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Backup Power Sources for Microchip's RTCCs and SRAMs

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INTRODUCTION

Many of Microchip's RTCCs and SRAMs have a VBAT pin intended for a backup source and are able to maintain the basic functions of the chip when the main power supply is absent. For RTCCs, this allows them to maintain operation of the clock for timekeeping, and for SRAMs, to keep data retention as long as possible.

The following application note offers guidance for choosing the most suitable backup source for RTCC or SRAM-based projects and for estimating the backup time, as well as calculating maximum charging current. Accordingly, this document describes several ways to sustain clock and data in products that are susceptible to power interruptions.

COMPARISON OF BACKUP SOURCES

Several backup solutions will be compared below:

- Lithium primary batteries
- Rechargeable nickel-based batteries
- Rechargeable lithium-based batteries
- Supercapacitors

Lithium Primary Batteries

These common coin cells, types BR or CR, (e.g., CR2032) with a lithium anode and a polycarbon fluoride cathode (BR type) or a manganese dioxide cathode (CR type), work close to industrial temperature range with a low self-discharge rate of about 1% per year. Usable backup time can be very long, even exceeding ten years in some cases, depending on the application.

Note:	Keep in mind that the self-discharge rate increases (sometimes dramatically) with temperature.

Some lithium primary batteries are available with solder tabs for direct soldering to a printed circuit board (PCB).

When installed with solder tabs onto PC boards, the batteries can be difficult to change. Alternatively, battery holders can be used to install the coin cells, but this would increase the cost of the project.

When lithium cells fail due to age or leakage, the PCB or surrounding circuits could be damaged. Lithium batteries are sometimes subject to transport restrictions owing to numerous examples of them being linked to explosions, however this is less restrictive when these batteries are installed in the application. As primary batteries cannot be recharged, no charging circuit is required, saving cost.

Rechargeable Nickel-Based Batteries (NiMH/NiCad)

This type of battery needs an external, relatively expensive charger which often requires monitoring the charge current and the cell temperature. Alternatively, the batteries might even be externally charged in order to avoid the increased cost of the basic application. After charging, the batteries may be installed in the application and used as non-rechargeable batteries. These cells typically have a 1.2V nominal voltage. To backup an RTCC or SRAM, two cells in series are needed to get 2.4V. Standard AA and AAA cells are popular and easy to be changed, but they need a battery holder. The cell ratings offer large capacity relative to other battery types, suggesting long use as backup, but their self-discharge rate is high and can greatly reduce practical backup time. An external charging circuit will increase the cost while the usable temperature range may not be suitable for some applications.

Since cadmium is a toxic heavy metal, NiCad batteries were gradually replaced by NiMH batteries. However, NiMH batteries have some disadvantages:

- Complex chargers (trickle charging, $\Delta V/\Delta t$ and $\Delta T/\Delta t$)
- Self-discharge rate and battery life vary greatly with temperature (a 20°C increase in temperature could halve battery life)

After 2005, Sanyo introduced the reduced self-discharge NiMH battery, which has a 15-30% self-discharge rate/year (typical value: Panasonic = 20%/year).

Rechargeable Lithium-Based Batteries (Li-Ion/Li-Mn)

Due to their small size, these batteries may be used as backup for RTCC/SRAM functions even in very small devices. They need a charging circuit and may also need a battery holder. The capacity of rechargeable lithium-based batteries is smaller than that of lithium primary batteries, around 70 mAh in the 2032 size. The nominal voltage for a Li-Ion cell is 3.7V and the nominal voltage for Li-Mn is 3.0V. These batteries have a usable temperature range from -20°C to +60°C. Just like primary lithium batteries, rechargeable lithium-based batteries are also subject to transport restrictions.

The main advantage is that they can be recharged when the main power source is available, extending their usable lifetime to decades.

The self-discharge rate is in a reasonable range:

- Sanyo: 1.5%-2%/month
- Maxell (ML2032): 6%/200 days

Note:	Keep in mind that one year of operation at +20°C is equivalent to 20 days of operation at +60°C.

Supercapacitors

Also called “supercaps” or “ultracapacitors”, these products are defined by large capacitance and low-leakage currents. Supercapacitors can be used as a backup solution with advantages over lithium cells:

- The same industrial temperature range and the possibility to be soldered on the printed circuit board (PCB) without the need for a socket or battery holder
- With no questionable chemistry, fewer regulations related to transport and disposal
- A simple charging circuit, which will note dramatically increase costs
- Total energy storage quite a bit less than that of rechargeable batteries; however, in many applications the backup time of days or weeks is quite sufficient.

The leakage current of supercapacitors is reasonable enough to support backup:

- Panasonic “Gold capacitor” series has a voltage decrease of 5.5V - 3V = 2.5V in 600 hours, which equates to a leakage current of about 1 µA (C = 1F)
- Maxwell supercapacitors have a leakage current of about 6 µA
- Murata supercapacitors have a leakage current of about 10 µA

TABLE 1: MANUFACTURERS OF BACKUP SOLUTIONS

Primary Lithium Batteries			
Panasonic	CR2032	3V	220 mAh
Autec	CR2032	3V	210 mAh
Duracell	CR2032	3V	220 mAh
Energizer	CR2032	3V	240 mAh
Rechargeable Nickel Batteries			
Panasonic	AAA	1.2V	750 mAh
Panasonic	AA	1.2V	1900 mAh
Energizer	AA	1.2V	2300 mAh
Duracell	AA	1.2V	1950 mAh
Rechargeable Lithium Batteries			
Hitachi-Maxell	CLB2032	3.7V	70 mAh
Hitachi-Maxell	ML2032	3.0V	65 mAh
Varta	CP1254	3.7V	50 mAh
Varta	CP1654	3.7V	100 mAh
Supercapacitors			
Maxwell	HC-Series	2.7V	1-150F
Panasonic	NF-Series	5.5V	1F
	HZ-Series	2.5V	3.3-10F
	HW-Series	2.3V	22-70F

MICROCHIP’S RTCC AND SRAM BACKUP REQUIREMENTS

Microchip’s RTCCs (except MCP7940M) feature a backup power supply input (V_{BAT}) that can be used to provide power to the timekeeping circuitry, RTCC registers and SRAM, while primary power is unavailable. The RTCC will automatically switch to backup power when V_{CC} falls below V_{TRIP}, and switch back to V_{CC} when primary power is above V_{TRIP} (with some hysteresis).

The VBATEN bit must be set in software to enable the V_{BAT} input and allow backup operation.

The following functions are maintained while operating on backup power:

- Timekeeping
- Alarms
- Alarm Output
- Digital Trimming
- RTCC Register and SRAM Contents

However, the following active features are not available while operating on backup power:

- I^2C/SPI Communication
- Square-Wave Clock Output
- General Purpose Output

The main backup-related parameters of the I2C RTCC (MCP794X) are:

Param.	Min.	Typ.	Max.
V_{TRIP}	1.3V	1.5V	1.7V
V_{BAT}	1.3V	—	5.5V
I_{BAT}	—	0.925 µA	1.2 µA @ 3V

In the case of the SPI RTCC (MCP79W1X/2X), these three parameters have the following values:

Param.	Min.	Typ.	Max.
V_{TRIP}	1.3V	1.5V	1.7V
V_{BAT}	1.3V	—	3.6V
I_{BAT}	—	—	0.7 µA @ 1.8V

In accordance with the data sheet, the V_{BAT} switchover operation is described for both SRAMs and RTCCs in Table 2.

TABLE 2: V_{CC}/V_{BAT} SWITCHOVER CONDITIONS

Supply Condition	Read/Write Access	Powered By
$V_{CC} < V_{TRIP}$ $V_{CC} < V_{BAT}$	No	V_{BAT}
$V_{CC} > V_{TRIP}$ $V_{CC} < V_{BAT}$	Yes	V_{CC}
$V_{CC} > V_{TRIP}$ $V_{CC} > V_{BAT}$	Yes	V_{CC}

A low-value series resistor and diode are recommended between the external battery and the V_{BAT} pin to reduce inrush current and also to prevent any leakage current reaching the external V_{BAT} source. In the RTCC devices, if the V_{BAT} feature is not used, it is recommended that the V_{BAT} pin be connected to V_{SS}. The V_{TRIP} point is defined as 1.5V, typical. When V_{CC} falls below 1.5V, the system continues to operate the RTCC and SRAM using the V_{BAT} supply. The conditions in Table 2 apply. For more information on V_{BAT} conditions, see ***"Recommended Usage of Microchip Serial RTCC Devices"* Application Note (DS00001365)**. The battery module of 23LCVXXX has practically the same mode of operation. The 23LCVXXX features an internal switch that will maintain the SRAM data contents in the event that the V_{CC} supply is not available; the voltage applied to the V_{BAT} pin serves as the backup supply.

The V_{BAT} trip voltage is the point at which the internal switch operates the device from the V_{BAT} supply and it is typically 1.8V (parameter V_{TRIP}). When V_{CC} falls below the V_{TRIP} point, the SRAM will no longer communicate, but it will continue to maintain the SRAM data contents. The conditions in Table 2 apply. The data sheet parameters below (for 23LCVXXX) are used for the calculations:

Param.	Min.	Typ.	Max.
V_{TRIP}	1.6V	1.8V	2.0V
V_{BAT}	1.4V	—	3.6V
I_{BAT}	—	1 µA @ 2.5V	—

CALCULATION OF THE BACKUP TIME FOR PRIMARY BATTERIES

EQUATION 1: BATTERY BACKUP TIME

$$t_{BAT} = \frac{C}{I_{BAT} + I_{LK}}$$

Where:

t_{BAT} = backup time in hours

C = capacity of battery in amperes-hour

I_{BAT} = backup current in amperes

I_{LK} = leakage current in amperes

CALCULATION OF THE LEAKAGE CURRENT FOR BATTERIES

Many battery manufacturers offer in data sheets the self-discharge rate and not the leakage current of these backup solutions. The relation between these two parameters is indicated in Equation 2:

EQUATION 2: LEAKAGE CURRENT

$$I_{LK} = SDR \times \frac{C}{\Delta t}$$

Where:

I_{LK} = leakage current in amperes

SDR = self-discharge rate

C = capacity of battery in amperes-hour

Δt = reference time interval

Since for primary lithium batteries SDR ~ 1%/year,

If:

C = 220 mAh

then

I_{LK} = 2.2 mAh/8760h = 2200 μAh/8760h ≈ 0.25 μA

Accordingly, the backup time would be:

220 mAh/1.25 μA = 220,000/1.25h = 176,000h,

which is 7333 days, or around 20 years (I_{BAT} ≈ 1 μA).

Typical rechargeable batteries such as NiMH and NiCad have a higher capacity, but due to their larger size compared to the other backup options, they are not suitable for basic backup for the very low currents needed in RTCCs and SRAMs. These batteries are better suited for stand-alone and high-consumption applications, such as digital cameras and video recorders.

CALCULATION OF THE BACKUP TIME FOR RECHARGEABLE BATTERIES (COIN CELLS – LI-ION/LI-MN)

Li-Ion or Li-Mn coin cells from Hitachi-Maxell (CLB2032, ML2032) have a capacity of about 70 mAh (Example 1). Note that this is one-third the rated capacity compared to primary lithium coin cells CR2032 (Autec or Panasonic).

EXAMPLE 1: ML2032 HIGHLIGHTS

SDR ≈ 6%/200days = 0.06/4800h at a capacity of 65 mAh

I_{LK} = 0.06x65,000 μAh/4800h ≈ 0.8 μA

ML2032 can be used as a power supply for different products, as indicated in Example 2.

EXAMPLE 2: CALCULATION OF BACKUP TIME USING ML2032

$$I = I_{BAT} + I_{LK}$$

If:

I_{LK} = 0.8 μA

then

I²C RTCC (**MCP7941X**)

I_{BAT} (typical) = 0.925 μA

Backup Time = 65,000 μAh/1.725 μA, which means 37,680 hours ≈ 1570 days, or about 4.3 years.

SPI RTCC (**MCP795W1X/2X**)

I_{BAT} max = 0.7 μA

Backup Time = 43,333h = 1805 days, or about 4.9 years.

SRAM (**23LCV1024**)

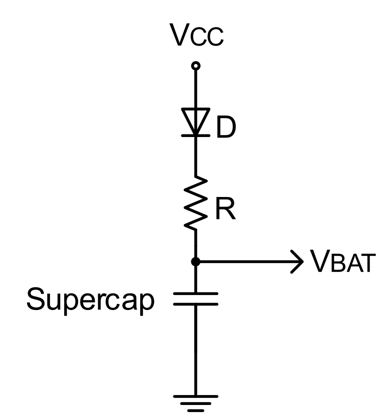
I_{BAT} (typical) = 1 μA

Backup Time = 36,111h = 1504 days, or about 4.12 years.

COMMENTS ON SUPERCAPACITOR CHARGING CIRCUIT

The schematic for charging the supercapacitor is presented in Figure 1.

FIGURE 1: SUPERCAPACITOR CHARGING CIRCUIT



Keep in mind that many supercapacitors are limited to a maximum of 2.7V. In Example 3, VCC is at 3.3V, which would require a diode with a 0.6V forward voltage to avoid exceeding the typical 2.7V limit. This prevents the use of some diode types, such as Schottky. However, if a supercapacitor with a higher voltage rating is used or if a lower VCC voltage is used, then potentially a Schottky diode can be utilized. This would allow the supercapacitor to be charged closer to VCC, allowing for more efficient operation.

EXAMPLE 3: TYPICAL VALUES OF SUPERCAPACITOR CHARGING CIRCUIT

VCC	=	3.3V
VDIODE	=	0.6V
R	=	270Ω
C	=	[1 – 10]F

CALCULATION OF THE CHARGING TIME FOR SUPERCAPACITORS

The charging time for supercapacitors can be significant, and should be taken into account. It can be calculated as shown in Equations 3 to 7.

EQUATION 3:

$$V_{SC} = V_{CC} \times \left[1 - exp\left(-\frac{t}{RC}\right)\right]$$

Where:

R = 270 ohms

C = 1F

EQUATION 4:

$$1 - exp\left(-\frac{t}{RC}\right) = \frac{V_{SC}}{V_{CC}}$$

EQUATION 5:

$$exp\left(-\frac{t}{RC}\right) = 1 - \frac{V_{SC}}{V_{CC}}$$

EQUATION 6:

$$-\frac{t}{RC} = ln\left(1 - \frac{V_{SC}}{V_{CC}}\right)$$

EQUATION 7:

$$t = (-RC) \times ln\left(1 - \frac{V_{SC}}{V_{CC}}\right)$$

Considering that the usual charging ratio is 90%, as indicated in Equation 8, the charging time in this example for a 1F supercapacitor is greater than 10 minutes (Example 4).

EQUATION 8: SUPERCAPACITOR CHARGING RATIO

$$\frac{V_{SC\_CHG}}{V_{CC}} = 90\%$$

EXAMPLE 4: ILLUSTRATION OF SUPERCAPACITOR CHARGING TIME

t_{CHG} = (-RC) x ln(0.1) = (-270 ohms x 1F) x (-2.3) = 270sec x 2.3 = 621 sec > 10 minutes

The charging current will be at its maximum when the supercapacitor is fully discharged.

Thus:

I_{max} = (VCC - VDIODE)/R = 2.7V/270Ω = 10 mA

CALCULATION OF THE BACKUP TIME FOR SUPERCAPACITORS

When calculating the backup time, the formula in Equation 9 must be taken into account:

EQUATION 9: SUPERCAPACITOR VOLTAGE AND CURRENT

$$I = C \times \frac{\Delta V}{\Delta t}$$

Where:

I	=	current in amperes
C	=	capacitance in farads
ΔV	=	voltage difference in volts
Δt	=	time difference in seconds

CALCULATION OF THE LEAKAGE CURRENT FOR SUPERCAPACITORS

Sometimes, supercapacitor data sheets do not offer directly the value of the leakage current.

Instead, they give the variation of the voltage in a determined period of time (Equation 9).

A good example in this respect is the "Gold capacitors" series of Panasonic (Example 5).

EXAMPLE 5: LEAKAGE CURRENT FOR GOLD CAPACITORS

If:

ΔV = 5.5V - 3V = 2.5V in 600 hours, or 2,160,000 seconds (C = 1F)

then

I_{LK} = 1.15 µA

For other manufacturers, the value of the leakage current can be found in corresponding data sheets:

- Maxwell: 6 µA
- Murata: 10 µA

If the terms in Equation 9 are rearranged, a new relation is obtained (Equation 10).

EQUATION 10: BACKUP TIME FOR SUPERCAPACITORS

$$t_{BAT} = C \times \frac{V0 - V_F}{I}$$

Where:

t_{BAT}	=	backup time (seconds)
C	=	capacitance (farads)
V0	=	initial capacitor voltage
V_F	=	final capacitor voltage (V_{BATMIN})
I_{BAT}	=	backup current (I_{BAT})
I_{LK}	=	leakage current (amperes)
I	=	$I_{BAT} + I_{LK}$

To calculate the backup time as indicated in Equation 10, keep in mind that ΔV is the supercapacitor discharge between V_0 and V_F, and that after backup time, V_F will reach the minimum acceptable value (V_{BATMIN}).

EQUATION 11: ILLUSTRATION OF BACKUP TIME CALCULATION FOR SUPERCAPACITORS

$$t_{BU} = 1F \times \frac{1.4V}{2.15\ \mu A}$$

Where:

I_{BAT}	≈	1 µA
I_{LK}	=	1.15 µA
C	=	1F
V_0	≈	2.7V (V_{CC} - V_{DIODE})
V_F	=	1.3V (V_{BATMIN})
I	=	2.15 µA

then

t_{BAT} ≈ 650,000 seconds, about 180 hours, or about 7.5 days

A higher value for the supercapacitor will increase the backup time proportionally. However, keep in mind that higher-valued supercapacitors typically have lower operating voltages.

CONCLUSION

This application note addresses the most common questions about how to use the backup capabilities of Microchip's RTCC and SRAM devices:

- What are the common backup solutions for RTCCs and SRAMs?
- Which factors determine the most suitable variant?

The application note also highlights a few batteries and supercapacitors of different manufacturers.

Finally, examples are provided to calculate the approximate backup time for each solution.

APPENDIX A: REVISION HISTORY

Revision A (December 2015)

Initial release of this document.

Note the following details of the code protection feature on Microchip devices:

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