



Lecture 4

February 12, 2026

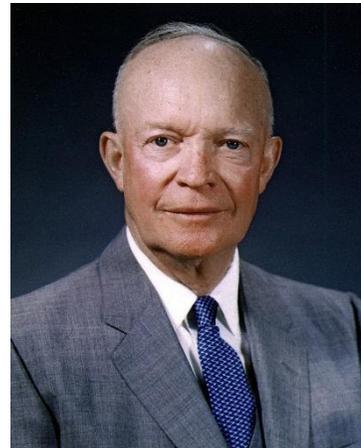
We're going to do team stuff, so sit with your team
We're going to use screens again today

TODAY

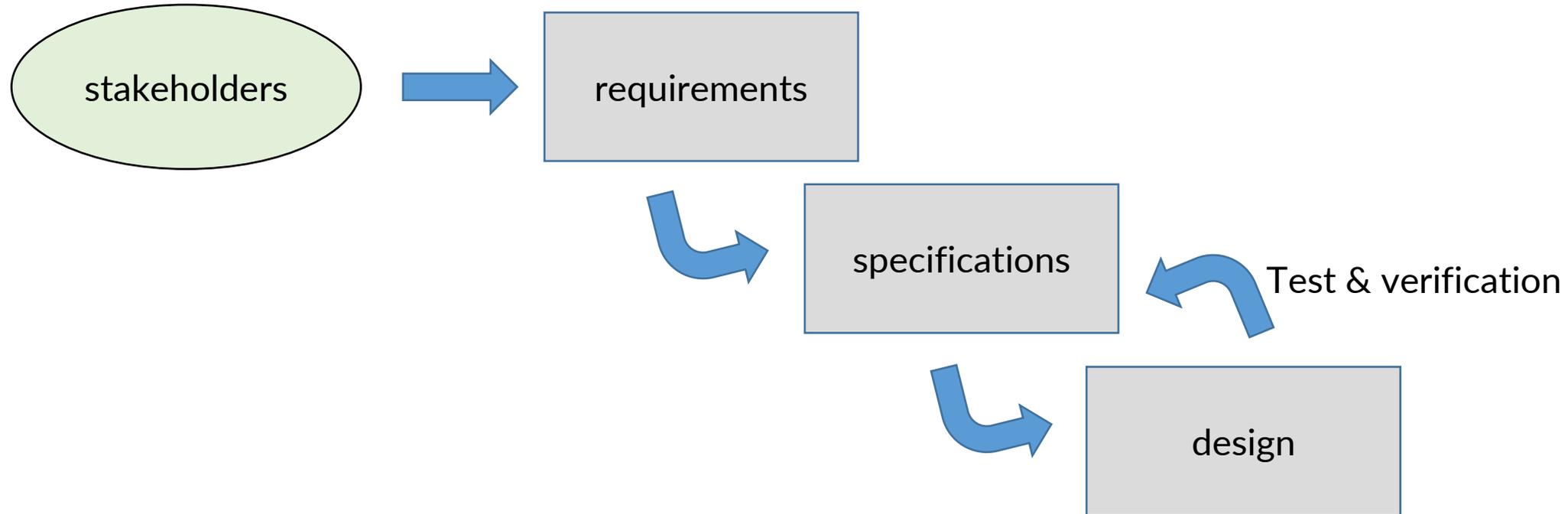
- The HW/SW product development process *with a focus on engineering design*
- Specifications → System design & partitioning
- Testing and verification
- Component selection
- PCB layout with Joe

“In preparing for battle I have always found that plans are useless, but planning is indispensable”

--Dwight D. Eisenhower



Requirements, specs, and so on



Done well, a design that passes all the tests will meet the specifications and thus the requirements, making the stakeholders happy

Case study: Flo by Moen smart water sensor

- Device to detect leaks in your plumbing and alert you



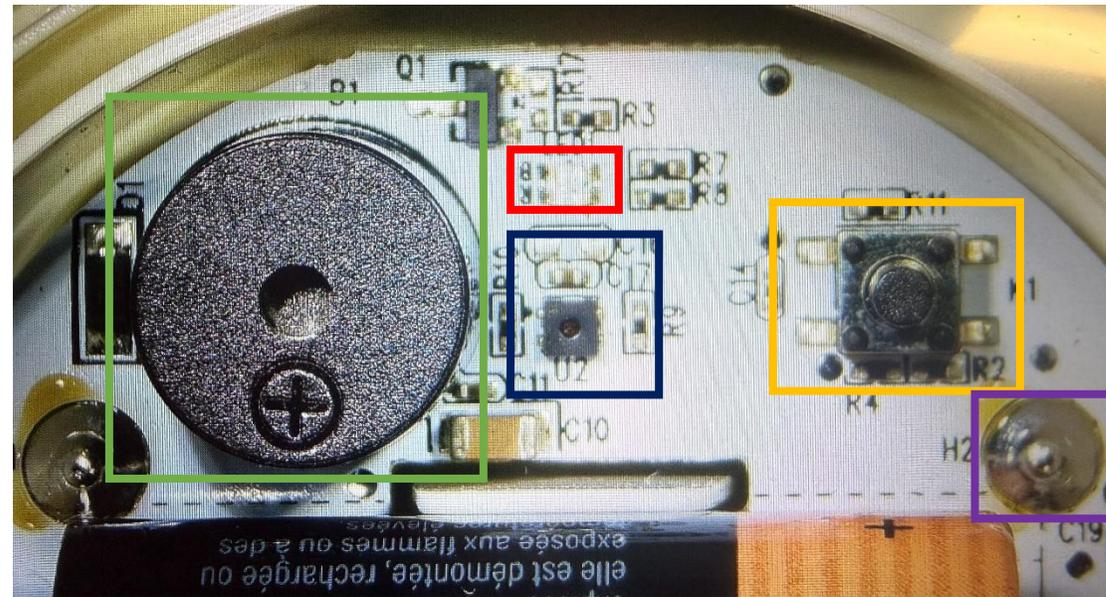
Teardown



~50USD

Piezo buzzer

CR123A Lithium battery
(3.0V@1470 mAh), lasts
~1y in my house

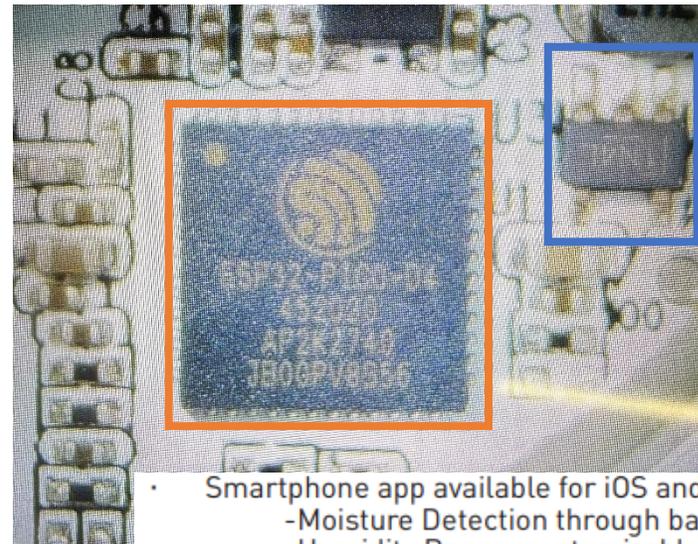


Status LED

RH/T sensor

Button

Liquid sensor
pin



Boost converter

ESP32 MCU

- Smartphone app available for iOS and Android that provides customizable alerts for:
 - Moisture Detection through base unit or included remote sensing disc
 - Humidity Range: customizable between 0-100% Relative Humidity (RH)
 - Room Temperature: customizable between 0 to 140 deg F / -18 to 60 deg C
 - Battery Level: customizable between 0-100%
- Automatic water shutoff feature: if a detector senses moisture, it can trigger the smart water shutoff to close (only available if the Flo Smart Water Monitor and Shutoff is installed on the main water supply line)
- Battery type: CR123A Lithium Cell (lasts up to 2 years, included with detector)

Case study: Flo by Moen smart water sensor

- Device to detect leaks in your plumbing and alert you

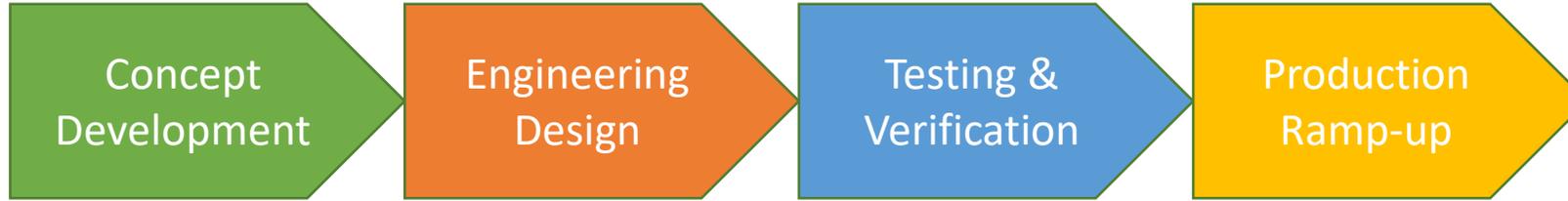
Stakeholder	Me (customer & end-user)
Requirement	Should alert me within a few minutes if there's a leak
Specifications	<p>Water sensor Detection time: <10 sec Minimum detectable wet area (MDWA): 5 cm x 5 cm x 1mm False negative rate: MDWA should alarm > 99.9% of trials False positive rate: Dry sensor should alarm <1/year</p> <p>Radio Transmission interval: every 5 min</p>



Requirements to specifications [10 min]

- With your project team
 - Choose one *challenging* requirement from your requirements list
 - Turn that requirement into measurable specifications
 - Add to your specifications & testing doc

Specifications, Concepts, & Design



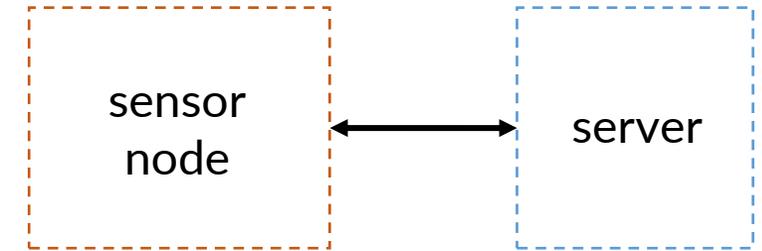
We iterate between:

- Developing and refining concepts: form and function
 - This will involve system design and partitioning
- Market research: what's out there and available, what do our competitors do?
- Update specifications document as needed ← this is a *working document*
- Even **NOW**, you can research, model, & prototype
 - Identify high-risk questions that threaten overall system
 - De-risk
- Once you have a system design & partition that is suitably stable – start detailed design & development

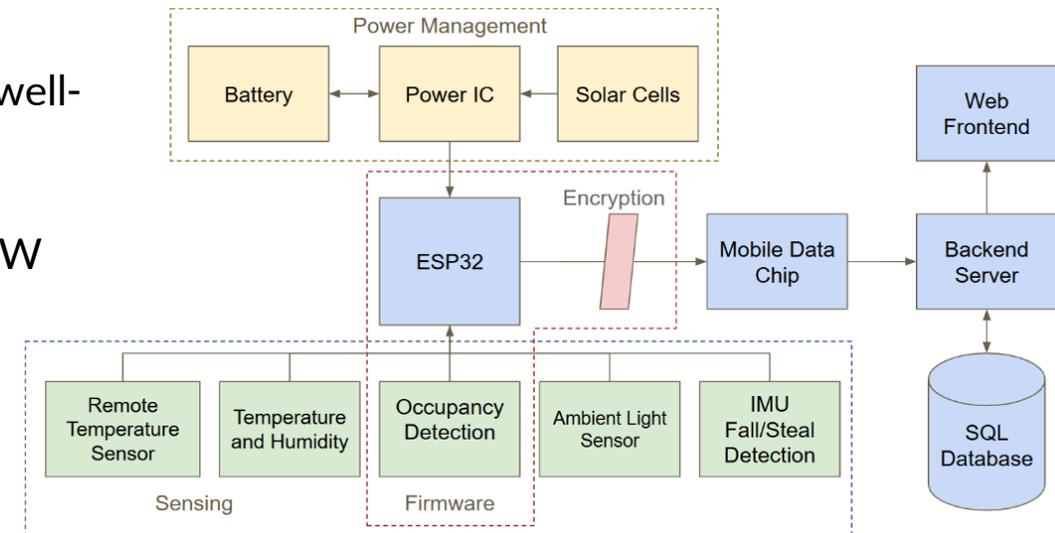
System design & partitioning

- As you refine your system diagram, you will need to consider partitioning
 - **Functional partitioning:** allocating functions to different parts of the system
 - **Physical partitioning:** What parts go where, how do they physically & electrically connect to each other
 - **HW/SW partitioning:** what to do in HW vs. in SW
 - **Local/server partitioning:** what to do on the sensor node (local, FW) vs. on the server (SW)
- We partition to manage complexity
 - Subsystems can be **designed independently** as long as interface is well-defined
 - Physical interface: pinouts, attachment points, etc.
 - APIs/function calls: between parts of FW, between FW and SW
 - Allows abstracting away details of other subsystems
- Partitioning can be applied recursively
 - Big blocks into smaller subblocks
- How far to go?
 - As far as needed to make it clear what to design, and so a person/team can start to design

Too coarse

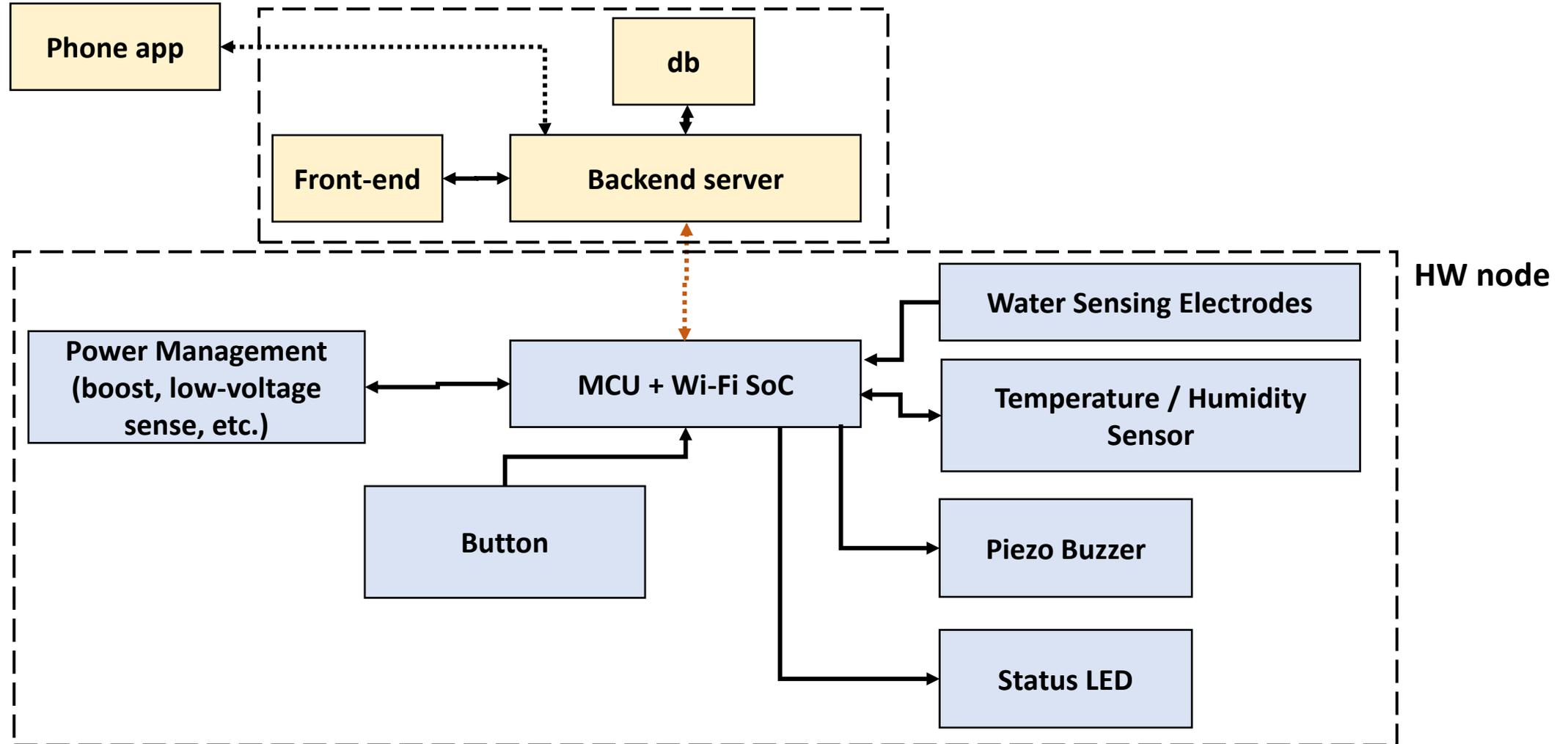


Final system diagram (2024)



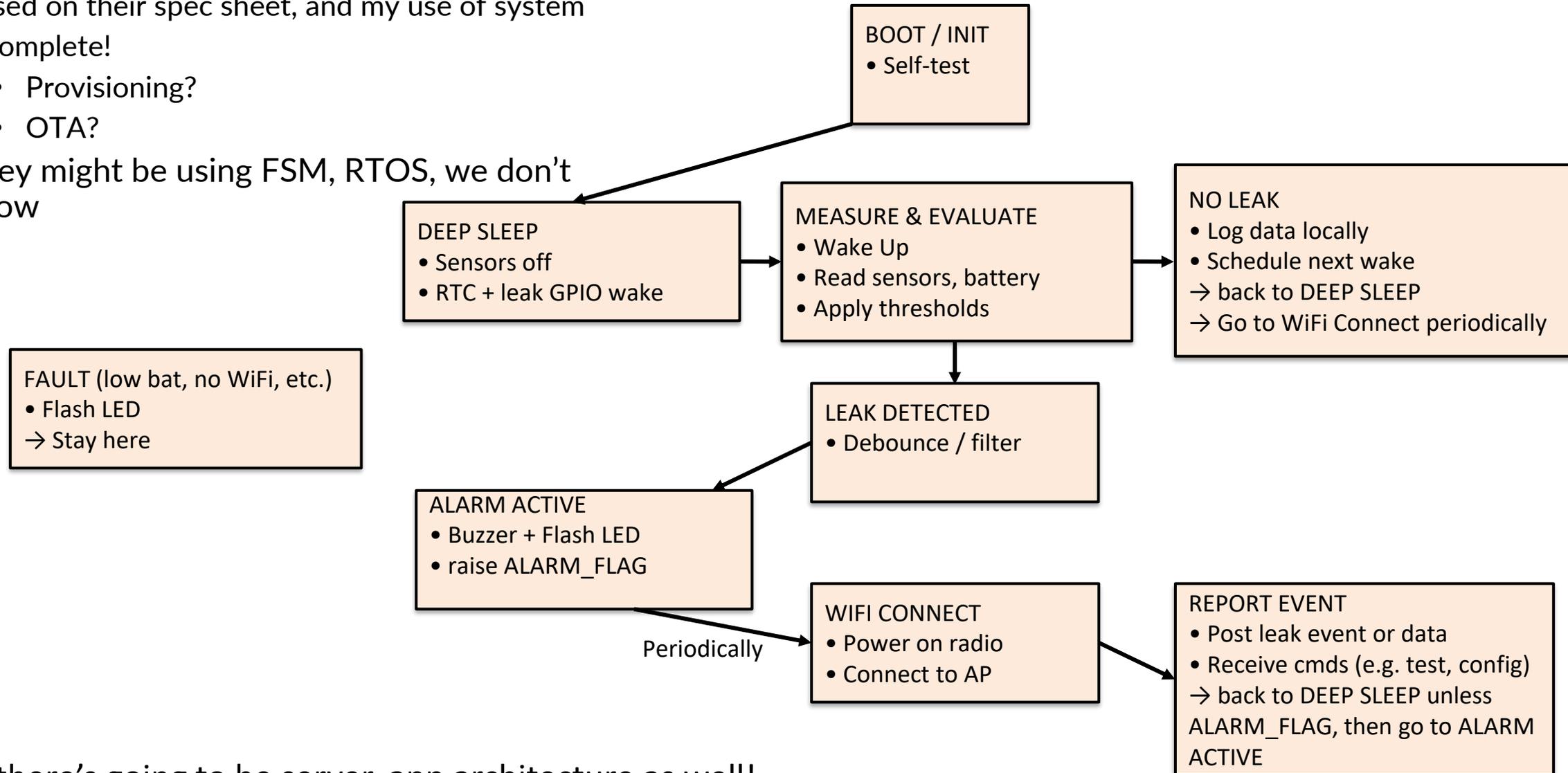
Case study: Flo by Moen smart water sensor

- This is my impression of their HW & SW architecture
 - Based on their spec sheet, and interior view



Case study: Flo by Moen smart water sensor

- One potential FW architecture
 - Based on their spec sheet, and my use of system
 - Incomplete!
 - Provisioning?
 - OTA?
 - They might be using FSM, RTOS, we don't know



And there's going to be server, app architecture as well!

Partitions: RH/T subsystem

- What is the interface between RH/T sensor and MCU?
- Physical interface
 - Chip-level comms is often via I2C, SPI, UART
 - 2+ traces on PCB, 2+ pins on MCU
 - More MCU pins → bigger MCU (sometimes), more expensive
 - Need to know voltage, current
- Functional interface
 - A digital communications protocol: I2C, SPI most common
 - MCU should have the needed communications peripheral (else you have to bit-bang your own)
 - An API/library
 - A set of commands from sensor manufacturer OR a library that encapsulates those commands
 - You can always write your own as well

The datasheet is your friend

5.2 Power-Up, Sleep, Wakeup

Upon VDD reaching the power-up voltage level V_{POR} , the SHTC3 enters the idle state after a duration of t_{PU} . After that, the sensor should be set to sleep mode with the command given in Table 9¹³.

Command	Hex. Code	Bin. Code
Sleep	0xB098	1011'0000'1001'1000

Table 9 Sleep command of the sensor.

When the sensor is in sleep mode, it requires the following wake-up command before any further communication, see Table 10:

Command	Hex. Code	Bin. Code
Wakeup	0x3517	0011'0101'0001'0111

Table 10 Wake-up command of the sensor.

5.3 Measurement Commands

The screenshot shows the ESP Registry website with a search bar containing 'sensirion'. Below the search bar, it displays 'Displaying 1-10 of total 10 components'. Two components are listed:

- esp-idf-lib/sht3x v1.0.8**
uploaded 6 months ago
Driver for Sensirion SHT30/SHT31/SHT35 digital temperature and humidity sensor
Targets: esp32, esp32c2, esp32c3, esp32c5, esp32c6, esp32c61, esp32h2, esp32p4, esp32s2, esp32s3
- esp-idf-lib/sht4x v1.0.7**
uploaded 6 months ago
Driver for Sensirion SHT40/SHT41/SHT45 digital temperature and humidity sensor
Targets: esp32, esp32c2, esp32c3, esp32c5, esp32c6, esp32c61, esp32h2, esp32p4, esp32s2, esp32s3

System partitioning [10 min]

- With your project team
 - Sketch a high-level system diagram of your project
 - Label interfaces between 2 key subsystems
 - Describe the physical & functional features of those interfaces

Yes, it's early days, so do your best!

Test and verification

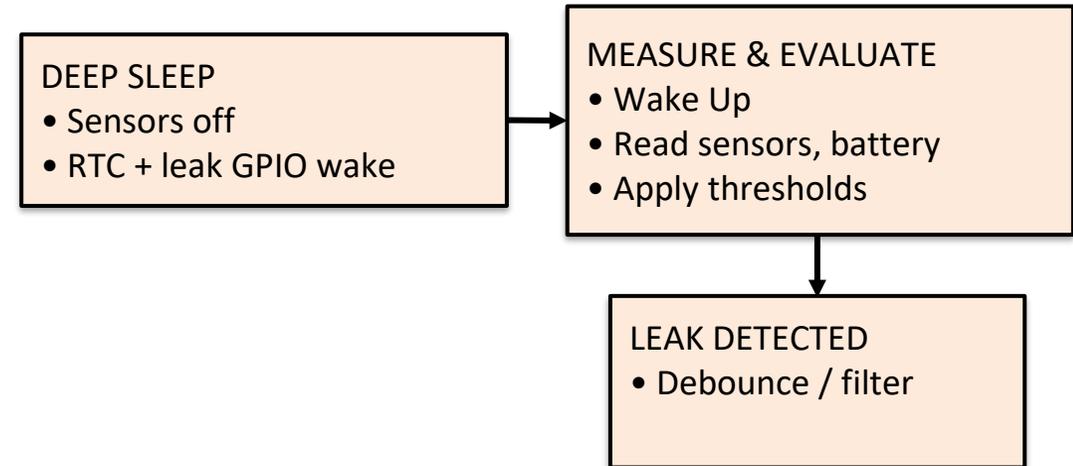
- Once you make it, does it work? **Does it meet spec?**
- For each spec, you need to have a way of testing it
- If you pass your tests
 - Then your design meets spec
 - And if you meet all your specs
 - Then you fulfill your requirements
 - And then success!

Test and verification

- There's a tradeoff between test difficulty and test accuracy
- **Power Management**
 - Specification: battery lifetime ≥ 1 year*
- Test options
 1. Calculate energy budget and thus lifetime using datasheets
 2. Measure energy consumption of components and use that to calculate lifetime
 3. Use new battery, run 100 systems using simplified FW for 3 mos, extrapolate to estimate lifetime
 4. Use new battery, run 100 systems using full FW, measure lifetime
- There's no perfect answer
- For your projects, you'll also have to consider what parts of the system are needed for a particular test
- Especially for March testing, you will not have the complete system ready so must make compromises

Test and verification: FW

- Test each state of your FSM (if using)
- May need a HW test rig for accurate tests
- Use
 - ESP LOG library
 - Toggle GPIOs (see LED or probe pin)
- Write defensive code...and use a watchdog



Prototyping for de-risking

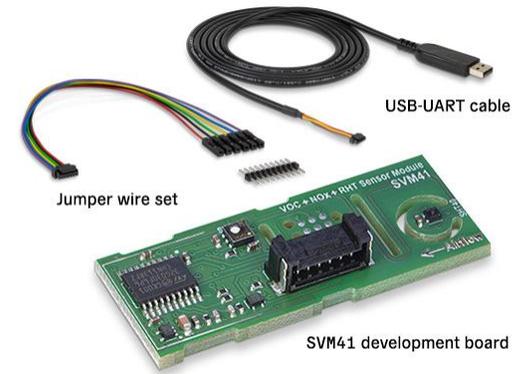
- Some HW aspects we can design and de-risk by research and modeling
- Many require prototyping
- Breakouts are fast/easy way to get started
 - With hardware design, firmware design
 - Breakouts are also useful inspiration when it is time to design your own board
 - **But breakouts only represent <1% of avail parts!**
- There are also evaluation kits (\$\$\$)
- For other parts (such as SMT ICs), you can get adapter boards – just need to know package
- Or make your own board (~2 wks or less, ~1 day in EDS for very simple boards)

We have parts available, or can order for your team!

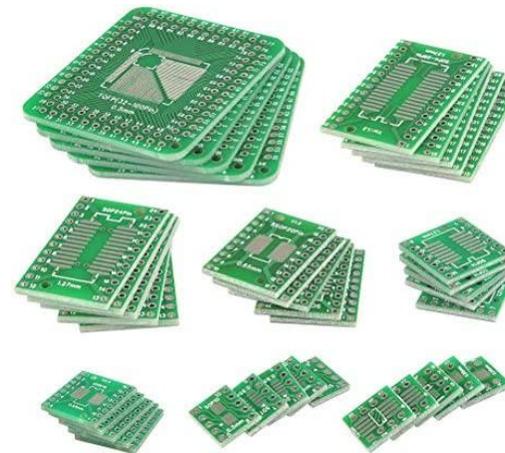


ESP32-C3-DevKitM-1 LeXin Tec
Embedded For Support Windc
Extra 2% Off
★★★★★ 5.0 - 1 Review
US \$3.30
US \$3.30 (w/ Orders over US \$4.00)
Color: ESP32-C3-M100-1-04
Quantity: 1 4877 Pieces available
Ships to United States
Shipping: \$3.52
Estimated delivery: Fri, Feb 23
From China to United States via All
Buy Now

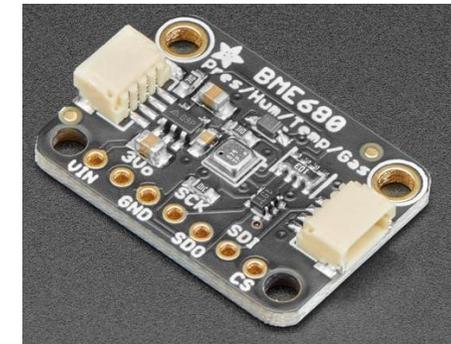
ESP32-C3 dev board
\$3.30 @ 1



USB-UART cable
Jumper wire set
SVM41 development board



SMD adapter boards



Adafruit Bosch BME680 breakout
\$19 @ 1

Part selection and datasheets

- Picking components is hard
- Picking components is fun
- Picking components can take a (long) while

Part selection and datasheets

- One approach (for electronics)
 - Query Google, ChatGPT, etc. to get to the relevant subsection in Digikey
 - Narrow parametric search down to reasonable number of parts
 - Not marketplace
 - In stock
 - Active
 - Select specs you are **pretty sure** make sense
 - Find either cheapest or most available parts
 - Look at datasheets to learn about the type of part
 - Go to manufacturer website
 - To find other parts
 - And also find application notes, selection guides to help learn about these types of parts

Datasheets

- There is no uniform format
- But, generally, for “electronics” parts
- First page
 - Overview
 - Main features

SNVS294S –NOVEMBER 2004–REVISED MAY 2016

LM3671/-Q1 2-MHz, 600-mA Step-Down DC-DC Converter

1 Features

- LM3671-Q1 is Qualified for Automotive Applications
- AEC Q100-Qualified With the Following Results
 - Device Temperature Grade 1: -40°C to $+125^{\circ}\text{C}$ Ambient Operating Temperature Range
- 16- μA Typical Quiescent Current
- 600-mA Maximum Load Capability
- 2-MHz PWM Fixed Switching Frequency (Typical)
- Automatic PFM-PWM Mode Switching
- Internal Synchronous Rectification for High Efficiency
- Internal Soft Start
- 0.01- μA Typical Shutdown Current
- Operates from a Single Li-Ion Cell Battery
- Only Three Tiny Surface-Mount External Components Required (One Inductor, Two Ceramic Capacitors)
- Current Overload and Thermal Shutdown Protection
- Available in Fixed Output Voltages and Adjustable Version

3 Description

The LM3671 step-down DC-DC converter is optimized for powering low voltage circuits from a single Li-Ion cell battery and input voltage rails from 2.7 V to 5.5 V. It provides up to 600-mA load current, over the entire input voltage range. There are several different fixed voltage output options available as well as an adjustable output voltage version range from 1.1 V to 3.3 V.

The device offers superior features and performance for mobile phones and similar portable systems. Automatic intelligent switching between PWM low-noise and PFM low-current mode offers improved system control. During PWM mode, the device operates at a fixed-frequency of 2 MHz (typical). Hysteretic PFM mode extends the battery life by reducing the quiescent current to 16 μA (typical) during light load and standby operation. Internal synchronous rectification provides high efficiency during PWM mode operation. In shutdown mode, the device turns off and reduces battery consumption to 0.01 μA (typical).

A high-switching frequency of 2 MHz (typical) allows use of tiny surface-mount components. Only three external surface-mount components, an inductor, and two ceramic capacitors, are required.

Datasheets

Somewhere inside

- Pin configurations & packages
- Tells you what each pin does
 - Often more details later on

6.1 Pinning

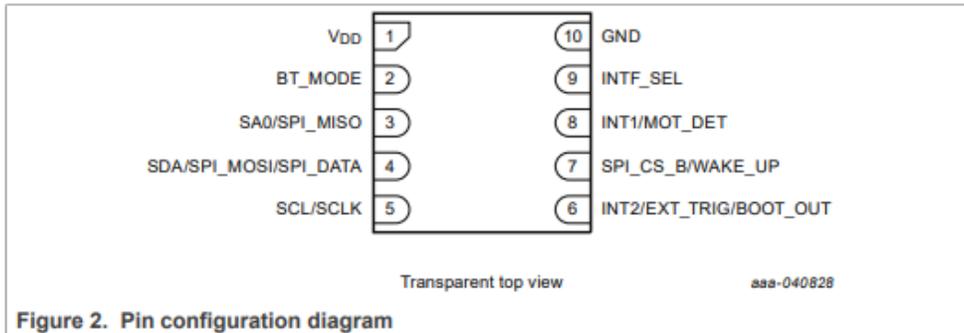


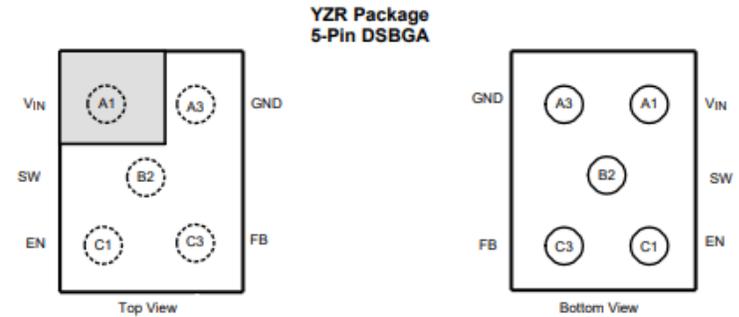
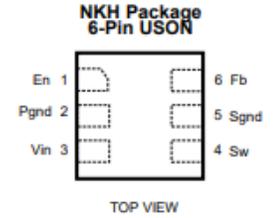
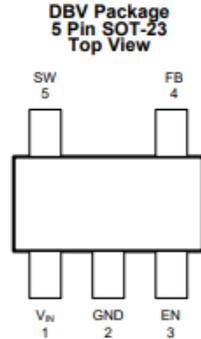
Figure 2. Pin configuration diagram

6.2 Pinning description

Table 3. Pin descriptions

Symbol	Pin	Description
V _{DD}	1	Sensor and digital interface supply voltage: 1.71 VDC to 3.6 VDC.
BT_MODE	2	Device boot mode selection. ^[1] GND: Default operating mode enabled V _{DD} : Motion Detection mode enabled
SA0 / SPI_MISO	3	Mode-dependent Multifunction serial interface pin. ^[2] INTF_SEL = V _{DD} : • SPI_MISO: In 4-wire SPI mode this pin functions as the serial

5 Pin Configuration and Functions



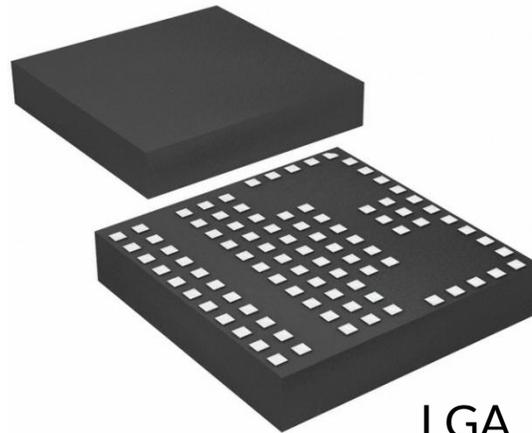
Pin Functions

PIN			NAME	TYPE	DESCRIPTION
LM3671, LM3671-Q1	LM3671				
SOT-23	DSBGA	USON			
1	A1	3	V _{IN}	Power	Power supply input. Connect to the input filter capacitor (see Input Capacitor Selection).
2	A3	2	GND	Ground	Ground pin.
3	C1	1	EN	Digital	Enable pin. The device is in shutdown mode when voltage to this pin is < 0.4 V and enabled when > 1 V. Do not leave this pin floating.
4	C3	6	FB	Analog	Feedback analog input. Connect directly to the output filter capacitor for fixed voltage versions. For adjustable version external resistor dividers are required (see Typical Application: ADJ Version). The internal resistor dividers are disabled for the adjustable version.
5	B2	4	SW	Analog	Switching node connection to the internal PFET switch and NFET synchronous rectifier.
—	—	5	S _{GND}	Ground	Signal ground (feedback ground).

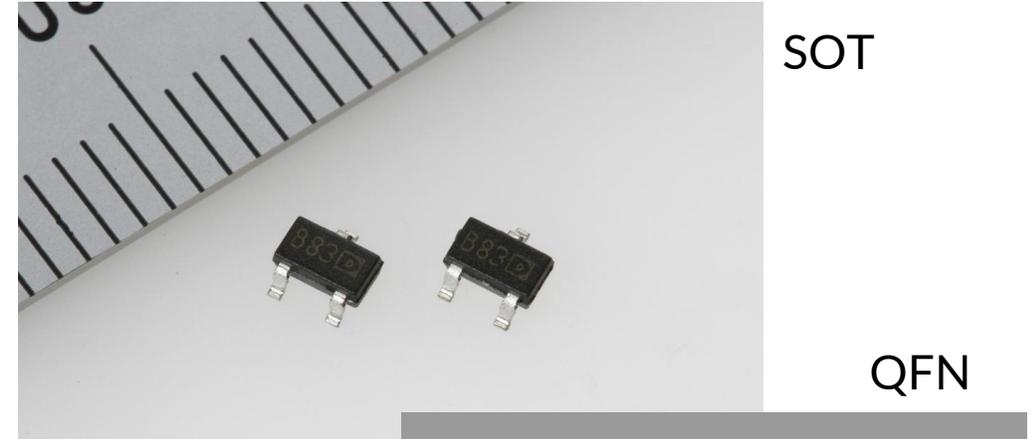
Datasheets

Pin configurations & packages

- There are many different electronics packages available
 - Even “standard” packages may be offered in “non-standard” configurations by the manufacturer
 - You may have to look it up to see what the package actually looks like
 - Our primary consideration is hand assembly
 - So we want
 - Something where we can see the leads (or BGA)
 - Not too many pins
 - Avoid
 - LGA
 - Tiny pitches

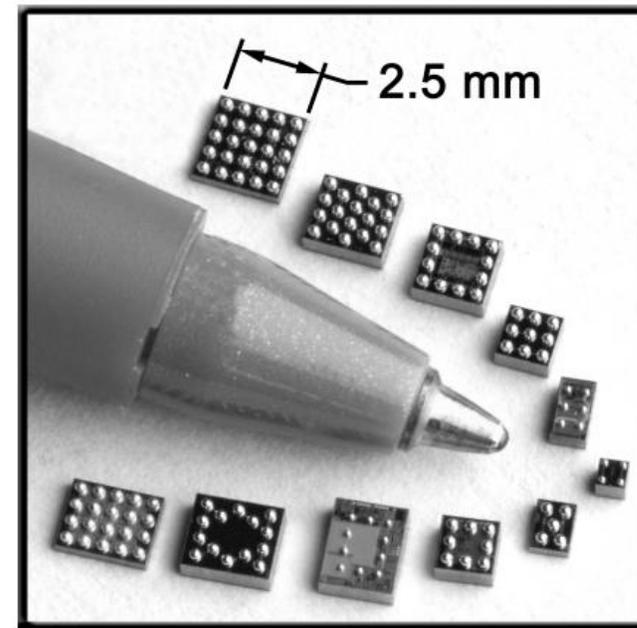


LGA



SOT

QFN



BGA

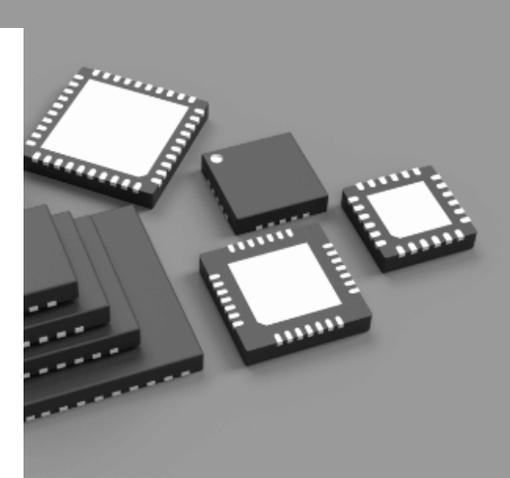


Figure 1. DSBGA 4–25 Bump

Datasheets

Absolute Maximum Ratings

- In almost all datasheets
- How to avoid breaking your part

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) ⁽¹⁾⁽²⁾

	MIN	MAX	UNIT
V _{IN} pin: voltage to GND	-0.2	6	V
FB, SW, EN pins	GND - 0.2	V _{IN} + 0.2	V
Continuous power dissipation ⁽³⁾	Internally Limited		
Junction temperature, T _{J-MAX}		125	°C
Maximum lead temperature (soldering, 10 sec.)		260	°C
Storage temperature, T _{stg}	-65	150	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) If Military/Aerospace specified devices are required, contact the Texas Instruments Sales Office / Distributors for availability and specifications.
- (3) Internal thermal shutdown circuitry protects the device from permanent damage. Thermal shutdown engages at T_J= 150°C (typical) and disengages at T_J= 130°C (typical).

LM3671

Table 4. Device absolute maximum ratings

Symbol	Rating	Min	Max	Unit
ACC _{max-2k}	Maximum applied acceleration, 0.5 ms duration	—	2,000	g
ACC _{max-10k}	Maximum applied acceleration, 0.1 ms duration	—	10,000	g
VDD _{MAX}	Maximum sensor supply voltage	0	+3.6	V
VIN _{MAX}	Maximum voltage level applied to any input pin	-0.3	VDD+0.3	V
T _{OP}	Operating temperature range	-40	+105	°C
T _{STG}	Storage temperature range	-40	+125	°C

FXLS8974

Datasheets

Specifications

- Will vary A LOT depending on the part
- Tabular...plots...programming

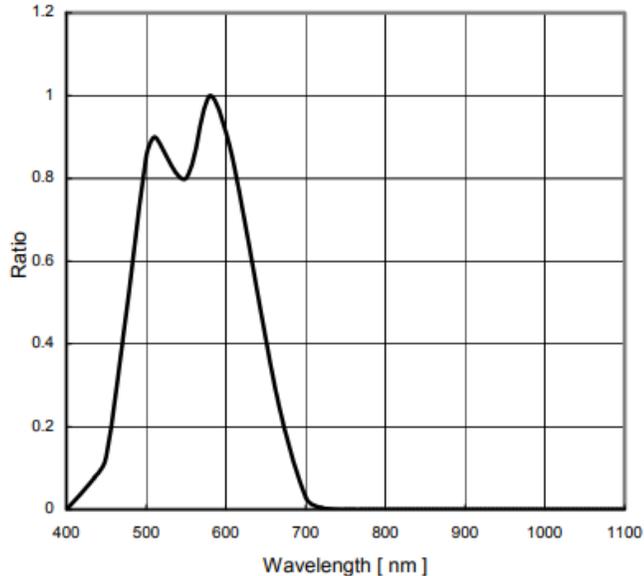


Fig.1 Spectral Response

BH1750

Table 7. Accelerometer sensor performance parameters...continued

$V_{DD} = 3.0\text{ V}$, $T = 25\text{ }^{\circ}\text{C}$, unless otherwise noted.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
SEN	Nominal sensitivity	$\pm 2\text{ g mode}$	—	0.98	—	mg/LSB
		$\pm 4\text{ g mode}$	—	1.95	—	
		$\pm 8\text{ g mode}$	—	3.91	—	
		$\pm 16\text{ g mode}$	—	7.81	—	
		$\pm 2\text{ g mode}$	—	1024	—	LSB/g
		$\pm 4\text{ g mode}$	—	512	—	
		$\pm 8\text{ g mode}$	—	256	—	
		$\pm 16\text{ g mode}$	—	128	—	
SEN _{TOL}	Sensitivity tolerance ^[1]	—	—	± 2.5	—	%SEN
TCS	Temperature coefficient of sensitivity ^[1]	$-40\text{ }^{\circ}\text{C to }+105\text{ }^{\circ}\text{C}$	—	± 0.01	—	%/ $^{\circ}\text{C}$
OFF	Zero offset, post-board mount, ESP	XY axes	—	±50	—	mg

FXLS8974

Datasheets

Design help

- Often some theory of operation or overview
 - Incredibly useful!

7.1 Overview

The LM3671, a high-efficiency step-down DC-DC switching buck converter, delivers a constant voltage from a single Li-Ion battery and input voltage rails from 2.7 V to 5.5 V to portable devices such as cell phones and PDAs. Using a voltage mode architecture with synchronous rectification, the LM3671 has the ability to deliver up to 600 mA depending on the input voltage, output voltage, ambient temperature and the inductor chosen.

There are three modes of operation depending on the current required: pulse width modulation (PWM), pulse frequency modulation (PFM), and shutdown. The device operates in PWM mode at load current of approximately 80 mA or higher. Lighter load current cause the device to automatically switch into PFM for reduced current consumption ($I_Q = 16 \mu\text{A}$ typical) and a longer battery life. Shutdown mode turns off the device, offering the lowest current consumption ($I_{\text{SHUTDOWN}} = 0.01 \mu\text{A}$ typical).

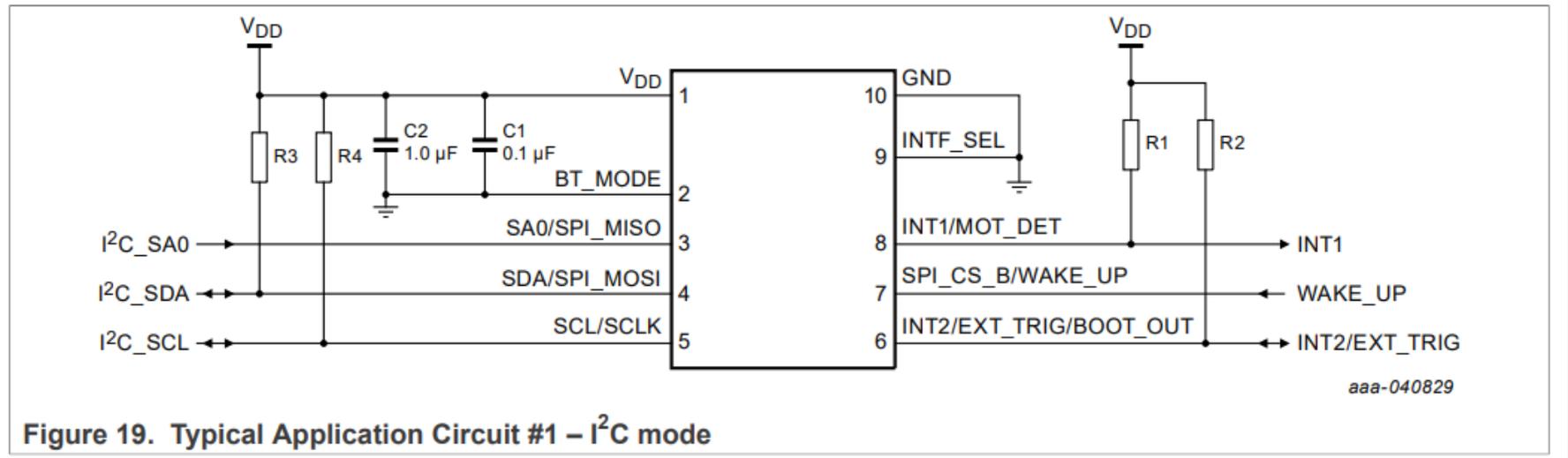
Additional features include soft-start, undervoltage protection, current overload protection, and thermal shutdown protection. As shown in the [Figure 35](#), only three external power components are required for implementation.

The device uses an internal reference voltage of 0.5 V. TI recommends keeping the device in shutdown until the input voltage is 2.7 V or higher.

Datasheets

Design help

- Often some theory of operation or overview
 - Incredibly useful!
- But also help on developing a design



Datasheets

Design help

- Some parts are very specific in terms of the PCB layout

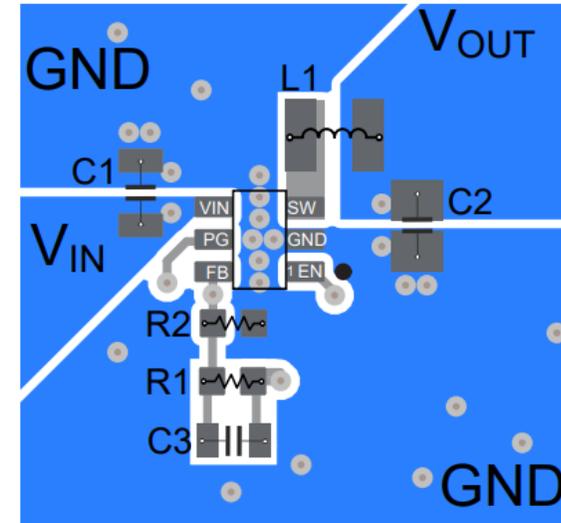
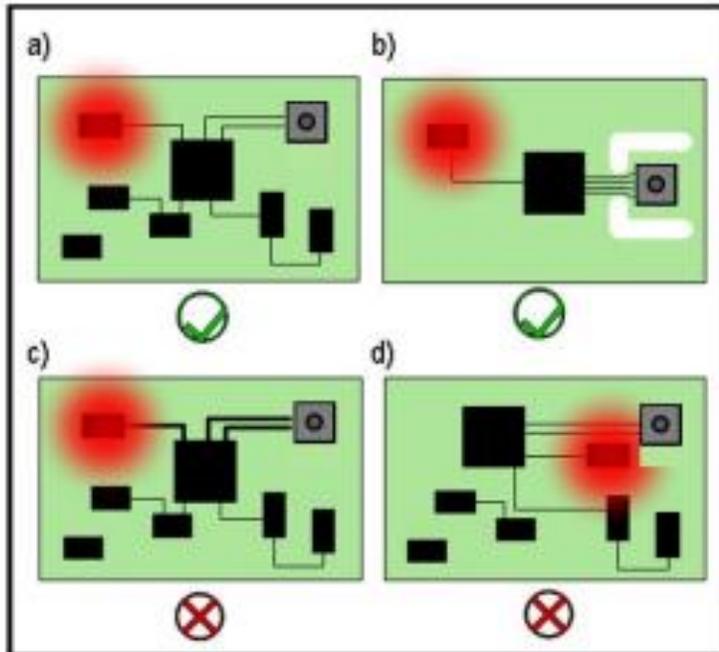


Figure 8-25. TPS62A0x (SOT23-6) PCB Layout Recommendation



SHTx RH/T sensor

Datasheets

Part numbers

- Finding difference between some part numbers can drive you crazy

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)
LM3671LC-1.2/NOPB	ACTIVE	USON	NKH	6	1000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		S39
LM3671LC-1.3/NOPB	ACTIVE	USON	NKH	6	1000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		S40
LM3671LC-1.6/NOPB	ACTIVE	USON	NKH	6	1000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		S41
LM3671LC-1.8/NOPB	ACTIVE	USON	NKH	6	1000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM		S42
LM3671MF-1.2/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBPB
LM3671MF-1.25/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SDRB
LM3671MF-1.375/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SEDB
LM3671MF-1.5/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBRB
LM3671MF-1.6/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SDUB
LM3671MF-1.8/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBSB
LM3671MF-1.875/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SDVB
LM3671MF-2.5/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SJRB
LM3671MF-2.8/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SJSB
LM3671MF-3.3/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SJEB
LM3671MF-ADJ/NOPB	ACTIVE	SOT-23	DBV	5	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBTB
LM3671MFX-1.2/NOPB	ACTIVE	SOT-23	DBV	5	3000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBPB
LM3671MFX-1.25/NOPB	ACTIVE	SOT-23	DBV	5	3000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SDRB
LM3671MFX-1.8/NOPB	ACTIVE	SOT-23	DBV	5	3000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SBSB
LM3671MFX-1.875/NOPB	ACTIVE	SOT-23	DBV	5	3000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SDVB
LM3671MFX-2.5/NOPB	ACTIVE	SOT-23	DBV	5	3000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 85	SJRB

Part selection

- How do we evaluate/compare components?
- There's often no single "best" solution
- Trade-off analysis
 - Make a table to compare
 - Assign importance to different aspects
- Often choose the cheapest and/or most popular part that meets spec