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A Note on Remote Temperature Measurements with DS18B20 Digital Sensors

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Digital temperature sensors provide an attractive means to conveniently record ice and water temperatures in remote locations. Unlike conventional analogue techniques, a digital sensor performs a physical measurement, interprets its result in terms of temperature and transmits that result to a logger or display system in digital form. Processing of digital signals is comparatively robust and cheap. Custom calibration may be applied to increase measurement accuracy. A popular example of a digital temperature sensor is the Maxim Integrated DS18B20, which is readily available as a bare sensor in a standard transistor casing, or from third-part providers as a probe with the sensor encased in a waterproofed metal sleeve. We found that the quality of water protection of the probes varies widely, and that bare sensors and sensors in probes offered by most third-party providers (i.e. not by official distributors) are almost always clones, i.e. not produced by Maxim Integrated. We summarize in this paper the spectrum of counterfeit sensors currently available and how they differ from authentic parts and specifications in the Maxim Integrated data sheet. Currently sold sensors are grouped into 7 families, 6 of them representing counterfeits. Awareness of the prevalence and characteristics of counterfeit sensors will help avoid surprises during costly experimental field work.

1. Introduction

Digital sensors are attractive peripherals in environmental data acquisition systems as they remove the challenge of temperature compensation from the logger design. By allowing all-digital logging solutions, logger designs become comparatively cheap and simple. In many cases it is also possible to connect several sensors to the same data bus, thereby greatly reducing the number of wires required for strings of sensors (e.g., I2C, 1-Wire, SDI-12 protocols). One popular digital temperature sensor is Maxim Integrated DS18B20, which is the successor of the DS1820 (Maxim 2009), both of which had been developed and produced by Dallas Semiconductor prior to its acquisition by Maxim Integrated. The DS18B20 has been produced for approximately 20 years and is used in commercially available sea ice buoys and individual research projects (e.g., Cui et al., 2015; Hills et al., 2018; Planck et al., 2019). Our group has used DS18B20 temperature sensors in an ice-borne temperature string since 2013 (Petrich et al., 2014), and at a much larger scale in ocean applications and construction projects since 2018 (e.g., Petrich et al., 2019). The prevalence of counterfeit DS18B20 sensors became apparent to us in the context of the most recent measurement series when we started to reject probes for their poor signal-to-noise performance. Following our initial suspicion, a systematic attempt was made with the support of Ice Mate AS to survey the state of counterfeit DS18B20 as of 2019. The main result of this study is a list of characteristics that is backed up by observations on large numbers of sensors.

Maxim Integrated temperature sensors DS18B20 integrate a bandgap-based thermal circuit with an analogue-to-digital converter, temperature calibration unit, and digital communication circuitry (Maxim, 2019). The manufacturer states an absolute temperature accuracy of ±0.5 °C over the temperature range from -10 to +85 °C while the operating range extends from -55 to +125 °C with ±2 °C accuracy. The temperature resolution is 0.0625 °C. The remaining temperature error vs. temperature relationship is parabolic (Maxim, 2013). This characteristic of all bandgap-based sensors allows for higher order correction in post-processing to increase the temperature accuracy. The sensors expose three pins: ground, supply voltage, and bi-directional data transfer. The low power requirements and integrated capacitor allows them to operate in “parasitic power mode” where the supply voltage pin is tied to the ground pin and the chip derives its power from the data line. Each sensor contains a unique 64-bit address (called ROM by the manufacturer) which allows communication with multiple sensors on the same data bus. The sensors are available in a TO-92 case among other options. The TO-92 case is a flattened cylinder of approximately 5 mm height and diameter. There are many third-party suppliers that will produce waterproof probes by soldering wires to the sensor, placing the sensor in a 6 mm outer diameter metal sleeve and waterproofing the connection with epoxy, glue, heat shrink, or a combination of those. Those waterproof probes can be bought on eBay often for less than the costs of a sensor from a Maxim-authorized retailer (based on prices for individual sensors).

DS18B20 sensors communicate through the 1-Wire protocol that allows multiple sensors to share the same data bus. Communication is always initiated by a bus controller (e.g., Dallas, 2019). The bus controller begins by sending a 0.5 ms reset pulse followed by the “Match ROM” command byte and the ROM code of the sensor it wants to communicate with. Subsequent communication will be between the bus controller and the sensor addressed until another ROM command is sent. Each interaction with the sensor begins with a reset pulse, followed by a function code, followed either by additional data from the bus controller or by clock signals from the bus controller and data from the sensor in response. A peculiarity of the protocol is that sending clock signals is indistinguishable from sending hexadecimal data

0xFF, and receiving no response is indistinguishable from receiving a 0xFF response. While this is not a limitation when communications follow documented protocol, it does affect attempts to reverse engineer sensor behavior. The 1-Wire protocol also includes a mechanism for the bus controller to discover the ROM codes of all sensors attached to the bus.

To receive a temperature measurement, the bus controller sends a function code that makes the sensor initiate measurement and data conversion. Following this, the bus controller can either query the sensor for completion of the data conversion or wait the maximum time for data conversion specified in the datasheet (i.e., 750 ms; Maxim, 2019). Temperature data are retrieved by sending a "Read Scratchpad" function code and receiving 9 bytes of data: the temperature measurement (bytes 0 and 1), two alarm registers (bytes 2 and 3), a configuration register (byte 4), three reserved bytes (bytes 5, 6, and 7), and a checksum (byte 8). The configuration register specifies whether the sensor operates with 9-bit (fastest), 10, 11, or 12-bit (slowest) resolution. The reserved bytes are useful to identify counterfeit sensors. Bytes 2, 3, and 4 can be overwritten by the user and stored in an EEPROM on the DS18B20. The temperature stored in bytes 0 and 1 between power-up and the first successful temperature conversation is 85 °C (Maxim, 2019).

There is no uniform definition of counterfeit parts across engineering and legal domains (cf. AIR6273). According to the definition of AIR6273 (2019), a counterfeit electrical part is "an unauthorized (a) copy, (b) imitation, (c) substitute, or (d) modified materiel or [electronic] part, which is knowingly, recklessly, or negligently misrepresented as a specified genuine item from an authorized manufacturer; or a previously used materiel or [electronic] part which has been modified and is knowingly, recklessly, or negligently misrepresented as new without disclosure to the customer that it has been previously used.". According to our survey in this study, the main problem affecting DS18B20 sensors are imitations (clones) that are misrepresented as genuine parts.

Throughout this paper we will distinguish between DS18B20 sensors (Figure 1a) and waterproof probes that contain DS18B20 sensors (Figure 1b). With the exception of one subsection in the Discussion, this manuscript is about DS18B20 sensors, whether sold separately or encased in a probe.

2. Methods

Over 1000 waterproof probes and sensors were purchased from over 70 different vendors on eBay, AliExpress, Amazon, or Alibaba, in addition to Maxim-authorized international retailers including Digikey, Mouser, Farnell, and RS-Electronics, regionally-focused retailers including Reichelt and Conrad Electronics, Elfa Distrelec, or Elektroimportøren, an authorized retailer for DS18B20 clones, LCSC, independent stores such as Kjell & Co, TELMAL, DROK, YourDuino, SparkFun, Adafruit and Banggood, and speciality vendor Quest Components.

To characterize sensor performance and calibration, an Arduino Uno was used to communicate with the sensor using the 1-Wire library "OneWire", Version 2.3, maintained by Jim Studt and Paul Stoffregen. Sensors were powered at 5 V, and a 1.2 kOhm pull-up resistor was used on the data line. Sensors were powered through the sensor supply voltage pin except while testing the performance in parasitic power mode.

We performed temperature calibration measurements in an ice–water bath in a thermos flask at nominally 0 °C on hundreds of sensors. The data were automatically evaluated for average, and standard deviation (i.e., discretization noise), and drift was checked for quality control. We followed Mangum (1995) for the preparation of the ice–water bath. Temperatures were polled every 10 seconds during sensor calibration, which avoided signs of self-heating (based on our tests, polling every second resulted in measurable self-heating of one discretization step of up to 0.06 °C). Measurements were repeatable to within the measurement resolution of the sensors.

The following had been recorded systematically for the classification of sensors: the ROM code, scratchpad register start-up values and content of reserved bytes, time required for temperature measurement, response to undocumented function codes, response to power cycling, and performance in parasite power mode. In addition, a small subsample was used to assess electrical performance (skipped here due to space), and to photograph the die (i.e., the electronic circuit). In order to prepare a die, we broke the TO-92 case open with pliers and detached the die from the plastic case by boiling in colophony, removed the colophony with acetone, and cleaned the die in acetone ultrasonically. Photos were taken with a USB camera.

3. Results

The sensors tested fall naturally into seven groups, henceforth referred to as families. In our naming convention, the family letter indicates the pattern of undocumented function codes.

3.1 Sensor Families

3.1.1 Family A1: Authentic Maxim

- ROM pattern: 28-xx-xx-xx-xx-00-00-xx
- Package label lasered.
- Indent mark: “P” or “THAI <letter>”. All current sensors are marked “P”.
- At 0 °C, the average temperature error is smaller and of different sign and the spread between devices is less than suggested by the datasheet.
- Startup value of reserved byte 6 of the scratchpad register is 0x0C.
- Following a successful temperature conversion, reserved byte 6 of the scratchpad register is: <byte 6> = 0x10 – (<byte 0> & 0x0F)
- Two calibration parameters (Trim1, Trim2) can be read with undocumented function codes 0x93 and 0x68, respectively (Maxim, undated). Parameter spreads over approximately 20 units within a batch.
- Default alarm register setting: 0x4B, 0x46
- Time for temperature conversion (Figure 3c): 584 to 615 ms at 12 bits.

There are also authentic chips being sold by unauthorized sources that have their calibration parameters (and alarm and configuration registers) set to 0x00. Until set to reasonable values, those sensors report temperatures around -39 °C at room temperature, and too low conversation times even at 12-bit resolution (cf. Figure 3c, section A1).

3.1.2 Family A2

- ROM pattern: 28-00-xx-00-xx-xx-xx-xx, 28-xx-00-xx-xx-xx-xx-xx, 28-xx-00-00-xx-xx-00-xx
- Package label is printed, indent is unmarked.
- <byte 6> behavior as Family A1
- Two calibration parameters (Trim1, Trim2) can be read with undocumented function codes 0x93 and 0x68, respectively. Parameter spreads over approximately 200 units.

- Random content of alarm registers.
- Some samples retain scratchpad content over a 100 ms power cycle.
- Default alarm register setting: 0x4B, 0x46
- Time for temperature conversion (Figure 3c): 325 to 502 ms at 12 bits.

3.1.3 Family B1

- ROM pattern: 28-AA-xx-xx-xx-xx-xx-xx (GXCAS), 28-xx-xx-xx-xx-xx-xx-xx (UMW)
- Package label is printed, indent is unmarked. Some chips are marked GXCAS or UMW rather than DALLAS (cf. Figure 1a).
- <byte 6> and <byte 7> can be overwritten with the "Write Scratchpad" function (UMW, undated)
- Does not return data on function code 0x68. Does return data following function codes 0x90, 0x91, 0x92, 0x93, 0x95, and 0x97. Response to 0x97 is 0x22.
- Last 7 bytes of ROM code can be overwritten with command sequence "96-Cx-Dx-94"
- Default alarm register setting: 0x4B, 0x46
- Time for temperature conversion (Figure 3c): 589 to 728 ms at 12 bits.

3.1.4 Family B2

- ROM pattern: 28-FF-xx-xx-xx-xx-xx-xx
- Package label is printed, indent is unmarked. Some chips are marked 7Q-Tek rather than DALLAS (cf. Figure 1a).
- <byte 6> and <byte 7> can be overwritten with the "Write Scratchpad" function (7Q-Tek, undated)
- Does not return data on function code 0x68. Does return data following function codes 0x90, 0x91, 0x92, 0x93, 0x95, and 0x97. Response to 0x97 is 0x31.
- ROM code cannot be overwritten with command sequence "96-Cx-Dx-94"
- Default alarm register setting: 0x4B, 0x46
- Time for temperature conversion (Figure 3c): 587 to 697 ms at 12 bits.

3.1.5 Family C

- ROM pattern: 28-FF-64-xx-xx-xx-xx-xx
- Package label is printed, indent is unmarked.
- <byte 6> is fixed at 0x0C.
- Configuration byte <byte 4> is fixed at 0x7F, i.e., 12-bit resolution.
- EEPROM endures only approximately 8 write cycles.
- Does not return data on any undocumented function code.
- Default alarm register setting: 0x55, 0x00
- Time for temperature conversion (Figure 3c): 28 to 30 ms.

3.1.6 Family D1

- ROM pattern: 28-xx-xx-77-91-xx-xx-xx, 28-xx-xx-46-92-xx-xx-xx
- Package label is printed, indent is unmarked.
- <byte 7> defaults to 0x66 (vs. 0x10 according to Maxim (2019))

- Does not return data on function code 0x68. Does return data or shows reaction following function codes
    - 0x4D, 0x8B (8 bytes), 0xBA, 0xBB, 0xDD (5 bytes), 0xEE (5 bytes), or
    - 0x4D, 0x8B (8 bytes), 0xBA, 0xBB.
- First byte following undocumented function code 0x8B is
    - 0x06: Sensors do not work with Parasitic Power. Sensors leave data line floating when powered parasitically.
    - 0x02: Sensors do work in parasitic power mode (and report correctly whether they are parasitically powered).
- ROM code can be overwritten following undocumented function code 0xA3. The family code (0x28) can also be changed.
- Reserved <byte 5>, <byte 6>, and <byte 7> can be overwritten following undocumented function code 0x66.
- Chips contain a supercapacitor rather than an EEPROM to hold alarm and configuration settings. I.e., the last temperature measurement and updates to the alarm registers are retained between power cycles for seconds to minutes.
- Default alarm register setting: 0x55, 0x05
- Default temperature reading: 25 °C (rather than 85 °C)
- Time for temperature conversion (Figure 3c): 11 ms regardless of specified resolution.
- Poor calibration accuracy at 0 °C (Figure 3a).
- Temperature readings fluctuate significantly (Figure 3b).

3.1.6 Family D2

- ROM pattern: 28-xx-xx-79-97-xx-xx-xx, 28-xx-xx-94-97-xx-xx-xx, 28-xx-xx-97-A2-xx-xx-xx, 28-xx-xx-16-A8-xx-xx-xx
- Package label is printed, indent is unmarked.
- <byte 7> defaults to 0x66 (vs. 0x10 according to Maxim (2019))
- Does not return data on function code 0x68. Does return data or shows reaction following function codes
    - 0x4D, 0x8B (9 bytes), 0xBA, 0xBB, 0xDD (3 bytes), 0xEE (3 bytes), or
    - 0x4D, 0x8B (8 bytes), 0xBA, 0xBB.
- First byte following undocumented function code 0x8B is 0x00.
- Sensors do not work with Parasitic Power. Sensors pull the data line low when powered parasitically.
- Default alarm register setting: 0x55, 0x05
- Default temperature reading: 25 °C (rather than 85 °C)
- Time for temperature conversion (Figure 3c) is independent of specified resolution:
    - "-79-97-" and "-94-97-" ROM codes: 494-523 ms, and
    - "-97-A2-" and "-16-A8-" ROM codes: 462-486 ms
- Poor calibration accuracy at 0 °C (Figure 3a).

3.2 Dies and Manufacturers

According to the markings on the die (Figure 4), Family B1 and B2 are produced by GXCAS (Beijing Zhongke Galaxy Core Technology Co., Ltd.) and 7Q-Tek (Beijing 7Q Technology Inc.), respectively. Some sensors obtained were marked on the case GXCAS or UMW (Family B1), or 7Q-Tek (Family B2) instead of DALLAS. While the origin of the die of Family A2 is unknown, we note the visual resemblance with the style of families A1 and B2, and that the measured conversion time is compatible with the specifications on the 7Q-Tek QS18B20 datasheet (7Q-Tek, undated). The dies of Families D1 and D2 resemble each other, indicating the same origin (Figure 4). The die of Family C is not related to any of the other design efforts shown in Figure 4.

4. Discussion

4.1 Temperature Performance

Figure 3a shows that most sensors available in 2019 gave reasonable readings at 0 °C, although not necessarily within the specified error limit of 0.5 °C. The most notable exceptions are in Families A2 and D1. Noise level in Figure 3b is at the discretization limit except for Families D1 and D2, i.e. the usable resolution of those sensors is below 12 bits. The time for temperature conversion in Figure 3c differs between Families but was below the datasheet-specified 750 ms for all sensors.

Families A2 and D1 are practically obsolete while Family D2 is very common and thus of potential concern. Notable are high temperature offsets of +0.8 °C seen in some sensors of Family A1. Those measurements are reproducible and come from sensors that were bought from third-party vendors with uncertain handling history. The comparatively low conversion times of some Family A1 sensors were third-party supplied sensors with invalid calibration constants (Trim1 and Trim2), which are unlikely to be encountered.

4.2 Power-up Reading vs. Valid Measurement

After power-up and before the first valid temperature conversion, Maxim-produced DS18B20 and many counterfeits will return a temperature of 85 °C (Maxim, 2019), which is well within the operating range of the sensor. In chips of Family A, the power-up temperature reading can be distinguished from a valid temperature reading in a simple and undocumented manner. Upon power-up, <byte 6> of the scratchpad register is initialized to 0x0C. After a successful temperature measurement of 85 °C it is 0x10.

4.3 Quality of Waterproofing of Probes

Waterproofing is tangential to this study and not related to the question of whether or not a sensor is counterfeit. However, it is highly relevant for operation in saltwater environments. Figure 2 shows examples of the content of the metal cylinders used to provide waterproofing. We found that the spectrum includes a wide range from no waterproofing apart from heat shrink on the outside of the cylinder, to the use of a glue gun, and solid epoxy fill of the cylinder. Also, the quality of the outer heat shrink varied considerably. We submerged a small sample of 8 probes purchased from different vendors in 10 cm of saltwater for 2 months. 3 probes failed after 10 hours, 2 more probes failed after 10 days, the remaining probes operated through the end of the test. Also, we have successfully operated waterproofed probes in a fjord environment for 10 months (cf. Petrich et al., 2019). These observations highlight the importance of testing the quality of the waterproofing of those probes that are to operate in saltwater environment.

4.4 Obsolete Counterfeits

Based on web searches we are aware of counterfeit DS18B20 with the following ROM patterns:

- 28-61-64-xx-xx-xx-xx-xx, and
- 28-xx-xx-xx-00-00-80-xx.

However, in spite of a large number of purchases, we were not able to obtain sensors with these ROM patterns in 2019, leading us to believe that they are obsolete.

5. Conclusion

The results of a market survey of counterfeit DS18B20 sensors and waterproof probes containing DS18B20 sensors are presented. We found that counterfeit sensors are easy to identify and to classify by performance. A significant fraction of counterfeit sensors (i.e., Families D1 and D2) had temperature calibration problems and a signal-to-noise ratio that exceeded that of authentic Maxim Integrated-produced DS18B20 sensors. Those should be avoided in a research setting.

As of 2019, the simplest (and apparently sufficient) test questions for authenticity of a recently produced DS18B20 sensor are: does the indent on the case show the letter “P”? And does the ROM code follow the pattern 28-xx-xx-xx-xx-00-00-xx? However, other metrices should be tested (e.g., the value of <byte 6> of the scratchpad register (Section 3.1.1)) since some sensors allow the ROM code to be changed. Test software is available from the repository at https://github.com/cpetrich/counterfeit_DS18B20.

As a side-effect of our investigations we identified an undocumented mechanism to distinguish the power-up temperature reading from successful temperature measurements.

We suggest that, until tested, one should assume that every sensor bought from a third-part retailer is counterfeit, and that every waterproof probe contains a counterfeit sensor. There are few exceptions to this rule. The quality of waterproofing of probes also varies widely. Acquisition of waterproof probes that are epoxy-filled and use authentic, Maxim-produced DS18B20 sensors requires time and money to identify sources and test the products.

Producing integrated circuits involves high up-front costs. The existence of several manufacturers that currently produce DS18B20 clones (i.e., counterfeits) is evidence of the relevance of digital temperature sensors for industrial applications, research, and hobby. Since the performance of the counterfeits varies widely, awareness of their prevalence is needed to avoid unpleasant surprises.

Acknowledgments

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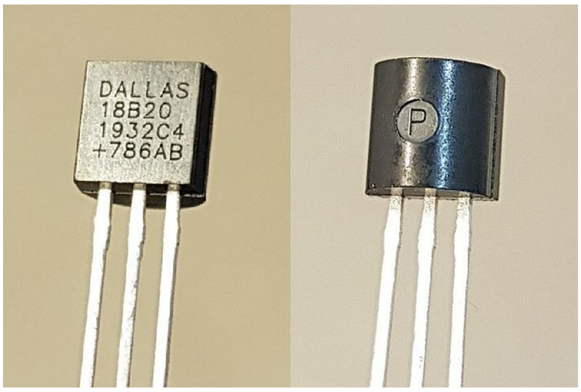
UMW, undated. UMW DS18B20. Datasheet, 22pp, in Mandarin.

Figures

(a) 

(b) 

Figure 1. (a) Maxim-produced DS18B20 sensor in TO-92 case (approx. 5 mm high), and (b) waterproof probe with 6 mm o.d. metal cylinder containing a DS18B20 sensor and cable attached.

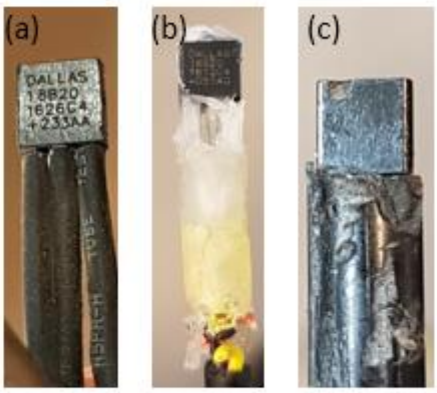


Figure 2. Example fill used inside the metal cylinders of waterproof DS18B20 probes: (a) air-fill, (b) glue gun-fill, and (c) epoxy-fill. All sensors are counterfeit, and (c) had been nicked during the opening of the cylinder.

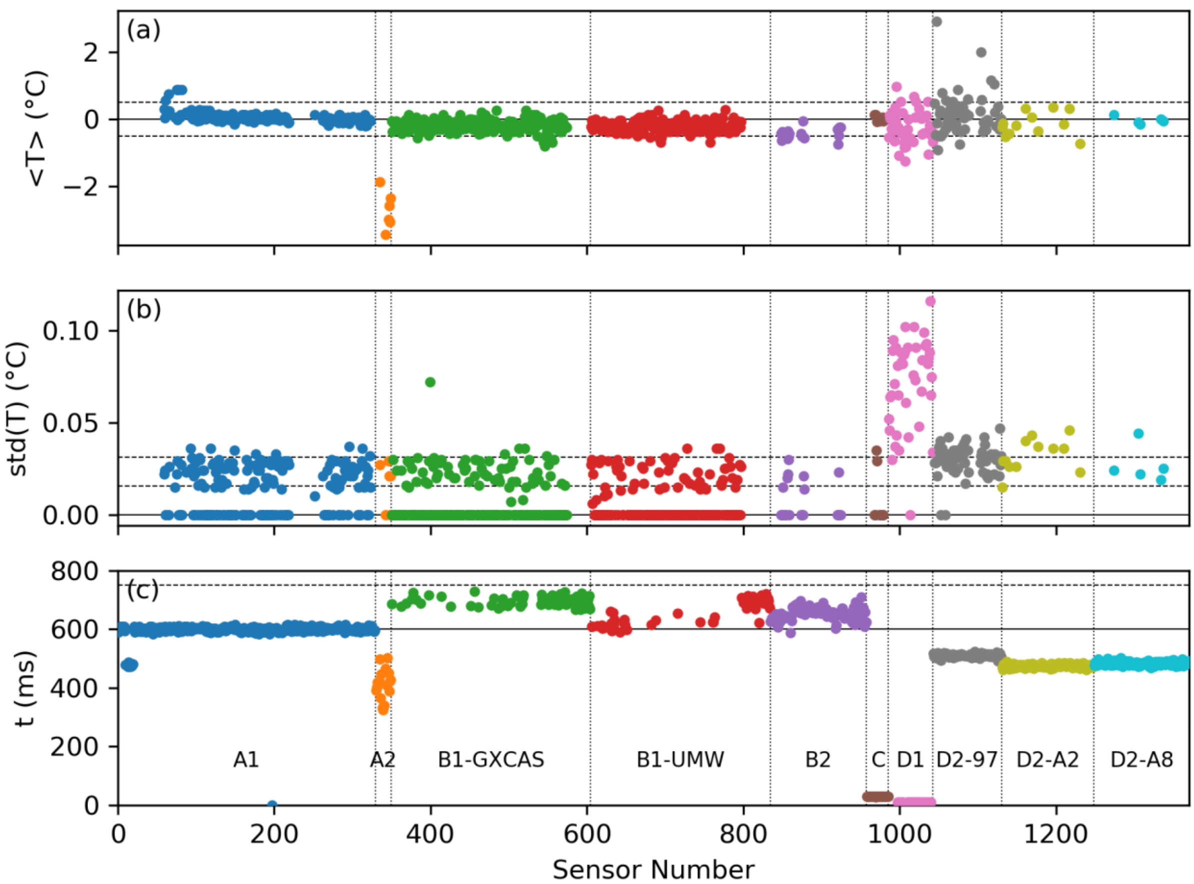


Figure 3. (a) Average temperature reading at 0 °C, (b) standard deviation of temperature readings at 0 °C (typically N=15 samples), and (c) reported time required for temperature conversion. Dashed lines indicate (a) allowable range according to data sheet, (b) expected standard deviation for fluctuations 1:14 and 1:2, (c) maximum time according to datasheet.

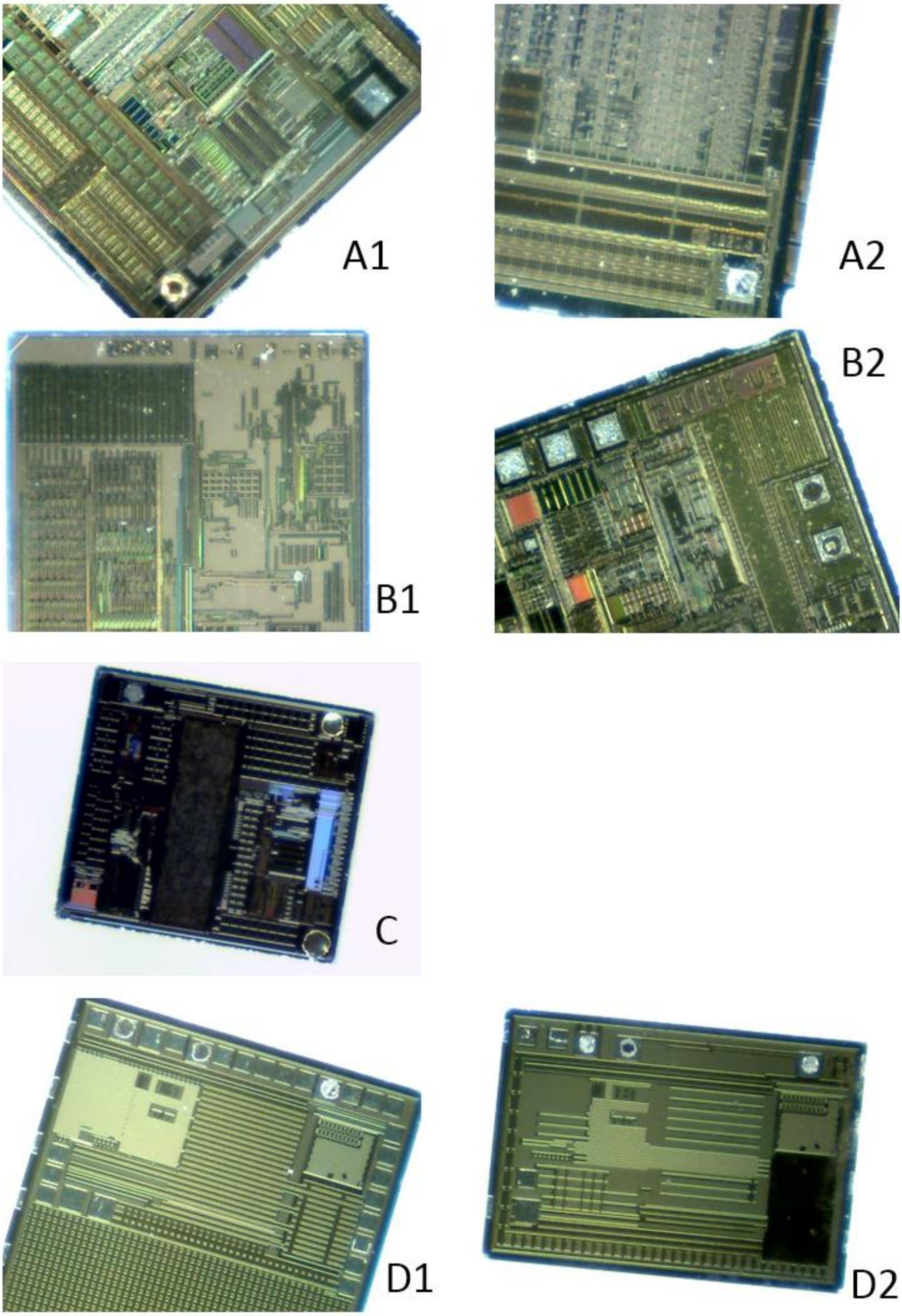


Figure 4. Photos of dies of Families A1, A2, B1, B2, C, D1, and D2. The width of each photo is approximately 1.4 mm.