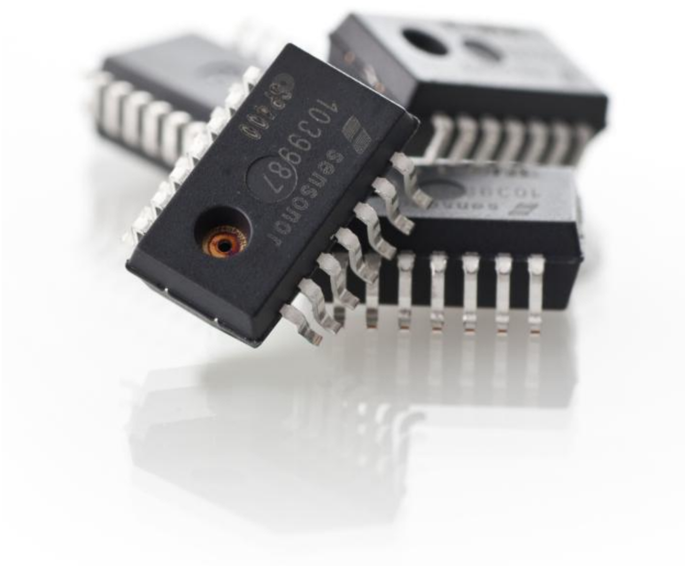

SP400 Wireless Digital Pressure Sensors

SP400 digital pressure sensors with embedded microcontroller, RF transmitter and LF receiver add a new level of integrity, and enables more compact, intelligent, low power, wireless pressure measurement systems than possible previously. Only a few external components, power sources and antenna designs are required to design small size, robust, high performance, yet complete wireless pressure transmitting systems with these sensors.

SP400 pressure sensors are offered in the range 1.5 to 20 bar. Tube connection options are offered up to 10 bar. Some sensors in this series have an additional accelerometer, e.g. for movement detection.

SP400 sensors have excellent media compatibility due to a patented bulk micromachined triple stack sensor die design, utilizing buried piezoresistive elements and backside media access to a pressure diaphragm. With this design the internal connectors and piezoresistive elements of the pressure bridge are isolated from the measurement media. This isolation is of great advantage in terms of sensor stability and reliability over a very long lifetime.

The SP400 pressure sensor design and technology has been proven in harsh environment applications during a period of more than 10 years, making these sensors ideal choices for demanding wireless applications where reliable and accurate pressure measurements are required.

SP400-1.5
SP400-1.5T
SP400-5A
SP400-5AT
SP400-10A
SP400-10AT
SP400-20

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Published by
Sensonor Technologies AS
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N-3192 Horten
Norway

Table of Contents

1 Product Description

1.1 Features

- Absolute pressure sensors
- 1.5 bar to 20 bar input pressure ranges
- I^2C programming/debugging interface
- 3 general purpose I/O pins
- 14 pin robust miniature surface mount transfer molded package
- 1.9 to 3.6V supply voltage range
- 0.7µA power down current
- -40 to 125°C temperature operating range
- Fully digitally calibrated and compensated sensors
- Embedded 8051 instruction set compatible microcontroller
- 6kbyte custom application program (flash) memory
- Embedded RF transmitter
- Selectable output power 5 or 8dBm (transformed into 50 ohm load)
- Configurable RF transmission data rates up to 10kbit/s Manchester coded (20kchips/s)
- ASK/FSK modulation capability
- Frequency deviation up to 50 kHz in FSK mode
- Fully integrated VCO and PLL Synthesizer
- On chip crystal oscillator tuning
- Embedded 2 channel LF receiver for triggering and data reception
- LF Receiver with very high input sensitivity
- LF Receiver data rate 3.9 kbit/s
- Sensor self diagnosis
- Unique electronic sensor IDs
- High reliability and accuracy over long lifetime
- High media compatibility
- Hardware manchester/bi-phase encoder for RF transmitter
- Hardware manchester decoder for LF receiver
- 16Bit hardware CRC generator
- 8Bit pseudo random number generator
- Watchdog timer
- Secondary sensing elements, accelerometers (for some versions)
- Embedded temperature and supply voltage sensors
- Tube connection options (for some versions)

1.2 Overview

SP400 sensors are highly integrated MEMS pressure sensors designed for air pressure measurements. The sensors have an I^2C programming/debugging interface, 8051 instruction set compatible microcontroller and 6kbyte of available flash memory for customer application code.

The sensors are housed in 14 pin small outline packages and require only a few external components, a power source (normally a battery) and an antenna design in order for the designer to obtain a small size, complete wireless pressure transmitting system.

Measurements of pressure, acceleration (available for some versions), temperature, and supply voltage are performed under software control, and data can be formatted and prepared for RF transmission by the microcontroller.

Intelligent wakeup mechanisms are available to reduce power consumption. An Interval Timer controls the timing of measurements and transmissions. The circuitry can be programmed to wakeup at regular intervals or on demand by the integrated LF Receiver, which furthermore also enables the SP400 to receive data. Additionally, wakeup is possible by an external wakeup source connected to a General Purpose Input/Output (GPIO) pin.

The instruction set of the integrated microcontroller is compatible with a standard 8051 processor. It is equipped with various peripherals (e.g. a hardware Manchester/Bi-Phase Encoder/Decoder and CRC Generator/Checker) enabling easy implementation of customer-specific applications.

The low power consumption RF Transmitter for 315/434 MHz contains a fully integrated PLL synthesizer, an ASK/FSK modulator and an efficient power amplifier. Fine tuning of the center frequency can be done either using the on-chip capacitors bank or adding external capacitors.

On-chip FLASH memory is integrated to store:

- The customer specific application program code
- The sensor calibration data

SP400 functional descriptions and special function registers are covered in more detail in the product user manual [1].

Additional on-chip ROM memory holds ROM library functions covering standard tasks used by the application program. ROM Library functions are described in a separate document

Figure 1 shows the SP400 product block diagram, an example where the MEMS pressure die includes both a pressure sensing element and an accelerometer sensing element. Notice that not all SP400 sensors have the accelerometer included.

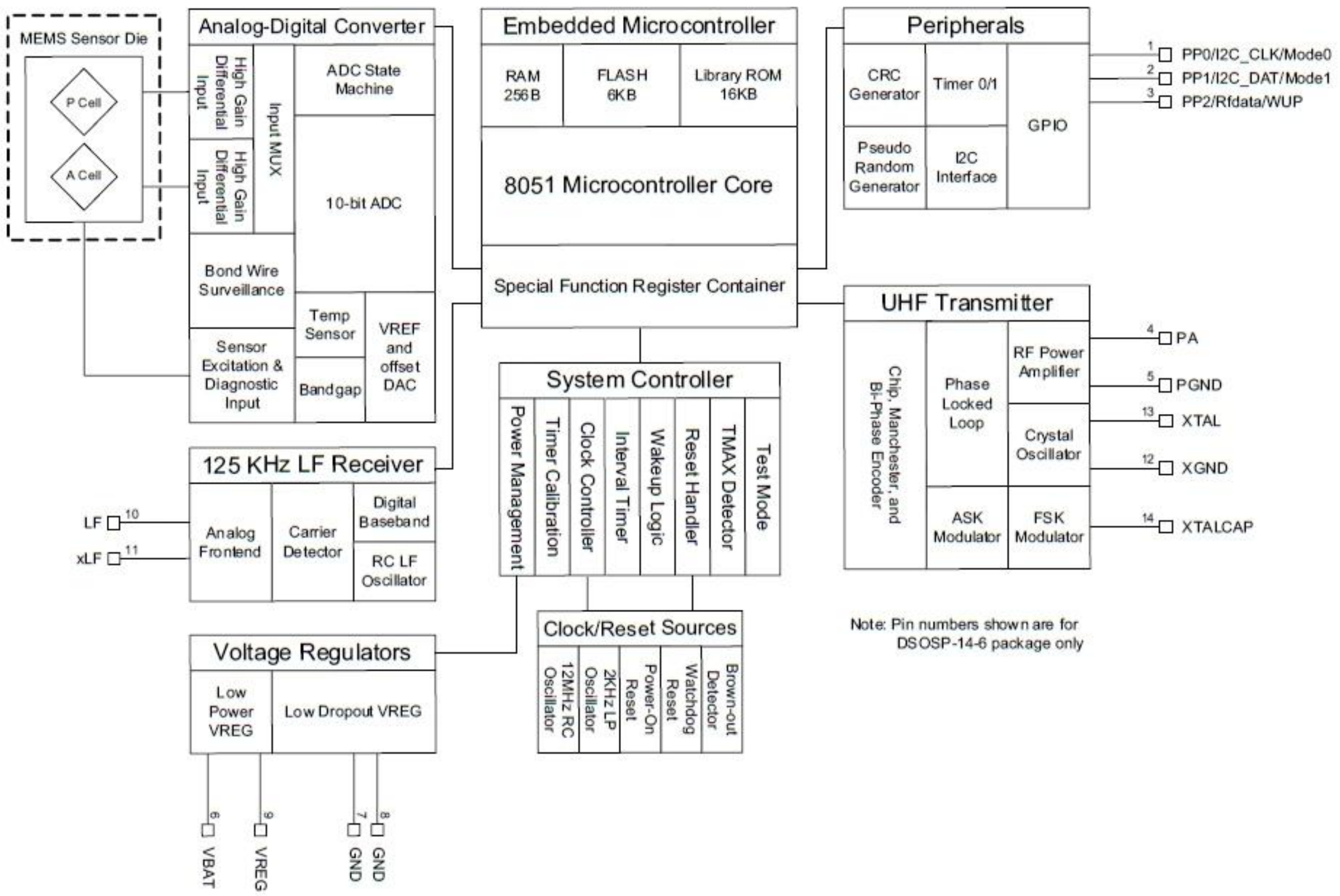

Figure 1: SP400 block diagram

1.3 Operating Modes and States

The sensor can be operated in four different modes:

- NORMAL mode
- PROGRAMMING mode
- DEBUG mode
- Internal production TEST mode, not for customer use

Table 1: SP400 operating modes

PP0	PP1	Operating mode	Device controlled by
1	1	NORMAL mode [1]	FLASH Program at 4000_H
0	1	PROGRAMMING mode	ROM firmware/external I^{2}C Master
1	0	DEBUG mode	ROM firmware/external I^{2}C Master
0	0	Internal production TEST mode [2]	ROM firmware/external I^{2}C Master

[1] Since PP0 and PP1 have internal pull-up resistors enabled at Power On Reset, the default start-up mode is NORMAL mode if PP0 and PP1 pins are left unconnected

[2] Do not enter this mode since unpredictable device behaviour might result

1.3.1 Status of Sensor Blocks in Different States

Unit	RUN state	IDLE state	POWER DOWN state	THERMAL SHUTDOWN state
Power On Reset	Active [1]	Active	Active	Active
Brown Out Detector	Active	Active	Inactive [2]	Inactive
TMAX Detector	Handled by ROM Library functions [3]	Inactive	Inactive	Active
Voltage Regulator (VREG)	Active	Active	Active	Active
System controller	Active	Active	Active	Active
Microcontroller	Active	Inactive	No supply [4]	No supply
Manchester/ Bi-Phase encoder, Timer	Active	Active	No supply	No supply
Peripheral modules CRC, I^2C, Pseudo Random Number Generator	Selectable inactive or active	Inactive	No supply	No supply
Watchdog timer	Active	Active	No supply	No supply
Upper 128Bytes RAM	Active	Inactive	No supply	No supply
Lower 128Bytes RAM	Active	Inactive	Selectable	No supply or inactive
FLASH	Active	Inactive	No supply	No supply
ROM	Active	Inactive	No supply	No supply
Crystal oscillator	Selectable inactive or active	Selectable inactive or active	No supply	No supply
2kHz RC LP Oscillator	Active	Active	Active	Inactive
12MHz RC HF Oscillator	Active	Active	No supply	No supply
Interval Timer	Active	Active	Active	Inactive
LF Receiver	Selectable inactive or active	Selectable inactive or active	Selectable inactive or active	Inactive
RF Transmitter	Selectable inactive or active	Selectable inactive or active	Inactive	Inactive
Sensor	Handled by ROM Library functions	Handled by ROM Library functions	No supply	No supply

1.4 Fault Protection

SP400 sensors feature multiple fault protection mechanisms which prevent the application from unexpected behavior and deadlocks. See [1] for details.

1.5 Sensors and Data Acquisitions

Three different sensor dies are used in combinations with different ASIC configurations, enabling a wide range of SP400 series pressure sensors. All of them are developed and produced on the same, well proven technology platform.

[1] Active: block is powered, active and keeps its register contents
[2] Inactive: block is powered, cannot be used, but keeps its register contents
[3] The ADC, the Sensor and VMIN Detector are controlled by ROM Library functions described in
[4] No supply: block is not powered, cannot be used and all register content is lost

1.5.1 Pressure Sensor

The SP400 pressure sensors consist of a single-crystal silicon, bulk micro machined membrane with an integrated Wheatstone piezoresistive bridge. The piezoresistors are placed on “back side” of the membrane, inside a vacuum reference chamber, whilst the pressure media to be measured in the application is applied to the opposite side. This gives excellent long-term properties for the sensors as the measurement bridge is protected from the environment. Pressure measurements are performed by a dedicated ROM library function.

1.5.2 Acceleration Sensor (for Sensors with the Letter ‘A’ Included in the Product Name)

The single-crystal silicon acceleration sensor consists of a bulk micro machined beam and mass with an integrated full Wheatstone piezoresistive bridge. The whole beam and mass are placed inside a hermetically sealed chamber and are therefore well protected from the environment. A diagnostic resistor is integrated along the edge of the beam which is used to check the mechanical integrity of the beam. Acceleration measurements are performed by a dedicated library ROM library function.

1.5.3 Embedded Temperature Sensor

The temperature sensor is integrated in the ASIC. This is read by the ADC referenced to a fixed (band gap) voltage. Temperature measurements are performed by a dedicated ROM library function.

1.5.4 Embedded Supply Voltage Sensor

The supply voltage sensor (typically used as a battery voltage sensor in the application) is a circuit providing a signal proportional to the supply voltage. The voltage is read by the ADC referenced to a fixed (band gap) voltage. Supply Voltage measurements are performed by a dedicated ROM library function.

1.5.5 Data Acquisition

The analog data is acquired and digitized by the internal 10 Bit ADC. Measurement routines for acquiring the environmental data are available within the ROM library functions.

1.6 Memory Organization

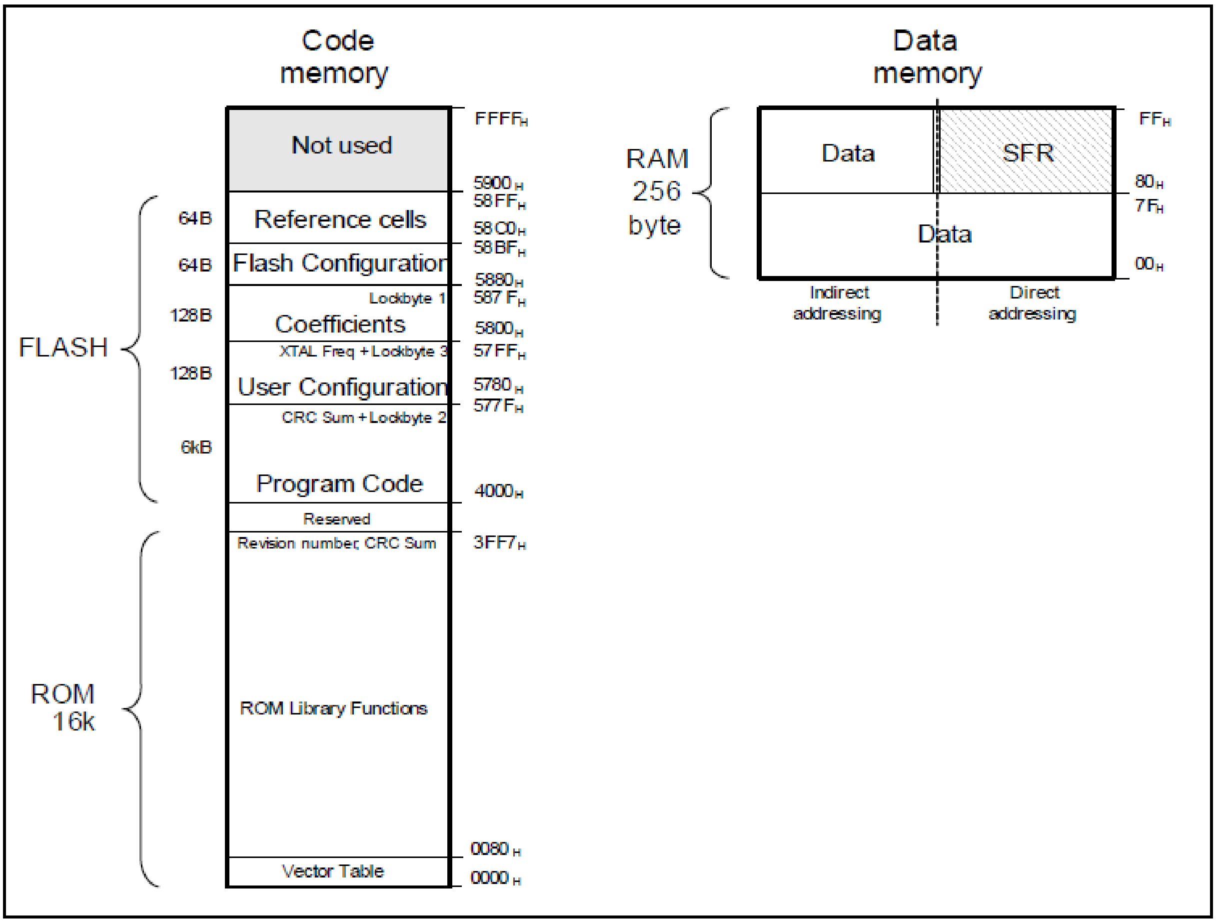

Figure 2: Memory map

The following memory blocks are implemented:

- 16 kByte ROM memory
- 6 kByte FLASH memory
- 256 Byte RAM memory
- 128 Byte SFR register

See [2] for details.

2 Functional Overview

Special Function Registers (SFRs) are used to control and monitor the state of the SP400 and its peripherals. See [2] for details.

2.1 Microcontroller

The SP400 incorporates an 8051 instruction set compatible microcontroller. It offers an 8-bit data path, several addressing modes (direct, register, register indirect, immediate, index), and accesses the built-in peripherals through SFRs. To handle sequential applications efficiently, wakeup and resume mechanisms are implemented instead of an interrupt controller.
The microcontroller incorporates basic SFRs. Accumulator (ACC), Register B (B) and Program Status Word (PSW) are bit addressable registers used to perform arithmetical and logical operations. The Stack Pointer (SP) and Data Pointer (DPTR) are included to allow basic programming structures. The Data Pointer (DPTR) is determined by SFR Data Pointer High (DPH) and SFR Data Pointer Low (DPL). SFR PSW holds the status of basic arithmetic operations.

2.2 General Purpose Registers

The SP400 incorporates 16 general purpose registers that can be used by the application to store data beyond a POWER DOWN state/THERMAL SHUTDOWN state period. The GPR Registers are not cleared after a System Reset. After a Power On Reset, the GPR contents will be undefined.

2.3 System Configuration Registers

The system configuration registers can be used for:

- Initiating state transitions
- Enabling or disabling peripherals
- Monitoring the operation mode, the system state and peripherals

2.4 System Controller

While the microcontroller controls SP400 in RUN state, the system controller takes over control in POWER DOWN state, IDLE state and THERMAL SHUTDOWN state. The system controller handles wakeup/resume events and system resets. It is clocked by the 2kHz RC LP Oscillator.

There is a difference between System Reset and Wakeup.

System Reset: The digital circuit is reset. Program execution starts at address 0000_H to perform reset initialization routines (including operation mode selection) and will jump to the FLASH at address 4000_H to execute the application program.

Wakeup: Only the program counter of the microcontroller and its peripheral units are reset. Program Execution starts at address 0000_H to perform wakeup initialization routines and jumps to the FLASH at address 4000_H to execute the application program.

Whenever a wakeup occurs, the SP400 leaves the POWER DOWN state and enters RUN state to execute the application program. This transition can be initiated from various sources:

- Watchdog Wakeup
- TMAX Wakeup
- LF Receiver Wakeup Event
- External PP2 Wakeup Event
- Interval Timer Wakeup Event

The wakeup source can be identified by reading SFR Wakeup flag register (WUF).

2.5 Interval Timer

The Interval Timer is responsible to wakeup the SP400 from the POWER DOWN state after a predefined time interval. It is clocked by the 2kHz RC LP Oscillator and incorporates two dividers:

- Precounter: can be calibrated to the system clock and represents the time base
- Postcounter: configures the Interval Timer duration in multiples of the time base

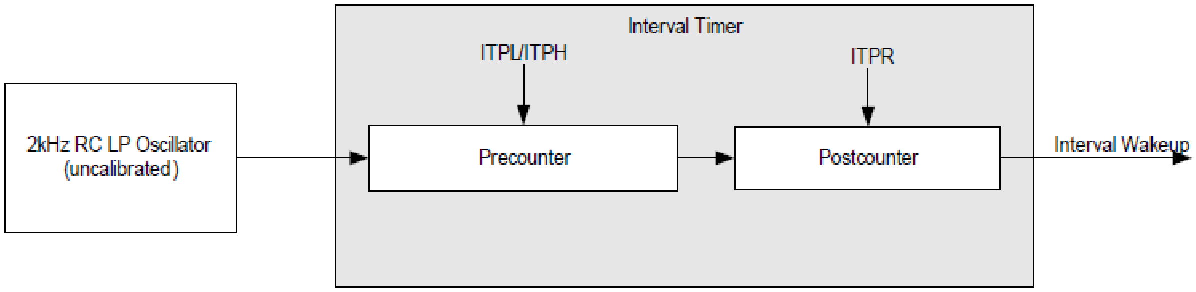

Figure 3: Interval timer block diagram

2.6 Clock Controller

The Clock Controller for internal clock management is part of the system controller. In the SP400 the microcontroller (CPU) clock source is always based on the 12 MHz RC HF Oscillator (system clock) to provide minimum current consumption. The internal clock divider (SFR DIVIC) may be used to slow down the speed of the microcontroller and to reduce the current consumption further. The crystal is used as clock source for the RF Transmitter and for the Timer Unit (e.g. for oscillator calibrations). The start up of the crystal (e.g. for RF Transmission) can be performed automatically by a ROM library function.

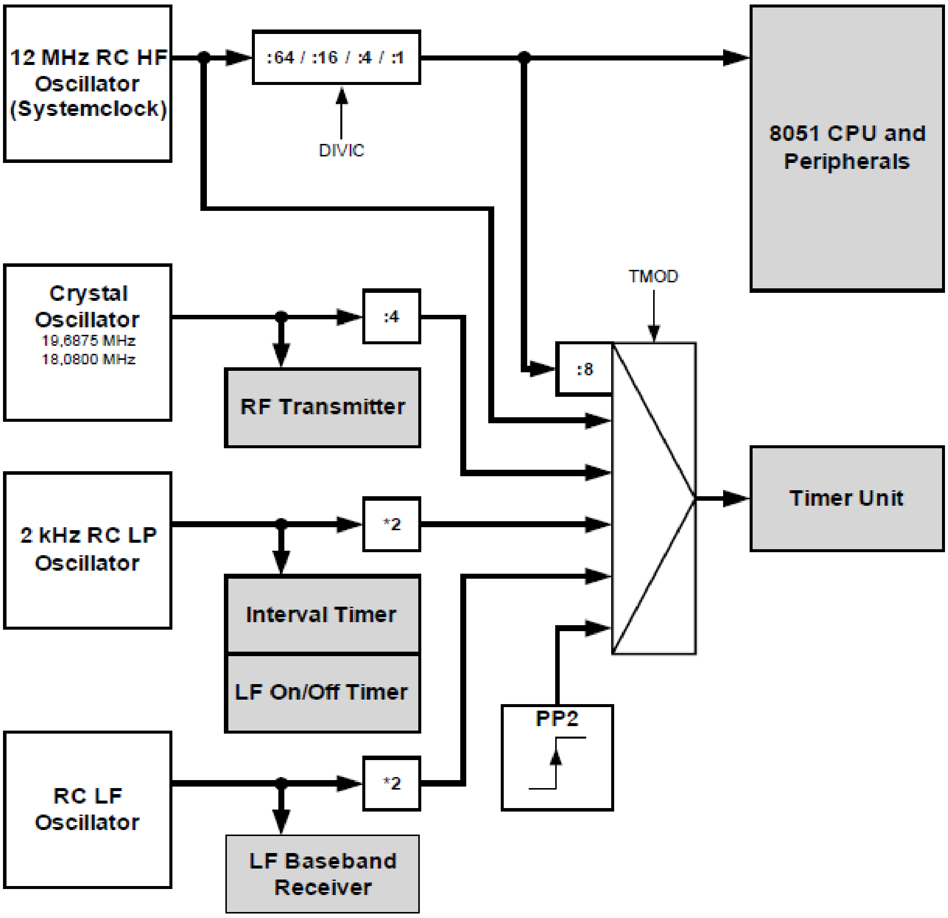

Figure 4: Clock concept

2.7 Crystal Pulling

To achieve FSK transmission, the reference frequency of the Negative Impedance Converter (NIC) crystal oscillator is detuned by switching between two different capacitances (one for the low and one for the high FSK frequency). These capacitance values are achieved with embedded switchable capacitors and/or with external capacitors, mounted in series to the crystal. For ASK transmission, the capacitance can be used to tune the center frequency.

2.8 RF 315/434 MHz FSK/ASK Transmitter

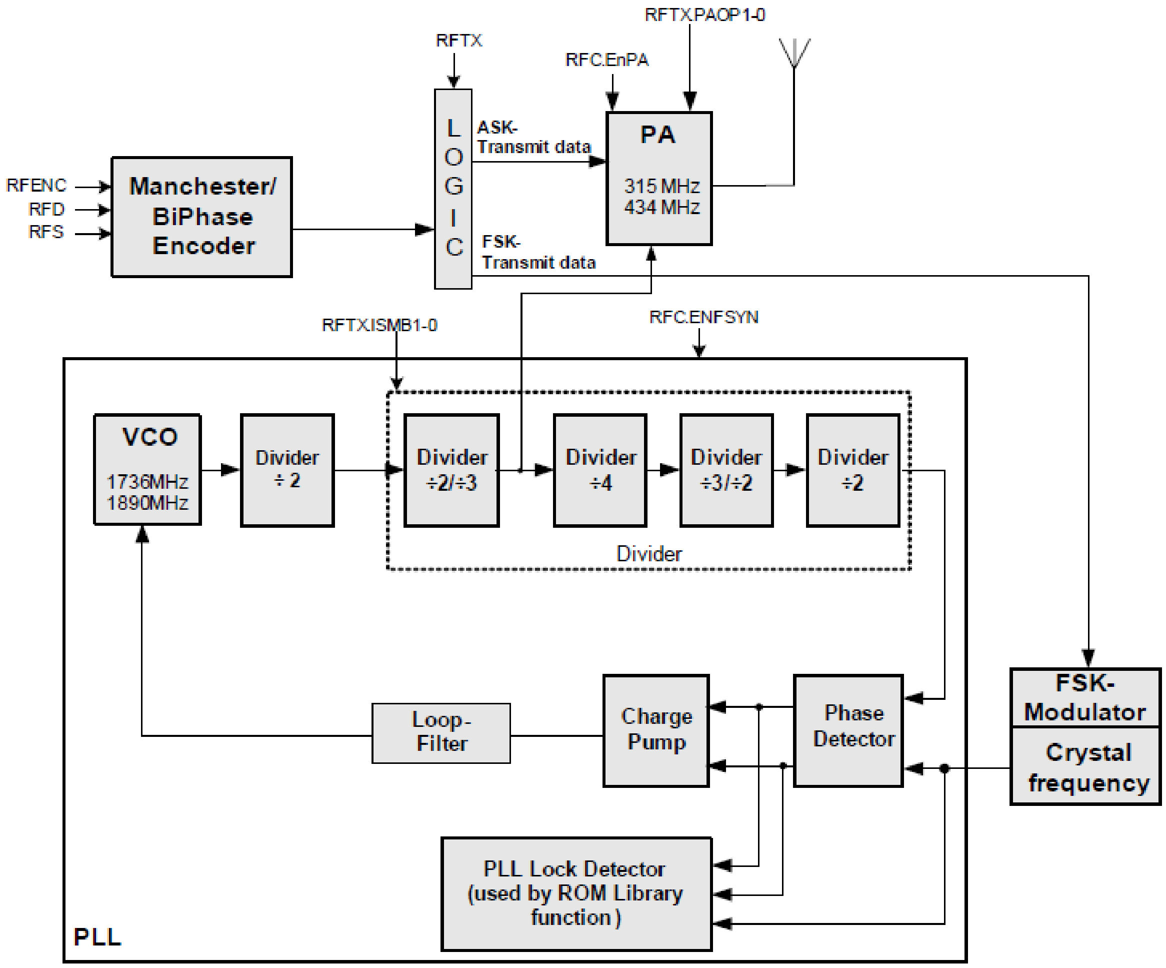

Figure 5: RF transmitter block digram

The RF-Transmitter can be configured for the 315/434 MHz ISM-Band frequencies by setting dedicated SFR bits, RFTX.3-2[ISMB1-0], and choosing the proper crystal according to Table 2.

Table 2: Crystal selection

Center Frequency [MHz]	PLL Divider Factor	Required XTAL Frequency [MHz]
433.92	24	18.0800
315.00	16	19.6875

2.9 Manchester/Bi-Phase Encoder

The SP400 offers a Hardware Manchester/Bi-Phase encoder which uses Timer 1 (see chapter 2.18) to configure the bitrate for the encoder. The application software needs to configure the timer and can subsequently send the raw uncoded data to the Manchester/Bi-Phase Encoder which takes care of encoding and the RF transmission itself (controlling the Power Amplifier). Using the Hardware encoder allows the CPU to be operated at a reduced clock rate thereby reducing the peak current consumption during RF transmission. The reduced CPU clock rate also reduces the possibility of clock noise artefacts in the RF signal. Furthermore, the encoder creates a resume event after sending each byte so that the application can enter the IDLE state while sending each databyte. It is recommended to use both reduced clock rate and IDLE mode for best performance during RF transmission.

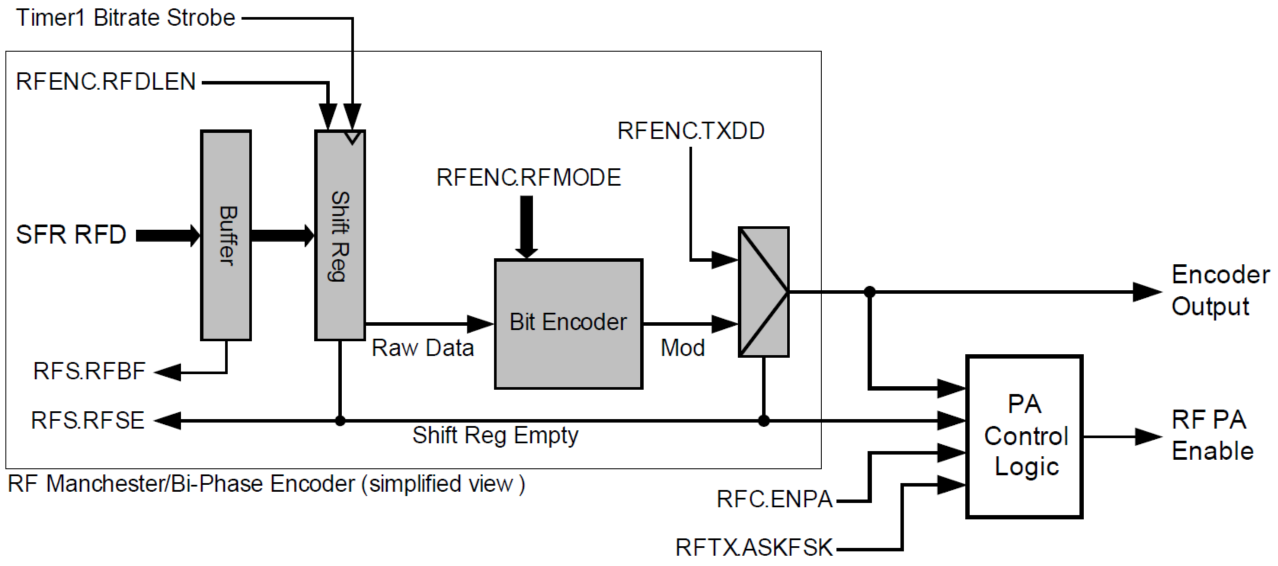

Figure 6: Manchester/Bi-Phase encoder

For different RF encoder modes see Figure 7.

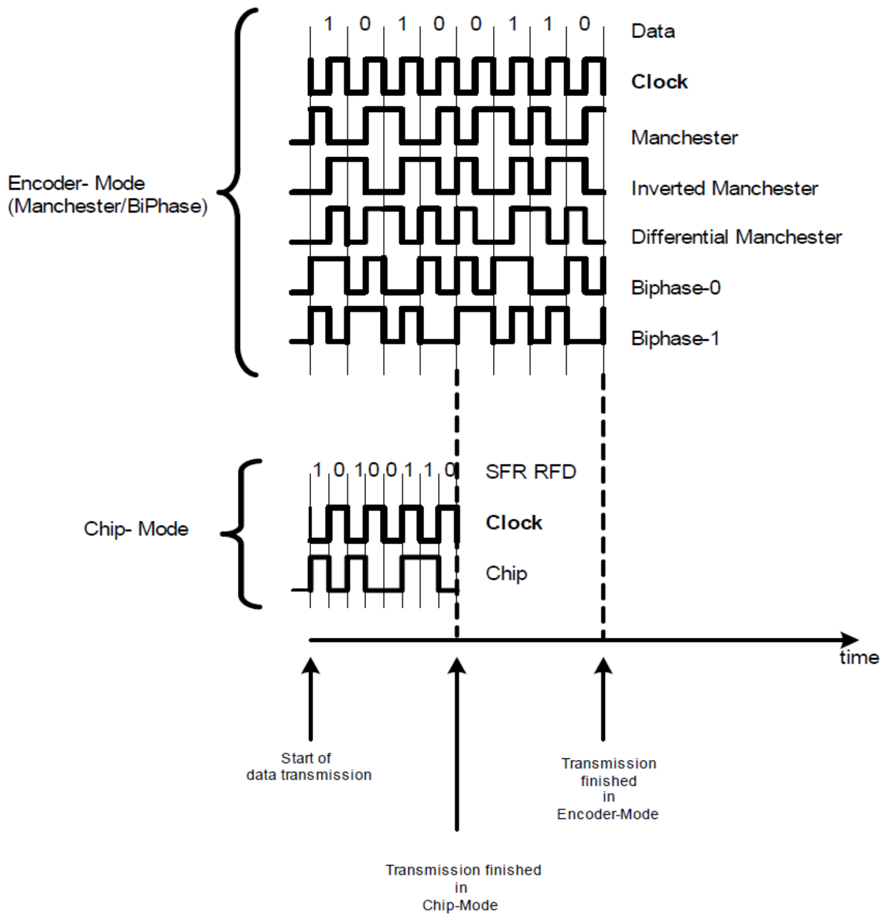

Figure 7: Diagram for different RF encoder modes

2.10 LF Receiver

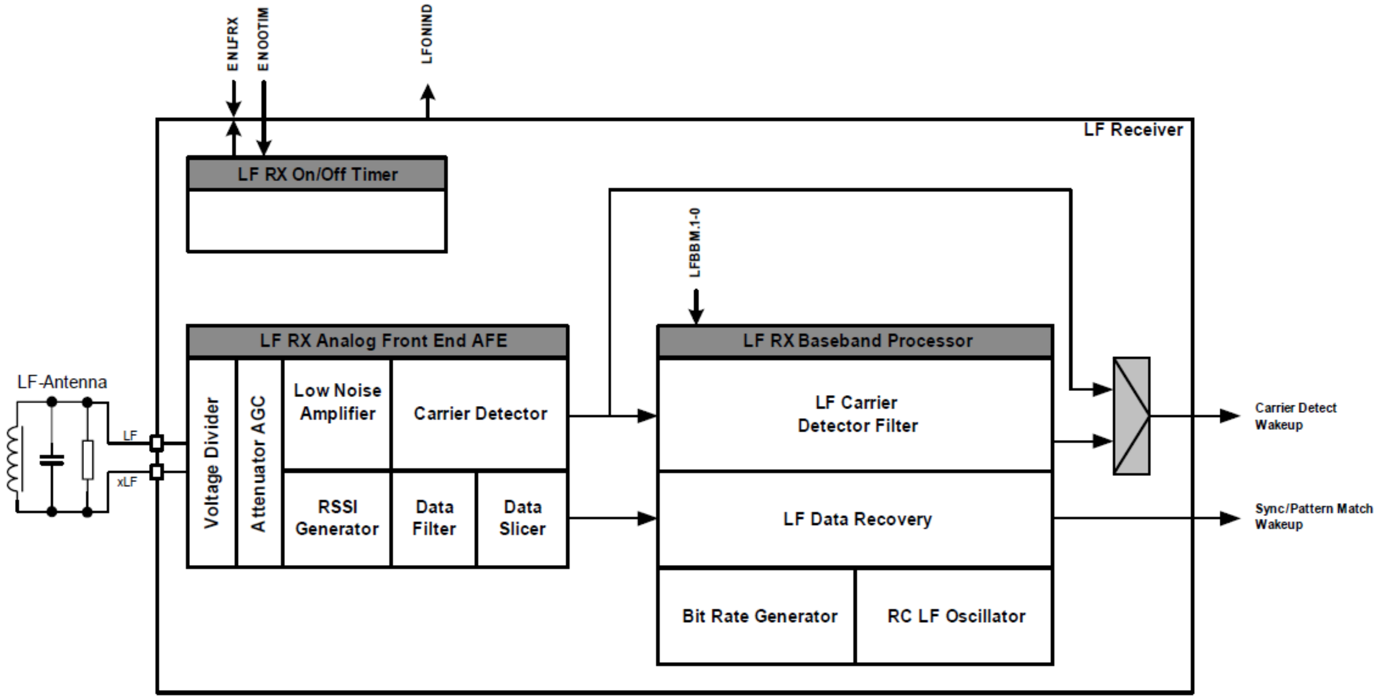

Figure 8: LF receiver block diagram

The LF Receiver is used for wireless data transmission to the SP400 and for waking up the device from the POWER DOWN state. It can generate a wakeup directly by the carrier detector if the carrier amplitude is above a predefined threshold, or it can decode the received data and wake up the microcontroller only if a sync match pattern or wakeup pattern is detected in the data stream.

Data recovery using a synchronizer and a decoder is available for Manchester coded data. The synchronizer can also handle Manchester code violations. Other coding scheme can be handled by the microcontroller at the chip level, thus no limitations on data coding schemes apply.

A LF On/Off Timer is implemented to generate periodical On/Off switching (polling) of the LF Receiver in POWER DOWN state to minimize current consumption.

2.11 LF Attenuator (AGC)

An input attenuator is provided to limit strong signals and interferers across the differential input. An Automatic Gain Control (AGC) block (fast attack, slow decay) is implemented to cover a high dynamic range of the LF input signal. The AGC threshold is determined by SFR bits. The attenuator attack time and decay slew rate are also determined by SFR bits.

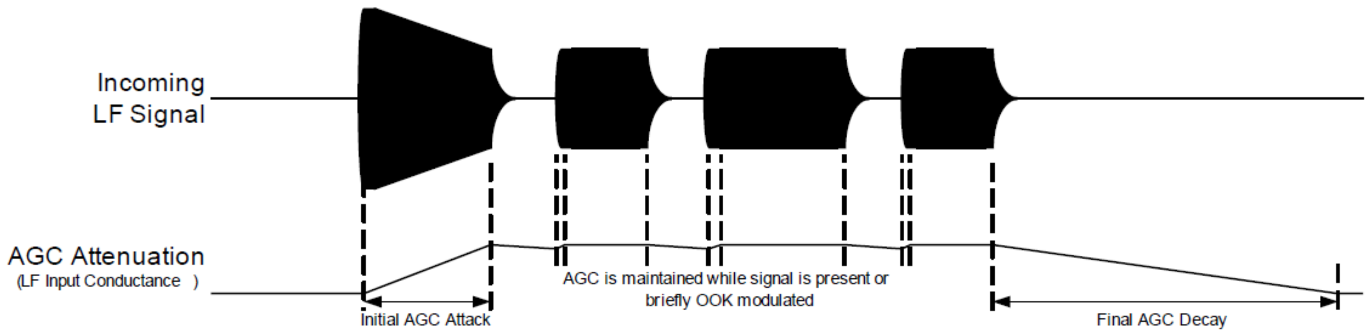

Figure 9: LF attenuator (AGC)

2.12 LF Carrier Detector

A level detection circuit is implemented to determine if the carrier amplitude is above a predetermined level. An LF input signal above the Carrier Detector threshold (CDETT) level may cause a device wakeup from the POWER DOWN state.

Three different Carrier Detector thresholds can be chosen by the application. In order to achieve LF sensitivity as specified, an appropriate Voltage Divider setting is used in conjunction with the adjustable threshold level.

During factory testing and calibration process, individually calibrated CDETT values are programmed into each device. The application software must thus retrieve the individual values from the Flash and apply them in conjunction with the predefined SELIN (LF receiver input selector) setting.

Figure 10 summarizes the LF Carrier Detector response versus input signal duration and amplitude.

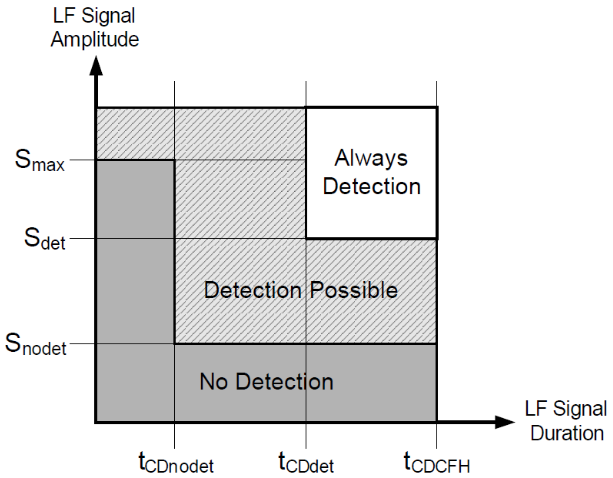

Figure 10: LF carrier detector response

2.13 LF Receiver On/Off Timer

An On/Off Timer is implemented to reduce the LF Receiver current consumption in the POWER DOWN state. The timer can be enabled/disabled by a dedicated SFR bit.

2.14 LF Telegram Format

The LF Receiver Baseband requires that an LF Telegram contains at least two elements: a Preamble sequence and a Synchronization Pattern. The LF Telegram may also contain a user defined "wakeup ID" field which may be either 8-bits or 16-bits in length. The LF Receiver baseband supports matching against two different wakeup ID patterns, e.g. to allow separate "broadcast address" and "unique address" ID patterns to be implemented. Finally, an LF Telegram will typically contain at least one data bit, so the reception of data as individual bits or groups of 8-bit bytes is supported.

The CPU must handle the unloading of buffered data bits or bytes to prevent data overflow. The LF Receiver Baseband is configured for a specific LF Telegram format via the SFR LFPCFG. Figure 11 illustrates the typical LF Telegram formats and the relationship of the telegram elements.

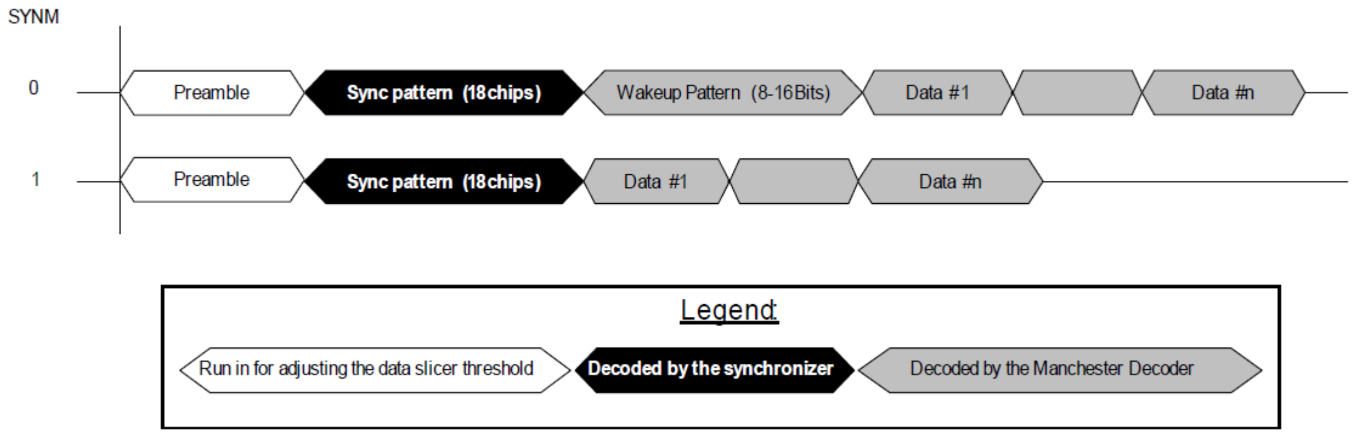

Figure 11: LF receiver baseband configurations

A LF Telegram must begin with a Preamble sequence, which serves to stabilize the LF Data Threshold within the LF Analog Front End. The Preamble typically consists of several Manchester symbols, all of equal value (i.e. all '0' or all '1' bits). A Preamble may consist of mixed value bits, but in this case the duration of the Preamble must be longer than that required for equal value bits. There is no maximum duration for the Preamble. The "raw data" output of the LF Data Comparator may be observed via a SFR bit.

A Synchronization ("Sync") pattern must follow the Preamble. The Sync pattern is 9.5 bits (18 chips) in duration, and includes non-manchester symbols so that it is not possible to accidentally encounter the Sync pattern in any other portion of a properly formatted LF Telegram. The Sync Matching circuit within the LF Receiver Baseband is responsible for monitoring the raw data output of the LF Data Comparator and determining when a Sync pattern has been received. Detection of the Sync pattern (a "Sync match") will cause a SFR bit to be set, and may be used as a CPU wakeup event. Figure 12 provides more details related to the Preamble sequence and Sync pattern.

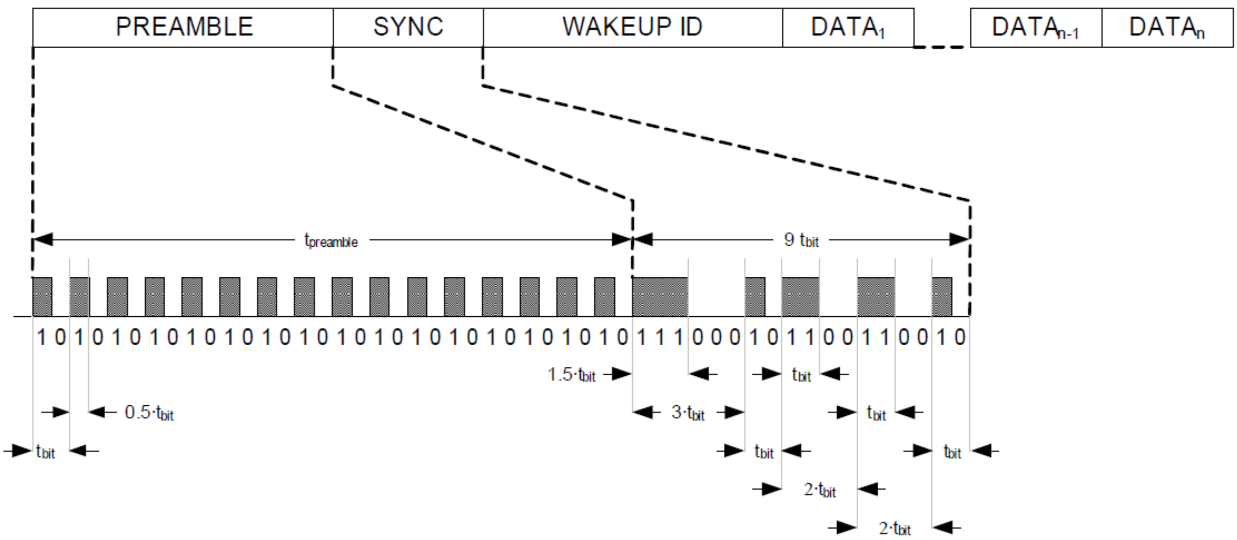

Figure 12: LF telegram format

2.15 Wakeup Pattern Detector

Two independent wakeup patterns - each with a length of 8 or 16 bits are available. A SFR bit determines by which pattern (pattern 0 only, or either pattern 0 or pattern 1) a wakeup can occur.

2.16 LF Receiver Data Interface

The received data can be read by the microcontroller using the following interfaces:

- 8 bit databyte (synchronized, Manchester decoded)
- Serial bitstream data (synchronized, Manchester decoded)
- RAW data (synchronized, chip level)
- RAW Carrier Detect (un-synchronized)

2.17 16 Bit CRC (Cyclic Redundancy Check) Generator/Checker

CRC is a powerful method to detect errors in data packets that have been transmitted over a distorted connection. The CRC Generator/Checker divides each byte of a data packet by a polynomial, leaving the remainder which represents the checksum. The CRC-Generator/Checker uses the 16Bit CCITT polynomial x^16+x^12+x^5+1. The 16 bit start value is determined by the initial contents of dedicated SFR registers (CRS0 and CRC1).

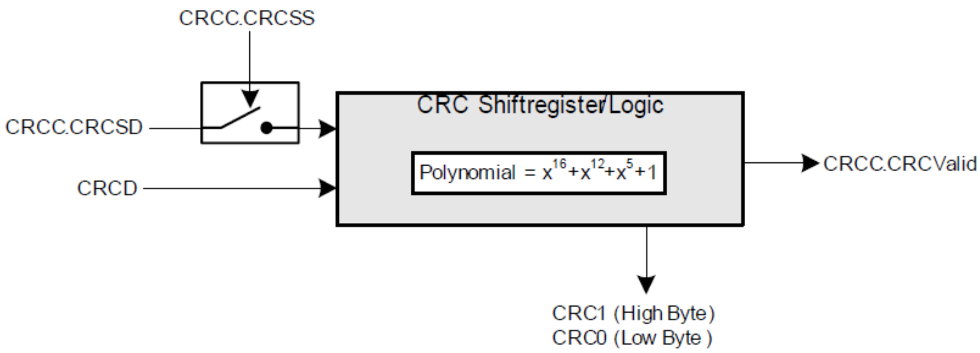

Figure 13: 16 bit CRC generator/checker

2.18 Timer Unit

The SP400 comprises two independent 16 bit timers which operate as down counters. Different timer modes are available for extended functionality.

Timer 0 and Timer 1 comprise two fully programmable 16-bit timers, which can be used for time measurements as well as for generating time delays. The clock source is selectable in order to enlarge the timer runtime. A dedicated SFR register is used to select the clock source and desired timer mode.

Setting dedicated SFR bits starts Timer 0 and Timer 1. The started timer counts down from the start value using the selected counter until the timer has elapsed. The start values of the timers are defined by SFR registers.

After a timer has elapsed there are two possibilities that can occur (dependant on the selected timer mode):

- Reload**:** If the selected timer mode uses timer reload, the timer is automatically reloaded and restarted
- Stop**:** If the selected timer mode doesn't use timer reload, the timer is stopped and the dedicated SFR bit set to start the timer is cleared

2.19 General Purpose Input/Output (GPIO)

The SP400 has three GPIO pins that are used for:

- General purpose uses by the application software
- Dedicated digital peripherals
- Operating mode selection

If configured for general purpose usage, the GPIO pins can be accessed directly by the CPU. All GPIO pins have selectable pull-up and pull-down resistors.

GPIO pins are configured as input with pull-up resistors enabled after reset. In the POWER DOWN and THERMAL SHUTDOWN states the GPIOs keep their configuration.

2.20 I^2C Interface

For communication between a host and the SP400 a I^2C slave interface is implemented.

- PP1 is used as serial data line (SDA)
- PP0 is used as serial clock line (SCL)
- SP400 responds to the I^2C Address $6C_H$ or a general call (if enabled) by addressing slave address 00_H. General call can be enabled by setting a dedicated SFR bit

The I^2C Interface is handled automatically by the mode handlers located in ROM in PROGRAMMING and DEBUG mode. Manual access to those registers is only required if the I^2C Interface is utilized in NORMAL mode.

1.1.1.1 PROGRAMMING mode operation

The SP400 is only accessible via the I²C Interface in PROGRAMMING mode. The device is operating using the internal 12 MHz RC HF Oscillator. If started up in PROGRAMMING mode, the SP400 waits until an I^2C commands is received. See Figure 14 for illustration.

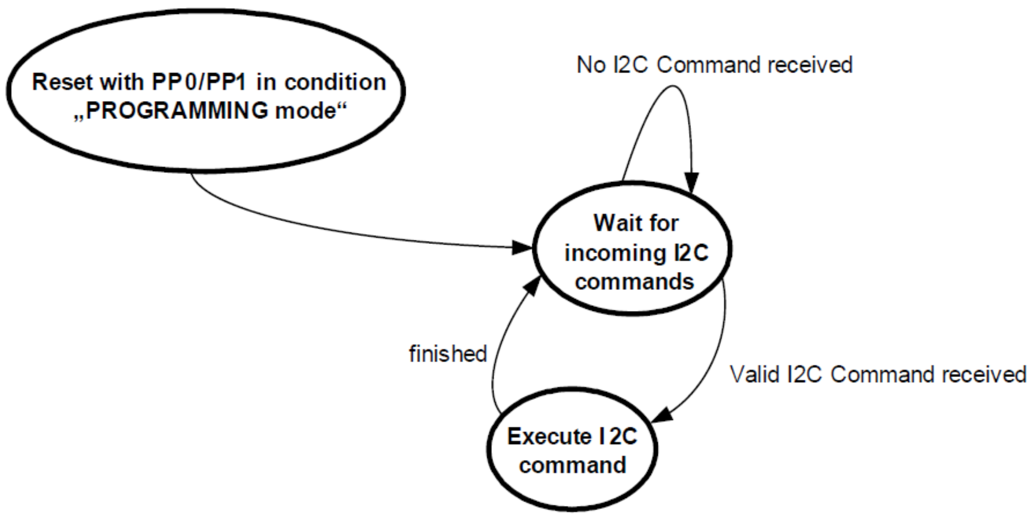

Figure 14: PROGRAMMING mode state diagram

1.1.1.2 DEBUG mode operation

DEBUG mode operation is automatically handled by the development environment for SP400. Manual changes of the SFR registers and/or usage of the Debugger Commands by other tools may result in undefined operation.

3 Specifications

3.1 Recommended Operating Conditions

To ensure correct operation of SP400, the following operating conditions must not be exceeding.

Parameter	Product	Symbol	Min	Typ	Max	Units
Temperature operating range	All SP400 sensors	T_{oper}	-40	-	125	°C
Temperature during programming/erasing	All SP400 sensors	T_{prog}	0	-	60	°C
Supply voltage[1]	All SP400 sensors	$V_{DD\ oper}$	2.1	-	3.6	V
Supply voltage for flash programming	All SP400 sensors	$V_{DD\ prog}$	2.5	-	3.6	V
Input pressure [2]	SP400-1.5 SP400-1.5T	-	0	-	150	kPa
	SP400-5A SP400-5AT	-	0	-	500	kPa
	SP400-10A SP400-10AT	-	0	-	1000	kPa
	SP400-20	-	0	-	2000	kPa
Input acceleration	SP400-5A SP400-5AT SP400-10A SP400-10AT	-	0	-	115	g

[1] Voltage range where measurement accuracy is specified
[2] Absolute pressure values

3.2 Absolute Maximum Ratings

Prolonged exposure to values between recommended operating conditions and absolute maximum ratings may affect the performance and reliability of the device.

Parameter	Product	Min	Typ	Max	Units
Input pressure	SP400-1.5 SP400-1.5T	-	-	600	kPa
	SP400-5A SP400-5AT SP400-10A SP400-10AT	-	-	1600	kPa
	SP400-20	-	-	3300	kPa
Peak soldering temperature [1]	All SP400 sensors	-	-	255	°C
Storage temperature [2]	All SP400 sensors	-55	-	150	°C
Supply voltage	All SP400 sensors	-0.3	-	4.0	V
ESD robustness, human body model (HBM) [3]	All SP400 sensors	-	-	±4500	V
ESD robustness, charge device model (CDM) [4]	All SP400 sensors	-	-	±500	V
Latch-up, transient current [5]	All SP400 sensors	-100	-	100	mA
Input voltage, Pin PP0, PP1, PP2	All SP400 sensors	-0.3	-	VDD + 0.3	V
Input voltage, Pin LF, XLF	All SP400 sensors	-0.3	-	0.3	V
Input voltage, Pin XTAL	All SP400 sensors	-0.3	-	Vreg + 0.3	V
Input current, Pin PP0, PP1, PP2	All SP400 sensors	-	-	4	mA
Input current, Pin LF, XLF	All SP400 sensors	-	-	4	mA
Static acceleration	All SP400 sensors	-	-	5000	g
Mechanical shock [6]	All SP400 sensors	-	-	4000	g

Note: Stresses outside maximum rating values may cause permanent damage to the device. Maximum ratings are absolute ratings; exceeding only one of these values may cause irreversible damage to the integrated circuit.

[1] Less than 3min, max 10 times over lifetime. The component will also withstand reflow soldering according to JEDEC JESD22-B102
[2] Max 1000hrs between 125°C and 150°C, accumulated over lifetime
[3] All pins. According to EIA/JESD22-A114-B
[4] All pins. According to ESDA STM
[5] According to AEC-Q100
[6] Level: 4000 g peak. Pulse duration: 0.3ms. Waveform: Half sine. Power: 3.0 V. 5 shocks each dir. +/- x-,y-,z-axis (according to MIL-STD 883E)

3.3 Measurement Performance

SP400 has a 10 bit ADC. Monotonic operation and no missing codes are guaranteed over the full operating range. The following specifications are to be understood as typical values (3σ statistics) over the whole temperature range unless otherwise stated.

3.3.1 Pressure Measurement Performance

Parameter	Product	Unit	Typ	Ambient conditions
Resolution	SP400-1.5 SP400-1.5T	kPa/lsb	1/16	-
	SP400-5A SP400-5AT	kPa/lsb	1/16	-
	SP400-10A SP400-10AT	kPa/lsb	1/16	-
	SP400-20	kPa/lsb	1/8	-
Accuracy	SP400-1.5 SP400-1.5T	kPa	±1.9	0 to 50°C
		kPa	±3.8	-
	SP400-5A SP400-5AT	kPa	±4.1	0 to 50°C
		kPa	±8.2	-
	SP400-10A SP400-10AT	kPa	±9.0	0 to 50°C
		kPa	±18	-
	SP400-20	kPa	±16	0 to 1000kPa, 0 to 50°C
		kPa	±32	0 to 1000kPa
		kPa	±22	1000 to 2000kPa, 0 to 50°C
		kPa	±44	1000 to 2000kPa
Measurement time	All SP400 sensors	ms	0.89	-

3.3.2 Temperature Measurement Performance

Parameter	Product	Unit	Typ	Ambient conditions
Resolution	All SP400 sensors	°C/lsb	1/128	-
Accuracy	All SP400 sensors	°C	±1.0	-20 to 70°C
		°C	±1.5	-
Measurement time	All SP400 sensors	ms	0.67	-

3.3.3 Acceleration Measurement Performance

Parameter	Product	Unit	Typ	Ambient conditions
Resolution	SP400-5A SP400-5AT SP400-10A SP400-10AT	g/lsb	1/16	-
Sensitivity error	SP400-5A SP400-5AT SP400-10A SP400-10AT	%	±5%	-
Offset error	SP400-5A SP400-5AT SP400-10A SP400-10AT	g	±2.0	-
Measurement time	SP400-5A SP400-5AT SP400-10A SP400-10AT	ms	0.91	-

3.3.4 Supply Voltage Measurement Performance

Parameter	Product	Unit	Typ	Ambient conditions
Resolution	All SP400 sensors	mV/lsb	1/8	-
Accuracy	All SP400 sensors	mV	±30	-
Measurement time	All SP400 sensors	ms	0.37	-

3.4 Current Consumption

Table 3: Supply currents

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Supply Current RF Transmission [1] Modulation: FSK SFR DIVIC[1:0]: 11_B	$I_{P\ Low,1.9V,-40}$	-	-	8	mA	V = 3.0 V, T= 25°C SFR RFTX.PAOP = 00_b P_{out} ~ 5 dBm $Z_{load,434MHz}$ ~ 500 Ohm $Z_{load,315MHz}$ ~ 650 Ohm
	$I_{P\ Low,3.0V,-40}$	-	-	9	mA	-
	$I_{P\ Low,3.0V,25}$	-	-	10	mA	-
	$I_{P\ Low,3.0V,125}$	-	-	12	mA	-
	$I_{P\ Med,1.9V,-40}$	-	-	10	mA	-
	$I_{P\ Med,3.0V,-40}$	-	-	12	mA	-
	$I_{P\ Med,3.0V,25}$	-	-	14	mA	-
	$I_{P\ Med,3.0V,125}$	-	-	15	mA	V= 3.0 V, T= 25°C SFR RFTX.PAOP = 01_b P_{out} ~ 8 dBm $Z_{load,434MHz}$ ~ 300 Ohm $Z_{load,315MHz}$ ~ 450 Ohm
	$I_{P\ High,1.9V,-40}$	-	-	12	mA	-
	$I_{P\ High,2.5V,125}$	-	-	16	mA	-
POWER DOWN current RAM lower memory block powered down SFR CFG2.PDLMB:1_b	$I_{PD,3.0V,25°C}$	-	-	700	nA	V= 3.0 V, T= 25°C
POWER DOWN current RAM lower memory block kept powered SFR CFG2.PDLMB:0_b	$I_{PD\_RAMen,3.0V,25°C}$	-	-	750	nA	V= 3.0 V, T= 25°C
THERMAL SHUTDOWN current RAM lower memory block powered down SFR CFG2.PDLMB:1_b	$I_{TS,3.0V,125°C}$	-	-	170	µA	V= 3.0 V, T= 125°C
THERMAL SHUTDOWN current RAM lower memory block kept powered SFR CFG2.PDLMB:0_b	$I_{TS\_RAMen,3.0V,125°C}$	-	-	175	µA	V= 3.0 V, T= 125°C
IDLE current SFR DIVIC: 00_B Timer0 active	$I_{Idle,3.0V,25°C}$	-	-	1	mA	V= 3.0 V, T= 25°C
RUN current (Peripheral units in active state) SFR DIVIC: 00_B	$I_{Run,3.0V,25°C}$	-	-	2.1	mA	V= 3.0 V, T= 25°C
RUN current (PLL enabled.) SFR DIVIC: 11_B	$I_{PLL,3.0V,25°C}$	-	-	8	mA	V= 3.0 V, T= 25°C

[1] These parameters were obtained using the SP400 Test Board. Tolerances of the passive elements (matching network) not taken into account. The environment of the customer application have not been taken into account

LF Receiver current SFR bits LFBBM: 00_B	$I_{LF\_Add,AFE}$	-	-	4	µA	-
LF Receiver current [1] SFR bits LFBBM: 01_B	$I_{LF\_Add,I}$	-	-	6.1	µA	V= 3.0 V, T= -40...90°C
	$I_{LF\_Add,f,}$	-	-	7.8	µA	V= 3.0 V, T=-40...125°C
LF Carrier Frequency Discriminator current [2] SFR bit LFFDEN: 1_B	$I_{LF\_Add,FD}$	-	5	10	µA	-

3.5 RF Transmitter

Table 4: RF transmitter specifications [3]

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Transmit Frequency	$f_{Tx,315MHz}$	-	315	-	MHz	-
	$f_{Tx,433.92MHz}$	-	433.92	-	MHz	-
Output Power transformed into 50 Ohm	$P_{low, 433.92 MHz}$	4	5	6	dBm	V= 3.0 V, T= 25°C SFR RFTX.PAOP = 00_b Zload~ 500 Ohm
	$P_{med, 433.92 MHz}$	7	8	9	dBm	V= 3.0 V, T= 25°C SFR RFTX.PAOP = 01_b Zload~ 300 Ohm
	$P_{High, 433.92 MHz}$	6	-	-	dBm	V= 2.5 V, T= 125°C SFR RFTX.PAOP = 11_b Zload~ 300 Ohm
	$P_{High, 433.92 MHz}$	3	-	-	dBm	V= 1.9 V, T= -40°C SFR RFTX.PAOP = 11_b Zload~ 300 Ohm
	$P_{low, 315 MHz}$	4	5	6	dBm	V= 3.0 V, T= 25°C SFR RFTX.PAOP = 00_b Zload~ 650 Ohm
	$P_{med, 315 MHz}$	7	8	9	dBm	V= 3.0 V, T= 25°C SFR RFTX.PAOP = 01_b Zload~ 450 Ohm
	$P_{High, 315 MHz}$	6	-	-	dBm	V= 2.5 V, T= 125°C SFR RFTX.PAOP = 11_b Zload~ 450 Ohm
	$P_{High, 315 MHz}$	3	-	-	dBm	V= 1.9 V, T= -40°C SFR RFTX.PAOP = 11_b Zload~ 450 Ohm
Output Power change	$dP_{-40°C}$	-	-	1	dB	V_{bat}= 3.0 V, T= -40°C

[1] This additional LF current is valid for all LF baseband conditions. The difference in current consumption between decoding and not decoding is negligible

[2] This additional LF current is consumed for the duration of the frequency measurement if the Frequency Discriminator is enabled and an LF signal above the detection threshold is present at the LF inputs

[3] The parameters in this table were obtained by using the SP400 Test Board. Tolerances of the passive elements (matching network) and the environment of the customer application have not been taken into account

over temperature	$dP_{125°C}$	-	-	-1.5	dB	V= 3.0 V, T= 125°C
Output Power change over supply voltage	$dP_{1.9V}$	-	-	-8	dB	V= 1.9 V, T= 25°C
	$dP_{2.5V}$	-	-	-2.8	dB	V= 2.5 V, T= 25°C
	$dP_{3.6V}$	-	-	2.8	dB	V= 3.6 V, T= 25°C
Datarate	DR_{RF}	-	-	10	kbit/s	Equivalent to 20 kchips/s
Datarate accuracy	dDR_{RF}	-	-	±1	%	$f_{crystal}$ = 18.080/19.6875MHz DR_{RF} = 9600Bit/s SFR TMOD.T1CLK = 01_b SFR TMOD.TCLKM = 1_b
Spurious emissions (incl. harmonics) @ f_{Tx} = 315 MHz	$P_{spurii,FCC}$	-	-	-28	dBc	FCC 15.231a/e 2nd - 10th harmonic other spurious <1GHz
Spurious emissions (incl. harmonics) @ f_{Tx} = 433.92 MHz	$P_{spurii,ETSI,RB}$	-	-	-54	dBm	ETSI EN300220 BW = 10 kHz, 47-74 MHz, 87.5 MHz-118 MHz, 174-230 MHz, 470-862 MHz
Spurious emissions (incl. harmonics) @ f_{Tx} = 433.92 MHz	$P_{spurii,ETSI,<1G}$	-	-	-36	dBm	ETSI EN300220 BW = 10 kHz other <1 GHz
Spurious emissions (incl. harmonics) @ f_{Tx} = 433.92 MHz	$P_{spurii,ETSI,>1G}$	-	-	-30	dBm	ETSI EN300220 BW = 10 kHz >1 GHz
Phase Noise	$P_{PN, 10kHz}$	-	-	-80	dBc/Hz	fCarrier +/- 10 kHz
	$P_{PN, 100kHz}$	-	-	-80	dBc/Hz	fCarrier +/- 100 kHz
	$P_{PN, 1 MHz}$	-	-	-90	dBc/Hz	fCarrier +/- 1 MHz
	$P_{PN, 10 MHz}$	-	-	-120	dBc/Hz	fCarrier +/- 10 MHz

3.6 LF Receiver

Table 5: LF receiver specifications (V= 1.9… 3.6V)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Differential Input Capacitance	$C_{Input,LF}$	8	-	12	pF	@ 125 kHz
Differential Input Resistance DC	$R_{Input,LF}$	1M	-		Ohm	AGC disabled
Differential Input Impedance AC SFR bits SELIN: 00_B	$Z_{Input,LF, 25°C}$	305	342	380	kOhm	@ 125 kHz AGC disabled
	$Z_{Input,LF}$	290	342	400	kOhm	@ 125 kHz AGC disabled
Differential Input Impedance AC SFR bits SELIN: 01_B	$Z_{Input,LF}$	640	833	990	kOhm	@ 125 kHz AGC disabled
Differential Input Impedance AC SFR bits SELIN: 10_B	$Z_{Input,LF}$	670	860	1030	kOhm	@ 125 kHz AGC disabled
LF Receiver Filter Characteristic	$f_{Cut-off, LF AFE}$	70	-	140	kHz	-

Table 6: LF receiver telegram specifications (V= 2.1… 3.6V, f_{LF}= 120… 130kHz)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Datarate	DR_{LF}	3.9	-	4.2	kBit/s	-
Datarate error	$DR_{error,c}$	-2.5	-	2.5	%	Using "LFBaudrate-Calibration" ROM Library function once for initial calibration in production @ V= 2.5 V, T= 25°C
Preamble length	$t_{preamble}$	2	4	-	ms	DR_{LF} = 3.9 kbit/s, t_{bit} = $1/DR_{LF}$
Settling time	$t_{settling}$	1.3	2	4.1	ms	At enabling LFRx Min/Max tolerances from 2 kHz RC Oscillator applied
Maximum Telegram Amplitude	$LF_{tele,Smax}$	4	-	-	Vpp	AGC enabled
LF Telegram Sensitivity	$LF_{tele,nodet,f}$	0.1	-	-	mVpp	-
	$LF_{tele,det,f}$	-	-	2.5	mVpp	-

Table 7: LF receiver telegram specifications (V= 2.3… 3.3V, T= -40… 90°C, f_{LF}= 120… 130kHz)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
LF Telegram Sensitivity	$LF_{tele,nodet,l}$	0.2	-	-	mVpp	-
	$LF_{tele,det,l}$	-	-	1.3	mVpp	-

```
//Defines
#define CDETT_Levels_Base_Address 0x580E
#define CDETT_Level 1//Configure Carrier Detector Threshold Level (values 1, 2 or 3)
#define CDFLT_Times_Base_Address 0x580B
#define CDFLT_Time 1//Configure Carrier Detector Filter Time (values 1, 2 or 3)
//Basic LF Carrier Detection Configuration, Sensitivity Settings, Filter Settings
LFCDM0 = 0x1C;//Carrier Detector Dynamic Treshold, Enable Autocalibration & Freeze Hold
//Load Carrier Detector Filter Time from Flash
LFCDFLT = CBYTE[CDFLT_Times_Base_Address-(CDFLT_Time-3)];
//Load Carrier Detector Threshold from Flash
LFRX0 = CBYTE[CDETT_Levels_Base_Address-(CDETT_Level-3)];
LFRX1 = 0x10;//AGC Decay Time Constant, Autocalibration Time
LFRX2 = 0x77;//AGC Attack Time Constant
LFRXC = 0x04;//Enable AGC, LF Baseband off, Enable LFRx
```

Figure 15: LF receiver special function register (SFR) settings for carrier detection

Table 8: LF receiver carrier detection (V= 2.1... 3.6V, f_{LF}= 120...130kHz)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Auto-Calibration time	$t_{calibration,1}$	4.1	6	10.8	ms	-
Maximum Continuous Wave Amplitude	$LF_{cd, cw}$	4	-	-	Vpp	-
Maximum Amplitude for Carrier Detector Filter	$S_{max,f}$	30	-	-	mVpp	-
LF Carrier Detect Threshold #1 [1]	$S_{nodet,1,f}$	0.33	-	-	mVpp	-
	$S_{det,1,f}$	-	-	3.35	mVpp	-
LF Carrier Detect Threshold #2 [1 2]	$S_{nodet,2,f}$	2	-	-	mVpp	Carrier Detector Filter Time #1
	$S_{det,2,f}$	-	-	11	mVpp	
LF Carrier Detect Threshold #3 [1]	$S_{nodet,3,f}$	10	-	-	mVpp	-
	$S_{det,3,f}$	-	-	50	mVpp	-
Carrier Detector Filter Time #1	$t_{CDnodet,1}$	62	-	-	µs	-
	$t_{CDdet,1}$	-	-	240	µs	-
Carrier Detector Filter Time #2	$t_{CDnodet,2}$	500	-	-	µs	-
	$t_{CDdet,2}$	-	-	800	µs	-
Carrier Detector Filter Time #3	$t_{CDnodet,3}$	800	-	-	µs	-
	$t_{CDdet,3}$	-	-	1150	µs	-
Carrier Detection Freeze Hold Time	$t_{CDCFH,125}$	2	-	-	s	T=125°C
	$t_{CDCFH,25}$	300	-	-	s	T=25°C

[1] For reliable carrier detection a minimum pulse length of 240µs is required
[2] Tested with LF carrier detector filter time 1 - verified by characterization/design for LF carrier detector filter times #2, #3

Table 9: LF receiver carrier detection (V= 2.3... 3.3V, T= -40… 90°C, f_{LF}= 120...130kHz)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Maximum Amplitude for Carrier Detector Filter	$S_{max,l}$	100	-	-	mVpp	-
LF Carrier Detect Threshold #2	$S_{nodet,2,l}$	3	-	-	mVpp	-
	$S_{det,2,l}$	-	-	10	mVpp	Carrier Detector Filter Time #1

```
//Defines
#define CDETT_Levels_Base_Address 0x580E
#define CDETT_Level 1//Configure Carrier Detector Threshold Level (values 1, 2 or 3)
#define CDFLT_Times_Base_Address 0x580B
#define CDFLT_Time 1//Configure Carrier Detector Filter Time (values 1, 2 or 3)
#define FD_Setting 1//Configure Frequency Discriminator for 20% error
//#define FD_Setting 2//Configure Frequency Discriminator for 10% error
//Basic LF Carrier Detection Configuration, Sensitivity Settings, Filter Settings
LFCDM0 = 0x1C;//Carrier Detector Dynamic Treshold, Enable Autocalibration & Freeze Hold
//Load Carrier Detector Filter Time from Flash
LFCDFLT = CBYTE[CDFLT_Times_Base_Address-(CDFLT_Time-3)];
//Load Carrier Detector Threshold from Flash
LFRX0 = CBYTE[CDETT_Levels_Base_Address-(CDETT_Level-3)];
LFRX1 = 0x10;//AGC Decay Time Constant, Autocalibration Time
#if (FD_Setting == 1)
LFRX2 = 0x87;//Enable Frequency Discriminator, FD Mode 0,
//FD Time 8 LF RC periods, AGC Attack Time Constant
LFFDH = 0x0F;//Frequency Discriminator High Limit for 140000 Hz
LFFDL = 0x08;//Frequency Discriminator Low Limit for 110000 Hz
#endif
#if (FD_Setting == 2)
LFRX2 = 0xB7;//Enable Frequency Discriminator, FD Mode 0,
//FD Time 64 LF RC periods, AGC Attack Time Constant
LFFDH = 0x6E;//Frequency Discriminator High Limit for 140000 Hz
LFFDL = 0x47;//Frequency Discriminator Low Limit for 110000 Hz
#endif
LFRXC = 0x04;//Enable AGC, LF Baseband off, Enable LFRx
```

Figure 16: LF receiver special function register settings for frequency discriminator

Table 10: LF receiver carrier detection (V= 2.1... 3.6V, $f_{LF,max}$= 300kHz)

Parameter	Symbol	Min	Typ	Max	Units	Conditions
LF Carrier Frequency Discriminator error	$FD_{error, 8p}$	-20	-	+20	%	LFFDT[1:0] = 00_B LFFDL = 08_H LFFDH = $0F_H$
	$FD_{error, 64p}$	-10	-	+10	%	LFFDT[1:0] = 11_B LFFDL = 47_H LFFDH = $6E_H$

3.7 LF Test Cases

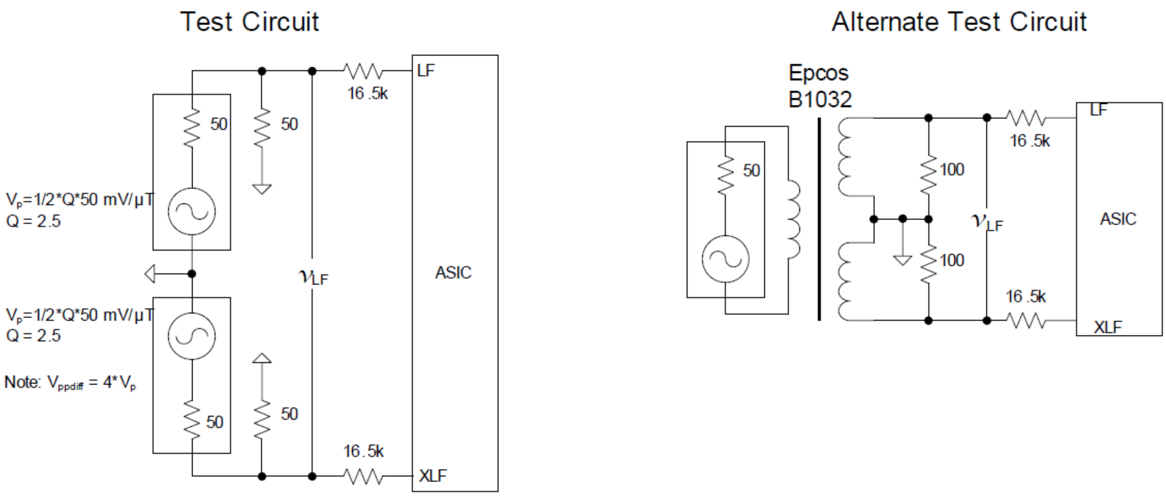

Figure 17: Test Circuit for large LF signal measurements

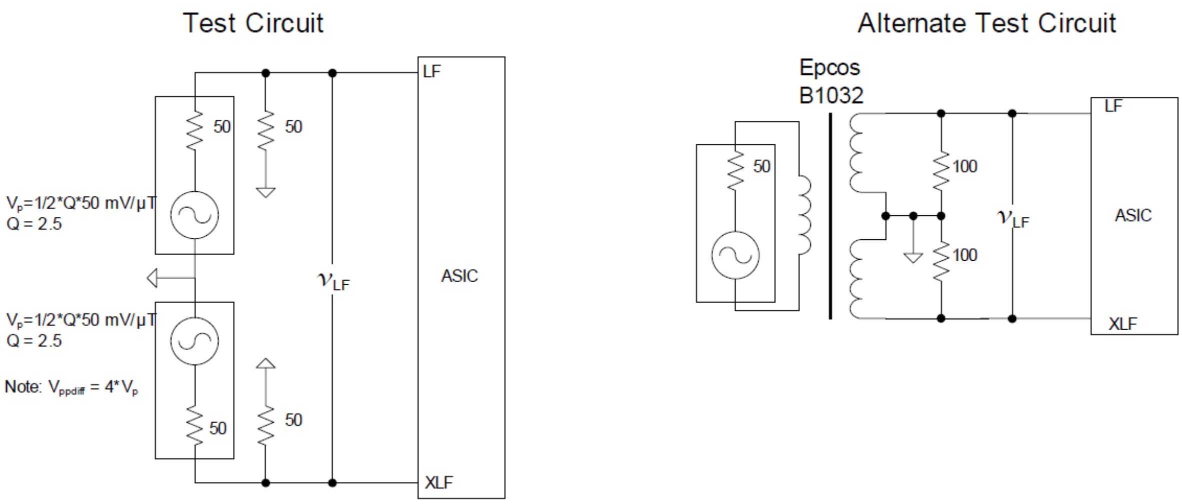

Figure 18: Test Circuit for small LF signal measurements

3.8 Crystal Oscillator

Table 11: Crystal Oscillator, fCrystal = 18 MHz...20 MHz

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Crystal startup time	$t_{XTAL,Startup}$	-	700	1250	µs	Measured on SP400 Test Board with crystal NX5032SD EXS00A-03552 C_L=12 pF, $f_{Crystal}$ = 18,08 MHz
Parasitic capacitance from XTAL pin to GND (PCB tracks, XTAL shield, etc.)	$C_{parasitic}$	-	-	4	pF	-
Serial resistance of the crystal	R_{Rmax}	-	-	60	Ohm	-
Input inductance revurder	$L_{OSC,\ 3.0V,25°C}$	2.0	2.9	3.8	µH	V= 3.0 V, T= 25°C
	L_{OSC}	1.8	2.9	4.3	µH	
Internal cap bank maximum capacitance	C_{bank}	36	40	44	pF	Between pin XTALCAP and pin XGND SFR XTAL1 = FF_H SFR RFENC.TXDD=1
FSK Switch ON resistance	$R_{Switch,ON}$	-	-	60	Ohm	Between pin XTALCAP and pin XGND SFR bit FSKSWITCH = 1_B SFR RFENC.TXDD=1
FSK Switch OFF resistance	$R_{Switch,OFF}$	100	-	-	kOhm	Between pin XTALCAP and pin XGND SFR bit FSKSWITCH = 0_B SFR RFENC.TXDD=1
FSK Switch OFF capacitance	$C_{Switch,OFF}$	3.2	3.5	3.8	pF	Between pin XTALCAP and pin XGND SFR XTAL1 = $0x00_B$ SFR bit FSKSWITCH = 0_B SFR RFENC.TXDD=1

3.9 12MHz RC HF Oscillator

Table 12: 12MHz RC HF oscillator specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Operating frequency	$f_{RC,HF}$	11.04	12.00	12.96	MHz	-

3.10 2kHz RC LP Oscillator

Table 13: 2kHz RC LP oscillator specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Operating frequency	$f_{RC,LP}$	1.3	2	2.7	kHz	V= 3.0 V, T= 25°C
Frequency drift	$df_{RC,LP}$	-7	-	7	%	-

3.11 Interval Timer & LF On/Off Timer

Table 14: Interval Timer & LF On/Off Timer specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Interval Timer Precounter calibration error	df_{ITP}	-0.083	-	0	%/Hz	Error is dependent upon Interval Timer time base specified to “Interval Timer Calibration” ROM Library function. This error does not include reference clock (XTAL or 12 MHz RC oscillator) and 2 kHz RC LP oscillator drift errors
LF On/Off Timer calibration error “On” Time	df_{LFON}	-1.64	-	4.92	%	Error is assumes usage of “Interval Timer Calibration” ROM Library function. This error does not include reference clock (XTAL or 12 MHz RC oscillator) and 2 kHz RC LP oscillator drift errors
LF On/Off Timer calibration error “Off” Time	df_{LFOFF}	-1.64	-	0	%	Error is assumes usage of “Interval Timer Calibration” ROM Library function. This error does not include reference clock (XTAL or 12 MHz RC oscillator) and 2 kHz RC LP oscillator drift errors

3.12 Power On Reset/Brown Out Reset

Table 15: Power On Reset/Brown Out Reset specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Power On Reset level	V_{POR}	0.2	0.4	1.7	V	Min. supply voltage level measured at Pin V_{REG} for a valid logic LOW at Power On Reset circuit
Power On Reset release level	V_{THR}	1.7	-	1.8	V	Measured at Pin V_{REG}
Power On reset time	t_{POR}	0.25	-	10	ms	
Brown Out detect level in RUN state	$V_{RUN,BRD}$	1.7	-	1.8	V	Measured at Pin V_{REG}
Brown Out detect level in POWERDOWN and THERMAL SHUTDOWN	$V_{PD,BRD}$	0.7	-	1.7	V	Measured at Pin V_{REG}
Mode selection time	T_{mode}	-	-	2.5	ms	-
Minimum detectable Brown Out glitch in RUN state	$t_{Brownout,RUN}$	-	-	1	µs	-
Minimum detectable Brown Out glitch in POWERDOWN and THERMAL SHUTDOWN state	$t_{Brownout,PD}$	-	-	100	µs	-

3.13 Voltage Regulator

Table 16: Voltage Regulator specifications [1]

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Regulated output voltage in RUN state	V_{REG}	1.9	2.1	2.4	V	V= 2.1 V - 3.6 V
Regulated output voltage at low battery in RUN state	$V_{REG,Low}$	1.8	-	2.1	V	V= 1.9 V - 2.1 V
Regulated output voltage in Programming mode	V_{REG}	2.3	2.5	2.75	V	V= 2.5 V - 3.6 V
Regulated output voltage in POWERDOWN and THERMAL SHUTDOWN	$V_{REG,PD}$	1.7	-	2.5	V	-
External Capacitance at Vreg Pin	C_{VREG}	60	100	-	nF	Maximum ESR 15 Ohm

[1] The voltage regulator is designed to supply only the internal blocks of the SP372 and not designed to drive any external circuitry, thus only the decoupling cap is allowed to be connected to pin Vreg. A 100nF decoupling cap with an maximum ESR of 15 Ohm is recommended for proper operation.

3.14 VMIN Detector

Table 17: VMIN Detector specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Low battery threshold warning level	TH_{LBAT}	2.0	2.1	2.2	V	Used by ROM Library functions only

3.15 FLASH Memory

Table 18: FLASH memory specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Erase/Program temperature	T_{FL}	0	-	60	°C	-
Erase/Program supply voltage	V_{bat3}	2.5	-	3.6	V	-
Endurance	En_{Flash}	100		-	cycles	Programming/erase cycles per wordline
Erase time	t_{Erase}	-	102	-	ms	Min/max can be derived by adding the tolerance and drift of the 12 MHz RC HF Osc.
Write time per FLASH line	$t_{Program}$	-	2.2	-	ms	FLASH line = 32 Byte min/max can be derived by adding the tolerance and drift of the 12 MHz RC HF Osc.

3.16 TMAX Detector

Table 19: TMAX detector specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
THERMAL SHUTDOWN release temperature	$T_{TMAX,Release}$	115.5	-	-	°C	Used by “ThermalShutdown” ROM Library function only. The TMAX enable temperature is verified to be above the release temperature
THERMAL SHUTDOWN enable temperature	$T_{TMAX, Enable}$	117	-	125	°C	

3.17 Watchdog Timer

Table 20: Watchdog timer specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Watchdog timeout	$t_{Watchdog}$	0.6	1	1.7	s	Min/max is derived by considering the tolerance and drift of the 2 kHz RC LP Osc.

3.18 Digital I/O Pins

Table 21: Digital I/O pins specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Input LOW voltage	V_{IL}	-0.2	-	0.4	V	-
Input HIGH voltage	V_{IH}	VBat - 0.4	-	VBat + 0.2	V	-
Output LOW voltage	V_{OL}	-	-	0.5	V	IOL= 1.6 mA
Output HIGH voltage	V_{OH}	VBat - 0.5	-	-	V	IOH= -1.6 mA
Output transition time	$t_{HL,\ LH}$	-	-	30	ns	20 pF load, 10% ... 90%
Parasitic capacitance	C_{pad}	-	-	5	pF	-
Internal pullup/ pulldown resistor	$R_{up/down}$	35	50	75	kOhm	Pin PP0, PP1
	$R_{up/down}$	175	250	335	kOhm	Pin PP2

3.19 I²C Interface

Table 22: I²C interface specifications

Parameter	Symbol	Min	Typ	Max	Units	Conditions
I²C bitrate	DR_{I2C}	8	-	400	kbit/s	-

4 Mechanical Specifications

4.1 Physical Dimensions and Laser Marking of Sensor Packages without Tube Connection

The SP400 sensor package is a proven 14 pin SOIC package, easily handled by automated production lines. [1]

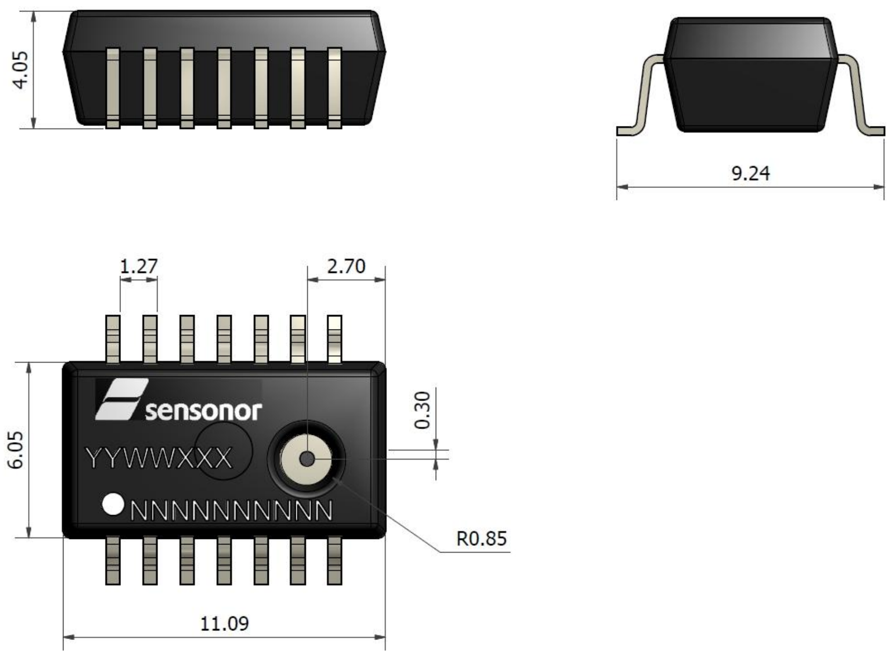

Figure 19: Physical dimensions and laser marking of sensor packages without tube connection

The variables of the laser marking of Figure 19 and Figure 20 have the following meaning:

YYWWXXX : Lot number
NNNNNNNNNN: Product name
O: Pin 1 marking

[1] Dimensions do not include mold flash, protrusions or gate burrs (this do not exceed 0.15mm per side), nor inter-lead flash or protrusions (this do not exceed 0.25mm per side)

4.2 Physical Dimensions and Laser Marking of Sensor Packages with Tube Connections (for Sensors with the Letter ‘T’ Included in the Product Name)

The SP400 models which includes the letter ‘T’ in the product name feature a tube connection. The tube connection is designed to fit 3.0mm hoses. Figure 20 shows the physical dimensions of the sensors with tube connections.

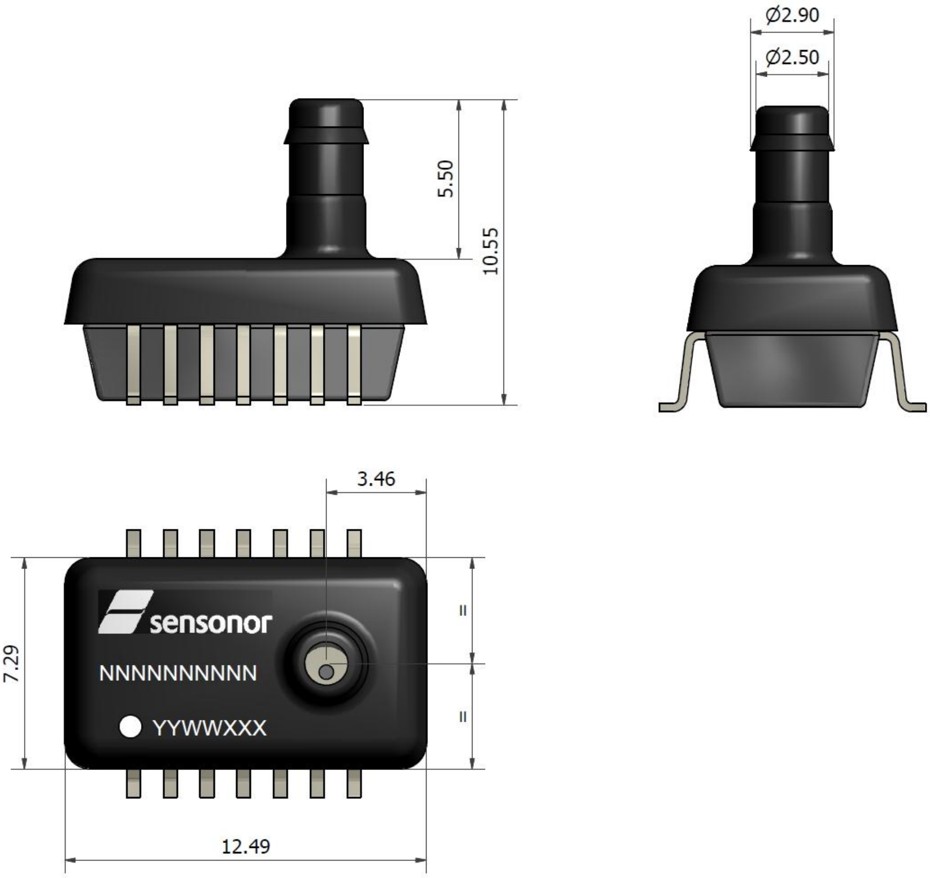

Figure 20: Physical dimensions and laser marking of sensor packages with tube connections (for sensors with the letter ‘T’ included in the product name)

4.3 Pin Out

Table 23: SP400 pin out description

Pin	Name	Type	Function
1	PP0	Digital I/O	GPIO PP0/I²C Clock/OpMode0
2	PP1	Digital I/O	GPIO PP1/I²C Data/OpMode1
3	PP2	Digital I/O	GPIO PP2/TxData
4	PA	Analog	RF Transmitter Output
5	PGND	Supply	RF Transmitter Ground
6	VDD	Supply	Supply Voltage
7	GND	Supply	Ground
8	GND	Supply	Ground
9	VREG	Supply	Voltage regulator output
10	LF	Analog	Differential LF Receiver Input 1
11	XLF	Analog	Differential LF Receiver Input 2
12	XGND	Supply	Crystal Oscillator Ground
13	XTAL	Analog	Crystal Oscillator Input
14	XTALCAP	Analog	Crystal Oscillator Load Capacitance

5 Referred Documents

Table 24: Referred Documents

Ref	Doc	Description
[1]	DOK356	User manual SP400
[2]	TS1549	ROM library guide SP400