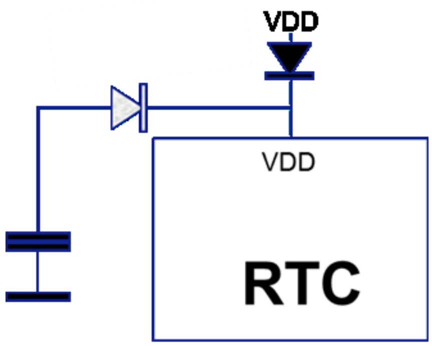
Realtime-Clock Modules with Power-Switch Function

Stefan Hartmann
Department Manager QD
Epson Europe Electronics GmbH

Introduction:
Realtime-Clock Modules are used in a big variety of applications to keep the time information even the main processor and system is not fully operating i.e. to save power. This fact logically leads to an increasing need for Realtime-Clock Modules with built in Power-Switch function to avoid the need of external circuits to perform the switch from the main power supply to the backup power supply ones the main supply is off.
This paper explains different implementations of Power-Switch Functions with its specialties and features.

Discrete Power-Switch function:

There are different ways to generate a basic battery backup function using conventional RTCs, every one of them however having its own characteristics and limitations. The easiest way to implement a battery backup function is, by adding a diode into the RTCs main power supply patch and in case of using a non-rechargeable battery as backup an additional diode between the backup battery and the RTCs main supply.

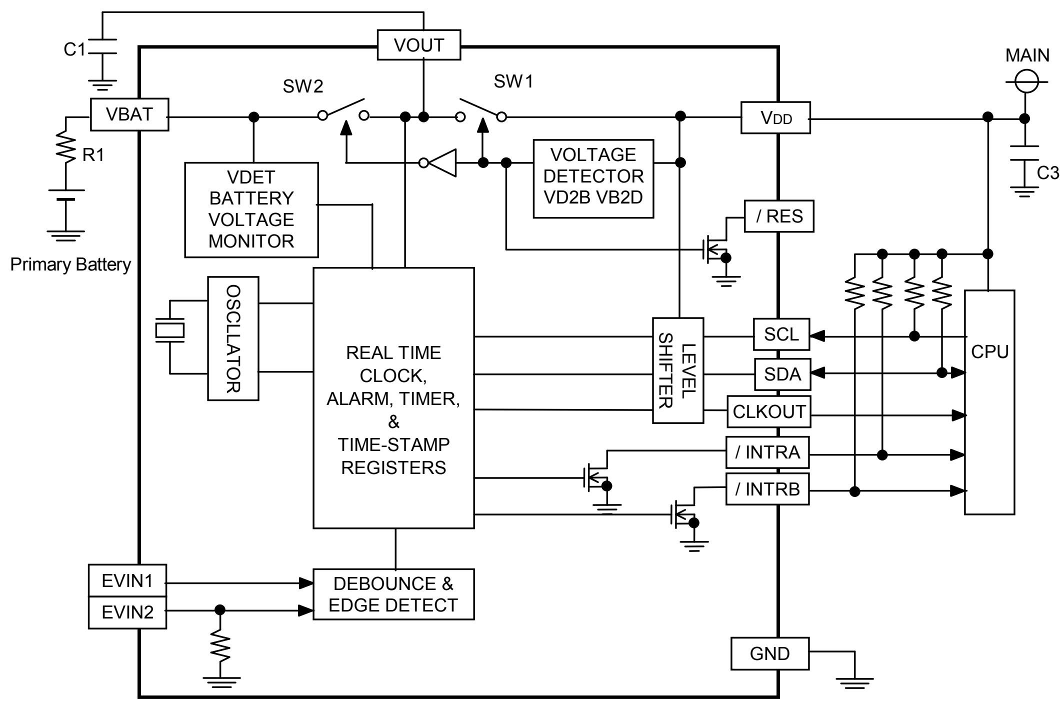


Picture 1: Basic Battery-Backup implementation

Ones the main supply voltage is falling, the backup battery will supply the RTC and thus discharges together with the main supply. In case VDD is either on or off (i.e. when supplying it from a mains supply), this is OK, but in case VDD is connected to a primary battery, this would mean that the backup battery would be discharged at the same rate than the main supply. As a result, there will not be enough charge left in the backup battery to secure functionality of the RTC for a long time in backup mode. A further limitation of this circuit is that the main supply, and in case of a non-rechargeable battery as well the backup battery, is connected to the RTC only via a diode and thus the usable voltage is lowered by the diodes forward voltage of about 0.4V or higher. The light grey diode would limit the usable time in backup mode and the solid diode would cause the RTC supply voltage to be lower than the one of the other electronics like the MCU, which might cause a problem with the Interface between the RTC and MCU as both would be running on different supply voltages. In order to keep these limitations small, the selected diode should have the smallest possible forward voltage (and thus min. voltage drop) but at the same time the lowest possible

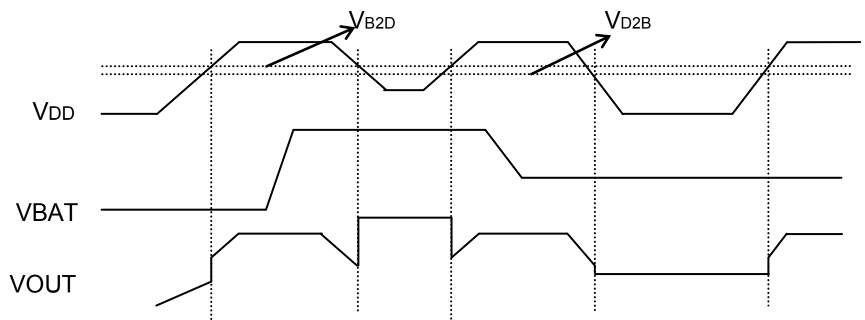
reverse current (as this would cause the backup supply to discharge into the system power supply) which are contra directional requirements.
In order to overcome these limitations, Epson has developed a whole range of RTC Modules with Power-Switch functions optimized for different power supply and backup options.

Power-Switch for primary batteries as backup supply (i.e. RX-x035):
Epson's RX-x035 series RTC Modules represent one possible integration of the Power-Switch function by using 2 switches, one between the main supply and another one between the backup supply and the internal supply voltage of the RTC. This solution is optimized for a backup supply using a primary battery, which does not need to be charged via the RTC Module.



Picture 2: Block diagram of Epson's RX-8035 RTC Module with Power-Switch function

The 2 switches SW1 and SW2 are used to assure that the backup battery never charges the main supply and thus "wastes" energy needed for the maximum backup time. For this purpose it is necessary to assure that SW1 and SW2 are never switched on at the same time. Consequently, this means that the internal supply of the RTC connected to the VOUT-pin is neither supplied via VDD nor via VBAT for a short time when switching between main and backup supply. To secure the supply of the RTC Module for this short time period, it is necessary to connect a capacitor to the VOUT-pin. The capacitor C1, which is connected to VOUT, will be charged via SW1 during normal operation. Ones the main supply drops, C1 will discharge over SW1 and VDD into the systems power supply till the supply voltage drops to the switching threshold (VD2B) at which the Voltage Detector will cause SW1 to open and SW2 to close. Even when using only a 0.1µF capacitor at the C1 position, this capacitor will have enough charge remaining to secure the RTCs voltage supply for the short switching period. As C1 will be quite discharged at the time SW2 closes, there is a rapid voltage swing from about VD2B to the voltage of the backup supply VBAT, which would cause the backup supply to charge C1 and thus suddenly cause a significant current to flow. The task of R1 is to limit this charge current into C1 to a reasonable level to protect the backup battery and capacitor. Picture 3 shows the different supply modes and relationships with VBAT and VOUT.



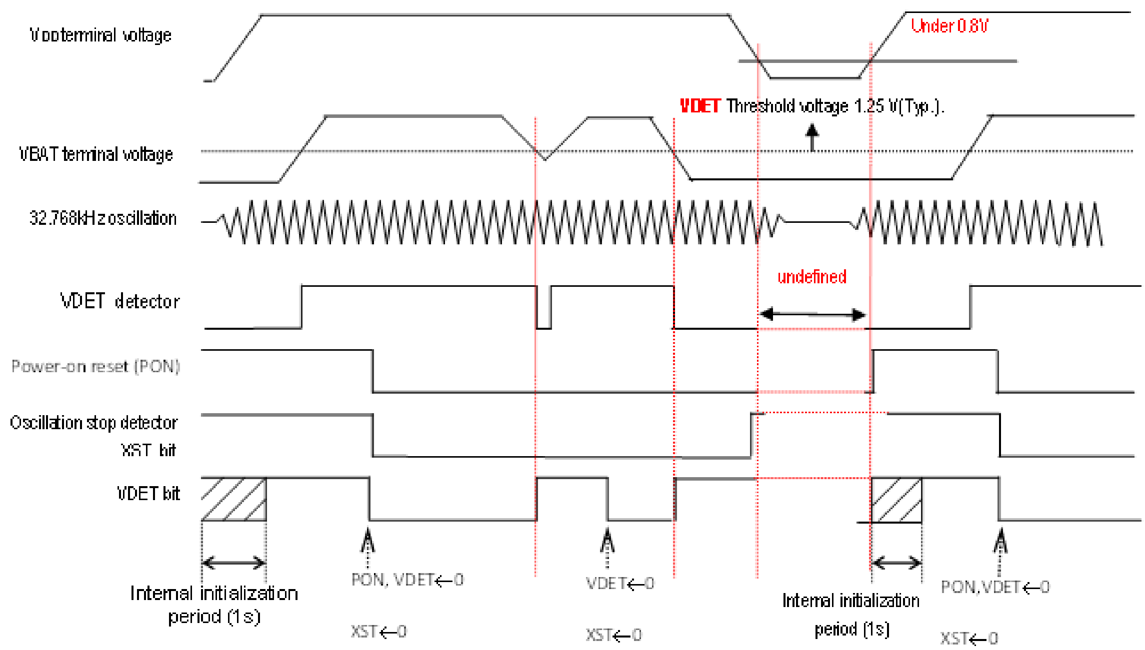
SW1	ON	ON	OFF	ON	OFF	ON
SW2	OFF	OFF	ON	OFF	ON	OFF
Status	I	II	III	II	III	II

Status	Explanations
I	When power is supplied from VDD only initially, VOUT voltage follows about 1/2 VDD voltage gradually before turn on internal circuits.
II	When VDD voltage is above VB2D, VOUT outputs VDD voltage.
III	When VDD is less than VD2B, VOUT is equal with VBAT.

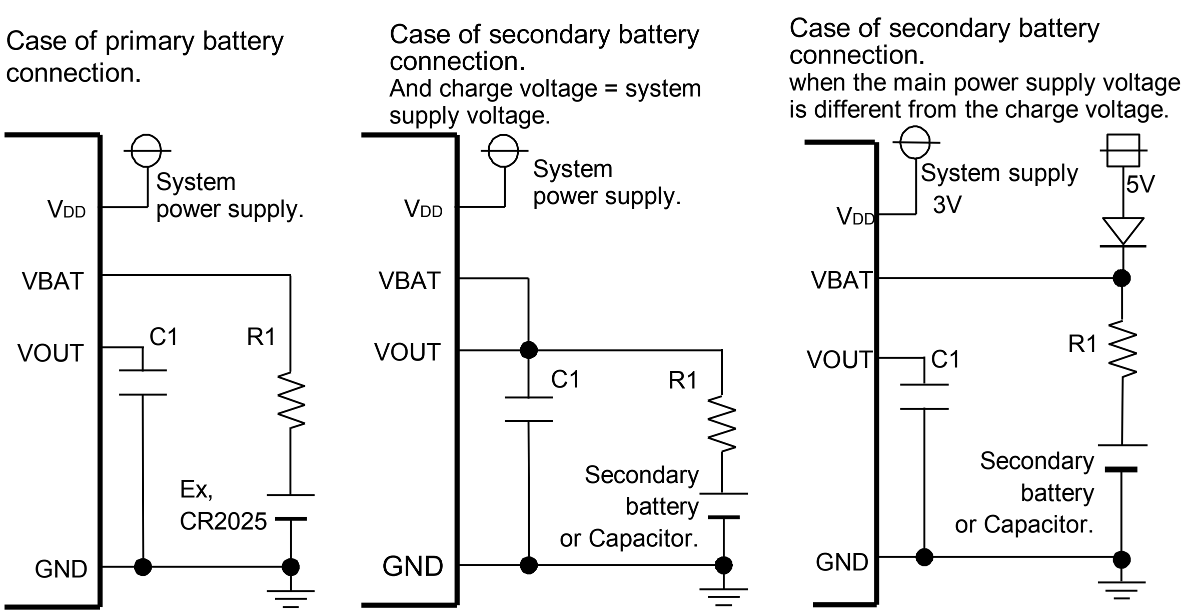
Picture 3: Supply voltage modes and relationship of VBAT, VDD and VOUT for RX-8035.

Beside the different supply voltage modes shown in Picture 3, the RX-8035 offers several register flags to indicate the status of the RTC and thus assure that the time indicated by the RTC Module is not compromised. This register flags indicate if the

- oscillation has stopped (“XSTP” in case of the RX-8035) and thus causing the RTCs time to be incorrect
- voltage detector has registered a voltage drop of the backup supply below the min. level (“VD2B” in case of RX-8035)
- power on reset and initialization started (“PON” in case of RX-8035), which is done in case both, the main and backup supply drop below the min. supply voltage and thus the internal RTC supply has not been assured. In this case, all registers will be reset and have to be initialized again by the systems CPU.

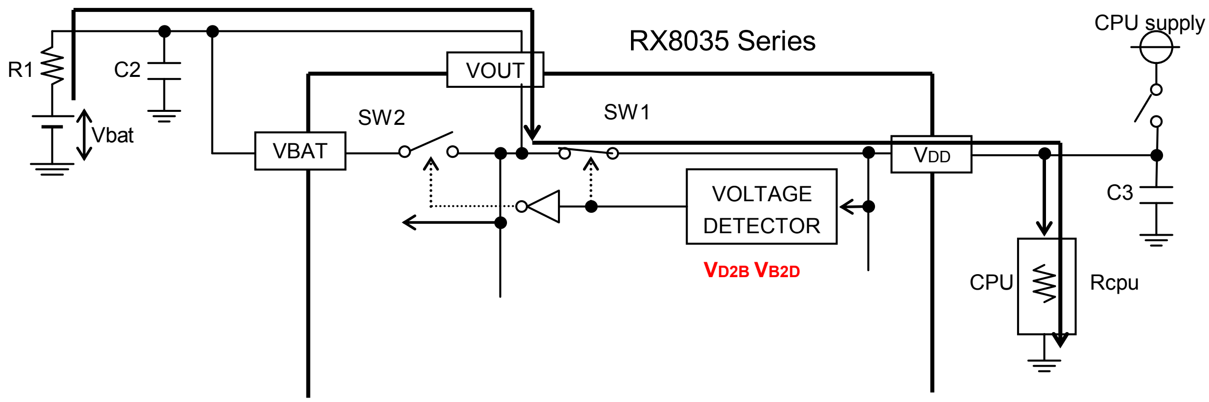


Picture 4: Diagram explaining function indicator flags of Epson's RX-8035 RTC Module with Power-Switch function



Picture 5: External Connection options for Epson's RX-8035 RTC Module with Power-Switch function for different power supply and backup media options

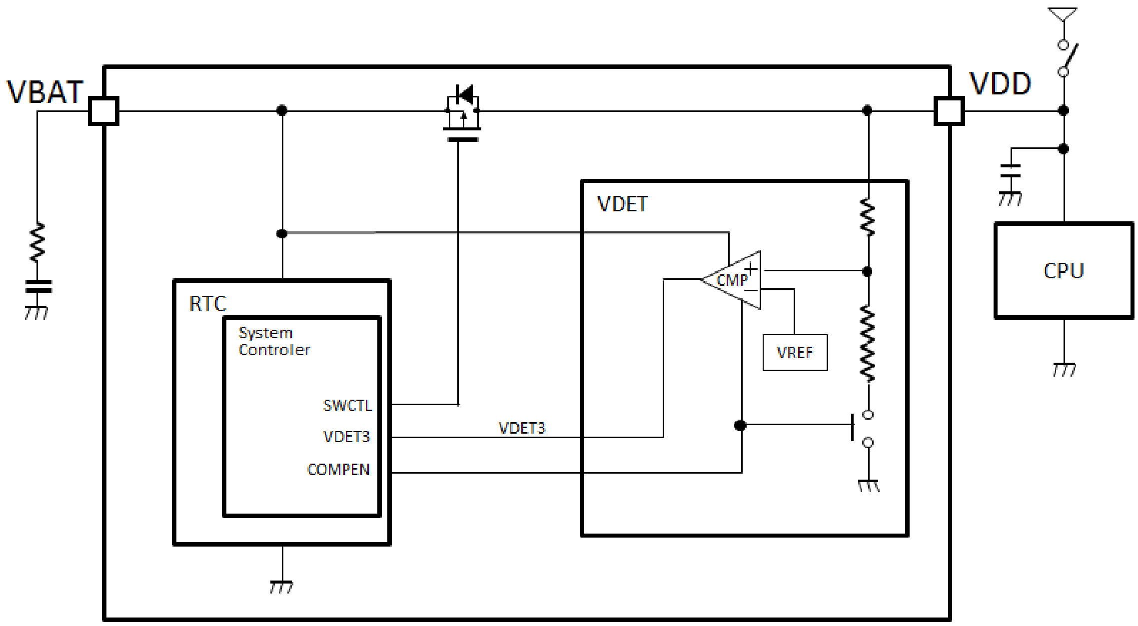
Picture 5 on the left side shows the external connections for a primary battery as backup supply which is the use case for which this type of Power-Switch function is optimized and designed for. While the Power-Switch realization with 2 switches is perfectly fitting the use of a primary battery as backup power supply, it would not perform well in case of using a capacitor or super cap as backup power supply. These devices would preferably be charged during normal operation, which RTCs with this type of Power-Switch function can’t perform unless connecting the backup supply to VOUT-pin as shown in the center of Picture 5. In this case VDD would charge the backup supply via SW1 and VOUT-pin. But as mentioned above, ones the main supply drops, the backup supply would supply the system and not only the RTC with power, unless the systems resistance on the supply line (Rcpu in picture 6) is very low compared to R1, so that the RTCs voltage detector sees a voltage below the detection threshold “VD2B”. The voltage seen by the RTCs voltage detector equals: R1 > Rcpu * ((VBAT – VD2B) / VD2B)



Picture 6: Circuit explaining the connection of a “chargeable” backup power supply to the VOUT-pin of RX-8035 RTC Module

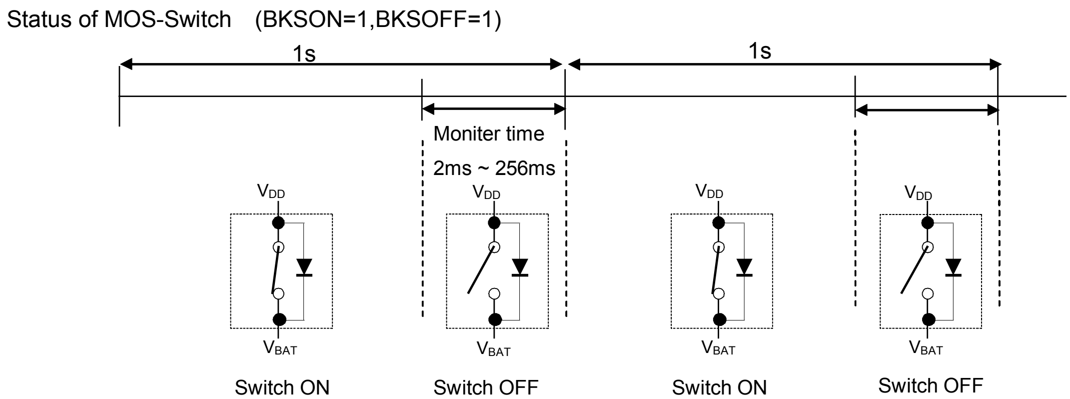
The connection diagram on the right side of Picture 5 shows how a rechargeable battery could be connected to this kind of RTC Module by not using the RTC itself for the charging function, but using some external circuit for this purpose. In this example the backup battery would be charged via the external diode with the advantage that the backup battery can be charged to a voltage even higher than the regular system supply voltage and thus reach longer backup times. As the RTCs interface and output pins are operated from the RTCs main supply VDD and not VBAT, they are not supplied in case of running the RTC in backup mode, so that it is not critical for the system that the RTCs internal supply voltage would be higher in backup-mode (when having charged the backup battery to a higher voltage than VDD) than the supply voltage of the MCU.

Power-Switch for rechargeable batteries, super caps, capacitors and the like as backup supply (i.e. RX6110 & automotive version RA8900):
Epsons RX6110 and RA8900 have been designed to overcome the limitations of before mentioned implementation of the Power-Switch function as far as the use of rechargeable batteries, super caps and capacitors is concerned. While the circuit of RX-xx35 series has some limitation for this use case, the RX6110 was optimized for the use on a power line supply (so a supply which does not discharge but is either fully up and running or not) as primary power source together with super caps, capacitors and other rechargeable batteries which do not need a specific charge control as backup supply.



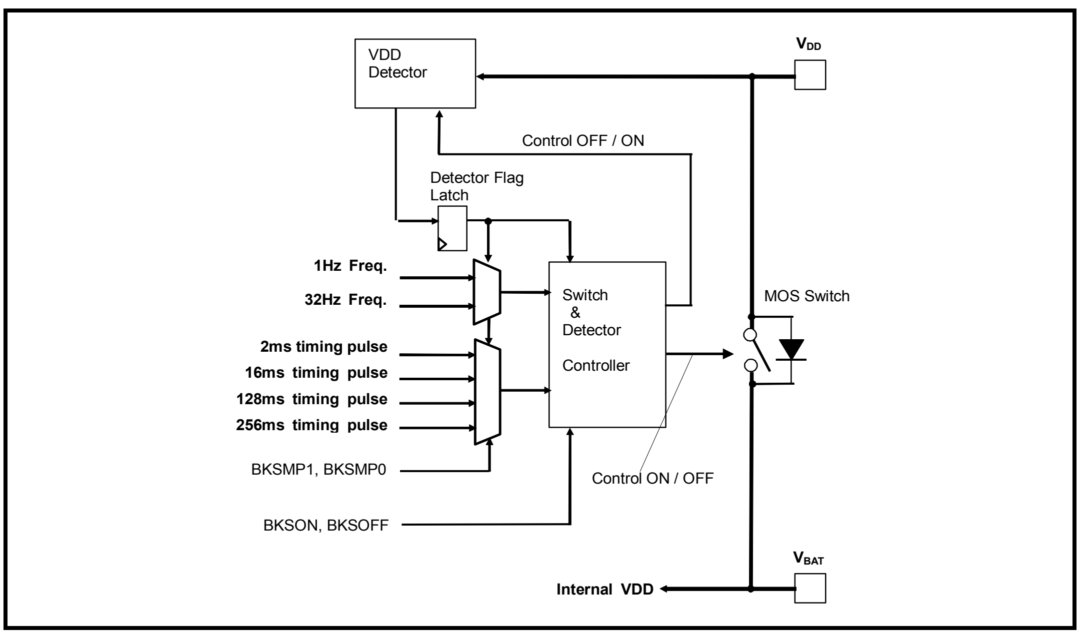
Picture 7: Circuit of the Power-Switch function inside RX6110

As shown in Picture 7, the realization of this Power-Switch function is done by means of a single low resistance MOS-switch with a parallel diode, both placed between the main supply VDD and the backup supply VBAT. The RTCs internal power supply is taken from VBAT and the task of the diode parallel to the MOS-switch is, to allow current to flow from the main supply to VBAT and the RTCs internal VDD even the MOS-switch is open, but avoid current to flow back into the main supply (as this would cause the backup battery to discharge faster by powering not only the RTC but as well other components on the circuit board). Reason for adding the MOS-switch is, that in case of using only the diode (able to handle a charge current up to about 30mA), there would be a voltage drop equal to the diodes forward voltage Vf from the main supply to VBAT. This would mean that the backup supply would not be charged to the max. available voltage and thus the time available in backup mode would be limited. By closing the MOS-switch this limitation can be overcome, as the Rson of the MOS-switch is extremely low, so that VBAT can be charged virtually up to VDD. In order to further extend the time available in backup mode, the RTC switches all I/O-ports and interrupts except IRQ1 to Hi-Z, which reduces the power consumption significantly. While the MOS-switch is closed, the backup supply would buffer the main supply, so that the voltage detector connected to the VDD input would not detect a voltage drop. This in turn means that the MOS-switch needs to open from time to time and thus disable the supply of VDD via VBAT to verify if VDD is still above the switching limit VDET-. The length of opening the MOS-switch to perform the VDD monitoring is controlled by the RTCs control bits BKSMP0 and BKSMP1 which allows setting VDD monitoring times between 2ms and 256ms (see Table 2). The length of the VDD monitoring time should be set in accordance to the “storage” capacity and load on the VDD-line, because it must be made sure that within this time VDD at the RTCs voltage detector falls below VDET- in case it is not actively supplied anymore from the primary power supply. The VDD monitoring is performed once per second in normal operation and once every 31.25ms in backup mode (while in backup mode the VDD monitoring time is fixed to 2ms). Picture 8 shows the MOS-switch position over 2 VDD monitoring cycles in normal operation mode of the RTC Module.



Picture 8: MOS-switch position over 2 VDD monitoring cycles in normal operation mode of the RX6110

In order to adopt the RX6110 to different use cases, it has a rather complex Power-Switch and MOS-switch control circuit, which is shown in Picture 7.



Picture 9: RX6110s MOS-switch control circuit allowing max. flexibility for all different use cases of power line supply on the primary input and rechargeable backup supply

The basic function of the MOS-switch and the VDD monitoring function are controlled by means of 4 bits in a control register of the RTC Module. “BKSON” and “BKSOFF” define if the MOS-switch should be always on, always off, or switched. Table 1 shows this different MOS-switch control setting options and their use cases.
Before mentioned registers BKSMP0 and BKSMP1 define if and how long the VDD voltage should be monitored within one measurement cycle. Table 2 shows

the different setting options of this 4 registers and the resulting Power-Switch characteristics.

BKSON	**BKSOFF**	**MOS-switch**	Description
0	0	BKSMP-controlled	Typical setting in case of using a rechargeable battery, super cap or capacitor as backup supply. As VDD monitoring is on all the time in normal operation mode, power consumption is however higher compared to BKSON=1, BKSOFF=1.
0	1	Always Off	In the case of using a primary battery (non-rechargeable) as backup supply or an absolute need to avoid even short term discharging of the backup supply into VDD even for less than a second (till the next voltage detection period) i.e. because of using small storage capacitance on VBAT and in case of an external charge circuit for the backup battery this setting would be the best option.
1	0	Always On	VBAT permanently connected to VDD, therefore VDD Monitor function off all the time! This means the RTC will never go into backup mode and thus I/O, IF and interrupt always operating till supply voltage as well of backup reaches min. supply voltage. Typically used in case of a primary battery as backup supply.
1	1	BKSMP-controlled	Typical setting in case of using a rechargeable battery, super cap or capacitor as backup supply. As VDD monitoring is on only in intervals controlled by BKSMPx registers, power consumption is lower compared to BKSON=0, BKSOFF=0, so this is the most common setting.

Table 1: MOS-switch control-bit settings, resulting features and main use cases

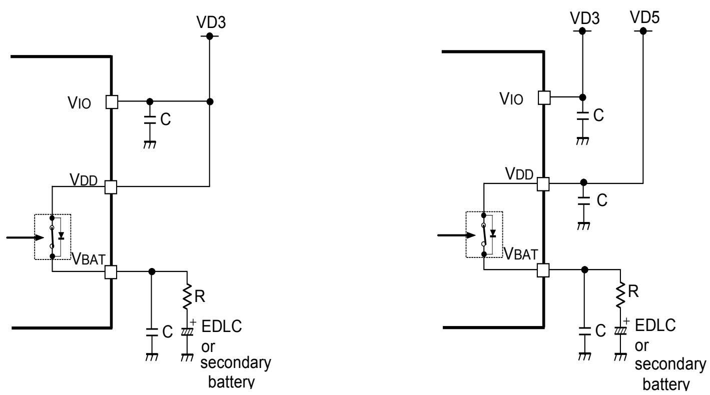
BKSON	BKSOFF	BKSMP1	BKSMP0	VDD monitor time		MOS-Switch ON/OFF
				Normal mode	Backup mode	
0	0	0	0	Always ON	Intermittent ON 2ms	Intermittent OFF 2ms
		0	1	Always ON		Intermittent OFF 16ms
		1	0	Always ON		Intermittent OFF 128ms
		1	1	Always ON		Intermittent OFF 256ms
1	1	0	0	Intermittent ON 2ms	Intermittent ON 2ms	Intermittent OFF 2ms
		0	1	Intermittent ON 16ms		Intermittent OFF 16ms
		1	0	Intermittent ON 128ms		Intermittent OFF 128ms
		1	1	Intermittent ON 256ms		Intermittent OFF 256ms
0	1	0	0	Intermittent ON 2ms	Intermittent ON 2ms	Always OFF
		0	1	Intermittent ON 16ms		Always OFF
		1	0	Intermittent ON 128ms		Always OFF
		1	1	Intermittent ON 256ms		Always OFF
1	0	1	1	Always OFF	Always OFF	Always ON

Intermittent period: Normal mode Once /1s
Backup mode Once / 31.25ms

Table 2: Power-Switch control bits and function overview

As this realization of the Power-Switch function connects the internal VDD of the RTC Module to VBAT, the circuit works best in case VDD is supplied from a

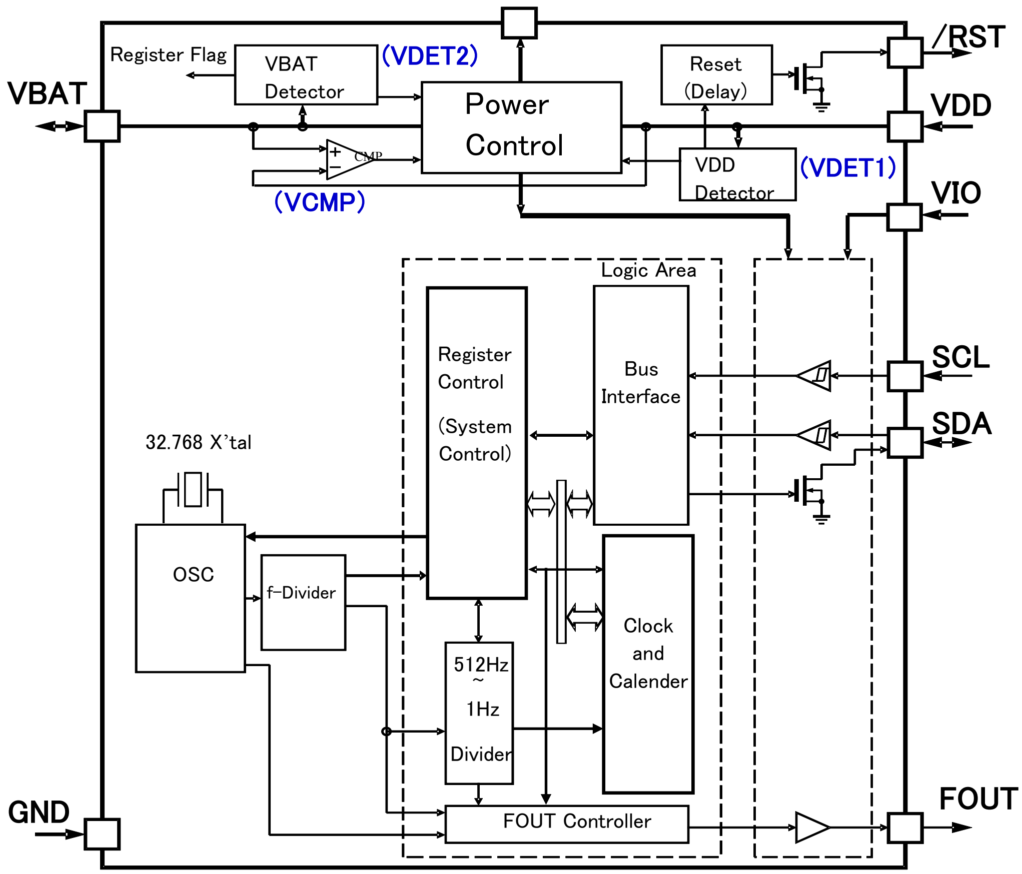
power line. In case the main supply is a discharging battery, no matter of the settings of the Power-Switch control bits, the backup supply would discharge together with the main supply, leaving only little time for the RTC to operate in backup mode.
Thanks to a dual voltage supply, VDD for the internal RTC function blocks and VIO for the I/O and interface pins to the MCU, it is possible to operate the RX6110 in many different supply voltage environments. So it is possible to operate the RTC on a higher internal core voltage VDD to have the max possible voltage on the backup supply, and use a lower VIO to assure the RTC Modules interface pins are operating on the same voltage as the MCU. As these 2 voltages are independent, the RX6110 can be adopted to virtually any supply voltage configuration within typical logic supply levels below 5.5V max.
Picture 10 shows some external connection examples in case of using the same RTC core voltage VDD and VIO (Picture 10 left) and using different voltages for VDD and VIO (Picture 10 right), where it does not matter for the RTC which voltage is higher as long as both stay within the limits of 1.6V ~ 5.5V.



Picture 10: External connection examples for RX6110 in case VDD = VIO (left) and VDD ≠ VIO (right)

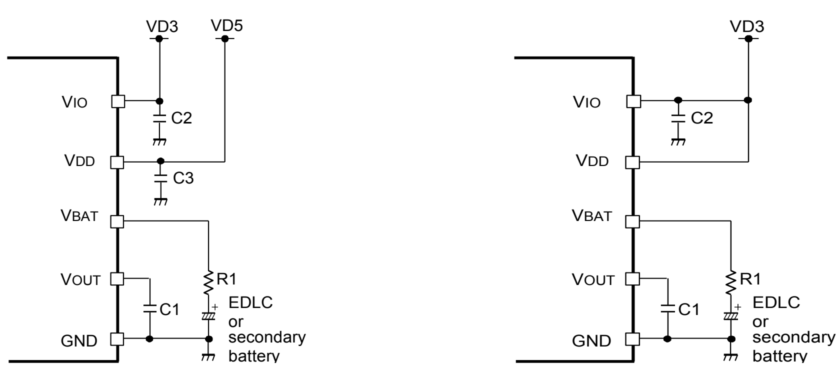
Power-Switch for rechargeable batteries (incl. Li-cells) as backup supply (i.e. RX8130):

The newly developed RX8130 is a RTC Module with a Power-Switch function optimized for the use of a rechargeable battery (including Li-cells) as backup power source, while it does not matter which kind of power source (be it a power line or any kind of primary battery) is connected to its main supply voltage pin VDD. This RTC Modules Power-Switch function is realized by 3 MOS-switches, a separate supply voltage monitoring function on the main supply VDD as well as the backup supply VBAT and a comparator for these 2 voltages. Picture 11 shows the block diagram of the RX8130 and the function blocks of the Power-Switch function.



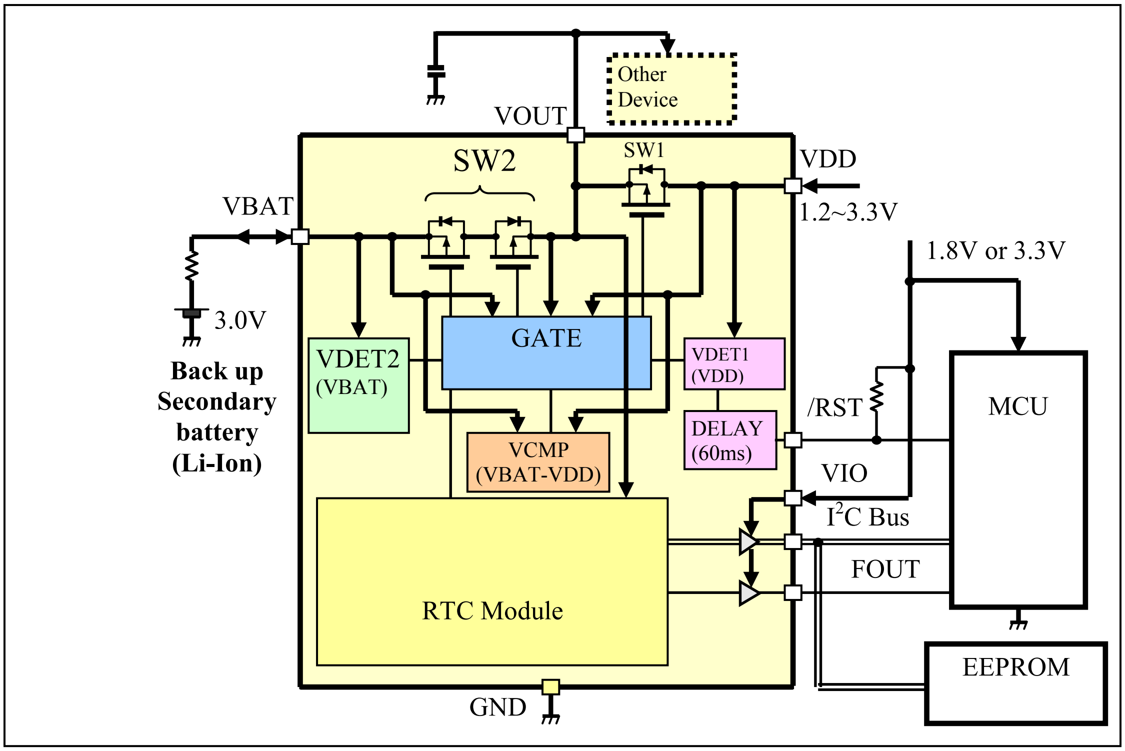
Picture 11: Block diagram of Epsons RX8130 with a Power-Switch function optimized for the use of a rechargeable Li-cells as backup power source

Like the RX6110, as well the RX8130 features a dual voltage supply, VDD for the internal RTC function blocks and VIO for the I/O and interface pins to the MCU. This makes it possible to operate the RX8130 in many different supply voltage environments with independent internal core voltage ranging from 1.2V to 3.3V and I/O voltage ranging from 1.8V to 3.3V. Consequently, a circuit like shown in Picture 12 (left) allows charging the backup-battery to a higher voltage than the supply voltage of other external circuit.



Picture 12: External connection examples for RX8130CE in case VDD ≠ VIO (left) and VDD = VIO (right)

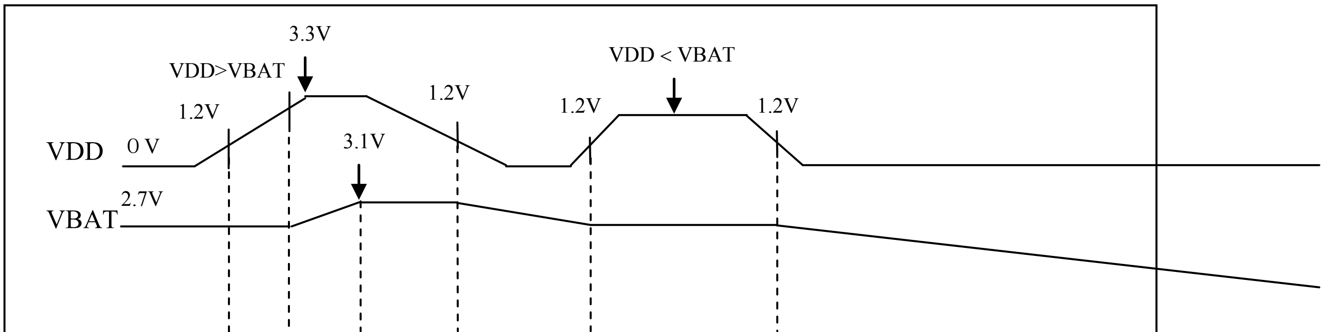
Picture 13 shows the circuit diagram of the RX8130 Power-Switch function (which is shown in Picture 10 as function block named “Power Control”) with its 3 MOS-switches. SW1 between the main supply voltage VDD and the RTCs internal power supply and the 2 serial MOS-switches between the RTCs internal supply and the backup supply VBAT forming SW2.



Picture 13: Circuit diagram of the RX8130 Power-Switch function and circuit around

Thanks to the use of the 3 MOS-switches, the 2 voltage detectors for VDD and VBAT and an intelligent switch control it is possible to charge the secondary battery connected to VBAT during normal operation. Only in case VDD is larger than VBAT, all MOS-switches are closed and the secondary battery connected to VBAT is charged. In order to avoid overcharge of the secondary battery connected to VBAT, there is a charge control circuit included in this RTC Module, which stops charging the backup battery when a user programmed voltage is reached. RX8130 features some control bits which allow the user choose to stop charging VBAT when reaching a voltage of 3.0V, 3.1V, 3.2V (so typ. voltages of Li-batteries) or optionally to not use this function and thus keep the backup storage connected to VDD for charging as long as VDD is higher than VBAT (which i.e. would be the mode typically used when connecting a capacitor or super cap to VBAT). In case VBAT is larger than VDD but VDD is higher than the min. supply voltage of 1.2V, SW2 is open but SW1 is closed, which means the secondary battery on VBAT is not connected to the internal circuit and the RTC runs from the main supply connected to VDD. In this mode a discharging main supply on VDD would not cause the voltage of the backup supply to drop (beside its own internal discharge and other secondary effects) and thus keep the backup supply charged to the max.

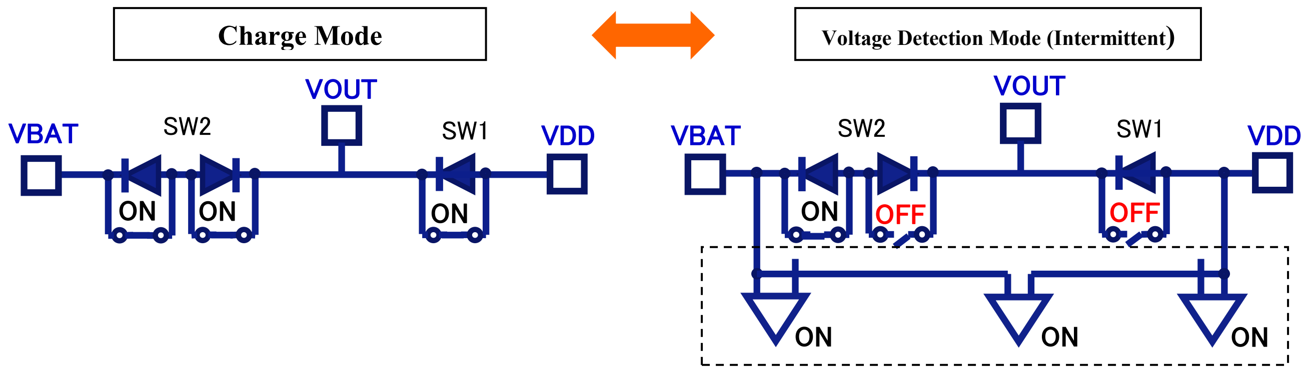
Picture 14 shows the different voltage constellations between VDD and VBAT and the resulting switch positions as well as when the backup supply would be charged.



SW1	OFF	ON			OFF	ON	OFF
SW2	OFF		ON	OFF	ON	OFF	ON
Charging	OFF		ON	OFF			

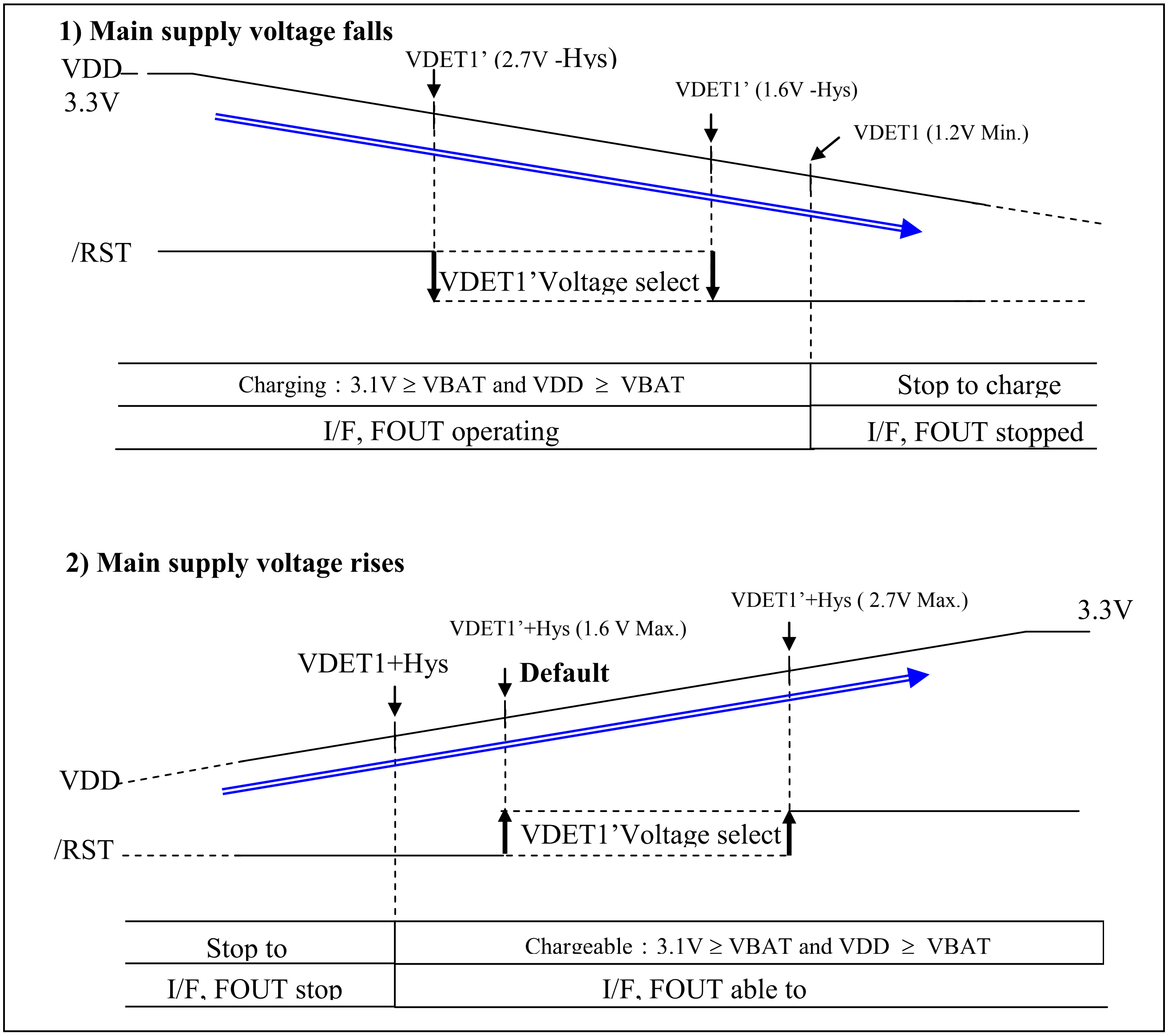
Picture 14: MOS-switch positions of RX8130 for different VDD & VBAT constellations

When charging the secondary battery connected to VBAT, all 3 MOS-switches are closed. This means that both voltage detectors (the one at VBAT and the one at VDD) see the same voltage. For correct detection of VDD and VBAT it is however necessary to avoid current to flow from VDD to VBAT and vice versa. This is realized by opening some of the MOS-switches from time to time for the voltage measurement. Picture 15 shows the MOS-switches closed during charging and some of them opened temporarily for a short time to perform the VBAT and VDD voltage detection. The circuit is designed in a way, which during the voltage detection either VDD or VBAT could supply the RTC with power, so that no matter is VDD is still above the limit or not, the function of the RTC is secured during this monitoring time. As Picture 11 shows, the RX8130 is not only measuring VDD and VBAT, but as well comparing them to make sure the charging mode is ended ones VBAT reaches or exceeds the VDD voltage. Even more, since Li-Ion batteries are sensitive to overcharging, it is important to control the charging process of the secondary Li-Ion battery to detect when it is fully charged. RX8130 with its Power-Switch function and voltage detectors is able to control the charging process and end the charging process when a user programmed voltage between 3.0V and 3.2V is reached, so that it can be used with rechargeable Li-Ion batteries as backup supply connected to VBAT.



Picture 15: MOS-switch positions during VBAT charge mode and detect mode

It is noticeable that the VOUT-pin, meaning the backed-up internal supply voltage pin of the RTC, can as well be used to supply some external circuit as long as the current required by the external circuit remains within the max. output current at VOUT-pin.
In order to avoid the VOUT voltage to jump during changes of the RTCs operation mode or at the time voltage detection is performed; a smoothing capacitor as shown in Picture 12 and 13 should be connected to the VOUT-pin.
Not only that the RTC switches off all I/O-pins and FOUT during backup mode (supply from VBAT), but in order to make the maximum use of the RTC Modules internal circuit, the RX8130 outputs a low active reset signal in case the main supply voltage is below a user defined threshold (see Picture 16). By connecting the /RES-signal of the RX8130 to external components like MCU,… it is possible to put them into sleep mode when VDD falls below the threshold and to ensure a proper power-on reset when VDD comes back. It should be noted that the RTC Module needs to be working (so be supplied via VDD or VBAT with a voltage above the min. level) to output the /RES-signal.



Picture 16: Function description of RX8130 /RES-output for power-on /-off reset