SECTION 6: LITHIUM/BATTERY BACKUP

Soft Microcontroller devices are lithium backed for data retention in the absence of V_{CC}. In the Soft Microcontroller the state of the microcontroller is also maintained, unlike a conventional processor system using an external NV RAM. This section is a comprehensive discussion of the lithium back up feature. It covers system design, battery attach procedure, I/O pin restrictions, lifetime calculations, and battery/RAM size tradeoffs. Some of the information is unnecessary to module users but will provide background information for proper handling and system design. Each section will highlight both chip and module considerations when there are differences.

When properly used, lithium backed microcontrollers provide better than 10 years of data retention in the absence of power. This means that a total of over 10 years in the absence of power at room temperature is guaranteed. Elevated temperatures cause higher than normal data retention current to be drawn by a RAM. However, these remarks are only relevant to a system that is powered down. While +5V is applied to the device, the lithium cell is isolated from any loading. Therefore, data retention must be viewed in the context of the power supply duty cycle. For example, if a system is rated for 10 years of data retention, but will have power applied for 12 hours per day, the expected lifetime is greater than 20 years.

DATA RETENTION

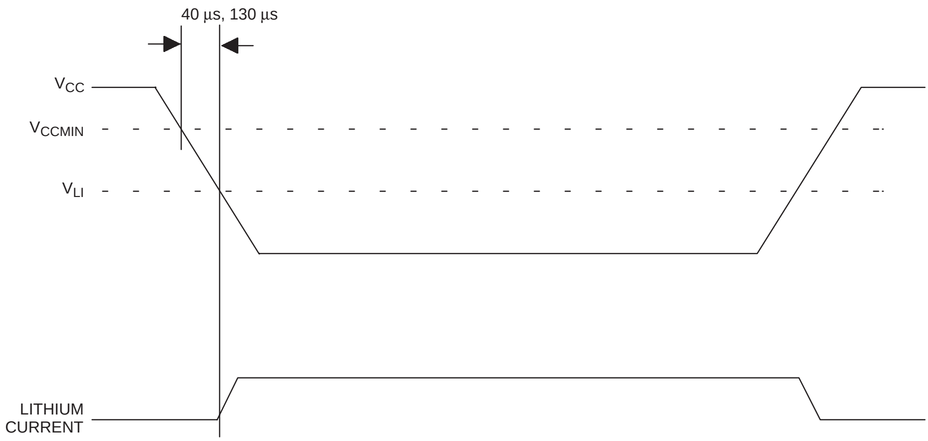
The Secure Microcontroller family provides nonvolatile storage in ordinary SRAM. It accomplishes this by battery–backing the memory in the absence of power. When power (V_{CC}) begins to fail, the processor generates an internal power–fail reset condition as discussed in the next chapter. At this time, SRAM chip enables are taken to a logic high inactive state. Also, I/O port pins also go to a logic high state. If power continues to fall and crosses below the lithium threshold, the microprocessor enters the data retention state, and power is drawn from the lithium cell. The power supply output to the SRAM (V_{CCO}) is switched from V_{CC} to the lithium cell. V_{CC} is subsequently ignored, except for comparators that monitor its level. Lithium backed chip enables are maintained at a logic high state with lithium power, but non–backed chip enables follow V_{CC} down. Individual product differences should be observed. Maintaining chip enables at an inactive level and lowering the power supply to approximately +3V causes the NV RAM to enter a data retention state. Thus the combination retains data for a long period as the circuits draw a very small current from the lithium cell. Modules easily attain better than 10 years of data retention. Chip solutions can be designed to achieve a much greater lifetime depending on the user's needs.

BATTERY BACKED CIRCUITS

The Secure Microcontroller is the only computer that is completely lithium backed. This means that both internal configuration and data are preserved when power is removed. However, unlike a simple NV RAM, the microprocessor is an extremely complex circuit that must be fully prepared for lithium backup. Once prepared, the microprocessor is guaranteed to draw less than 75 nA from its backup source. This number is typically 5 nA. The user's selection of RAM will determine the total loading on the lithium cell. In the case of a module, Dallas has screened the RAM to make certain that the total loading guarantees better than 10 years of data retention for the selected lithium cell at room temperature.

In order to achieve this ultra–low power state, special logic in the microprocessor places all internal nodes in a predictable (low power) state. This occurs during system power down while V_{CC} is falling below the reset voltage threshold and is still above the lithium voltage. If the power supply slews between these threshold voltages faster than 40 µs (130 µs for DS5001/2), the circuits may not complete the backup procedure and the microprocessor backup current could be substantially greater than 75 nA, and/or program/data corruption could occur. Fortunately, a modest amount of system capacitance is enough to prevent fast slewing. The actual value will depend on the total system loading. This slew rate must be met for either a chip or module solution. In either case, the microprocessor must have time to prepare for lithium backup. Figure 6–1 illustrates the power supply conditions that should be met.

POWER SUPPLY SLEW RATE Figure 6–1



Each time V_{CC} is restored, the lithium backed functions will remain as they were left. A result is that many of these values are not altered on a reset condition except for the 'no battery reset'. In the documentation, this is referred to as 'No V_{LI} reset'. This will occur after the first time V_{CC} is applied to the microprocessor. The 'no battery reset' state is documented in the section on resets. A module user will never see the 'no battery reset' condition as it was cleared during assembly and test prior to leaving the factory.

BATTERY ATTACH PROCEDURE

This section applies to microprocessor chips only, not modules. When a microprocessor is received from the factory, it is completely uninitialized. All nonvolatile functions are absent since there is no backup source connected to the chip. As mentioned above, the microprocessor must place circuits in a low power state to prepare for lithium backup. If a battery were attached to an uninitialized chip, the backup current would be unpredictable. For this reason, the following battery attach procedure must be followed.

1. Apply V_{CC} to the microprocessor.
2. Attach the lithium cell to the V_{LI} input.
3. Configure and program the device as normal. (Optional at this time.)
4. Power down the microprocessor (remove V_{CC}) using the guidelines discussed above while leaving the battery attached.

The first time a battery is attached to the microprocessor is a special event. When power is applied in the absence of a lithium cell, the device performs a No V_{LI} Reset. This allows the microprocessor to initialize control bits that are ordinarily nonvolatile and unaffected by a reset. The microprocessor will never be completely in this state again unless all power (including battery) is removed by the user. In order to provide the extremely low back up currents (<75 nA), the circuits must configure themselves for lithium backup. This is done when V_{CC} is removed from the chip. That is, the microprocessor IS NOT CONFIGURED FOR LITHIUM BACKUP when it is received. Therefore, the battery should be attached with V_{CC} at +5V. This will prevent the microprocessor from placing a load on the lithium cell until V_{CC} is removed. At this time, the microprocessor performs its power down procedure and prepares for ultra low power data retention. Attaching the battery to an unpowered microprocessor places an unknown load on the lithium cell. This may drain the cell excessively and should not be done.

BATTERY LIFETIME

The calculations of data retention lifetime are helpful for chip or module users. They can serve as design and system reliability guidelines. All lithium backed microcontroller modules are rated for better than 10 years of data retention in the absence of V_{CC} at 25°C. Following these guidelines, similar performance can be achieved using chips. It is also not difficult to achieve better than

10 years depending on the user's actual environment and design goals.

The system lifetime can be determined from three parameters: 1) Data retention current, 2) Lithium cell capacity, 3) Lithium self–discharge. Current production lithium cells have extremely good self–discharge performance. Manufacturer's data and Dallas Semiconductor characterization has determined that the self–discharge of a coin cell lithium battery is less than 0.5% per year at 25°C. Consequently, even after 15 years of shelf life, the lithium cell would have 90% of its capacity remaining. Therefore when using a lithium coin cell, the self–discharge mechanism is not a consideration for rating equipment life.

Data retention current is a combination of RAM, microprocessor, Real–time clock (RTC), and other lithium backed circuits, if any. In a Dallas module, these are screened for combination with the appropriate battery. In using a chip, the user must balance the size/cost of a larger lithium cell with the data retention current/cost of SRAMs.

When designing a chip–based system and selecting the appropriate SRAM, the important specification is data retention current. This is not the same as standby current. Data retention current should be specified with $\overline{CE} = V_{IH}$ and V_{CC}=3V. This specification is usually available at 25°C, and possibly for other temperatures. Selected RAMs have been provided in chapter 5 with the manufacturer specified data retention current. The lifetime calculations are illustrated below. The formula for data retention life in years is as follows:

$$\frac{\text{Battery capacity in amp hours}}{\text{Data retention current in amps * \# days in a year * \# of hours in a day}}$$

As an example, the Microprocessor rated for 75 nA, SRAM for 500 nA, RTC for 400 nA for a total of 950 nA. A Panasonic CR1632 lithium cell is used with a capacity of 120 mAh.

$$\frac{120 * 10^{-3}}{(75 + 500 + 400) * 10^{-9} * 24 * 365)} = \frac{120 * 10^{-3}}{8.54 * 10^{-3}} = 14 \text{ years}$$

Thus a system with less than 1 µA of data retention current and a CR1632 lithium cell will achieve well over 10 years of data retention in the absence of V_{CC}. Referring to the recommended RAM chart in the previous section, the user will find a variety of RAMs that allow this at room temperature. It makes no difference if the system operates at 70°C, as long as data retention is at 25°C. If storage is at elevated temperature, than the data retention current should be derated accordingly. If the manufacturer does not specify data retention current over temperature, a conservative number is a 70% increase per 10°C. Thus if a RAM in data retention mode draws 1 µA at 25°C, it will draw approximately 1.7 µA at 35°C.

A second example illustrates the case of elevated temperature storage.

In this example, the system is constructed using a DS5001FP chip with a Sony CXK581000P–LL 128K x 8 SRAM. The system will be stored at 40°C. As shown in the table in chapter 5, the data retention current of this RAM is 2.4 µA at 40°C. The DS5001FP data retention current will actually drop as temperature increases, so the maximum of 75 nA is conservative. This gives a total data retention current of 2475 nA. In this system, a Rayovac BR2325 with a capacity of 180 mAh is used.

$$\frac{180 * 10^{-3}}{(2400 + 75) * 10^{-9} * 24 * 365)} = \frac{180 * 10^{-3}}{21.68 * 10^{-3}} = 8.3 \text{ years}$$

Note that these ratings are for continuous data retention so V_{CC} is assumed absent for the entire period. Actual performance have a longer lifetime based on the ratio of time when V_{CC} is applied vs. data retention time.

LITHIUM BATTERY USAGE

In the vast majority of applications, lithium batteries provide a reliable means of backing up data and configuration. The voltage varies only slightly over its useful life, so it is difficult to measure capacity. A CR chemistry will begin life at 3.3V and drop to 2.9V near the end of life. As a consequence, some users choose to incorporate battery clips so that lithium cells are easily replaced. This is not recommended since such clips are susceptible to shock and vibration. It is possible that the connection to a lithium cell would be momentarily lost during such a shock, resulting in a potential loss of data. Therefore, soldered battery tabs are recommended. If a user elects to use a battery clip with a capacitor (to support momentary disconnect), the leakage of the capacitor should be considered in the lifetime calculations.

FRESHNESS SEAL

The Secure Microcontroller family is designed to maximize the lifetime of a lithium backup source. The circuits described above contribute to a long life. There is one further provision that will benefit users that intend to store their systems in an unpowered state, but that do not require it to retain data during this period. An example might be a completed system stored in inventory. Since data retention is not required, there is no benefit to using even the modest lithium current that will normally be drawn. For this reason, Secure Microcontrollers incorporate the Freshness Seal. The Freshness Seal electrically isolates the lithium cell from any external loading. Thus even in the absence of power, the SRAM and Real–Time Clock leakage currents will not be drawn from the lithium cell for as long as the Freshness Seal is applied.

This feature is available to module users of the DS5000 series [DS5000(T), DS2250T] and all users of the DS5001/2 series [DS5001FP, DS5002FP, DS2251T, DS2252T]. In the case of DS5000 and DS2250 modules, the factory ships these with the Freshness Seal applied. In the case of a DS5001, DS5002 series device, the Freshness Seal can be applied via the Bootstrap Loader at any time. Thus if the Freshness Seal is not removed, the time that a Secure Microcontroller based system is stored in inventory will not reduce the data retention lifetime since the lithium cell is unloaded.

To clear the Freshness Seal, simply apply V_{CC}. On a DS5000 series device, the Freshness Seal can not be restored by the user. Therefore, if Freshness Seal is desired for storage, the part should not be powered up when received or installed. Since a DS5001/DS5002 series device can invoke the Freshness Seal via the Loader, this restriction does not apply. To invoke the Freshness Seal on a DS5001, DS5002 series device, the "N" command should be issued to the Bootstrap Loader.

IMPORTANT APPLICATION NOTE

The pins on a Secure Microcontroller chip or module are generally as resilient as other CMOS circuits. They have no unusual susceptibility to electrostatic discharge (ESD) or other electrical transients. **However, no pin on a Soft Microcontroller chip or module should ever be taken to a voltage below ground.** Negative voltages on any pin can turn on internal parasitic diodes that draw current directly from the battery. If a device pin is connected to the "outside world" where it may be handled or come in contact with electrical noise, protection should be added to prevent the device pin from going below –0.3V. It is also common for power supplies to give a small undershoot on power up, which should be prevented. Application Note 93, Design Guidelines for Microcontrollers Incorporating NV RAM, discusses how to protect devices against these conditions.