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AS39513

NFC Sensor Tag and Data Logger IC

General Description

The AS39513 is a semi-passive tag chip optimized for battery-powered smart labels with sensor functionality. The chip is ideal for applications using thin and flexible batteries but it also supports fully passive operation without a battery using the RF field from an RFID reader as a power source.

The RFID interface is fully ISO 15693 and NFC-V (T5T) compliant. External power can be supplied from a single-cell battery (typically 1.5 V) or a dual-cell battery (typically 3 V).

The chip has a fully integrated temperature sensor with a programmable temperature range (default -20ºC to 55ºC). The external sensor interface (S_{EXT}) is an analog input and allows the connection of an external sensor.

A real-time clock can be used to generate logging times and track the device lifetime. An SPI-like interface is available for chip initialization or communication with a microcontroller. The chip has the capability to energy harvesting from reader field up to 3mA.

Configuration and logging data is stored on a configurable 9-kbit EEPROM.

Ordering Information and Content Guide appear at end of datasheet.

Key Benefits & Features

The benefits and features of this device are listed below:

Figure 1:
Added Value of Using AS39513

Benefits	Features
• Versatile data logging with selectable option	• Programmable logging modes
• Logging storage capacity up to 1020 events (8-bit logging mode) with time stamp	• On-chip 9-kbit EEPROM • Real-time clock (RTC)
• Supports data logging from various sensors	• On-chip temperature sensor • Analog input for external resistive sensor
• On-chip temperature sensor	• Default range: -20ºC to 55ºC (±0.5ºC over -20ºC to 10ºC, gold bumped die) • Temperature range is programmable
• Flexible supply options [(1)]	• Fully passive mode: no battery • Semi-passive (BAP) mode: 1.5V or 3V battery
• Provides supply for external circuitry	• Energy harvesting from reader field up to 3mA

Benefits	Features
• Autonomous data logging with long battery life of ~1 year (with 30mAh printed battery)	• Standby current (RTC enabled): 2.14µA$_{TYP}$ (@ 3.0V) • Operating current (logging, 16ms): 166µA$_{TYP}$ (@ 3.0V)
• Works with NFC-enabled phones and HF readers	• ISO 15693/NFC-V (T5T) compliant • Cool-Log™ commands for logging functions
• Precludes manipulation and unauthorized usage of data	• EEPROM access from reader perpetual protected by password
• Flexible range of packages for inlay and PCB surface mount assembly	• Gold bumped die 2403µm x 2313µm • Thin WL-CSP 5x5 bumps @ 0.4mm pitch 2403µm x 2313µm, 316µm typ thick

Note(s):

1. After battery is exhausted, the chip will continue working in passive mode (no RTC).

Applications

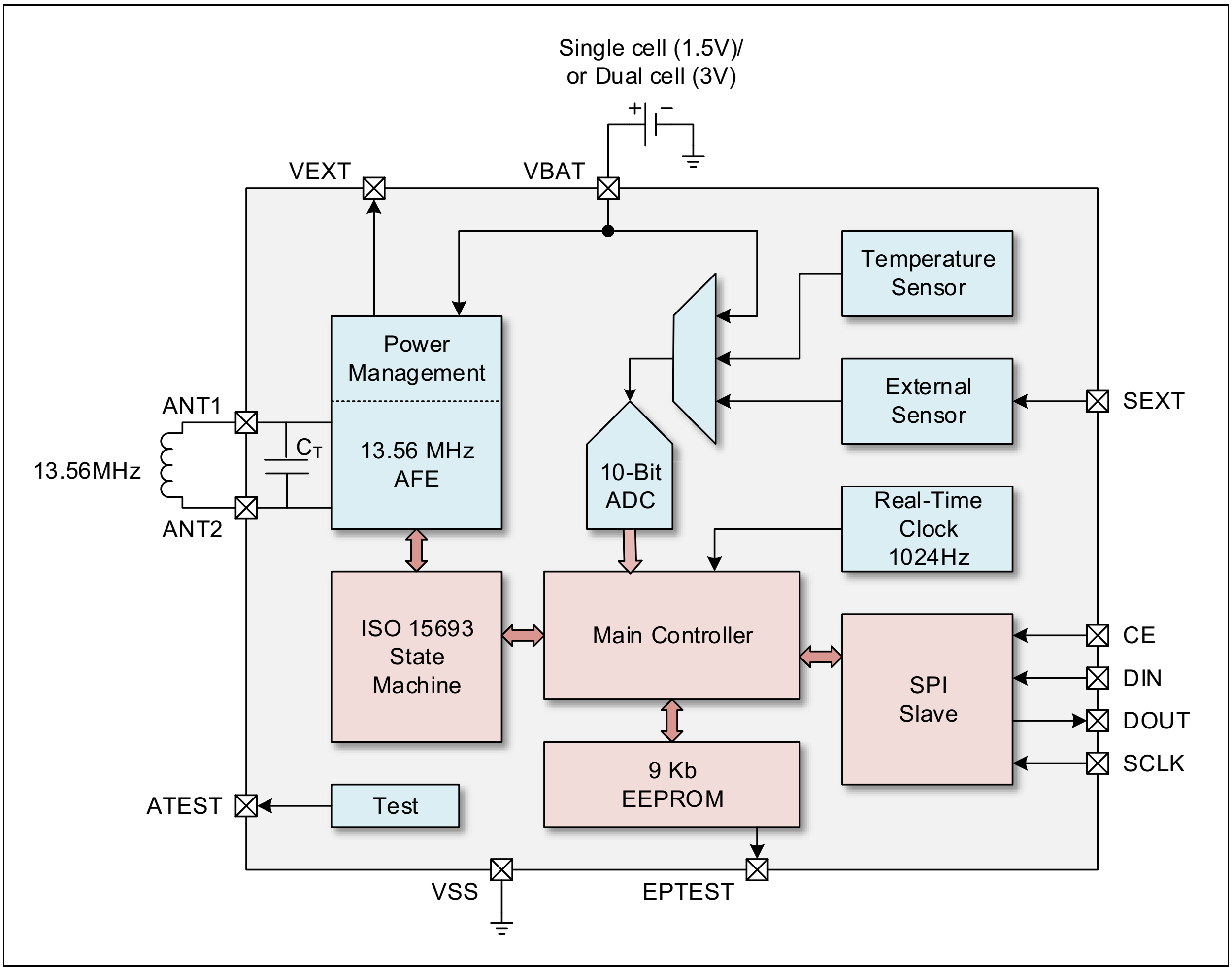
The AS39513 applications include:

- Cold Chain: Monitoring and tracking of temperature-sensitive products
- Temperature monitoring of medical products
- Pharmaceutical logistics
- Monitoring of fragile goods transportation

Block Diagram

The functional blocks of this device are shown below:

Figure 2:
Functional Blocks of AS39513

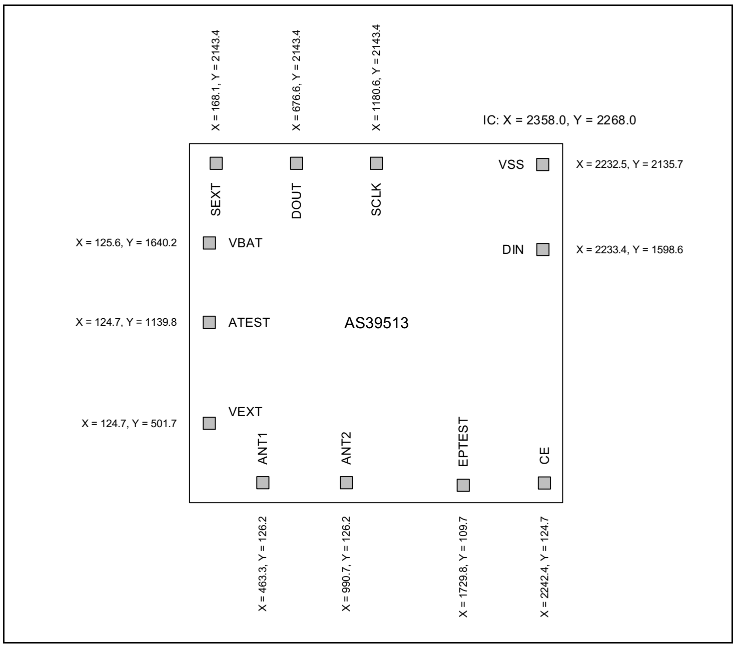


Pin and Pad Layout

The AS39513 can be shipped as bare die with gold bumps or as thin WL-CSP.

When packaged as a bare die, the pad arrangement is as depicted below (measures are reported in µm).

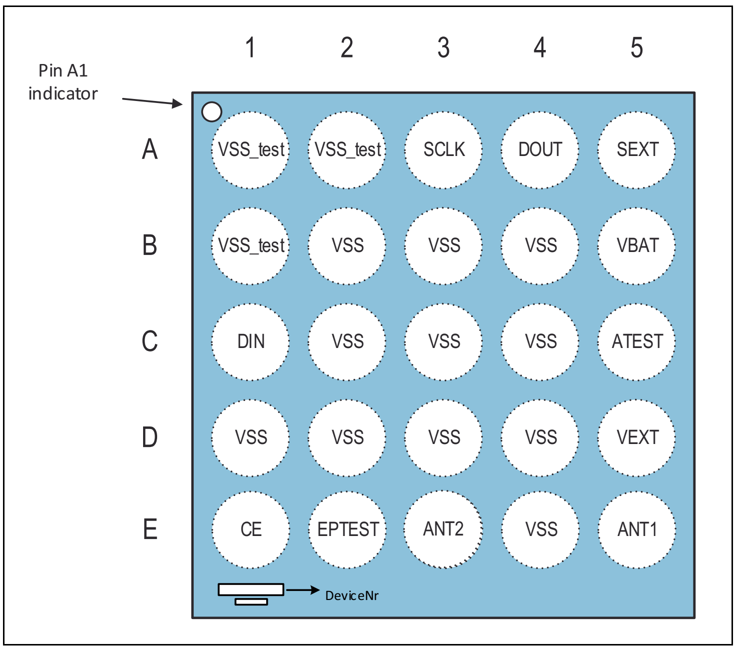
Figure 3:
Bare Die with Gold Bumps Pinout



Note(s):

1. Bondpad spacing is ≥ 400µm

Figure 4:
Thin WL-CSP



Pin Description

Figure 5:
Pin Description of AS39513 in WL-CSP

Pin	Pin Name	Pin Type	Description
A1	VSS_test	S	Negative supply and ground.
A2	VSS_test	S	Negative supply and ground.
A3	SCLK	I	SPI CLK input
A4	DOUT	O	Digital data output.
A5	SEXT	I	Analog input for external sensor.
B1	VSS_test	S	Negative supply and ground.
B2	VSS	S	Negative supply and ground.
B3	VSS	S	Negative supply and ground.
B4	VSS	S	Negative supply and ground.
B5	VBAT	S	Battery input.
C1	DIN	I	Digital data input.
C2	VSS	S	Negative supply and ground.
C3	VSS	S	Negative supply and ground.
C4	VSS	S	Negative supply and ground.
C5	ATEST	O	Analog test output.

Pin	Pin Name	Pin Type	Description
D1	VSS	S	Negative supply and ground.
D2	VSS	S	Negative supply and ground.
D3	VSS	S	Negative supply and ground.
D4	VSS	S	Negative supply and ground.
D5	VEXT	O	Power output for external circuit, generated by RF field.
E1	CE	I	SPI enable input. Note this is active high.
E2	EPTEST	O	Test pin for EEPROM. Do not connect.
E3	ANT2	I	RF input from antenna.
E4	VSS	S	Negative supply and ground.
E5	ANT1	I	RF input from antenna.

The abbreviations used in Figure 5 are given below:

S = Supply

X = Not Connected

O = Output

I = Input

Absolute Maximum Ratings

Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under Operating Conditions is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Figure 6:
Absolute Maximum Ratings of AS39513

Symbol	Parameter	Min	Max	Unit	Comments
Electrical Parameters					
V_{BAT} /V_{GND}	Supply Voltage to Ground	-0.3	3.7	V	
V_{IN}	Input Pin Voltage to Ground except ANT1, ANT2 and SEXT	-0.3	3.3	V	
	Input Pin Voltage to Ground at ANT1 and ANT2	-0.5	6.5	V	
	Input Pin SEXT Voltage to Ground	-0.3	1.8	V	
I_{IN}	Peak Current Induced on Pin ANT1 and ANT2		30	mA	
I_{SCR}	Input Current (latch-up immunity)	± 100		mA	JEDEC JESD78D Nov 2011 Class 1
Electrostatic Discharge					
ESD_{HBM}	Electrostatic Discharge HBM	± 2		kV	JEDEC JESD22-A114F
ESD_{CDM}	ESD - Charged Device Models	± 500		V	
Temperature Ranges and Storage Conditions					
T_{JUNC}	Operating Junction Temperature	-20	65	°C	
T_{STRG}	Storage Temperature Range	-55	150	°C	
T_{BODY}	Package Body Temperature		260	°C	IPC/JEDEC J-STD-020 (1)
RH_{NC}	Relative Humidity (non-condensing)	5	85	%	

Symbol	Parameter	Min	Max	Unit	Comments
MSL	Moisture Sensitivity Level for thin WL-CSP	1			Represents an unlimited floor life time
t_{STRG_DOF}	Storage Time for DOF/Die or Wafers on Foil		3	months	Refers to indicated date of packing
T_{STRG_DOF}	Storage Temperature for DOF/Die or Wafers on Foil	17	28	°C	
RH_{OPEN_DOF}	Relative Humidity for DOF/Die or Wafers on Foil in Open Package		15	%	Opened package
RH_{UNOPEN_DOF}	Relative Humidity for DOF/Die or Wafers on Foil in Sealed Package	40	60	%	Sealed bag

Note(s):

1. The reflow peak soldering temperature (body temperature) is specified according IPC/JEDEC J-STD-020 "Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices".

Electrical Characteristics

All limits are guaranteed. The parameters with min and max values are guaranteed with production tests or SQC (Statistical Quality Control) methods.

Figure 7:
Electrical Characteristics of AS39513

Symbol	Parameter	Min	Typ	Max	Unit	Conditions
V_{BAT3V}	3V Battery Supply Voltage	2.2		3.3	V	See note (3)
$V_{BAT1.5V}$	1.5V Battery Supply Voltage	1.35		1.8	V	See note (3)
V_{BAT_SU}	Minimum Start-Up Input Voltage		0.7		V	T= 6°C Battery assisted mode
V_{ANT}	Power On Voltage	2.5			V_P	
I_{BAT-SD}	Shutdown Current into V_{BAT}		0.5		µA	V_{BAT} = 3.6V; 25°C
I_{EXT}	Maximum Current from V_{EXT} Output		3		mA	In electromagnetic field
V_{EXT}	V_{EXT} Limiter Voltage		3.85		V	In electromagnetic field
R_{VEXT}	V_{EXT} Output Resistance		750		Ω	V_{EXT} internally connected to rectifier output for supply of external circuits
C_{TG}	On Chip Capacitance		35		pF	Between ANT1 and ANT2 for die with gold bump
f_{SCLK}	SCLK Serial Data Clock			100	kHz	
f_C	Carrier Frequency		13.56		MHz	
E_{WCYC}	EEPROM Erase/Write Cycles	10000			Cycles	
t_{DR}	EEPROM Data Retention Time	10			Years	T_{JUNC} = 25°C
$t_{E/W}$	EEPROM Erase/Write Speed (four-byte block)	6		10	ms	
T_{ACCGB}	Temperature Sensor Accuracy, Gold Bumped Die (logging mode only)(4)	-0.5		0.5	°C	-20°C to 10°C

Symbol	Parameter	Min	Typ	Max	Unit	Conditions
$H_{min3Vbat}$	Sensitivity 3V battery assisted mode		150		mA/m	Class ID-1 antenna VBAT=3.0V
H_{min1_5Vbat}	Sensitivity 1.5V battery assisted mode		150		mA/m	Class ID-1 antenna VBAT=1.5V
$H_{minpass}$	Sensitivity passive mode		280		mA/m	Class ID-1 antenna
CMOS Digital Input with 100k Ohm Pull-Down: CE, SCLK and DIN with Pull-Down Enabled(2)						
V_{IH}	High Level Input Voltage	0.7* V_{BAT}			V	
V_{IL}	Low Level Input Voltage			0.3*V_{BAT}	V	
I_{LEAK}	Input Leakage Current			1	µA	V_{IL} = 0V
R_D	Pull-Down Resistance		100		kΩ	
I_{PD}	Pull-Down Current	10		50	µA	$V_{IH} = V_{BAT}$
CMOS Digital Input with 30k Ohm Pull-Up Active: DIN with Pull-Up Enabled						
V_{IH}	High Level Input Voltage	0.7* V_{BAT}			V	
V_{IL}	Low Level Input Voltage			0.3*V_{BAT}	V	
I_{LEAK}	Input Leakage Current	-1		1	µA	$V_{IH} = V_{BAT}$
R_U	Pull-Up Resistance on DIN (optional see DIMD[1:0])		30		kΩ	
I_{PU}	Pull-Up Current	30		160	µA	V_{IL} = 0V
CMOS Digital Output DOUT						
R_{OSO}	Output Resistance Source		1.85		kΩ	
R_{OSI}	Output Resistance Sink		200		Ω	

Note(s):

1. Temperature 25°C, supply V_{BAT}=3.3V from RF field unless noted otherwise
2. CMOS inputs CE and SCLK have 100k Ohm pull down resistor permanently connected. CMOS Input DIN can be configured with pull up or pull down. See DIMD[1:0].
3. Below VBAT=1.35V operation and performance of AS39513 is not guaranteed.
4. Temperature sensor accuracy measured performance on wafer with gold bumped die measured at 3.0V for 3V trimmed devices and 1.5V for 1.5V trimmed devices. Assembly method can influence the temperature sensor accuracy.

Figure 8:
Current Consumption in Different Modes

Symbol	Parameter	V_{BAT}	Typ			Unit	Conditions
			-20°C	25°C	65°C		
I_{idle}	Idle Mode Current (RTC off)	3.0V	0.85	0.84	1.05	µA	
		1.5V	0.19	0.23	0.40	µA	
I_{wait}	Wait Mode Current (RTC on)	3.0V	2.10	2.14	2.31	µA	
		1.5V	0.76	0.95	1.15	µA	
I_{active}	Active Mode Current (RTC on)	3.0V	2.11	2.14	2.32	µA	
		1.5V	0.76	0.95	1.15	µA	
$I_{loggingT}$	Logging Mode – Temperature Only	3.0V		166		µA	Logging time 16ms typ
		1.6V		150		µA	Logging time 27ms typ
$I_{loggingAll}$	Logging Mode: Temperature, Battery, Ext. Sensor with Battery Check Enabled	3.0V		170		µA	Logging time 20ms typ

Note(s):

1. The values at -20°C and 65°C are typical but not measured in final test.

Figure 9:
Operating Conditions

Symbol	Parameter	Min	Max	Unit	Comments
V_{BAT}	Battery Voltage	1.35	3.6	V	
I_{LIM}	Limiter Current		30	mA	

Detailed Description

The AS39513 is designed for use in smart semi-passive labels as well as in full passive labels. Smart semi-passive labels are defined as thin and flexible labels that contain an integrated circuit and a power source. Semi-passive smart labels, also known as battery-assisted back-scattered passive labels, enable enhanced functionality and performance over passive labels. The IC includes sensor functionality and logging of sensor data.

The RFID portion of the AS39513 operates at 13.56 MHz and is fully ISO15693 and NFC-V (T5T) compliant. The sensor controller runs with an independent 1.92 MHz clock. The chip is supplied from a single-cell battery of typically 1.5V, or from a dual cell battery of typically 3V. The on-chip temperature sensor and real-time clock (RTC) accommodate temperature data logging with time stamps.

Power Management

The AS39513 is supplied from either the battery or through the power coupled from the RFID reader. The device (sensors, ADC, real-time clock and logic) is normally supplied from the battery unless there is no battery attached (passive label), or when the battery is drained. When no battery power is available, these circuits will be powered by the RFID reader. The RFID AFE is always powered by the reader.

Note 1.5V and 3V batteries are supported but the battery supply voltage range is not continuous from 1.35V to 3.3V. Please see electrical characteristics. Also it is assumed the battery will be connected when the RF field is not present. Correct operation is not guaranteed if the battery is connected in the presence of an RF field.

Energy Harvesting

AS39513 has harvesting capability. The regulated voltage output pin for energy harvesting is VEXT. If an RFID reader is present, the harvested reader power is then available externally through the VEXT pin. An internal regulator limits the voltage at VEXT 3.85V nominal. The output impedance of this voltage source is fixed and it is approximately 750Ω.

Analog Front End (AFE)

The analog front end (AFE) operates at a carrier frequency of 13.56 MHz according to the ISO 15693 and NFC-V type 5 tag standards. The incoming data is demodulated from the received ASK (Amplitude Shift Keying) signal, with either 10- 30% modulation index or 100% modulation index. Outgoing data is transmitted from the AS39513 using load modulation and employs Manchester coding with one or two sub-carrier frequencies: 423.75 kHz (fc/32) or 484.28 kHz (fc/28).

Processing and Digital Control

The AS39513 is fully ISO15693 compliant. The processing of the incoming data is executed by the ISO15693 CODEC block that formats the data in a frame according to the ISO specification.

Both data coding modes (1 out of 256 and 1 out of 4) are supported by the AS39513. The reader (interrogator) makes the mode selection as part of the SOF (Start of Frame). The 1-of-256 data coding mode has a data rate of 1.65 kbit/s (fc/8192) meaning that the transmission of one byte takes 4.833 ms. The 1-of-4 coding has a rate of 26.48 kbit/s (fc/512) with the transmission of one byte requiring 302.08 µs.

This RFID interface can be used to access most of the EEPROM storage and to control the operating mode of the AS39513.

Slave Serial Interface (SPI-like)

The integrated serial interface (SPI-like) can be used to configure and test the chip.

The SPI-like bus can also be used for the communication between a microcontroller externally attached to the AS39513.

With the correct access password, it can also be used to access all regions of the EEPROM and the AS39513 test modes.

Please note SPI enable is active high. The SPI Read command also has 2 timing issues which need to be observed and are explained in the section SPI timing.

Real-Time Clock (RTC)

The on-chip real-time clock (RTC) is an integrating RC-type oscillator that is factory trimmed to 1.024 kHz with a typical accuracy of ±3% over the operating range of the device. This oscillator is used to generate logging intervals (between 1 second and 9.1 hours) and track the time since the chip was first initialized. The start time for the logging process can be programmed in UPC format by writing the related parameter in the EEPROM configuration.

Temperature Sensor

The on-chip temperature sensor is configured and calibrated to measure temperatures between -20ºC to 55ºC. The gold bumped die achieve an accuracy of ±0.5ºC over -20ºC to 10ºC. The on-chip sensor can be reconfigured for a number of different temperature ranges but the sensor requires recalibration after each temperature range change.

The temperature sensor is intended to be used in logging mode. The temperature sensor accuracy is only guaranteed in this mode and not in the presence of a strong RF field from a reader. When placed in the presence of a reader, strong RF fields can cause self heating of the chip depending on the field strength, antenna and length of time in the field. The accuracy of the on-chip temperature sensor can then not be guaranteed.

External Sensor

The on-chip external sensor interface provides a means for using both resistive and voltage-based sensors. The voltage at the sensor node can be scaled and shifted in order to cover a voltage range of 0V to 1V, or a subset of that range.

The external sensor input S_{EXT} can be also used for event-triggered logging. In this condition the logging is not triggered in predefined time intervals from the internal timer, but can be triggered externally, either with a sensor, switch or a microcontroller.

The S_{EXT} has in fact a very low power sensing interface that can be used to trigger logging events when the sensor voltage crosses one of four selectable thresholds. In addition an optional drive current can be supplied to the sensor.
The maximum allowable voltage on the SEXT pin is 1.8V.

Analog to Digital Converter

The chip has an integrated 10-bit analog to digital converter (ADC) with selectable voltage references. It is used for voltage conversion from the temperature sensor, the external sensor, and the external battery voltage.

Data Protection

The 9-kbit EEPROM is accessed through a controller that manages the overall chip operation. Every address in the memory map is assigned to one of four types of access levels. There is write protection for three memory areas (System, Application, and Measurement) using three different 32-bit passwords. All three memory areas are open for read at all times. A fourth memory area, called the Factory area, is much more restricted and is not accessible via RF except for the lock bits and passwords. This is used for passwords, memory lock bits, and some calibration information.

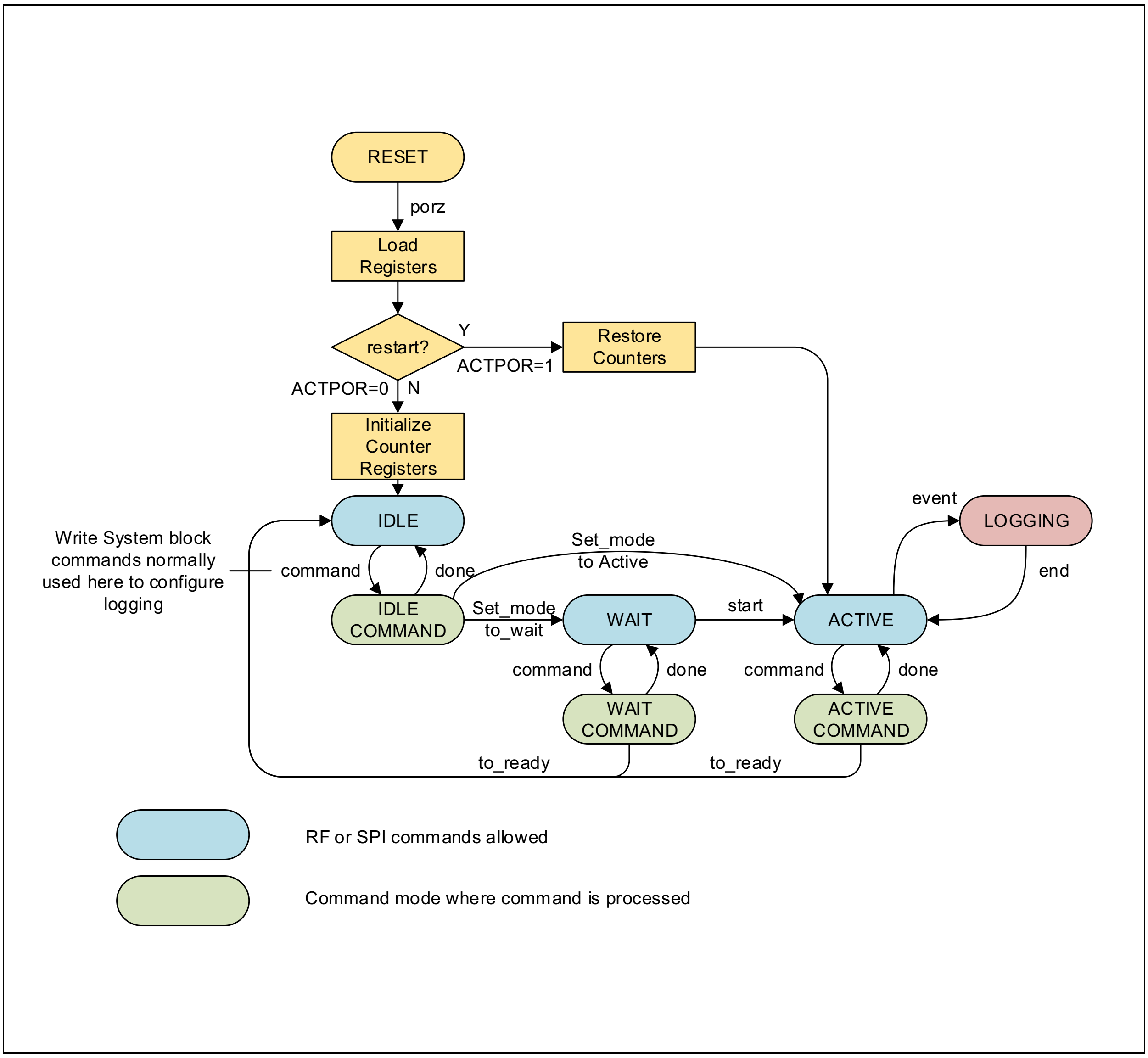
For the Application, Measurement and System Access areas the access via RF remains open until the RF field is removed (the access via RF will close with the loss of RF field even if the logic is continuously powered by an external battery). Note if the chip is powered by a battery these areas will still be accessible by SPI.

The chip also supports a one-time use secure mode. When this mode is used, the RFID write capability for all Application and Measurement blocks is blocked. The measurement area can still be written through the logging operations, but the logging results cannot be overwritten through the RFID interface even if the 32-bit password is known.

System Description & Modes of Operation

Once the AS39513 has been powered either from a battery or the RFID interface, the controller logic manages the operation of the IC according to the state diagram below.

Figure 10:
State Transition Diagram



The description of each operation mode is reported in the next sections.

Initializing the Chip

A virgin chip (not initialized) can be initialized either through the SPI port or through RFID interface from a reader. Once the battery voltage is applied to the VBAT pin or the supply voltage is extracted from the RF field, the AS39513 boots up with the default factory configuration. Within about 300 µs after power is applied, the logging controller goes to the IDLE state where it waits for configuration. Once all of the configuration information has been written to the device using write system block commands, the RFID "Set Mode" command is used to place the AS39513 either into the WAIT state or into the ACTIVE state directly. If in the WAIT state, a timer or input action can move the device into the ACTIVE state. Once in the ACTIVE state, the AS39513 will begin logging data whenever a logging event occurs.

RESET Mode

Once the chip powers up, either from the battery or the RF field, and the power is stable, the initialization process begins. At this point, the controller logic will read specific EEPROM addresses and load them into "shadow" registers.

During this phase the battery type will be determined by checking System parameter BTYPE available in the EEPROM field.

Two of the other EEPROM fields that will be read during this phase are the System parameters WAKEMD (wakeup mode) and ACTIVE (true if last state was ACTIVE). If both of these fields are high, it means that the chip was reinitialized from a previous ACTIVE mode and the restart condition flag ACTPOR will be set to high.

If the restart condition is true (ACTPOR is high) then the measurement pointers and counters are reloaded from the last available state and the device returns to the ACTIVE mode.

If the restart condition is false (ACTPOR is low), the register pointers and counters are initialized assuming that no measurements have been made but the MEASCNT and MEASPTR values in EEPROM will be retained, and the device enters IDLE mode. This means that if for example the battery voltage dropped during a logging event and caused a POR, the chip would enter idle mode ie stop, but the MEASCNT and MEASPTR values would be retained in EEPROM. If the mode is subsequently changed to Active (i.e. logging is restarted), the EEPROM MEASCNT and MEASPTR are zeroed. (The bit fields ACTPOR, WAKEMD, and ACTIVE are further documented in the Memory Map section).

IDLE Mode

In the IDLE mode the device is waiting for commands either from the RFID or SPI interface. In this state the device can be first initialized after the first power up by setting the related EEPROM parameters. Initiating either interface and sending a command enables the internal "command" signal that moves the device into IDLE COMMAND mode.

In IDLE mode the data logging parameters can be configured using Write System Block commands. Once fully configured a Set mode command can be used to either commence logging or change state to the WAIT state.

WAIT Mode

In WAIT mode the device is waiting before to enter in the ACTIVE mode for a defined condition that is dependent on the System parameters (Logging Control Parameters) set in the EEPROM. WAIT mode provides in fact a mechanism to delay the start of logging after the Set Mode command is issued.

If the parameter TMSRT is set to 1, then the WAIT mode will transition to the ACTIVE mode after LOGDEL*512 seconds, where LOGDEL is also part of the System Parameters.

If the parameter DIMD[1:0] is 2'b10, then the WAIT mode will transition to the ACTIVE mode when the DIN pin is pulled low.

If TMSRT is 0 and DIMD is not 2'b10, then the WAIT mode will transition without delay to the ACTIVE mode. (The bit fields TMSRT, DIMD, and LOGDEL are further documented in the Memory Map section.)

Commands from either the RFID or SPI interfaces are accepted in the WAIT mode. If a command request and a start event occur at the exact same time, the command processing has priority; the mode will transition to ACTIVE when the command is done. If a command is being processed when a start event occurs, the start event is pending until the command is completed and then the transition to ACTIVE mode occurs.

When the device transitions from the WAIT to the ACTIVE mode, the real time clock counter (RTC) is reset to 0. In this way, the baseline time of the AS39513 is the time that the device was placed in ACTIVE mode.

ACTIVE Mode

In ACTIVE mode, the device waits for a logging event to begin logging. The logging events can be generated by the real-time clock, a voltage level on the SEXT pin, or a digital signal on the DIN pin. Each type of logging event can be individually enabled by System parameters in the EEPROM. When any one of the enabled logging events occur, the mode transitions to the LOGGING mode and the data measurement and logging commences. If two logging events happen to occur in the exact same clock cycle, only one logging operation will be performed.

Commands from either the RFID or SPI interfaces are accepted in the ACTIVE mode. If a command request and a logging event occur at the exact same time, the command request has priority. If a command is being processed when a logging event occurs, the logging event is pending until the command is completed and then the logging commences.

COMMAND Mode

The COMMAND modes process a command either from the RFID or SPI interface. Whichever interface issues the command first gets priority. The other interface will get a “device busy” error until the first command is completed. If both interfaces happen to request a command on the exact same clock edge (very unlikely), the RFID interface will get priority.

There are three versions of COMMAND mode, one for each of the calling modes: IDLE, WAIT, and ACTIVE. The only difference in these COMMAND modes is that when the command processing is complete, the mode will return to the mode that initiated the command.

The exception is the command that purposely generates a mode change, Set Mode. For example, if the device is in the IDLE mode and the Set Mode command is called to change to the WAIT mode, the device returns from the IDLE COMMAND mode to the WAIT mode.

LOGGING Mode

In LOGGING mode, a sequence of measurements followed by an optional sequence of storing logging values takes place. This sequence is described in the following subsections.

Battery Check

Before executing any measurement it is possible to check the status of the battery by performing the so called Battery Check. Battery check is recommended and enabled by default. It is executed if the System parameter BATCHK is set to 1, then a coarse battery check is enabled. The reason of performing this check is that the power-on-reset only ensures that the battery voltage is enough for the logic to function but it does not guarantee that the battery voltage is within the tolerances for accurate measurements.

The battery check involves the following steps. First, the battery check sensor elements are enabled. There is a brief wait for the analog circuits to settle. Using the battery type determined during RESET mode, the battery check comparator output will indicate if the battery voltage is acceptable. If it is, then the rest of the logging continues, if it is not, the logging stops, and the error flag, present in the System parameter, LOWBAT is set. Note that if a logging event was skipped because of low battery, the measurement counter is still incremented to give some indication of how many measurements were skipped. Because the battery may be too weak for a reliable write, the measurement counter will not be written to EEPROM if the battery voltage check has failed.

Figure 11:
Battery Check Threshold Voltages

Battery Type	BCKSEL [1:0]	Threshold Voltage (V)
1.5V	00	1.2
3V	00	2.2
3V	01	2.1
3V	10	2.0
3V	11	1.9

Sensor Measurements

After the battery check, the sensor measurements are made. The three possible measurement that consist of Temperature, External Sensor and Battery Voltage are independently enabled by the System parameters TSMEAS, EXMEAS, and BVMEAS part of the System EEPROM fields, and they are executed in a fixed sequence as they are reported below.

First, there is the temperature measurement. If TSMEAS is 1, the temperature circuits are enabled, and the temperature configuration values for the references and ADC are loaded. After a wait period for analog settling, an ADC measurement is taken, and the result is stored in ts_res_ff[9:0].

Next is the external sensor measurement. If EXMEAS is 1, the external sensor circuitry is enabled, including the optional current drive for the external sensor. The external sensor values for the references and ADC are loaded, and a wait period ensues to allow for analog settling. After the wait period, an ADC measurement is taken, and the result is stored in ex_ref_ff[9:0].

Finally, there is the battery voltage measurement. If BVMEAS is 1, the battery measurement circuits are enabled, and the battery voltage configuration values for the reference and ADC are loaded. After a wait period for analog settling, an ADC measurement is taken, and the result is stored in bv_res_ff[9:0].

Limit Check Algorithm

Once all the enabled measurements are done, an optional limit check algorithm begins. The AS39513 can be set to only record logging information if certain limit conditions are met. The internal temperature sensor and external sensor each have independent limit conditions. The ADC result for each sensor measurement is compared to four thresholds to determine the limit result. The limit thresholds are each 8-bit in length and are the 8 MSB values when compared to the 10-bit ADC values.The limit results follow the tables below. If a sensor is not enabled for logging, its limit result is taken to be 3'b000.

Figure 12:
Limit Check Results for Temperature Sensor

Step	Condition	ts_lim
1	ts_res_ff ≥ { TXHILIM, 2'b00 }	3'b100
2	ts_res_ff ≤ { TXLOLIM, 2'b11 }	3'b101
3	ts_res_ff ≥ { THILIM, 2'b00 }	3'b110
4	ts_res_ff ≤ { TLOLIM, 2'b11 }	3'b111
5	Otherwise	3'b000

Figure 13:
Limit Check Results for External Sensor

Step	Condition	ex_lim
1	ex_res_ff ≥ { EXHILIM, 2'b00 }	3'b100
2	ex_res_ff ≤ { EXLOLIM, 2'b11 }	3'b101
3	ex_res_ff ≥ { EHILIM, 2'b00 }	3'b110
4	ex_res_ff ≤ { ELOLIM, 2'b11 }	3'b111
5	Otherwise	3'b000

Note that in the computation of the limit result, the conditions are checked in the order given in the tables above. It is possible that more than one condition can be met at the same time, because there is no check on the relative values of the four limit parameters for each sensor. The first condition that is true in the order given in the table is the condition that determines the limit result.

The limit check algorithm is as follows. The limit result for each sensor is computed. For each limit result that is non-zero, the limit counter that corresponds to that limit flag is incremented.[1] The over limit count flag OVLIM will be set if any of the following conditions are true: TXHICNT > 0, TXLOCNT > 0, THICNT > THIMAX, TLOCNT > TLOMAX, EXHICNT > 0, EXLOCNT > 0, EHICNT > EHIMAX, or ELOCNT > ELOMAX (These System parameters are further documented in the Memory Map section).

There are two types of limit check modes: normal and limit crossing.

If normal limit mode is selected (LOGMD = 2’b10), then logging will occur if, and only if, at least one of the two sensor’s limit results is non-zero.

If limit crossing mode is selected (LOGMD = 2’b11), then logging will occur if, and only if, the limit result for either sensor is different from that sensor’s previous measurement limit result. At initialization, the “previous” limit result for each sensor is assumed to be 3’b000. Therefore, the first measurement that will be logged will be the first time that at least one of the two sensor’s limit results is non-zero.

If neither of the limit modes are selected (LOGMD[1] = 0), then no limits are checked, the limit counters are not changed, and the measurement results are always logged.

Measurement Results Logging

If one of the limit criteria are satisfied, or if the device is in the no-limit logging mode (LOGMD = 2’b00 or 2’b01), than the measurement results are logged.

Memory Check: Prior to writing the log values in EEPROM, the logging measurement pointer MEASPTR[11:0] is checked to insure that there will be room for the log data.

If there is no room and STRMD is 0, the data is not logged, and the error flag EEFULL is set.

1. The limit counters are simple binary counters. If a limit count exceeds 16’hFFFF (65,535), then the count will wrap around to zero.

Memory Pointer: Assuming the data can and should be logged, the logging begins at the current value of the MEASPTR[11:0], where MEASPTR[11:2] represents the EEPROM address for the first log data, and 2*MEASPTR[1:0] is the bit position at which to start the log data. The data is logged in the following order, with increasing pointer addresses for each log value.

Once all the logging values are stored, and if the adjust logging information ADJUST parameter is set to 1, then the MEASPTR is rounded up to the nearest byte boundary. This wastes some memory space in return for being able to easily calculate the byte position of each log point.

Format Options: In order to minimize EEPROM usage, data is logged at 2-bit boundaries according to the format options LOGFMT: all measurement data is logged using either 8 or 10 bits.

The 8-bit format is used if both logging mode LOGMD = 2’b00 and logging format LOGFMT = 0. Otherwise, 10 bits are used.

Measurement Storing Sequence: First, if a temperature measurement was made, the result in ts_res_ff is written. Second, if an external measurement was made, the value in ex_ref_ff is written. Third, if a battery voltage measurement was made, the result in bv_res_ff is written.

Note the number of bits (8 or 10) stored for the temperature, external sensor and battery voltage measurements depends on the LOGFMT and LOGMD configuration settings.

Optional Status Signals: After the measurements are recorded, the status of two digital signals can optionally be recorded. If the optional logging data DLOG is 1, then the values of the digital signals at the DIN pin (the digital input din_i) and the external sensor interrupt SEXT (extirq_i) are recorded using the 2-bit value { din_i, extirq_i }.

Note that if DLOG is the only logging option selected, that means, there are no ADC measurements enabled, then the logging state machine will wait about 3ms (the approximate time for one ADC conversion) in order for the external voltage at the SEXT pin to settle.

Note that if the value of the extirq_i signal want to be used, then the Enable external sensor interrupt EIEN field must be set to 1 in order to enable the comparator that generates the extirq_i interrupt event.

Logging Modes: Finally, information about this measurement are written, depending on the logging mode.

If interrupt logging mode is used (LOGMD = 2’b01), then the 30-bit real-time clock counter value is logged, followed by a two-bit value that indicates the logging event trigger source (further detail will follow in the Memory Map section).

If one of the two limit logging modes is used (LOGMD = 2’b01 or LOGMD = 2’b11), the 16-bit log counter LOGCNT is written into the EEPROM.

Status Parameters: As a last step in the logging operation, the measurement count, MEASCNT, is incremented.

If update counts SKIP16 = 0 or MEASCNT[3:0] = 4'b1111, then MEASCNT, the status bits ACTIVE, EEFULL, OVWRT, ADCERR, LOWBAT, and OVLIM, and the ending measurement pointer MEASPTR are written into EEPROM.

Even if no logging occurred (because the limit conditions were not met or the EEPROM was full), the measurement count MEASCNT is still incremented and written into EEPROM (still using the SKIP16 option to only write once every 16 measurements). The measurement counter MEASCNT clips at 16'hFFFF so that it does not wraparound to 0. The measurement pointer MEASPTR is only updated if data was logged to the EEPROM; it always points to just after the end of the data that was actually written to EEPROM.

Logging Arbitration: In the condition that another enabled logging event occurs before the logging of the current event is complete, the next logging event will be queued and will commence at the completion of the current logging operation.

If an RFID or SPI command request occurs during logging, the command is ignored in order to prevent conflicts in EEPROM access.

Power Modes

The controller modes described above also control which of the sensor blocks are enabled.

If the controller is in any of the COMMAND modes, the LOGGING mode or the RESET initialization, there is a high-speed (1.92 MHz) ring oscillator that is enabled to clock the controller logic and the EEPROM.

In the LOGGING mode, there are three additional power modes. Battery check mode (bchk_md) enables all the sensor circuits needed to do the coarse battery check, which is basically everything in the sensor system except the ADC. Measure mode (meas_md) enables basically everything in the sensor system except the battery check circuit; this mode is used for temperature and external sensor measurements. Battery voltage mode (both bchk_md and meas_md enabled) is used to measure the battery voltage.

If the AS39513 is not in one of the modes requiring the ring oscillator, the ring oscillator is disabled and the lowpow signal is asserted. This signal causes the power switch in the AFE to switch to an unregulated supply for the logic, further reducing the power consumption. The only circuits that are operational in this low power mode that would draw current from the external battery are the real time oscillator (if OSCEN = 1) and the external interrupt comparator (if EIEN = 1).