Temperature compensated Real-Time Clock with back-up power supply

Rolf Schütz
Product Engineer at Micro Crystal
Grenchen, Schweiz
rolf.schuetz@microcrystal.ch

Markus Hintermann
Technical Marketing / Sales Manager at Micro Crystal
markus.hintermann@microcrystal.ch

Date: December 2015 Revision N°: 1.0E

Inhalt

1. Summary

The White Paper describes the combination of the Real-Time Clock Module RV-8803-C7 with an eco-friendly Supercap*.
The low power consumption of the RTC Module RV-8803-C7 allows for the first time to keep the actual time over extended periods by using a simple Supercap back-up power supply. This eco-friendly solution permits the user to continue tracking time with high precision even during power down condition.
The back-up circuit requires, beside the Supercap and the RTC Module RV-8803-C7, just one Schottky-diode plus a resistor to limit the inrush current during charging.

*) Capacitors with ultra-high capacitance typically in the range of 20’000 µF to several F are commonly referred to as Supercap, Ultracap, Gold Cap, double-layer cap, multilayer cap and there more. In this paper they are generally referred to as Supercaps.

2. Temperature compensated RTC Module RV-8803-C7

The temperature compensated RTC Module RV-8803-C7 from Micro Crystal currently offers the highest accuracy of ±3 ppm across the entire industrial temperature range of -40 to +85°C. This corresponds to a maximum deviation of ±0.26 seconds per day with a current consumption of merely 240 nA at 3 V. This exceptionally low power consumption, in parallel with the full functionality of temperature sensing and frequency compensation, even down to a supply voltage of 1.5 V, prolongs the system power autonomy considerably.
Asides from the lowest power consumption in combination with the highest accuracy, it also features the smallest SMD ceramic package with remarkable dimensions of only 3.2 x 1.5 x 0.8 mm.
It allows the device to be used in a wide field of applications where accurate timing is required, also in power-down mode.

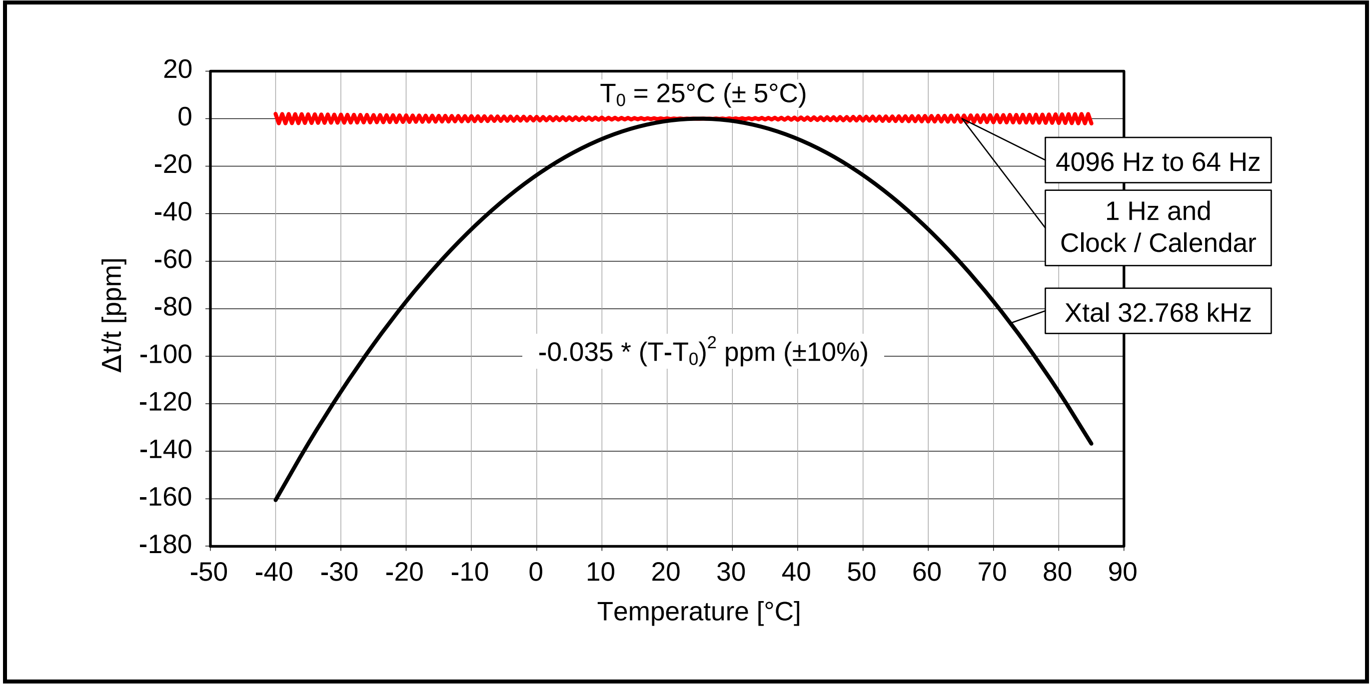
Examples:

- Portable medical systems
- Automotive applications
- POS-terminals
- Utility metering
- Embedded modules
- Data loggers
- White Goods

Key parameters of the RTC Module RV-8803-C7:

- Ultra-miniature ceramic SMD package: 3.2 x 1.5 x 0.8 mm
- Highest accuracy (±3 ppm) over the whole industrial temperature range of -40 to +85°C
- Wide supply voltage range: 1.5 to 5.5 V
- Lowest power consumption of just 240 nA / 3 V
- I²C-bus interface
- AEC-Q200 qualified

Time accuracy as function of ambient temperature:



3. Power back-up with Supercap.

The Supercap is the predestined solution for the secondary supply of RTC applications, since it features an equivalent performance of a battery.

3.1. Super Capacitor

Keep in mind: Supercaps are polarized!

Parameter:

- Large range of capacities available 0.022 F to 70 F (and larger)
- Connection in parallel or serial possible to enlarge capacity or voltage range
- Nominal voltage 5.5 V
- Temperature range up to 85°C
- Available for reflow and wave soldering
- Three package types: coin-cell, stacked coin-cell and fitted with wire leads

Advantages:

- Ideal as battery replacement
- Fast charging and discharging possible
- Unlimited number of charge / discharge cycles
- No chemical leaking or outgassing
- GREEN product, RoHS compliant , no recycling limitations
- No safety measures during charging necessary
- Operation and full performance also at very low temperature (sub-freezing)
- Maintenance free

Short coming:

- Linear discharge voltage characteristic (i = constant) prevents to use the full energy stored

Comparison of Supercap with Battery:

	Supercap	Battery
Eco friendly	Good	Bad
Number of cycles for charging / discharging	Unlimited	Very limited
Temperature range	Full range	Limited
Capacity	Equivalent	Good

3.1.1. Supercaps tested

When selecting Supercaps, check for devices with low leakage current. Supercaps for high current applications typically have high leakage currents and must therefore be avoided.

Evaluated Supercaps from Panasonic (Gold Capacitors):

- 0.1 F EECS0HD104H (5.5 V, Series SD)
- 0.47 F EECS5R5H474 (5.5 V, Series SG)
- 1.0 F EECS5R5V105 (5.5 V, Series SG)

Temperature	Max. operating voltage	Capacity	Tolerance of capacity(*)	R_{ESR} @ 1kHz	Typ. R_{ISO} @ +25°C	Package	Size (L x B x H)	Unit cost in $ (25+)
-25°C to 70°C	5.5 V	0.1 F	0.080 to 0.180 F	≤ 75 Ω	32 MΩ	horizontal	11.5 x 10.5 x 5.5	1.30
		0.47 F	0.376 to 1.41 F	≤ 30 Ω	24 MΩ	horizontal	20.5 x 19.5 x 6.5	1.99
		1.0 F	0.80 to 1.80 F	≤ 30 Ω	13 MΩ	vertical	19.0 x 5.5 x 21.0	2.01
(*) The capacity tolerances are typical (-20/+80%). The listed 0.47 F-type, however, is specified with (-20/+300%)!								

Characteristics at low temperatures

- Capacity at -25°C: ±30% of the nominal value referenced at +20°C
- Internal resistance R_{ESR} at -25°C: ≤5x the nominal value referenced at +20°C

Performance after 1000 hours 5.5 V, +70°C

- Capacity change: ±30%
- R_{ESR}: ≤ 4x larger

Storage capability after 1000 hours at +70°C not charged

- The capacitor maintains the specified performance

3.1.2. Life time calculation

According to the equation from Arrhenius (doubling the lifetime for lowering the temperature by 10K):

$$L_X = L_{Spec} * 2^{\frac{T_0 - T_A}{10}}$$

Example: Life time of the capacitor at +30°C and charged to 5.5V:

$$L_{30} = 1000 * 2^{\frac{70-30}{10}} = 16'000 \text{ hours}$$

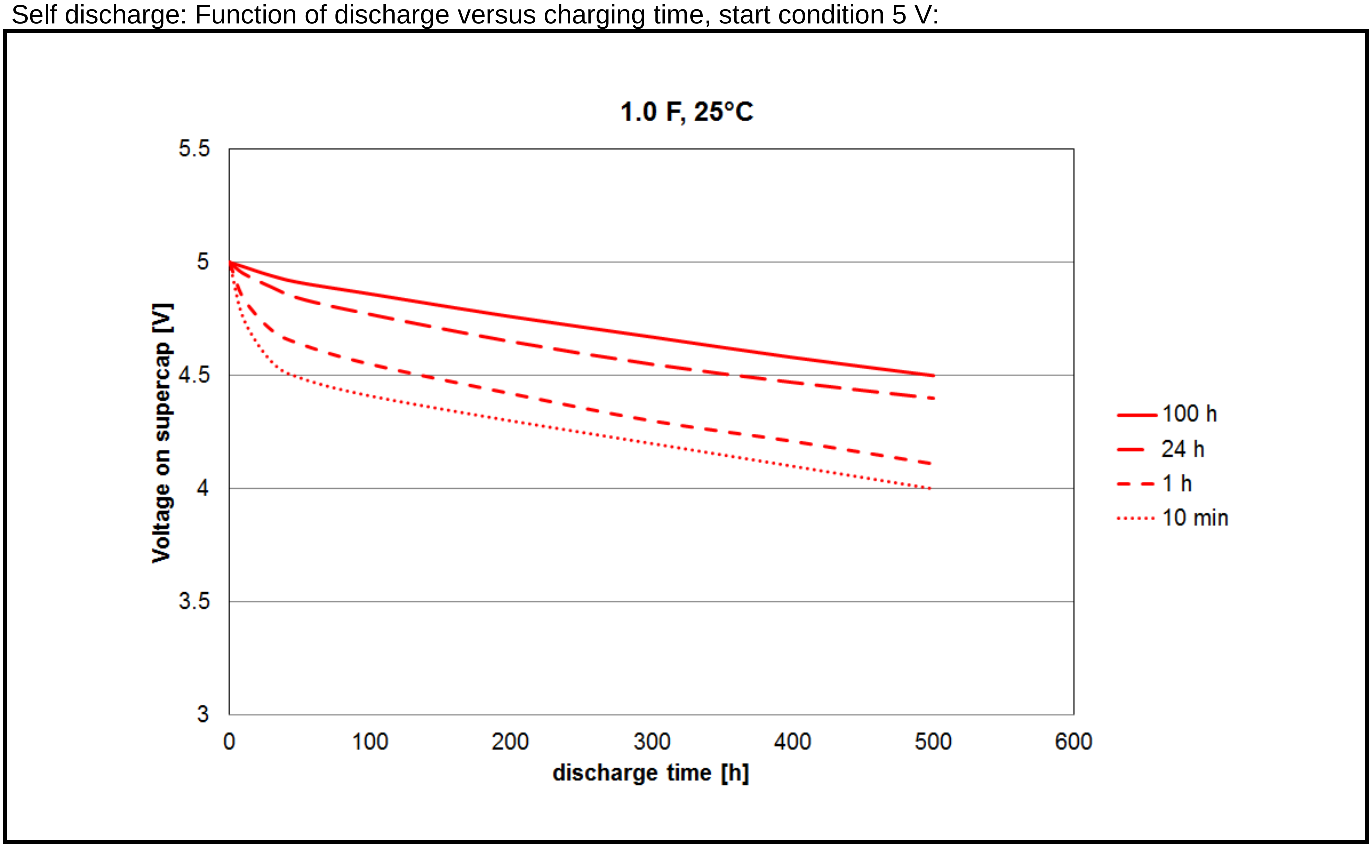
$$\rightarrow \; 16'000 \text{ h} * \frac{1 \text{ day}}{24 \text{ h}} = \underline{\underline{667 \text{ days}}}^{(*)}$$

Parameter	Comments
L_{Spec} = Life time as specified	1000 h at 5.5 V, +70°C(*)
L_X = Life time target	
T_0 = Max ambient temperature	+70°C
T_A = Ambient temperature of capacitor	
(*) The lower the supply voltage the longer the life time: (e.g. 3000 h at 4 V, +70°C)	

3.1.3. Self discharge

With short charging times (e.g. 10 minutes) the capacitor is not fully charged due to variations of the internal isolation resistance and leakage currents*. Therefore the inital voltage drop is larger.

Self discharge: Function of discharge versus charging time, start condition 5 V:

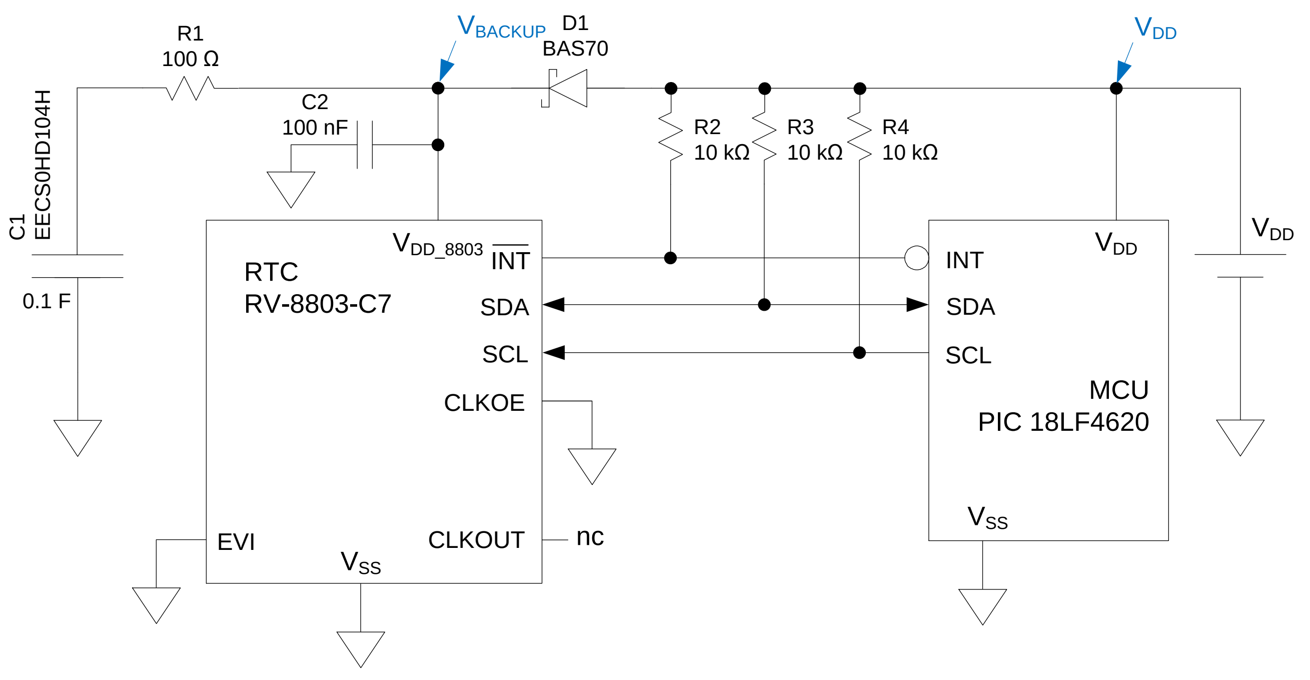


*) Source: Panasonic “Gold Capacitors ABC0000PE103_TechnGuide_Oct 1st 2014”

3.2. Application diagram

During V_{DD}-Operation the Supercap C1 will be charged through the Schottky-diode D1. The I²C-bus interface (SDA, SCL) and the interrupt signal ($\overline{\text{INT}}$) are accessible by the MCU.
In V_{BACKUP}-Operation, V_{DD} = 0 V, the RTC Module is only supplied by the Capacitor C1. The I²C interface and interrupt are not accessible, since the MCU is in power down mode. The RTC Module is fully functioning as long as V_{BACKUP} is ≥ 1.5 V. For longest autonomy the CLKOUT signal must be switched off. (CLKOE = 0 V). Power consumption derives now only from the operating current of the RTC Module, and the leakage currents of C1 and D_1.
As soon as V_{DD} is switched on again the RTC can be accessed and the Supercap C1 gets recharged.

Circuit diagram of the RTC Module RV-8803-C7 with back-up Supercap:



C1	Supercap e.g. EECS0HD104H (0.1 F, 5.5 V)
D1	Schottky-Diode BAS70
R1	100 Ω Resistor to limit the initial charging current
C2	100 nF capacitor for decoupling close to the RTC package
R2, R3, R4	The I²C-bus connections SCL and SDA, and the $\overline{\text{INT}}$ output have open drain configuration and require a pull-up resistor of typically 10 kΩ (active only during V_{DD}-Operation)
CLKOUT	Not used to minimize the current consumption (CLKOE connected to V_{SS})

3.3. V_{DD}-Operation

The voltages V_I and V_O at the inputs and outputs of the RV-8803-C7 must not exceed V_{BACKUP} at pin V_{DD_8803} by more than 0.3 V. Therefore a Schottky-diode with a low forward voltage drop of V_F = 0.3 V at 200 µA and +25°C is used.

3.3.1. Maximal inrush current

The Supercap does not per se require a dropping resistor. The current is just limited by the internal resistance R_{ESR} of the capacitor. The determined conditions for the largest current I_{C1max} (Worst-Case) are: R_{ESR} of the Supercap, at maximum Voltage V_{DD} = 5.5 V and maximum ambient temperature T_A = 70°C. If needed R1 can be used for further limiting the inrush current I_{C1max} (R_{ESR} + R1).

Resistor R1 may be necessary to limit the current:

- To protect the Schottky-diode. The max current for the BAS70 (D1) Schottky-Diode I_{Fmax} = 70 mA
- If the DC/DC-Converter or voltage regulator of the main supply is not capable of delivering sufficient current.

3.3.2. Charging current of the Supercap

The charging current depends on the maximum possible voltage V_{BACKUP} and the forward voltage V_F of the Schottky-diode. The charging current is the sum of the current for charging the ideal capacitor and its leaking current though the isolation resistance R_{ISO}. The current will therefore never be zero. The charging current after 24 hours of a 0.1 F Supercap at 25°C will be in the order of IC1= 0.9 µA, the VF will drop to 0.2 V.
Expected charging current I_{C1} after long time charging with V_{DD} = 5.5 V, 20°C:

C1	Charging current I_{C1}	
	After 24 hours	After 100 hours
0.1 F	0.9 µA	0.3 µA
0.47 F	1.8 µA	0.5 µA
1.0 F	3 µA	0.8 µA

3.3.3. Internal resistance of the Supercap

The internal resistance of the Supercap influences:

- The inrush current
- The charging and discharging time of C1 after V_{DD} is turned on
- The voltage drop during V_{BACKUP}-Operation

The estimation of the max inrush current depends on the smallest internal resistance R_{ESR} of the fresh (not aged) Supercap. Suppliers specify it as ESR = Equivalent Series Resistance, measured at 1 kHz.

Smallest internal resistor R_{ESR}:

C1	R_{ESR}		
	T_A = -20°C	T_A = +25°C	T_A = +70°C
0.1 F	110 Ω	30 Ω	25 Ω
0.47 F	40 Ω	10 Ω	9 Ω
1.0 F	40 Ω	10 Ω	9 Ω
Source: Panasonic “Gold Capacitors ABC0000PE103_TechnGuide_Oct 1st 2014”			

To estimate the longest charging time of the uncharged Supercap C1 after V_{DD} is applied, the internal DC-resistance $R_{DC} \approx R_{ESR}$ and the subsequently calculated serial resistor R1 are relevant. The shortest discharge time is not of importance since it would only apply if V_{BACKUP} is shorted.

For the time constant T:

$$T = (R_{DC} + R1) * C1$$

Longest charging time t expressed as a factor of T:

C1	R_{DC}	R1	t = T ($V_{BACKUP} \approx$ 63%)	t = 5*T (V_{BACKUP} > 99%)
0.1 F	75 Ω	100 Ω	18 s	88 s
0.47 F	30 Ω	100 Ω	61 s	306 s
1.0 F	30 Ω	100 Ω	130 s	650 s

The largest voltage drop across the Supercap depends on its internal resistance and the limiting resistor R1 during V_{BACKUP}-Operation. Relevant are also the largest load current and largest internal resistance $R_{DC} \approx R_{ESR}$, the max current of the RTC Module $I_{DD\_8803max}$ and the maximum leakage current I_{D1_Lmax} of the Schottky-diode.

Largest voltage drop V_{C1max}:

$$V_{C1max} = (I_{max}) * (R_{DCmax} + R1)$$

$$V_{C1max} = (I_{DD\_8803max} + I_{D1\_max}) * (R_{DCmax} + R1)$$

With C1 = 0.1 F:

$$V_{C1max} = (350\text{ nA} + 110\text{ nA}) * (75\ \Omega + 100\ \Omega) = \underline{\underline{0.08\text{ mV}}}$$

With C1 = 0.47 F and 1.0 F:

$$V_{C1max} = (350\text{ nA} + 110\text{ nA}) * (30\ \Omega + 100\ \Omega) = \underline{\underline{0.06\text{ mV}}}$$

This shows the max voltage drop V_{C1max} is negligible and therefore will not be considered in the following calculations (V_{C1} = 0 V).

3.3.4. Dimensioning of R1

Worst-case: $V_{DD} = 5.5$ V, $T_A = 70$°C
Schottky BAS70: At $I_{Fmax} = 70$ mA and $T_A = 70$°C: $V_F = 0.9$ V
→ Max inrush current: $I_{C1max} = 70$ mA

$$I_{C1max} = \frac{V_{DD} - V_F}{R_{ESR} + R_1}$$

Necessary limiting resistor R1:

$$R_1 = \frac{V_{DD} - V_F}{I_{C1max}} - R_{ESR}$$

EECS0HD104H (0.1 F, 5.5 V, Series SD):

$$R_1 = \frac{5.5\text{ V} - 0.9\text{ V}}{70\text{ mA}} - 25\ \Omega = 41\ \Omega$$

R1 selected = 100 Ω

EECS5R5H474 (0.47 F, 5.5V, Series SG) and EECS5R5V105 (1.0 F, 5.5 V, Series SG):

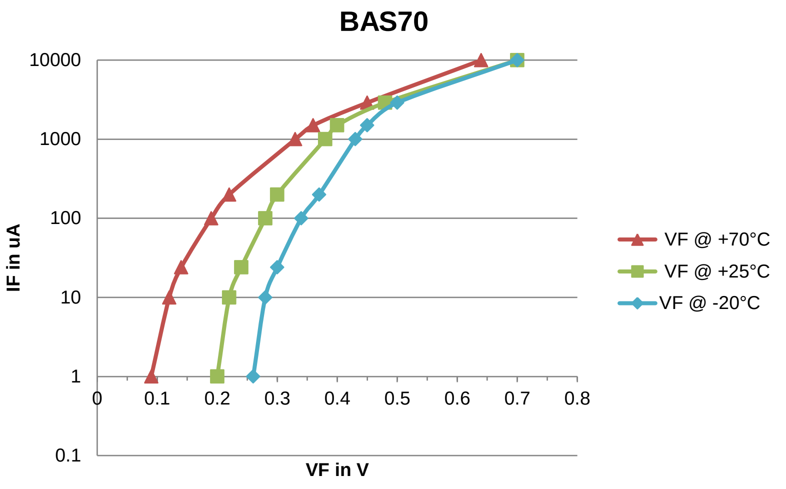
$$R_1 = \frac{5.5\text{ V} - 0.9\text{ V}}{70\text{ mA}} - 9\ \Omega = 57\ \Omega$$

R1 selected, also = 100 Ω

3.3.5. Schottky-Diode

BAS70 is a Schottky-diode with very small leakage current and the preferred small forward voltage drop V_F. When for example the charging current for the 0.1F Supercap has dropped after 24 hours to 0.9 µA, the resulting V_F is then reduced to just 0.2 V.

Schottky-Diode BAS70 V_F vs. I_F:

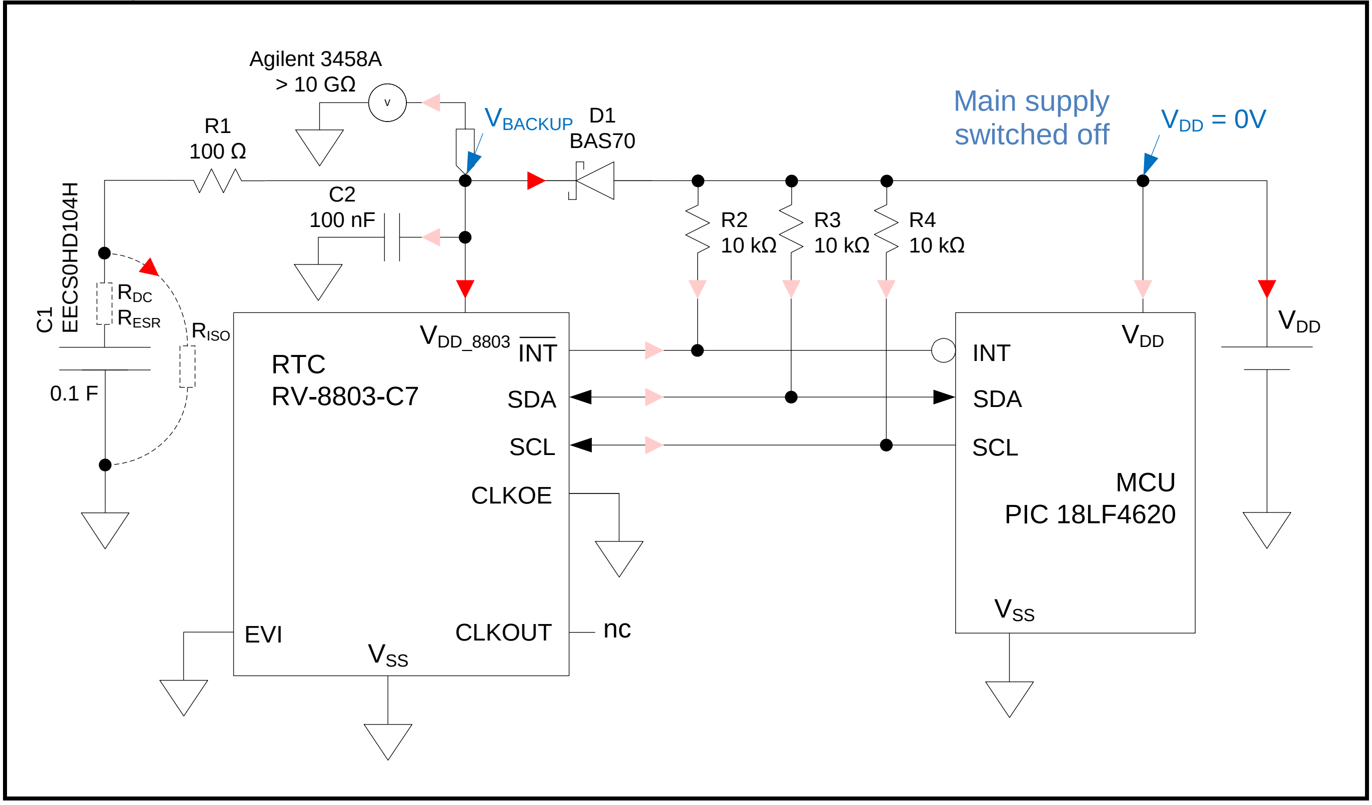


3.4. V_{BACKUP}-Operation

As soon as V_{DD} is switched off (goes to 0 V) the Supercap is taking over automatically and supplies the power to the RTC Module RV-8803-C7. The starting value of V_{BACKUP} depends on the originally applied voltage V_{DD} and the voltage drop across the Schottky-diode $V_{F.}$ V_{BACKUP} however depends also on the charging level of the capacitor and the ambient temperature.

During V_{BACKUP}-Operation the Supercap is discharged by the sum of the 3 currents: operating current of the RTC Module RV-8803-C7 and the two leakage currents of the capacitor and of the Schottky-diode.
To monitor the discharge voltage it is advised to use a high impedance meter such as an Agilent 3458A multimeter. At the 10V range it features an internal resistance of >10 GΩ. This adds a negligible discharge current of <0.55 nA at 5.5 V.

V_{BACKUP}-Operation:



3.4.1. Verification of the time tracking accuracy

The verification of the correct time of the RTC Module cannot be tested with the above circuit during V_{BACKUP}-Operation (time keeping). V_{DD} must be switched on to activate the MCU for I²C-bus communication and interrupt.

Procedure:

1. V_{DD}-Operation:
    a. Charging the Supercap
    b. Start measurement of V_{BACKUP} with Agilent 3458A (>10 GΩ) and recording with e.g. VEE Pro software. (V_{BACKUP} and reference-time)
    c. RTC initialization via I²C-bus interface (time, date and setting all flags to 0)
2. V_{DD} is switched off:
    a. Circuitry is in V_{BACKUP}-Operation (time keeping)
3. If e.g. $V_{BACKUP} \leq 1.5$ V:
    a. Turn on V_{DD}
    b. Read RTC-time and the flags F1V and F2V via I²C-bus
    c. If the flags F1V and F2V are still at 0, the RTC Module was operating continuously during the back-up time. The read RTC-time can now be compared with the reference time.

Hint:

The circuit can be adapted such that the RTC-time can be monitored with little impact to the back-up time.

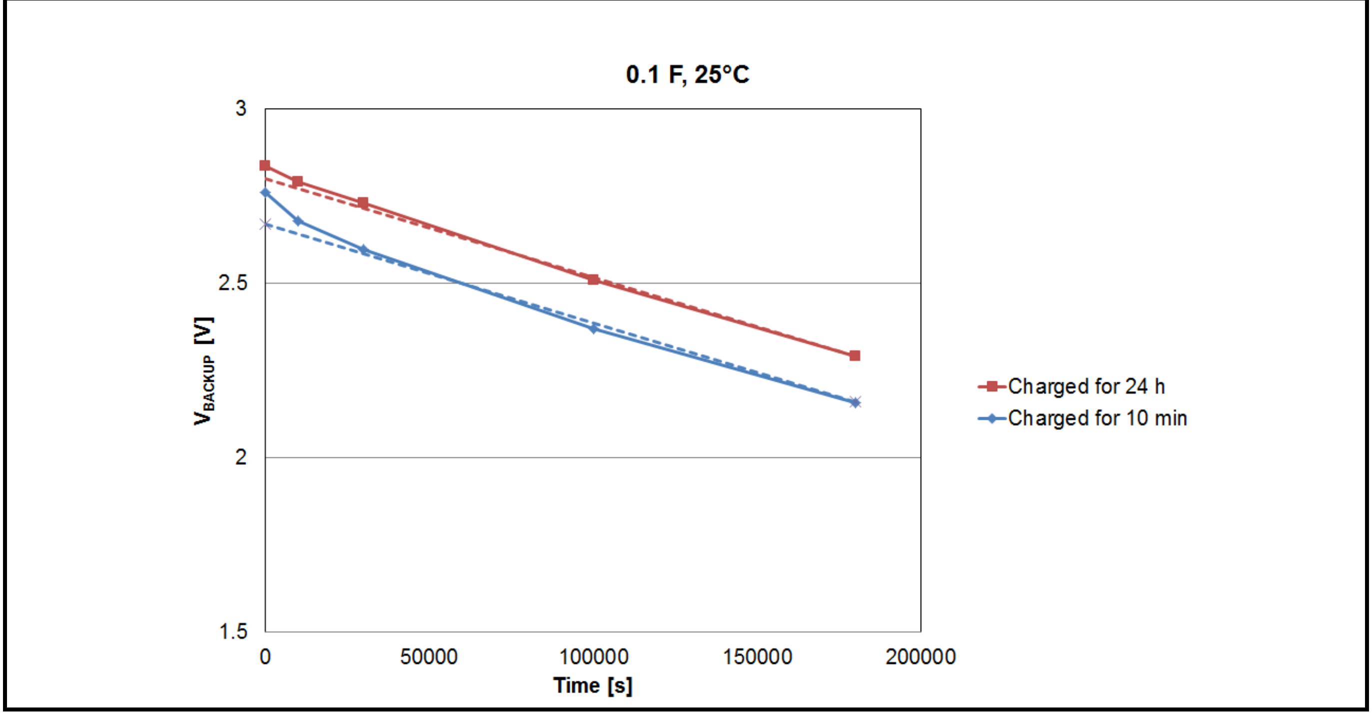
1. Increase pull-up resistor R2 to 100 kΩ. Connect it between the RTC-Pin $\overline{\text{INT}}$ and the cathode of the Schottky-diode (Pull-up to V_{BACKUP})
2. Cut the $\overline{\text{INT}}$ connection to the PIC, since the input impedance of the PIC pin is only 25kΩ
3. Program One-minute-interrupt (pulse duration 15.6 ms)
4. With the help of a high impedance probe (e.g. HIP101, input impedance: $10^{12}\Omega$ 0.1 pF input capacitance typ. 0.3 pA, max. 1 pA) the interrupt signal can be used to measure the period with a Timer/Counter.

The average current consumption of this circuitry with V_{BACKUP} = 3 V and 25°C is increased by only ≈ 9 nA (derived from the leakage current and the 15.6 ms pulse on the RTC-pin $\overline{\text{INT}}$).

3.4.2. V_{BACKUP} discharge characteristic

The application circuit includes also the test setup for measuring the discharging characteristic of the capacitor at V_{BACKUP}.

V_{BACKUP} discharging behavior with 0.1 F, 25°C, charging condition V_{DD} = 3.0 V, charging times 10 min and 24 hours:



After a long charging time (24 h) a very small charging current of 1 µA is present. (This is almost independent of the size of C1 and V_{DD}). Across the Schottky-diode we reach the low V_F.
After a short charging time (10 min) the Supercap is not fully charged (inhomogeneity of double layer capacitor structure) a significantly larger charging current is flowing through the Schottky-diode (up to some mA). The increased forward voltage V_F and the missing part of the charge voltage of C1 can be replaced by a constant term in the equation. In addition to the forward voltage V_F the correction voltage V_K must be subtracted from V_{DD}.

For the starting voltage V_0 in V_{BACKUP}-Operation results:

$$V_0 = V_{DD} - V_F - V_K$$

Forward voltage V_F in function of the charging time:

Charging time	V_F		
	T_A = -20°C	T_A = +25°C	T_A = +70°C
24 hours	0.25 V	0.2 V	0.1 V
10 minutes			

Correction voltage V_K in function of the charging time:

Charging time	V_K
24 hours	0 V
10 minutes	0.13 V

3.4.3. Leakage current of Supercaps

It is beneficial to determine the isolation resistance R_{ISO} of the Supercap. This way the average leakage current I_{C1_L} can be calculated for any average back-up supply voltage $\varnothing V_{BACKUP}$. The isolation resistance R_{ISO} decreases with rising temperature. It can be calculated with the help of the suppliers' specified discharge characteristics, or based on bench tested parameters:

$$R_{ISO} = \frac{t_2 - t_1}{C1 \quad * \ln\left(\frac{U_2}{U_1}\right)}$$

Procedure with help of the measured voltage discharge characteristics:

1. Determine the capacity of C1 by discharging the capacitor with a constant current I_{CONST} (1 mA/F as reference):
$$C1 = I_{CONST} * \frac{t_2 - t_1}{U_1 - U_2}$$
2. Acquire data for the discharge characteristics (no load)
3. Calculate R_{ISO}

The average leakage current I_{C1_L} is now calculated based on R_{ISO} and the average back-up voltage $\varnothing V_{BACKUP} = (V_0 + V_1) / 2$

$$I_{C1\_L} = \frac{\varnothing V_{BACKUP}}{R_{ISO}}$$

Example:

Charging conditions:

- $T_A = +25°C$
- $V_{C1} = 5$ V, 24 hours with C1 = 0.1 F,
- $t_1 = 0$ s, $t_2 = 100$ hours = 360'000 s, $U_1 = 5$ V, $U_2 = 4.47$ V:

$$R_{ISO} = -\frac{360'000 \text{ s} - 0 \text{ s}}{0.1 \text{ F} * \ln\left(\frac{4.47 \text{ V}}{5 \text{ V}}\right)} = 32'129 \text{ k}\Omega$$

The average leakage current is calculated for the average back up voltage

$$\varnothing V_{BACKUP} = (2.8 \text{ V} + 1.5 \text{ V}) / 2 = 2.15 \text{ V}:$$

$$I_{C1\_L} = \frac{2.15 \text{ V}}{32'129 \text{ k}\Omega} = \underline{\underline{67 \text{ nA}}}$$

Isolation resistance R_{ISO}:

Charging conditions	C1	R_{ISO}		
		T_A = -20°C	T_A = +25°C	T_A = +70°C
V_{C1} = 5 V, 24 hours	0.1 F	178'000 kΩ (*)	32'100 kΩ	4'310 kΩ
	0.47 F	133'084 kΩ (*)	24'000 kΩ (*)	3'222 kΩ (*)
	1.0 F	74'305 kΩ (*)	13'400 kΩ	1'799 kΩ (*)
Data from Panasonic "Gold Capacitors ABC0000PE103_TechnGuide_Oct 1st 2014" (*) Missing values were calculated by linear interpolation or extrapolation				

Average leakage currents I_{C1_L} at different average backup voltages $\varnothing V_{BACKUP}$:

$\varnothing V_{BACKUP}$	C1	I_{C1_L}		
		T_A = -20°C	T_A = +25°C	T_A = +70°C
(2.8 V + 1.5 V) / 2 = 2.15 V (V_{DD} = 3.0 V, 24 hours)	0.1 F	12 nA	67 nA	499 nA
	0.47 F	16 nA	90 nA	667 nA
	1.0 F	29 nA	160 nA	1195 nA
(5.3 V + 1.5 V) / 2 = 3.4 V (V_{DD} = 5.5 V, 24 hours)	0.1 F	19 nA	106 nA	789 nA
	0.47 F	26 nA	142 nA	1055 nA
	1.0 F	46 nA	254 nA	1890 nA

3.4.4. Current consumption RV-8803-C7

To be considered: The RTC Module RV-8803-C7 performs one temperature measurement every second. For a short pulse of 1.3 ms the supply current $I_{DD\_8803\_PULS}$ will be increased to some 19 µA. To take an accurate measurement the current must be integrated over one second.

Typical current consumption I_{DD_8803} of the RTC Module RV-8803-C7:

$\varnothing V_{BACKUP}$	I_{DD_8803}		
	T_A = -20°C	T_A = +25°C	T_A = +70°C
1.5 V	195 nA	235 nA	330 nA
2.15 V	200 nA	240 nA	335 nA
3 V	200 nA	240 nA	345 nA
3.4 V	200 nA	245 nA	350 nA
5.5 V	210 nA	250 nA	360 nA

3.4.5. Leakage current of the Schottky-Diode

Typical leakage current I_{D1_L} of the Schottky-Diode BAS70:

$\varnothing V_{BACKUP}$	I_{D1_L}		
	T_A = -20°C	T_A = +25°C	T_A = +70°C
2.15 V	0.03 nA	1.3 nA	47 nA
3.4 V	0.05 nA	2 nA	75 nA
5 V	0.07 nA	3 nA	110 nA

3.4.6. Back-up time calculation

The standard formula to calculate the discharge time of a capacitor assumes a constant current is applied. The total current is the sum of the operating current of the RTC plus the leakage currents of the Schottky-diode and the Supercap. The average back-up voltage is $\varnothing V_{BACKUP} = (V_1 + V_0)/2$.

Example:
Supercap C1 = 0.1 F (EECS0HD104H), $V_{DD} = 3.0$ V, $T_A = 25$°C, after charging it for 24 hours.

$$t = \frac{C_1 * (V_0 - V_1 - V_{C1})}{I}$$

$$t = \frac{C_1 * (V_{DD} - V_F - V_K - V_1 - V_{C1})}{I_{C1\_L} + I_{DD\_8803} + I_{D1\_L}}$$

$$t = \frac{0.1\text{ F} * (3.0\text{ V} - 0.2\text{ V} - 0\text{ V} - 1.5\text{ V} - 0\text{ V})}{67\text{ nA} + 240\text{ nA} + 1.3\text{ nA}} = \underline{\underline{421'711\text{ seconds}}}$$

$$= 117 \text{ hours}$$

$$= \underline{4.9\text{ days}}$$

Parameter		Details and example values
t = back-up time in seconds, target value to calculate		
C1 = capacity in Farad		C1 = 0.1 F
T_A = ambient temperature		$T_A = 25$°C
V_{DD} = main power supply		$V_{DD} = 3.0$ V
V_0 = starting voltage , $V_{BACKUP} = V_0$		$V_0 = V_{DD} – V_F – V_K$
	V_F = forward voltage of the Schottky-Diode	
	V_K = correction voltage	after charging for 24 hours $V_K = 0$ V
V_1 = final voltage after back-up time t, $V_{BACKUP} = V_1$		$V_1 = 1.5$ V (V_{DD_MIN} of RV-8803-C7)
V_{C1} = voltage drop across internal resistance R_{DC} (ca. R_{ESR}) and current limiting resistor R1. Negligible.		$V_{C1} = (I_{DD\_8803} + I_{D1\_L}) * (R_{DC} + R1)$ $\rightarrow V_{C1} = 0$ V
$\varnothing V_{BACKUP}$ = average back-up voltage V		$\varnothing V_{BACKUP} = (V_0 + V_1)/2$ (used to calculate the currents)
I = constant discharging current in A		$I = I_{C1\_L} + I_{DD\_8803} + I_{D1\_L}$
	I_{C1_L} = average leakage current of the Supercap	$I_{C1\_L} = \varnothing V_{BACKUP} / R_{ISO}$
	I_{DD_8803} = average power consumption of the RTC Module RV-8803-C7	
	I_{D1_L} = average leakage current of the Schottky-diode	

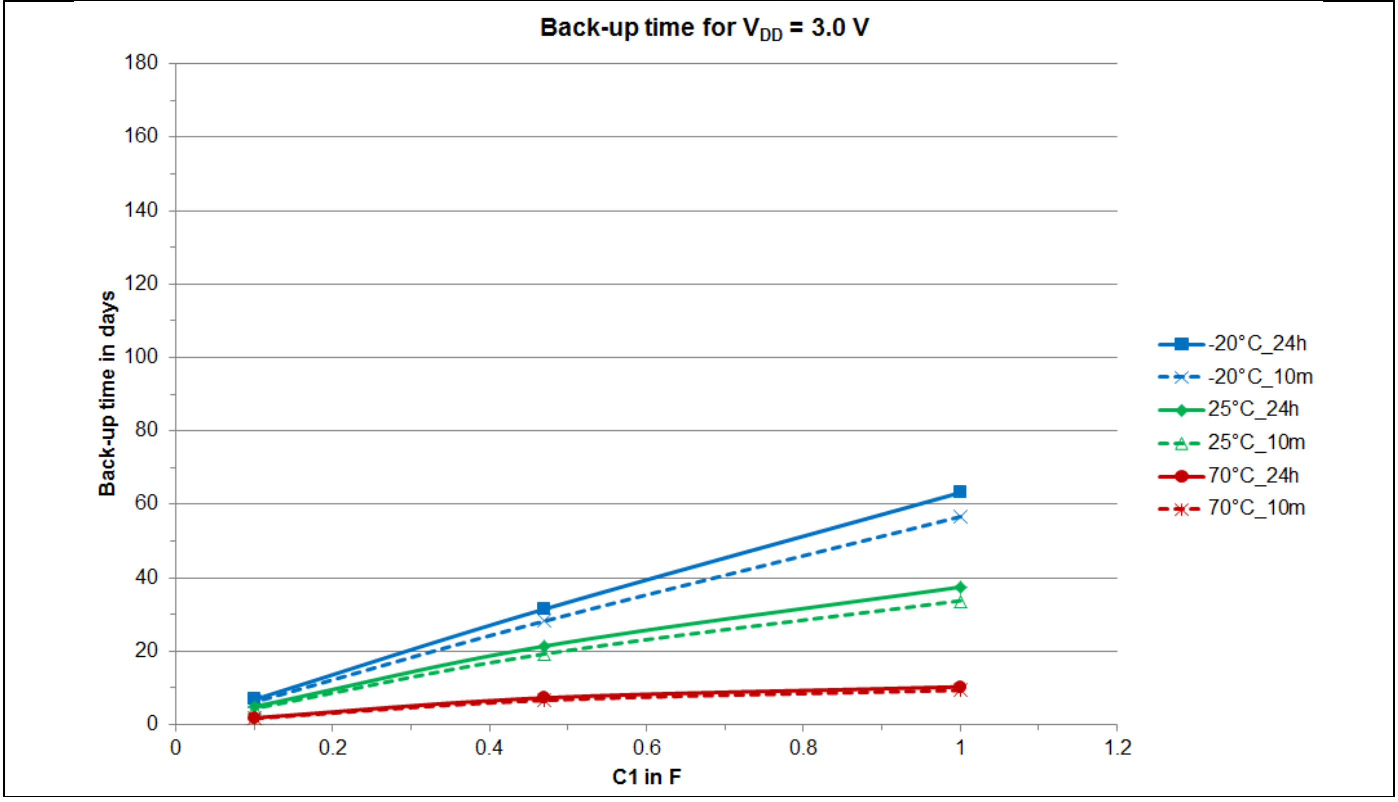
3.4.7. Buffered back-up time

Back-up time as function of capacitor size, C1 (0.1 F, 0.47 F, 1 F), charge time of the Supercap (10 minutes or 24 hours), ambient temperature (-20°C, 25°C, 70°C) and the operating voltage V_{DD} (3.0 V, 5.5 V).

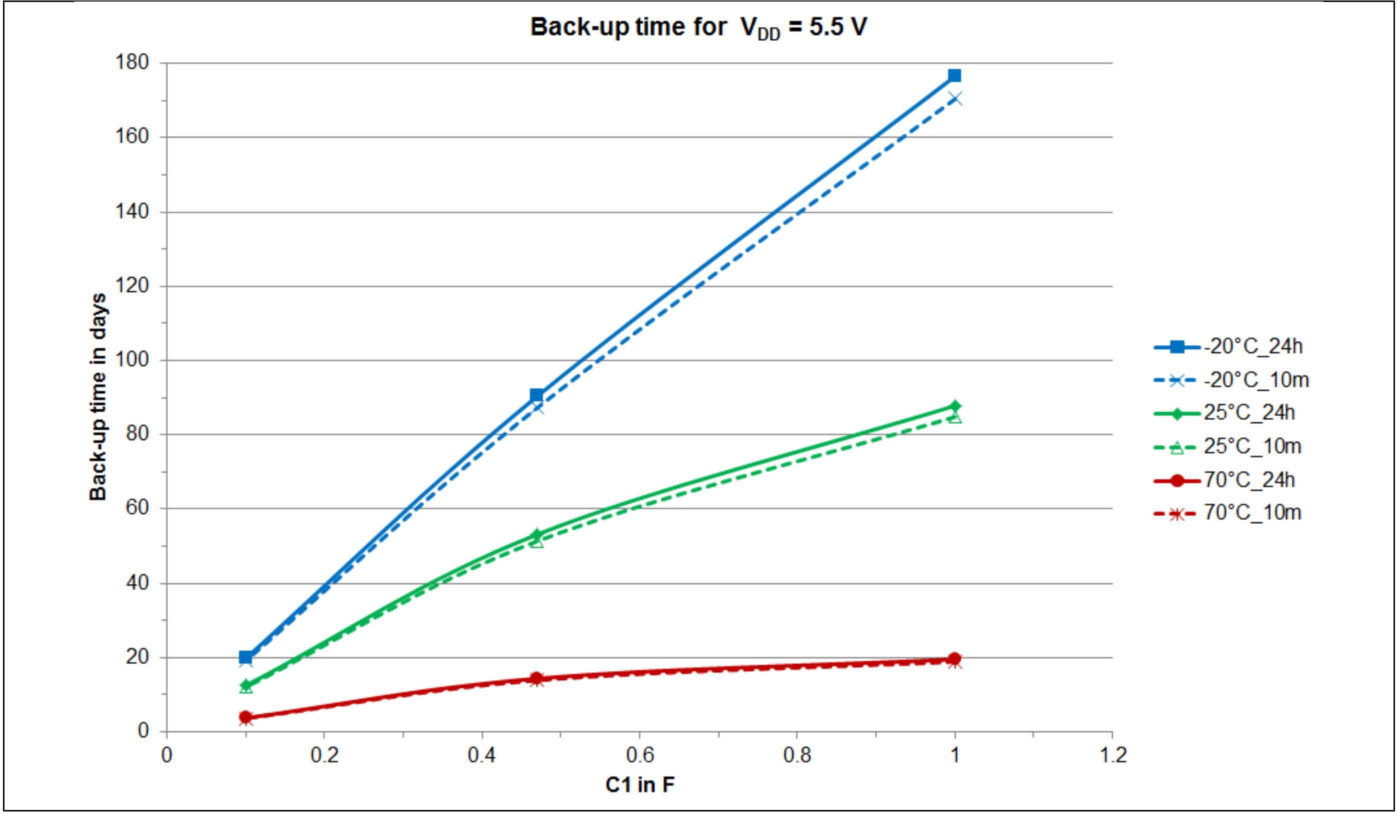
Backup-time in days:

T_A	C1	V_{DD} = 3.0 V		V_{DD} = 5.5 V	
		Charged 10 min	Charged 24 h	Charged 10 min	Charged 24 h
-20°C	1.0 F	57	63	170	177
	0.47 F	28	31	87	90
	0.1 F	6.1	6.8	19	20
+25°C	1.0 F	34	37	85	88
	0.47 F	19	21	51	53
	0.1 F	4.4	4.9	12	12
+70°C	1.0 F	9	10	19	20
	0.47 F	6.6	7.3	14	14
	0.1 F	1.7	1.8	3.6	3.7

Graphic chart back-up time in function of size of the Supercap (V_{DD} = 3.0 V):



Graphic chart back-up time in function of size of the Supercap (V_{DD} = 5.5 V):



4. Conclusion

It is the exceptionally low power consumption of the Micro Crystal RTC Module RV-8803-C7 that allows the industry, for the first time, to implement user friendly Supercaps as the back-up power supply.

The resulting prolonged back-up times that are realized by implementing the proposed solution are very beneficial for many different applications. Since the impact of the key factors, leakage currents, ambient temperatures and voltage ranges can be quantified, the desired minimum time of available power back-up can be determined by selecting the correctly sized Supercap.

All the tests and measurements discussed in this paper were conducted using actual hardware. The goal was to identify the different leakage currents and to make sure the calculated back-up times for the selected capacitor sizes corresponded with the actual results.

Low cost RTC back-up solutions utilizing minimal PC-board area and requiring little BOM impact, can now be designed-in simply by using a Supercap, a Schottky-diode, and the RTC Module RV-8803-C7 manufactured by Micro Crystal.

5. Document version

Date	Version #	Changes
Juni 2015	0.90	Erster Entwurf in English
Juni 2015	0.91	Geändert Wort Anwender Entfernt Kapazitätsbereich Ergänzt erste Schaltung Ergänzt IC1_Lmax und IDD_8803max Ergänzt Schottky BAS70 Vereinfacht zweite Schaltung Separiert Beispiel Leckstrom des Superkondensators Ergänzt Stromverbrauch RV-8803-C7 Vereinfacht Berechnung der Backup-Zeit Vereinfacht Backup-Zeiten
August 2015	0.92	Geändert, „der RTC“ zu „die Echtzeituhr“ und „das RTC-Modul“ Kleine Änderungen in Satzstellungen
September 2015	0.93	Hinzugefügt: Autor Kleine Textänderungen Ergänzt Verwendete Superkondensatoren Ergänzt Überwachung der RTC-Zeit mit abgeänderter Schaltung Geändert Darstellung der Backup-Zeiten (neu: 3.0 V / 5.5 V)
December 2015	1.0E	English version