

 ABRACON CORPORATION <i>The Power of Linking Together</i>	ABX8XX Application Note Using Low Cost Ceramic Capacitors for RTC Backup Power	 RoHS Compliant
Date of Issue: June 20 th , 2013		 ESD Sensitive
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1.0 Introduction

This application note describes the use of low-cost capacitors as a backup power source for the ABX8XX real time clock (RTC) families. The ultra-low power consumption of the ABX8XX enables designers to use small ceramic capacitors as a backup power source and still meet the required RTC data and time retention period for many applications. The ABX8XX, with unprecedented low power, is the first product in the industry enabling use of low-cost ceramic capacitors as a RTC backup power source. This cuts the cost of the backup capacitor by up to 13X when compared to the supercapacitor needed for other competitive solutions. In addition, the space required for the backup capacitor is reduced by 5-6X or more. The fully integrated VBAT switchover capabilities of the ABX8XX, requiring no additional external components, minimizes the BOM resulting in further cost and space savings.

2.0 Application

In a typical ABX8XX RTC backup application, a main system power source is supplied to both the ABX8XX and the MCU. A rechargeable backup power source, such as a supercapacitor, battery, or ceramic capacitor, is attached the ABX8XX VBAT pin. Using the ABX8XX internal trickle charger, the backup power source can be charged directly from main system power. A small size ceramic capacitor (100µF or less) will typically be charged to within 400mV of the main system power supply voltage in less than 1 second. When the main system power fails or is removed, the MCU loses power completely and the ABX8XX will automatically switch over to the backup power source on the VBAT pin. A block diagram of this typical application is shown in Figure 1 below.

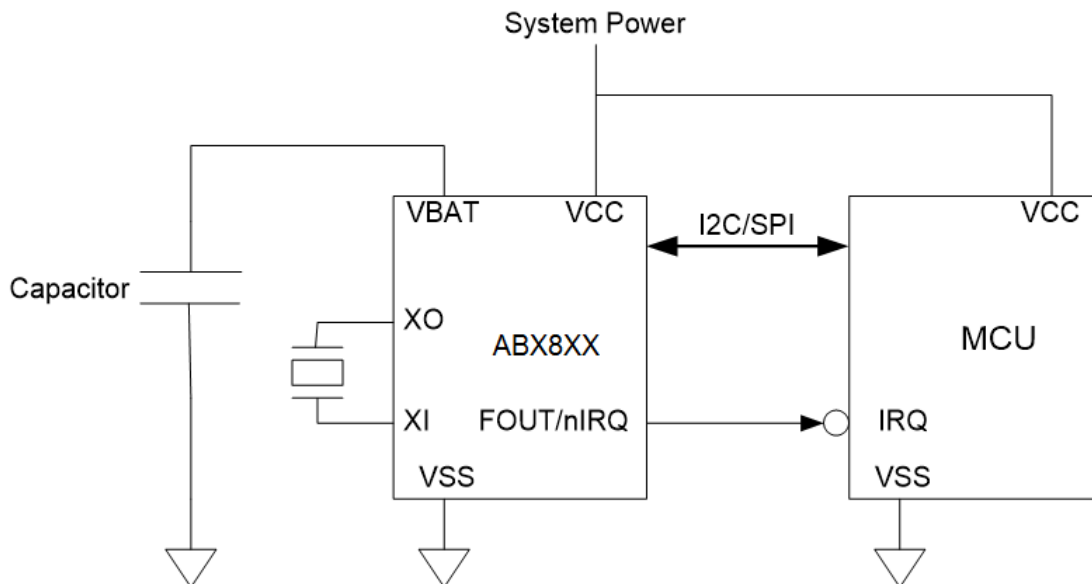





Figure 1 – RTC Capacitor Backup Application

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During and after the process of switchover to the VBAT backup supply, the ABX8XX will continue counting and retain date and time information. With up to 256 bytes of user programmable RAM, the ABX8XX can also retain important user data, which the MCU can write to the ABX8XX RAM prior to main system power failure.

There are many applications that can use the ABX8XX combined with a ceramic capacitor as a RTC backup solution. In many cases, using such a solution would provide adequate backup time during the following conditions:

- A power grid outage or disturbance
- Portable device or automotive battery replacement
- Changing wall outlets for appliances or industrial equipment

3.0 Backup Time Factors

When using a capacitor for backup power, the length of time the ABX8XX can retain date, time, and data information will be dependent upon several factors listed below.

1. ABX8XX mode of operation
2. Voltage of the main system power supply, which is used to charge the capacitor on the VBAT pin
3. Max voltage rating of the capacitor
4. Size/capacity of the capacitor
5. Capacitor leakage current or insulation resistance
6. Initial VBAT voltage drop on the capacitor during switchover

3.1 ABX8XX Operating Mode

The ABX8XX has 3 basic modes of operation that offer different tradeoffs between accuracy and power levels. Each of these modes will have a different average current consumption, which will affect the length of backup time. By a significant margin, the ABX8XX is the lowest power RTC available in the industry.

XT mode: In this mode, the ABX8XX requires a 32.768 kHz crystal, which runs continually. This mode has very high accuracy but also has higher current consumption than the other two modes.

Autocalibration mode: In this mode, the ABX8XX also requires a 32.768 kHz crystal, but it only runs for 50 seconds during each autocalibration cycle, which is programmable to either 512 or 1024 seconds. This substantially lowers the average current consumption compared to XT mode because the majority of the time is spent in RC mode. Autocalibration mode has timing accuracy that is very close to XT mode with current consumption that is very close to RC mode.

RC mode: In this mode, the ABX8XX does not require a 32.768 kHz crystal and the crystal oscillator circuitry is turned off completely. The ABX8XX runs continually from its internal RC oscillator. This mode consumes the least amount of current compared to the other two modes.

Table 1 summarizes the timing accuracy and average current consumption from the VBAT pin in each mode.

Mode	Timing Accuracy (25°C)*	Typ. Current VBAT = 3.0V	Typ. Current VBAT = 1.3V	Average Current (3.0V to 1.3V)
XT	+/- 2 ppm	58 nA	55 nA	56.5 nA
RC	+/- 1%	15 nA	12 nA	13.5 nA
Autocalibration (512 second period)	35 ppm (24 hour run time) 20 ppm (1 week run time) 10 ppm (1 month run time) 3 ppm (1 year run time)	20 nA	16 nA	18 nA

Table 1 – ABX8XX Timing Modes

* Note: Timing accuracy is specified at 25°C after digital calibration of the internal RC oscillator and 32.768 kHz crystal. A typical 32.768 kHz tuning fork crystal has a negative temperature coefficient with a parabolic frequency deviation, which can result in a change of up to 150ppm across the entire operating temperature range of -40°C to 85°C in XT mode. Autocalibration mode timing accuracy is specified relative to XT mode timing accuracy across the entire operating temperature range. The typical RC frequency variation across temperature is +/- 3.5% from -10°C to 70°C and +/- 10% across the entire temperature range of -40°C to 85°C.

3.2 Capacitor Characteristics

The ABX8XX trickle charges the VBAT capacitor from the voltage supply connected to the VCC pin. Therefore, the ABX8XX internal trickle charger cannot charge the VBAT capacitor any higher than the system power voltage level. The capacitor voltage is also limited to its maximum voltage rating. To maximize backup time, the capacitor voltage rating should be at least as high as the system power voltage. When a switchover to the VBAT capacitor occurs, a higher starting capacitor voltage will increase the backup time.

When the system is running with currents of only tens of nanoamps, one important factor that can be easily overlooked is the capacitor leakage current or insulation resistance. The leakage current caused by the insulation resistance can substantially decrease the capacitor's ability to retain charge, resulting in decreased backup time. The leakage current of large value capacitors can easily exceed the ABX8XX operating current. An equivalent low frequency circuit model (not including inductive effects) for a ceramic capacitor is shown below in Figure 2.

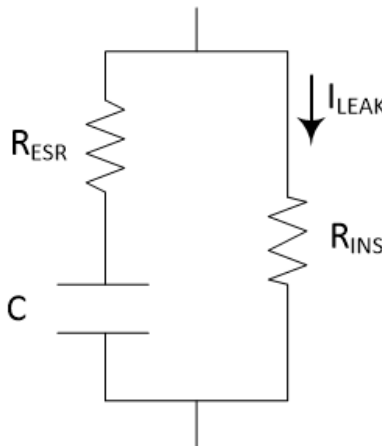





Figure 2 – Low Frequency Capacitor Model

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Where:

R_{ESR} = equivalent series resistance (ESR)

R_{INS} = insulation resistance

I_{LEAK} = leakage current due to insulation resistance

C = capacitance value

A ceramic capacitor ESR is typically under 0.1 ohms. The ESR of a supercapacitor is substantially larger and typically ranges from single digit ohms to hundreds of ohms. For large current loads, R_{ESR} must be taken into consideration due to the voltage drop. However, due to the ultra-low current consumption of the ABX8XX, R_{ESR} can be ignored when calculating backup time.

The insulation resistance of a ceramic capacitor represents the ratio between the applied voltage and the leakage current after a set period of time. In ceramic capacitor datasheets, this is usually specified in megohms (M Ω) or ohm-farads (Ω F) and tested at the rated voltage after 1-2 minutes.

Immediately after a DC voltage is applied to the capacitor, an inrush (charge) current will occur. The absorption current occurs due to the dielectric loss of the capacitor and decreases exponentially with time. The leakage current is then measured as the constant current flowing through the capacitor after the absorption current has decreased to an acceptable level.

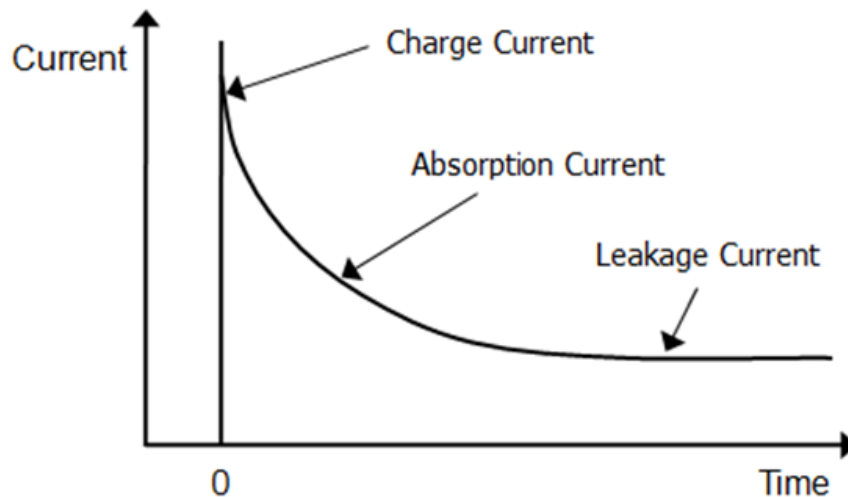





Figure 3 – Ceramic Capacitor Current Profile

As can be seen in the ceramic capacitor current profile curve in Figure 3, to properly specify the insulation resistance or leakage current, the timing of the measurement after the applied voltage must also be specified.

Tests have been conducted on the leakage currents of typical inexpensive ceramic capacitors ranging from 10-100 μ F. Table 2 shows typical leakage currents of the capacitors 10 minutes after applying 3.3V across the capacitor terminals at room temperature.

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Capacitor Value (μF)	Package Case Code	Size (mm) (LxWxH)	Leakage Current (nA)
100	1206	3.2x1.6x1.6	11
47	0805	2.0x1.25x.95	5.5
22	0603	1.6x0.8x0.8	2.6
10	0402	1.0x0.5x0.7	1.1

Table 2 – Ceramic Capacitor Leakage Currents

Note that ceramic capacitor leakage currents may be slightly different than those in Table 2 dependent upon the manufacturer and product variation. Lower leakage capacitors can also be obtained with tradeoffs between cost, size, and backup time. The ceramic capacitor manufacturer should be consulted for leakage current specifications and system testing performed to determine the system specific leakage current.

3.3 Initial Capacitor Voltage Drop

The ABX8XX will switch over to the VBAT supply immediately after the VCC voltage drops below the switchover threshold voltage (typically 1.4V). The energy required for the ABX8XX to complete the switchover operation will pull charge from the backup capacitor, resulting in an initial step voltage loss. The charge pulled from the capacitor, and therefore the voltage loss, will decrease as the starting VBAT voltage decreases because the ABX8XX requires less energy to complete the switchover operation at lower VBAT voltages. The typical capacitor voltage loss immediately after switchover with VBAT = 3.3V is shown in Figure 4 below.

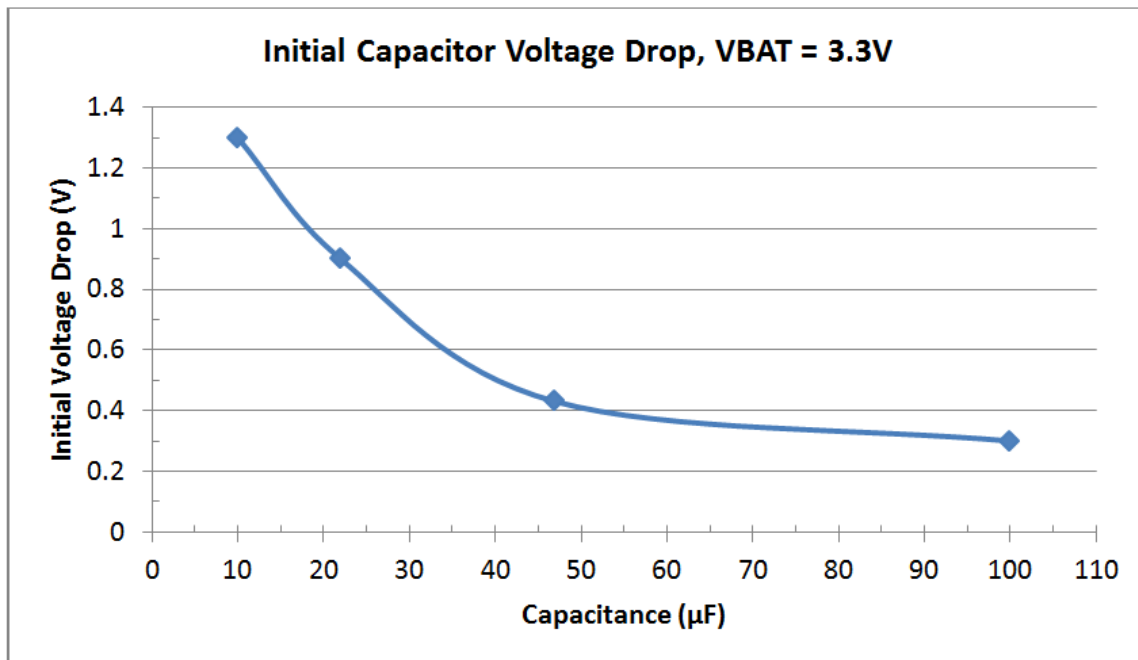





Figure 4 – Initial Capacitor Voltage Loss

After the initial capacitor voltage loss occurs, the capacitor will discharge at a rate determined by the ABX8XX operating mode as described in section 3.1.

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4.0 Estimating Backup Time

With the important factors affecting backup time taken into account, it can be estimated using the following equation.

$$\text{BackupTime} = \frac{C * (V_{\text{BATO}} - V_{\text{LOSS}} - V_{\text{BATMIN}})}{I_{\text{LEAK}} + I_{\text{ABX8XX}}}$$

Where:

C = Capacitor value

V_{BATO} = Initial VBAT voltage prior to switchover

V_{LOSS} = Initial capacitor voltage loss due to the ABX8XX energy required to complete the switchover operation (see Figure 4).

V_{BATMIN} = Minimum battery voltage that can be applied to VBAT before an ABX8XX reset occurs.

I_{LEAK} = capacitor leakage current (see Table 2)

I_{ABX8XX} = ABX8XX average current consumption (see Table 1) from V_{BATO}-V_{LOSS} to V_{BATMIN}.

For example, operating in autocalibration mode with a 100μF ceramic capacitor charged to 3.3V prior to switchover, and a typical ABX8XX minimum VBAT voltage of 1.2V results in a backup time as follows:

$$\text{BackupTime} = \frac{C * (V_{\text{BATO}} - V_{\text{LOSS}} - V_{\text{BATMIN}})}{I_{\text{LEAK}} + I_{\text{ABX8XX}}} = \frac{100\mu\text{F} * (3.3\text{V} - 0.3\text{V} - 1.2\text{V})}{11\text{nA} + 18\text{nA}} * \frac{1\text{hr.}}{3600\text{s}} = 1.72\text{hours}$$

Therefore, nearly 2 hours of backup time can be achieved in autocalibration mode using only a 100μF capacitor as the backup power source. Table 3 summarizes the expected backup time for various ceramic capacitor sizes and ABX8XX operating modes and Figure 5 plots the data.



Capacitor Value (μF)	Package Case Code	Size (mm) (LxWxH)	Leakage Current (nA)	Hours of Backup Time (3.3V – 1.2V)		
				XT mode	Acal Mode	RC Mode
100	1206	3.2x1.6x1.6	11	0.74	1.72	2.04
47	0805	2.0x1.25x.95	5.5	0.35	0.93	1.15
22	0603	1.6x0.8x0.8	2.6	0.12	0.36	0.46
10	0402	1.0x0.5x0.7	1.1	0.04	0.12	0.15

Table 3 – Backup Times

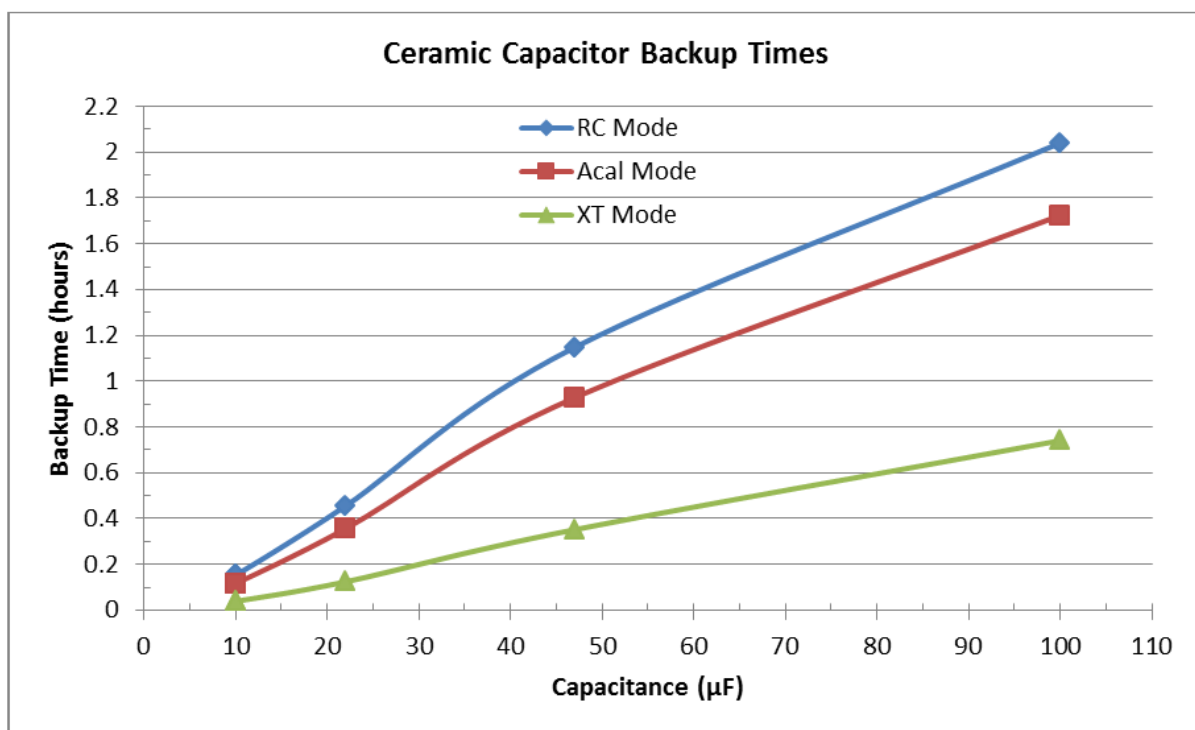


Figure 5 – Ceramic Capacitor Backup Times

The expected backup times calculated in Table 3 correlated strongly with actual measurement data on the real hardware. One such example is shown in Figure 6, which shows actual measurement data for an autocalibration mode application using a 100 μ F ceramic backup capacitor. Looking at the higher current pulses on red curve (VBAT current), the autocalibration cycles can clearly be seen as crystal oscillator (and autocalibration engine) is periodically turned on/off. The blue curve (VBAT voltage) shows the extremely slow capacitor discharge rate, which gives a backup time of 1.7 hours as expected.

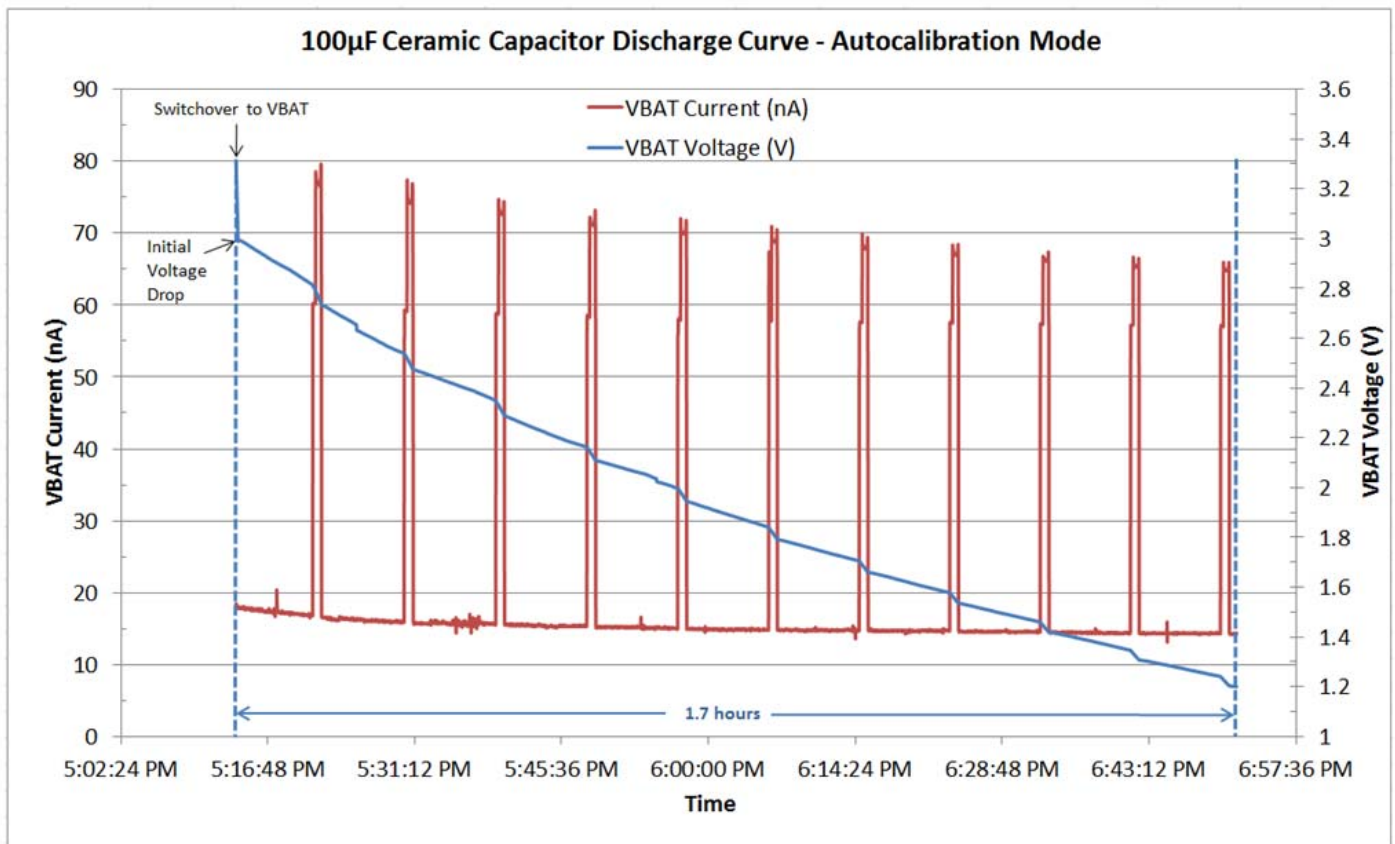





Figure 6 – Autocalibration Mode Backup Example

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5.0 Implementation

The extremely small size and low cost of ceramic capacitors combined with the unprecedented low power, minimal footprint and BOM of the ABX8XX enable highly economical RTC backup solutions and modules to be created, requiring minimal space. A ceramic capacitor based ABX8XX RTC backup timing solution requires only 3 components:

- ABX8XX device supporting the VBAT function
- Standard 32.768kHz tuning fork crystal (no crystal load capacitors required)
- Ceramic capacitor

One such backup solution is shown in Figure 7, which uses an FR4 substrate populated with the ABX8XX QFN package (3mm x 3mm), 32.768 kHz tuning fork crystal, and a 47 μ F ceramic capacitor. The module size shown is 6.1mm x 8.8mm, but further placement and routing optimizations can reduce its size to 3.3mm x 6.2mm. This solution provides 30 minutes to over 1 hour of backup time dependent upon the ABX8XX operating mode.






Figure 7 – ABX8XX RTC Backup Module on FR4 Substrate

Ceramic capacitors can also be placed in parallel to optimize the cost, height, and backup time (see Table 3). The 32.768 kHz crystal can be eliminated if running the ABX8XX in RC mode only.

6.0 Summary

The unprecedented low power of the ABX8XX and its VBAT switchover capabilities now makes it possible, for the first time in the industry, to use inexpensive ceramic capacitors as an RTC backup power source. Adequate backup time is achieved using this solution for many different types of applications. Taking into account the various sources that affect current consumption, both under static conditions and during ABX8XX switchover, the backup time can be determined given the ceramic capacitor value. Actual measurements and testing should be performed to identify all leakage sources and that the expected backup time matches actual backup time. Extremely low cost RTC backup solutions and modules with minimal space and BOM requirements can now be developed using a single ceramic capacitor and the ABX8XX.

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7.0 Notes

- i) The parts are manufactured in accordance with this specification. If other conditions and specifications which are required for this specification, please contact ABRACON for more information.
- ii) ABRACON will supply the parts in accordance with this specification unless we receive a written request to modify prior to an order placement.
- iii) In no case shall ABRACON be liable for any product failure from in appropriate handling or operation of the item beyond the scope of this specification.
- iv) When changing your production process, please notify ABRACON immediately.
- v) ABRACON Corporation's products are COTS – Commercial-Off-The-Shelf products; suitable for Commercial, Industrial and, where designated, Automotive Applications. ABRACON's products are not specifically designed for Military, Aviation, Aerospace, Life-dependant Medical applications or any application requiring high reliability where component failure could result in loss of life and/or property. For applications requiring high reliability and/or presenting an extreme operating environment, written consent and authorization from ABRACON Corporation is required. Please contact ABRACON Corporation for more information.
- vi) All specifications and Marking will be subject to change without notice.

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2. Taxes: Unless otherwise specified in the quotation, the prices shown do not include any taxes, import, or export duties, tariffs, or customs charges. The Buyer agrees to pay AB the amount of any federal, state, county, municipal, or other taxes, duties, tariffs, or custom charges levied by any jurisdiction, foreign or domestic, which AB is required to pay on account of the ownership at the place of installation or during transit of the material or equipment which is the subject of this contract, or an account of the transportation, sale, or use of the material or equipment.

3. Payment Terms: Unless otherwise stated in a separate agreement or in AB's quotation, payment terms are thirty days net from the date of invoice, subject to approval from AB of amount and terms of credit. AB reserves the right to require payment in advance or C.O.D. and otherwise modified credit terms. When partial shipments are made, payments therefore shall become due in accordance with the above terms upon submission of invoices. If, at the request of the Buyer, shipment is postponed for more than thirty days, payment will become due thirty days after notice to the Buyer that products are ready for shipment. These terms apply to partial as well as complete shipments on the debt at the lesser of 18% per year, or the maximum then permitted by California law, from the due date until the Buyer pays the debt in full.

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4. Shipment: All shipments will be made F.O.B. AB's shipping point. In the absence of specific instructions, AB will select the carrier. Title to the material shall pass to the Buyer upon delivery thereof by AB to the carrier or delivery service. Thereupon the Buyer shall be responsible therefore. Products held for the Buyer, or stored for the Buyer, shall be at the risk and expense of the Buyer. Claims against AB for shortages must be made in writing within ten days after the arrival of the shipment. AB is not required to notify the Buyer of the shipment.

5. Delivery: Shipping dates are approximate.

6. Packing: Unless otherwise specified, prices quoted herein include normal AB packaging. If special packaging is required by the Buyer, an additional charge will be made.

7. Inspection: Unless the Buyer notifies AB in writing within ten days from the date of receipt of any products that says the products are rejected, they will be deemed to have been accepted by the Buyer. In order for the notice of rejection to be effective, it must also specify the reasons why the products are being rejected. Any rejected products must be returned to AB within thirty days of rejection or the rejection shall be void and of no effect. Notwithstanding the preceding sentence, no returned goods will be accepted for credit unless written permission is first obtained from AB.

8. Limitation of Liability: AB shall not be liable for any loss, damage, cost of repairs, or incidental or consequential damages of any kind whether or not based upon express or implied warranty, negligence, or strict liability arising out of or in connection with the design, manufacture, sale, use, repair, or delivery of the product, or the engineering designs supplied to the Buyer. Without limiting the generality of the foregoing: if conditions arise which prevent compliance with delivery schedules, AB shall not be liable for any damage or penalty for delay in delivery, or for failure to give notice of delay, and such delay shall not constitute grounds for cancellation or price adjustment: in addition, AB shall not be liable for delay in delivery without regard to the cause of the delay, and delivery dates shall be deemed extended for a period equal to such delay.

9. Fair Labor Standards Act: AB certifies that products furnished hereunder have been or will be produced in compliance with the Fair Labor Standards Act, as amended and regulations and orders of the U.S. Department of Labor issued thereunder, AB agrees that this statement may be considered as the written assurance contemplated by the October 26, 1949 amendment to said Act.

10. Modifications: Unless otherwise provided, AB reserves the right to modify the specifications of products ordered by the Buyer providing that the modifications do not materially affect the performance.

11. Termination: In the event of the complete or partial termination or cancellation of this order for the convenience of the Government, settlement shall be made by negotiations in accordance with the Termination Clause for Subcontractors set forth in Armed Services Procurement Regulation 8-706. If the Buyer attempts to terminate or cancel this order, entirely or partially, other than for the convenience of the Government, it shall constitute a material breach of contract unless consent to said termination is obtained by the Buyer from AB in writing. In any event, the prices of all items delivered, and all items which have been furnished but not yet delivered, will be adjusted upward to the applicable price for the lesser quantities thereby purchased. AB may terminate or cancel this order in whole or in part at any time prior to the completion of performance by written notice to the Buyer without incurring any liability to the Buyer for breach of contract or otherwise.

12. Indemnity and Waiver of Subrogation: Buyer agrees to indemnify and hold AB harmless from any cost, liability or expense, including attorney's fees, which arises from or relates to any third party claim for personal injury (or death), property damages, or other loss allegedly based upon defective design, material, or workmanship of any product sold or furnished by AB, or allegedly based on any breach by AB of any of its contractual or other obligations. The Buyer represents that any liability insurance policies which the Buyer may have shall provide that subrogation rights against supplies such as AB are waived.

13. Governing Law: The terms of this agreement and all rights and obligations under it shall be governed by the laws of the State of California.

14. Errors: AB reserves the right to correct clerical or stenographic errors or omissions.

15. Entire Contract: The provisions of the Agreement and any accompanying documents constitute all the terms and conditions agreed upon by the parties and replace and supersede any inconsistent provisions on the face and the reverse side of the Purchase Order, Invoice, and Packing Slip. No modifications of this Agreement shall be valid unless in writing and duly signed by a person authorized by AB. The provisions of this Agreement shall not be modified by any usage of trade, or any course of prior dealing or acquiescence in the course of performance.

16. Disputes: Disputes between AB and the Buyer shall be resolved in accordance with the laws of the State of California without resort to said state's Conflict of Law rules. Pending final resolution of a dispute, AB shall proceed diligently with the performance of an order in accordance with AB's decision. In any legal action, arbitration, or other proceeding brought to enforce or interpret the terms of this agreement, the prevailing party shall be entitled to reasonable attorneys' fees and any other costs incurred in that proceeding in addition to any other relief to which it is entitled.