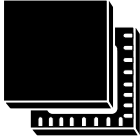


## Compact automotive NFC reader for CCC digital key car access



VFQFPN24  
(4 x 4 mm)

### Product status

ST25R501

### Features

AEC-Q100 qualified



#### Operating modes

- Reader/writer

#### RF communication - reader/writer

- NFC-A/ISO/IEC 14443A up to 848 kbit/s
- NFC-B/ISO/IEC 14443B up to 848 kbit/s
- NFC-V/ISO/IEC 15693 up to 212 kbit/s
- NFC-F/FeliCa™ up to 424 kbit/s
- Low-level modes to implement MIFARE Classic®-compliant and protocols (Kovio BC, CTS, B')

#### Key characteristics

- NFC Forum reader device
- CCC digital key reader
- Low-power inductive card detection
- I/Q demodulator with baseband channel summation
- Passive P2P mode (Initiator)
- Dynamic power output (DPO) controls the field strength to stay within given limits (software feature)
- Active wave shaping (AWS) reduces both overshoots and undershoots
- Noise suppression receiver (NSR) allows reception in a noisy environment
- Serial peripheral interface (SPI) up to 10 Mbit/s
- Possibility to drive one differential or two independent single-ended antennas

#### Electrical characteristics

- Wide supply voltage range: 2.7 V to 5.5 V
- Wide peripheral communication supply range: 1.65 V to 5.5 V
- Wide ambient temperature range: -40 °C to +125 °C
- Quartz oscillator capable of operating with 27.12 MHz crystal with fast startup

## Application

The ST25R501 is suitable for a wide range of applications, among them:

- Automotive access control
- Center console applications including digital key
- CCC digital key
- Automotive infrastructure application

## 1 Description

The ST25R501 is a very small and powerful automotive grade high-performance CCC DK NFC reader device housed in a QFN 4x4 mm wettable flank package. Designed for CCC (Car Connectivity Consortium®) digital key applications, the device enables fast product development for car access/start applications in areas like door handles or center consoles.

Being very robust and noise tolerant while at the same time reducing electromagnetic emission, the device works even under harsh conditions, supporting a smoother certification process for electromagnetic immunity and electromagnetic emission.

The device includes an advanced analog front end (AFE) and a highly integrated data framing system for NFC-A/B (ISO/IEC 14443A/B) reader, including higher bit rates up to 848 kbps, NFC-F (FeliCa™) reader and NFC-V (ISO/IEC 15693) reader up to 212 kbps.

The device features high RF power with dynamic power output to directly drive antennas at high efficiency, achieving large interaction distances even with small antenna sizes common indoor handles.

The device includes additional features, making it incomparable for low-power applications. It offers low-power card detection by performing a measurement of the I and Q channel, which represent the real and imaginary parts of the antenna signal.

It meets the most demanding requirements put in place by car and phone OEMs, delivering market-leading performance and ensuring a superior user experience.

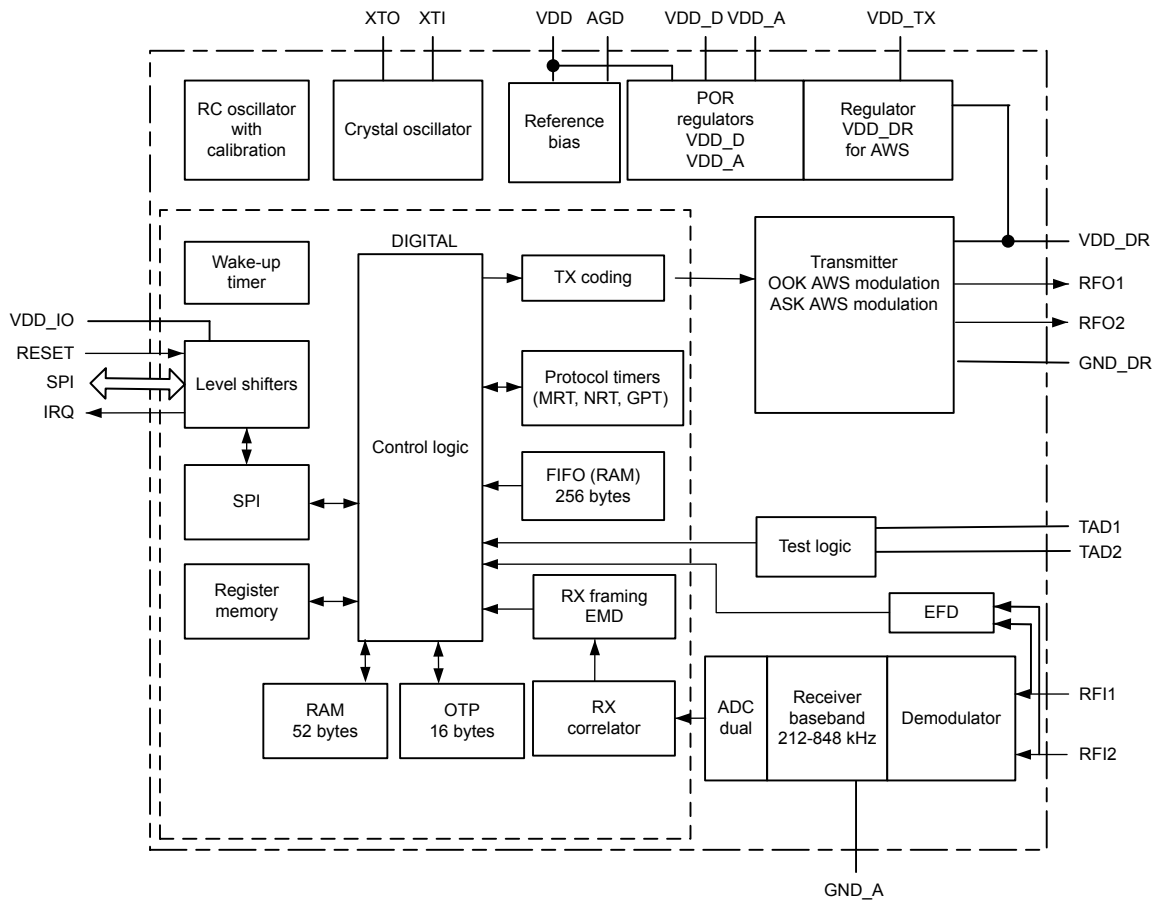
It is designed to operate from a wide power supply range (from 2.7 V to 5.5 V), ambient temperature range from -40°C to +125°C, and a wide peripheral I/O voltage range (from 1.65 V to 5.5 V). Due to this combination of high RF output power, low-power modes, wide supply range, and AEC-Q100 grade 1 qualification, the device is perfectly suited for automotive applications.

## 2 Functional overview

### 2.1 Block diagram

The block diagram is shown in the following figure.

Figure 1. ST25R501 block diagram



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### 2.1.1 Transmitter

The transmitter incorporates the drivers, which drive the external antenna through pins RFO1 and RFO2. Both single-ended and differential antenna configurations are supported. The transmitter block also generates the OOK or AM modulation of the transmitted RF signal during [Reader operation](#).

### 2.1.2 Receiver

The receiver detects card modulation superimposed on the 13.56 MHz carrier signal. The receiver chain incorporates several features that enable reliable operation in challenging and noisy conditions.

The receiver is connected to the antenna via the pins RF11 and RF12. The output of the receiver is connected to the framing block that decodes the demodulated and digitized subcarrier signal.

### 2.1.3 Quartz crystal oscillator

The quartz crystal oscillator operates with 27.12 MHz crystals. At oscillator startup, the transconductance of the oscillator is increased to achieve a fast startup. Since the startup time varies with crystal type, temperature, and other parameters, the oscillator amplitude is monitored, and an I\_osc interrupt is sent when stable oscillator operation is reached.

### 2.1.4 Power supply regulators

Integrated power supply regulators ensure a high-power supply rejection ratio for the complete system. Different voltage regulators supply separate blocks to decouple from noise sources.

### 2.1.5 POR and bias

This block provides bias currents and reference voltages to all other blocks. It also incorporates a power on reset (POR) circuit, which provides a reset at power-up and at low supply levels.

### 2.1.6 RC oscillator and wake-up timer

The RC oscillator allows the wake-up timer to run and periodically trigger a measurement of the surroundings for low-power card detection mode.

### 2.1.7 Tx coding

This block encodes the transmit frames according to the selected RF communication mode and bit rate. It generates the start of frame (SOF), end of frame (EOF), cyclic redundancy check (CRC), and parity bits automatically. The data to be transmitted is taken from the FIFO.

### 2.1.8 Rx framing

This block decodes received frames according to the selected RF communication mode and bitrate. The SOF, EOF, CRC, and parity bits are automatically checked and removed by this block, except for the CRC. The received data is then placed in the first-in first-out (FIFO) buffer.

### 2.1.9 Control logic

This block drives all activity of the device based on the commands received through the serial interface and the configurations present on the registers.

### 2.1.10 FIFO

A 256-byte FIFO is available for exchanging data through the transmitter and receiver. Depending on the mode, it contains either data that has been received or must be transmitted.

### 2.1.11 SPI

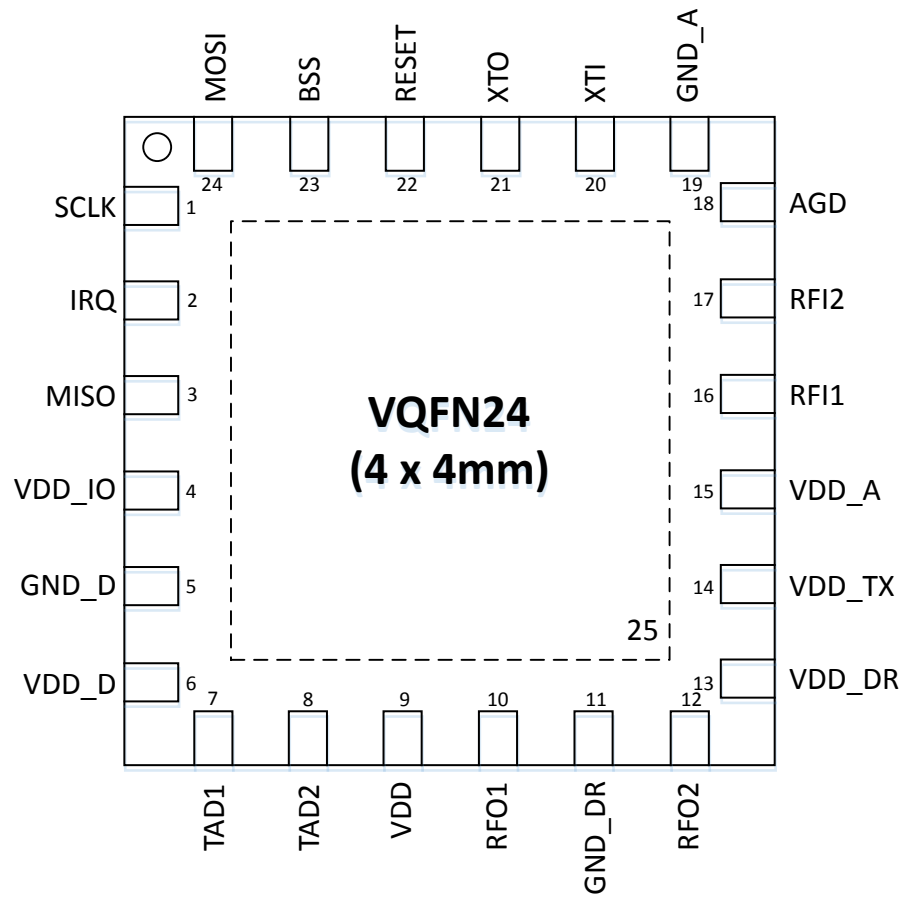
A 4-wire SPI is available for communication between the device and the host.

### 2.1.12 External field detector (EFD)

The external field detector signals the presence of an external NFC field during NFC field on direct command.

### 3 Pin and signal description

Figure 2. VFQFPN24 pinout (top view)



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**Table 1. VFQFPN24 pin assignment**

Package	Pin name	Type <sup>(1)</sup>	Description
VFQFPN24			
1	SCLK	DI	Serial peripheral interface clock
2	IRQ	DO	Interrupt request output
3	MISO	DO_T	Serial peripheral interface data output
4	VDD_IO	S	External peripheral communication supply
5	GND_D	S	Digital ground: it must be connected to the thermal pad via the shortest possible connection.
6	VDD_D	AOS	Regulated supply for digital block
7	TAD1	ADIO	Analog/Digital test pin. When not being used, it must be kept not connected.
8	TAD2	ADIO	Analog/Digital test pin. When not being used, it must be kept not connected.
9	VDD	S	External main positive supply
10	RFO1	AO	Antenna driver output
11	GND_DR	S	Antenna driver ground, driver V <sub>SS</sub> . It must be connected to thermal pad via the shortest possible connection.
12	RFO2	AO	Antenna driver output
13	VDD_DR	AOS	Regulated supply for antenna driver
14	VDD_TX	S	External main positive supply for driver
15	VDD_A	AOS	Regulated supply for analog
16	RFI1	AI	Receiver input
17	RFI2	AI	Receiver input
18	AGD	AIO	Analog reference voltage
19	GND_A	S	Analog ground: it must be connected to the thermal pad via the shortest possible connection.
20	XTI	AI	Crystal oscillator input
21	XTO	AO	Crystal oscillator output
22	RESET	DI	Reset input
23	BSS	DI	Serial peripheral interface enable (active low)
24	MOSI	DI	Serial peripheral interface data input
25	VSS	S	Exposed pad, ground, die substrate potential, via exposed die pad

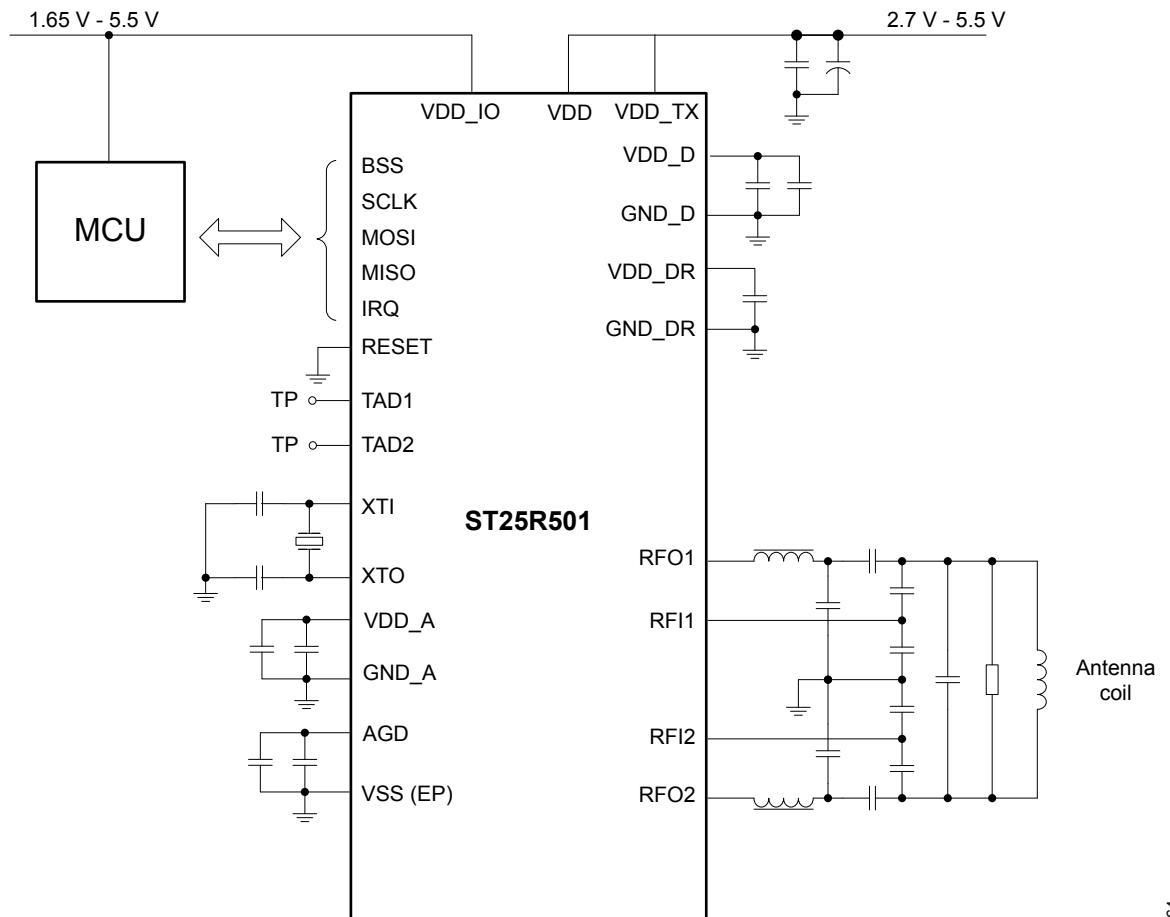
1. S: power supply pin, AIO: analog I/O, AI: analog input, AO: analog output, ADIO: analog/digital input/output, AOS: analog output/supply input, DI: digital input, DO: digital output, DO\_T: digital output/tri-state.

## 4 Device description

### 4.1 System diagram

The minimum system configuration is shown below for a differential antenna configuration.

**Figure 3. Minimum system configuration**



D177964



## 5 Application information

### 5.1 Operation modes

The device supports four operating modes.

#### 5.1.1 Reset mode (RESET)

When the device is supplied with VDD, VDD\_TX, and VDD\_IO, and the RESET pin is high, the device is in reset mode.

All blocks are deactivated, no clock is present, and current consumption is minimized.

#### 5.1.2 Power-down mode (PD)

If the RESET pin is low at power-up or after the RESET pin state changes from high to low, the device enters power-down mode. In this mode, the AFE static power consumption is very low, but SPI communication is possible, in addition to register access to those in the PD domain.

The following blocks are active in PD mode:

- VDD\_D regulator (1 V) in low-power mode
- Registers in the PD domain
- SPI block and IRQ logic

#### 5.1.3 Wake-up mode (WU)

Wake-up mode is controlled through the wu\_en bit. In this mode, the device senses changes in antenna properties at regular time intervals and triggers an IRQ if a change is detected.

The following blocks are active in WU mode:

- VDD\_D regulator (1 V) in low-power mode
- Registers in PD domain
- RC oscillator
- WU timer
- SPI block and IRQ logic

#### 5.1.4 Ready mode (RD)

Ready mode is controlled by the en bit. In this mode the regulators and crystal oscillator are enabled, and the device is ready to transmit or receive.

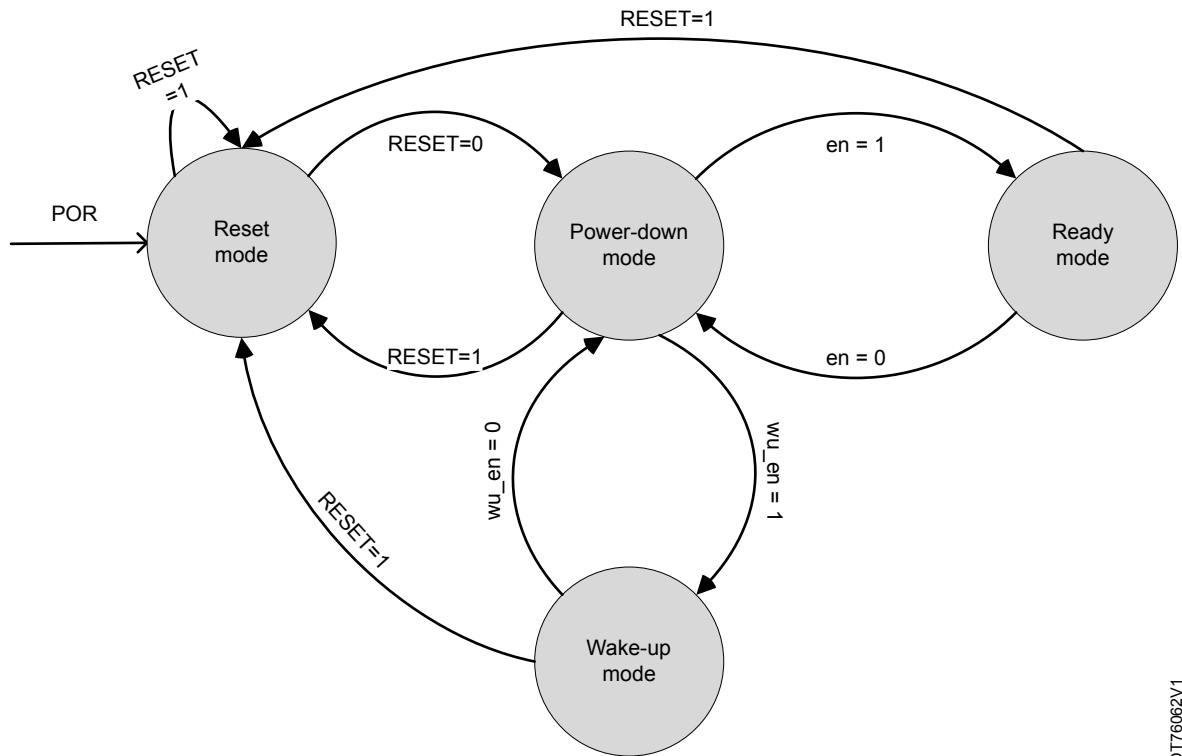
The following blocks are active in RD mode:

- VDD\_D regulator (1 V) in normal power mode
- All registers (both in PD and RD domain)
- Main logic
- VDD\_A and VDD\_DR regulators
- Crystal oscillator
- SPI block and IRQ logic

When RD mode is reached, the device issues an l\_osc interrupt.

The following diagram shows the transition from one state to another:

Figure 4. Transition from one state to another



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## 5.2 Power-on sequence

Once powered and once the RESET pin is low, the device enters the PD mode. The content of all registers is set to its default state. The device can be set into any other operation mode except RESET by changing the configuration in the [Operation register](#).

Changing from PD mode to RD mode and preparing for communication comprises:

- Apply the appropriate configuration on registers: operation and general configuration registers
- Set en = 1 in the operation register and wait for the device to get ready with the oscillator stabilized (notified by the l\_osc interrupt and osc\_ok status)
- The adjust regulator direct command should be executed when the carrier is enabled. When coming from RD mode with disabled VDD\_DR and disabled field, execute the following:
  - Set vdddr\_en to 1
  - Wait at least 10 μs
  - Set tx\_en and rx\_en to 1
  - Execute adjust regulator direct command
- Additionally, the direct command calibrate RC must be issued.

Once the above-mentioned points are done, the device is ready for communication.

## 5.3 Transmitter

The transmitter contains two identical push-pull driver blocks connected to the RFO1 and RFO2 pins. These drivers are differentially driving the external antenna LC tank via the antenna matching network. It is also possible to operate only one of the two drivers by setting the single bit in the [General configuration register](#) and selecting which RFO/RFI to be used on rfo2 bit.

### 5.3.1 Output resistance

Each driver is composed of eight segments having binary weighted output resistance. The MSB segment typical ON resistance is  $2 \times RRFO$ . When all segments are turned on, the output resistance is defined by  $RRFO$ . Usually, all segments are turned on to define the normal transmission (unmodulated) level. It is also possible to switch off certain segments when driving the unmodulated level to drive the circuitry with a higher impedance driver.

The `d_res` bits in the [Tx driver configuration register](#) define the resistance during the normal transmission. The default setting is the minimum available resistance.

When using the single driver mode, the number of external components and therefore the cost of the antenna LC tank components is halved, but also the output power is reduced. In single mode it is possible to connect two antenna LC tanks to the two RFO outputs and multiplex between them by controlling the `rfo2` bit in the [General configuration register](#).

To transmit data, the transmitter output level needs to be modulated. AM and OOK modulation principles are supported. The type of modulation is defined by setting the `tr_am` bit in the [Tx modulation register 1](#).

### 5.3.2 Driver Tx modulation

During the OOK modulation (for example, NFC-A or NFC-V), the transmitter drivers stop driving the carrier frequency. Therefore, the amplitude of the antenna LC tank oscillation decays. The time constant of the decay is defined by the LC tank Q factor.

AM modulation (for example, NFC-B) is done via a reduction of the `VDD_DR` regulator-regulated voltage that supplies the drivers during the modulation state.

The AM modulation level is set by the `am_mod` bits in the [Tx modulation register 1](#).

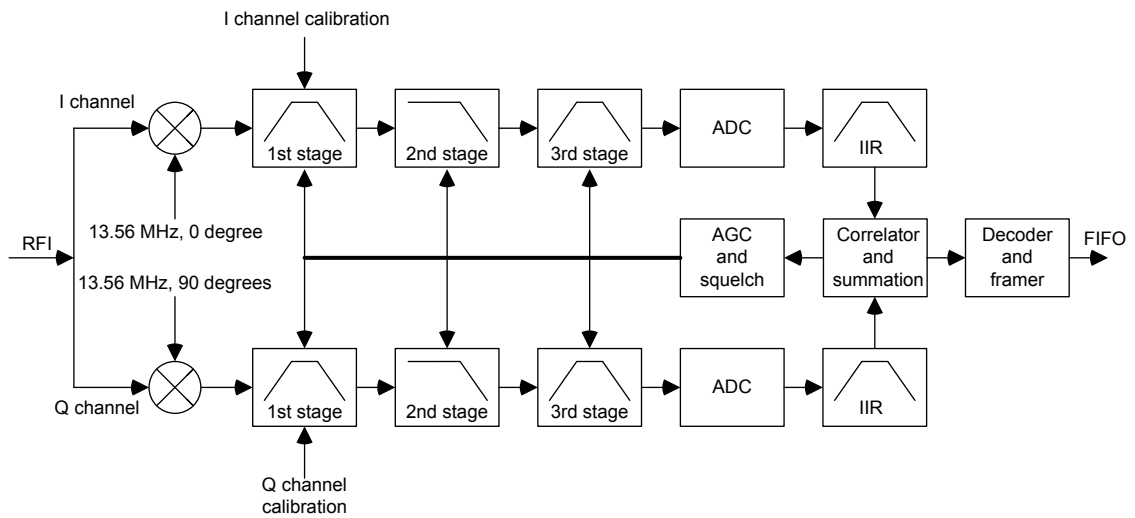
AM modulation must be enabled and the modulation index must be set correctly for the following protocols:

- NFC-B
- FeliCa

Depending on the applicable standard, the modulation index is set in a range between 8% and 97% in the [Tx modulation register 1](#). The modulation scheme, AM modulation or OOK modulation, can be selected by the `tr_am` bit in the [Tx protocol register 1](#).

## 5.4 Receiver

The receiver performs the demodulation of the tag subcarrier modulation that is superimposed on the 13.56 MHz carrier frequency. It performs an I/Q demodulation, amplification, band-pass filtering, and digitization of the subcarrier signals. It also performs RSSI measurements, automatic gain control (AGC), and squelch functions. The reception chain has two separate channels for the I and Q demodulation. I and Q channels result in mixing the 13.56 MHz carrier signal coming from the antenna with a local 13.56 MHz clock generated by the crystal oscillator. The I and Q mixing clock are 90 degrees phase-shifted. The reception framing is done automatically by the receiver logic. The receiver is switched on when the `rx_en` bit in the [Operation register](#) is set to 1.

**Figure 5. Receiver block diagram**


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#### 5.4.1 Demodulation stage

The I/Q demodulation made up of two mixer circuits, each driven by local oscillator signals that are phase-shifted by 90° relative to each other and derived from the crystal oscillator. The outputs of the two mixers are connected to two equal baseband reception chains and to the decoding logic.

#### 5.4.2 Filter and gain stages

The receiver chain has band pass filtering characteristics. This band pass filter consists of three stages. Each stage has a static gain and an AGC controlled attenuation. The filtering is optimized to pass the subcarrier frequencies while rejecting the carrier frequency, low frequency noise, and DC component. The first and third stages have a selectable first order high pass filter and a fixed first order low pass filter. The high pass filter characteristics of the first and third stages can be controlled via the `hpf_ctrl` bits in the [Rx analog settings register 1](#). The low pass filter characteristics are fixed for both stages. The second stage consists of a second order fixed low pass filter.

The maximum gain of the first and the second stage is 20 dB and can be reduced in 3 dB steps by the AGC. The gain of the third stage is 6 dB if `gain_boost` is enabled by setting the `gain_boost` bit to 1 in the [Rx analog settings register 1](#), which increases the max gain by an additional 3 dB. The total gain of the filter and gain stage is 49 dB including the gain boost. A default gain reduction for the AGC can be configured via the `afe_gain_rw` bits in the [Rx analog settings register 2](#).

The same filter blocks can also be used for other operation modes. In all modes, the starting gain is set through the corresponding gain reduction. The gain in wake-up mode can be configured by the `afe_gain_td` in [Rx analog settings register 2](#).

The chip features a secondary filter stage after the analog to digital converter. It consists of an infinite impulse response (IIR) low pass filter and an IIR high pass filter. Its coefficient can be configured in the [Rx digital settings register 1](#) by setting the `lpf_coef` and `hpf_coef` bits.

#### 5.4.3 Analog-to-digital converter

The analog-to-digital converter digitizes the signal coming from the filter and the gain stages. In wake-up mode, the ADC output is stored in the [I-channel WU ADC display register](#) and the [Q-channel WU ADC display register](#).

#### 5.4.4 Correlator system

The correlation system is designed to maximize the receiver sensitivity and the selectivity to the subcarrier frequencies found in a tag's reply. To achieve this, the subcarrier signal coming from the tag is compared to a local subcarrier clock. The best signal to noise ratio is achieved if these two signals match. I and Q channel signals are combined via the summation block to remove the need for a channel selection while simultaneously improving the performance. The same topology is used to achieve NFC-A and NFC-B 106-848 kbit/s, FeliCa 212 kbit/s and 424 kbit/s, and NFC-V single subcarrier 26 kbit/s, 52 kbit/s 106 kbit/s and 212 kbit/s demodulation.

The correlator has two main modes of operation - Manchester and BPSK (binary phase shift keying). Manchester refers to the Manchester code subcarrier modulation used in NFC-A 106 kbit/s and NFC-V single subcarrier protocols. BPSK refers to the subcarrier modulation used in the remaining protocols and data rates. In BPSK mode, the local subcarrier clock follows the phase of the input subcarrier signal. The bit information is coded into the phase of the input subcarrier, so a comparison between the input phase and clock phase returns the bit data. In Manchester mode, the local subcarrier clock does not follow the phase of the input subcarrier signal as the bit information is coded into subcarrier presence (amplitude). The correlator comprises an additional circuitry, used by both modes, for symbol recognition and subcarrier presence detection.

The `iir_coef1` and `iir_coef2` bits in the [Correlator settings register 2](#) adjust the correlator internal filter.

#### 5.4.5 Automatic gain control

The automatic gain control configures the gain reduction in the filter and gain stage to input an optimal signal into the correlator. It can be enabled in the [Rx digital settings register 1](#) by setting the `agc_en` bit to 1. As long as the input signal is larger than the threshold defined by the `agc_thr` bits in the [Correlator settings register 2](#), the gain is reduced in 3 dB steps. The AGC is only active at the start of reception. The result of the gain reduction after the AGC is complete can be read in the `afe_gain` bits of the [Analog display register 2](#). It displays the actual gain reduction during the last reception.

#### 5.4.6 Squelch

The squelch is reducing the receiver gain based on the noise level. Due to the high starting gain of the receiver, noise could be decoded and corrupt the communication between reader and card. The squelch enables the reception in noisy environments if the signal level is above the noise level.

Automatic squelch is enabled by the `sq_en` option bit in the [Mask receive timer configuration register 1](#). It is activated automatically after the end of the transmission. The delay can be configured in the [Mask receive timer configuration register 1](#) by setting the `sq_del` bits. The squelch is terminated when the mask receive timer (MRT) reaches the value defined in the [Mask receive timer configuration register 2](#) or the squelch timer defined in the [Squelch timer configuration register](#) is expired.

This mode is primarily intended to suppress the noise generated by the tag processing before the tag response (covered by MRT) and environmental noise.

After the squelch time is expired, the determined gain setting is applied for the next reception.

The gain setting acquired by the squelch is cleared by sending a direct command clear Rx gain.

If the card response starts during the squelch, the gain is reduced to ignore the modulation. Such scenarios are happening, for example, during the ISO10373-6 EMD recovery tests.

#### 5.4.7 RSSI

The RSSI is an indication of the estimated signal level at the input of the IC. It is used for diagnostic and observational purposes. The RSSI is calculated from the amplitude of the signal at the input of the correlator. The measurements take place in intervals that start when the receiver is enabled and end when the receiver is disabled. The information about the I and Q RSSI measurements is reset only when the receiver is opened for a valid reception (when issuing the `rx_start` interrupt) or when a direct command to clear the Rx gain is issued. The RSSI information can be read after a tag reply without any timing constraints. The result takes the AGC gain reduction into account. The result of the measurement can be read from the [RSSI display register 1](#) and the [RSSI display register 2](#).

#### 5.4.8 Digitizing stage

The digitizing stage produces a digital representation of the subcarrier signal from the receiver. This digital signal is processed by the receiver framing logic.

#### 5.4.9 ADC to RAM recording

The envelope of the carrier signal can be sampled and stored in the RAM. This feature can be used to measure the rising and falling edge of the modulation signal in reader operation. The feature can be enabled by setting the trigger to falling, rising, or both edges using the `adc_ce` bit in the test register ADC to RAM. The sampling rate can be selected by setting the bit `adc_ce_rate` to 13.56 MHz or 6.78 MHz, which allows recording 3.83  $\mu$ s or 7.67  $\mu$ s.

The input source can be selected by setting the bit `adc_ce_src` to ADC or correlator input. The input source ADC returns a 6-bit result which is saturated to a value of 63. The input source correlator returns an 8-bit result which is saturated to a value of 250. The input gain can be configured by the bits `afe_gain_ce` in the [Rx analog settings register 3](#).

## 5.5 RC oscillator

The RC oscillator is used to support the low-power WU mode and it runs at a nominal frequency of 26.48 kHz. It is enabled when the device enters the WU mode, and disabled when the device goes to PD or RD mode. Additionally, it may be enabled by executing the direct command to start the wake-up timer.

## 5.6 Quartz crystal oscillator

The quartz crystal oscillator operates at 27.12 MHz. This operation is enabled when the option bit `en` is set to 1. An `I_osc` interrupt is sent to inform the microcontroller when the oscillator amplitude is sufficiently high, meaning that the frequency is stable. The oscillator is based on an inverter stage supplied by a controlled current source. A feedback loop controls the bias current to regulate the amplitude on XTI pin to approximately  $1 V_{PP}$ .

The amplitude of the XTI signal depends on the parameters of the crystal. Depending on these parameters, the XTI signal can be greater than  $1 V_{PP}$  at the lowest possible drive level. It must be ensured that `VOSC_PP` in the operating conditions table is not exceeded.

Division by two ensures that the 13.56 MHz signal has a duty cycle of 50%.

The oscillator is additionally enabled and the transition to RD mode is triggered when the wake-up timer expires and a wake-up measurement is performed.

The status of the oscillator can be observed by checking the bit `osc_ok`. This bit is set to one when the oscillator frequency is stable.

## 5.7 Timers

The ST25R501 contains several timers, which eliminate the need to run counters in the controller, thus reducing the effort of the controller's code implementation and improve the portability of the code to different controllers.

Every timer has one or more associated configuration registers in which the timeout duration and different operating modes are defined. These configuration registers must be set while the corresponding timer is not running. Any modification of timer configuration while the timer is active may result in unpredictable behavior. All timers are stopped by the direct command `stop all activities`.

### 5.7.1 Mask receive timer (MRT)

In reader operation, this timer blocks the receiver and the reception process in the framing logic by keeping the `rx_on` signal low after the end of the Tx during the time the tag reply is not expected. While the mask receive timer is running, the squelch is automatically turned on when enabled. The MRT does not produce an IRQ.

The MRT timeout is configured in the [Mask receive timer configuration register 2](#) and is automatically started at the end of the data transmission (at the end of EOF). The MRT can be triggered by the start mask receive timer direct command. In this case, the squelch is enabled according to the [Squelch timer configuration register](#).

### 5.7.2 No-response timer (NRT)

The purpose of this timer is to observe whether a response is detected during a configured time starting at the by end of the transmission. The `I_nre` flag in the [IRQ status register 2](#) is signaling an interrupt event resulting from this timer timeout. The NRT value is defined by writing the [NRT and GPT configuration register 2](#) and the [NRT and GPT configuration register 3](#). Operation options are defined by setting the `nrt_emv` and `nrt_step` bits in the [NRT and GPT configuration register 1](#). The NRT is automatically started at the end of the transmission. The `nrt_step` bit configures the time step of the no-response timer. Two steps are available,  $64/f_C$  (4.72  $\mu$ s) and  $4096/f_C$  covering, respectively, the range up to 309 ms and up to 19.8 s. The `nrt_emv` bit controls the timer operation mode.

When this bit is set to 0 (default mode), the `I_nre` interrupt is produced if the NRT expires before a start of a response is detected. The `rx_on` bit is set low to disable the receiver. In the opposite case, when the start of a tag reply is detected before the timeout, the timer is stopped, and no IRQ is produced.

When this bit is set to 1, the timer unconditionally produces an IRQ when it expires. This means that the IRQ is independent from whether or not a tag reply was detected. When a tag reply is processed during a timeout, no other action is taken and the reply is normally received. In the opposite case, when no tag response is processed, the receiver is disabled.

The NRT can also be started using a start no-response timer direct command. The purpose of this command is to extend the no-response timer timeout beyond the range defined in the no-response timer control registers. If this command is sent while the timer is running, it is reset and restarted.

The NRT can be terminated using stop no-response timer or stop all activities direct command. The timer is terminated and no IRQ is sent. It is expected to be used in the nrt\_emv mode, when the incoming reception does not stop the no-response timer.

### 5.7.3 General-purpose timer (GPT)

The GPT value is defined by writing the [NRT and GPT configuration register 4](#) and the [NRT and GPT configuration register 5](#). It can be used to survey the duration of the reception process (triggered by the start of reception, after SOF) or to time out the PCD to PICC response time (triggered by the end of reception, after EOF). The trigger source can be configured through the gptc bit in the [NRT and GPT configuration register 1](#). The possible trigger configurations can be seen in [Table 49. General purpose timer trigger source](#).

The GP timer can also be started by sending the start general-purpose timer direct command. If this command is sent while the timer is running, it is reset and restarted.

### 5.7.4 Wake-up timer (WUT)

This timer is primarily used in the wake-up mode.

It can also be triggered by sending the start WUT direct command. When this command is sent, the RC oscillator, which is used as the clock source for the wake-up timer, is started. When the timer expires, an IRQ with the l\_wut flag is sent.

As the RC oscillator is the clock source for the WUT, it can run during PD mode. The other timers, which are based on the crystal oscillator, cannot be used in PD or WU mode.

Note: The tolerance of WUT is defined by the tolerance of the RC oscillator. During WU mode, a calibration mechanism can be enabled to compensate the RC inaccuracies, as detailed in [Section 5.8.5: Wake-up timer calibration](#).

## 5.8 Wake-up mode

Once in PD mode, the wu\_en bit sets the ST25R501 into wake-up mode (WU), which is used to perform low-power card detection. An integrated low-power 26.48 kHz RC oscillator and configurable wake-up timer (WUT) are used to trigger periodic measurements.

Usually, the presence of a card is detected by the RF/NFC polling. In this process, the reader field is periodically turned on, and the host checks whether a card is present using RF commands. This procedure consumes considerable energy since the reader emits a field for long periods before a command can be issued due to guard time fulfillment.

Low-power detection of card presence is performed by detecting a change in the reader environment, produced by an approaching detuning element. When a change is detected, an interrupt is sent to the host. The host can then perform the regular RF/NFC polling afterward.

In wake-up mode, the ST25R501 performs periodic measurements and sends an IRQ to the host when a difference to the configured reference value is detected.

The device monitors the I and Q channels to assess a variation in the antenna surroundings.

The latest measurement value is shown in i\_adc and q\_adc, and the current reference is defined on i\_ref and q\_ref. ADC values are provided in 8-bit signed values using two's complement representation. The delta/difference to the reference that triggers a wake-up interrupt is defined in i\_diff and q\_diff.

Besides periodic execution via the wake-up timer, the measurement and processing of the measured data can be triggered by the trigger wake-up event direct command. This mechanism allows synchronization with external events.

### 5.8.1 Card detection

The presence of a card close to the reader antenna coil produces a change of the antenna LC tank signal. The reader field activation time required to perform the measurement is extremely short, compared to the activation time required to send a protocol activation command.

The power level during the measurement can be lower than that during normal operation as the card does not have to be powered to produce a coupling effect. The emitted power can be configured by changing the RFO driver resistance.

An IRQ is sent when the difference between a measured value and reference value is larger than the configured delta/diff value. There are two possibilities how to define the reference value, controlled by the bit `iq_aaref`:

- The ST25R501 can automatically calculate the reference based on previous measurements (auto-averaging)
- The host determines the reference value and sets it on `i_ref` and `q_ref`

### 5.8.2 Automatic averaging

In case auto-averaging is enabled (`iq_aaref = 1`) the reference value is recalculated after every measurement. The last measurement value, the old reference value, and the weight are used in this calculation.

The following formula is used to calculate the new reference value:

$$\text{new\_reference} = \text{old\_reference} - (\text{old\_reference} - \text{measured\_value}) / \text{weight}$$

The `i_iirqm` and `q_iirqm` bits define whether a measurement that causes an interrupt is taken into account for the average value calculation.

The influence that the new measurement has over the reference can be configured by a weight defined in `i_aaw` and `q_aaw` bits.

### 5.8.3 Calibration

The wake-up mode has an additional calibration step that can be executed manually or automatically. The `skip_cal` and `skip_recal` bits control the automatic calibration behavior.

When starting the wake-up mode, if `skip_cal = 0`, a calibration step is performed automatically on the first WUT timeout.

While the wake-up mode is running and `skip_recal = 0`, if  $\text{reference} \pm \text{delta/diff}$  is larger than 63, a recalibration is performed.

### 5.8.4 Wake-up IRQ

The device allows configuring the conditions when a wake-up IRQ is sent to the host.

This behavior is defined by `i_tdi_en` and `q_tdi_en` bits and the following three conditions can be used:

- `I_wui/q` IRQ when the latest measurement is above the upper limit:  $i/q\_adc > i/q\_ref + i/q\_diff$
- `I_wui/q` IRQ when the latest measurement is in between the upper and lower limit:  $i/q\_ref - i/q\_diff \leq i/q\_adc \leq i/q\_ref + i/q\_diff$
- `I_wui/q` IRQ when the latest measurement is below the lower limit:  $i/q\_adc < i/q\_ref - i/q\_diff$

If the bits `i_tdi_en = 0`, the I channel is not used during WU, and the same applies for the Q channel when `q_tdi_en = 0`.

During WU mode the ST25R501 produces additional IRQs that may be masked, or used for diagnostics:

- `I_wut` IRQ when the WUT timer expires, indicating that the device temporarily enables itself in RD mode and performs a measurement
- `I_wutme` IRQ when the device has concluded the WU measurement event, and goes back to WU mode

### 5.8.5 Wake-up timer calibration

The WUT uses the RC oscillator as its clock source. The RC oscillator is process and temperature dependent, which may result in a deviated WU period from the target defined by the WUT bits. A wake-up timer duration of  $100 \text{ ms} \pm 5 \text{ ms}$  can only be guaranteed with a wake-up timer calibration.

In applications where an accurate WU period is required, a calibration mechanism can be enabled to minimize the RC variations. It is not recommended to use the wake-up timer calibration on a wake-up timer period of less than 100 ms. When the WU mode is started, and WUT calibration is enabled by setting `wut_cal = 1`, the wake-up timer is calibrated based on the crystal oscillator.

Therefore, the crystal oscillator is kept enabled for a certain calibration duration. The calibration is executed in wake-up mode whenever the wake-up timer expires and the chip transitions from PD to RD mode. A longer calibration duration results in increased accuracy of the WUT period.

The calibration duration of the WUT calibration step is defined by the `wut_cal_len` bits.

The below table shows the calibration time and the achieved target accuracy based on the selected `wut_cal_len`.



Wut_cal_len <1:0>	Calibration duration (ms)	Target accuracy (%)
0	0.781	3.33
1	1.562	1.67
2	3.125	0.83
3	6.248	0.43

As an example, using a `wut_cal_len = 0` and a wake-up timer period of 100 ms, the expected timer period is between 96.7 ms and 103.33 ms. Since this calibration is performed every time the wake-up timer expires, temperature and other effects are neglected. The calibration is based on the crystal quartz oscillator and is therefore dependent on its frequency. An accurate and stable oscillator frequency is mandatory for the calibration. The bit `rc_vdig_lp` can be used to increase the accuracy of the wake-up timer calibration. It should be used together with `wut_cal_len` setting  $\geq 2$ .

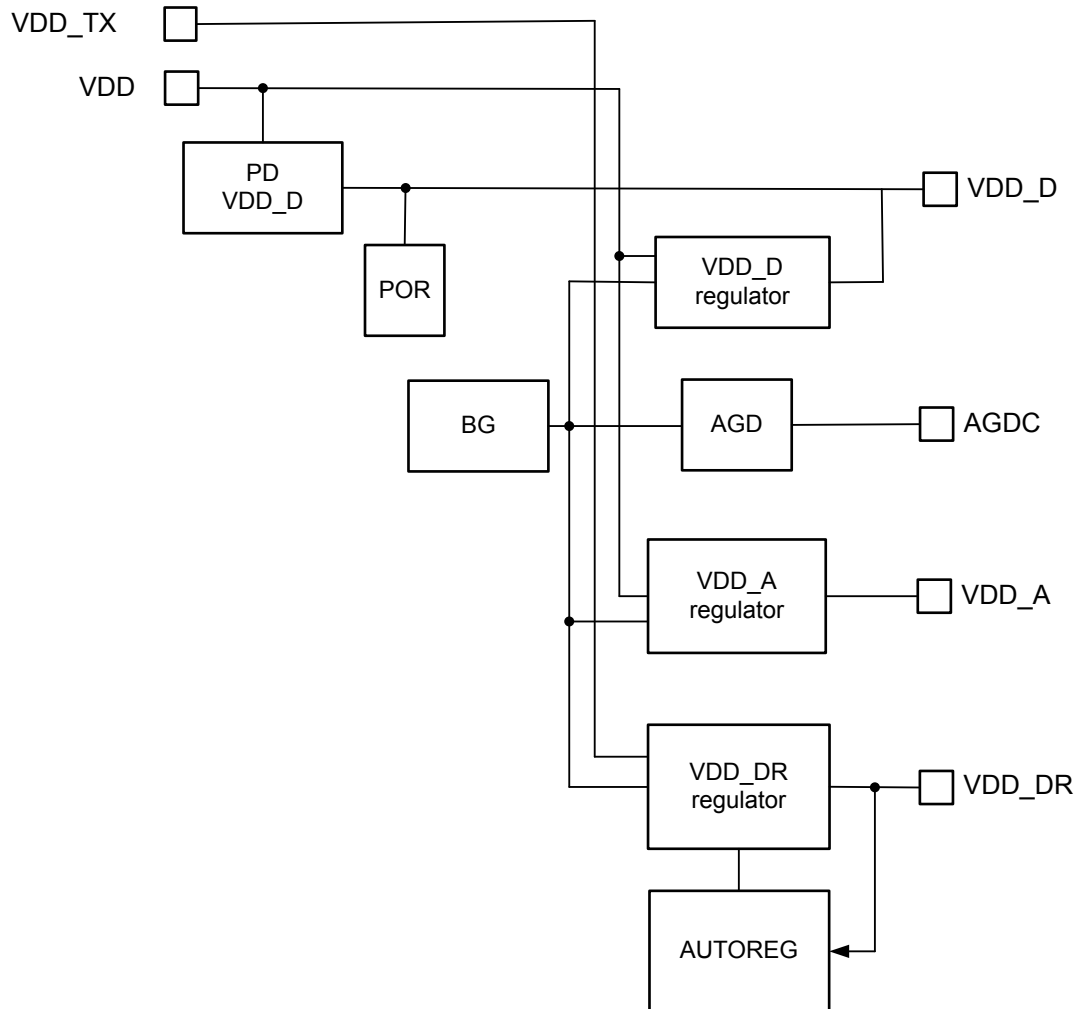
## 5.9 Power supply system

The ST25R501 features three positive supply pins, VDD, VDD\_TX and VDD\_IO:

- VDD is the main power supply pin. It supplies the ST25R501 blocks through two regulators (VDD\_A, VDD\_D)
- VDD\_TX is the transmitter supply pin. It supplies the transmitter via the VDD\_DR regulator. VDD / VDD\_TX range from 2.7 to 5.5 V is supported. VDD and VDD\_TX must be connected to the same power supply.
- VDD\_IO is used to define supply level for the digital communication pins (BSS, MISO, MOSI, SCLK, IRQ, MCU\_CLK). Digital communication pins interface to the ST25R501 logic through level shifters, therefore the internal supply voltage can be lower than VDD\_IO. VDD\_IO range from 1.65 to 5.5 V is supported.

The following figure details the building blocks of the ST25R501 power supply system.

Figure 6. Power supply system



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- Note:
- *BG*: Bandgap reference
  - *AUTOREG*: Automatic regulator adjustment

The power supply system contains three regulators, a power-down support block (POR), a block generating the analog reference voltage (AGD) and a block performing the automatic power supply adjustment procedure. The three regulators provide supply to the analog (VDD\_A), logic (VDD\_D), and the transmitter (VDD\_DR) blocks. VDD\_D, VDD\_DR, and VDD\_A pins are not intended for supplying power to the chip. The VDD\_A, VDD\_D, and VDD\_DR regulators must be used for supplying power to the chip.

A decoupling capacitor pair of 10 nF in parallel with 2.2  $\mu$ F must be connected to the V<sub>DD</sub> and V<sub>DD\_TX</sub> supply, shown in Figure 3. [Minimum system configuration](#).

The decoupling capacitors should be placed close to the VDD\_TX pin. The PCB trace between the VDD\_TX pin and the decoupling capacitor should not be longer than 3 mm, with no vias in between. The trace width should be wider than 0.25 mm. Another decoupling capacitor pair is recommended to be placed at the VDD pin.

### 5.9.1 Power-down block

In the power-down mode, the regulators are disabled to save power. In this mode, a low-power power-down support block maintains the VDD\_D voltage level.

### 5.9.2 VDD\_A regulator

The VDD\_A regulator supplies the analog part of the receiver and the crystal oscillator. Its nominal voltage is 3.0 V. Below 3.0 V output voltage, the VDD\_A regulator follows the VDD\_DR voltage setting. A decoupling capacitor pair of 10 nF in parallel with 2.2  $\mu$ F must be connected and placed close to the IC with good connectivity to the positive and negative supply pins of VDD\_A. The 10nF decoupling capacitor should be placed as close as possible to the positive and negative supply pins.

### 5.9.3 VDD\_D regulator

The VDD\_D regulator supplies the digital logic. Its nominal voltage is 1.15 V. A decoupling capacitor pair of 10 nF in parallel with 2.2  $\mu$ F must be connected and placed close to the IC with good connectivity to the positive and negative supply pins of VDD\_D. The 10nF decoupling capacitor should be placed as close as possible to the positive and negative supply pins.

### 5.9.4 VDD\_DR regulator

The VDD\_DR regulator is supplying the TX driver via the VDD\_TX pin. The decoupling capacitor connected to the VDD\_DR pin should be 47 nF. The decoupling capacitor should be placed as close as possible to the positive and negative supply pins. To avoid oscillations on the output this decoupling capacitor should be directly connected with the shortest possible traces to the VDD\_DR and GND\_DR pin. Its LDO dropout voltage can be configured between 200 mV and 550 mV using the `regd` bits in the [Tx driver configuration register](#). The LDO drop is based on the IC internal measurement thus the VDD\_DR voltage measured outside of the IC, at its pins, can vary.

The regulator can also be configured to an absolute voltage. The `reg_s` bit in the VDD\_DR regulator configuration register switches between the automatic adjustment based on the configured LDO drop (`reg_s = 0`) and the manual one defined by an absolute voltage. The absolute voltage can be configured by setting `reg_s` bit set to one and configuring `rege` bits according to [Table 11. Regulated voltages](#).

The regulator features an internal current limiter. The limiter threshold is set above the 500mA current limit. Its threshold is dependent on internal mechanisms to achieve the maximum output current without damaging the ST25R501. When the current limiter is operating, the `i_lim` bit in the [Analog display register 1](#) is set. Although the limiter is active, the ST25R501 can still operate normally for a short period of time. As a result of the limiter being active, the VDD\_DR voltage is being reduced. Nevertheless, the device should be designed not to exceed the limits specified in the absolute maximum ratings section.

Besides the definition of a static voltage in unmodulated state, the VDD\_DR regulator is used to generate AM modulation and shaping of the OOK modulation in modulated state.

Further details about the shaping of the modulation signal can be found in [Section 5.10: Active wave shaping](#).

## 5.10 Active wave shaping

The ST25R501 supports active wave shaping of the modulation signal. The supported modes of operations are

- Field on and off transitions
- OOK modulation
- AM modulation

During the OOK modulation, the driver is stopped during the modulated state (also called pause). When in AM modulation operation, the driver switches between two voltage levels.

The device supports two AM modulation methods which can be combined with each other:

- Resistance am modulation (`res_am`)
- Regulator shaped modulation (`rgs_am`)

Both can be enabled in the [Tx modulation register 1](#). When using the regulator shape modulation, the VDD\_DR voltage level changes between the modulated and the unmodulated voltage level (modulation state change). The unmodulated voltage level is defined by the `am_mod` bits. The transition between the modulated and the unmodulated voltage level follows an exponential filter curve. The time constant of this filter curve can be modified for the falling and rising edge of the modulation signal individually. The filter can be modified in the [AWS configuration register 2](#) by setting the `am_fall` and `am_rise` bits. The value of the filter should be in conjunction with the Q-factor of the reader antenna. A too high value can cause non-standard compliant wave shape timings. For example ISO/IEC 14443-2 `t3` and `t4` could be too slow. A too low value could cause over- or undershoots. The filter curve defined by `am_fall` and `am_rise` bits is generated by an RC network inside of the ST25R501. By enabling the `dig_aws_en` bit, the same signal is generated by a digital logic, reducing the device to device variation.

The resistive am modulation (res\_am) allows switching between the unmodulated driver resistance (d\_res) and the modulated driver resistance (md\_res). The switch between d\_res to md\_res is occurring at the modulation state change after a certain number of carrier clock cycles defined in the tdres1 (falling edge) and tdres2 (rising edge) bits. The tdres1 bits can be configured in the [AWS timing register 1](#), the tdres2 bits can be configured in the [AWS timing register 3](#).

When res\_am is used in combination with OOK modulation (tr\_am=0), then the driver is being stopped after a certain number of carrier cycles defined in tentx1 bits. The tentx1 bits can be configured in the [AWS timing register 1](#). The usage of tentx1 different from 0 can be beneficial when enabling also rgs\_am in the OOK modulation scheme.

The ST25R501 also features two voltage sinking mechanisms.

- Dynamic passive sink
- Active sink

The voltage sink is used to reduce the energy stored in the VDD\_DR decoupling capacitor while transitioning from the modulated state to the unmodulated state. The sinks can only be enabled when the regulator is used for shaping (rgs\_am = 1).

The dynamic passive sink is enabled during the modulated state. It is drawing an additional continuous current during the modulation. This sink can be activated in combination with very high ohmic matchings to reduce the energy stored in the VDD\_DR capacitor. It can be delayed by a certain number of carrier cycles by setting the tpasssinkx1 (falling edge modulation signal) and tpasssinkx2 (rising edge of the modulation signal) bits. The tpasssinkx1 bits can be configured in the [AWS timing register 2](#) and the tpasssinkx2 bits can be configured in the [AWS timing register 4](#).

The active sink can be enabled by setting the act\_sink\_en bit to 1 in the [AWS configuration register 1](#). In addition, the offset measurement must be enabled by setting the sink\_offset\_en and dyn\_sink\_offset bits in the [AWS configuration register 1](#) to 1. This configuration enables the active sink during the modulation pulse. It is only drawing additional current out of the VDD\_DR capacitor, if the VDD\_DR voltage is above the offset. The offset is following the reference signal defined by am\_fall and am\_rise. Using the bits tsinkoff1 in [AWS timing register 2](#) and tsinkoff2 in the [AWS timing register 4](#) can delay the operation of the active sink after the modulation state change. It is recommended to keep tsinkoff1 and tsinkoff2 at a value of 0 for accurate shaping of the modulation pulse during the complete modulation pulse.

The internal current limiter can be temporarily disabled during the modulation by setting the bit dyn\_ilim\_aws = 1. Due to the active and passive sink, the current consumption could increase during the modulation of the carrier. It is recommended to activate the internal short circuit protection by setting the sc\_prot\_en bit to 1. Both bits can be found in the [AWS configuration register 1](#).

Additional overshoots or undershoots can be reduced by configuring the over- and undershoot protection. The bit pattern can be defined using the bits ov\_pattern defined in the [Overshoot protection register](#) and un\_pattern defined in the undershoot protection register. To enable the over- and undershoot protection both bits, ov\_pattern and un\_pattern must be different from 0 and res\_am = 1. The driver then switches from d\_res to md\_res during the configured carrier cycles after the modulation state change.

## 5.11 Reader operation

The ready mode must be entered by setting the en bit in the [Operation register](#). In this mode the oscillator is started and the regulators are enabled. When the oscillator operation is stable, the I\_osc interrupt is sent, and the osc\_ok bit indicates it.

The operation mode and data rate must then be configured by writing to the [Tx protocol register 1](#) and the [Tx protocol register 2](#). The receiver and transmitter operation options related to operation mode must be defined too. If the selected operation mode uses AM modulation for the reader-to-tag communication, the modulation depth must be configured.

Before sending any command to a card, the VDD\_DR regulator must be enabled by setting the vddr\_en bit and waiting 10  $\mu$ s. Then, the transmitter and the receiver must be enabled by setting the rx\_en and tx\_en bits. A guard time for each technology is defined by the NFC standards (for example 5 ms for ISO/IEC 14443) requiring that the reader field must be turned on for some time before the first command is sent. A general-purpose timer can be used to count this time or NFC field on command with a defined time by the NFC field on guard timer register.

Preparation and execution of a transceiver sequence:

- Execute the stop all activities direct command
- Execute the [Clear Rx gain](#) direct command
- Configure the timers accordingly

- Define the number of transmitted bytes in the [Tx frame configuration register 1](#) and [Tx frame configuration register 2](#)
- Write the bytes to be transmitted in the FIFO
- Send the transmit data or the transmit next slot (NFC-V) direct command

When all the data is transmitted, the `I_txe` interrupt is generated to inform the microcontroller that the transmission is finished (IRQ due to the end of transmission)

After the transmission is executed, the ST25R501 receiver automatically starts to observe the RFI inputs to detect a card response. The RSSI monitoring and AGC (if enabled) are started. The framing block processes the subcarrier signal from the receiver and fills the FIFO with data. When the reception is finished, and all the data is in the FIFO, the `I_rxe` interrupt is sent to the microcontroller (IRQ due to end of receive), and the [FIFO status register 1](#) and [FIFO status register 2](#) display the number of bytes in the FIFO so the microcontroller can proceed with the data download.

If an error or a collision bit are detected during reception, the `I_rxe` interrupt with the appropriate flag is sent, and the microcontroller can take appropriate action.

When the data packet is longer than the FIFO size, the above mentioned procedure changes.

The FIFO is prepared with the data before the transmission starts. The `I_wl` interrupt is sent during the transmission to signal when the remaining number of bytes is lower than the water level (IRQ due to FIFO water level). The microcontroller then adds more data in the FIFO. When all the data are transmitted the `I_txe` interrupt is sent to inform the microcontroller that the transmission is finished.

The situation during the reception is similar. When the FIFO is loaded with more data than the received water level, the `I_wl` interrupt is sent, and the microcontroller reads the data from the FIFO. When the reception is finished, the `I_rxe` interrupt is sent to the microcontroller (IRQ due to end of receive) the [FIFO status register 1](#) and [FIFO status register 2](#) display the number of the bytes in the FIFO still to be read.

## 5.12 External field detection

The external field detector (EFD) is automatically enabled during the execution of the NFC field on command. The status of the EFD can be observed through the bit `efd_on`, and when the EFD is active (`efd_on = 1`), its output can be monitored by the bit `efd_out`. EFD activation (`efd_at<3:0>`) and deactivation (`efd_dt<3:0>`) thresholds can be configured individually in the external field detector register. Another method to detect the presence of an external field is the usage of the sense RF direct command.

## 5.13 Host interface

### 5.13.1 Communication with an external microcontroller

The device communicates with a microcontroller via an SPI interface where it acts as a target device, relying on the microcontroller to initiate all communication.

To notify the microcontroller of completed commands or external events the device signals an interrupt on the IRQ pin.

A RESET pin is available to reset the device logic and put the device registers to default state.

### 5.13.2 Interrupt interface

There are three interrupt registers implemented in the device. When an interrupt condition is met, the source of the interrupt bit is set and the IRQ pin transitions to high.

The microcontroller can read the interrupt registers to distinguish between different interrupt sources. After a particular interrupt register is read, its content is reset to 0.

*Note:* *There can be more than one interrupt bit set if the microcontroller does not immediately read the interrupt registers after the IRQ signal is set and another event causing an interrupt occurs. In this case, the IRQ pin transitions to low after the last bit causing the interrupt is read.*

If an interrupt from a certain source is not required, it can be disabled by setting the corresponding bit in the mask interrupt registers. In the case of masking a certain interrupt source the IRQ line is not set high, but the interrupt status bit is still set in the IRQ status registers.

By reading the IRQ status registers the masked interrupt bits are also retrieved and cleared.

In case an interrupt is masked and set to high due to a previous IRQ event and then the host unmask this IRQ source, the IRQ line is immediately set to high. This notifies the host system that there are some interrupt events not yet read out.

### 5.13.2.1 Serial peripheral interface (SPI)

The device has a standard SPI with clock polarity of 0, a clock phase of 1, and an active low target select signal. SPI speeds up to 10 Mbit/s are supported. The communication starts with the controller pulling BSS low. The MOSI pin is sampled on the falling edge of SCLK, and the state of the MISO pin is updated on the rising edge of the SCLK signal. Data is transferred byte-wise, the most significant bit first. Read and write commands support an address auto increment to reduce communication time.

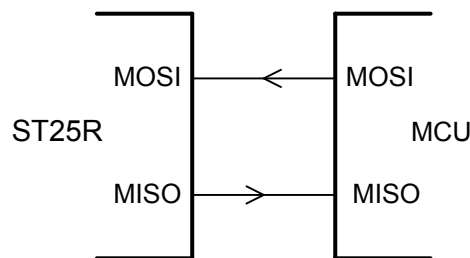
Table 2. SPI signal lines

Name	Signal	Signal Level	Description
BSS	Digital input	CMOS	SPI enable (active low)
MOSI	Digital input	CMOS	Serial data input
SCLK	Digital input	CMOS	Clock for serial communication
MISO	Digital output with tristate	CMOS	Serial data output

MISO output is mostly in a tristate condition and is only driven when output data is available.

While the MISO output is in a tristate condition, it is possible to switch on a 10 kΩ internal pull-down resistor by activating the option bits `miso_pd1` and `miso_pd2` in the [General configuration register](#).

Figure 7. SPI data signals with a host



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The following addressing scheme is used:

- Bit 7 indicates the direction of the operation (0-Write /1-Read)
- 88 addressable registers (0x00 - 0x57)
- 32 command codes (0x60 - 0xF9)
- FIFO access (0x5F)
- Test register access (0xFC)
- RAM access (0x58)

Table 3. SPI operation modes

Mode	Mode pattern (com. bits)								Related data
	R/W	B6	B5	B4	B3	B2	B1	B0	
Register write	0	A6	A5	A4	A3	A2	A1	A0	Data byte (or more bytes in case of auto-incrementing) A<6:0> = 0x57 max
Register read	1	A6	A5	A4	A3	A2	A1	A0	Data byte (or more bytes in case of auto-incrementing) A<6:0> = 0x57 max
Commands	C7	1	1	C4	C3	C2	C1	C0	-
Test	1	1	1	1	1	1	0	0	Address and data byte (or more bytes in case of auto incrementing)
RAM write	0	1	0	1	1	0	0	0	Write RAM
RAM read	1	1	0	1	1	0	0	0	Read RAM

Mode	Mode pattern (com. bits)								Related data
	R/W	B6	B5	B4	B3	B2	B1	B0	
FIFO write	0	1	0	1	1	1	1	1	One or more bytes of FIFO data
FIFO read	1	1	0	1	1	1	1	1	One or more bytes of FIFO data



### 5.13.2.2 Writing of data to addressable registers (write mode)

The following figures show cases of writing a single byte and writing multiple bytes with an auto-incrementing address. After the SPI operation direction bit, the address of the register to be written is provided. Then one or more data bytes are transferred from the SPI, always from the MSB to the LSB. The data byte is written in a register on falling edge of its last clock. In case the communication is terminated by putting BSS high before a packet of 8 bits composing one byte is sent, writing of this register is not performed. In the case the register on the defined address does not exist or it is a read only register, no write is performed.

Figure 8. SPI communication: writing of single byte

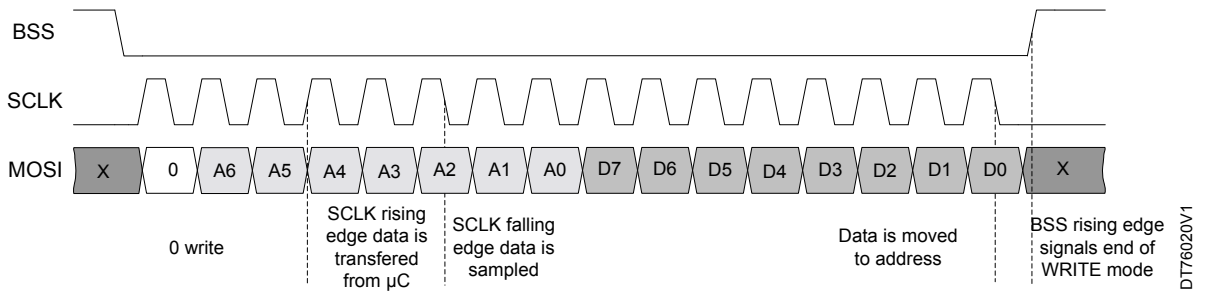
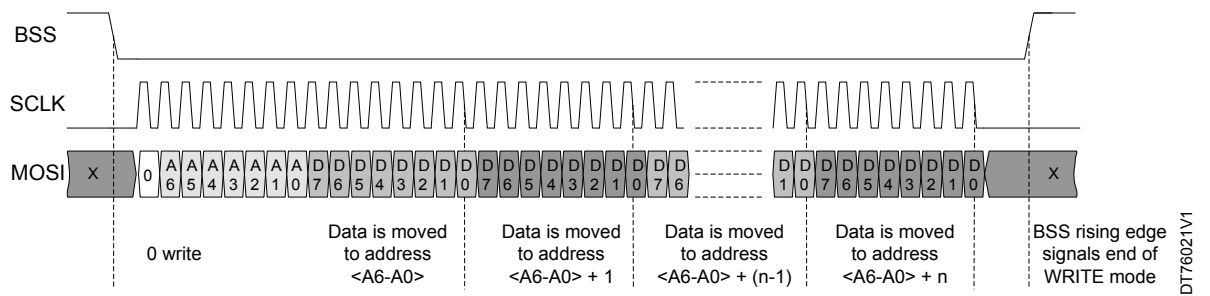


Figure 9. SPI communication: writing of multiple bytes



### 5.13.2.3 Reading of data from addressable registers (read mode)

After the SPI operation direction bit, the address of the register to be read must be provided from the MSB to the LSB. Then one or more data bytes are transferred to the MISO output, always from the MSB to the LSB. Analogous to the write mode, also the read mode supports auto-incrementing address.

MOSI is sampled at the falling edge of SCLK (like shown in the following diagrams), data to be read from the device internal register is driven to MISO pin on the rising edge of SCLK and is sampled by the controller at the falling edge of SCLK.

In the case the register on the defined address does not exist, all 0 data is sent to MISO.

Figure 10. SPI communication: reading of single byte

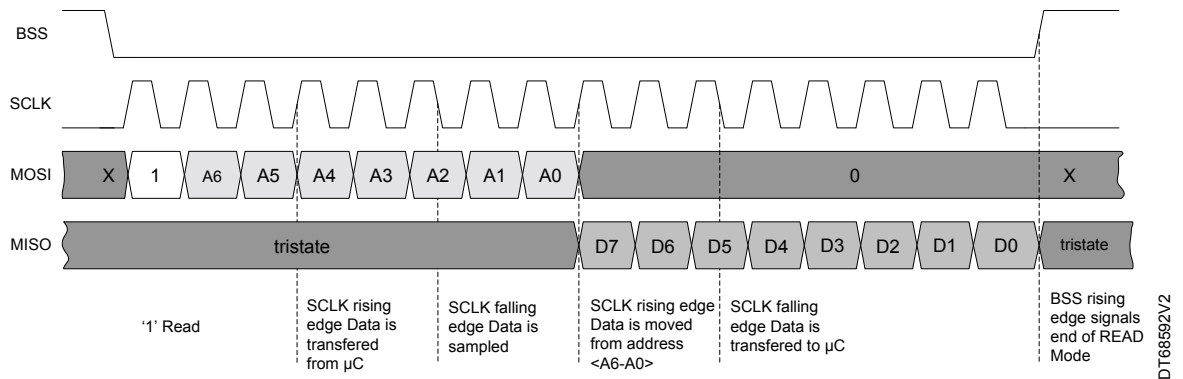
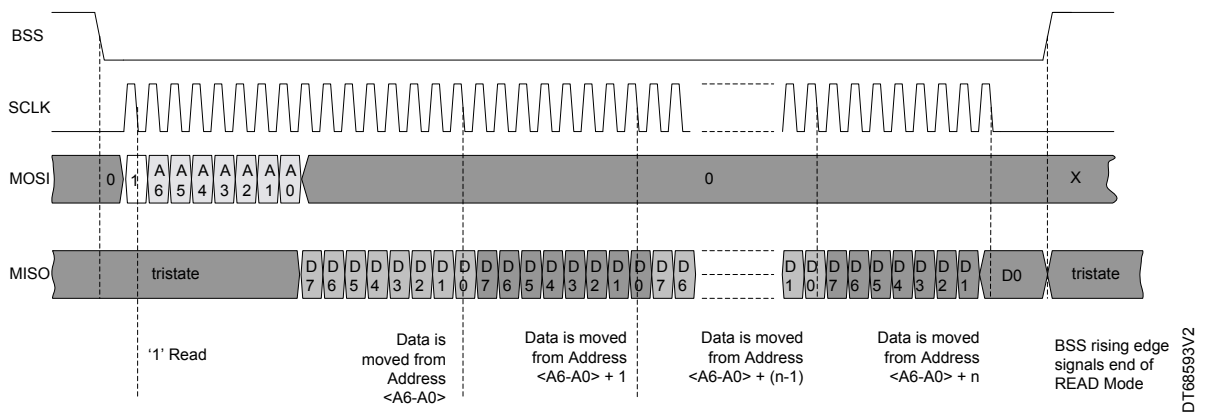


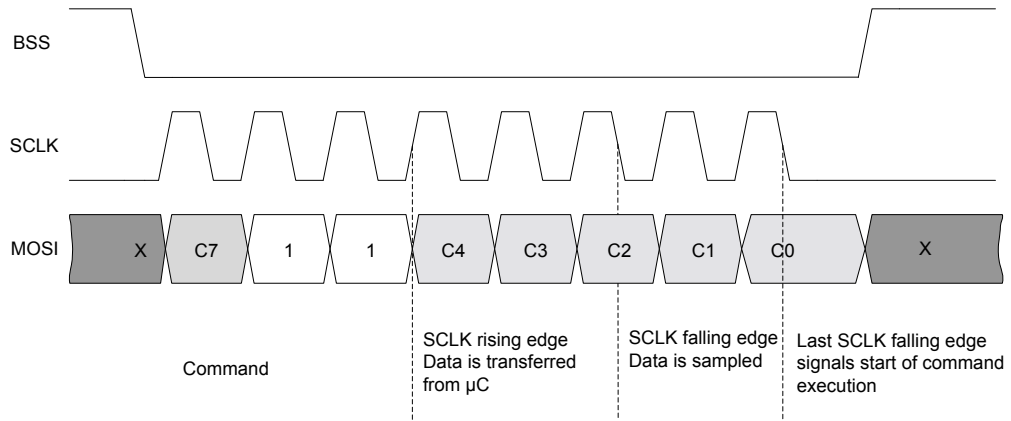
Figure 11. SPI communication: reading of multiple bytes



5.13.2.4 **Direct command mode**

The direct command mode has no additional data apart from the command code itself, therefore a single byte is sent MSB first. Execution of the direct command starts after the last clock.

**Figure 12. SPI communication: direct command**

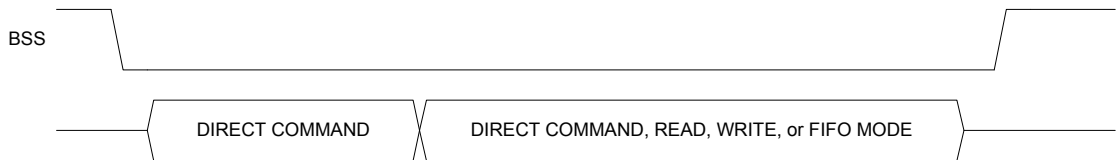


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While the execution of some direct commands is immediate, others start a process of a certain duration, for example, calibration or measurements. During the execution of such commands, it is not allowed to start another activity over the SPI. An IRQ is sent when the execution has terminated.

Direct commands with immediate execution can be followed by another SPI mode (direct command, read, write, or FIFO) without deactivating the BSS signal in between.

**Figure 13. SPI communication: direct command chaining**

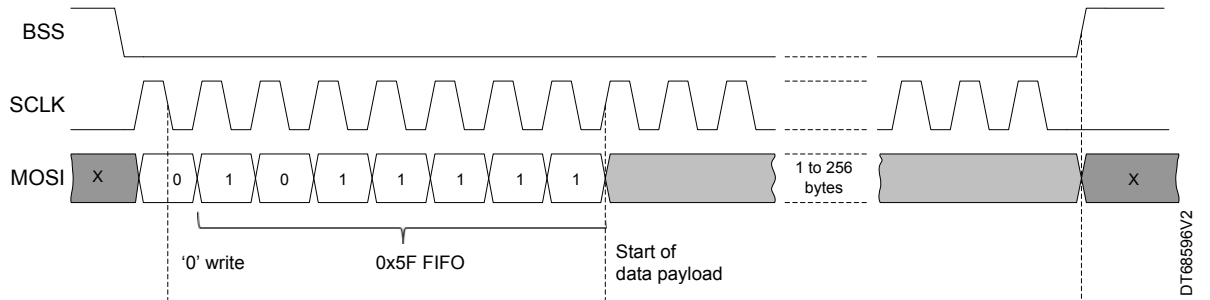


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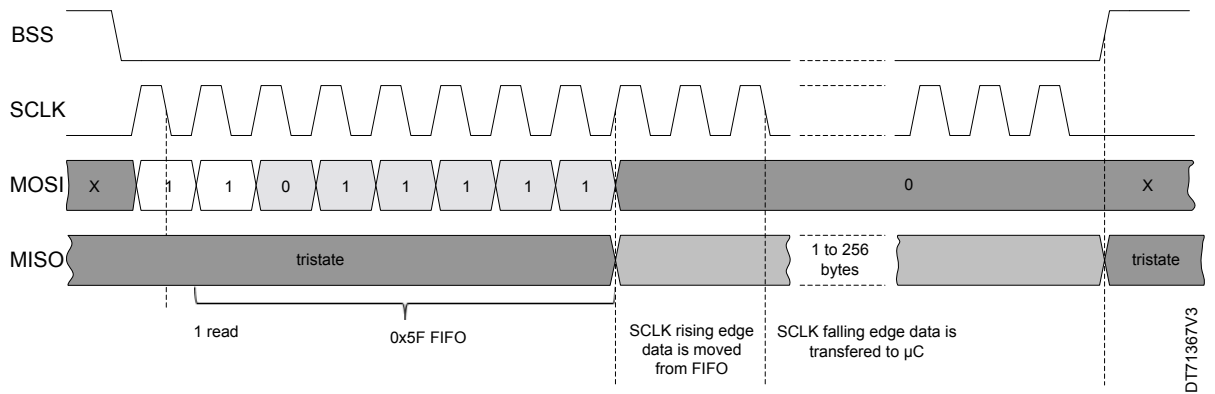
5.13.2.5 **FIFO mode**

Reading the received data from the FIFO is similar to reading the data from the addressable registers. Read and write operations are performed by accessing the address 0x5F.

**Figure 14. SPI communication: writing bytes into FIFO**



**Figure 15. SPI communication: reading bytes from FIFO**



## 5.14 Direct commands

**Table 4. Direct commands**

Code (hex) <sup>(1)</sup>	Command	Comments	Operation mode	I_dct after termination
60, 61	Set default	Puts the device into a power-up state	RD or PD	No
62, 63	Stop all activities	Stops all activities: transmission, reception, direct commands execution, timers, clears FIFO, collision, and IRQ status	RD	No
64, 65	Clear FIFO	Clears FIFO and collision status	RD	No
66, 67	Clear Rx Gain	Clears the current squelch setting and loads the manual gain reduction from the register	RD	No
68, 69	Adjust regulators	Adjusts supply regulators according to the current supply voltage level	RD	Yes
6A, 6B	Transmit data	Starts a data transmit sequence	RD	No
6C, 6D	Transmit next slot	Transmits an ISO15693 EOF; Single modulation pulse	RD	No
6E, 6F	NFC field on	Performs initial RF collision avoidance and field-on	RD	Yes
70, 71	Mask receive data	Masks the receiver; Incoming data after this command is ignored	RD	No
72, 73	Unmask receive data	Unmasks the receiver; Incoming data after this command is normally processed	RD	No
74, 75	Calibrate WU measurement	Calibrates the WU measurement	RD or PD	Yes
76, 77	Clear WU calibration	Clears previous calibration data	RD or PD	No
78, 79	WU measurement	The I and Q components of the RFI signal are measured similarly as in WU mode	RD or PD	Yes
7A, 7B	I/Q measurement	The I and Q components of the RFI signal are measured, with or without the transmitter enabled	RD	Yes
7C, 7D	Sense RF	Senses RF signal presence on RFI inputs, with or without the transmitter enabled	RD	Yes
7E, 7F	Trigger wake-up event	Triggers event that is normally triggered by WU timer in WU mode	PD	Yes
E2, E3	Start GPT	Manually starts the general-purpose timer	RD	No
E4, E5	Start WUT	Manually starts the wake-up timer	PD or RD	No
E6, E7	Start MRT	Manually starts the mask receive timer	RD	No
E8, E9	Start NRT	Manually starts the no response timer	RD	No
EA, EB	Stop NRT	Manually stops the no response timer	RD	No
EE, EF	Calibrate RC	Calibrate AWS time constant	RD	No
F8, F9	Trigger diagnostic measurement	-	RD	Yes
FC	Test register access	Enable access to test registers	PD or RD	No

1. The command codes not explicitly listed in this table can't be used.

#### 5.14.1 Set default

This direct command puts the device in the same state as power-up initialization:

- Performs stop all activities direct command
- Sets all registers to default state
- Clears IRQ line and IRQ status bits
- Clears collision bits

#### 5.14.2 Stop all activities

This direct command:

- Performs a Clear FIFO command direct command
- Stops data transmission and reception
- Stops all timers
- Clears IRQ line and IRQ status bits
- Terminates NFC Field on command (but does not switch off the field, if already on, due to command or earlier)

The command does not switch off the field in reader/writer operation.

In CE operation, the reception is interrupted and re-enabled. This command is accepted in RD mode when the en bit is set and the oscillator frequency is stable `osc_ok=1`.

Direct command chaining can be used with this command.

#### 5.14.3 Clear FIFO

This direct command clears the FIFO and the FIFO status registers. It does not clear the IRQ line or IRQ status bits. To prepare a transmission, send this command first before writing data into the FIFO. If a clear FIFO command is sent during an ongoing data transmission, then the data transmission is aborted, and FIFO status registers are cleared.

Direct command chaining can be used with this command.

#### 5.14.4 Clear Rx gain

This command initializes the AGC and squelch. Sending this command stops squelch operation, in case it is going on, and clears the current squelch setting and loads the manual gain reduction as in `afe_gain_rw`.

Direct command chaining can be used with this command.

#### 5.14.5 Adjust regulators

The system can adjust the VDD\_DR and VDD\_A regulator voltage drop as defined in the `regd` bits. Using this method, the power supply rejection is optimized and the maximum available driver supply is used.

The command starts with the maximal target voltage setting and decreases the target until the configured voltage drop in the regulator is reached.

Before the command is triggered, the `tx_en` and `rx_en` bits should be enabled, to perform the adjustment at realistic load conditions.

Command is accepted in PD or RD mode when `reg_s = 0`.

#### 5.14.6 Transmit data

Transmit data command is accepted if the transmitter is enabled (the `tx_en` bit is set).

Before sending the transmit data command, the clear FIFO direct command must be sent, followed by the definition of the number of transmitted bytes and by writing data to be transmitted in the FIFO.

The `a_tx_par`, `tx_crc`, `f_tx_len`, `b_tx_sof_0`, `b_tx_sof_1`, `b_tx_eof` and `b_tx_half` bits have an impact on the transmitted data. For example, CRC or parity bits are added.

The `I_txe` IRQ is signaled after the transmit command has been finished.

#### 5.14.7 Transmit next slot

Transmit next slot command is accepted in case the transmitter is enabled (`tx_en` bit is set).

For the transmit next slot direct command, the ISO 15693 mode is set and it is not necessary to send the clear FIFO direct command before as the FIFO is not used.

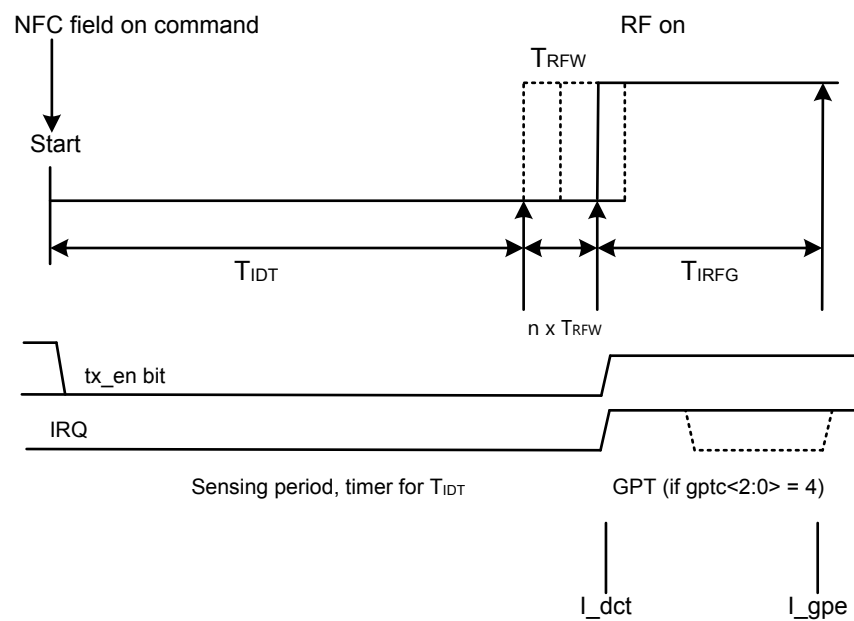
At the end of the transmission an I\_txe interrupt is produced, and the device moves into the reception mode.

### 5.14.8 NFC field on

The NFC field on direct command is used to perform the RF collision avoidance. The external field detector is activated (efd\_on = 1) for this commands to work correctly. The collision avoidance threshold defined in the efd\_at bits is used to observe the RFI input voltage and to determine whether there is some other device, which is emitting the 13.56 MHz field, close to the antenna.

If no external field is detected, then the ST25R501 transmitter is switched on automatically (the tx\_en bit in the [Operation register](#) is set) and an I\_dct IRQ is signaled. After the RF, the guard time (t\_IRFG) defined in the GP timer register (gptc) has passed an I\_gpe IRQ is signaled. At this point the controller can initiate a data transmission using a transmit command.

**Figure 16. Direct command NFC field on (no RF collision)**



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**Table 5. Timing parameters of NFC field on commands**

Parameter	Symbol	Value	Unit	Note
Initial delay time	$T_{IDT}$	4096	$1/f_C$	NFC initial field ON (302 $\mu$ s)
RF waiting time	$T_{RFW}$	512	$1/f_C$	$n = 0 \dots 3$ ( $0 \dots 3 \times 37.8 \mu$ s)
Initial guard time	$T_{IRFG}$	GPT	N/A	GPT timer

If the external field is detected the field is not switched on automatically (bit tx\_en = 0) and IRQ with I\_dct is sent. In such a case a transmission cannot be performed, the NFC Field on command must be repeated as long as the collision is not detected anymore.

The NFC initial field on command performs initial collision avoidance according to the NFCIP-1 standard. The number n is defined by bits nfc\_n in the [General configuration register](#).

### 5.14.9 Mask receive data

After the mask receive data direct command, the receiver output and the receive data framing block are disabled. This command is useful to mask the receiver and receive framing from processing the data when there is no input signal expected and only noise would be processed (for example in cases where a card processing time after receiving a command from the reader is long).

Direct command chaining can be used with this command.

#### 5.14.10 Unmask receive data

The unmask receive data direct command is enabling normal processing of the received data by enabling the received data framing block. A common use of this command is to enable again the receiver operation after it was masked by the mask receive data command. In case the mask receive timer is running while the unmask receive data command is received, the reception is enabled, the mask receive timer is reset.

Direct command chaining can be used with this command.

#### 5.14.11 Calibrate WU measurement

The command calibrates the wake-up mechanism to optimize the ADC input signal. The calibration value is visible in the [I-channel WU calibration register](#) and the [Q-channel WU calibration register](#).

The command is automatically executed when enabling wake-up operation or if the input signal of the ADC drifts too far from the optimal area.

If the ST25R501 is in PD mode, it first temporarily enables the oscillator. After the oscillator is stable, the field is temporarily turned on, and the calibration is executed.

#### 5.14.12 Clear WU calibration

The clear WU calibration direct command clears the previously obtained calibration data. The ADC calibration is reset to the default value.

This command must be used prior to the I/Q measurement or the amplitude measurement in case one wants to do the measurement without previous calibration. This enables approximate absolute measurement, but for a decreased resolution.

#### 5.14.13 WU measurement

This command performs the wake-up measurement. It is automatically executed at each wake-up timer expiration in wake-up mode.

It can be triggered manually and is accepted from RD and PD mode.

If the IC is in PD mode, it first temporarily enables the oscillator and waits for the oscillator to be stable. Afterward, the field is temporarily enabled, and the measurement is performed.

If the IC is in RD mode, it only temporarily enables the field and then performs the measurement.

#### 5.14.14 I/Q measurement and sense RF

These commands allow the user to measure the I and Q components of the RFI signal, whether it is measured at an external or self-emitted field.

The measurements are similar to the WU measurement but they can only be triggered once in RD mode and the state of the transmitter is kept. Depending on tx\_en it measures its own field or checks for the presence of an external field.

Before executing the measurement, a clear WU calibration command is executed.

The measurement result is available at:

- I/Q measurement: i\_adc in the [I-channel WU ADC display register](#) and q\_adc in the [Q-channel WU ADC display register](#)
- Sense RF: sense\_adc as a combination of I and Q in the [Sense RF display register](#)

#### 5.14.15 Trigger wake-up event

The trigger wake-up event direct command triggers a wake-up measurement and the processing of the measurement data, the same as the normal wake-up mechanism. The following activities are executed if enabled:

- Wake-up calibration
- Reference measurement
- Wake-up measurement
- IRQ generation
- Recalibration
- Auto averaging



Instead of the wake-up timer, the MCU can trigger the execution of the single wake-up measurements. This mechanism allows the MCU to synchronize the wake-up measurements with other external events. The direct command is accepted when the `wu_en` bit is set to 1 and the wake-up timer is configured to 0xf which is an infinite wake-up timer period.

#### 5.14.16 Start GPT

This command manually starts the general-purpose timer.

#### 5.14.17 Start WUT

This command manually starts the wake-up timer.

#### 5.14.18 Start MRT

This command manually starts the mask receive timer. Along with the MRT, Start MRT command starts the NRT if `nr<15:0> ≠ 0`.

#### 5.14.19 Start NRT

This command manually starts the no response timer.

#### 5.14.20 Stop NRT

This command manually stops the no response timer.

#### 5.14.21 Calibrate RC

The AWS filter curve is defined by an internal RC network if the `dig_aws_en` bit is set to 0. This command calibrates the RC network to show less spread over process, voltage, and temperature to maintain a constant time constant.

The command is accepted in RD mode only.

#### 5.14.22 Trigger diagnostic measurement

Internal signals can be routed in the receiver block. The receiver can execute a DC level measurement to estimate those signals. The measurement can only be performed in ready mode when the receiver is enabled. Up to 52 measurements can be defined and scheduled in the RAM. The completion of the execution is signaled via the `I_dct` interrupt. The estimation result is stored in the FIFO. There are 4 bytes produced per measurement: Command byte, calibration MSB, calibration LSB and one RFU byte. Calibration data is 9 bits unsigned and can be converted to mV/mA by multiplying with the conversion factor.

The following steps are an example to execute such a measurement:

1. Enable ready mode and enable the receiver (`rx_en = 1`)
2. Clear RAM and FIFO
3. Specify the measurement to be executed in the RAM (for example, write 0x11 0x00 into RAM to perform one measurement of VDD).
4. Execute the direct command trigger diagnostic measurement
5. Retrieve the result from the FIFO, (for example, read the 4 bytes 0x11 0x01 0xAB 0x41. Calibration value 0x1AB corresponds to 5 V).

The following commands can be specified in the RAM:

**Table 6. Diagnostic measurement**

Command byte	Function	Comment	Conversion factor
00h	Terminate diagnostic measurement mode	-	-
01h	I_VDD_DR <sup>(1)</sup>	current through the VDD_DR regulator	3.2 (mA)
02h	VDD_TX	VDD_TX	11.7 (mV)
03h	VDD_DR <sup>(1)</sup>	VDD_DR	11.7 (mV)
04h	VDD_IO	VDD_IO	11.7 (mV)
0Ch	VDD_D	VDD_D	5.9 (mV)
0Dh	VDD_A	VDD_A	11.7 (mV)
11h	VDD	VDD	11.7 (mV)
12h	AGD	AGD	5.9 (mV)

1. The measurements performed at rege/regc settings below 3.3 V are inaccurate and should not be used.

### 5.14.23 Test register access

This command allows access to the device's test registers.

Test registers are not part of the normal register address space. After sending the direct command, test registers can be accessed using the normal read/write register operation.

Access to test registers is possible in a chained command sequence where the command test register access is sent first, followed by the read/write operation to test registers. The test registers are set to the default state at power-up.

## 5.15 Registers

The 7-bit register addresses below are defined in hexadecimal notation. The possible addresses range from 00h to 57h.

There are two types of registers available in this device:

- Configuration registers
- Display registers

Configuration registers can be read and written (RW) through the SPI and hold the device configuration.

Display registers are read only (RO) and contain information about the device's internal state.

Additionally, registers are grouped in two different power domains:

- Power down (PD)
- Ready (RD)

When the device is not in Ready mode, only the register belonging to the PD domain can be accessed. In ready mode all registers can be accessed.

The registers are set to their default state at power-up, and reset after execution of the direct command set default.

**Table 7. Registers**

Type	Address(hex)	Register name	Type, power domain
Operation	0	Operation register	RW, PD
Configuration	1	General configuration register	RW, PD
	2	VDD_DR regulator configuration register	RW, PD
	3	Tx driver configuration register	RW, PD
	4	Tx modulation register 1	RW, PD
	5	Tx modulation register 2	RW, PD
	7	TAD configuration register	RW, PD
	8	GPIO control register	RW, PD
	9	Rx analog settings register 1	RW, PD
	A	Rx analog settings register 2	RW, PD
	B	Rx analog settings register 3	RW, PD
	C	Rx analog settings register 4	RW, RD
	D	Rx digital settings register 1	RW, RD
	E	Correlator settings register 1	RW, RD
	F	Correlator settings register 2	RW, RD
	10	Correlator settings register 3	RW, RD
11	Correlator settings register 4	RW, RD	
12	Correlator settings register 5	RW, RD	
13	Correlator settings register 6	RW, RD	
Protocol	14	Protocol register 1	RW, RD
	15	Tx protocol register 1	RW, RD
	16	Tx protocol register 2	RW, RD
	17	Rx protocol register 1	RW, RD
	18	Rx protocol register 2	RW, RD
	19	Rx protocol register 3	RW, RD
EMD	1A	EMD configuration register	RW, RD
	1B	EMD configuration register 2	RW, RD

Type	Address(hex)	Register name	Type, power domain
Timers	1F	Mask receive timer configuration register	RW, PD
	20	Mask receive timer configuration register 2	RW, PD
	21	Squelch timer configuration register	RW, RD
	22	NRT and GPT configuration register 1	RW, RD
	23	NRT and GPT configuration register 2	RW, RD
	24	NRT and GPT configuration register 3	RW, RD
	25	NRT and GPT configuration register 4	RW, RD
	26	NRT and GPT configuration register 5	RW, RD
Wake-up	27	Wake-up control register 1	RW, PD
	28	Wake-up control register 2	RW, PD
	29	Wake-up control register 3	RW, PD
	2A	I-channel WU configuration	RW, PD
	2B	I-channel WU difference	RW, PD
	2C	I-channel WU calibration	RO, PD
	2D	I-channel WU ADC display register	RO, PD
	2E	I-channel WU reference register	RO, PD
	2F	Q-channel WU configuration	RW, PD
	30	Q-channel WU difference	RW, PD
	31	Q-channel WU calibration	RO, PD
	32	Q-channel WU ADC display register	RO, PD
	33	Q-channel WU reference register	RO, PD
Tx/Rx frame	34	Tx frame configuration register 1	RW, RD
	35	Tx frame configuration register 2	RW, RD
	36	FIFO register status 1	RO, RD
	37	FIFO register status 2	RO, RD
	38	Rx collision display register	RO, RD
IRQ mask	39	IRQ mask register 1	RW, RD
	3A	IRQ mask register 2	RW, RD
	3B	IRQ mask register 3	RW, RD
IRQ status	3C	IRQ status register 1	RO, RD
	3D	IRQ status register 2	PD, RD
	3E	IRQ status register 3	RO, PD
Identity	3F	IC identity	RO, PD
Status	40	Status register 1	RO, PD
	41	Status register 2	RO, RD
	42	Static status register 1	RO, PD
	43	Static status register 2	RO, RD
	44	Static status register 3	RO, RD
	47	Wake up status register	RO, PD
Display	48	Analog display register 1	RO, PD
	49	Analog display register 2	RO, RD

Type	Address(hex)	Register name	Type, power domain
Display	4A	RSSI display register 1	RO, RD
	4B	RSSI display register 2	RO, RD
	4C	Sense RF display register	RO, PD
AWS	4D	AWS configuration register 1	RW, RD
	4E	AWS configuration register 2	RW, RD
	4F	AWS timing register 1	RW, RD
	50	AWS timing register 2	RW, RD
	51	AWS timing register 3	RW, RD
	52	AWS timing register 4	RW, RD
	53	Overshoot protection register	RW, RD
	54	Undershoot protection register	RW, RD
EFD	57	External field detector	RW, PD

### 5.15.1 Operation register

Address: 00h

Type: RW

**Table 8. Operation register**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	tx_en	0	1: Enables TX operation	-
5	rx_en	0	1: Enables RX operation	-
4	vdddr_en	0	1: Enables VDD_DR regulator	vdddr_en should be enabled at least 10 $\mu$ s ahead of tx_en
3	en	0	1: Enables ready mode (RD)	Enables oscillator and V <sub>DD_A</sub> /V <sub>DD_D</sub> regulator
2:1	RFU <1:0>	0x0	RFU	-
0	wu_en	0	1: Enables WU operation	Wake-up operation

### 5.15.2 General configuration register

Address: 01h

Type: RW

**Table 9. General configuration register**

Bit	Name	Default	Function	Comment
7:6	RFU<1:0>	0	RFU	-
5	Single	0	0: Differential antenna operation 1: Single ended antenna operation	Choose between differential and single driving of antenna.
4	rfo2	0	0: RFO1, RF11 1: RFO2, RF12, and field detector sense at RF12	Chose which output driver and which input will be used in case of single driving
3	miso_pd2	0	1: Pull down on MISO, when BSS is low and MISO is not driven	-
2	miso_pd1	0	1: Pull down on MISO when BSS is high	-
1:0	nfc_n<1:0>	0	Definition of n for NFC field on command	-

### 5.15.3 VDD\_DR regulator configuration register

Address: 02h

Type: RW

**Table 10. VDD\_DR regulator configuration register**

Bit	Name	Default	Function	Comment
7	reg_s	0	0: regulated voltages are defined by result of <i>Adjust Regulators</i> command 1: regulated voltages are defined by rege<6:0> bits	-
6:0	rege<6:0>	0x7F	Regulator target voltage Used when manual voltage setting is used (reg_s =1 )	-

The following table shows the VDD\_DR regulated voltage inside the integrated circuit (IC). Voltages at the decoupling capacitors might be slightly higher due to the voltage drop across the bond wire and package contacts.

**Table 11. Regulated voltages**

rege<6:0>	Typical regulated voltage (V)	rege<6:0>	Typical regulated voltage (V)	rege<6:0>	Typical regulated voltage (V)
0x32	2.39	0x4C	3.61	0x66	4.83
0x33	2.44	0x4D	3.66	0x67	4.88
0x34	2.48	0x4E	3.70	0x68	4.92
0x35	2.53	0x4F	3.75	0x69	4.97
0x36	2.58	0x50	3.80	0x6A	5.02
0x37	2.63	0x51	3.84	0x6B	5.06
0x38	2.67	0x52	3.89	0x6C	5.11
0x39	2.72	0x53	3.94	0x6D	5.16
0x3A	2.77	0x54	3.98	0x6E	5.20
0x3B	2.81	0x55	4.03	0x6F	5.25
0x3C	2.86	0x56	4.08	0x70	5.30
0x3D	2.91	0x57	4.13	0x71	5.34
0x3E	2.95	0x58	4.17	0x72	5.39
0x3F	3.00	0x59	4.22	0x73	5.44
0x40	3.05	0x5A	4.27	0x74	5.48
0x41	3.09	0x5B	4.31	0x75	5.53
0x42	3.14	0x5C	4.36	0x76	5.58
0x43	3.19	0x5D	4.41	0x77	5.63
0x44	3.23	0x5E	4.45	0x78	5.67
0x45	3.28	0x5F	4.50	0x79	5.72
0x46	3.33	0x60	4.55	0x7A	5.77
0x47	3.38	0x61	4.59	0x7B	5.81
0x48	3.42	0x62	4.64	0x7C	5.86
0x49	3.47	0x63	4.69	0x7D	5.91
0x4A	3.52	0x64	4.73	0x7E	5.95
0x4B	3.56	0x65	4.78	0x7F	6.00

### 5.15.4 Tx driver configuration register

Address: 03h

Type: RW

**Table 12. Tx driver configuration register**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:4	regd<2:0>	2	Regulator target drop Used in adjust regulators command (reg_s = 0)	-
3:0	d_res<3:0>	0	RFO driver resistance, during active transmission	-

**Table 13. VDD\_DR Regulator Drop**

Regd<2:0>	Target drop (mV)	Regd<2:0>	Target drop (mV)
0x0	200	0x4	400
0x1	250	0x5	450
0x2	300	0x6	500
0x3	350	0x7	550

**Table 14. Driver resistance multiplier**

d_res<3:0>	d_res3	d_res2	d_res1	d_res0	Driver output resistance (normalized) <sup>(1)</sup>
0x0	0	0	0	0	1.01
0x1	0	0	0	1	1.12
0x2	0	0	1	0	1.24
0x3	0	0	1	1	1.38
0x4	0	1	0	0	1.51
0x5	0	1	0	1	1.67
0x6	0	1	1	0	1.86
0x7	0	1	1	1	2.21
0x8	1	0	0	0	2.56
0x9	1	0	0	1	3.05
0xA	1	0	1	0	4.09
0xB	1	0	1	1	6.19
0xC	1	1	0	0	12.8
0xD	1	1	0	1	27.4
0xE	1	1	1	0	64.0
0xF	1	1	1	1	High Z

1. The value must be multiplied by the RFO resistance from [Section 6: Electrical characteristics](#) to obtain the driver output resistance for the corresponding d\_res setting.



**5.15.5 Tx modulation register 1**

Address: 04h

Type: RW

**Table 15. Tx modulation register 1**

Bit	Name	Default	Function	Comment
7:4	am_mod<3:0>	0x07	AM modulation index	-
3	mod_state	0	0: Unmodulated state 1: Modulated state	Switch RFO output between modulated and unmodulated AM voltage
2	rgs_am	0	0: disable regulator shape modulation 1: enable Regulator shape modulation	Can be combined with res_am
1	res_am	0	0: disable Resistive AM modulation 1: enable Resistive AM modulation	Can be combined with tr_am = 0
0	RFU	0	RFU	-

**Table 16. AM modulation index**

am_mod<3:0>	am_mod3	am_mod 2	am_mod 1	am_mod 0	Modulation index target
0x0	0	0	0	0	8%
0x1	0	0	0	1	10%
0x2	0	0	1	0	11%
0x3	0	0	1	1	12%
0x4	0	1	0	0	13%
0x5	0	1	0	1	14%
0x6	0	1	1	0	15%
0x7	0	1	1	1	20%
0x8	1	0	0	0	30%
0x9	1	0	0	1	40%
0xA	1	0	1	0	50%
0xB	1	0	1	1	60%
0xC	1	1	0	0	70%
0xD	1	1	0	1	80%
0xE	1	1	1	0	88%
0xF	1	1	1	1	97%

**5.15.6 Tx modulation register 2**

Address: 05h

Type: RW

**Table 17. Tx modulation register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:0	md_res<6:0>	0	Resistive modulation	-

**Table 18. md\_res setting**

md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>
0x00	1.005	0x20	1.561	0x40	3.050	0x60	6.190
0x01	1.016	0x21	1.600	0x41	3.100	0x61	6.400
0x02	1.027	0x22	1.641	0x42	3.150	0x62	6.620
0x03	1.038	0x23	1.684	0x43	3.200	0x63	6.860
0x04	1.049	0x24	1.730	0x44	3.250	0x64	7.110
0x05	1.061	0x25	1.761	0x45	3.310	0x65	7.380
0x06	1.073	0x26	1.794	0x46	3.370	0x66	7.680
0x07	1.085	0x27	1.829	0x47	3.430	0x67	8.000
0x08	1.097	0x28	1.864	0x48	3.490	0x68	8.350
0x09	1.110	0x29	1.901	0x49	3.560	0x69	8.730
0x0A	1.123	0x2A	1.939	0x4A	3.620	0x6A	9.140
0x0B	1.136	0x2B	1.979	0x4B	3.690	0x6B	9.600
0x0C	1.150	0x2C	2.021	0x4C	3.760	0x6C	10.100
0x0D	1.164	0x2D	2.065	0x4D	3.840	0x6D	10.700
0x0E	1.178	0x2E	2.110	0x4E	3.920	0x6E	11.300
0x0F	1.193	0x2F	2.157	0x4F	4.000	0x6F	12.000
0x10	1.208	0x30	2.207	0x50	4.090	0x70	12.800
0x11	1.223	0x31	2.259	0x51	4.170	0x71	13.700
0x12	1.239	0x32	2.313	0x52	4.270	0x72	14.800
0x13	1.255	0x33	2.370	0x53	4.360	0x73	16.000
0x14	1.272	0x34	2.430	0x54	4.470	0x74	17.500
0x15	1.289	0x35	2.494	0x55	4.570	0x75	19.200
0x16	1.306	0x36	2.560	0x56	4.680	0x76	21.300
0x17	1.324	0x37	2.630	0x57	4.800	0x77	24.000
0x18	1.343	0x38	2.704	0x58	4.920	0x78	27.400
0x19	1.362	0x39	2.743	0x59	5.050	0x79	32.000
0x1A	1.381	0x3A	2.783	0x5A	5.190	0x7A	38.400
0x1B	1.401	0x3B	2.824	0x5B	5.330	0x7B	48.000
0x1C	1.422	0x3C	2.866	0x5C	5.490	0x7C	64.000
0x1D	1.455	0x3D	2.909	0x5D	5.650	0x7D	96.000

md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>	md_res	Driver output resistance (normalized) <sup>(1)</sup>
0x1E	1.488	0x3E	2.954	0x5E	5.820	0x7E	192.000
0x1F	1.512	0x3F	3.000	0x5F	6.000	0x7F	High Z

1. The value must be multiplied by the RFO resistance from [Section 6: Electrical characteristics](#) to obtain the driver output resistance for the corresponding md\_res setting.

### 5.15.7 TAD configuration register

Address: 07h

Type: RW

**Table 19. TAD configuration register**

Bit	Name	Default	Function	Comment
7:5	RFU<2:0>	0x0	RFU	-
4	tad_dig_en	0	0: Push-pull disabled 1: Push-pull output on tad1, tad2	Tad2/1 can be used as TRIM pins for antenna tuning via external HV MOS
3:0	RFU	0x1	Reserved for future use (RFU)	-

### 5.15.8 GPIO control register

Address: 08h

Type: RW

**Table 20. GPIO control register**

Bit	Name	Default	Function	Comment
7:4	RFU<3:0>	0	RFU	-
3:2	trim_rw<1:0>	0	Defines TAD2/1 value in read operation	TAD2/1 can be used as TRIM pins for antenna tuning in reader operation, MSB: TAD2, and LSB: TAD1
1:0	RFU<1:0>	0	RFU	-

### 5.15.9 Rx analog settings register 1

Address: 09h

Type: RW

**Table 21. Rx analog settings register 1**

Bit	Name	Default	Function	Comment
7:4	dig_clk_dly<3:0>	0x5	Digital clock delay	Recommended value: 0x7
3	RFU	0	RFU	-
2	gain_boost	0	1: Increased gain in Rx path by 3 dB	Can be used in read operation and wake-up operation
1:0	hpf_ctrl<1:0>	0x3	00: 80kHz, 01: 160kHz, 10: 240kHz, 11: 380kHz	Analogue 1 and 3 <sup>rd</sup> stage HPF setting (2 <sup>nd</sup> stage: LPF, 2 <sup>nd</sup> order, 2MHz) For WU: 0x11

### 5.15.10 Rx analog settings register 2

Address: 0Ah

Type: RW

**Table 22. Rx analog settings register 2**

Bit	Name	Default	Function	Comment
7:4	afe_gain_rw<3:0> <sup>(1)</sup>	0x0	3dB start gain reduction in read operation	-
3:0	afe_gain_td<3:0> <sup>(2)</sup>	0x8	3dB start gain reduction in WU mode	-

1. Choosing a gain different from 0x0 requires *dis\_agc\_noise\_meas* = 1.

2. For applications used at  $V_{DD\_A} \leq 2.7\text{ V}$  and at  $-40\text{ }^\circ\text{C}$ , a minimum `afe_gain_td` of  $\geq 0x5$  must be used. The `gain_boost` can be set to either `0x0` or `0x1`.

### 5.15.11 Rx analog settings register 3

Address: 0Bh

Type: RW

**Table 23. Rx analog settings register 3**

Bit	Name	Default	Function	Comment
7:4	<code>afe_gain_ce&lt;3:0&gt;</code>	0x8	gain reduction in ADC 2 RAM operation	Maximum reduction: $3\text{ dB} * 0xB = 33\text{ dB}$
3:0	RFU <3:0>	1	RFU	-

### 5.15.12 Rx analog settings register 4

Address: 0Ch

Type: RW

**Table 24. Rx analog settings register 4**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	<code>en_rect_cor</code>	0	1: Enable rectifier correction after subcarrier start	-
5:0	RFU<5:0>	0x0	RFU	-

**5.15.13 Rx digital settings register 1**

Address: 0Dh

Type: RW

**Table 25. Rx digital settings register 1**

Bit	Name	Default	Function	Comment
7	agc_en	1	0: AGC disabled 1: AGC enabled	-
6:4	lpf_coef<2:0>	4	1 <sup>st</sup> -order IIR coefficient	-
3:2	hpf_coef<1:0>	3	1 <sup>st</sup> -order IIR coefficient	-
1:0	RFU <1:0>	0x0	RFU	-

**5.15.14 Correlator settings register 1**

Address: 0Eh

Type: RW

**Table 26. Correlator settings register 1**

Bit	Name	Default	Function	Comment
7:4	iir_coef2<3:0>	0xC	1 <sup>st</sup> -order IIR coefficient	-
3:0	iir_coef1<3:0>	0x1	1 <sup>st</sup> -order IIR coefficient	-

**5.15.15 Correlator settings register 2**

Address: 0Fh

Type: RW

**Table 27. Correlator settings register 2**

Bit	Name	Default	Function	Comment
7:4	agc_thr_squelch<3:0>	0x5	Read operation: Squelch threshold	-
3:0	agc_thr<3:0>	0xA	Read operation: AGC threshold	-

**5.15.16 Correlator settings register 3**

Address: 10h

Type: RW

**Table 28. Correlator settings register 3**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	en_subc_end	0	BPSK only 0: No subcarrier end detection (reception stops with valid EOF or timeout) 1: Fast subcarrier end detection	-
5:0	start_wait<5:0>	0x7	Wait time for subcarrier detection	-

**5.15.17 Correlator settings register 4**

Address: 11h

Type: RW

**Table 29. Correlator settings register 4**

Bit	Name	Default	Function	Comment
7:4	coll_lvl<3:0>	0xA	Manchester: collision level ratio collision level ratio	-
5:0	data_lvl<3:0>	0xA	Manchester: data level ratio BPSK: Subcarrier end detection level	-

### 5.15.18 Correlator settings register 5

Address: 12h

Type: RW

**Table 30. Correlator settings register 5**

Bit	Name	Default	Function	Comment
7	dis_noise_leak	0	0: Automatic noise level adjustment when no signal 1: disabled	-
6	dis_noise_meas	0	0: Noise level adjustment 1: disabled	-
5	dis_soft_sq	0	0: noise measurement after start of reception 1: disabled	-
4	dis_agc_noise_meas	0	0: AGC effect on internally used noise level 1: disabled	-
3	no_phase	0	1: Disables phase correction after signal start detection (BPSK only)	-
2:0	dec_f<2:0>	3	Decimation factor for IIR filters	-

### 5.15.19 Correlator settings register 6

Address: 13h

Type: RW

**Table 31. Correlator settings register 6**

Bit	Name	Default	Function	Comment
7:4	init_noise_lvl<3:0>	0x3	I and Q correlator initial noise level setting	-
5:0	agc_freeze_cnt<3:0>	0x0	AGC freeze before the subcarrier start is detected	BPSK protocols in reader operation (NFC-A HBR, NFC-B, NFC_F) Step size: 1/(2 * bitrate)

**Table 32. Initial correlator noise level**

init_noise_lvl3:0	init_noise_lvl3	init_noise_lvl2	init_noise_lvl1	init_noise_lvl0	Correlator initial Noise level
0x0	0	0	0	0	5
0x1	0	0	0	1	10
0x2	0	0	1	0	15
0x3	0	0	1	1	20

init_noise_lv13:0	init_noise_lv13	init_noise_lv12	init_noise_lv11	init_noise_lv10	Correlator initial Noise level
0x4	0	1	0	0	25
0x5	0	1	0	1	30
0x6	0	1	1	0	35
0x7	0	1	1	1	40
0x8	1	0	0	0	50
0x9	1	0	0	1	60
0xA	1	0	1	0	70
0xB	1	0	1	1	80
0xC	1	1	0	0	90
0xD	1	1	0	1	100
0xE	1	1	1	0	110
0xF	1	1	1	1	120

### 5.15.20 Protocol register 1

Address: 14h

Type: RW

**Table 33. Protocol register 1**

Bit	Name	Default	Function	Comment
7:6	rx_rate<1:0>	00	Set rx bit rate according to technology: NFC-A, NFC-B, NFC-F or NFC-V	Selects bit rate for Rx
5:4	tx_rate<1:0>	00	Set tx bit rate according to technology: NFC-A, NFC-B, NFC-F or NFC-V	Selects bit rate for Tx
3:0	om<3:0>	0x1	Operation mode (protocol)	-

**Table 34. rx\_rate**

rx_rate 1	rx_rate 0	NFC-A	NFC-B	NFC-F	NFC-V
0	0	106 kbps	106 kbps	-	26kbps
0	1	212 kbps	212 kbps	212 kbps	53 kbps
1	0	424 kbps	424 kbps	424 kbps	106 kbps
1	1	848 kbps	848 kbps	-	212 kbps

**Table 35. tx\_rate**

tx_rate 1	tx_rate 0	NFC-A	NFC-B	NFC-F	NFC-V
0	0	106 kbps	106 kbps	-	26kbps
0	1	212 kbps	212 kbps	212 kbps	-
1	0	424 kbps	424 kbps	424 kbps	-
1	1	848 kbps	848 kbps	-	-



**Table 36. Operation modes**

om3	om2	om1	om0	Reader operation
0	0	0	0	N/A
0	0	0	1	ISO14443-A/NFC-A
0	0	1	0	ISO14443-B/NFC-B
0	0	1	1	NFC-F
0	1	0	0	Topaz
0	1	0	1	ISO15693/NFC-V
1	1	0	1	N/A
1	1	1	0	N/A
1	1	1	1	N/A

### 5.15.21 Tx protocol register 1

Address: 15h

Type: RW

**Table 37. Tx protocol register 1**

Bit	Name	Default	Function	Comment
7	a_nfc_f0	0	1: support of NFCIP-1 transport frame format	Add SB (F0) and LEN bytes during Tx and skip SB(F0) byte during Rx.
6	a_tx_par	1	1: parity bit is generated during Tx	Parity and CRC is generated and transmitted
5	tx_crc	1	1: CRC is generated during Tx	CRC is generated and transmitted
4	tr_am	0	0: OOK 1: AM	Tx modulation type in digital control
3:0	p_len<3:0>	0x0	OOK modulation duration	Modulation pulse width NFC-A/ NFC-V. Defined in number of 13.56 MHz clock periods

**Table 38. OOK modulation pulse width**

p_len	p_len3	p_len2	p_len1	p_len0	Pulse width in number of $1/f_c$ for different bit rates				
					NFC-A and NFC-V				
					$f_c/512$	$f_c/128$	$f_c/64$	$f_c/32$	$f_c/16$
0x7	0	1	1	1	128	42	-	-	-
0x6	0	1	1	0	124	41	24	-	-
0x5	0	1	0	1	120	40	23	-	-
0x4	0	1	0	0	116	39	22	13	-
0x3	0	0	1	1	112	38	21	12	8
0x2	0	0	1	0	108	37	20	11	7
0x1	0	0	0	1	104	36	19	10	6
0x0	0	0	0	0	100	35	18	9	5
0xF	1	1	1	1	96	34	17	8	4
0xE	1	1	1	0	92	33	16	7	3
0xD	1	1	0	1	88	32	15	6	2
0xC	1	1	0	0	84	31	14	5	-
0xB	1	0	1	1	80	30	13	-	-
0xA	1	0	1	0	76	29	12	-	-
0x9	1	0	0	1	72	28	-	-	-
0x8	1	0	0	0	68	27	-	-	-

### 5.15.22 Tx protocol register 2

Address: 16h

Type: RW

**Table 39. Tx protocol register 2**

Bit	Name	Default	Function	Comment
7:5	RFU<7:5>	0	RFU	-
4	f_tx_len	1	1: NFC-F, length byte is generated and transmitted	LEN byte is generated and transmitted RW
3	b_tx_sof_0	0	0: 10 etu, 1: 11 etu	SOF, number of etu with logic 0 (10 or 11)
2	b_tx_sof_1	0	0: 2 etu, 1: 3 etu	SOF, number of etu with logic 1 (2 or 3)
1	b_tx_eof	0	0: 10 etu, 1: 11 etu	EOF, number of etu with logic 0 (10 or 11)
0	b_tx_half	0	1: SOF 10.5, 2.5, EOF: 10.5	Sets SOF and EOF settings in middle of specification

**5.15.23 Rx protocol register 1**

Address: 17h

Type: RW

**Table 40. Rx protocol register 1**

Bit	Name	Default	Function	Comment
7:6	RFU<7:6>	0	RFU	-
5	b_rx_sof	1	1: Expects SOF PICC to PCD	According to ISO14443-3 chapter 7.10.3.3. Support of B' (no SOF)
4	b_rx_eof	1	1: Expects EOF PICC to PCD	According to ISO 14443-3 chapter 7.10.3.3
3	a_rx_par	1	1: Receive with parity check	When set to 1, parity check is performed
2	rx_crc	1	1: Receive with CRC check	When set to 1, CRC check is performed
1	rx_nbtx	0	1: Received bits are positioned according to nbtx<2:0> setting	The nbtx<2:0> bits define position of the first bit in the first byte in consecutive reception. To be used for SDD_REQ.
0	antcl	0	1: NFC-A/V: Anti-collision frame	Has to be set to 1 when NFC-A/ NFC-V bit oriented anti-collision frame is expected. <ul style="list-style-type: none"> <li>coll_lvl is used to detect colliding bits</li> <li>The first parity bit is ignored in case the split happens within the byte</li> </ul>

**5.15.24 Rx protocol register 2**

Address: 18h

Type: RW

**Table 41. Rx protocol register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:0	tr1_min_len<6:0>	0x3A	Minimum remaining TR1 length (Type B) in subcarrier periods (0-127)	If received TR1 is shorter than the minimum specified length, a soft error interrupt is generated. TR1 in this register starts after the subcarrier is detected (see start_wait<5:0> setting)

**5.15.25 Rx protocol register 3**

Address: 19h

Type: RW

**Table 42. Rx protocol register 3**

Bit	Name	Default	Function	Comment
7:0	tr1_max_len<7:0>	0xC0	Maximum remaining TR1 length (Type B) in subcarrier periods (1-255). 0x00: No check	If received TR1 is longer than the maximum specified length, a soft error interrupt is generated. TR1 in this register starts after the subcarrier is detected (see start_wait<5:0> setting)

**5.15.26 EMD configuration register 1**

Address: 1Ah

Type: RW

**Table 43. EMD configuration register 1**

Bit	Name	Default	Function	Comment
7:4	emd_thld<3:0>	0x4	EMD threshold definition in number of received bytes	If the received message length is less than the number of bytes defined by emd_thld then EMD suppression is triggered.
3	emd_thld_ff	1	0: emd thld applies for the error limit 1: emd_thld applies for the full frame size	When disabled the emd_thld applies to the error location independently of the full frame length
2:1	RFU<1:0>	0	RFU	-
0	emd_en	0	0: Disable HW EMD Suppression 1: Enable HW EMD Suppression	-

**5.15.27 EMD configuration register 2**

Address: 1Bh

Type: RW

**Table 44. EMD configuration register 2**

Bit	Name	Default	Function	Comment
7:0	RFU<7:0>	0x0	RFU	-

**5.15.28 Mask receive timer configuration register 1**

Address: 1Fh

Type: RW

**Table 45. Mask receive timer configuration register 1**

Bit	Name	Default	Function	Comment
7:6	sq_del<1:0>	0	00: 18.88us 01: 2x18.88us = 37.76us 10: 4x18.88us = 75.52us 11: 8x18.88us = 151.04us	Defines the delay of the squelch enable, with respect to end of Tx
5:4	mrt_step<1:0>	2	00: 16/f <sub>C</sub> (1.18us) 01: 32/f <sub>C</sub> (2.36us) 10: 64/f <sub>C</sub> (4.72us) 11: 512/f <sub>C</sub> (37.8us)	Selects the Mask-receive timer step
3:1	RFU<2:0>	0	RFU	-
0	sq_en	1	1: Automatic squelch activation after end of Tx	Activated 18.88us after end of Tx, terminated with Mask Receive timer expiration

### 5.15.29 Mask receive timer configuration register 2

Address: 20h

Type: RW

**Table 46. Mask receive timer configuration register 2**

Bit	Name	Default	Function	Comment
7:0	mrt<7:0>	0x0B	<p>Defined in mrt_step&lt;1:0&gt; (<math>16/f_C \dots 512/f_C</math>).</p> <p>Timeout = mrt&lt;7:0&gt; * mrt_step&lt;1:0&gt;</p> <p>Range: <math>16/f_C</math> (1.18us) at <math>16/f_C</math> to <math>130560/f_C</math> (~9.6 ms) at <math>512/f_C</math></p>	<p>Defines time after end of Tx during which receiver output is masked (ignored).</p> <p>In case mrt &lt; sq_del, rx_on goes high at sq_del</p>

### 5.15.30 Squelch timer configuration register

Address: 21h

Type: RW

**Table 47. Squelch timer configuration register**

Bit	Name	Default	Function	Comment
7:0	sqt<7:0>	0x0B	<p>In steps equal to the mask receive timer (mrt_step).</p>	<p>Squelch is enabled 18.88us-151us after the end of reader data transmission, as defined in sq_del&lt;1:0&gt;.</p> <p>Squelch is enabled till the time defined by sqt&lt;7:0&gt;.</p> <p>In case sqt &lt; sq_del, there is no squelch period (and Gain reduction from previous reception is used as Starting point for AGC).</p> <p>In case sqt &gt; mrt, squelch is enabled until the mrt expires.</p> <p>Setting in afe_gain_rw is a starting point for squelch.</p> <p>Gain reduction due to squelch is locked and used as a starting point for AGC.</p>

**5.15.31 NRT and GPT configuration register 1**

Address: 22h

Type: RW

**Table 48. NRT and GPT configuration register 1**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:4	gptc<2:0>	0x0	Defines the GP timer trigger source	-
3:2	RFU<1:0>	0	RFU	-
1	nrt_emv	0	1: EMV mode of no-response timer	-
0	nrt_step	0	0: 64/f <sub>C</sub> 1: 4096/f <sub>C</sub>	No-response timer step

**Table 49. General purpose timer trigger source**

gptc2	gptc1	gptc0	Trigger source
x	x	x	The timer starts always with direct command start general purpose timer
0	0	0	No additional trigger source
0	0	1	Additionally starts at End of Rx (after EOF)
0	1	0	Additionally starts at Start of Rx
0	1	1	Additionally starts at end of Tx frame
1	0	0	Additionally starts at Field on (en_tx 0 to 1 transition) – To be used at NFC field on command to mark 'Guard time expire'
1	x	x	RFU

**5.15.32 NRT and GPT configuration register 2**

Address: 23h

Type: RW

**Table 50. NRT and GPT configuration register 2**

Bit	Name	Default	Function	Comment
7:0	nrt<15:8>	0x00	No-response timer definition MSB bits Defined in steps of 64/f <sub>C</sub> (4.72 μs), range from 0 to 309ms  In case the bit nrt_step is set the step is changed to 4096/f <sub>C</sub> (302 μs), range 19.8 s.	Defines timeout after end of Tx. In case this timeout expires without detecting a response a No- response interrupt is sent.  All 0: No-response timer is not started.  No-response timer can also be reset and restarted with start no-response timer direct command.

**5.15.33 NRT and GPT configuration register 3**

Address: 24h

Type: RW

**Table 51. NRT and GPT configuration register 3**

Bit	Name	Default	Function	Comment
7:0	nrt<7:0>	0x00	No-response timer definition LSB bits	-

### 5.15.34 NRT and GPT configuration register 4

Address: 25h

Type: RW

**Table 52. NRT and GPT configuration register 4**

Bit	Name	Default	Function	Comment
7:0	gpt<15:8>	0x00	General purpose timeout definition MSB bits. Defined in steps of $8/f_C$ (590 ns) Range from 590 ns to 38.7 ms	-

### 5.15.35 NRT and GPT configuration register 5

Address: 26h

Type: RW

**Table 53. NRT and GPT configuration register 5**

Bit	Name	Default	Function	Comment
7:0	gpt<7:0>	0x00	General purpose timeout definition LSB bits.	-

### 5.15.36 Wake-up control register 1

Address: 27h

Type: RW

**Table 54. Wake-up control register 1**

Bit	Name	Default	Function	Comment
7:4	wut<3:0>	0	Wake-up timer timeout value ( $wu\_en = 1$ ) (in WU mode)	See the following table
3:1	RFU<2:0>	0	RFU	-
0	fast_efd_irq	0	0: Efd IRQs generated by 26.24 kHz clk 1: Efd IRQs generated by 262.4 kHz clk	-

**Table 55. Wake- up timer periode / WPT measure sampling period (wut/wpt)**

wut<3:0>	WU time (wu_en=1) nominal (ms)
0x0	12.5
0x1	25
0x2	50
0x3	75
0x4	100
0x5	125
0x6	150
0x7	200
0x8	250
0x9	300
0xA	350
0xB	400
0xC	500
0xD	800
0xE	1000
0xF	Inf.

### 5.15.37 Wake-up control register 2

Address: 28h

Type: RW

**Table 56. Wake-up control register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	wut_cal	0	0: No WU timer calibration 1: Calibrate WU period during WU event (valid for wut > 3)	higher WU period accuracy at increased RD time (wut_cal_len)
5:4	wut_cal_len<1:0>	0	WU timer calibration length	0: 0.781ms 1: 1.562ms 2: 3.125ms 3: 6.248ms
3	weak_disch	0	0: AGD and VDD_A discharged in PD mode and WU operation 1: Only weak / self discharge on AGD and VDD_A in PD mode and WU operations	1: Weak discharge allows capacitors to remain mainly charged between WU events, decreasing overall wake-up consumption.
2	rc_vdig_lp	0	0: RC osc. supplied with VDD_D 1: RC osc. supplied with a dedicated regulator	To be used in combination with wut_cal_len >= 2 to increase wake-up timer accuracy
1:0	tagdet_len<1:0>	0	Field-on time fixed to 00: td_mt setting 01: 36 * 16/f <sub>C</sub> (42.5 us) 10: 44 * 16/f <sub>C</sub> (51.9 us)	Real measurement at the second half of available field-on duration



Bit	Name	Default	Function	Comment
			11: $52 * 16/f_C$ (61.4 us)	

### 5.15.38 Wake-up control register 3

Address: 29h

Type: RW

**Table 57. Wake-up control register 3**

Bit	Name	Default	Function	Comment
7	skip_recal	0	1: Disable automatic recalibration	-
6	skip_cal	0	1: Disable automatic calibration	-
5	skip_twcal	0	1: Disable calibration delay at start	-
4	skip_twref	0	1: Disable reference delay at start	-
3	iq_aaref	0	0: Manually defined reference for both I and Q channel 1: Enable auto average reference for both I and Q channel	-
2	td_mf	0	Wake-up measure time	-
1:0	td_mt<1:0>	0	Wake-up measure time	-

**Table 58. Wake-up measurement time**

td_mt	td_mf	Measurement pulse $\mu$ s
0x0	0x0	26.0
0x1	0x0	29.5
0x2	0x0	34.2
0x3	0x0	43.7
0x0	0x1	10.6
0x1	0x1	14.2
0x2	0x1	18.9
0x3	0x1	28.3

**5.15.39 I-channel WU configuration register**

Address: 2Ah

Type: RW

**Table 59. I-channel WU configuration register**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	i_iirqm	0	0: exclude the IRQ measurement 1: include all measurements	-
5:3	i_aaw<2:0>	0	000: 4 001: 8 010: 16 011: 32 100: 50 101: 64 110: 100 111: 128	Define weight of last measurement result for auto-averaging
2	i_tdi_en2	0	1: IRQ if $i\_adc > i\_ref + i\_diff$	All 0: I-channel wake-up measurement, disabled, including receiver circuitry and correlator clock (to minimize consumption)
1	i_tdi_en1	0	1: IRQ if $i\_ref - i\_diff \leq i\_adc \leq i\_ref + i\_diff$	
0	i_tdi_en0	0	1: IRQ if $i\_adc < i\_ref - i\_diff$	

**5.15.40 I-channel WU difference register**

Address: 2Bh

Type: RW

**Table 60. I-channel WU difference register**

Bit	Name	Default	Function	Comment
7	i_cal<8>	1	MSB unsigned calibration result (Unsigned)	-
6	RFU	0	RFU	-
5:0	i_diff<5:0>	0x0A	ADC to reference difference that triggers IRQ	Unsigned

**5.15.41 I-channel WU calibration register**

Address: 2Ch

Type: RW

**Table 61. I-channel WU calibration register**

Bit	Name	Default	Function	Comment
7:0	i_cal<7:0>	0x00	8-bit unsigned calibration result (unsigned)	-

**5.15.42 I-channel WU ADC display register**

Address: 2Dh

Type: RW

**Table 62. I-channel WU ADC display register**

Bit	Name	Default	Function	Comment
7:0	i_adc<7:0>	0	8-bit signed ADC part Range: -128 to 127	-

**5.15.43 I-channel WU reference register**

Address: 2Eh

Type: RW

**Table 63. I-channel WU reference register**

Bit	Name	Default	Function	Comment
7:0	i_ref<7:0>	0	8-bit signed reference Range: -128 to 127	If iq_aaref = 1 the reference is automatically calculated, and this register is RO. When iq_aaref = 0 the reference shall be set manually, and this register becomes RW

**5.15.44 Q-channel WU configuration register**

Address: 2Fh

Type: RW

**Table 64. Q-channel WU configuration register**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	q_iirqm	0	0: exclude the IRQ measurement 1: include all measurements	-
5:3	q_aaw<2:0>	0	000: 4 001: 8 010: 16 011: 32 100: 50 101: 64 110: 100 111: 128	Define weight of last measurement result for auto-averaging
2	q_tdi_en2	0	1: IRQ if q_adc > q_ref + q_diff	All 0: Q-channel wake-up measurement disabled, including receiver circuitry and correlator clock (to minimize consumption)
1	q_tdi_en1	0	1: IRQ if q_ref - q_diff ≤ q_adc ≤ q_ref + q_diff	
0	q_tdi_en0	0	1: IRQ if q_adc < q_ref - q_diff	

**5.15.45 Q-channel WU difference register**

Address: 30h

Type: RW

**Table 65. Q-channel WU difference register**

Bit	Name	Default	Function	Comment
7	q_cal<8>	1	MSB unsigned calibration result (Unsigned)	-
6	RFU	0	RFU	-
5:0	q_diff<5:0>	0x0A	ADC to reference difference that triggers IRQ	Unsigned

**5.15.46 Q-channel WU calibration register**

Address: 31h

Type: RW

**Table 66. Q-channel WU calibration register**

Bit	Name	Default	Function	Comment
7:0	q_cal<7:0>	0x00	8-bit unsigned calibration result (Unsigned)	-

**5.15.47 Q-channel WU ADC display register**

Address: 32h

Type: RW

**Table 67. Q-channel WU ADC display register**

Bit	Name	Default	Function	Comment
7:0	q_adc<7:0>	0	8-bit signed ADC part Range: -128 to 127	-

**5.15.48 Q-channel WU reference register**

Address: 33h

Type: RW

**Table 68. Q-channel WU reference register**

Bit	Name	Default	Function	Comment
7:0	q_ref<7:0>	0	8-bit signed reference Range: -128 to 127	If iq_aaref = 1 the reference is automatically calculated, and this register is RO. When iq_aaref = 0 the reference shall be set manually, and this register becomes RW

### 5.15.49 Tx frame configuration register 1

Address: 34h

Type: RW

Table 69. Tx frame configuration register 1

Bit	Name	Default	Function	Comment
7:0	ntx<12:5>	0x000	Number of full bytes to be transmitted	Maximum supported number of bytes is 8191

### 5.15.50 Tx frame configuration register 2

Address: 35h

Type: RW

Table 70. Tx frame configuration register 2

Bit	Name	Default	Function	Comment
7:3	ntx<4:0>	0x000	Number of full bytes to be transmitted	Maximum supported number of bytes is 8191
2:0	nbtx<2:0>	0x0	Number of bits transmitted after the last full byte. Nbtx<2:0> = 0 only full bytes to be transmitted	The valid bits are in the LSB part. Applicable for NFC-A: <ul style="list-style-type: none"> <li>bit oriented anti-collision frame in case last byte is split byte</li> <li>Tx is done without parity bit generation</li> </ul>

### 5.15.51 FIFO status register 1

Address: 36h

Type: RO

Table 71. FIFO status register 1

Bit	Name	Default	Function	Comment
7:0	fifo_b<7:0>	0x00	Number of bytes currently in the FIFO (LSB part)	Valid range: 0 to 255

*Note:* At power-up, at start of data reception, and after the direct commands set default and clear FIFO, the content of this register is set to 0.

**5.15.52 FIFO status register 2**

Address: 37h

Type: RO

**Table 72. FIFO status register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	-	-
6	fifo_b<8>	0	Number of bytes currently in the FIFO (MSB part)	-
5	fifo_unf	0	FIFO underflow	Readout from an empty FIFO or FIFO or too fast FIFO read (>10 Mb/s)
4	fifo_ovr	0	FIFO overflow	Write into a full FIFO or too fast FIFO write (>10 Mb/s)
3:1	fifo_lb<2:0>	0	Number of bits in last FIFO byte in case it was not complete	In case of incomplete byte the LSB part is valid In case of I_hfe the bits may be invalid
0	np_lb	0	Parity bit is missing in last byte	The bit is set if the last byte was complete with 8 data bits and only the parity bit is missing. This is a framing error. In case of I_hfe the bit may be invalid

*Note:* At power-up, at start of data reception, and after the direct commands set default and clear FIFO, the content of this register is set to 0.

**5.15.53 Rx collision display register**

Address: 38h

Type: RO

**Table 73. Rx collision display register**

Bit	Name	Default	Function	Comment
7:4	c_byte<3:0>	0x0	Position of the first bit collision (number of bytes and bits)	The Collision display register range covers NFC-A bit oriented anti-collision frame. In case collision (or framing error which is interpreted as collision) happens in a longer frame, the collision register is not set. In case of I_hfe the bits may be invalid.
3:1	c_bit<2:0>	0x0		
0	c_pb	0	Collision in parity bit	Error, reported in case it is the first collision detected In case of I_hfe the bit may be invalid.

**5.15.54 IRQ mask register 1**

Address: 39h

Type: RW

**Table 74. IRQ mask register 1**

Bit	Name	Default	Function	Comment
7	M_subc_start	0	Mask IRQ due to subcarrier start	-
6	M_col	0	Mask IRQ due to bit collision	-
5	M_wl	0	Mask IRQ due to FIFO water level	-
4	M_rx_rest	0	Mask IRQ due to automatic reception restart	-
3	M_rxe	0	Mask IRQ due to end of receive	-
2	M_rxs	0	Mask IRQ due to start of receive	-
1	M_txe	0	Mask IRQ due to end of transmission	-
0	M_rx_err	0	Mask IRQ due to Reception error	-

**5.15.55 IRQ mask register 2**

Address: 3Ah

Type: RW

**Table 75. IRQ mask register 2**

Bit	Name	Default	Function	Comment
7	M_gpe	0	Mask IRQ due to general purpose timer expire	-
6	M_nre	0	Mask IRQ due to No-response timer expire	-
5:0	RFU <5:0>	0	RFU	-

**5.15.56 IRQ mask register 3**

Address: 3Bh

Type: RW

**Table 76. IRQ mask register 3**

Bit	Name	Default	Function	Comment
7	M_wutme	0	Mask IRQ after each WU measurement event (Calibration, wake-up measurement, Recal.)	-
6:5	RFU <1:0>	0x0	RFU	-
4	M_dct	0	Mask IRQ due to termination of direct command	-
3	M_wuq	0	Mask IRQ due to WU Q-channel Measurement	-
2	M_wui	0	Mask IRQ due to WU I-channel Measurement	-
1	M_wut	0	Mask IRQ due to wake-up timer	-
0	M_osc	0	Mask IRQ when oscillator is ready	-

**5.15.57 IRQ status register 1**

Address: 3Ch

Type: RO

**Table 77. IRQ status register 1**

Bit	Name	Default	Function	Comment
7	I_subc_start	0	IRQ due to subcarrier start	-
6	I_col	0	IRQ due to bit collision	-
5	I_wl	0	IRQ due to FIFO water level	-
4	I_rx_rest	0	IRQ due to automatic reception restart	-
3	I_rxe	0	IRQ due to end of receive	-
2	I_rxs	0	IRQ due to start of receive	-
1	I_txe	0	IRQ due to end of transmission	-
0	I_rx_err	0	IRQ due to Reception error	-

**5.15.58 IRQ status register 2**

Address: 3Dh

Type: RO

**Table 78. IRQ status register 2**

Bit	Name	Default	Function	Comment
7	I_gpe	0	IRQ due to general purpose timer expire	-
6	I_nre	0	IRQ due to No-response timer expire	-
5:0	RFU <5:0>	0x0	RFU	-

**5.15.59 IRQ status register 3**

Address: 3Eh

Type: RO

**Table 79. IRQ status register 3**

Bit	Name	Default	Function	Comment
7	I_wutme	0	IRQ after each WU measurement event (Calibration, wake-up measurement, Recalibration)	-
6:5	RFU <1:0>	0x0	RFU	-
4	I_dct	0	IRQ due to termination of direct command	-
3	I_wuq	0	IRQ due to WU Q-channel Measurement	-
2	I_wui	0	IRQ due to WU I-channel Measurement	-
1	I_wut	0	IRQ due to wake-up timer	-
0	I_osc	0	IRQ when oscillator is ready (represents all_ok-including agd_ok and wait_ok)	-

**5.15.60 IC identify register**

Address: 3Fh

Type: RO

**Table 80. IC identify register**

Bit	Name	Default	Function	Comment
7:3	ic_type<4:0>	0x16	5-bit IC type code	5-bit IC type code



Bit	Name	Default	Function	Comment
		10110b	Code for ST25R501: 10110	
2:0	ic_rev<2:0>	0	IC revision code 001: rev 1.1	3-bit IC revision code

### 5.15.61 Status register 1

Address: 40h

Type: RO

**Table 81. Status register 1**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	wut_on	0	1: WU timer is running	-
5	agd_ok	0	1: AGD stable	-
4	osc_ok	0	1: Oscillator stable	-
3	RFU	0	RFU	-
2	tmp_on	0	1: Oscillator temporary enabled	-
1	efd_out	0	1: External field above the threshold	Only valid if efd_on = 1
0	efd_on	0	1: External field detector active	-

**5.15.62 Status register 2**

Address: 41h

Type: RO

**Table 82. Status register 2**

Bit	Name	Default	Function	Comment
7	subc_on	0	1: Subcarrier detected	-
6	gpt_on	0	1: General purpose timer is running	-
5	nrt_on	0	1: No-response timer is running	-
4	mrt_on	0	1: Mask receive timer is running	-
3	rx_act	0	1: Receive is receiving a message	-
2	rx_on	0	1: Receive decoder is enabled	-
1	tx_on	0	1: Transmission is active (data)	-
0	RFU	0	RFU	-

**5.15.63 Static status register 1**

Address: 42h

Type: RO

**Table 83. Static status register 1**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:5	RFU<1:0>	0x0	RFU	-
4	s_dct	0	Command terminated	-
3:0	RFU<3:0>	0x0	RFU	-

*Note:* Each bit can be individually cleared by setting it to 1.

**5.15.64 Static status register 2**

Address: 43h

Type: RO

**Table 84. Static status register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	RFU	0	RFU	-
5	s_rx_err	0	Reception error detected	-
4	s_rxe	0	Reception ended	-
3	s_rx_rest	0	Reception restarted	-
2	s_col	0	Collision detected	-
1	s_rxs	0	Data reception started	-
0	RFU	0	RFU	-

*Note:* Each bit can be individually cleared by setting it to 1.

**5.15.65 Static status register 3**

Address: 44h

Type: RO

**Table 85. Static status register 3**

Bit	Name	Default	Function	Comment
7	s_crc	0	CRC error	-
6	s_par	0	Parity error	-
5	s_hfe	0	Hard framing error	-
4	s_sfe	0	Soft framing error	-
3:0	RFU<3:0>	0	RFU	-

*Note:* Status bits are cleared at the start of reception.  
 Each bit can be individually cleared by setting it to 1

**5.15.66 Wake up status register**

Address: 47h

Type: RO

**Table 86. Wake up status register**

Bit	Name	Default	Function	Comment
7	RFU	1	RFU	-
6	q_tdi2	0	1 in case q_adc is above q_ref + q_diff	-
5	q_tdi1	0	1 in case q_adc is between or equals q_ref - q_diff, q_ref + q_diff	-
4	q_tdi0	0	1 in case q_adc is below q_ref - q_diff	-
3	RFU	0	RFU	-
2	i_tdi2	0	1 in case i_adc is above i_ref + i_diff	-
1	i_tdi1	0	1 in case i_adc is between or equals i_ref - i_diff, i_ref + i_diff	-
0	i_tdi0	0	1 in case i_adc is below i_ref - i_diff	-

**5.15.67 Analog display register 1**

Address: 48h

Type: RO

**Table 87. Analog display register 1**

Bit	Name	Default	Function	Comment
7	i_lim	0	1: VDD_DR regulator in current limit mode	-
6:0	regc<6:0>	0x7F	Actual regulator control setting	-

**5.15.68 Analog display register 2**

Address: 49h

Type: RO

**Table 88. Analog display register 2**

Bit	Name	Default	Function	Comment
7:4	RFU<3:0>	0	RFU	-
3:0	afe_gain<3:0>	0	Read operation and wake-up operation: Actual AFE Rx gain	-

**5.15.69 RSSI display register 1**

Address: 4Ah

Type: RO

**Table 89. RSSI display register 1**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:0	rss_i<6:0>	0	Reader operation: I channel RSSI (7 bit)	-

**5.15.70 RSSI display register 2**

Address: 4Bh

Type: RO

**Table 90. RSSI display register 2**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6:0	rss_q<6:0>	0	Reader operation: Q Channel RSSI (7 bit)	-

**5.15.71 Sense RF display register**

Address: 4Ch

Type: RO

**Table 91. Sense RF display register**

Bit	Name	Default	Function	Comment
7:0	sense_adc<7:0>	0	Result of sense RF direct command	-

**5.15.72 AWS configuration register 1**

Address: 4Dh

Type: RW

**Table 92. AWS configuration register 1**

Bit	Name	Default	Function	Comment
7	dig_aws_en	0	1: Digital filter in AWS path	-
6	dyn_ilim_aws	1	1: Dynamic limiter for AWS mode	-
5	dyn_sink_offset	1	1: Dynamic offset in Act. sink	-
4	dyn_pass_sink	1	1: Dynamic passive sink	-
3	sc_prot_en	1	1: Enable short circuit protection	-
2	sink_offset_en	1	1: Enable Active Sink offset	-

Bit	Name	Default	Function	Comment
1	act_sink_en	1	1: Enable Active sink	-
0	RFU	0	RFU	-

**5.15.73 AWS configuration register 2**

Address: 4Eh

Type: RW

**Table 93. AWS configuration register 2**

Bit	Name	Default	Function	Comment
7:4	am_fall<3:0>	0x7	Filter for AM reference (AWS) fall time	-
3:0	am_rise<3:0>	0x7	Filter for AM reference (AWS) rise time	-

**5.15.74 AWS timing register 1**

Address: 4Fh

Type: RW

**Table 94. AWS timing register 1**

Bit	Name	Default	Function	Comment
7:4	tentx1<3:0>	3	Time	In $f_C$ periods
3:0	tdres1<3:0>	3	Time	In $f_C$ periods

**5.15.75 AWS timing register 2**

Address: 50h

Type: RW

**Table 95. AWS timing register 2**

Bit	Name	Default	Function	Comment
7:4	tpasssinkx1<3:0>	0	Time	In $f_C$ periods
3:0	tsinkoff1<3:0>	0	Time	In $f_C$ periods

**5.15.76 AWS timing register 3**

Address: 51h

Type: RW

**Table 96. AWS timing register 3**

Bit	Name	Default	Function	Comment
7:4	tilim2<3:0>	0xF	Time	In $f_C$ periods
3:0	tdres2<3:0>	3	Time	In $f_C$ periods

**5.15.77 AWS timing register 4**

Address: 52h

Type: RW

**Table 97. AWS timing register 4**

Bit	Name	Default	Function	Comment
7:4	tpasssinkx2<3:0>	0	Time	In $f_C$ periods
3:0	tsinkoff2<3:0>	0	Time	In $f_C$ periods

**5.15.78 Overshoot protection register**

Address: 53h

Type: RW

**Table 98. Overshoot protection register**

Bit	Name	Default	Function	Comment
7:0	ov_pattern<7:0>	0	Bit pattern controlling low to high transition	Bit Value 0: Drive with d_res impedance Bit Value 1: Drive using md_res impedance LSB is transmitted first Pattern applies only if res_am=1

**5.15.79 Undershoot protection register**

Address: 54h

Type: RW

**Table 99. Undershoot protection register**

Bit	Name	Default	Function	Comment
7:0	un_pattern<7:0>	0	Bit pattern controlling high to low transition	Bit value 0: Drive with md_res impedance Bit value 1: Drive using d_res impedance LSB is transmitted first Pattern applies only if res_am=1

**5.15.80 External field detector**

Address: 57h

Type: RW

**Table 100. External field detector**

Bit	Name	Default	Function	Comment
7:4	efd_dt<3:0>	2	Deactivation threshold	-
3:0	efd_at<3:0>	3	Activation threshold	-

**Table 101. External field detector threshold**

efd_dt<3:0> efd_at<3:0>	efd_dt3 efd_at3	efd_dt2 efd_at2	efd_dt1 efd_at1	efd_dt0 efd_at0	V_RF1/2 (mVp)
0x0	0	0	0	0	50
0x1	0	0	0	1	100
0x2	0	0	1	0	150
0x3	0	0	1	1	200
0x4	0	1	0	0	250
0x5	0	1	0	1	300
0x6	0	1	1	0	350
0x7	0	1	1	1	400
0x8	1	0	0	0	12.5
0x9	1	0	0	1	25

efd_dt<3:0> efd_at<3:0>	efd_dt3 efd_at3	efd_dt2 efd_at2	efd_dt1 efd_at1	efd_dt0 efd_at0	V_RF1/2 (mVp)
0xA	1	0	1	0	37.5
0xB	1	0	1	1	50
0xC	1	1	0	0	62.5
0xD	1	1	0	1	75
0xE	1	1	1	0	87.5
0xF	1	1	1	1	100

Note: efd\_dt3 or efd\_at3 = 1: Additional pre-amplifier enabled, which causes increased current consumption when the external field detector is enabled.

## 5.16 Test registers

Table 102. Test registers

Type	Address(hex)	Register name	Type , , power domain
Test register	08	ADC to RAM register	RW, PD
	0E	Oscillator timing control register	RW, PD
	13	Manual timing register	RW, PD
	14	Diagnostic measurement register	RW, PD
	30	Receive start timer display register 1	RO, RD
	31	Receive start timer display register 2	RO, RD
	32	Receive end timer display register 1	RO, RD
	33	Receive end timer display register 2	RO, RD

### 5.16.1 ADC to CE Memory register

Address: Test register 08h

Type: RW

Table 103. ADC to CE memory register

Bit	Name	Default	Function	Comment
7:4	RFU<3:0>	0	RFU	-
3	adc_ce_src	0	0: ADC I-channel (6 bit) 1: Correlator input I-channel (8 bit)	Input source selection
2	adc_ce_rate<1:0>	0	0: 13.56 MHz 1: 6.78 MHz	Sampling rate selection
1:0	adc_ce	0	00: sampling disabled 01: sampling falling edge 10: sampling rising edge 11: sampling falling and rising edge	Select sampling of the modulation signal



### 5.16.2 Oscillator timing control register

Address: Test register 0Eh

Type: RW

**Table 104. Oscillator timing control register**

Bit	Name	Default	Function	Comment
7:6	RFU<1:0>	0	RFU	-
5:0	wait_ok_count_set <5:0>	0	Additional oscillator startup delay in 38.11 $\mu$ s steps	-

### 5.16.3 Manual timing register

Address: Test register 13h

Type: RW

**Table 105. Manual timing register**

Bit	Name	Default	Function	Comment
7	RFU	0	RFU	-
6	man_wait_ok	0	0: disable delay 1: enable delay	Additional oscillator startup delay (man_wait_count_set)
3:0	RFU<3:0>	0	RFU	-

### 5.16.4 Diagnostic measurement register

Address: Test register 14h

Type: RW

**Table 106. Diagnostic measurement register**

Bit	Name	Default	Function	Comment
7:3	RFU<4:0>	0	RFU	-
2	discon_tad_out	0	1: TAD1 and TAD2 pad output is disconnected during diagnostic measurement	To be set to 1 during diagnostic measurements
1:0	RFU<1:0>	0	RFU	-

### 5.16.5 Receive start timer display register 1

Address: Test register 30h

Type: RO

**Table 107. Receive start timer display register 1**

Bit	Name	Default	Function	Comment
7:0	t_rxs <15:8>	0x00	Time (based on NRT setting) between transmission end (l_txe) to start of reception (l_rxs)	msb part

Note: *t\_rxs* is displayed for each reception without error.

### 5.16.6 Receive start timer display register 2

Address: Test register 31h

Type: RO

**Table 108. Receive start timer display register 2**

Bit	Name	Default	Function	Comment
7:0	t_rxs <7:0>	0x00	Time (based on NRT setting) between transmission end (l_txe) to start of reception (l_rxs)	lsb part

*Note:* t\_rxs is displayed for each reception without error.

### 5.16.7 Receive end timer display register 1

Address: Test register 32h

Type: RO

**Table 109. Receive end timer display register 1**

Bit	Name	Default	Function	Comment
7:0	t_rxe <15:8>	0x00	Time (based on NRT setting) between transmission end (l_txe) to end of reception (l_rxe)	msb part

*Note:* t\_rxe is displayed for each reception without error.

### 5.16.8 Receive end timer display register 2

Address: Test register 33h

Type: RO

**Table 110. Receive end timer display register 2**

Bit	Name	Default	Function	Comment
7:0	t_rxe <7:0>	0x00	Time (based on NRT setting) between transmission end (l_txe) to end of reception (l_rxe)	lsb part

*Note:* t\_rxe is displayed for each reception without error.

## 6 Electrical characteristics

### 6.1 Absolute maximum ratings

Any stress beyond the limits listed in the following table may permanently damage it. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated in the following table is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**Table 111. Absolute maximum ratings**

Symbol	Parameter	Min	Max	Unit	Note
$V_{DD}^{(1)}$	Positive supply voltage	-0.3	6.5	V	Pin numbers: 9 and 14
$V_{DD\_IO}^{(1)}$	Peripheral communication supply voltage	-0.3	6.5		Pin number: 4
$\Delta(V_{DD} - V_{DD\_TX})^{(1)}$	$V_{DD\_DIFF}$	-0.3	0.3		Pin numbers: 9 and 14
$V_{GND}^{(1)}$	Negative supply voltage	-0.3	0.3		Pin number: 5, 11, 19 and 25
$V_{PIO}^{(1)}$	Voltage for peripheral I/O communication pins	-0.3	6.5		Pin number: 1 - 3 and 22 - 24
$V_{P5V}^{(1)}$	Pin voltage in the 5 V domain	-0.3	6.5		Pin numbers: 7, 8, 10, 12 and 13
$V_{P3V}^{(1)}$	Pin voltage in the 3 V domain	-0.3	4.6		Pin numbers: 15 - 18, 20, 21
$V_{P1V}^{(1)}$	Pin voltage in the 1 V domain	-0.3	2.0		Pin number: 6
$V_{RFO}^{(1)}$	Maximum voltage on RFO1 and RFO2	-	6.6	$V_P$	-
$T_{Jun}^{(2)}$	Junction temperature	-40	135	°C	-
$I_{SCR}$	LU immunity	-200	200	mA	Norm: JESD78F
HBM <sup>(3)</sup>	ESD immunity	-2000	2000	V	Norm: JS-001-2024
CDM	ESD immunity	-500	500	V	Norm: JS-002-2022
$T_{strg}$	Storage temperature	-40	135	°C	-
$T_{bod}^{(4)}$	Package body temperature	-	260	°C	Norm: IPC/JEDEC J-STD-020F
-	Humidity non-condensing	5	85	%	-
$I_{VDD\_PEAK}$	Maximum peak driver current using internal voltage regulator	-	500	mA	-
$I_{VDD}$	Maximum continuous driver current using internal voltage regulator	-	375	mA	-

1. Referenced to  $V_{SS}(EP)$ .
2. Provide good thermal management to ensure that junction temperature remains below the specified value.
3. Positive and negative pulses applied on different combinations of pin connections, according to AEC-Q100-002 (compliant with ANSI/ESDA/JEDEC JS-001 standard,  $C1 = 100 \text{ pF}$ ,  $R1 = 1500 \text{ }\Omega$ ).
4. Reflow peak soldering temperature (body temperature) is specified according to the IPC/JEDEC J-STD-020 "Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices".

## 6.2 Operating conditions

**Table 112. Operating condition**

Symbol	Parameter	Min	Max	Unit	Note
$V_{DD}^{(1)}$	Positive supply voltage	2.7	5.5		Pin number 9 and 14
$V_{DD\_IO}^{(1)(2)}$	Peripheral communication supply voltage	1.65	5.5		Pin number 4
$\Delta(V_{DD} - V_{DD\_TX})$	$V_{DD\_DIFF}$	-0.2	0.2		Pin numbers: 9 and 14
$V_{PIO}^{(1)}$	Voltage for peripheral IO communication pins	0	5.5	V	Pin number 1 - 3 and 22 - 24
$V_{P5V}^{(1)}$	Pin voltage in the 5 V domain	0	5.5		Pin number 7, 8, 10, 12 and 13
$V_{P3V}^{(1)}$	Pin voltage in the 3 V domain	0	3.6		Pin number 15 - 18, 20, 21
$V_{P1V}^{(1)}$	Pin voltage in the 1 V domain	0	1.4		Pin number 6
$V_{RFI\_A}$	RFI input amplitude	0.15	3	$V_{PP}$	The maximum value must not exceed $V_{DD\_A}$ voltage.
$T_{Jun}$	Junction temperature	-40	135	°C	-
$V_{OSC\_PP}^{(1)}$	Oscillator amplitude in steady state	1	3	$V_{PP}$	-

1. Referenced to  $V_{SS}$
2.  $V_{DD\_IO} \leq V_{DD}$

### 6.3 Electrical specification

**Table 113. ST25R501 electrical characteristics ( $V_{DD} = V_{DD\_TX} = 5.5\text{ V}$ ,  $V_{DD\_IO} = 5.5\text{ V}$ )**

Symbol	Parameter	Condition	Min	Typ	Max	Unit
$I_{RESET}$	Supply current in hold RESET: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(1)}$	-	0.03	2	$\mu\text{A}$
		$T_{Jun} = 25\text{ °C}^{(1)}$	-	0.2	2	
		$T_{Jun} = 85\text{ °C}^{(1)(2)}$	-	1.5	15	
		$T_{Jun} = 125\text{ °C}^{(1)(2)}$	-	8.5	40	
$I_{PD}$	Supply current in power-down mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(3)}$	-	1.3	3	
		$T_{Jun} = 25\text{ °C}^{(3)}$	-	2.2	7	
		$T_{Jun} = 85\text{ °C}^{(2)(3)}$	-	8.2	35	
		$T_{Jun} = 125\text{ °C}^{(2)(3)}$	-	35	110	
$I_{WU}$	Supply current in wake-up mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(4)}$	-	2.0	8	
		$T_{Jun} = 25\text{ °C}^{(4)}$	-	2.9	8	
		$T_{Jun} = 85\text{ °C}^{(2)(4)}$	-	9	35	
		$T_{Jun} = 125\text{ °C}^{(2)(4)}$	-	36.1	110	
$I_{RD}$	Supply current in ready mode: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40\text{ °C}^{(5)}$	-	2.7	4	$\text{mA}$
		$T_{Jun} = 25\text{ °C}^{(5)}$	-	3	4	
		$T_{Jun} = 85\text{ °C}^{(2)(5)}$	-	3.2	8	
		$T_{Jun} = 125\text{ °C}^{(2)(5)}$	-	3.5	8	
		$T_{Jun} = 135\text{ °C}^{(2)(5)}$	-	3.6	8	
$I_{ALL}$	Supply current all active: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40\text{ °C}^{(6)}$	-	11.7	20	
		$T_{Jun} = 25\text{ °C}^{(6)}$	-	12	20	
		$T_{Jun} = 85\text{ °C}^{(2)(6)}$	-	12.5	20	
		$T_{Jun} = 125\text{ °C}^{(2)(6)}$	-	13	20	
		$T_{Jun} = 135\text{ °C}^{(2)(6)}$	-	13.5	20	
$R_{RFO}$	RFO1 and RFO2 driver output resistance	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(8)(9)}$	-	0.63	1.5	$\Omega$
$R_{RFI}$	RFI input resistance	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)}$	-	11.1	15	$\text{k}\Omega$
$V_{POR}$	Power on reset voltage	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)}$	-	0.8	1.3	V
$V_{AGD}$	AGD voltage	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)}$	1.44	1.5	1.56	V
$t_{RESET}$	Minimal duration of RESET in high state	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)}$	10	-	-	us
$t_{BOOT}$	Time between power On/reset high-to-low transition and first SPI operation	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)}$	70	140	900	us
$R_{TAD}$	Test output pin resistance in push-pull configuration	$T_{Jun} = -40\text{ °C to }135\text{ °C}^{(7)(10)(11)}$	-	54	90	$\Omega$

- Reset pin set to high level.
- Evaluated by characterization - not tested in production.
- Registers are at default state.
- Register 00h set to 01h, while other registers are in their default state.
- Register 00h set to 08h, while other registers are in their default state.
- Register 00h set to 78h and register 03h set to 0Fh, while other registers are in their default state.

7.  $V_{DD} = 6\text{ V}$  instead of  $5.5\text{ V}$ .
8. Tested at  $T_{Junc} = 25\text{ °C}$  in production. Other temperatures are evaluated by characterization - not tested in production.
9. Register 00h set to 78h and register 03h to 20h, while other registers are at default state, and XTI pin is forced to GND.
10. Tested in production at  $T_{Junc} = -40\text{ °C}$  and  $25\text{ °C}$ . Other temperatures are evaluated by characterization - not tested in production.
11. Register 00h set to 08h, register 07h set to D1h register 08h set either to 00h or 0fh, while other registers are set at default state.

**Table 114. ST25R501 electrical characteristics ( $V_{DD} = V_{DD\_TX} = 3.3\text{ V}$ ,  $V_{DD\_IO} = 3.3\text{ V}$ )**

Symbol	Parameter	Condition	Min	Typ	Max	Unit
$I_{RESET}$	Supply current in hold RESET: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(1)}$	-	0.02	1	$\mu\text{A}$
		$T_{Jun} = 25\text{ °C}^{(1)}$	-	0.07	1	
		$T_{Jun} = 85\text{ °C}^{(1)(2)}$	-	0.8	8	
		$T_{Jun} = 125\text{ °C}^{(1)(2)}$	-	5	30	
$I_{PD}$	Supply current in power-down mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(3)}$	-	0.8	2	
		$T_{Jun} = 25\text{ °C}^{(3)}$	-	1.4	5	
		$T_{Jun} = 85\text{ °C}^{(2)(3)}$	-	6.6	30	
		$T_{Jun} = 125\text{ °C}^{(2)(3)}$	-	30.5	90	
$I_{WU}$	Supply current in wake-up mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40\text{ °C}^{(4)}$	-	1.5	3	
		$T_{Jun} = 25\text{ °C}^{(4)}$	-	2	6	
		$T_{Jun} = 85\text{ °C}^{(2)(4)}$	-	7.3	30	
		$T_{Jun} = 125\text{ °C}^{(2)(4)}$	-	31.1	90	
$I_{RD}$	Supply current in ready mode: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40\text{ °C}^{(5)}$	-	2.5	4	$\text{mA}$
		$T_{Jun} = 25\text{ °C}^{(5)}$	-	2.8	4	
		$T_{Jun} = 85\text{ °C}^{(2)(5)}$	-	3	6	
		$T_{Jun} = 125\text{ °C}^{(2)(5)}$	-	3.3	7	
		$T_{Jun} = 135\text{ °C}^{(2)(5)}$	-	3.3	7	
$I_{ALL}$	Supply current all active: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40\text{ °C}^{(6)}$	-	10.9	15	
		$T_{Jun} = 25\text{ °C}^{(6)}$	-	11.3	15	
		$T_{Jun} = 85\text{ °C}^{(2)(6)}$	-	11.7	17	
		$T_{Jun} = 125\text{ °C}^{(2)(6)}$	-	12	17	
		$T_{Jun} = 135\text{ °C}^{(2)(6)}$	-	12.2	17	
$R_{RFO}$	RFO1 and RFO2 driver output resistance	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(2)(7)}$	-	1	2	$\Omega$
$R_{RFI}$	RFI input resistance	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(2)}$	-	11.1	15	$\text{k}\Omega$
$V_{POR}$	Power on reset voltage	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(8)}$	-	0.8	1.3	V
$V_{AGD}$	AGD voltage	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(8)}$	1.44	1.5	1.56	V
$t_{RESET}$	Minimal duration of RESET in high state	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(2)}$	10	-	-	$\mu\text{s}$
$t_{BOOT}$	Time between power on/RESET high-to-low transition and first SPI operation	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(2)}$	70	140	900	$\mu\text{s}$
$R_{TAD}$	Test output pin resistance in Push-Pull configuration	$T_{Jun} = -40\text{ °C}$ to $135\text{ °C}^{(2)(9)}$	-	64	110	Ohm

1. Reset pin set to high level.

2. Evaluated by characterization - not tested in production.
3. Registers set at their default state.
4. Register 00h set to 01h, while other registers are set at default state.
5. Register 00h set to 08h, while other registers are set at default state.
6. Register 00h set to 78h and Register 03h to 0Fh, while other registers are set at default state.
7. Register 00h set to 78h and Register 03h to 20h, , while other registers are set at default state, and XTI pin is forced to GND.
8. Tested at  $T_{Junc} = -40^{\circ}C$  and  $25^{\circ}C$  in production. Other temperatures are evaluated by characterization - not tested in production.
9. Register 00h set to 08h, register 07h set to D1h, register 08h set to either 00h or 0Fh, while other registers are at their default state.

**Table 115. ST25R501 electrical characteristics ( $V_{DD} = V_{DD\_TX} = 2.7 V$ ,  $V_{DD\_IO} = 2.7 V$ )**

Symbol	Parameter	Condition	Min	Typ	Max	Unit
$I_{RESET}$	Supply current in hold RESET: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40^{\circ}C^{(1)}$	-	0.02	1	$\mu A$
		$T_{Jun} = 25^{\circ}C^{(1)}$	-	0.06	1	
		$T_{Jun} = 85^{\circ}C^{(1)(2)}$	-	0.7	6	
		$T_{Jun} = 125^{\circ}C^{(1)(2)}$	-	4.5	25	
$I_{PD}$	Supply current in power-down mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40^{\circ}C^{(3)}$	-	0.7	2	
		$T_{Jun} = 25^{\circ}C^{(3)}$	-	1.2	5	
		$T_{Jun} = 85^{\circ}C^{(2)(3)}$	-	6.3	30	
		$T_{Jun} = 125^{\circ}C^{(2)(3)}$	-	29.3	85	
$I_{WU}$	Supply current in wake-up mode: $V_{DD} + V_{DD\_TX}$	$T_{Jun} = -40^{\circ}C^{(4)}$	-	1.3	3	
		$T_{Jun} = 25^{\circ}C^{(4)}$	-	1.8	6	
		$T_{Jun} = 85^{\circ}C^{(2)(4)}$	-	6.9	30	
		$T_{Jun} = 125^{\circ}C^{(2)(4)}$	-	29.9	85	
$I_{RD}$	Supply current in ready mode: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40^{\circ}C^{(5)}$	-	2.2	3	$mA$
		$T_{Jun} = 25^{\circ}C^{(5)}$	-	2.4	3	
		$T_{Jun} = 85^{\circ}C^{(2)(5)}$	-	2.6	6	
		$T_{Jun} = 125^{\circ}C^{(2)(5)}$	-	3	6	
		$T_{Jun} = 135^{\circ}C^{(2)(5)}$	-	3	6	
$I_{ALL}$	Supply current all active: $V_{DD} + V_{DD\_TX} + V_{DD\_IO}$	$T_{Jun} = -40^{\circ}C^{(6)}$	-	10.4	15	
		$T_{Jun} = 25^{\circ}C^{(6)}$	-	10.9	15	
		$T_{Jun} = 85^{\circ}C^{(2)(6)}$	-	11.3	17	
		$T_{Jun} = 125^{\circ}C^{(2)(6)}$	-	11.6	17	
		$T_{Jun} = 135^{\circ}C^{(2)(6)}$	-	11.7	17	
$R_{RFO}$	RFO1 and RFO2 driver output resistance	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(2)(7)}$	-	1.2	2.5	$\Omega$
$R_{RFI}$	RFI input resistance	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(2)}$	-	11.1	15	k $\Omega$
$V_{POR}$	Power on reset voltage	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(8)}$	-	0.8	1.3	V
$V_{AGD}$	AGD voltage	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(8)}$	1.44	1.5	1.56	V
$t_{RESET}$	Minimal duration of RESET in high state	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(2)}$	10	-	-	us
$t_{BOOT}$	Time between power on/RESET high-to-low transition and first SPI operation	$T_{Jun} = -40^{\circ}C$ to $135^{\circ}C^{(2)}$	70	140	900	us

Symbol	Parameter	Condition	Min	Typ	Max	Unit
R <sub>TAD</sub>	Test output pin resistance in push-pull configuration	T <sub>Jun</sub> = -40 °C to 135 °C <sup>(2)(9)</sup>	-	64	110	Ω

1. Reset pin set to high level.
2. Evaluated by characterization - not tested in production.
3. Registers are at default state.
4. Register 00h set to 01h, while other registers are at their default state.
5. Register 00h set to 08h, while other registers are at their default state.
6. Register 00h set to 78h and Register 03h to 0Fh, while other registers are at their default state.
7. Register 00h set to 78h and Register 03h to 20h, while other registers are at their default state, and XTI pin forced to GND.
8. Tested at T<sub>Junc</sub> = -40 °C and 25 °C in production. Other temperatures are evaluated by characterization - not tested in production.
9. Register 00h set to 08h, register 07h set to D1h, register 08h set to either 00h or 0Fh, while other registers are at their default state.

**Table 116. V<sub>DD\_IO</sub> supply current**

Symbol	Parameter	Condition	Min	Typ	Max	Unit
I <sub>VDD_IO</sub>	Supply current in reset mode	T <sub>Jun</sub> = -40 °C <sup>(1)</sup>	-	0.0008	1	μA
		T <sub>Jun</sub> = 25 °C <sup>(1)</sup>	-	0.0041	1	
		T <sub>Jun</sub> = 85 °C <sup>(1)(2)</sup>	-	0.082	5	
		T <sub>Jun</sub> = 125 °C <sup>(1)(2)</sup>	-	0.8	6	
		T <sub>Jun</sub> = 135 °C <sup>(1)(2)</sup>	-	1.4	10	
I <sub>VDD_IO</sub>	Supply current in ready mode	T <sub>Jun</sub> = -40 °C <sup>(1)</sup>	-	0.5	2	
		T <sub>Jun</sub> = 25 °C <sup>(1)</sup>	-	0.6	2	
		T <sub>Jun</sub> = 85 °C <sup>(1)(2)</sup>	-	0.75	4	
		T <sub>Jun</sub> = 125 °C <sup>(1)(2)</sup>	-	1.52	8	
		T <sub>Jun</sub> = 135 °C <sup>(1)(2)</sup>	-	2	10	
I <sub>VDD_IO</sub>	Supply current in reset mode	T <sub>Jun</sub> = -40 °C <sup>(3)</sup>	-	0	1	
		T <sub>Jun</sub> = 25 °C <sup>(3)</sup>	-	0.001	1	
		T <sub>Jun</sub> = 85 °C <sup>(2)(3)</sup>	-	0.06	2	
		T <sub>Jun</sub> = 125 °C <sup>(2)(3)</sup>	-	0.61	3	
I <sub>VDD_IO</sub>	Supply current in ready mode	T <sub>Jun</sub> = 135 °C <sup>(2)(3)</sup>	-	1.1	10	
		T <sub>Jun</sub> = -40 °C <sup>(3)</sup>	-	0.25	2	
		T <sub>Jun</sub> = 25 °C <sup>(3)</sup>	-	0.3	2	
		T <sub>Jun</sub> = 85 °C <sup>(2)(3)</sup>	-	0.41	3	
I <sub>VDD_IO</sub>	Supply current in ready mode	T <sub>Jun</sub> = 125 °C <sup>(2)(3)</sup>	-	1	6	
		T <sub>Jun</sub> = 135 °C <sup>(2)(3)</sup>	-	1.44	10	
		T <sub>Jun</sub> = -40 °C <sup>(4)</sup>	-	0	1	
		T <sub>Jun</sub> = 25 °C <sup>(4)</sup>	-	0.0015	1	
I <sub>VDD_IO</sub>	Supply current in reset mode	T <sub>Jun</sub> = 85 °C <sup>(2)(4)</sup>	-	0.053	2	
		T <sub>Jun</sub> = 125 °C <sup>(2)(4)</sup>	-	0.6	3	
		T <sub>Jun</sub> = 135 °C <sup>(2)(4)</sup>	-	1.04	10	



Symbol	Parameter	Condition	Min	Typ	Max	Unit
I <sub>VDD_IO</sub>	Supply current in ready mode	T <sub>Jun</sub> = -40 °C <sup>(4)</sup>	-	0.2	1	uA
		T <sub>Jun</sub> = 25 °C <sup>(4)</sup>	-	0.23	1	
		T <sub>Jun</sub> = 85 °C <sup>(2)(4)</sup>	-	0.32	2	
		T <sub>Jun</sub> = 125 °C <sup>(2)(4)</sup>	-	0.9	3	
		T <sub>Jun</sub> = 135 °C <sup>(2)(4)</sup>	-	1.3	10	
I <sub>VDD_IO</sub>	Supply current in reset mode	T <sub>Jun</sub> = -40 °C <sup>(5)</sup>	-	0	1	
		T <sub>Jun</sub> = 25 °C <sup>(5)</sup>	-	0	1	
		T <sub>Jun</sub> = 85 °C <sup>(2)(5)</sup>	-	0.02	2	
		T <sub>Jun</sub> = 125 °C <sup>(2)(5)</sup>	-	0.14	3	
		T <sub>Jun</sub> = 135 °C <sup>(2)(5)</sup>	-	0.22	10	
I <sub>VDD_IO</sub>	Supply current in ready mode <sup>(5)</sup>	T <sub>Jun</sub> = -40 °C <sup>(5)</sup>	-	0.09	1	
		T <sub>Jun</sub> = 25 °C <sup>(5)</sup>	-	0.11	1	
		T <sub>Jun</sub> = 85 °C <sup>(2)(5)</sup>	-	0.14	2	
		T <sub>Jun</sub> = 125 °C <sup>(2)(5)</sup>	-	0.28	3	
		T <sub>Jun</sub> = 135 °C <sup>(2)(5)</sup>	-	0.36	10	

1. V<sub>DD</sub> = V<sub>DD\_TX</sub> = V<sub>DD\_IO</sub> = 5.5 V
2. Evaluated by characterization - not tested in production.
3. V<sub>DD</sub> = V<sub>DD\_TX</sub> = V<sub>DD\_IO</sub> = 3.3 V
4. V<sub>DD</sub> = V<sub>DD\_TX</sub> = V<sub>DD\_IO</sub> = 2.7 V
5. V<sub>DD</sub> = V<sub>DD\_TX</sub> = V<sub>DD\_IO</sub> = 1.65 V

## 6.4 DC/AC characteristics for digital inputs and outputs

**Table 117. Table 7: Characteristics of CMOS I/Os**

Type	Symbol	Parameter	Condition	Min	Typ	Max	Unit
Input	$V_{IH}$	High level input	See note <sup>(1)</sup>	$0.8 \times V_{DD\_IO}$	-	-	V
	$V_{IL}$	Low level input voltage	See note <sup>(1)</sup>	-	-	$0.2 \times V_{DD\_IO}$	
	$I_{LEAK}$	Input leakage current	$V_{DD\_IO} = 1.65 - 5.5 V$	-	-	10	$\mu A$
Output	$V_{OH}$	High level output voltage	See note <sup>(1)</sup> $I_{SOURCE} = 1 mA^{(2)}$	$0.9 \times V_{DD\_IO}$	-	-	V
	$V_{OL}$	Low level output voltage	See note <sup>(1)</sup> $I_{SOURCE} = 1 mA^{(2)}$	-	-	$0.1 \times V_{DD\_IO}$	
	$C_{L-SPI}$	Capacitive load	See note <sup>(1)</sup>	-	-	50	pF
	$R_O$	Output resistance	See note <sup>(1)</sup>	-	60	260	$\Omega$
	$R_{PD}$	Pull-down resistance pin MISO	See note <sup>(1)</sup>	7	10	15	k $\Omega$

1.  $V_{DD} = 2.7 - 5.5 V$  and  $V_{DD\_IO} = 1.65 - 5.5 V$

2.  $I_{SOURCE} = 0.5 mA$  when  $V_{DD\_IO} < 2.7 V$

## 6.5 SPI characteristics

**Table 118. SPI characteristics (up to 10 MHz)**

Operation	Symbol	Parameter	Condition	Min	Typ	Max	Unit
General <sup>(1)</sup>	T <sub>SCLK</sub>	SCLK period	T <sub>SCLK</sub> = T <sub>SCLKL</sub> + T <sub>SCLKH</sub>	100	-	-	ns
	T <sub>SCLKL</sub>	SCLK low	-	45	-	-	
	T <sub>SCLKH</sub>	SCLK high	-	45	-	-	
	T <sub>SSH</sub>	SPI reset (BSS high)	-	100	-	-	
	T <sub>NCSL</sub>	BSS falling to SCLK rising	First SCLK pulse	25	-	-	
	T <sub>NCSH</sub>	SCLK falling to BSS rising	Last SCLK pulse	25	-	-	
	T <sub>DIS</sub>	Data in setup time	-	10	-	-	
	T <sub>DIH</sub>	Data in hold time	-	10	-	-	
	T <sub>DOD</sub>	Data out delay	C <sub>Load</sub> < 50 pF	-	20	45	
	T <sub>DOHZ</sub>	Data out to high impedance delay	C <sub>Load</sub> < 50 pF	-	20	-	
Read <sup>(1)</sup>	T <sub>DOD</sub>	Data out delay	C <sub>Load</sub> < 50 pF	-	20	45	ns
	T <sub>DOHZ</sub>	Data out to high impedance delay	C <sub>Load</sub> < 50 pF	-	20	-	

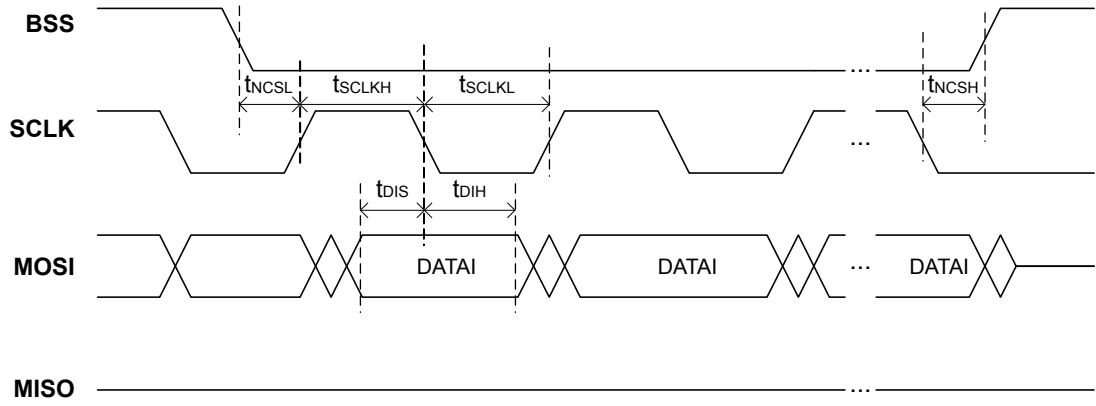
1. V<sub>DD\_IO</sub> = 2.7 V to 5.5 V, V<sub>DD</sub> = 2.7 V to 5.5 V, with V<sub>DD\_IO</sub> ≤ V<sub>DD</sub>.

**Table 119. SPI characteristics (up to 5 MHz)**

Operation	Symbol	Parameter	Condition	Min	Typ	Max	Unit
General <sup>(1)</sup>	T <sub>SCLK</sub>	SCLK period	T <sub>SCLK</sub> = T <sub>SCLKL</sub> + T <sub>SCLKH</sub>	200	-	-	ns
	T <sub>SCLKL</sub>	SCLK low	-	90	-	-	
	T <sub>SCLKH</sub>	SCLK high	-	90	-	-	
	T <sub>SSH</sub>	SPI reset (BSS high)	-	100	-	-	
	T <sub>NCSL</sub>	BSS falling to SCLK rising	First SCLK pulse	25	-	-	
	T <sub>NCSH</sub>	SCLK falling to BSS rising	Last SCLK pulse	25	-	-	
	T <sub>DIS</sub>	Data in setup time	-	10	-	-	
	T <sub>DIH</sub>	Data in hold time	-	10	-	-	
	T <sub>DOD</sub>	Data out delay	C <sub>Load</sub> < 50 pF	-	30	90	
	T <sub>DOHZ</sub>	Data out to high impedance delay	C <sub>Load</sub> < 50 pF	-	20	-	
Read <sup>(1)</sup>	T <sub>DOD</sub>	Data out delay	C <sub>Load</sub> < 50 pF	-	30	90	ns
	T <sub>DOHZ</sub>	Data out to high impedance delay	C <sub>Load</sub> < 50 pF	-	20	-	

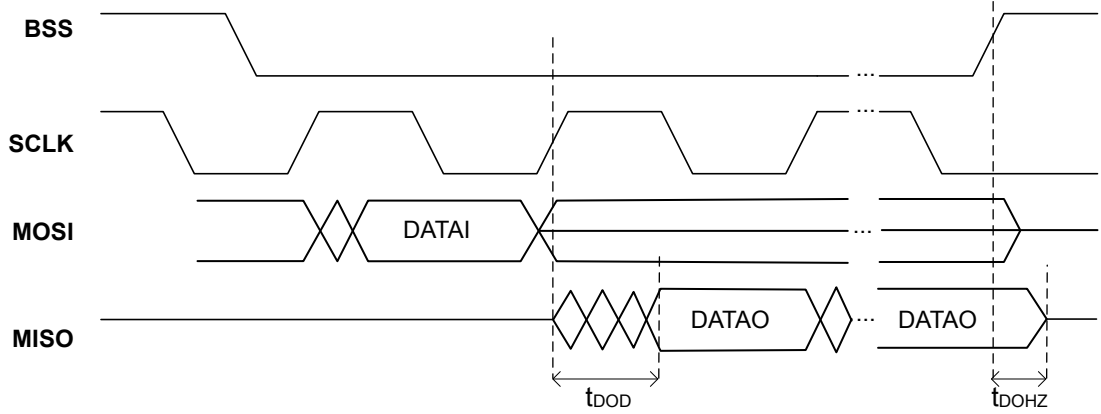
1. V<sub>DD\_IO</sub> = 1.65 V to 2.7 V, V<sub>DD</sub> = 2.7 V to 5.5 V, with V<sub>DD\_IO</sub> ≤ V<sub>DD</sub>.

**Figure 17. SPI timing diagram - General operation**



DT73092V1

**Figure 18. SPI timing diagram - Read operation**



DT73093V1

## 7 Package information

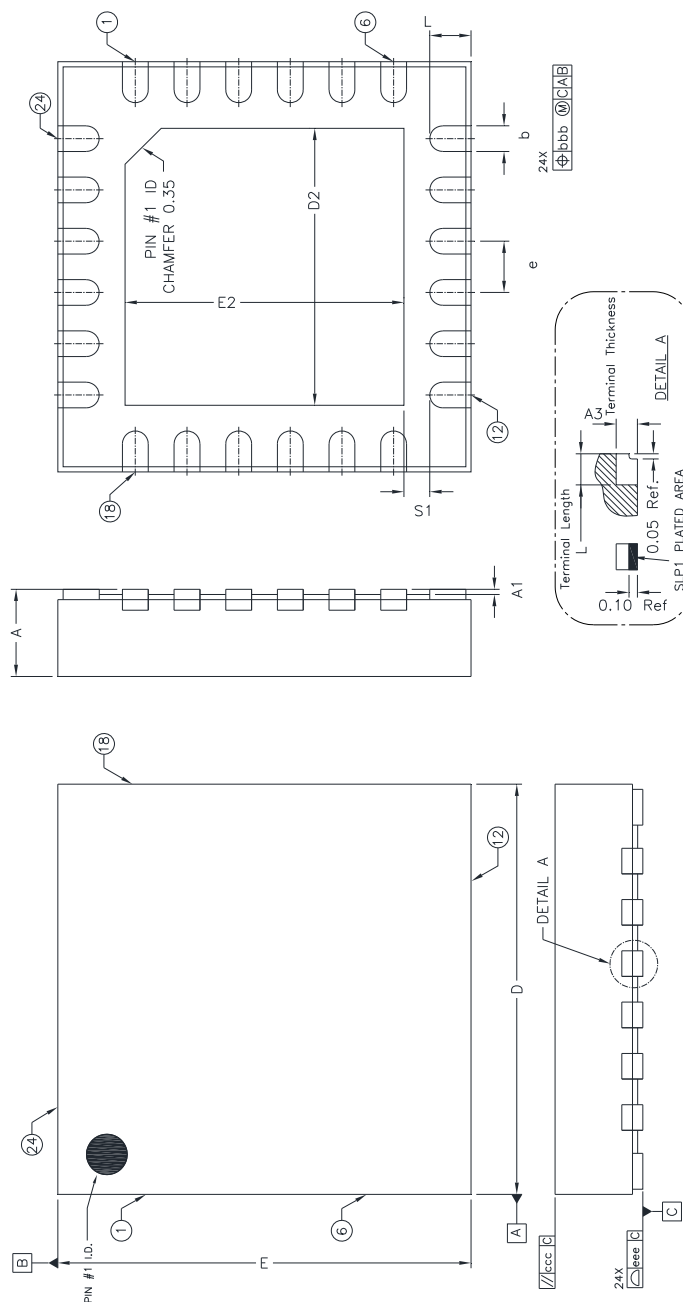
To meet environmental requirements, ST offers these devices in different grades of ECOPACK packages, depending on their level of environmental compliance. ECOPACK specifications, grade definitions, and product status are available at [www.st.com](http://www.st.com). ECOPACK is an ST trademark.

PI under development

### 7.1 VFQFPN24 package information (A2)

This VFQFPN (Very thin fine pitch quad flat package no lead) is a 24-lead package with dimensions of 4 x 4 mm and a 0.5 mm pitch.

**Figure 19. VFQFPN24 - Outline**



1. Drawing is not to scale

**Table 120. VFQFPN24 - Mechanical data**

Symbol	Millimeters			Inches <sup>(1)</sup>		
	Min	Typ	Max	Min	Typ	Max
A <sup>(2)</sup>	0.80	0.90	1.00	0.0315	0.0354	0.0394
A1 <sup>(3)</sup>	-	-	0.05	-	-	0.0020
A3	0.20 REF			0.0079 REF		
L	0.30	0.40	0.50	0.0118	0.0157	0.0197
b <sup>(4)</sup>	0.18	0.25	0.30	0.0071	0.0098	0.0118
D <sup>(5)</sup>	4.00 BSC			0.1575 BSC		
E <sup>(5)</sup>	4.00 BSC			0.1575 BSC		
e <sup>(5)</sup>	0.50 BSC			0.0197 BSC		
D2 <sup>(5)(6)</sup>	2.60	2.70	2.80	0.1024	0.1063	0.1102
E2 <sup>(5)(6)</sup>	2.60	2.70	2.80	0.1024	0.1063	0.1102
S1 <sup>(5)(6)</sup>	0.25 REF			0.0098 REF		
bbb <sup>(7)</sup>	-	0.10	-	-	0.0039	-
ccc <sup>(7)</sup>	-	0.10	-	-	0.0039	-
eee <sup>(7)</sup>	-	0.08	-	-	0.0031	-

1. Values in inches are converted from mm and rounded to four decimal digits.
2. The profile height A is the distance from the seating plane to the highest point on the package. It is measured perpendicular to the seating plane.
3. A1 is defined as the distance from the seating plane to the lowest point on the package body.
4. Dimension b is measured at the maximum diameter of the terminal (ball) in a plane parallel to datum C.
5. BSC stands for BASIC dimensions. It corresponds to the nominal value and has no tolerance. For tolerances, refer to the form and position table. On the drawing, these dimensions are framed. For the tolerances, refer to form and position values.
6. e represents the solder balls grid pitches.
7. Tolerance of form and position drawing

## 8 Ordering information

**Table 121. Ordering information scheme**

Example:	ST25	R	501	-	H	MW	T
<b>Device type</b>	ST25 = NFC/RFID tags and readers						
<b>Product type</b>	R = NFC/HF reader						
<b>Product feature</b>	501 = Automotive NFC reader for CCC DK and center console for space constrained applications						
<b>Ambient temperature range</b>	H = - 40 to 125 °C						
<b>Package/Packaging</b>	MW = Wettable flank QFN 24 (4 x 4 mm)						
<b>Tape and reel</b>	T = 4000 pcs/reel						

## Revision history

**Table 122. Document revision history**

Date	Revision	Changes
27-Jun-2025	1	Initial release.



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