Application Note

Battery lifetime

This document describes how to anticipate the lifetime of battery driven mobile applications, wearable devices and off-the-grid systems.

The general setups of such systems consist of at least:

- a battery or a combination of batteries,
- an electronic circuit for voltage conversion (optional)
- one micropump controller chip and possible additional circuitry,
- one or more micropump(s) and a fluidic system for liquid or gas application.

How long such a device will be operational is dependent on all of the above.

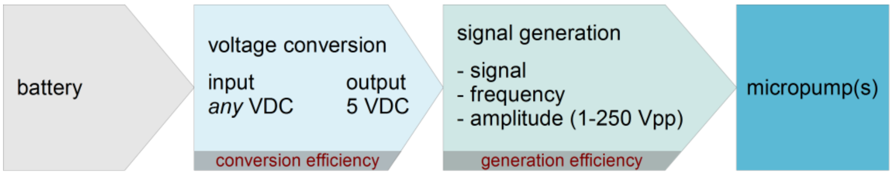

Figure 1 From battery to micropump(s) (example)

Battery and voltage conversion

It is possible to compare batteries by voltage and charge capacity (mAh), but this is not the only characteristic to observe. The different battery technologies, i.e. internal chemistry, have different characteristics for maximal charge, discharge curve (see left image in Figure 2) and maximal discharge currents.

Example 1:

Four AA alkaline batteries are used to provide 6 V (= 4x1.5 V). This voltage is too high and would damage the OEM driver electronic (mp6-OEM and mp6-QuadOEM). With a low-dropout voltage regulator (LDO or LDO-VREG), the voltage is converted down to 5 V. When the battery voltage has decreased over time and dropped below a certain voltage level, the LDO is not able to maintain the 5 V level. In the example shown in the middle image of Figure 2, the LDO (LP2951-50D, Texas Instruments) has its minimal working voltage at ~5.5 V. Within the green colored time, the supply voltage to the driver electronics is converted to 5 V and the micropump is performing correctly.

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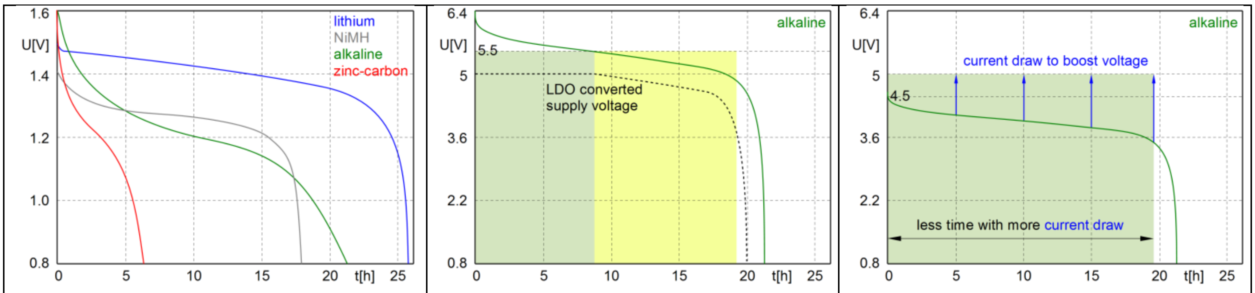
Bartels Mikrotechnik GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany
www.bartels-mikrotechnik.de, microComponents@bartels-mikrotechnik.de
Tel: +49-231-47730-500, Fax: +49-231-47730-501

In the yellow colored time, the battery voltage is below 5.5 V but the still working LDO will lower the supply voltage below the 5 V limit. Hence, the micropump performance will decrease. It depends on the application when this will be so dramatic that the micropump cannot work anymore. Once the supply voltage to the driver electronic is too low (end of yellow area), the micropump will stop completely. Typically before that, the battery can be regarded as empty.

Example 2:

Three AA alkaline batteries are used to provide 4.5 V (= 3x1.5 V). As this voltage is too low for the OEM driver electronic to maintain the full performance of the micropump, a BOOST converter (TPS61070, Texas Instruments) is used to increase the supply voltage up to 5 V. With the decreasing voltage of the battery over time, the BOOST converter has to draw more and more current to maintain the 5 V (see right side image of Figure 2). This will empty the battery a bit faster due to the increasing current draw. However, the micropump will be operational without decreasing performance during the whole time.

At one time, the current draw of the BOOST converter may be too large for the battery and the battery life is shortened heavily. Depending on the type of the BOOST converter, the battery has to be chosen according to the current demand.



Discharge curve of different batteries (1.5 V) with similar charge capacity at same discharge current.	Example 1 with four AA alkaline batteries (4x1.5 = 6 V) and LDO voltage regulation.	Example 2 with three AA alkaline batteries (3x1.5 = 4.5 V) and BOOST converter.

Figure 2 Battery use with micropump controller mp6-OEM and mp6-QuadOEM (images for explanation only, no real data). Left: General comparison of batteries. Middle: LDO voltage regulation. Right: BOOST converter.

The examples given above are only two possible ways of voltage conversion from battery source to OEM driver electronics. Any voltage conversion solution will have its own pros and cons – minimal required supply voltage, type and number of circuit components, efficiency (i.e. battery power required for the conversion) and others. Additionally, the type of the application is also of interest here. Is it important to have constant performance of the micropump or is variation depending on the supply voltage allowed?

Bartels Mikrotechnik GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany
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Example: Maybe the micropump should deliver a medium flow rate. With an LDO-VREG, the performance decreases after some time. The amplitude of the pump can be raised to compensate that; how and in which way depends on the application.
The adequate battery technology has to be selected according to the application too. In general, alkaline or better is recommended. Button cells are typically not suitable to power these micropump electronics due to their limited current supply capabilities.

Signal generation and the micropump

The micropump requires a certain driving signal – signal shape, frequency and amplitude - that is generated by the controller out of the 5 V supply voltage. Similar to the voltage conversion the signal generation also has its own efficiency; some amount of converted battery power will be lost during the signal generation. The current draw of the micropump controller mp6-OEM depends on driving parameters, i.e. signal shape, amplitude or frequency. The electrical load of the micropump mp6 (50 mW@100 Hz) does not have such a strong effect as the signal generation of the mp6-OEM.
For the mp6-QuadOEM controller, which is able to control up to four micropumps with frequencies up to 800 Hz, the electrical load has more influence.

The different controllers are shown with their general power consumption[1] in the overview in Figure 3.
One aspect of the power consumption is the operation of the micropump. The actuators are charged and discharged continuously to move up and down. The repetitive discharges of the actuator capacitances in the micropump are not reused and therefore lost. However, the main factor for current consumption will be the internal signal generation of the controller.

Controller		Supply voltage	Current consumption	Power consumption
mp6-OEM		5 V	30 mA	150 mW
mp6-QuadOEM	1 micropump 4 micropumps	5 V	30 mA 80 mA	150 mW 400 mW

Figure 3 Power consumption of the micropump controller:
mp6-OEM: single mp6, 100 Hz, max amplitude, signal = similar to rectangular
mp6-QuadOEM: one and four mp6, 100 Hz, max amplitude, signal = sine

[1] More details about current consumption can be found in the "TechNote Controller Overview".

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Battery lifetime test

A lifetime test was made with the mp6-OEM and the mp6-QuadOEM controllers, the two above discussed voltage conversions and different battery voltages.

Below, results for the mp6-OEM are shown with the diagrams of Figure 4. The result for the mp6-QuadOEM is given with Figure 5. Battery sets of Duracell AA Alkaline LR6 ID1500 were used for all experiments.

<u>mp6-OEM</u>

The BOOST-converter was used to generate 5 V out of 2x AA (2x1.5 = 3 V). The blue curve represents the input voltage of the BOOST-converter, i.e. the battery voltage and the red curve is the output voltage of the BOOST-converter, which drives the mp6-OEM. As described above the output voltage is cut down after some time, until then the micropump is at full performance. In this experiment, the micropump stopped working after 43.7 h as ~0.9 V is too low for the BOOST-converter to work properly anymore and the mp6-OEM switches off when its supply is below ~2 V.

Due to some recovery effect of the batteries, the red curve is jumping a lot at the end as the mp6-OEM switches on and off repeatedly with the recovering and failing voltage level.

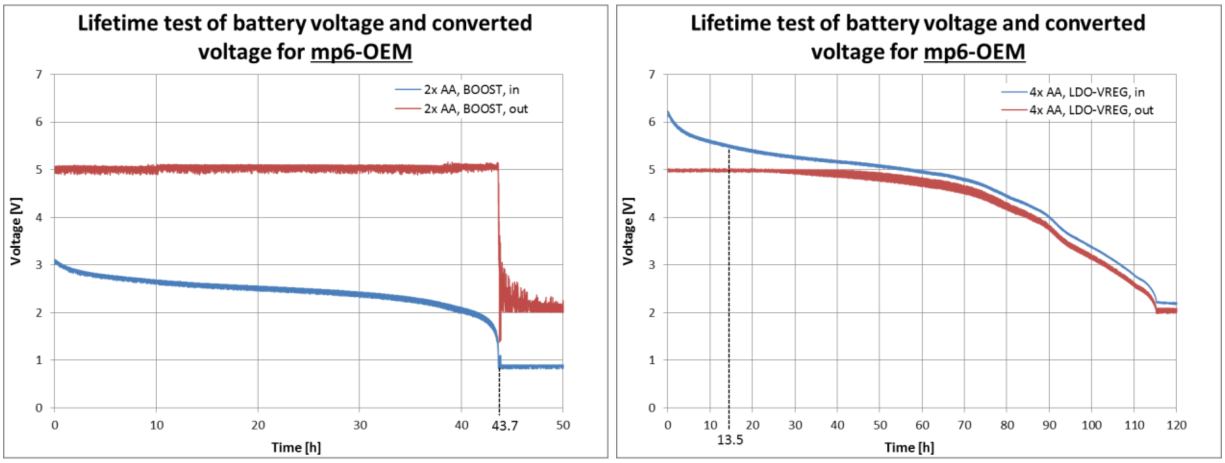

Figure 4 Lifetime test of battery voltage with mp6-OEM: BOOST-converter with 2x AA and LDO-VREG with 4x AA.

For the LDO-VREG experiment 4x AA (4x1.5 = 6 V) were used. The battery voltage is again the blue curve and the output is the red curve. The output voltage to the mp6-OEM can be kept up for 13.5 h, after that the output is decreasing slowly until the output voltage is at ~2 V and the mp6-OEM stops working. Hence, the remaining voltage of the batteries (blue curve) is a bit higher than with the BOOST-converter.

As mentioned with "example 1" the output voltage starts dropping when the supply voltage of the LDO-VREG drops below 5.5 V. The micropump was at full performance during the initial 13.5 h. After that,

Bartels Mikrotechnik GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany
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the performance is decreasing constantly with the decreasing voltage to the mp6-OEM until, at ~115 h, the micropump stops with the mp6-OEM.

mp6-QuadOEM

The mp6-QuadOEM was tested with LDO-VREG. Similar to the result of the mp6-OEM the red output voltage line starts to decrease when the battery voltage drops below 5.5 V. The output voltage can be kept up for 21.6 h, with full performance of the micropump. The mp6-QuadOEM stops working at ~146 h.

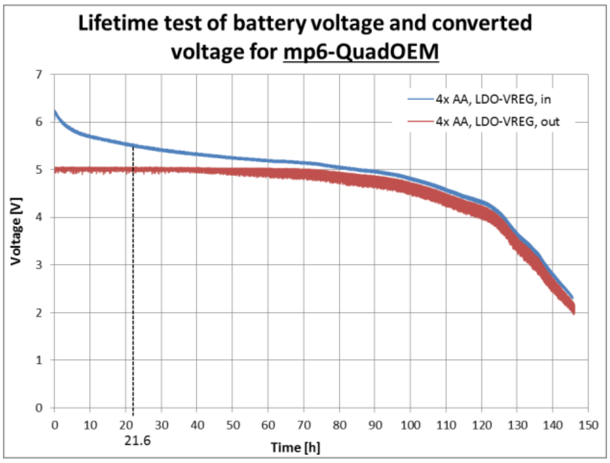

Figure 5 Lifetime test of battery voltage with mp6-QuadOEM: LDO-VREG with 4x AA.

There is a difference between the lifetime of mp6-OEM and mp6-QuadOEM when connected to the same LDO-VREG and battery sources. The reason is that the given current consumption of both controllers (see Figure 3 above) represents only a mean value over time, peak currents during the operation are not measured. It can be assumed that the mp6-OEM has more peak currents than the mp6-QuadOEM. Thus, the batteries are depleted a bit earlier.

For an application based on battery power it is also necessary to keep in mind that new batteries may not always have the same initial charge. The charge is decreasing with prolonged shelf life, the storage conditions have quite some impact here. Additionally the same battery type exists from many different vendors and quality differences are very high.

A low-dropout voltage regulator (LDO-VREG) was used here because it can operate down to ~5.5 V where as a normal VREG would need at least 2 V more than its target output voltage.

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