How Chip-Scale MCU Technology Measures up to the Size Constraints of Wearable Designs

Decades of consumer electronic product development have resulted in countless devices used for every purpose, from professional to personal. While diverse in terms of capability and function, consumer electronics tend to follow the same design trend: devices become progressively more powerful, compact and power efficient. Wearables epitomize this trend by demanding that a portable, battery-powered, integrated device be responsible for everything from high-precision analog measurement to intuitive human interfaces. Wearable device developers must carefully partition the product's requirements among a cluster of integrated circuits (ICs), juggling sometimes conflicting priorities.

Let’s consider, for example, a clever wearable design that pushes the boundaries of what is possible in terms of size, battery life and functionality while not losing sight of what makes wearables special: their personal functionality and appeal. Our example wearable device falls into the “does one thing well” category. It’s a screen-less, coin cell-powered step counter that alerts users when they need to move around while also keeping track of the number of steps throughout the day. A simple capacitive sensing touch interface enables user input, and a tri-colored LED provides just enough expressive output to give the product a helpful and attentive personality. This product's

design shows how powerful ICs squeezed into small packages helps to facilitate innovation and product differentiation.

Our product's requirements

Let's start by sketching out the basic requirements of our product. After defining the feature set, we can choose the components responsible for each feature. This product is a step counter refined down to its essence. Offering no screens, buzzers or iPhone apps, this device is meant to stand out by its simplicity and small size. Its user interface needs to be similarly straightforward.

Basic design requirements include:

- Smallest achievable size: the product with case should be as close in size as possible to a CR2032 battery in all dimensions so that a user can carry the device on a pocket or even attach it to their keychain.
- User input: on one side of the coin cell-shaped case, provide a capacitive touch interface that recognizes the following inputs:
    - Swipe - Disable the alarm indicating that the user needs to stand
    - Tap and hold - Start a new day (reset the step counter)
    - Tap - Check the step count for the day
- Simple output: LED exposed somewhere on the case provides all output:
    - Red: A periodic, short flash expresses that the user has been stationary for too long
    - Green double-flash: Occurs when a user starts a new day by tapping and holding the device
    - 1 second red/orange/green output - Indicates 33 percent, 66 percent and 100 percent of steps counted for the day, persisting for a few seconds after a tap on the touch surface

How small can we make it?

The size of a CR2032 battery is 20 mm in diameter and 3 mm in depth. Obviously, our system has to be somewhat bigger than that, but how small can we truly make the wearable device? Let’s assume that the product’s plastic case can be made thin enough so that it adds no more than about 5 mm in diameter while still supporting easy battery replacement. That leaves the depth. How can we minimize the depth of this design and keep it roughly coin-sized? In the product’s stack up, its depth is composed of four components: the battery, the printed circuit board (PCB), any components on the PCB and the product's plastic case. PCB thickness could be as small as about 0.5 mm for a four-layer PCB. Minimizing the depth of the components to be soldered to this PCB requires careful part selection. This is where the benefits of finding high-performance chip-scale package devices becomes crucial to our design.

Chip-scale package benefits

The wafer-level chip-scale package (WLCSP) represents the culmination of years of incremental advances in manufacturing and chip assembly technology. In WLCSP packaging, the silicon is directly connected to solder balls on one side of the package, as opposed to older technologies that route silicon port pads to package pins through bond wires. The effect of this design is that packages can be designed with a width and height that is nearly as small as the interior silicon itself.

IC vendors are racing to take advantage of the benefits of such tiny package types by releasing variants of existing devices in WLCSP packages. The challenge: some vendor silicon is sizable, which puts an uncompetitive lower limit on the package size that can be achieved. Silicon Labs’ EFM8SB1 MCU is uniquely suited to the CSP package type because, while extremely functionally dense, the MCU already fits into small packages such as a 3 mm x 3 mm QFN package. The WLCSP package of the EFM8SB1 MCU measures only 1.8 mm x 1.7 mm x 0.5 mm in size.

Some of the features that make the EFM8SB1 a great choice for this design and other wearables include:

- The 8-bit SB1 MCU offers an ultra-low-power, highly sensitive capacitive sensing input.
- An on-chip real-time clock will periodically wake the system from an ultra-low power (~300 nA) state. In this design, one use of this clock will be to measure the amount of time since the last detected step and signal an activity alert to motivate the end user to stand up and move around.
- 2-8 kB flash and 512 bytes of RAM retained across low-power cycling combined with a 25 MHz 8051 core give this small device the power to execute algorithms and take on numerous system responsibilities.

Next up is pedometer selection. To take full advantage of the thin profile afforded by the CSP packaged SB1 MCU, all integrated circuits on a board will ideally be CSP package devices as well. For this reason, our on-board accelerometer would ideally also be offered in a CSP package. The newly released Bosch BMA355 gives the design a highly integrated sensor that does much of the 3 axis event detection on chip, communicating qualified events through a SPI interface that can be interfaced by using the EFM8 MCU.

Because both ICs along with the few necessary discrete passive devices can be low profile, the product's plastic case can be made thin and close to the capacitive sensing surface, which optimizes touch sensitivity. The product case could even be tapered slightly in the area near the capacitive sensing pads to close the small air gap created between the board PCB and the board components. Figure 1 shows an example of a board stackup.

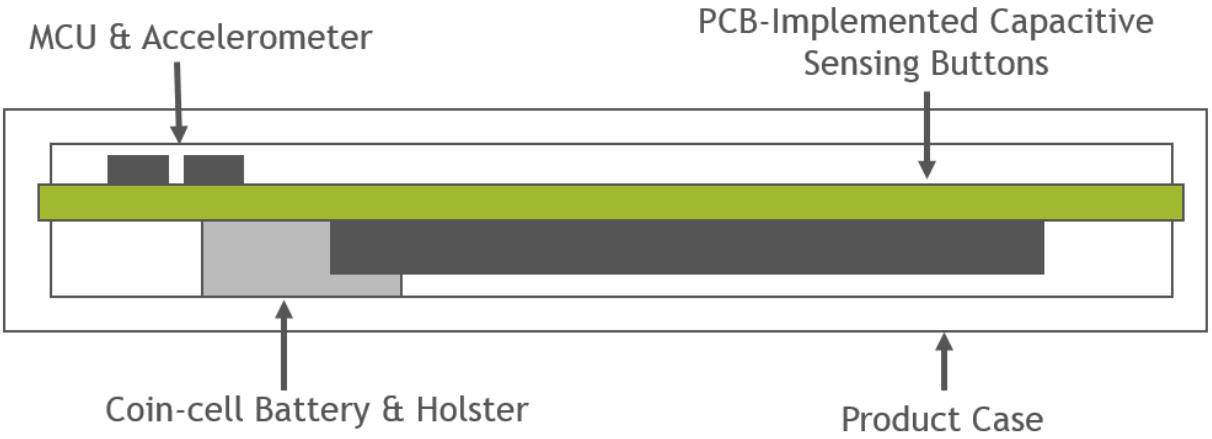

Figure 1: Board stackup

Board layout

Using CSP package devices maximizes the amount of board space that can be afforded to go to our PCB implemented capacitive sensing interface. Both the MCU and the accelerometer can be clumped along the edge of one side of the roughly circular PCB, along with an LED that can be exposed, possibly through a hole in the device's packaging.

To detect a finger swipe, the board must have two capacitive sensors--ideally two sensors of equal size--interdigitated slightly along their common edge. These two sensors should take up the bulk of the surface area on the MCU side of the board, although they should be surrounded by a third thin sensor that also surrounds the other two sensors as shown in Figure 2. This third sensor provides crucial information during human interaction that our MCU will use during touch and slider qualification.

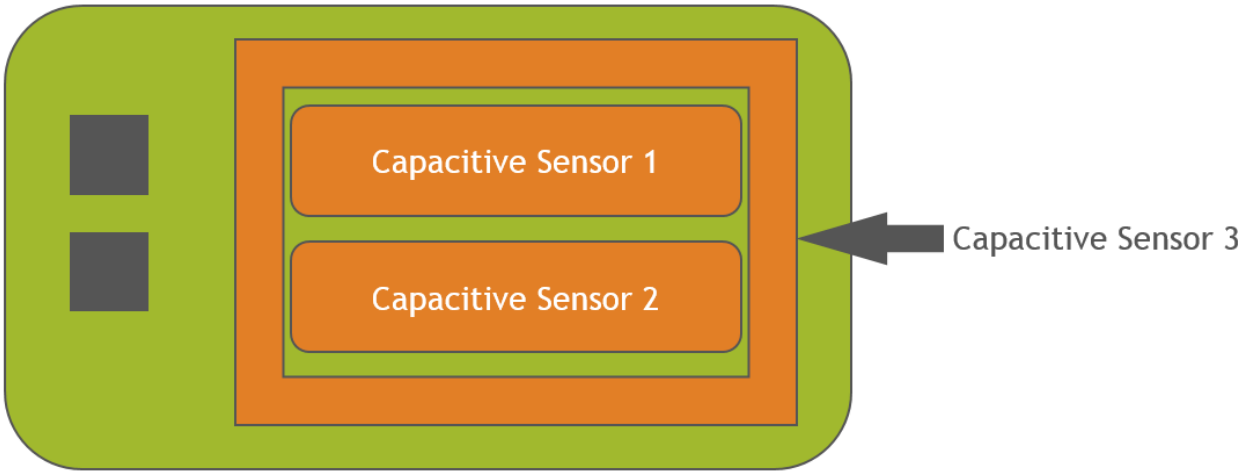

Figure 2: Board Layout

Touch qualification

The extreme portability of wearables means that these devices will be found on the body or in-hand often. For a device that measures proximity of conductive material such as hands and skin, the near-constant human contact seen by a device could lead to touch qualification issues. Fortunately, features of the MCU and accelerometer chosen for this design help the developer overcome these challenges.

While the system has three capacitive sensors, it actually has four touch inputs. The accelerometer provides an interrupt-driven tap detector that can provide our interface with one more means by which firmware can qualify touch events. By taking advantage of the accelerometer's tap detector, touch qualification by the EFM8SB1 MCU goes through the following stages:

- Detect positive delta on perimeter sensor along edges of device, enforcing an input use case where the user holds the device along the edges of it, or cups the device in the palm of one hand, followed shortly by:
- A tap detection event signaled by accelerometer, coinciding with
- A positive delta of sufficient magnitude detected on one or both of the center capacitive sensors

The EFM8SB1 firmware can take advantage of the capacitive sensing firmware library offered by the Silicon Labs Simplicity Studio development environment for all capacitive sensing touch qualification and filtering.

Low power functionality

The accelerometer and the MCU can both be configured to operate in low power modes of operation. The capacitive sensing firmware library enables the EFM8SB1 MCU to enter a ~300 nA sleep mode, waking periodically to check for activity on the capacitive sensors. The SB1 MCU will also use a port match wake event to asynchronously wake if the accelerometer signals that an event has been detected and data is ready for retrieval.

The EFM8SB1 will remain in a low power state and will consume less than 1 uA unless one of the following events occurs:

- A touch qualification event requiring more responsive monitoring of the capacitive sensing inputs
- Accelerometer activity such as a tap detection or step detection interrupt requiring that the MCU wake to service those interrupts
- An activity alert event when the device pulses the LED to motivate the user to get up and walk around

Meanwhile, the accelerometer will be configured to tend to its lowest-power operational states and signaling only when a tap event or a change has been detected on one of the three axes. On-chip buffered data minimizes the interactions needed between the MCU and the accelerometer, further optimizing battery life.

After the EFM8SB1 MCU has read the buffered data from the accelerometer, some additional examination and analysis on that data must be executed to determine if a step has occurred. Once the three axes of data have been compared to the history of

data stored on the SB1 device, the MCU can update its step counter and quickly return to a low power state.

What comes next?

This example shows a product at the ”do one thing well” end of the spectrum of wearables devices. The functional density, precision and energy efficiency with which CSP-sized integrated circuits operate in this example also illustrates how useful and empowering such IC devices can be. For instance, the product described in this article could be viewed as a subsystem of a larger product in which the EFM8SB1 MCU operates as a low-power sensor hub managing both a touch interface and an accelerometer. As silicon vendors manage to pack more features into smaller packages, it is up to system developers to take advantage of these innovations and get creative with product design.

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