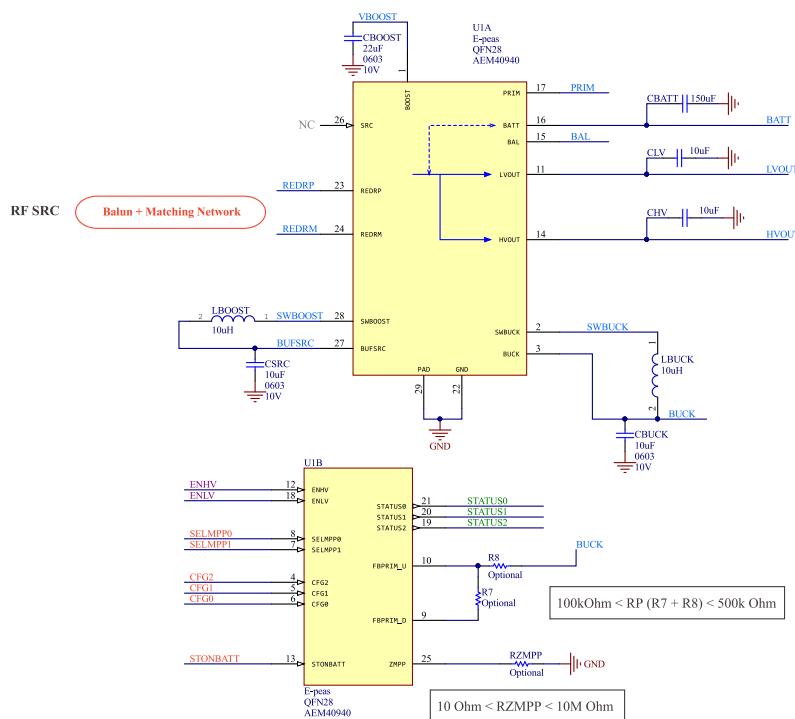


Figure 19: Schematic example

Designator	Description	Quantity	Supplier	Link
CBATT	Cap Ceramic 150 μ F, 6.3 V, 20 %, X5R	1	Farnell	http://be.farnell.com/2494474
CBOOST	Cap Ceramic 22 μ F, 10 V, 20 %, X5R 0603	1	Farnell	http://be.farnell.com/2426957
CBUCK	Cap Ceramic 10 μ F, 10 V, 20 %, X5R	1	Farnell	http://be.farnell.com/2309028
CHV	Cap Ceramic 10 μ F, 10 V, 20 %, X5R	1	Farnell	http://be.farnell.com/2309028
CLV	Cap Ceramic 10 μ F, 10 V, 20 %, X5R	1	Farnell	http://be.farnell.com/2309028
CSRC	Cap Ceramic 10 μ F, 10 V, 20 %, X5R	1	Farnell	http://be.farnell.com/2309028
LBOOST	Power Inductor 10 μ H - 0,55 A - LPS4012	1	Farnell	http://be.farnell.com/2408076
LBUCK	Power Inductor 10 μ H - 0,25 A	1	Farnell	http://be.farnell.com/2215635
U1	AEM40940 - Symbol QFN28	1		order at sales@e-peas.com
	Matching network	1		order at sales@e-peas.com

Table 9: BOM example for AEM40940 and its required passive components

12 Layout

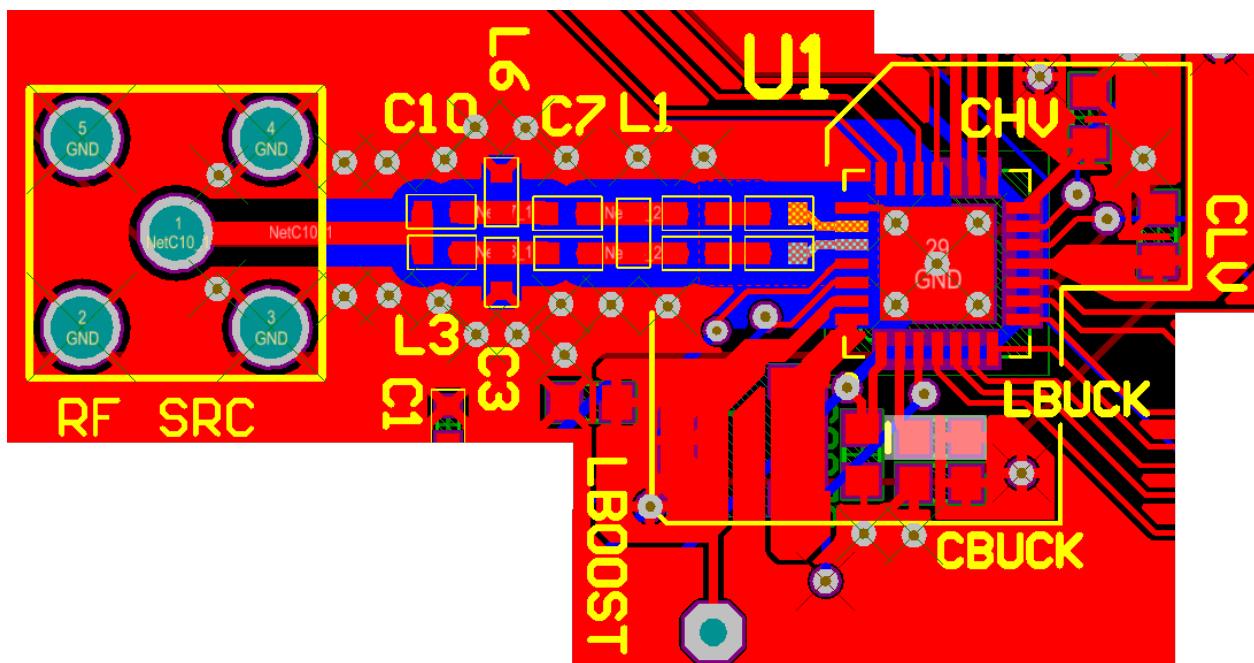


Figure 20: Layout example for the AEM40940 and its passive components

Note: Schematic, symbol and footprint for the e-peas component can be ordered by contacting the e-peas support : support@e-peas.com

13 Package Information

13.1 Plastic quad flatpack no-lead (QFN28 5x5mm)

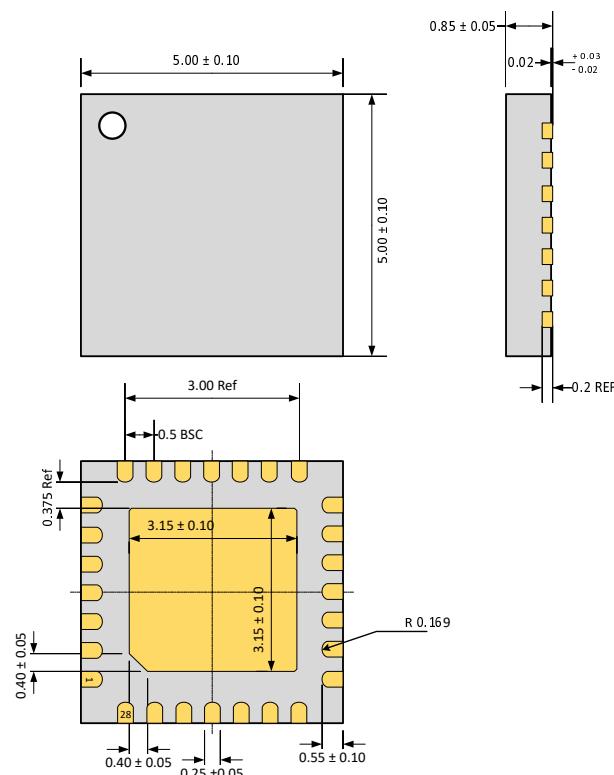


Figure 21: QFN28 5x5mm

13.2 Board layout

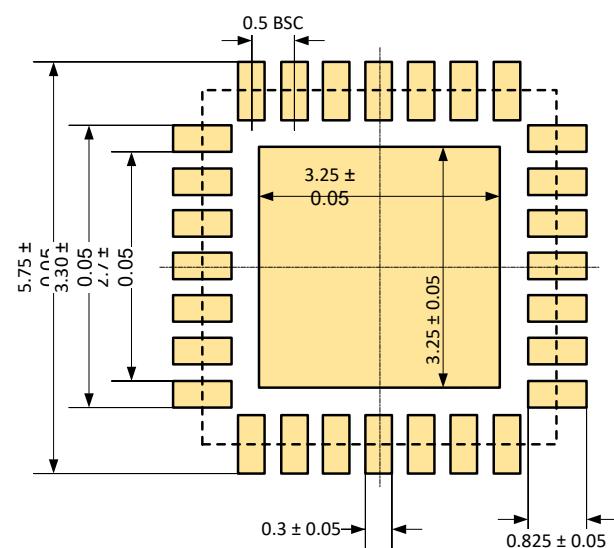


Figure 22: Board layout