Department of Electrical and Computer Engineering

University of Colorado at Boulder

ECEN5833 - Low Power Embedded Design Techniques

Fall 2024, ECEN 5833

Course Project Report

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Contents

List of Figures

List of Tables

PDF is clickable

1 Project Proposal

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2 Project Rationale and Goals

For the ECEN 5833 Low Power Embedded System Design course, our team is developing an advanced mechanical keyboard called "The Insane Keyboard". This project aims to create a high-performance input device that combines ergonomic design, customization options, and some cool features.

2.1 Project Rationale

Our analysis of the mechanical keyboard market revealed several issues:

- Ergonomic keyboards often lack additional features or are expensive
- Many feature-rich keyboards are wired, limiting mobility
- Affordable keyboards offer limited customization
- Few keyboards combine ergonomic design, wireless capability, programmable lighting, and smart functions
- Keyboards with displays or extra features often have poor power efficiency

2.2 Project Goals

We aim to create a mechanical keyboard with the following features:

- Split ergonomic design to reduce physical strain
- Wireless connectivity using Bluetooth Low Energy.
- Programmable RGB lighting with addressable LEDs
- Hot-swappable key switches for easy customization
- Low-power E-ink display for additional information
- Multi-device compatibility
- Advanced power management techniques
- Environment temperature and pressure sensing.
- Real Time clock module for timer, stopwatch and time features.
- Potential energy harvesting from typing (Yet to be seen)

- Open-source firmware for extensive customization
- Cost-effective design for market accessibility

2.3 Unique Features

"The Insane Keyboard" has unique features like:

- Integration of multiple desirable features in one device
- Optimized power management for extended use
- Potential energy harvesting from typing motions
- Open-source firmware for community-driven development
- Adaptable design for future upgrades

2.4 Expected Outcomes

Upon completion, this project could:

- Improve ergonomics in daily computer use
- Advance keyboard power management and energy harvesting
- Foster a community of keyboard enthusiasts and developers
- Demonstrate practical applications of low-power embedded design

3 Existing Products and Ideas from products

Figure 1: Split Keyboard without display(Wired)

Figure 2: Keyboard which is expensive and have a Display

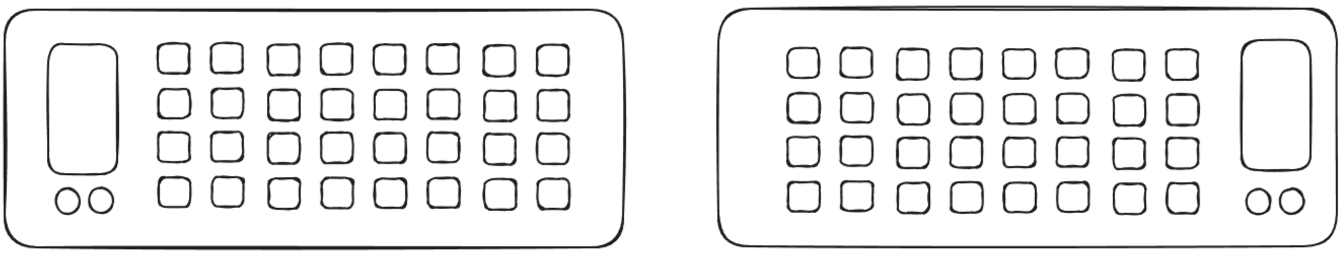

Figure 3: Conceptual Design of The Insane Keyboard

4 Project Timeline

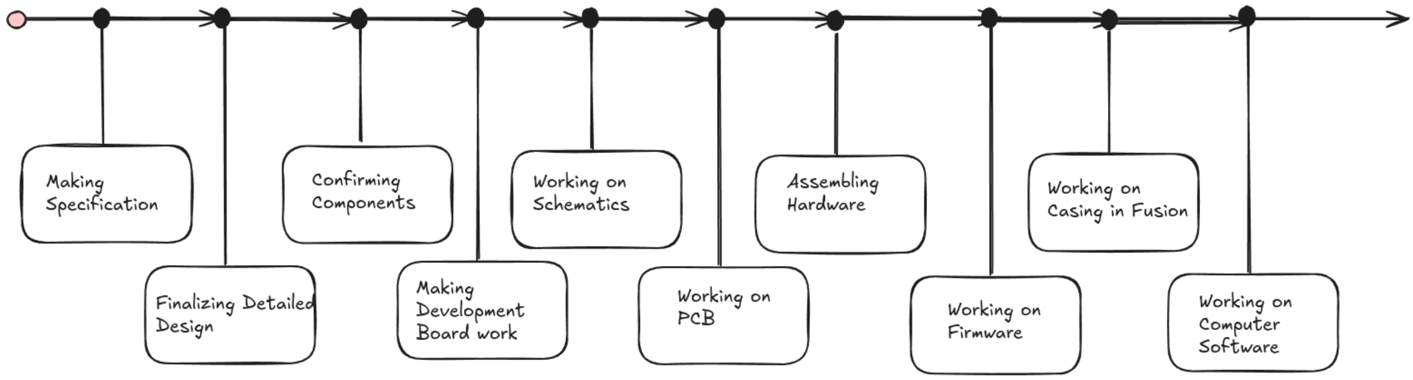

Figure 4: Conceptual Design of The Insane Keyboard

Kanban chart for project management, link for github :
GITHUB Project
GITHUB Code link

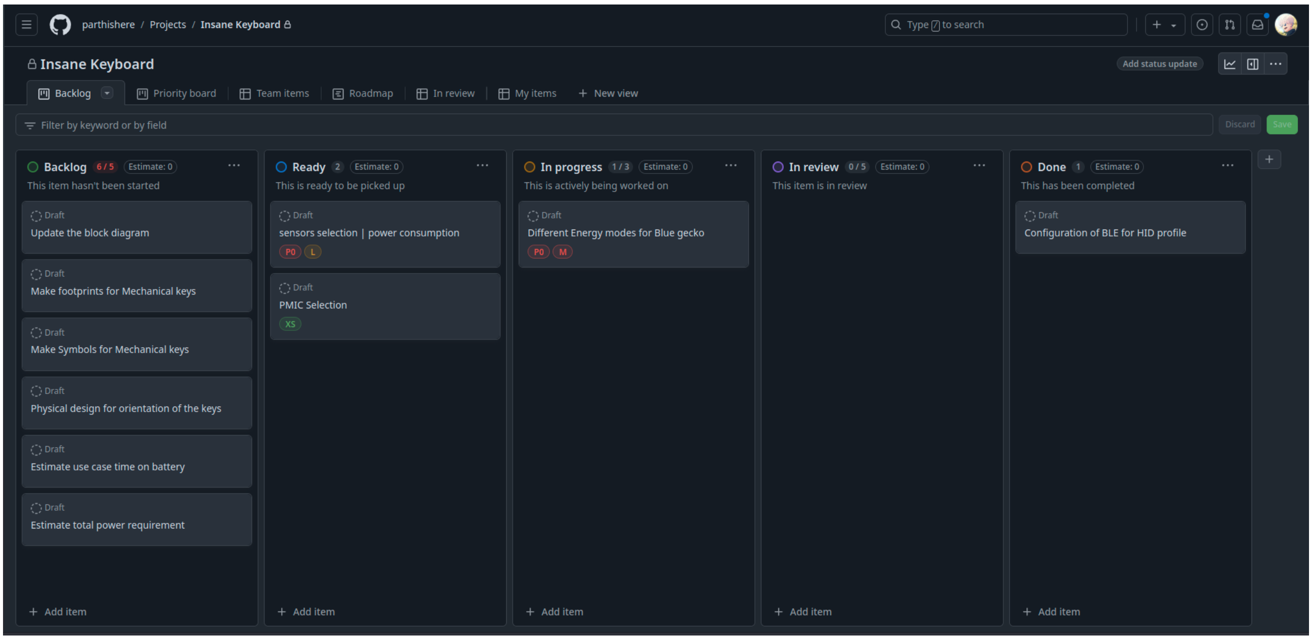

Figure 5: Kanban Board

5 High Level Requirements

5.1 General Requirements

- Two EFR32BG13 boards (one per module)
- Should be Ergonomic
- 75% keyboard layout (TKL layout)
- IO expander for each MCU
- Temperature sensor

- Pressure sensor
- Real-Time Clock (RTC)
- Connectivity to three host devices
- Computer software for LED customization
- Individually customizable LEDs
- E-ink display on each module
- Energy harvesting on each module
- Charging circuit with Type-C connector
- Charging indicator
- Battery indicator
- Minimum 6-key rollover
- HID protocol communication between modules
- Smart power states (active, idle, deep sleep)
- RTOS: FreeRTOS (Yet to be decide)
- PWM-based RGB LED control
- Hot-swappable key switches
- Time, date, battery status, current profile, custom graphics
- Spotify integration for music control and now-playing information(yet to be seen)

5.2 Components

Component	**Quantity**	**Function**	**Interface**	**URL**
EFR32BG13	2	Microcontroller	-	EFR32BG13 Series 1
TCA6408A	2	IO Expander	I2C	TCA6408A Expander
Waveshare E-ink Display	1	Display	SPI	Waveshare E-ink display
Load Switch (TPS22919)	1	Load power management	SPI	Load Switch
PMIC Super Cap Vishay 4F 3 Cell	2 2	Power management	- Energy harverstor	BQ25570 196hvc
SI7021	1	Temperature and Humidity Sensor	I2C	SI7021 Sensor
Schottky Diodes	1	Power Management	-	-
Gateron G Black Pro 2.0	68	Key Switches	-	Gateron G black Pro 2.0
Mechanical Key hotswap	68	Hot swap	-	hotswap
Cherry MX Key Caps	68	Key Caps	-	Cherry MX Key Caps
Rotary Encoders	2	Input Device	-	Rotary Encoders

Table 1: Component List for The Insane Keyboard

6 Keyboard Layout and Design

6.1 Main Board Key Layout

Function Row						
ESC ~ ‘	F1 1 !	F2 2 @	F3 3 #	F4 4 $	F5 5 %	F6 6 ˆ
QWERTY Row						
TAB	Q	W	E	R	T	
Home Row						
CAPS	A	S	D	F	G	
Bottom Row						
SHIFT	Z	X	C	V	B	
Modifier Row						
CTRL	OPT	WIN/MAC	ALT	SPACE		

Additional Inputs:

- 2 × Rotary Encoders (Knobs)
- 3 × Extra Buttons

Additional Components

- E-Ink display
- Battery
- Battery Charging and Power Management Unit (Not in Secondary module)
- Tempurature Sensor (Not in Secondary module)
- Real time Clock (Not in Secondary module)

6.2 Secondary Module Key Layout

Function Row							
F7	F8	F9	F10	F11	F12	BKSP	HOME
QWERTY Row							
Y	U	I	P	{[	}]	—\	DEL
Home Row							
H	J	K	L	; :	” ’	ENTER	PGUP
Bottom Row							
N	M	, ¡	. ¿	/ ?	SHIFT	↑	PGDN
Modifier Row							
	SPACE	ALT/MAC	FN	CTRL	←	↓	→

Additional Inputs:

- 2 × Rotary Encoders (Knobs)
- 3 × Extra Buttons

Additional Components:

- E-Ink display
- Battery
- Power Management Unit

7 Technical Considerations

7.1 Functional hardware block diagram

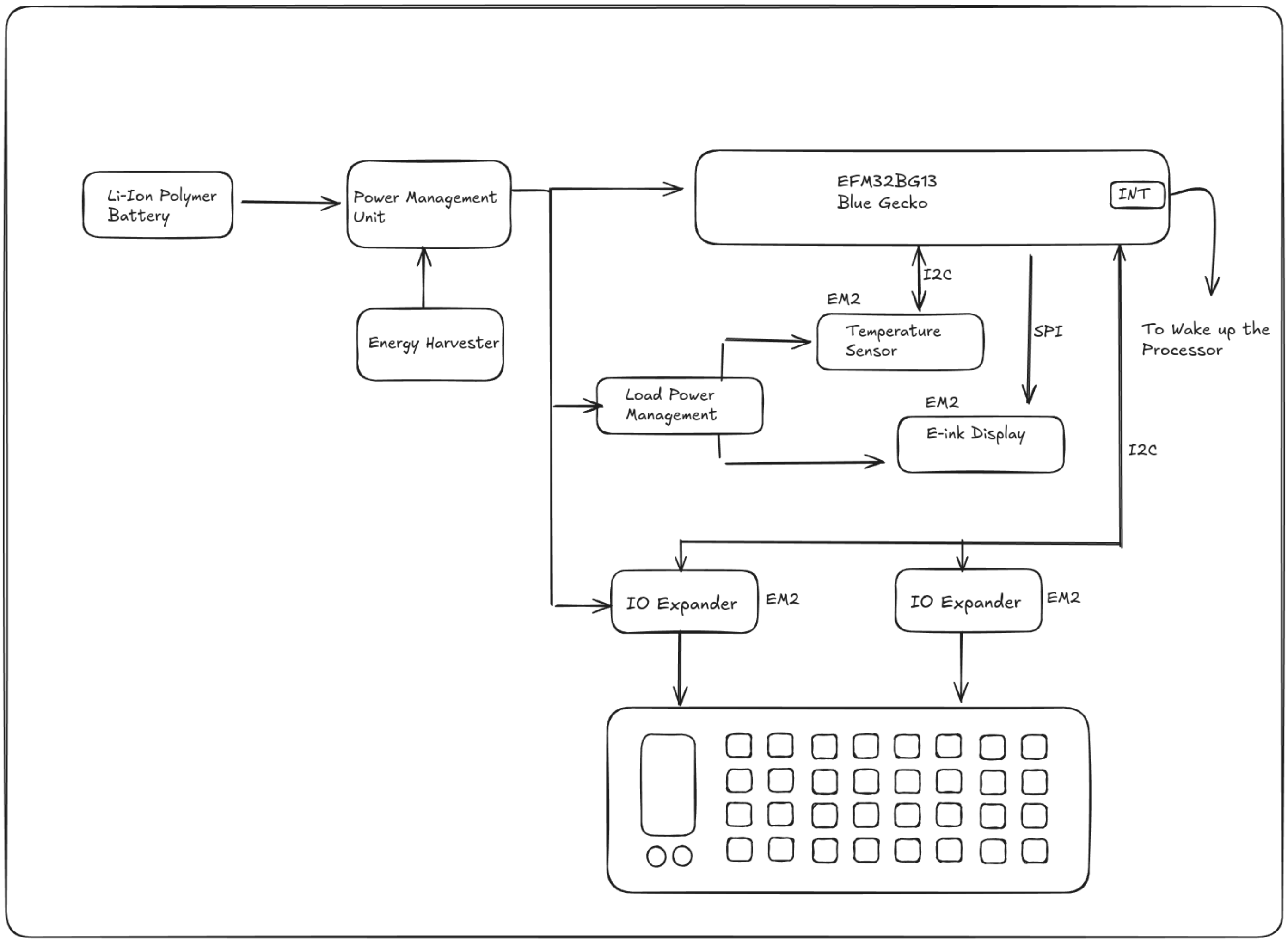

Figure 6: Hardware block diagram

0-Key Rollover (Normal Matrix)

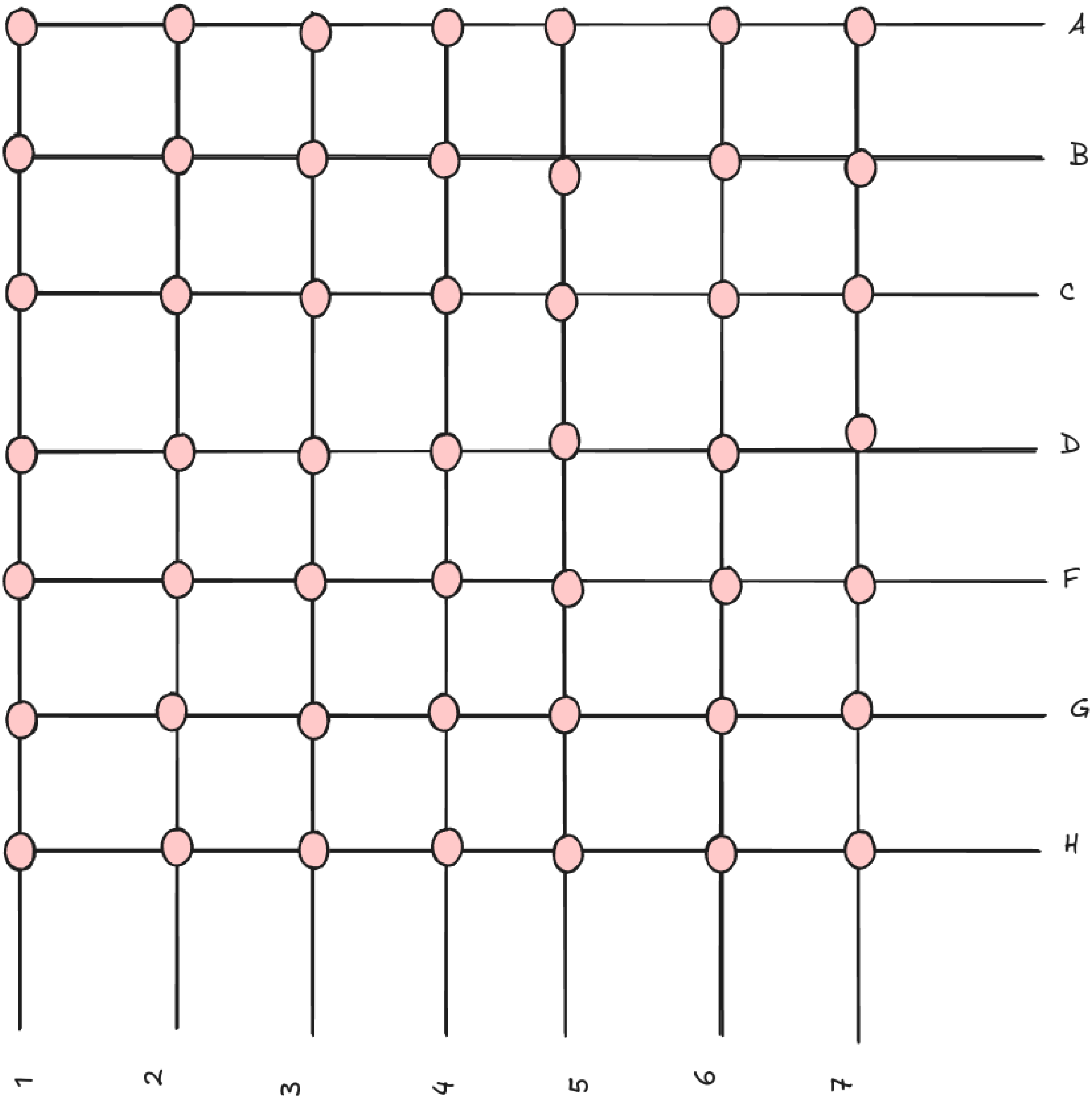

Figure 7: Normal Matrix for no key roll over

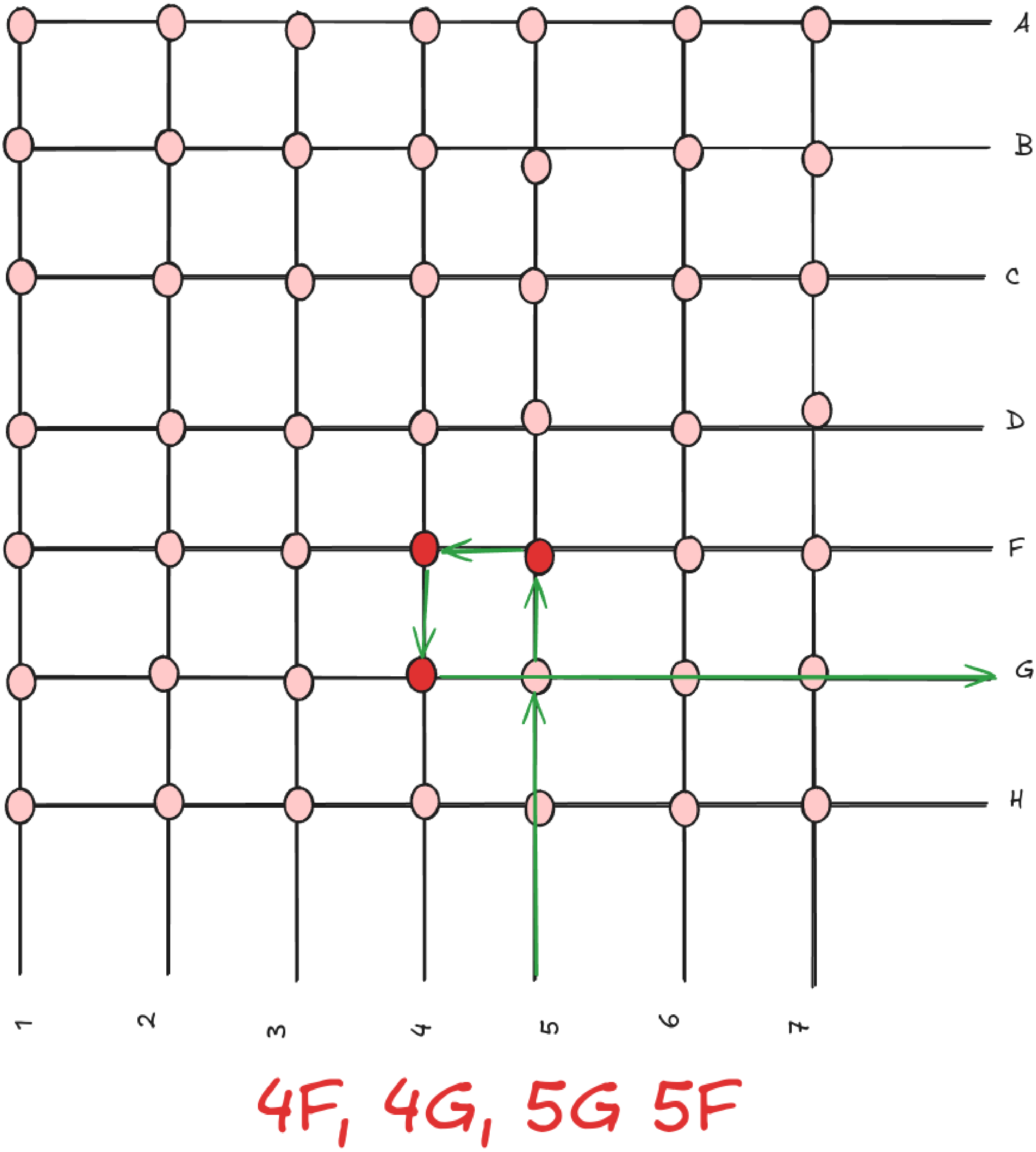

Figure 8: Decoding wrong button press

N-Key Rollover feature with Diodes

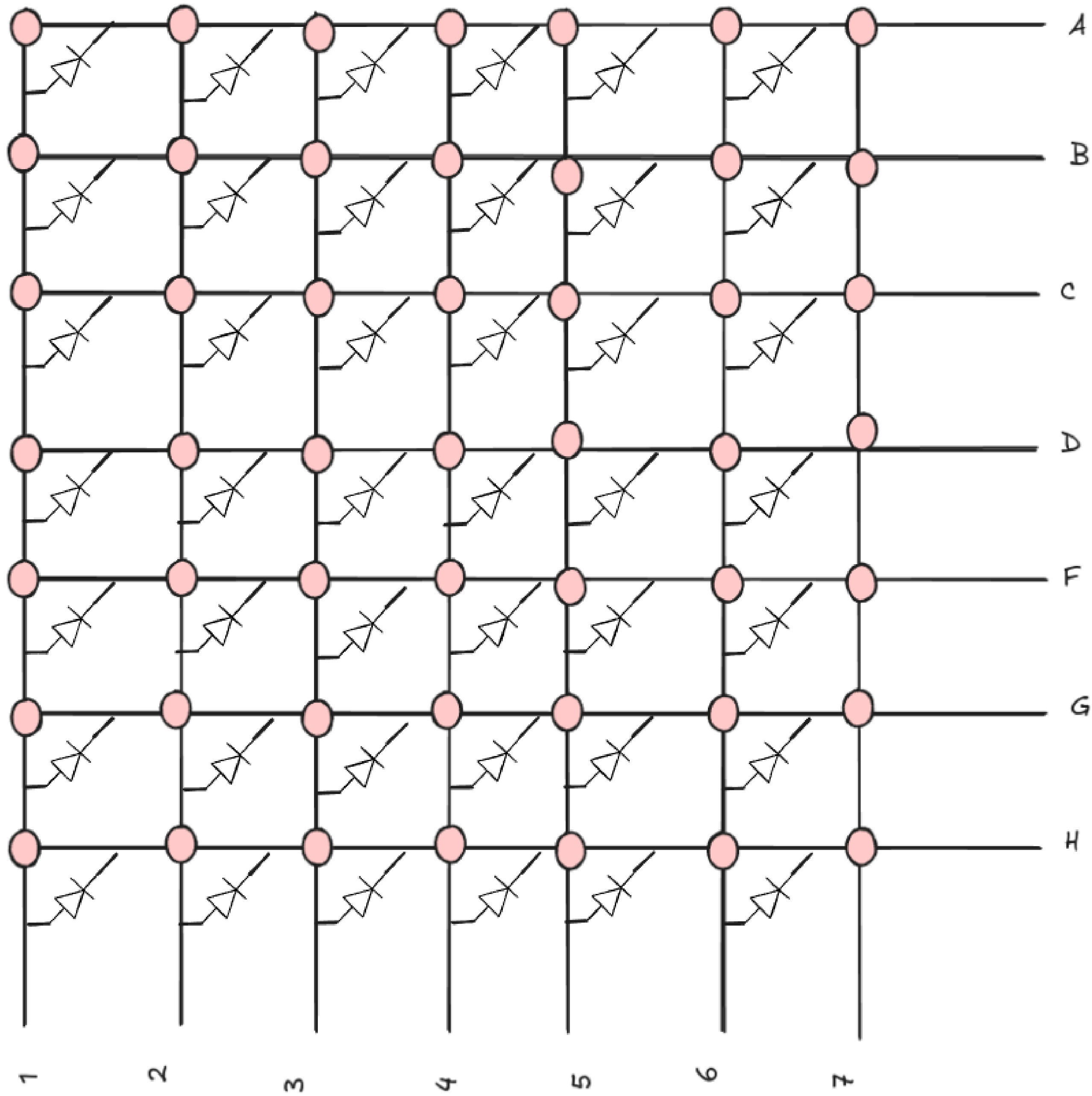

Figure 9: N-Key Rollover

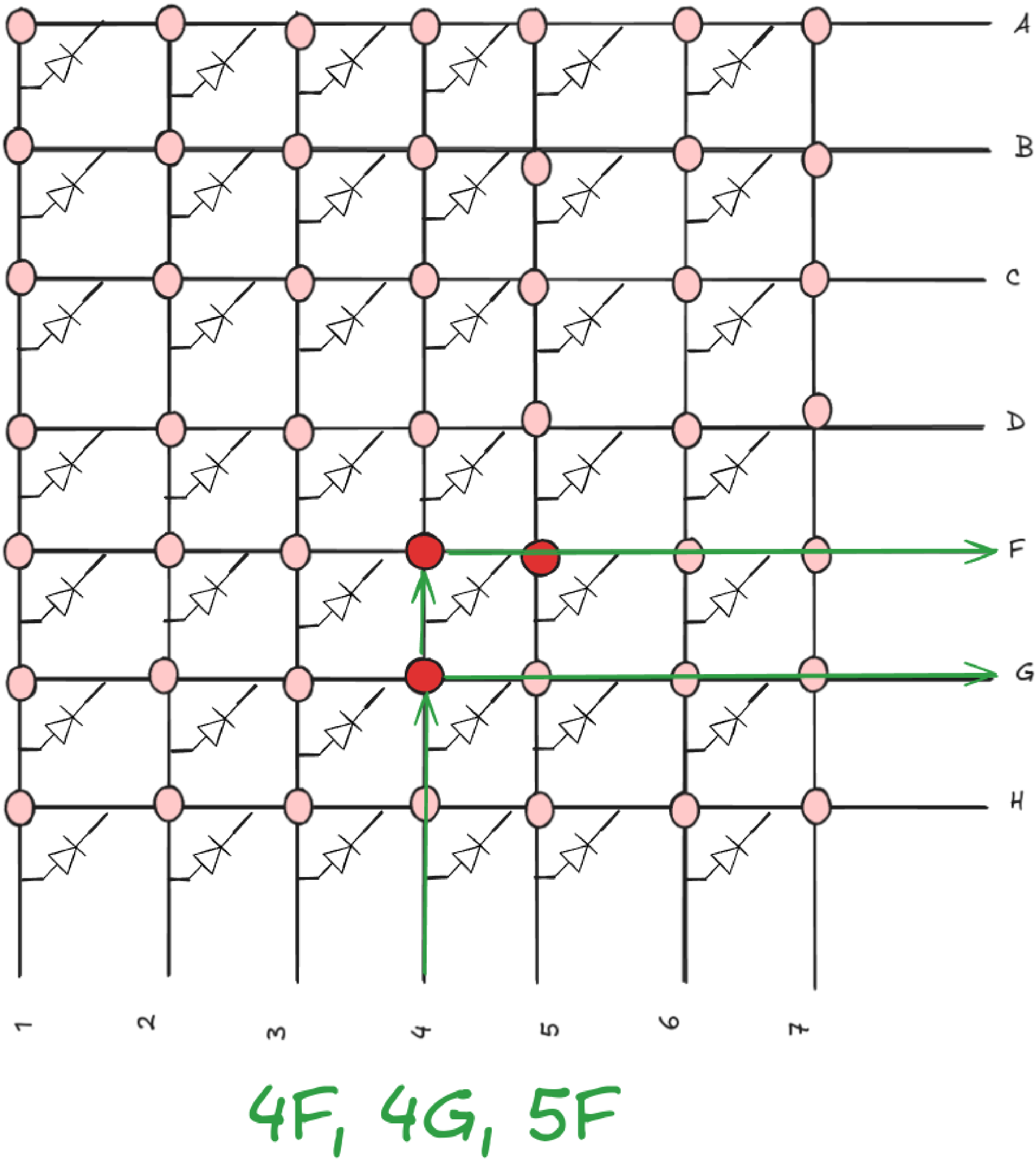

Figure 10: Multiple keys pressed

The keyboard uses a matrix layout, which is an efficient way to manage multiple key inputs with fewer microcontroller pins. In the images, we see an 8x7 matrix (rows A-H, columns 1-7).
Scanning Process:

The microcontroller scans this matrix by activating one column at a time and reading the state of all rows. When a key is pressed, it connects a row and column, which the microcontroller detects.

Ghosting and Its Prevention:
Ghosting is a problem in simple matrix designs where pressing multiple keys can lead to false key registrations. Example (Image 1):

If keys at 4F, 4G, and 5F are pressed simultaneously, the matrix might also falsely register 5G.

Solution (Images 2 and 3):
Diodes are added to each key switch. These diodes allow current to flow in only one direction, preventing the "phantom" current paths that cause ghosting. With diodes, when 4F, 4G, and 5F are pressed, 5G is not falsely registered.

N-Key Rollover (NKRO):
NKRO allows the keyboard to correctly register any number of simultaneous key presses.
Implementation:

Each key gets its own diode, ensuring independent registration. The microcontroller scans the entire matrix rapidly, detecting all pressed keys without conflicts.

Hardware Components:
Central Microcontroller:
EFM32BG13 Blue Gecko: This MCU manages all keyboard functions and interfaces with other components.

Sensors:
TMP117: Measures temperature, humidity, and pressure, potentially for environmental adaptation or user information.
DS3231 RTC Module: Provides accurate timekeeping, useful for time-based functions or logging.

Display:
E-Ink Display (800x600, 4.3inch): Offers a low-power way to show keyboard status, settings, or other information.

Expansion:
MCP23017 IO Expander: Increases the number of available pins for the key matrix, allowing for more keys or other inputs.

Power Management:
Power Management Unit: Manages power distribution and consumption.
Li-Ion Polymer Battery: Provides portable power.
Energy Harvester: Potentially extends battery life by capturing ambient energy.

Key Switches and Caps:
Gateron G Black Pro 2.0 switches: Known for smooth linear action. Cherry MX key caps: Industry-standard keycaps for customization.

Additional Inputs:
Rotary encoders: Provide alternative input methods, possibly for volume control or menu navigation.

PCB Design:
4-layer PCB: Allows for more complex routing and better signal integrity.
Two versions:

Main Module with all sensors and charging capabilities.
Simplified Secondary Module without temperature, humidity, RTC, and LiPo charger.

8 Wireless Communication and Software Architecture

8.1 Wireless Communication Details

Char	Properties	Data Type	Length	Description
Keyboard Input Report	Read, Notify	Uint8Array	8 bytes	• Byte 0: Modifier keys • Byte 1: Reserved • Bytes 2-7: Pressed key codes
Keyboard Output Report	Read, Write	Uint8Array	1 byte	• Bit 0: Num Lock • Bit 1: Caps Lock • Bit 2: Scroll Lock • Bit 3: Compose • Bit 4: Kana • Bits 5-7: Reserved
Protocol Mode	Read, Write	Uint8	1 byte	• 0x00: Boot Protocol • 0x01: Report Protocol
HID Information	Read	Uint16, Uint8, Uint8	4 bytes	• Bytes 0-1: bcdHID • Byte 2: bCountryCode • Byte 3: Flags
HID Control Point	Write	Uint8	1 byte	• 0x00: Suspend • 0x01: Exit Suspend
Report Map	Read	Uint8Array	Variable	Defines the format of Input and Output reports

Table 2: HID Profile Characteristics for Keyboard

8.2 Functional software block diagram

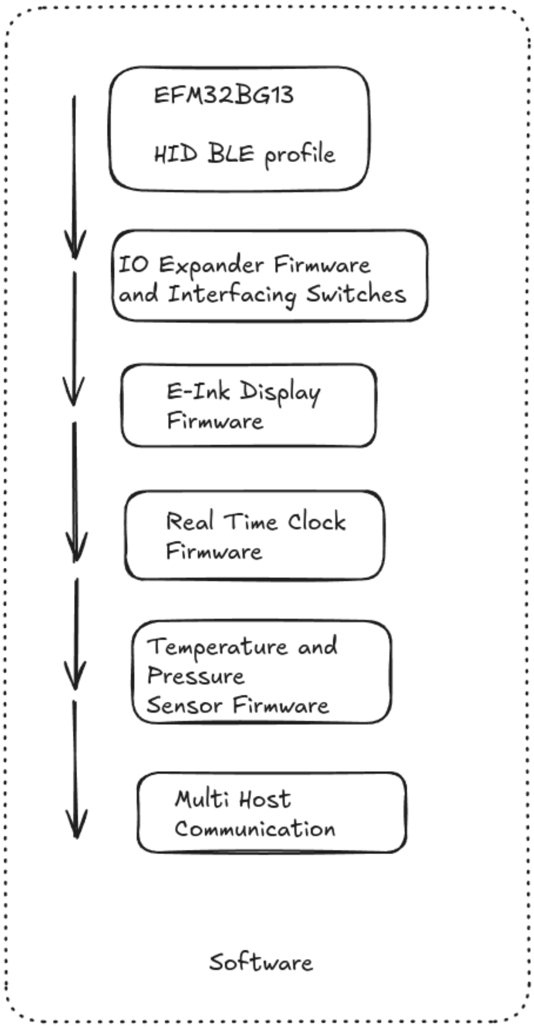

Figure 11: Software block diagram

8.3 Calculation

Component	Description			Current	Start up	Active	Sleep	Deep Sleep
BlueGecko								
	EM3	RTCC	Using ULFRCO	0.000003		1	1	1
	EM2		Using PLFRCO	0.0000033		0	1	
	EM0		38.4MHz clock	0.0049152		1		
Power Supply								
	Quiescent			0.0000007	1	1	1	1
Eink display								
	RefreshPower			0.03		1	1	
	Standby			0.000017		1	1	
	Quiesent Current							
Load Switch x2								
	Quiescent			0.00003	1	1	1	1
	Resistance ON State		0.2 OHMS					
Si7021								
	Standby			0.00000006	1	1	1	1
	Startup			0.004	1			
	I2C transaction			0.004				
	Humidity and temp reading			0.00018				
	Average Current during reading			0.0008		1	1	
IO expander								
TCA6408A	Quiscent current			0.0000015	1	1	1	1
				Current(A)	0.00403226	0.0308493	0.030849	3.23E-05
				Power(W)	0.01330646	0.1018026	0.101803	0.000106
				Time (s)	105	86400	86400	403200
				%Time	0.00018226	0.1499727	0.149973	0.699872
				Energy(J) = Power x %Time	2.4252E-06	0.0152676	0.015268	7.45E-05
				Average power(W)	0.03061213			
				Energy required for 24 hour(J)	2644.88832			
				Min capacitance (F)	0.38265167			
				Energy needs of the device and application (mins)	1.9047619			

Figure 12: Calculations

9 Challenges and Considerations

- Managing state machines with complex software like e-ink display drivers
- Integrating drivers with BLE firmware
- Implementing RTC driver and temperature control driver
- Ensuring reliable wireless connectivity
- Implementing multi-host communication and switching
- Developing HID profile in BLE stack
- Implementing anti-ghosting techniques
- Optimizing keyboard scan rate for low latency
- Achieving N-key rollover or 6-key rollover