APPLICATION NOTE

Artasie AMX8X5 Using Low-Cost Ceramic Capacitors for RTC Backup Power

Ultra-low power coupled with a highly sophisticated feature set

A-RTCX85-ANGA02EN v2.0

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Revision History

Revision	Date	Description
1.0	February 2017	Initial Release.
1.1	June 2017	Updated document to reflect only the AMX8X5 part numbers.
2.0	January 18, 2023	Updated document template

Reference Documents

Document ID	Description

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1

Introduction

This application note describes the use of low-cost capacitors as a backup power source for the AMX8X5 real time clock (RTC) families. The ultra-low power consumption of the AMX8X5 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 AMX8X5, with unprecedented low power, is the first product in the industry enabling use of low-cost ceramic capacitors as an 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 AMX8X5, requiring no additional external components, minimizes the BOM resulting in further cost and space savings.

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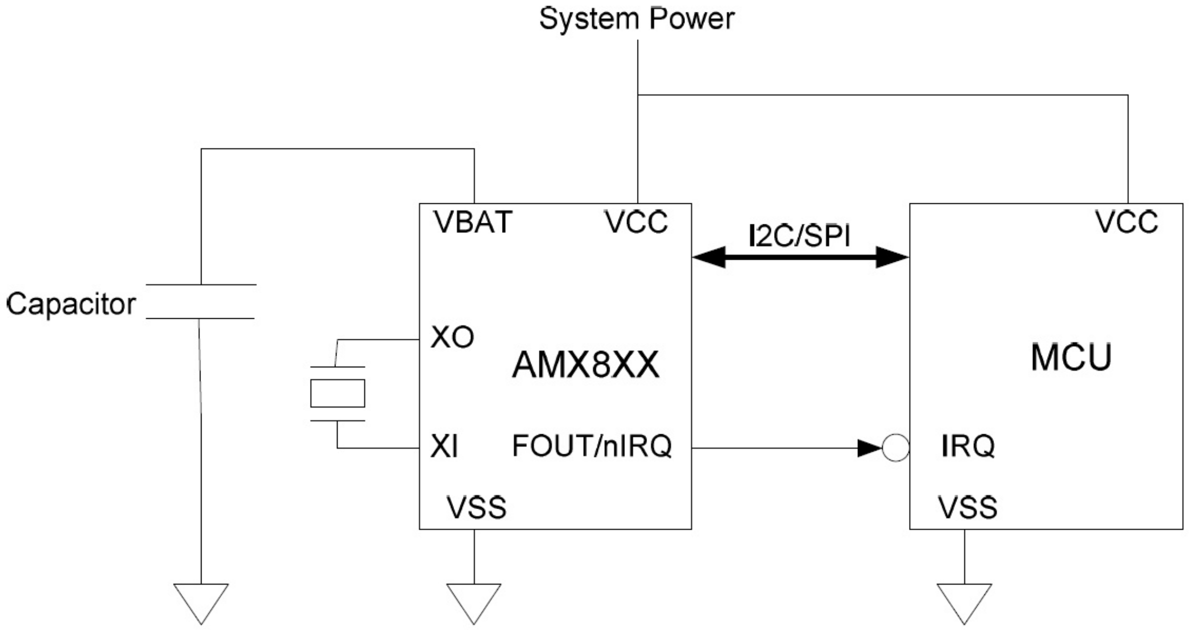
Applications

In a typical AMX8X5 RTC backup application, a main system power source is supplied to both the AMX8X5 and the MCU. A rechargeable backup power source, such as a supercapacitor, battery, or ceramic capacitor, is attached the AMX8X5 VBAT pin. Using the AMX8X5 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 AMX8X5 will automatically switch over to the backup power source on the VBAT pin. A block diagram of this typical application is shown in Figure 2-1 below.

Figure 2-1: RTC Capacitor Backup Application



During and after the process of switchover to the VBAT backup supply, the AMX8X5 will continue counting and retain date and time information. With 256 bytes of user programmable RAM, the AMX8X5 can also retain important user data, which the MCU can write to the AMX8X5 RAM prior to main system power failure.

There are many applications that can use the AMX8X5 combined with a ceramic capacitor as an 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

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Backup Time Factors

When using a capacitor for backup power, the length of time the AMX8X5 can retain date, time, and data information will be dependent upon several factors listed below.

1. AMX8X5 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 AMX8X5 Operating Mode

The AMX8X5 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 Ambiq AMX8X5 is the lowest power RTC available in the industry.

- **XT mode**: In this mode, the AMX8X5 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 AMX8X5 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 AMX8X5 does not require a 32.768 kHz crystal and the crystal oscillator circuitry is turned off completely. The AMX8X5 runs continually from its internal RC oscillator. This mode consumes the least amount of current compared to the other two modes.

Table 3-1 summarizes the timing accuracy and average current consumption from the VBAT pin in each mode.

Table 3-1: AMX8X5 Timing Modes

Mode	Timing Accuracy (25°C)[1]	Typ. Current VBAT = 3.0V	Typ. Current VBAT = 1.3V	Avg 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)	22 nA	16 nA	18 nA

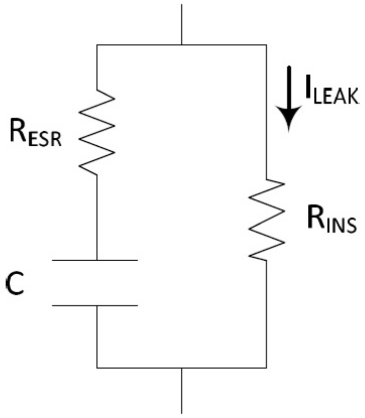
[1] Timing accuracy is specified at 25°C after digital calibration of the internal RC oscillator and 32.768 kHz crystal. A typical 32.768 kHz tuning fork crystal has a negative temperature coefficient with a parabolic frequency deviation, which can result in a change of up to 150ppm across the entire 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 AMX8X5 trickle charges the VBAT capacitor from the voltage supply connected to the VCC pin. Therefore, the AMX8X5 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 AMX8X5 operating current. An equivalent low frequency circuit model (not including inductive effects) for a ceramic capacitor is shown below in Figure 3-1 on page 12.

Figure 3-1: Low Frequency Capacitor Model



Where:

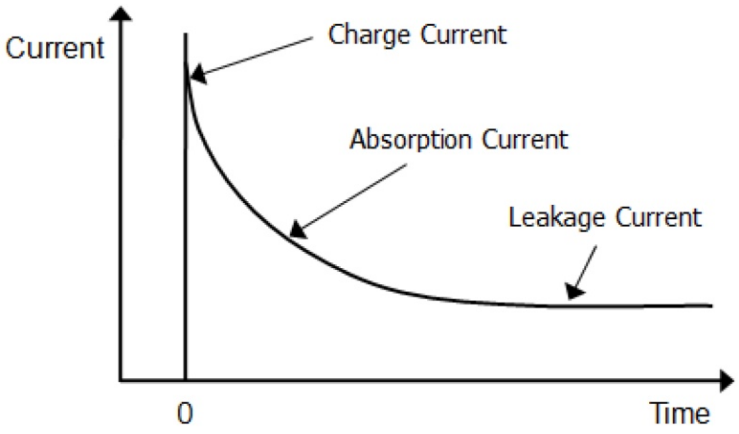
- R_{ESR} = equivalent series resistance (ESR)
- R_{INS} = insulation resistance
- I_{LEAK} = leakage current due to insulation resistance
- C = capacitance value

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 AMX8X5, 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 (MΩ) or ohm-farads (ΩF) 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 3-2: Ceramic Capacitor Current Profile



As can be seen in the ceramic capacitor current profile curve in Figure 3-2, to properly specify the insulation resistance or leakage current, the timing of the measurement after the applied voltage must also be specified.

Ambiq has tested the leakage currents of typical inexpensive ceramic capacitors ranging from 10-100µF. Table 3-2 shows typical leakage currents of the capacitors 10 minutes after applying 3.3V across the capacitor terminals at room temperature.

Table 3-2: Ceramic Capacitor Leakage Currents

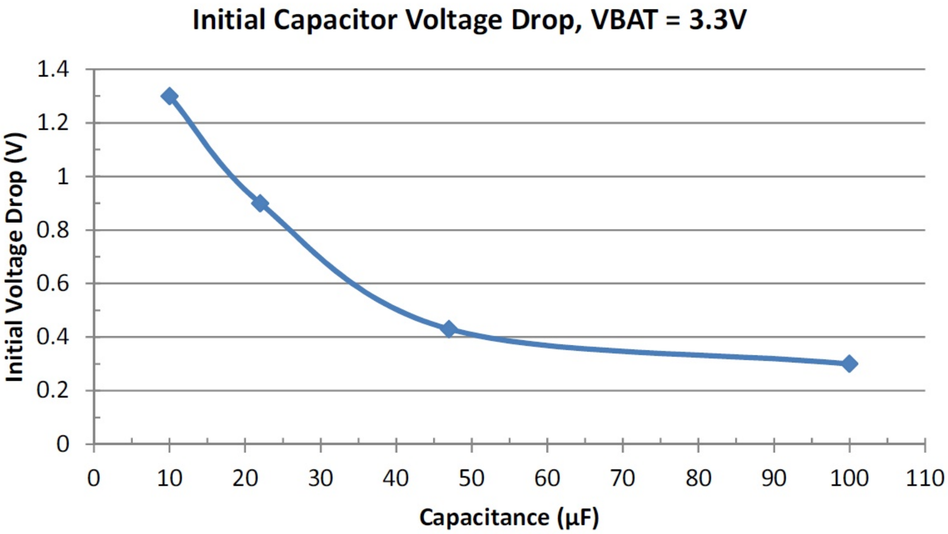
Capacitor Value (µF)	Package Case Code	Size (mm) (LxWxH)	Leakage Current (nA)
100	1206	3.2 x 1.6 x 1.6	11
47	0805	2.0 x 1.25 x 0.95	5.5
22	0603	1.6 x 0.8 x 0.8	2.6
10	0402	1.0 x 0.5 x 0.7	1.1

Note that ceramic capacitor leakage currents may be slightly different than those in Table 3-2 dependent upon the manufacturer and product variation. Lower leakage capacitors can also be obtained with trade-offs 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 AMX8X5 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 AMX8X5 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 AMX8X5 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 3-3 below.

Figure 3-3: Initial Capacitor Voltage Loss



After the initial capacitor voltage loss occurs, the capacitor will discharge at a rate determined by the AMX8X5 operating mode as described in *Section 3.1 AMX8X5 Operating Mode on page 10*.

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Estimating Backup Time

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

$$\text{Backup Time} = \frac{C * (V_{BATO} - V_{LOSS} - V_{BATMIN})}{I_{LEAK} + I_{AMX8XX}}$$

Where:

- C = Capacitor value
- V_{BATO} = Initial VBAT voltage prior to switchover
- V_{LOSS} = Initial capacitor voltage loss due to the AMX8X5 energy required to complete the switchover operation (see Figure 3-3 on page 14).
- V_{BATMIN} = Minimum battery voltage that can be applied to VBAT before an AMX8X5 reset occurs.
- I_{LEAK} = capacitor leakage current (see Table 3-2 on page 13)
- I_{AMX8X5} = AMX8X5 average current consumption (see Table 3-1 on page 11) from VBATO-VLOSS to VBATMIN.

For example, operating in autocalibration mode with a 100µF ceramic capacitor charged to 3.3V prior to switchover, and a typical AMX8X5 minimum VBAT voltage of 1.2V results in a backup time as follows:

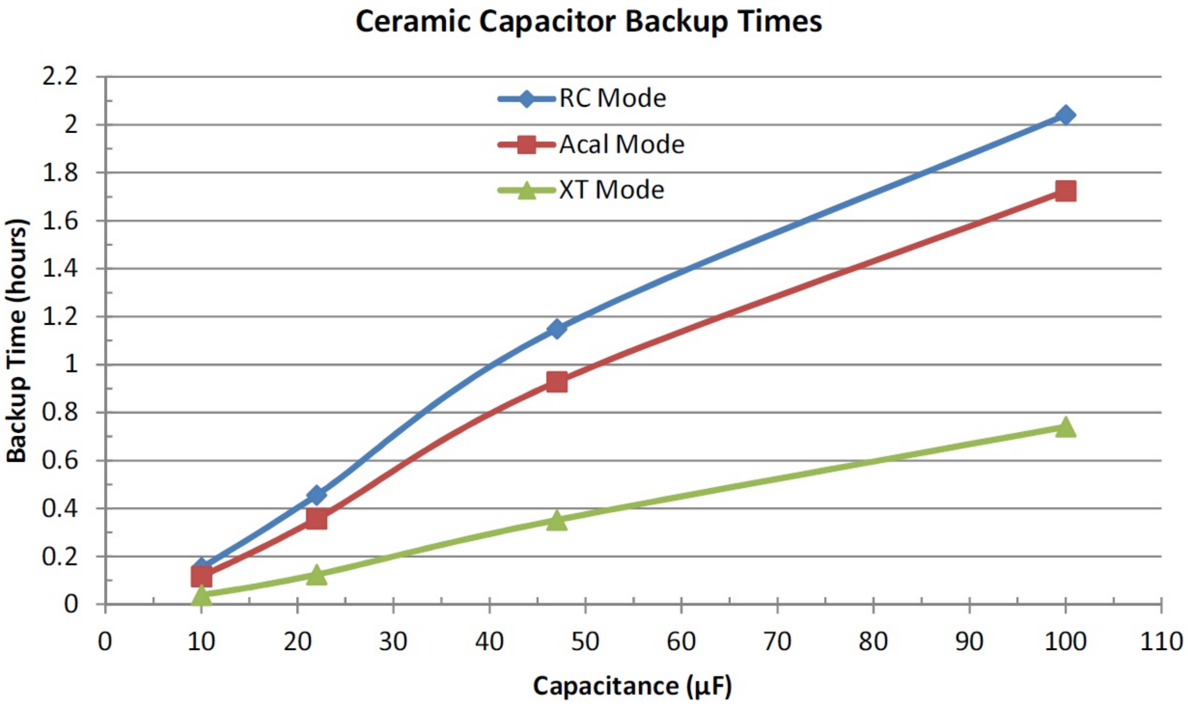
$$\text{Backup Time} = \frac{C * (V_{BATO} - V_{LOSS} - V_{BATMIN})}{I_{LEAK} + I_{AMX8XX}} = \frac{100\mu F * (3.3V - 0.3V - 1.2V)}{11nA + 18nA} * \frac{1\ hr.}{3600\ s} = \ 1.72\ hours$$

Therefore, nearly 2 hours of backup time can be achieved in autocalibration mode using only a 100µF capacitor as the backup power source. Table 4-1 on page 16 summarizes the expected backup time for various ceramic capacitor sizes and AMX8X5 operating modes and Figure 5 plots the data.

Table 4-1: Backup Times

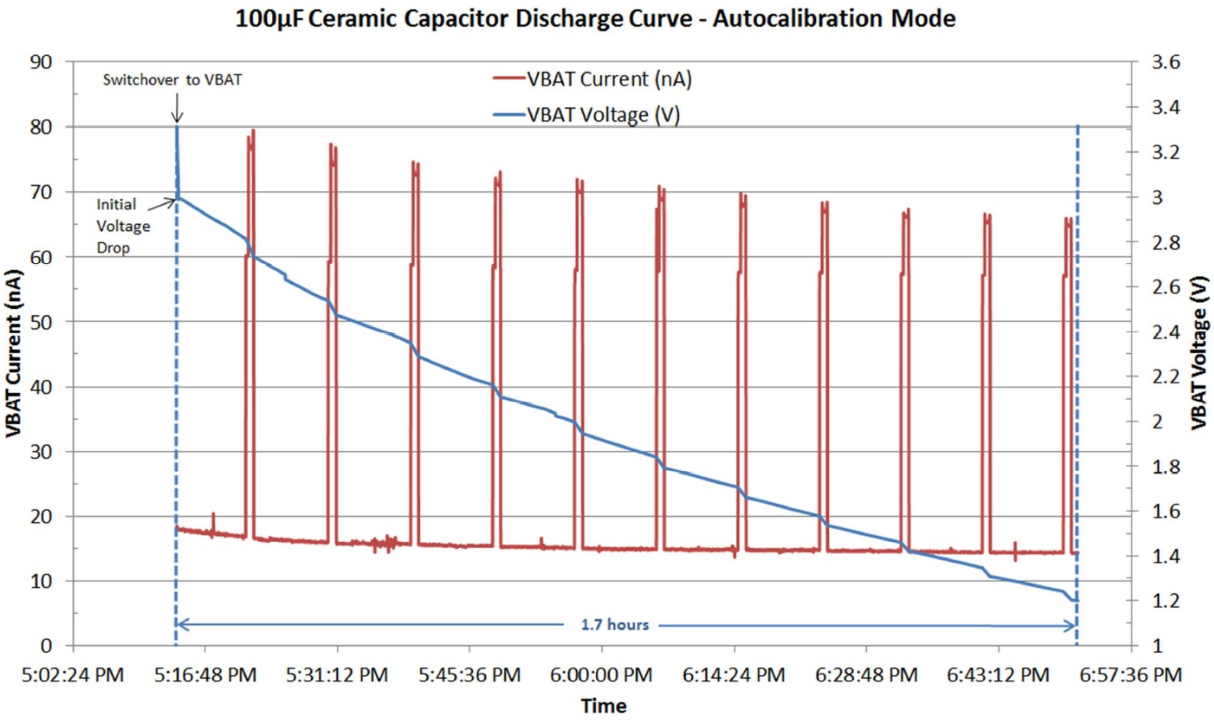
Capacitor Value (µF)	Package Case Code	Size (mm) (LxWxH)	Leakage Current (nA)	Hours of Backup Time (3.3V - 1.2V)		
				XT Mode	Acal Mode	RC Mode
100	1206	3.2 x 1.6 x 1.6	11	0.74	1.72	2.04
47	0805	2.0 x 1.25 x 0.95	5.5	0.35	0.93	1.15
22	0603	1.6 x 0.8 x 0.8	2.6	0.12	0.36	0.46
10	0402	1.0 x 0.5 x 0.7	1.1	0.04	0.12	0.15

Figure 4-1: Ceramic Capacitor Backup Times



The expected backup times calculated in Table 4-1 correlated strongly with actual measurement data on the real hardware. One such example is shown in Figure 4-2 on page 17, which shows actual measurement data for an autocalibration mode application using a 100µF 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 4-2: Autocalibration Mode Backup Example



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5

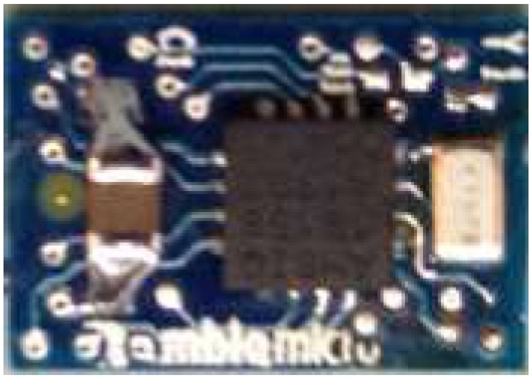
Implementation

The extremely small size and low cost of ceramic capacitors combined with the unprecedented low power, minimal footprint and BOM of the AMX8X5 enable highly economical RTC backup solutions and modules to be created, requiring minimal space. A ceramic capacitor based AMX8X5 RTC backup timing solution requires only 3 components:

- AMX8X5 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 5-1, which uses an FR4 substrate populated with the AMX8X5 QFN package (3mm x 3mm), 32.768 kHz tuning fork crystal, and a 47µF 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 AMX8X5 operating mode.

Figure 5-1: AMX8X5 RTC Backup Module on FR4 Substrate



Ceramic capacitors can also be placed in parallel to optimize the cost, height, and backup time (see Table 4-1 on page 16). The 32.768 kHz crystal can be eliminated if running the AMX8X5 in RC mode only.

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Summary

The unprecedented low power of the AMX8X5 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 AMX8X5 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 AMX8X5.

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