Grab an attendance sheet

6.900

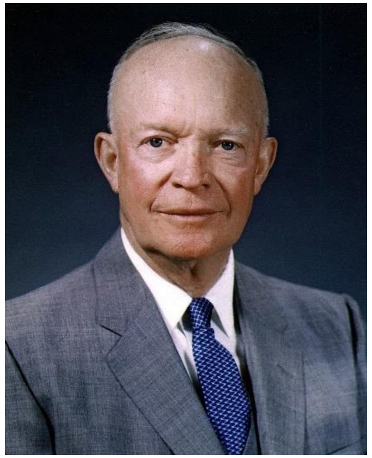
Lecture 4

February 13, 2025

TODAY

- The HW/SW product development process *with a focus on engineering design*
- System partitioning
- Testing and verification
- Component selection & datasheets

"In preparing for battle I have always found that plans are useless, but planning is indispensable"
--Dwight D. Eisenhower



MITOS Campus Heat Monitor

1. It should accurately measure the air temperature and humidity, with dynamics appropriate for the use case.***
2. It should measure ground surface temperature, with dynamics appropriate for the use case.*
3. It should operate without being connected to line voltage.***
4. It should be portable and able to be set up by an average person in a variety of outdoor environments on the MIT campus, including on a tripod or attached to poles of various dimensions.***
5. It should be able to be physically attached to a HOBO MX2302A data logger.*
6. It should report faults, such as battery failure, falling, vandalism, etc.**
7. It should be as inexpensive as possible.***
8. Data from a sensor node should be able to be tied to a location.***
9. It should maintain privacy.***
10. It should operate independently without user intervention for 3+ months.***
11. It should be rugged and able to withstand a summertime Boston-area environment (heat, rain, wind and curious people).***
12. Multiple systems should be able to be used simultaneously.***
13. It should engage with the community.**
14. The system should present the information on a dashboard (with real-time data outputs to a dashboard if possible), and also allow downloading of raw data.***

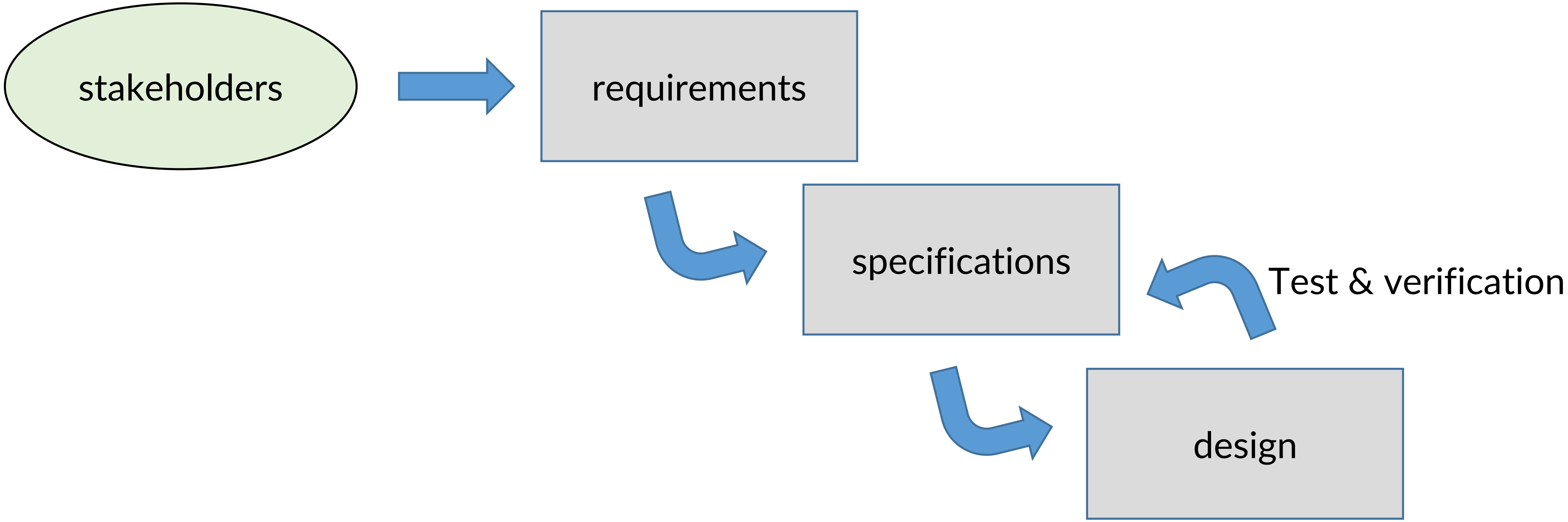
* → ***: level of importance

City of Cambridge Bike Lane Monitor

1. It should measure bicycle volume (number and direction, velocity is less critical) across a variety of Cambridge separated bike paths.***
2. It should operate without being connected to line voltage.***
3. It should be installable by a technician, and should be easy to set up without requiring alteration to the roadway.***
4. It should report faults, such as battery failure, falling, vandalism, etc.**
5. It should be as inexpensive as possible, with no or minimal on-going cost.**
6. It should operate ideally at all times, though if you really want to sleep, you could do so 1am to 6am.***
7. It should communicate data wirelessly, ideally in real time.**
8. Data from a sensor node should be able to be tied to a location.***
9. It should not identify individuals.***
10. It should operate independently without user intervention or servicing for at least one year.**
11. It should be rugged and able to withstand operation across typical Cambridge weather.***
12. Multiple systems should be able to be used simultaneously.***
13. The system should present information to the end-user in a useful way.*

* → ***: level of importance

Requirements, specs, and so on

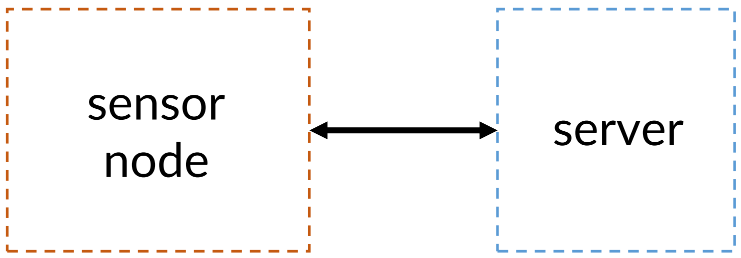


Done well, a design that passes all the tests will meet the specifications and thus the requirements, making the stakeholders happy

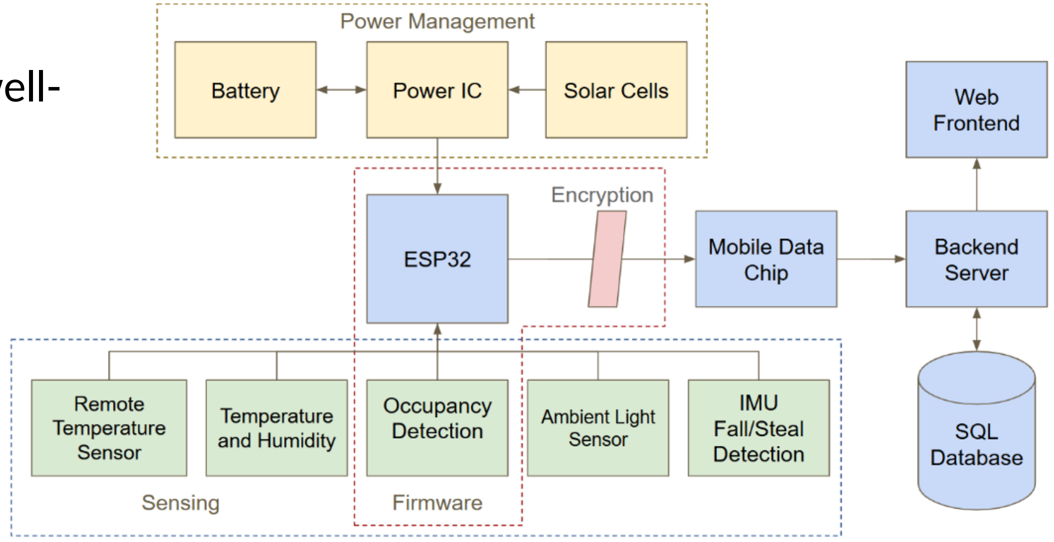
System design & partitioning

- As you refine your system diagram, you will need to consider patitioning
  - 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: cable, screws, glue, 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



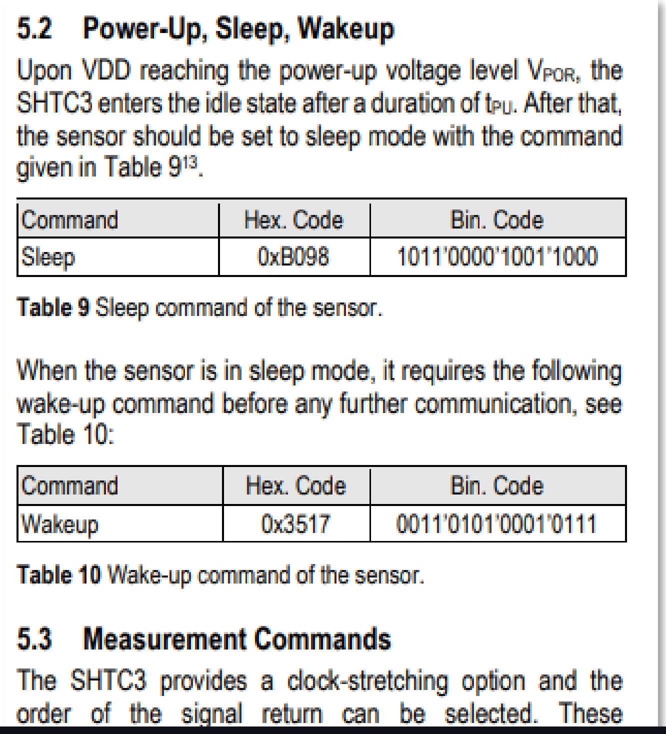
Final system diagram



Example: sensor subsystem

- What is the interface between RH/T sensors 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
- 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 9[13].

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

Table 9 Sleep command of the sensor.

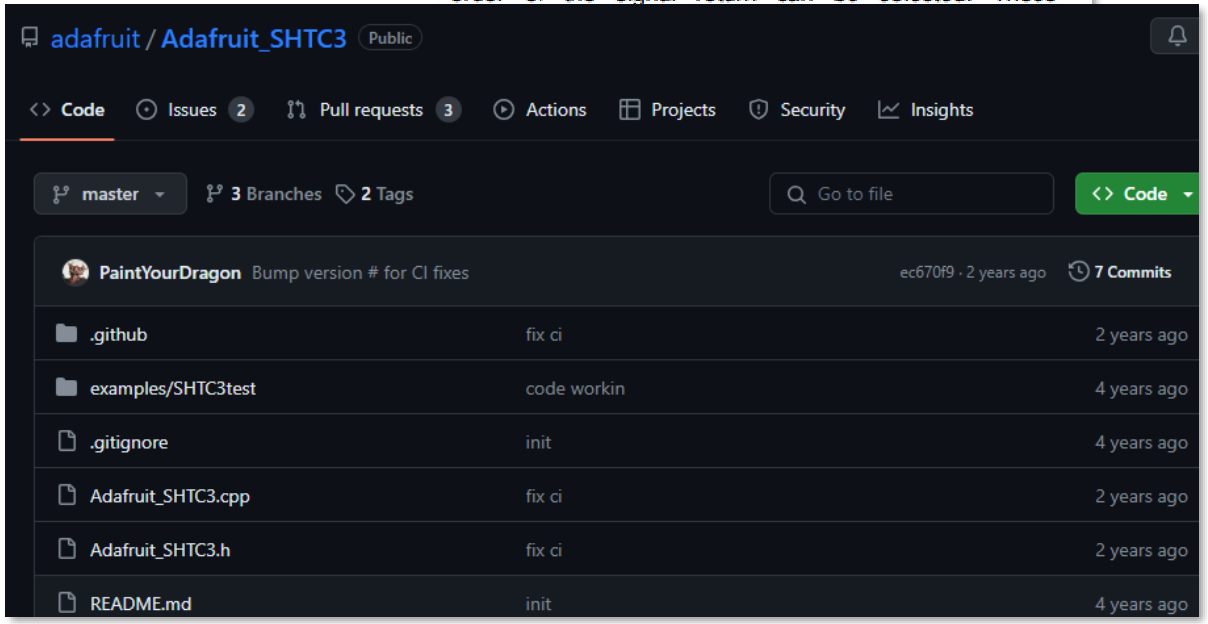
When the sensor is in sleep mode, it requires the following wake-up command before any further communication, see Table 10:

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

Table 10 Wake-up command of the sensor.

5.3 Measurement Commands

The SHTC3 provides a clock-stretching option and the order of the signal return can be selected. These



Test and verification

- Once you make it, does it work? **Does it meet spec?**
- For each spec, you want 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

- Some tests are easy to write

Weight: < 300 g

Test: weigh complete system

Test and verification

- Some are more difficult
- *Energy Management*
  Lifetime between charging: >12 h

Calculate energy budget and thus lifetime using datasheets

Test and verification

- Some are more difficult
- *Energy Management*
  Lifetime between charging: >12 h

Measure energy consumption of components and use that to calculate lifetime

Test and verification

- Some are more difficult
- *Energy Management*

  Lifetime between charging: >12 h

Fully charge battery, run system using simplified FW, measure lifetime

Test and verification

- Some are more difficult
- *Energy Management*

    Lifetime between charging: >12 h

Fully charge battery, run system using simplified FW, measure consumption using energy meter, measure lifetime inside and outdoors

What do we need for this test?

Test and verification

- Some are more difficult
- *Energy Management*
  Lifetime between charging: >12 h

Fully charge battery, run system using simplified FW, measure consumption using energy meter, measure lifetime inside and outdoors

What do we need for this test?

Some options

- *ESP32 + PM board + battery on breadboard*
- *ESP32 + PM board + battery on breadboard in housing*
- *ESP32 + [sensor subsystem] + battery on breadboard in housing*
- *Etc.*

- Think about what testbed you need
- Who will develop it?
- How long will that take?
- What does its development depend on?

Test and verification

- Some are more difficult
- *Energy Management*
  - *Lifetime between charging: >12 h*

Fully charge battery, run system using simplified FW, measure consumption using energy meter, measure lifetime inside and outdoors

What do we need for this test?

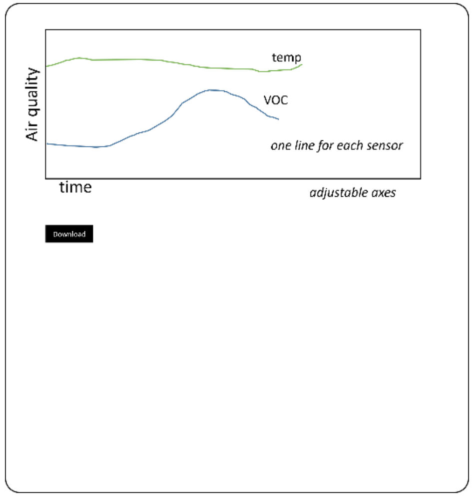
There is no correct answer here

The more sophisticated the test, the more complicated it will be to execute

Especially for March testing, you will not have the complete system ready so must make compromises

Test and verification

- Another simple one
  - **Software [on server]**
    - *Web front-end*
      - *Framework: TBD*



Compare wireframe to implemented front-end, visually determine pass

Test and verification

- More difficult
- **Software [on server]**
  - *Store data perpetually in SQLite table*
    - *Index number [int32], Timestamp [datetime], ID [int32], RH [float], T [float], SOC [float]*

Perpetuity is a long time…

Thinking about testing helps us understand the flaws in the spec

Test and verification

- More difficult
- **Software [on server]**
  - *Store data for system lifetime in SQLite table*
    - *Index number [int32], Timestamp [datetime], ID [int32], RH [float], T [float], SOC [float]*

- Send 100 measurements, measure storage needed, extrapolate to 80% size of HD size

Is there a max SQLite db file size?
Does server need certain amount of free disk to operate robustly (w/o crashing)?

Test and verification: FW & SW

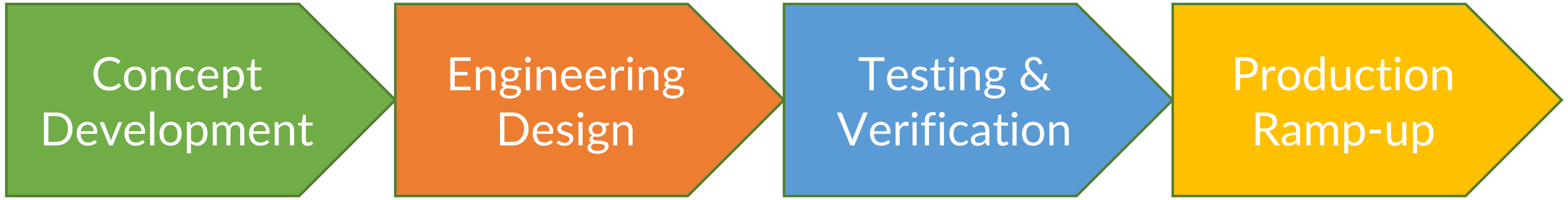
- Tests of each function (unit tests) and overall FW
- Not just “best case” when everything works, but consider common failures
  - WiFi down…
  - Reset
  - Sensors fail
  - And so on…

```
void setup() {
  Serial.begin(9600); //begin serial
  while (!Serial) {
      delay(100);
  }

  WiFi.begin(network, password);
  //if using channel/mac specification for crowded bands use the following:
  //WiFi.begin(network, password, channel, bssid);
  uint8_t count = 0; //count used for Wifi check times
  Serial.print("Attempting to connect to ");
  Serial.println(network);
  while (WiFi.status() != WL_CONNECTED && count < 6) { //can change this to more attempts
    delay(500);
    Serial.print(".");
    count++;
  }
```

What happens if WiFi goes down?

Iterating



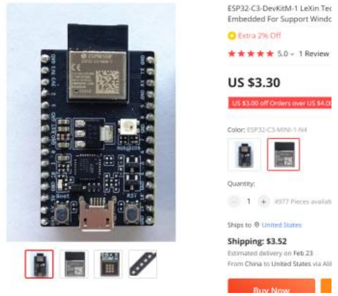
We iterate between:

- Developing and refining concepts: form and function
  - This will involve system design and partitioning
- Research: what's out there and available, what do our competitors do?
- Update specifications document as needed (incl. tests!) ← remember this is a *working document*
- Even **NOW**, you can research, model, prototype & test
  - 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

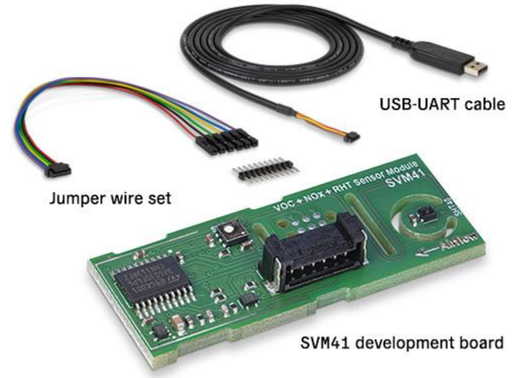
Prototyping for de-risking

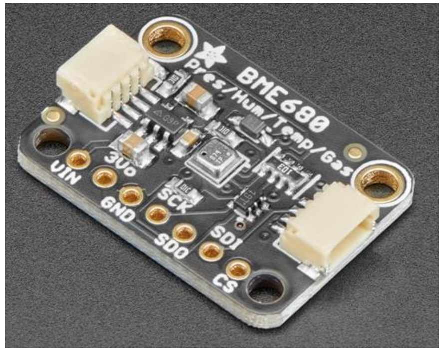
We have parts available, or can order for your team!

- 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!**
    - Many/most of these are available substantially cheaper from China…but may take longer to arrive, may be *sketchy*
- 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)

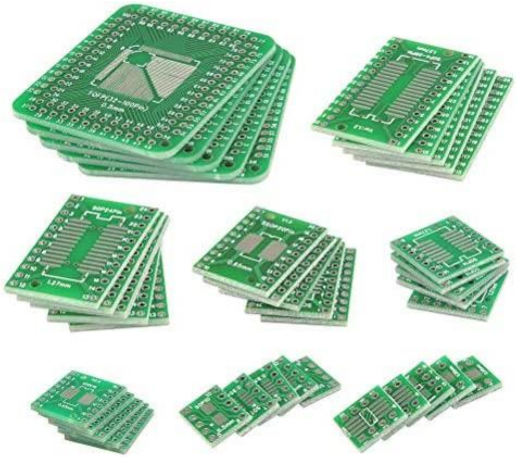


ESP32-C3 dev board
$3.30 @ 1





Adafruit Bosch BME680 breakout
$19 @ 1



SMD adapter boards

VEML7700-TT

Power management

It should operate independently without user intervention for 3+ months.***

It should operate without being connected to line voltage. ***

It should operate independently without user intervention or servicing for at least one year.**

It should operate without being connected to line voltage. ***

- Implies battery-powered
- Last year used battery w/ solar panel to recharge

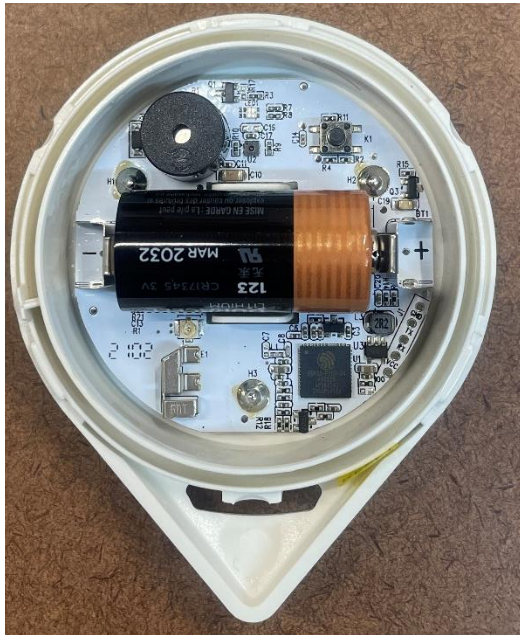
That's not the only potential design

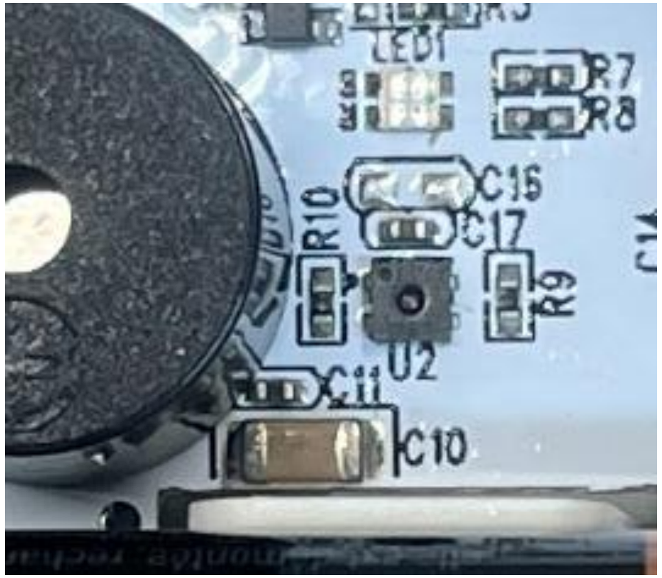
Joe will talk about power management in detail next week

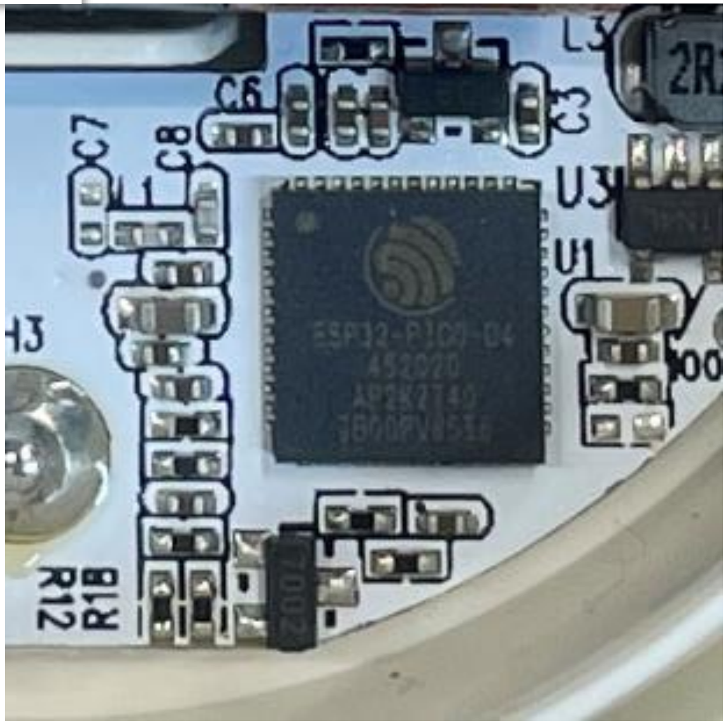
Power management

- Flo by Moen Smart water detector
  - Leak detector, also RH/T

- 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)

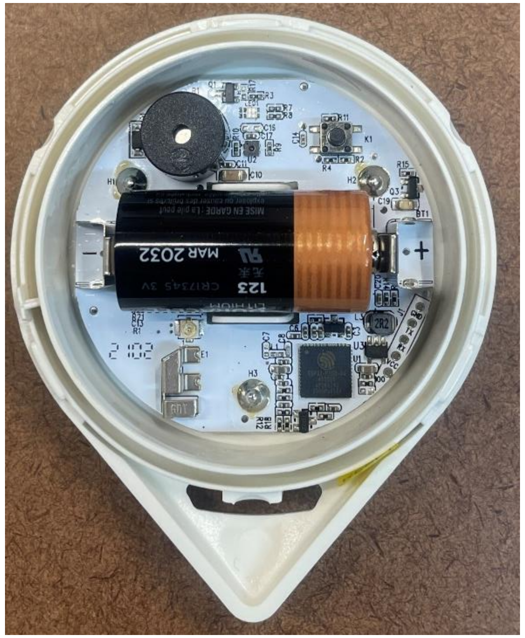


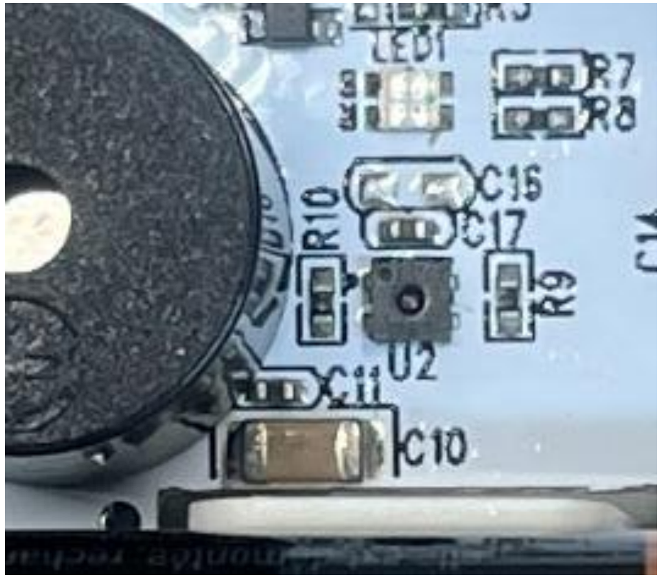


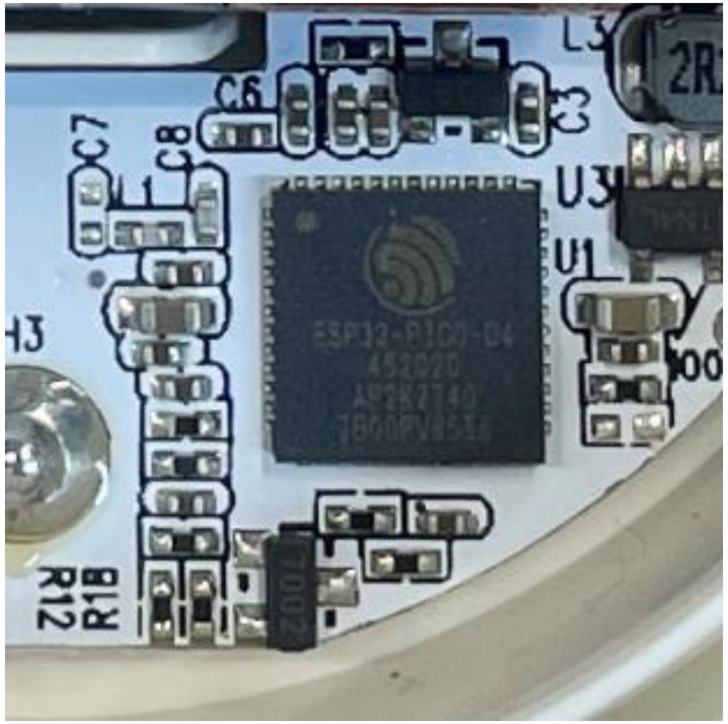


Power management

- Flo by Moen Smart water detector
  - Leak detector, also RH/T
  - Connects to WiFi, uploads every few minutes
  - Battery is 3V@1470 mAh, lasts around 1 y in my house







Power management

- Solely use battery power
  - Probably lower BOM cost [no solar panel]
  - Fewer parts to break, simpler industrial design
  - More work on firmware
  - Limited lifetime (but might be long enough)
- Solar charger
  - Likely higher cost
  - More complicated industrial design
  - FW is simpler
  - Lifetime potentially indefinite

BXS001 IP67 panel mount battery holder

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
  - 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 type sof parts

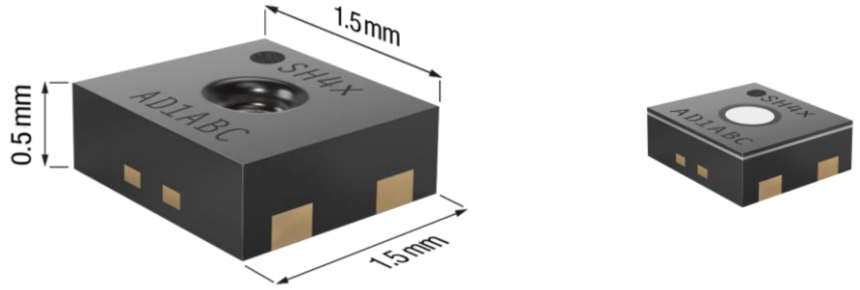
Datasheets

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

SENSIRION

Datasheet – SHT4x

4th Gen. Relative Humidity and Temperature Sensor



Highlights

- Accuracies Δ*RH* = ±1.0 %RH, Δ*T* = ±0.1 °C
- VDD = 1.08 V … 3.6 V
- Avg. current: 0.4 μA, Idle current: 80 nA
- I2C FM+, CRC checksum, multip. I2C addr.
- Patented protection options [1], PTFE membrane and removable protective cover
- Operating range: 0 … 100 %RH, −40…125 °C
- Fully functional in a condensing environment
- Power heater, true NIST-traceability
- JEDEC JESD47 qualification
- Sensor-specific calibration certificate acc. to ISO 17025: 2017, 3-point temp. calibration

SHT4x is a digital sensor platform for measuring relative humidity and temperature at different accuracy classes. Its I2C interface provides several preconfigured I2C addresses while maintaining an ultra-low power budget (0.4 μW). The power-trimmed internal heater can be used at three heating levels thus enabling sensor operation in demanding environments. The four-pin dual-flat-no-leads package is suitable for surface mount technology (SMT) processing and comprises an optional on-package patented PTFE [1] membrane or a removable protective cover. Sensor specific calibration certificates according to ISO17025, identifiable through unique serial numbers, are available.

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°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

First page

- Different parts

Device Overview

Product	Details
SHT40-xD1B	base RH&T accur., possible I2C addr.: 0x44, 0x45, 0x46
SHT40-AD1F	SHT40-AD1B with PTFE membrane
SHT40-AD1P	SHT40-AD1B with protective cover
SHT41-AD1B	intermed. RH&T accur., 0x44 I2C addr.
SHT43-ADCB	ISO17025 3-point calibration certificate
SHT45-AD1B	±1.0 %RH, ±0.1 °C accur., 0x44 I2C addr.

See full product list on page 21.

Just a subset!

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE
LM3671	USON (6)	2.00 mm × 2.00 mm (NOM)
LM3671 LM3671-Q1	SOT-23 (5)	2.90 mm × 1.60 mm (NOM)
	DSBGA (5)	1.413 mm × 1.083 mm (MAX)

(1) For all available packages, see the orderable addendum at the end of the datasheet.

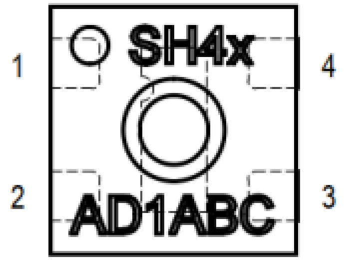
Datasheets

Pin configurations & packages

- Tells you what each pin does
  - Often more info later on about that

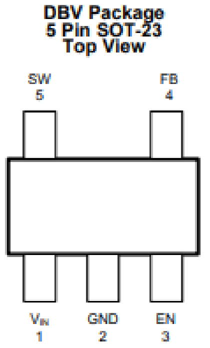
5.4 Pin Assignment & Laser Marking

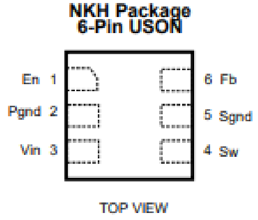
Pin	Name	Comments
1	SDA	Serial data, bidirectional
2	SCL	Serial clock, unidirectional input
3	VDD	Supply voltage
4	VSS	Ground

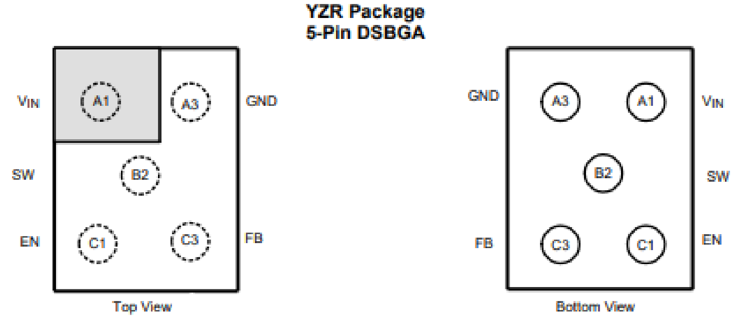


This is on page 16

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).

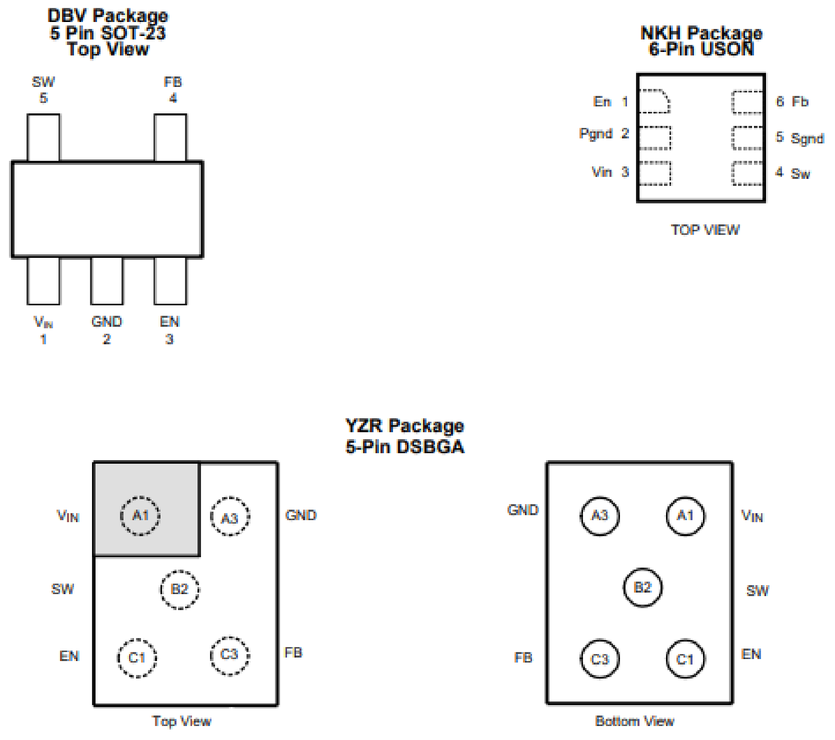
This is on page 3

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

5 Pin Configuration and Functions



LM3671

Pin Functions

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SOT-23	DSBGA	USON			
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2	A3	2	GND	Ground	Ground pin.
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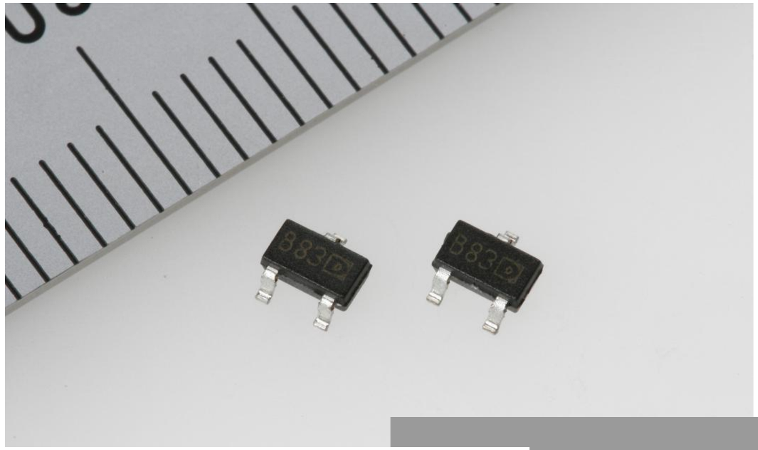
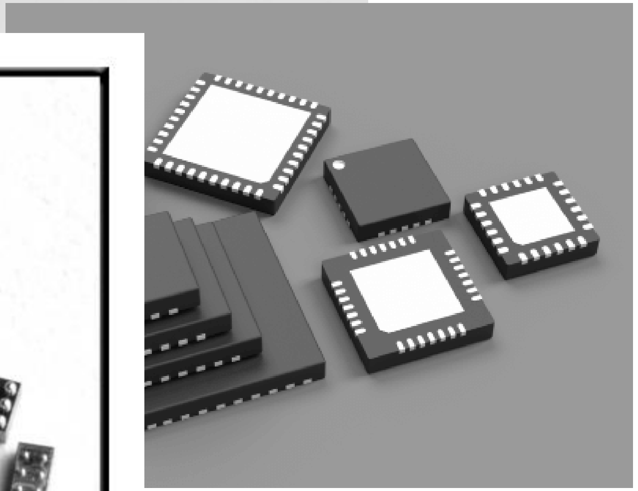
Datasheets



SOT
SOT

QFN



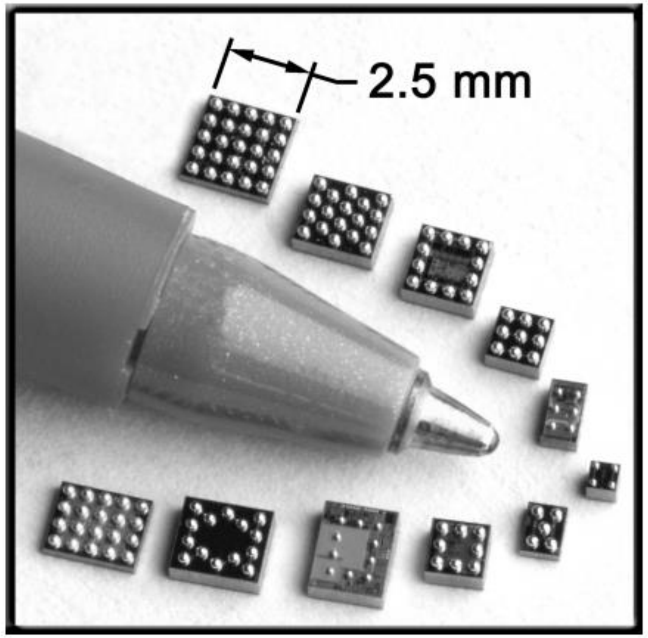
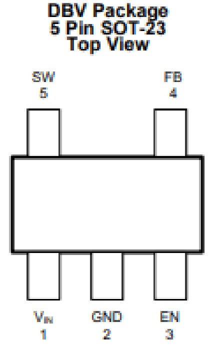
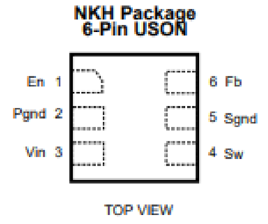


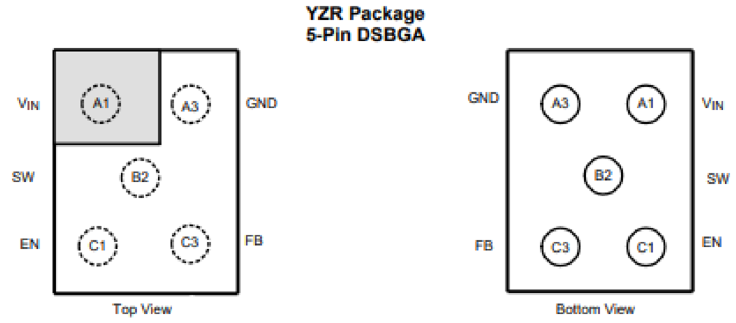
Figure 1. DSBGA 4–25 Bump

BGA

5 Pin Configuration and Functions







LM3671

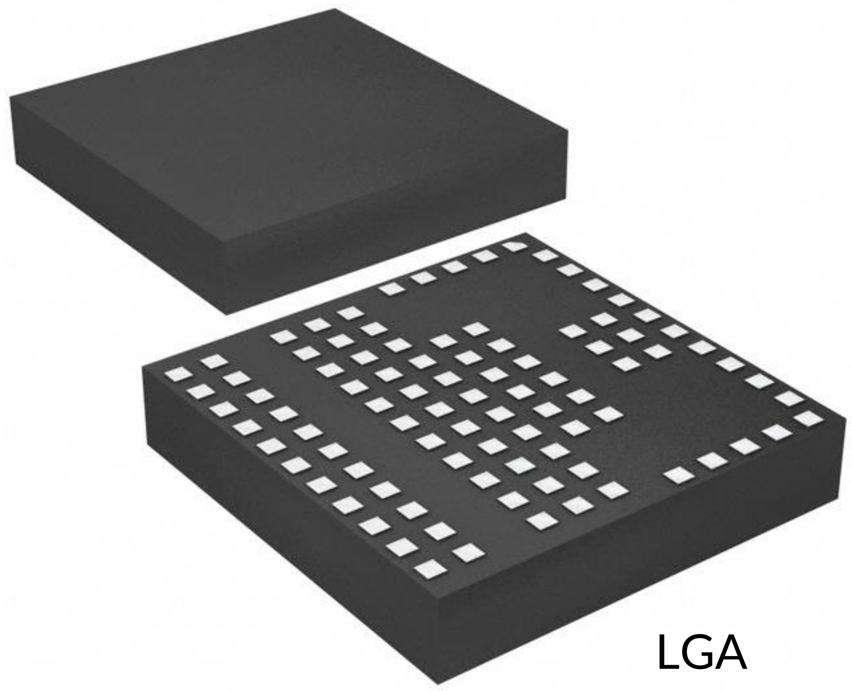
Pin Functions

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
  - Try to avoid LOTS of pins
  - LGA or where you can't see any part of pin
  - Tiny pitches



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

3.2 Absolute Maximum Ratings

Stress levels beyond those listed in **Table 6** may cause permanent damage or affect the reliability of the device. These are stress ratings only and functional operation of the device at these conditions is not guaranteed. Ratings are only tested each at a time.

Parameter	Rating
Max. voltage on any pin	VSS −0.3 V ... VDD +0.3 V
Operating temperature range	−40 °C ... 125 °C
Storage temperature range	−40 °C ...150 °C
ESD HBM	2 kV
ESD CDM	500 V
Latch up, JESD78 Class II, 125 °C	±100 mA

SHT4x

Datasheets

Specifications

- Will vary A LOT depending on the part
- Some is tabular
- Some are plots

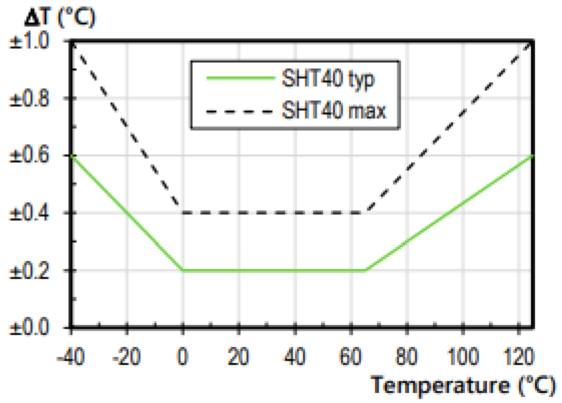


Figure 10. SHT40 typical and maximal temperature accuracy.

2.2 Temperature

Parameter	Conditions	Value	Units
SHT40 *T* Accuracy[1]	typ.	±0.2	°C
	max.	see **Figure 10**	-
SHT41 *T* Accuracy[1]	typ.	±0.2	°C
	max.	see **Figure 11**	-
SHT43 *T* Accuracy[1]	max.	see **Figure 12**	-
SHT45 *T* Accuracy[1]	typ.	±0.1	°C
	max.	see **Figure 13**	-
Repeatability[2]	high	0.04	°C
	medium	0.07	°C
	low	0.1	°C
Resolution[4]	-	0.01	°C
Specified range[5]	-	–40 to +125	°C
Response time[9]	$\tau_{63\%}$	2	s
Long-term drift[10]	typ.	<0.03	°C/y
Long-term drift for SHT43	typ.	<0.01	°C/y

Table 2. General Temperature Sensor specifications.

Datasheets

Specifications

- Will vary A LOT depending on the part
- Some is tabular
- Some are plots

6.4 Recommended Operating Conditions

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

	MIN	MAX	UNIT
Input voltage(3)	2.7	5.5	V
Recommended load current	0	600	mA
Junction temperature, T_J	–40	125	°C
Ambient temperature, T_A(4)	–40	85	°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) All voltages are with respect to the potential at the GND pin.
(3) The input voltage range recommended for ideal applications performance for the specified output voltages are given below: V_{IN} = 2.7 V to 4.5 V for 1.1 V ≤ V_{OUT} < 1.5 V V_{IN} = 2.7 V to 5.5 V for 1.5 V ≤ V_{OUT} < 1.8 V_{IN} = (V_{OUT} + $V_{DROPOUT}$) to 5.5 V for 1.8 V ≤ V_{OUT} ≤ 3.3 V where $V_{DROPOUT}$ = I_{LOAD} × ($R_{DSON,\ PFET}$ + $R_{INDUCTOR}$).
(4) In applications where high power dissipation and/or poor package resistance is present, the maximum ambient temperature may have to

Datasheets

Specifications

- Will vary A LOT depending on the part
- Some is tabular
- Some are plots

6.7 Electrical Characteristics

Unless otherwise noted, limits apply for for T_J = 25°C, and specifications apply to the LM3671MF/TL/LC with V_{IN} = EN = 3.6 V[(1)(2)(3)]

PARAMETER		TEST CONDITION	MIN	TYP	MAX	UNIT
V_{IN}	Input voltage	−40°C to 125°C, see[(4)]	2.7		5.5	V
V_{FB}	Feedback voltage (fixed) MF	PWM mode[(5)], −40°C to 125°C	−4%		4%	
	Feedback voltage (fixed) TL		−2.5%		2.5%	
	Feedback voltage (fixed) LC		−4%		4%	
	Feedback voltage (ADJ) MF[(6)]	PWM mode[(5)], −40°C to 125°C	−4%		4%	
	Feedback voltage (ADJ) TL		−2.5		2.5	
	Line regulation	2.7 V ≤ V_{IN} ≤ 5.5 V, I_O = 10 mA		0.031		%/V
	Load regulation	100 mA ≤ I_O ≤ 600 mA, V_{IN} = 3.6 V		0.0013		%/mA
V_{REF}	Internal reference voltage			0.5		V
I_{SHDN}	Shutdown supply current	EN = 0 V		0.01		μA
		EN = 0 V, −40°C to 125°C			1	
I_Q	DC bias current into V_{IN}	No load, device is not switching (FB forced higher than programmed output voltage)		16		μA
		No load, device is not switching (FB forced higher than programmed output voltage), −40°C to 125°C			35	
$R_{DSON\ (P)}$	Pin-pin resistance for PFET	V_{IN} = V_{GS} = 3.6 V		380	500	mΩ
$R_{DSON\ (N)}$	Pin-pin resistance for NFET	V_{IN} = V_{GS}= 3.6 V		250	400	mΩ
I_{LIM}	Switch peak current limit	Open loop[(7)]		1020		mA
		Open loop[(7)], −40°C to 125°C	830		1150	
V_{IH}	Logic high input	−40°C to 125°C	1			V
V_{IL}	Logic low input	−40°C to 125°C			0.4	V
I_{EN}	Enable (EN) input current			0.01		μA
		−40°C to 125°C			1	
f_{OSC}	Internal oscillator frequency	PWM Mode[(5)]		2		MHz
		PWM Mode[(5)], −40°C to 125°C	1.6		2.6	

Datasheets

Specifications

- Will vary A LOT depending on the part
- Some is tabular
- Some are plots

LM3671MF/TL/LC, circuit of *Figure 32*, V_{IN} = 3.6 V, V_{OUT} = 1.5 V, T_A = 25°C, unless otherwise noted.

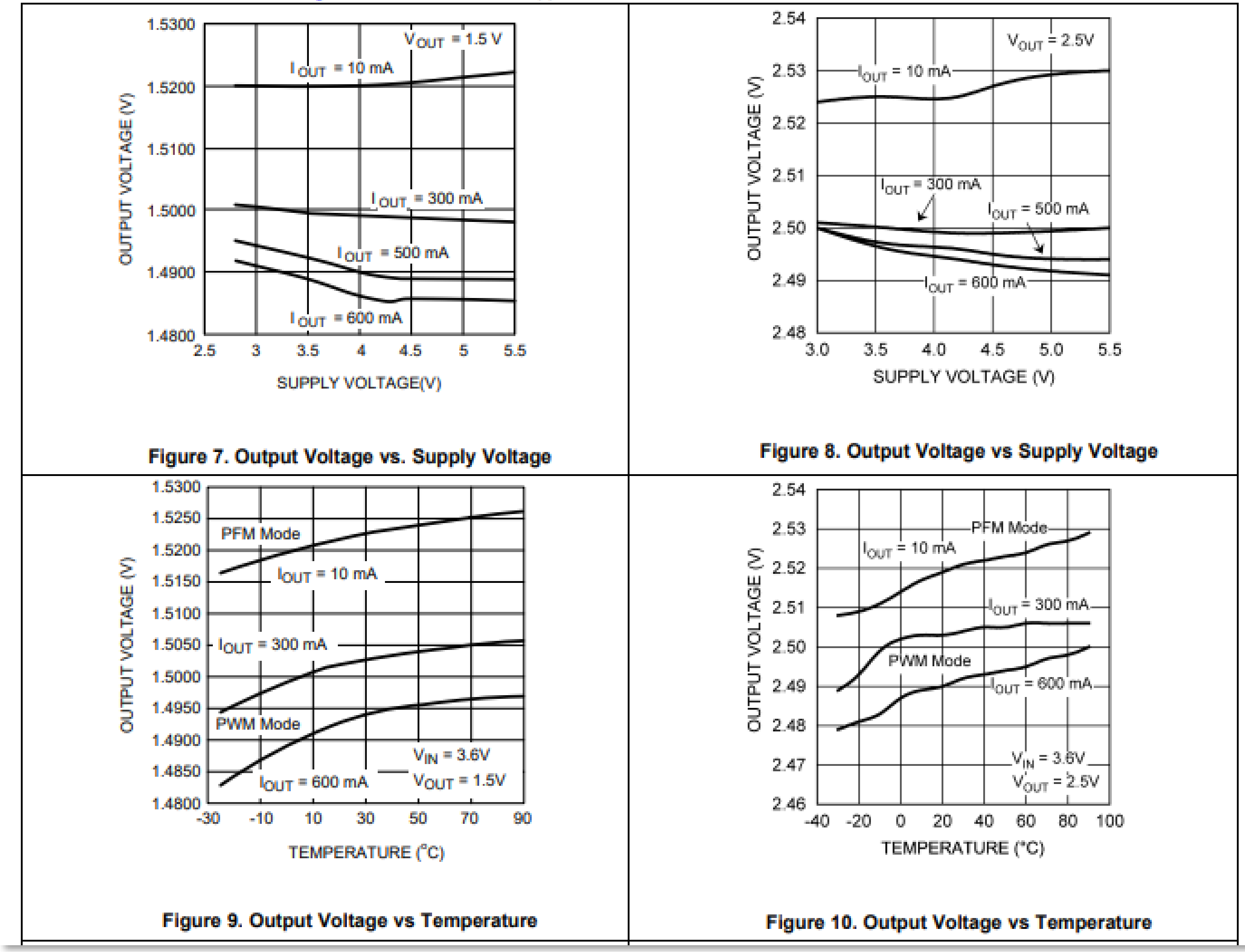


Figure 7. Output Voltage vs. Supply Voltage

Figure 8. Output Voltage vs Supply Voltage

Figure 9. Output Voltage vs Temperature

Figure 10. Output Voltage vs Temperature

Datasheets

Design help

- Often some theory of operation or overview
  - I find these sections 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 µA typical) and a longer battery life. Shutdown mode turns off the device, offering the lowest current consumption ($I_{SHUTDOWN}$ = 0.01 µA 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
  - I find these sections incredibly useful
- But also help on developing a design

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The external control of this device is very easy. First make sure the correct voltage been applied at V_{IN} pin, then simply apply the voltage at EN pin according to the *Electrical Characteristics* to enable or disable the output voltage.

8.2 Typical Application

8.2.1 Typical Application: Fixed-Voltage Version

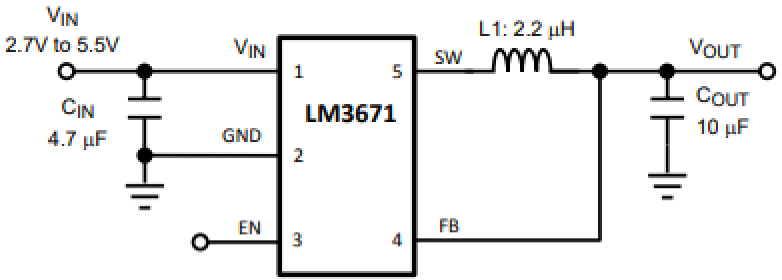


Figure 32. LM3671 Fixed-Voltage Typical Application Circuit

8.2.1.1 Design Requirements

Two ceramic capacitors and one inductor required for this application. These three external components need to be selected very carefully for property operation. Please read *Detailed Design Procedure*.

8.2.1.2 Detailed Design Procedure

Datasheets

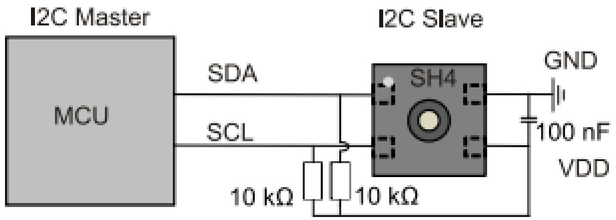
Design help

- Often some theory of operation or overview
  - I find these sections incredibly useful
- But also help on developing a design

1 Quick Start Guide

A typical application circuit for SHT4x is shown on the left-hand side of **Figure 1**. After reaching the minimal supply voltage and allowing for the maximal power-up time of 1 ms the sensor is ready for I2C communication. The quickest way to measure humidity and temperature is pseudo-coded on the right-hand side of **Figure 1**. Together with the conversion formulae given in equations (1), (2) & (3)the digital signals can be translated into relative humidity and temperature readings.

Typical application circuit



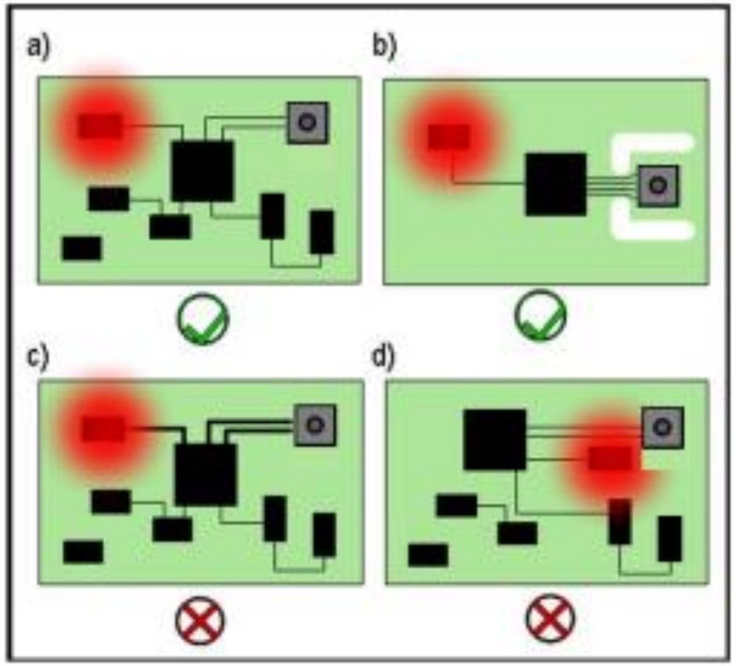
Pseudo code

```
i2c_write(i2c_addr=0x44, tx_bytes=[0xFD])
wait_seconds(0.01)
rx_bytes = i2c_read(i2c_addr=0x44, number_of_bytes=6)
t_ticks = rx_bytes[0] * 256 + rx_bytes[1]
checksum_t = rx_bytes[2]
rh_ticks = rx_bytes[3] * 256 + rx_bytes[4]
checksum_rh = rx_bytes[5]
t_degC = -45 + 175 * t_ticks/65535
rh_pRH = -6 + 125 * rh_ticks/65535
if (rh_pRH > 100):
      rh_pRH = 100
if (rh_pRH < 0):
      rh_pRH = 0
```

Datasheets

Design help

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



10.2 Layout Example

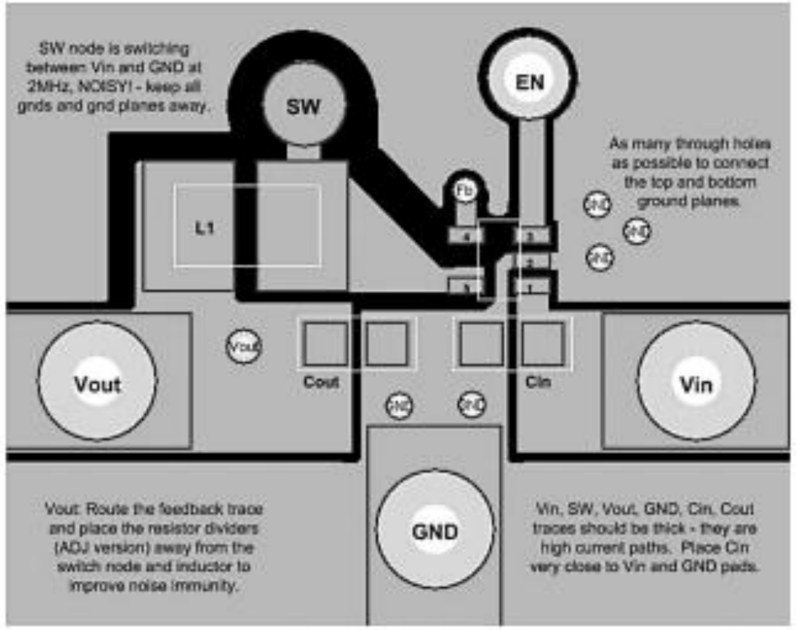


Figure 38. Top Layer Board Layout for SOT-23

Datasheets

Part numbers

- Finding difference between some part numbers will 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

Datasheets

Part numbers

- Finding difference between some part numbers will drive you crazy

9 Nomenclature

Position	Value(s)	Explanation
1	S	Sensirion
2	H	Humidity Signal
3	T	Temperature Signal
4	4	Fourth product generation
5	0 1 5 3	Base accuracy Intermediate accuracy Best accuracy ISO17025 certified
6	-	delimiter
7	A B C	I2C interface with 0x44 address I2C interface with 0x45 address I2C interface with 0x46 address
8	D	DFN package
9	1 C	Reserved 3-point calibrated and certified
10	B F P	Blank package Package with integrated, patented PTFE membrane Package with removable protective cover for conformal coating (coming soon)
11	-	delimiter
12	R	Tape on reel packaging
13	2 3	Packaging article contains 2'500 pieces Packaging article contains 10'000 pieces

Table 11. SHT4x product nomenclature. For ordering information, kindly refer to **Table 12**.

Better

Part selection

- How do we evaluate/compare components & designs?
- 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