MICRO CRYSTAL SWITZERLAND

RV-1805-C3
Application Note

APPLICATION NOTE

RV-1805-C3

Using
Low-Cost MLCC Ceramic Capacitors
for
RTC Backup Power

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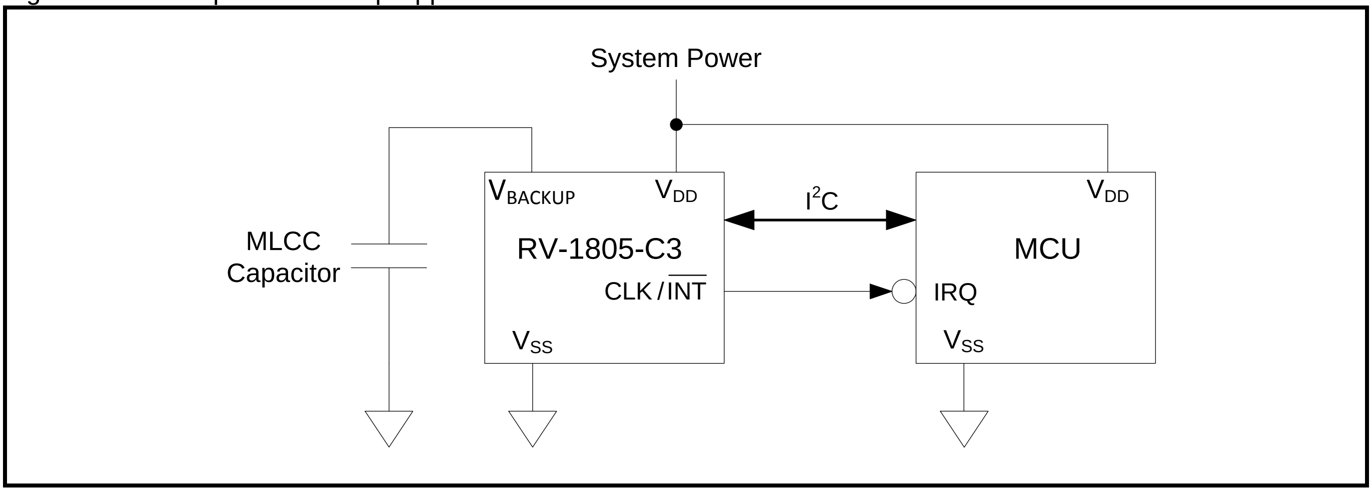
1. INTRODUCTION

This application note describes the use of low-cost MLCC capacitors as a backup power source for the RV-1805-C3 real time clock (RTC). The ultra-low power consumption of the RV-1805-C3 enables designers to use small MLCC ceramic capacitors as a backup power source and still meet the required RTC data and time retention period for many applications. The RV-1805-C3, with unprecedented low power, is the first product in the industry enabling use of low-cost MLCC 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 V_{BACKUP} switchover capabilities of the RV-1805-C3, requiring no additional external components, minimizes the BOM resulting in further cost and space savings.

2. APPLICATIONS

In a typical RV-1805-C3 RTC backup application, a main system power source is supplied to both the RV-1805-C3 and the MCU. A rechargeable backup power source, such as a supercapacitor, battery, or MLCC ceramic capacitor, is attached the RV-1805-C3 V_{BACKUP} pin. Using the RV-1805-C3 internal trickle charger, the backup power source can be charged directly from main system power. A small size MLCC ceramic capacitor (100 µF or less) will typically be charged to within 400 mV 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 RV-1805-C3 will automatically switch over to the backup power source on the V_{BACKUP} pin. A block diagram of this typical application is shown in the Figure 1 below.

Figure 1: RTC Capacitor Backup Application



During and after the process of switchover to the V_{BACKUP} backup supply, the RV-1805-C3 will continue counting and retain date and time information. With up to 256 bytes of user programmable RAM, the RV-1805-C3 can also retain important user data, which the MCU can write to the RV-1805-C3 RAM prior to main system power failure.

There are many applications that can use the RV-1805-C3 combined with a MLCC 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

3. BACKUP TIME FACTORS

When using a capacitor for backup power, the length of time the RV-1805-C3 can retain date, time, and data information will be dependent upon several factors listed below.

1. RV-1805-C3 mode of operation
2. Voltage of the main system power supply, which is used to charge the capacitor on the V_{BACKUP} pin
3. Max voltage rating of the capacitor
4. Size/capacity of the capacitor
5. Capacitor leakage current or insulation resistance
6. Initial V_{BACKUP} voltage drop on the capacitor during switchover

3.1. RV-1805-C3 OPERATING MODE

The RV-1805-C3 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 RV-1805-C3 is the lowest power RTC available on the market.

XT mode: In this mode, the RV-1805-C3 uses the 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 RV-1805-C3 also uses the 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 RV-1805-C3 does not use the 32.768 kHz crystal and the crystal oscillator circuitry is turned off completely. The RV-1805-C3 runs continually from its 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 V_{BACKUP} pin in each mode.

Table 1: RV-1805-C3 Timing Modes

Mode	Timing Accuracy (25°C)*	Typ. Current V_{BACKUP} = 3.0 V	Typ. Current V_{BACKUP} = 1.3 V	Average Current (3.0 V to 1.3 V)
XT	+/- 2 ppm	63 nA	60 nA	61.5 nA
RC	+/- 1% (maximum jitter)	19 nA	16 nA	17.5 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)	25 nA	21 nA	23 nA

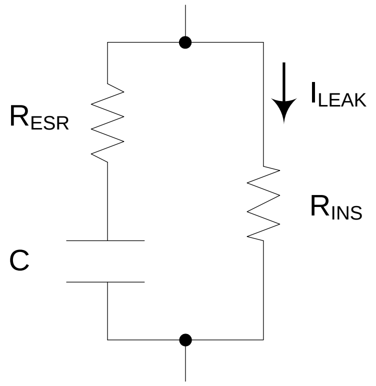
* Note: Timing accuracy is specified at 25°C after digital calibration of the RC oscillator and 32.768 kHz crystal. The 32.768 kHz tuning fork crystal has a negative temperature coefficient with a parabolic frequency deviation, which can result in a change of up to -160 ppm across the entire operating temperature range of -40°C to 85°C in XT mode. Autocalibration mode timing accuracy is specified relative to XT mode timing accuracy from -10°C to 60°C. The typical RC frequency variation (maximum jitter) 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 RV-1805-C3 trickle charges the V_{BACKUP} capacitor from the voltage supply connected to the V_{DD} pin. Therefore, the RV-1805-C3 internal trickle charger cannot charge the V_{BACKUP} 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 V_{BACKUP} 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 RV-1805-C3 operating current. An equivalent low frequency circuit model (not including inductive effects) for a MLCC ceramic capacitor is shown below in the Figure 2.

Figure 2: Low Frequency Capacitor Model



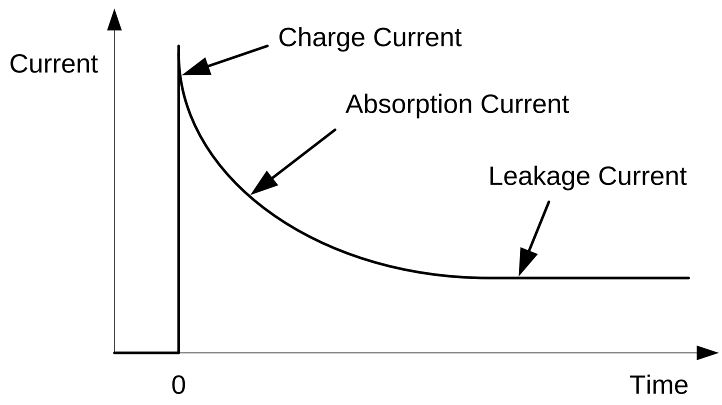
Where:
R_{ESR} = equivalent series resistance (ESR)
R_{INS} = insulation resistance
I_{LEAK} = leakage current due to insulation resistance
C = capacitance value

A MLCC 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 RV-1805-C3, R_{ESR} can be ignored when calculating backup time.

The insulation resistance of a MLCC ceramic capacitor represents the ratio between the applied voltage and the leakage current after a set period of time. In MLCC 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: MLCC Ceramic Capacitor Current Profile



As can be seen in the MLCC 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.

A comparison of the leakage currents of typical inexpensive MLCC ceramic capacitors ranging from 10 to 100 µF can be done. Table 2 shows typical leakage currents of the capacitors 10 minutes after applying 3.3 V across the capacitor terminals at room temperature.

Table 2: MLCC Ceramic Capacitor Leakage Currents

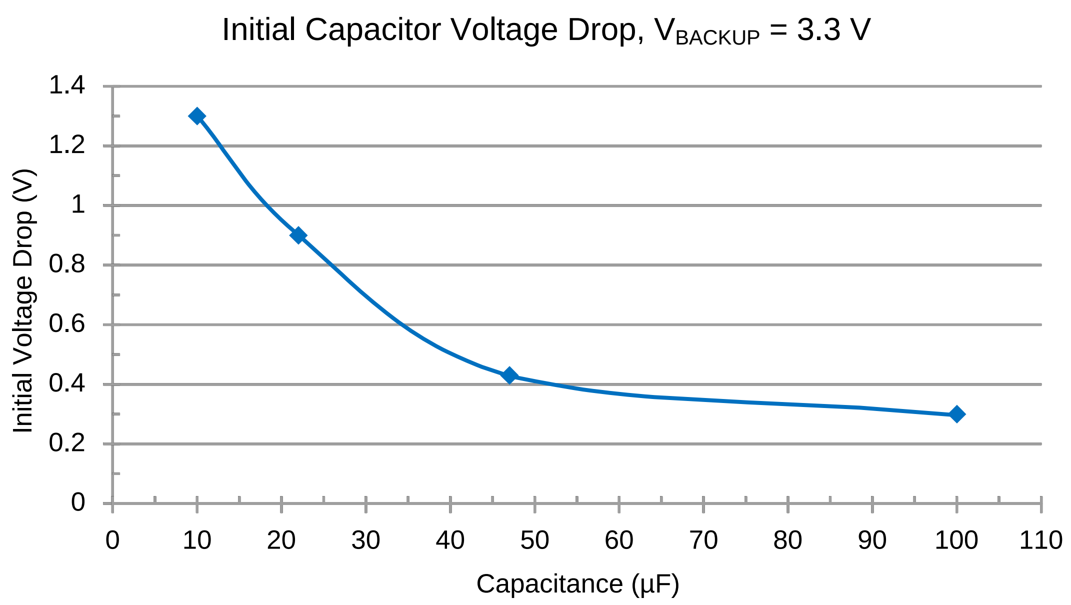
Capacitor Value (µF)	Package Case Code	Size (mm) (L x W x H)	Leakage Current (nA)
100	1206	3.2 x 1.6 x 1.6	11
47	0805	2.0 x 1.25 x 0.95	5.5
22	0603	1.6 x 0.8 x 0.8	2.6
10	0402	1.0 x 0.5 x 0.7	1.1

Note that MLCC 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 MLCC 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 RV-1805-C3 will switch over to the V_{BACKUP} supply immediately after the V_{DD} voltage drops below the switchover threshold voltage (typically 1.5 V). The energy required for the RV-1805-C3 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 V_{BACKUP} voltage decreases because the RV-1805-C3 requires less energy to complete the switchover operation at lower V_{BACKUP} voltages. The typical capacitor voltage loss immediately after switchover with V_{BACKUP} = 3.3 V 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 RV-1805-C3 operating mode as described in section 3.1.

4. ESTIMATING BACKUP TIME

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

$$\text{Backup Time} = \frac{C * (V_{BACKO} - V_{LOSS} - V_{BACKMIN})}{I_{LEAK} + I_{RV\text{-}1805\text{-}C3}}$$

Where:
C = Capacitor value
V_{BACKO} = Initial V_{BACKUP} voltage prior to switchover
V_{LOSS} = Initial capacitor voltage loss due to the RV-1805-C3 energy required to complete the switchover operation (see Figure 4).
$V_{BACKMIN}$ = Minimum battery voltage that can be applied to V_{BACKUP} before an RV-1805-C3 reset occurs.
I_{LEAK} = capacitor leakage current (see Table 2)
$I_{RV\text{-}1805\text{-}C3}$ = RV-1805-C3 average current consumption (see Table 1) from V_{BACKO} - V_{LOSS} to $V_{BACKMIN}$.

For example, operating in autocalibration mode with a 100 µF MLCC ceramic capacitor charged to 3.3 V prior to switchover, and a typical RV-1805-C3 minimum V_{BACKUP} voltage of 1.2 V results in a backup time as follows:

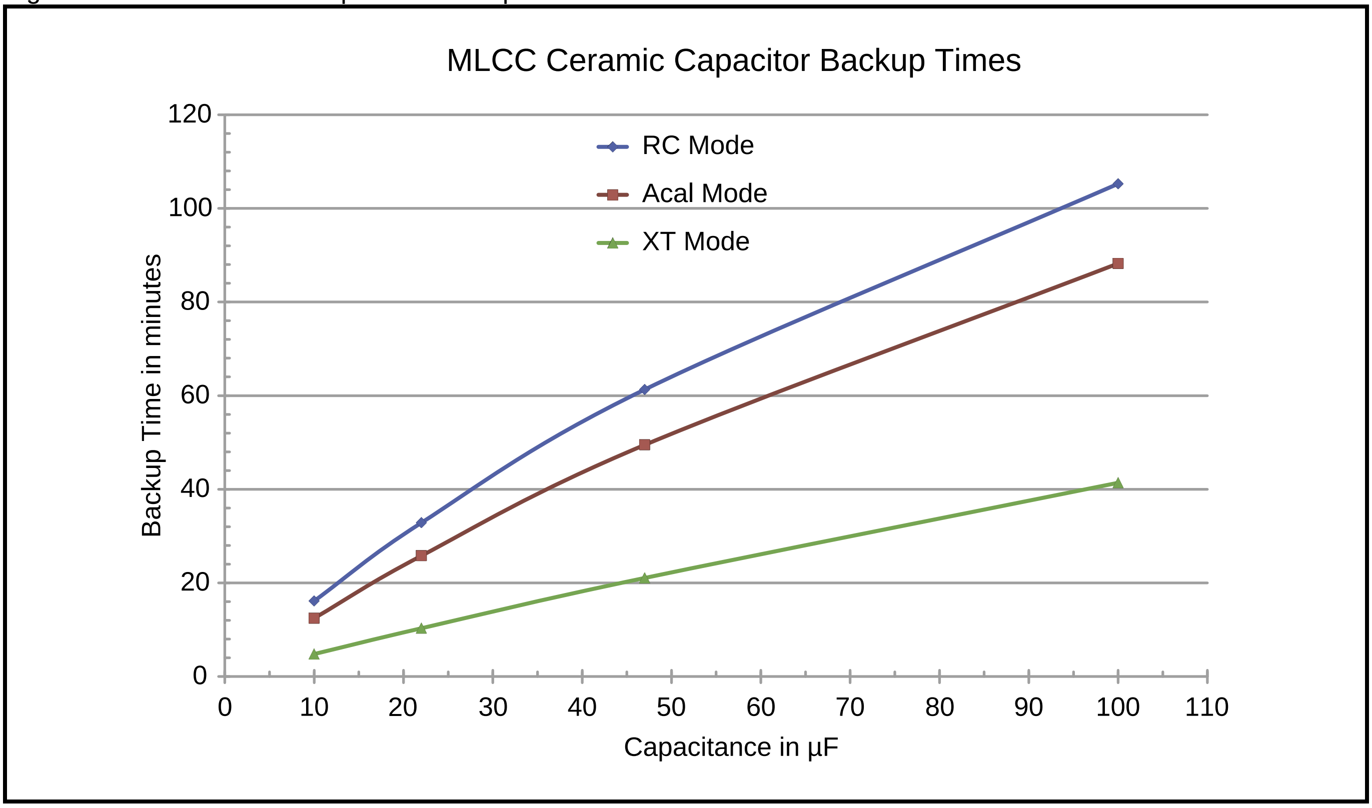
$$\text{Backup Time} = \frac{C * (V_{BACKO} - V_{LOSS} - V_{BACKMIN})}{I_{LEAK} + I_{RV\text{-}1805\text{-}C3}} = \frac{100\ \mu F * (3.3\ V - 0.3\ V - 1.2\ V)}{11\ nA + 23\ nA} * \frac{1\ hr.}{3600\ s} = 1.47\ \text{hours}$$

Therefore, up to 1.5 hours of backup time can be achieved in autocalibration mode using only a 100 µF capacitor as the backup power source. Table 3 summarizes the expected backup time for various MLCC ceramic capacitor sizes and RV-1805-C3 operating modes and Figure 5 plots the data.

Table 3: Backup Times

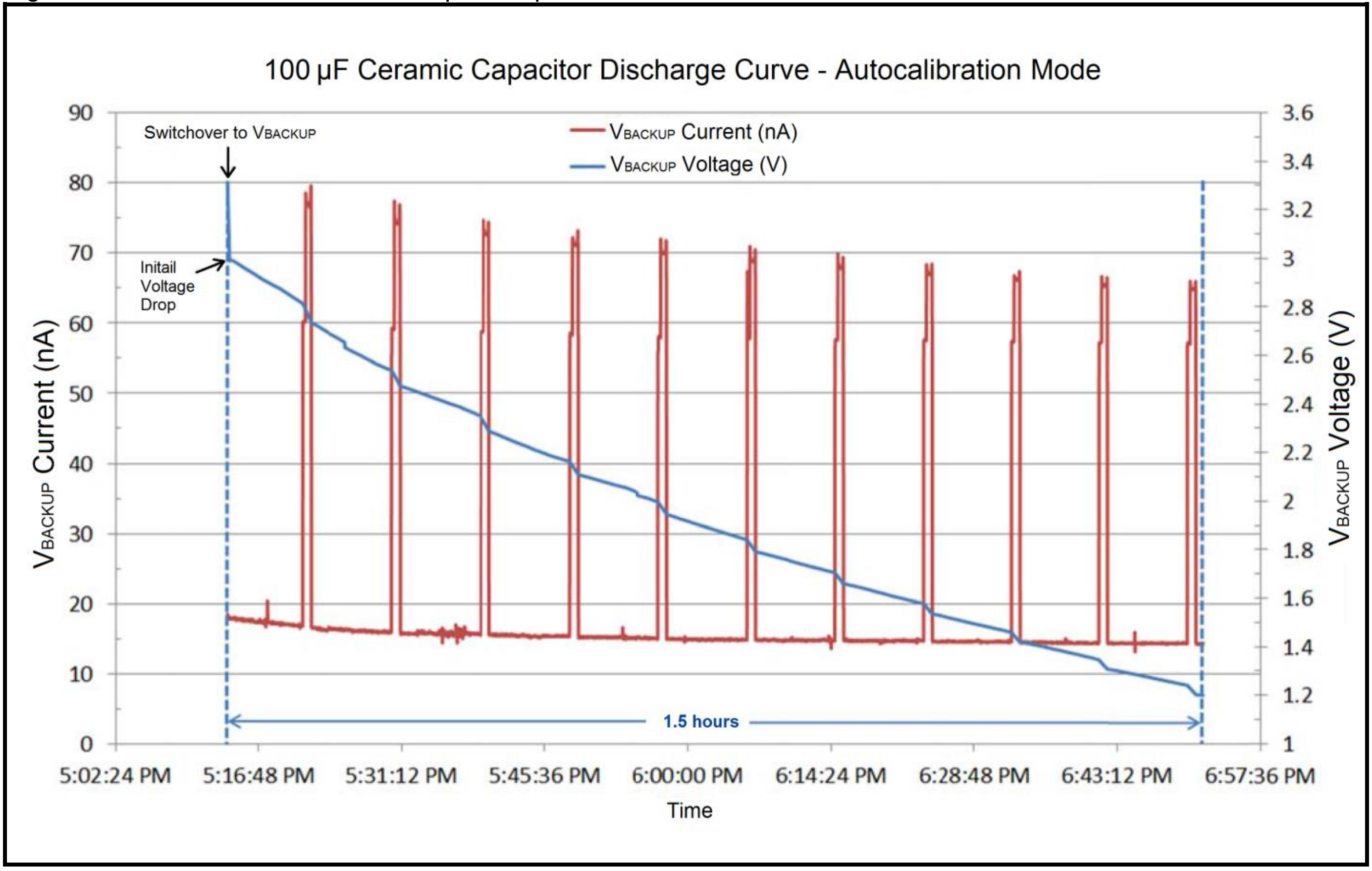
Capacitor Value (µF)	Package Case Code	Size (mm) (L x W x H)	Leakage Current (nA)	Backup Time (3.3 V to 1.2 V) in [h:mm]		
				XT Mode	Acal Mode	RC Mode
100	1206	3.2 x 1.6 x 1.6	11	0:41	1:28	1:45
47	0805	2.0 x 1.25 x 0.95	5.5	0:21	0:49	1:01
22	0603	1.6 x 0.8 x 0.8	2.6	0:10	0:26	0:33
10	0402	1.0 x 0.5 x 0.7	1.1	0:05	0:12	0:16

Figure 5: MLCC 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 µF MLCC ceramic backup capacitor. Looking at the higher current pulses on red curve (V_{BACKUP} current), the autocalibration cycles can clearly be seen as crystal oscillator (and autocalibration engine) is periodically turned on/off. The blue curve (V_{BACKUP} voltage) shows the extremely slow capacitor discharge rate, which gives a backup time of 1.5 hours as expected.

Figure 6: Autocalibration Mode Backup Example



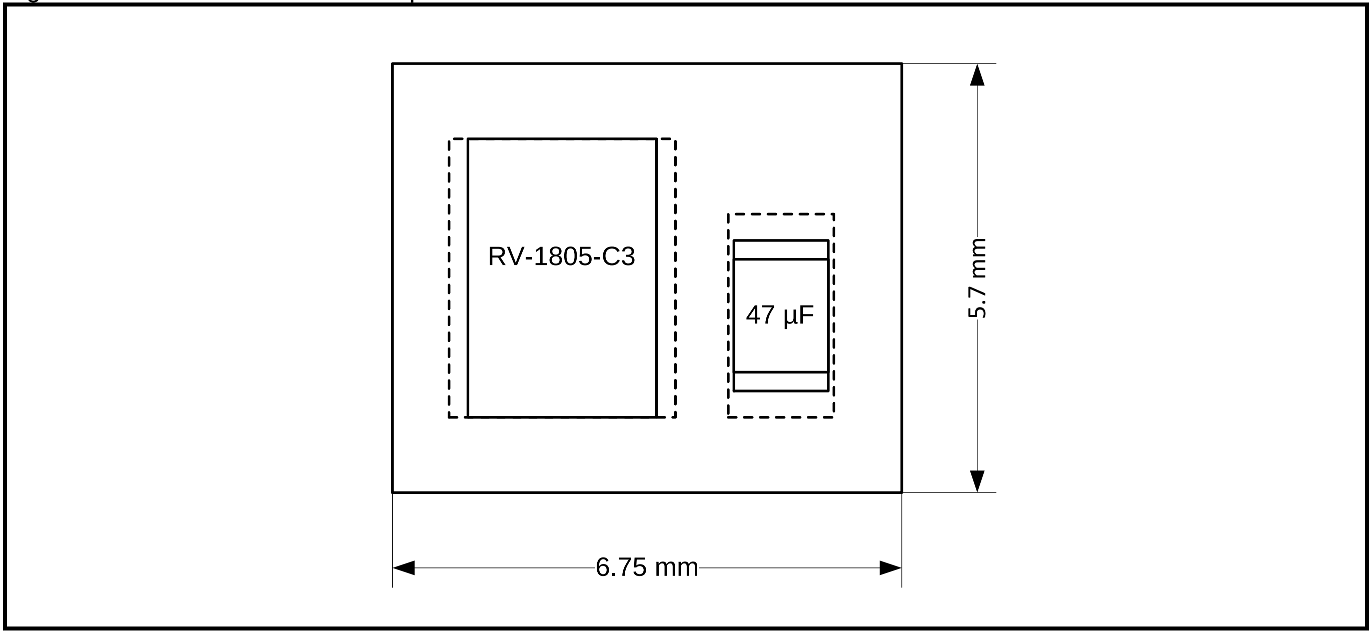
5. IMPLEMENTATION

The extremely small size and low cost of MLCC ceramic capacitors combined with the unprecedented low power, minimal footprint and BOM of the RV-1805-C3 enable highly economical RTC backup solutions and modules to be created, requiring minimal space. A MLCC ceramic capacitor based RV-1805-C3 RTC backup timing solution requires only 2 components:

- RV-1805-C3 device supporting the V_{BACKUP} function
- MLCC ceramic capacitor

A draft of a backup solution is shown in Figure 7, which can use an FR4 substrate populated with the RV-1805-C3 package (3.70 mm x 2.50 mm) and a 47 µF MLCC ceramic capacitor (2.0 mm x 1.25 mm). The module size shown is 5.70 mm x 6.75 mm, but further placement and routing optimizations can reduce its size even more. This solution provides 20 minutes to 1 hour of backup time dependent upon the RV-1805-C3 operating mode.

Figure 7: RV-1805-C3 RTC Backup Module on FR4 Substrate



MLCC ceramic capacitors can also be placed in parallel to optimize the cost, height, and backup time (see Table 3).

6. SUMMARY

The unprecedented low power of the RV-1805-C3 and its V_{BACKUP} switchover capabilities now makes it possible, for the first time in the industry, to use inexpensive MLCC 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 RV-1805-C3 switchover, the backup time can be determined given the MLCC 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 MLCC ceramic capacitor and the RV-1805-C3.

7. DOCUMENT REVISION HISTORY

Date	Revision #	Revision Details
April 2014	1.0	Initial draft version
June 2014	1.1	With term “maximum jitter”
July 2014	1.2	Released Version - Modified part number to RV-1805-C3 - Added MLCC
January 2015	1.3	- Corrected a few typographical errors