Technical White Paper

E-latch Design Overview

ABSTRACT

The automotive industry is experiencing a trend away from traditional highly mechanical door latching systems and toward electronically controlled designs, commonly referred to as E-latches. This paper introduces the architecture, functionality, advantages, and implementations of E-latches.

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1 Introduction

First let's define some terms. In a car door, the latch provides *safety* by holding the door closed, while the lock provides *security* by preventing the latch from being released. The latch is a mechanical device that engages with a striker on the door frame to keep the door shut. The lock, often integrated with the latch mechanism, uses a key or electronic system to prevent the latch from disengaging, thus securing the door.

Traditional automotive doors rely on complex mechanical linkages to engage and disengage a pawl with a striker, enabling door opening and closure. Electric locks have been common for years, but these have typically simply added a small electric motor to drive the existing mechanical linkages.

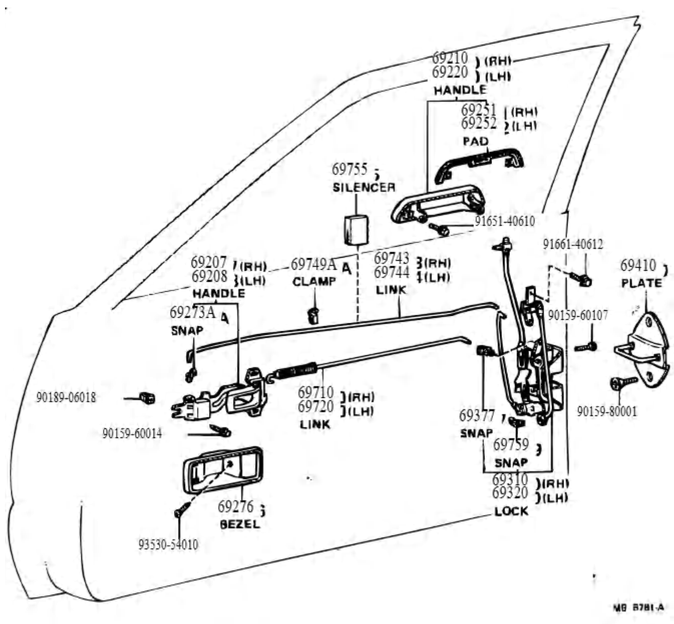

Figure 1-1. Typical Mechanically Complex Door Latch and Lock Example

E-latch systems, in contrast, tend to *replace* the mechanical linkages with electronics and electrical wiring. These "E-latches" offer new functionalities and design possibilities that surpass the capabilities of mechanical predecessors. With the increasing integration of electronics and advanced features in vehicles, the transition to electronically controlled latches is gaining traction.

With the electrification of the latches and locks, these functions become dependent on the electric power typically supplied by the car battery. For safety reasons, a backup power supply is often part of the E-latch system.

2 E-latch System Architecture

A typical E-latch system is made up of several components and can be arranged as either a centralized system or in a distributed manner. In a centralized system, a single module provides the backup power and optionally redundant drivers, which are required for operation of all the latches and locks throughout the vehicle. This arrangement is often called a crash protection module (CPM) or crash unlock protection module (CUPM). In a distributed system, the energy storage and drivers for each door are controlled and driven locally.

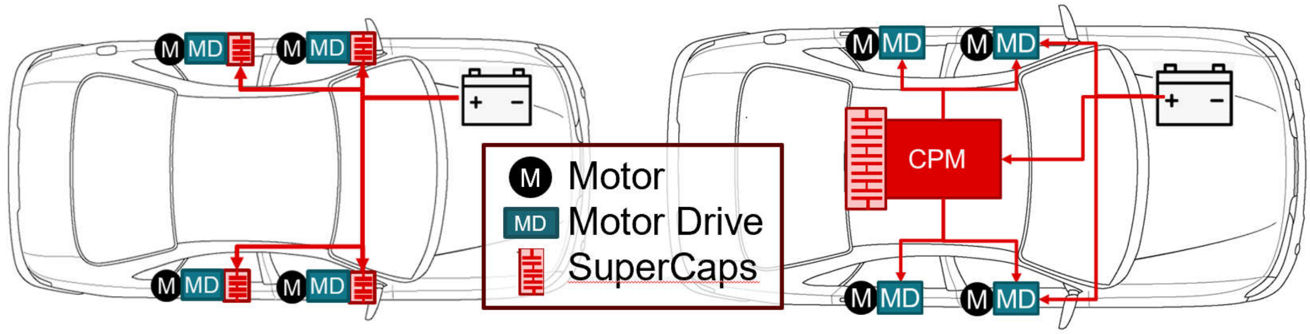

Figure 2-1. Distributed (Left) and Centralized (Right) E-latch Architectures

There can also be hybrid arrangements, for example with each side of the vehicle having an E-latch system for the doors.

3 Typical Design

A block diagram for a typical E-Latch system is shown in Figure 3-1. This diagram is also found on-line at E-Latch design resources | TI.com with links to applicable components, technical documents, and tools.

The key components of the design are discussed in the sections below.

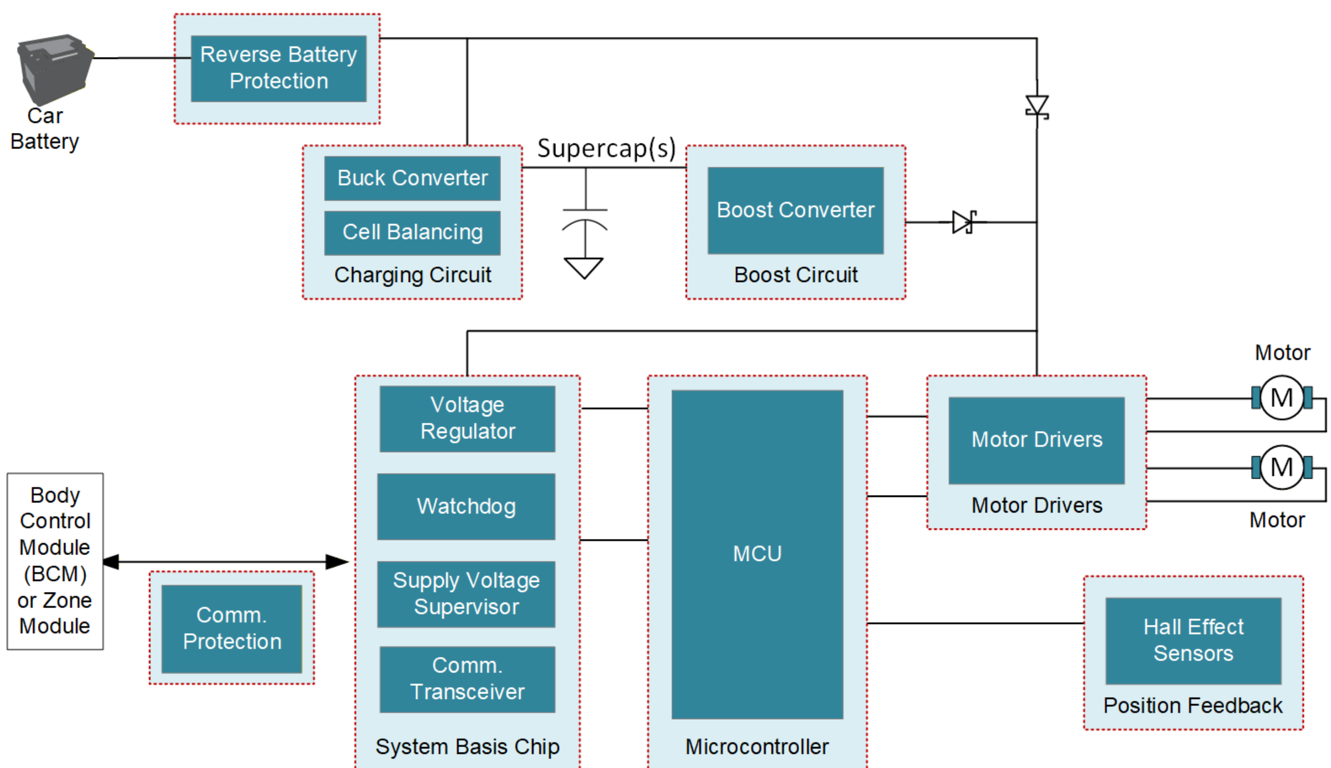

Figure 3-1. Block Diagram of E-latch

3.1 Motor Drivers

A motor driver is needed for each electric motor; there can be a single lock motor, or several motors in each door, providing features such as safe-lock, child-lock, handle presenter, soft close, or door presenter. Each motor is typically a brushed DC type and needs a full bridge (two half bridges) driver to provide the bidirectional actions, for example lock and unlock. In some cases, a brushless DC (BLDC) motor is used, requiring a driver with three half bridges.

There are various arrangements for the motor drive circuits; three examples are shown in Figure 3-2 through Figure 3-4. For the distributed E-latch system, each motor is driven by a full bridge of transistors, enabling bi-directional motion. The local supercaps provide a redundant power source to only the local circuits.

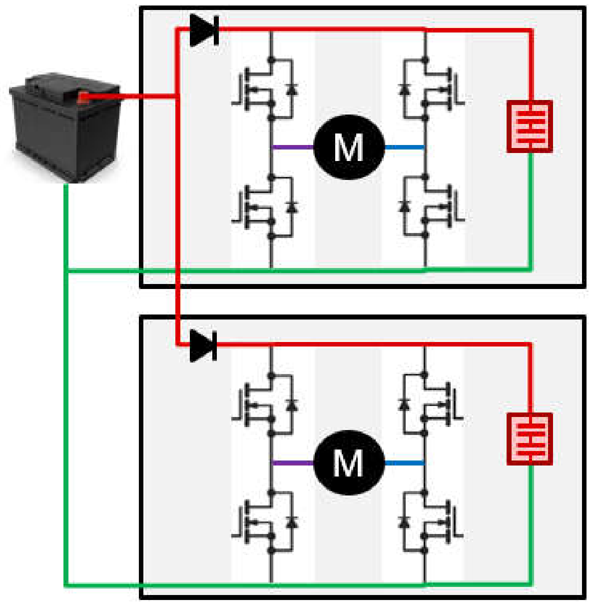

Figure 3-2. Distributed E-latch System with Local Backup Power and Motor Drivers

For systems with a centralized backup power source, the local motor driver full bridge in each door enables bidirectional motion, and is powered by the main battery during normal operation, or by the centralized backup supercapacitors in case of battery disconnect.

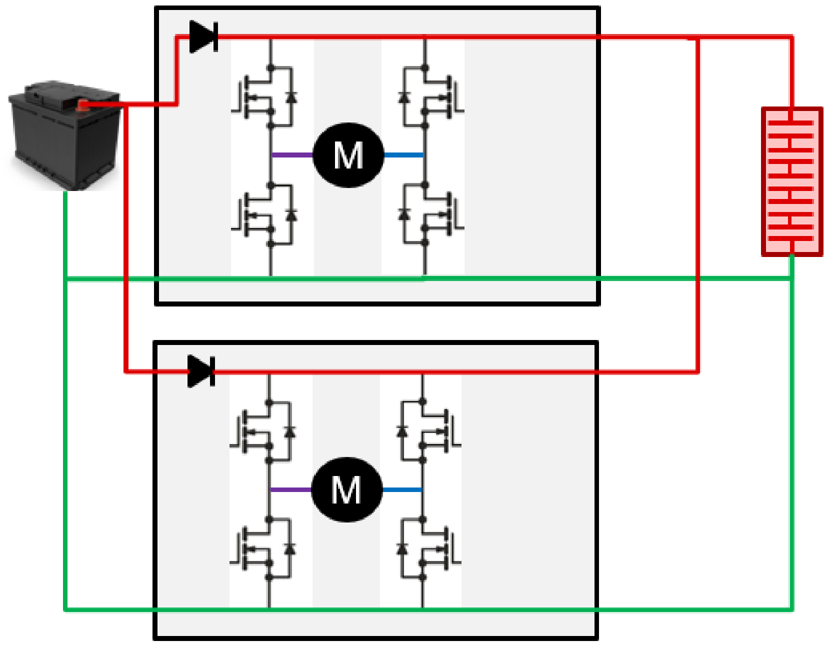

Figure 3-3. Centralized Backup Power and Local Motor Drives

In designs with redundant drivers in the central CPUM, the unlock motor drive voltages, rather than the backup power, is connected to each of the motors.

Note that diodes are required throughout these circuits to prevent back-driving from one power source to another through the body diodes of the transistors. Designers must also consider the effect of these enhanced circuits on the diagnostic features of the motor drivers.

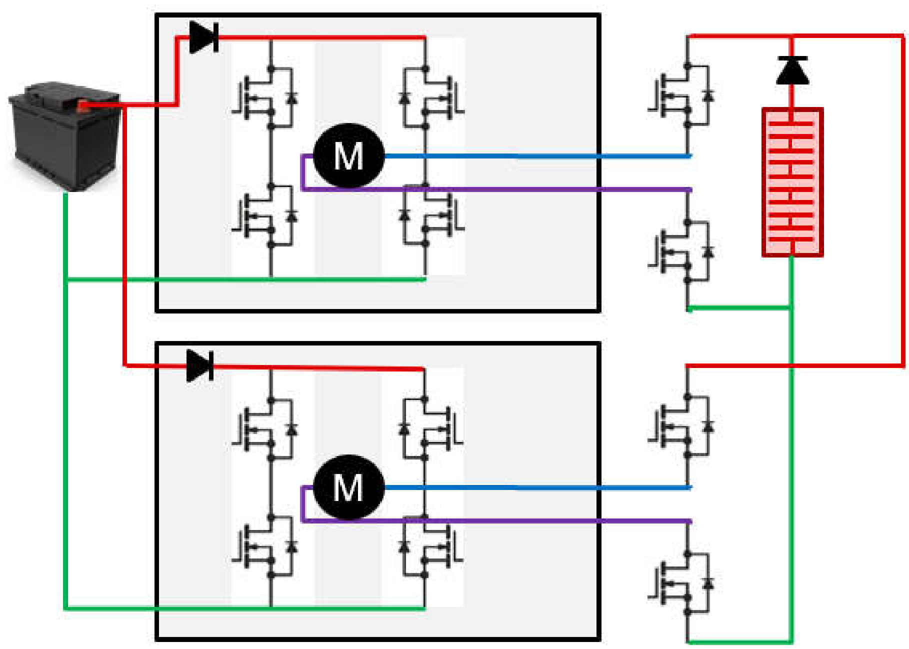

Figure 3-4. Centralized Backup Power and Redundant Motor Drives

Texas Instruments has a broad portfolio of automotive motor drivers for these applications. See more information at Motor drivers | TI.com.

3.2 Network Connection

The E-latch circuitry is connected to the vehicle network, typically through either a CAN or LIN connection. The E-latch circuitry receives commands regarding actions to perform and responds with status and diagnostic information. Often a single device, a system basis chip (SBC), includes the network transceiver, 12V-to-logic voltage regulator (either buck converter or linear LDO), and common functions such as a watchdog timer, voltage monitor, and so forth.

Texas Instruments has a broad portfolio of SBCs, see System Basis Chips on ti.com for more information.

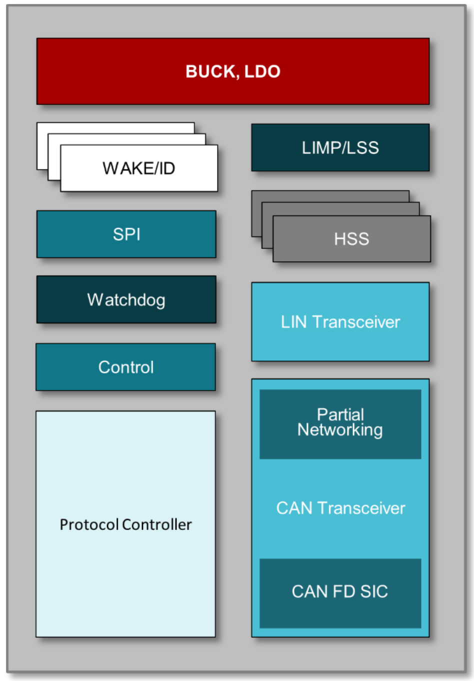

Figure 3-5. Generic SBC Block Diagram

3.3 Microcontroller

A microcontroller (MCU) receives messages from the vehicle network, and makes logic decisions about actions to take, such as charging the supercaps or unlocking the door. The MCU typically also configures the other integrated circuits in the design, monitors the state of health (SOH) of the supercapacitors, and runs diagnostic routines on the motor driver circuitry. This is illustrated in Figure 3-6, showing typical signals for the E-latch functions.

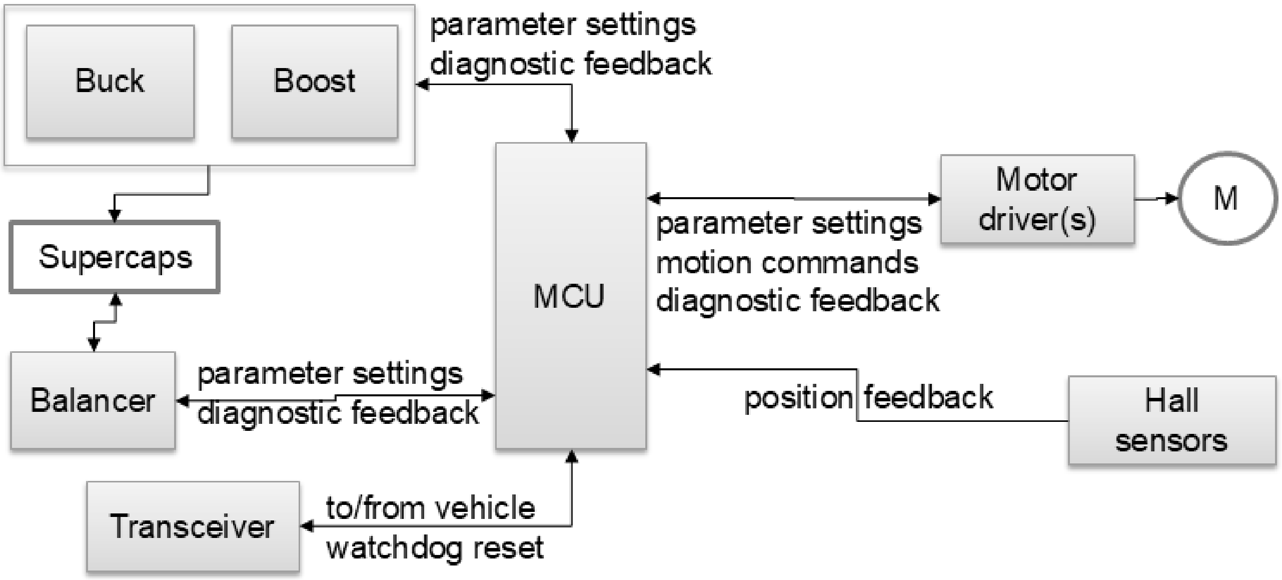

Figure 3-6. Signals To and From the Microcontroller for E-latch Functions

In cases where the E-latch functions are part of a larger electronics control unit, for example a door control unit, the MCU can control many other functions in addition to the E-latch. In these cases, the requirements for the MCU can include higher levels of processing power and expanded peripherals.

Based on typical requirements for processing power, memory and vehicle network capabilities, TI's family of MSP microcontrollers enables engineers to simplify design, reduce system cost, and accelerate time-to-market for next-generation automotive systems. See the wide selection of automotive microcontrollers for body applications at Automotive Body and Lighting MCUs on ti.com .

3.4 Backup Power

In case a collision severs the connection to the main vehicle battery, there must still be a way to unlock the car door. One implementation is to provide a mechanical handle to disengage the lock. However, this adds mechanical complexity which goes against the desire to reduce the linkages, weight, and cost associated with the system. Also, in case the driver is incapacitated, emergency responders can be unable to access the interior mechanical handle. So, an alternate approach is to provide a backup power source to provide the energy needed to unlock the door, and initiate an unlock automatically in case of a collision.

Supercapacitors are commonly used for this local power source because supercapacitors can charge quickly and store a high level of energy. Since the supercapacitors are typically rated for around 3V, the supercapacitors can be stacked in series to store higher voltages. For distributed systems, three or fewer supercapacitors form a typical stack, with series voltage from around 3V to 9V. So a step-down (buck) converter is used to charge the supercapacitors from the 12V battery supply. A step-up (boost) converter is also needed to provide the voltage required to drive the lock motor.

For a centralized CPM system, there can be several supercapacitors in series in the stack, creating a stack voltage higher than 12V when fully charged, so a buck-boost converter can be needed to charge the supercapacitors. A boost converter can not be needed on the discharge side, since the supercapacitor stack voltage can be sufficient to drive the motors without stepping up the voltage.

3.4.1 Discussion of Energy Requirements

Consideration of the energy requirements of the system involve several factors, including the energy needed to reliably activate the loads of interest (motors, illumination, and so forth), the quantity of usable energy in the backup power source, and the need to derate the supercapacitors for effects due to temperature, voltage stress, and aging.

3.4.1.1 Energy Needed By A Single Motor

To design the backup power circuits, we need to look at the voltage and current requirements of the motors and other loads to be driven. The motors in a lock mechanism are relatively small, typically 12V-rated brushed DC motors, with maximum current of a few Amps. Operation time is short, typically significantly less than one second. The total energy necessary to actuate each motor is:

$$E_{total} = \int v(t) \times i(t)\,dt \tag{1}$$

Where v(t) is the voltage supplied to the motor, and i(t) is the motor current, and the integration is over the total time of motor activation.

As an example, Figure 3-7 shows the current profile of a lock motor activation, with a 12V supply and a 500mΩ sense resistor, giving a scale factor of 2A/V. The profile can be divided into two segments, with the first (in yellow) showing the initial high current as voltage is applied to the motor, decreasing as the motor speed and back EMF increase. The second segment (in red) is when the mechanism reaches a mechanical limit, and the motor stalls after an initial bounce. Not shown is the deactivation of the motor when the control circuit recognizes the lock has reached the limit and the drive is shut off. Note that in this case, the motor is rotating for only about 25ms, and then stalls for at least 55ms. The stall current is about 2.4A.

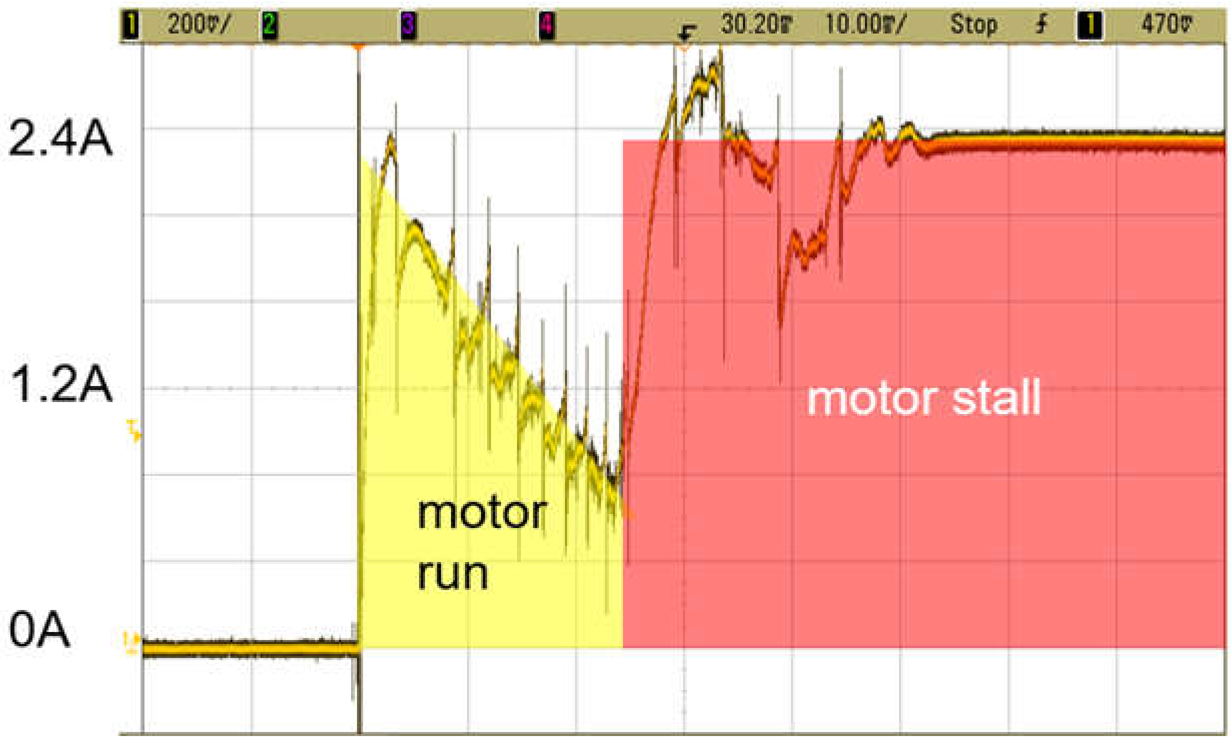

Figure 3-7. Current Profile of a Lock Motor Activation

For this example, the energy dissipated during an unlock event can be approximated as the sum of the energy during motor rotation, and the energy during motor stall. The energy during the motor rotation is:

$$E_{rotation} = 12V \times \frac{24A + 0.8A}{2} \times 25ms = 0.48J \tag{2}$$

The energy during motor stall depends on how quickly the motor is deactivated after reaching the mechanical limit; for this example assume the motor is turned off at the end of the oscilloscope trace about 55ms after the motor stops turning. This gives a stall energy of:

$$E_{stall} = 12V \times 24A \times 55ms = 1.58J \tag{3}$$

These sum to give a total energy needed for this example of around 2 Joules. Note that the duration of the motor stall phase significantly influences the total energy needed. Thus the time for detection of end of travel and subsequent disabling the motor drive can strongly affect the design.

3.4.1.2 Requirements for Multiple Motors

In many cases, especially for centralized CPMs, there are multiple loads (motors, lighting, and so forth) potentially needing power from the backup energy source. The energy required for each motor can be calculated as described in Section 3.4.1.1. The total energy is then the sum of all the motors to be driven after a collision. There can also be requirements for multiple attempts to activate the motors, in case the initial activation is unsuccessful.

In addition to the total energy needed, another consideration is the maximum current required; this is an important parameter is designing the power conversion circuits. As discussed above, the maximum current for each motor occurs during the first phase of activation and when the motor stalls at the end of travel; in both cases the motor rotation is effectively zero.

If multiple motors are to be activated, there are two options in terms of timing: either simultaneous activation or sequential activation. With simultaneous activation, all motors are activated at the same time, and the maximum current needed is the sum of all the maximum motor currents. This method has the advantage in being the quickest to activate the motors, and is simple to implement.

With sequential activation, the motors are activated in sequence, so that the maximum current is that needed by only one motor at a time. This has the advantage of reducing the peak current requirement for any boost circuit supplying the motors from the supercapacitors. However, the time to activate all the motors is longer, and this method is more complex to control the sequence of activation.

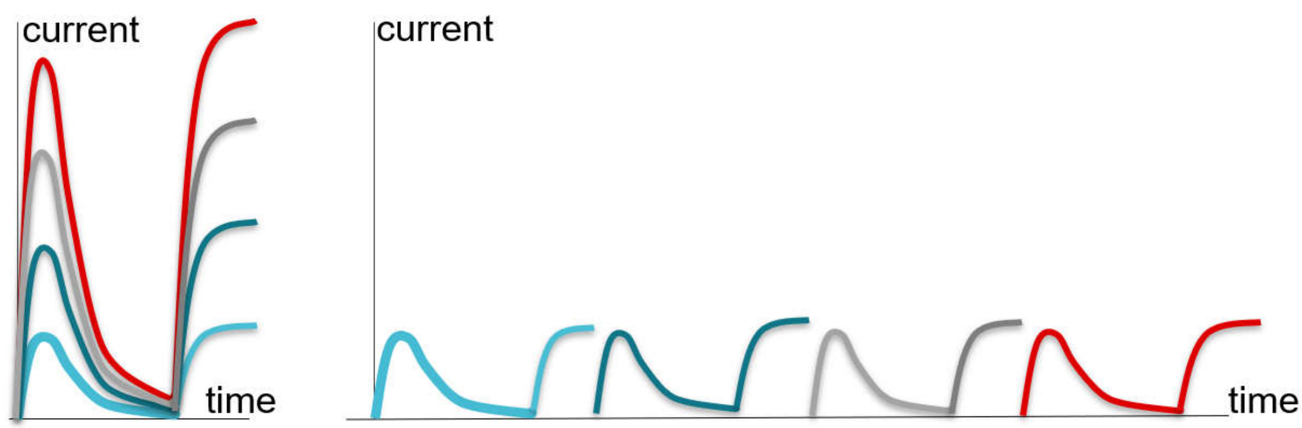

Figure 3-8. Simultaneous (Left) and Sequential (Right) Current Profiles

3.4.1.3 Usable energy stored

The total energy stored in supercapacitors is given by:

$$E = \frac{1}{2} C \times V^2 \quad (4)$$

Where C is the total capacitance of the stack and V is the voltage across the stack. However, not all of this stored energy is usable, because as the stack voltage decreases, at some point the discharge circuit and load driver no longer functions effectively. Thus the *usable* energy is:

$$E = \frac{1}{2}\left(V^2{}_{full} - V^2{}_{min}\right) \quad (5)$$

As an example, a stack of five 25F supercapacitors can have a fully charged voltage of 13.5V, and can drive lock motors reliably until the stack voltage drops to 9V. This gives usable stored energy of:

$$E = \frac{1}{2}5F \times \left(13.5V^2 - 9V^2\right) = 253J \quad (6)$$

If a boost circuit is added to allow the motors to drive until the stack voltage drops to 3V, the usable stored energy is increased to:

$$E = \frac{1}{2}5F \times \left(13.5V^2 - 3V^2\right) = 433J \quad (7)$$

Thus a boost circuit increases the usable energy available from any given value of capacitance.

3.4.1.4 Derating the Capacitance

When sizing the supercapacitors based on the load requirements and discharge circuitry, the effects of aging, voltage stress, and temperature must be considered. Based on analysis by supercapacitor suppliers, the effective capacitance must be derated significantly; Figure 3-9 shows the results of one such investigation.

Note that as temperature increases, the aging of the supercapacitors is accelerated. The voltage to which the supercapacitors are charged also affects the aging effect; reducing the voltage below the rated 2.7V extends the time for the capacitance to remain close to the initial value.

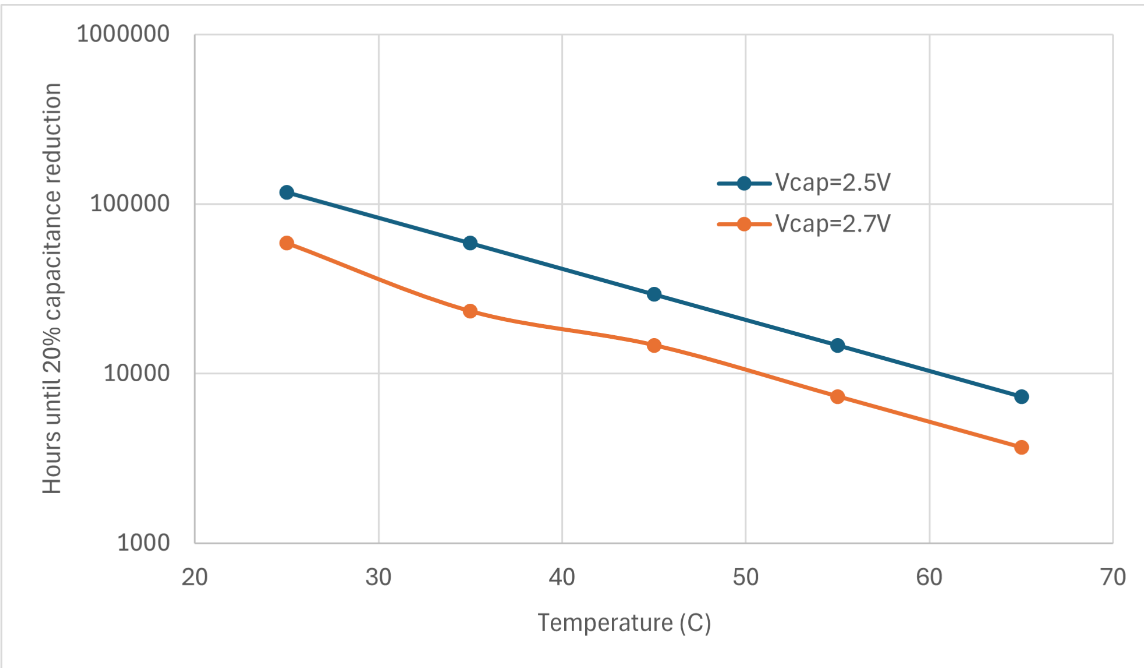

Figure 3-9. Supercapacitor Degradation Dependence on Temperature and Voltage

For automotive E-latch applications, designers must consider oversizing the capacitance to account for the degradation in effective capacitance as well as other parameters such as equivalent series resistance and self-discharge rate.

3.4.2 Charging Circuit

The circuit for charging the local storage supercapacitors depends on parameters such as the number and capacitance of the supercapacitors in series, and the time allowed for charging. If the maximum voltage of the fully-charged supercapacitor stack is lower than the supply voltage, for example a stack of three 2.7V supercaps with a 12V battery, then a step-down (buck) regulator is needed. If the fully-charged stack can have a voltage higher than the supply, such as a stack of five 2.7V supercaps and a 12V battery, then a buck-boost regulator is needed to fully charge the stack.

The current required to charge the supercapacitors depends on the capacitance, final voltage, and time allowed for charging:

$$I_{charge} = C_{stack} \times \frac{V_{charge}}{t_{charge}} \quad (8)$$

As an example, if a stack of two 30F supercaps must be charged to 5V in 15 seconds, the charging current is:

$$I_{charge} = C_{stack} \times \frac{V_{charge}}{t_{charge}} = 15F \times \frac{5V}{15s} = 5A \quad (9)$$

This assumes the current is constant over the whole range of supercapacitor voltage during charging, which requires a constant-current buck or buck/boost device.

Once the design parameters for the charging circuit are determined, Texas Instruments has a wide variety of buck and buck-boost chips available, as well as tools such as WEBENCH-CIRCUIT-DESIGNER and POWERSTAGE-DESIGNER .

3.4.3 Discharging Circuit

If the supercapacitor stack supplies a sufficient voltage to drive the motor, a diode or switch circuit can be used to connect the backup supply directly to the motor driver circuit. For example a series of five supercapacitors can be charged to about 13.5V, sufficient to supply motors designed for a 12V battery system. However, as discussed above, the usable energy from the supercapacitors is limited by the minimum voltage needed to reliably drive the motors.

To more effectively use the stored energy, and in cases where the supercap charged voltage is less than the minimum motor voltage, the discharge circuit can use a step-up (boost) configuration. Selection of the boost circuit components depends on the minimum and maximum supercapacitor voltages, as well as the maximum current needed to driver the motors.

Once the design parameters for the discharging circuit are determined, Texas Instruments has a wide variety of buck and buck-boost chips available, as well as tools such as WEBENCH-CIRCUIT-DESIGNER and POWERSTAGE-DESIGNER .

3.4.4 Bidirectional Charge and Discharge Circuits

In addition to separate buck circuits for charging and boost circuits for discharging, Texas Instruments also offers chips with both charging and discharging functions in the same chip. These chips, such as the TPS61383-Q1, LM51772-Q1, and BQ25853-Q1 have the advantage of a single inductor rather than one for buck and one for boost, as well as features such as automatic switch-over from charging to discharging when needed.

3.4.5 Cell Balancing Circuit

In E-latch designs where more than one supercapacitor is stacked in series, a cell balancing circuit is recommended to equally distribute the total stack voltage among the supercapacitors. Cell balancing is essential for supercapacitors connected in series because even small variations in capacitance, leakage current, or internal resistance between the supercapacitors can cause uneven voltage distribution. Without balancing, some of the supercapacitors can be driven above the rated voltage during charging, leading to accelerated aging, reduced capacity, or even catastrophic failure. Balancing maintains that each supercapacitor operates within safe voltage limits, improving reliability, extending service life, and maintaining consistent performance. This preventive measure is especially important in automotive applications, where the cost of failure or maintenance is significant.

For designs using up to seven supercapacitors in series, the BQ76907-Q1 provides a highly integrated, high accuracy design for monitoring, protecting, and balancing of individual caps in a series stack. If a safety-rated device is needed, the BQ78709-Q1 is a similar device with an ASIL-B rating.

3.5 Position Sensors

Sensors are needed throughout the latching and locking system to verify that the intended actuations have occurred when commanded, or to alert the driver of faults. Hall effect sensors are typically used in conjunction with magnets to detect motor rotation and mechanism position. These sensors not only verify that the mechanism is behaving as intended, but can also indicate when the mechanism has reached the limit, signaling that the motor drive circuit can shut down and conserve energy for other motors.

Texas Instruments has a wide variety of Hall effect sensors that are an excellent choice for these applications, see Hall-effect latches & switches | TI.com.

4 Future Trends and Innovations

E-latch technology is expected to experience continued innovation. Future developments can include adapting to a 48V electrical standard, closer integration with ADAS systems, and interaction with autonomous driving technologies for improved safety and functionality. There can also be advances in smart latch systems that interact with remote access applications and advanced security features.

5 Conclusion

E-latches represent a notable advancement in automotive door technology, offering benefits in safety, convenience, security, and flexibility of design. Texas Instruments has a broad portfolio of integrated circuits designed for E-latch and CPM designs.

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