AN5993

Application note

Wake-up mode for the ST25R200 and ST25R100

Introduction

The ST25R200 multipurpose NFC transceiver brings the convenience of contactless interaction to a variety of end applications.

This document describes the wake-up mode of the ST25R200, which features different low-power modes to detect the presence of a card. The device has two wake-up sources, which are monitored periodically through inductive measurements.

This document is based on the ST25R200, but also applies to the ST25R100.

For further information, refer to the datasheets (DS13658 and DS14139).

1 Terminology

The table below defines acronyms and other terms mentioned in this application note.

Table 1. Acronyms

Acronym	Definition
ADC	Analog-to-digital converter
AGD	Analog reference voltage
IRQ	Interrupt request
LPCD	Low power card detection
MCU	Microcontroller unit
NFC	Near Field Communication
OSC	Oscillator
PD	Power down
PCB	Printed circuit board
RC	Resistor-capacitor
RF	Radio frequency
RFAL	Radio frequency abstraction layer
WU	Wake-up
WUT	Wake-up timer
XTAL	Crystal

2 Wake-up mode

Card detection is usually performed by a polling cycle, which requires the reader to periodically turn on its field, wait for a certain period to fulfill the guard time (typically 5 to 20 ms), and then send a poll request.

As this procedure is inefficient in terms of power consumption and detection time, the ST25R products offer a low-power wake-up (WU) mode.

The ST25R200 wake-up mode is used to perform low-power card detection (LPCD), to inform or wake-up the system that a card is approaching. The low-power detection of the card 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.

Once in WU mode, the device operates an internal low-power RC oscillator, which triggers periodically the measurements of an emitted RF pulse:

- The measured values are internally compared against the deviation and intervals set by the user.
- During the inductive measurements, the signals received on RFI pins are processed, decomposed into I and Q channels, and converted using an ADC.
- The measured values are visible on two registers as 8-bit signed values, using two's complement representation, ranging from -128 to 127.

ST25R200 allows to configure the conditions when a wake-up IRQ is sent to the host, granting flexibility in how to use the WU mode.

It allows the MCU/host to remain in sleep mode while the device autonomously detects changes in its antenna surroundings.

Once the MCU has been woken up by the interrupt pin, it can proceed normally and then start typical NFC polling.

2.1 Wake-up period

In WU mode, the low-power RC oscillator is running, and most of the time is spent in this state where power consumption is minimal (refer to I_{WU} on the ST25R200 datasheet, DS13658).

Once the defined period elapses, ST25R200 gets enabled temporarily and a WU measurement is performed.

Several wake-up periods are available and are defined by `wut<3:0>` bits, as detailed below.

Table 2. Typical wake-up period/time

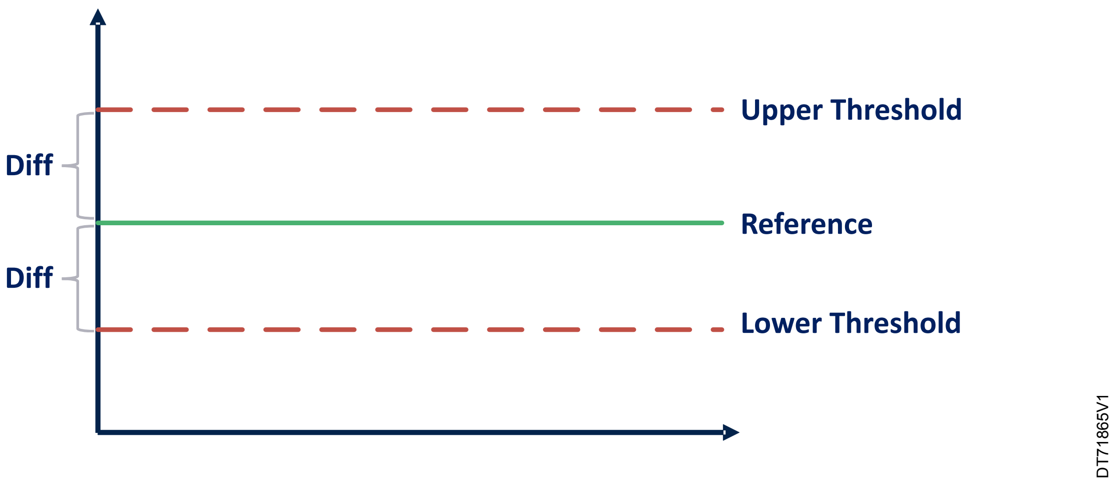
wut<3:0>	Wake-up period (ms)
0	9.7
1	13.3
2	19.3
3	26.6
4	38.7
5	53.2
6	77.3
7	106.3
8	154.7
9	212.7
10	309.3
11	425.3
12	618.6
13	850.6
14	1237.3
15	1701.2

2.2 Wake-up mechanism

When WU is running, the device performs periodic measurements and compares them against the configuration set by the host.

The host must set a delta or difference on the `i_diff/q_diff` bits. This value represents the variation from the current reference, defining the upper and lower thresholds (reference ± *diff*), used by the device assesses the WU trigger conditions.

Figure 1. WU trigger boundaries



Once the WU is calibrated (see Section 2.4: Wake-up calibration for more info), a reference value for the WU is set automatically or manually by the host. To set the reference manually, use the WU measurement command.

After setting `iq_aaref = 0`, the measured value must be transferred by the host from `i_adc/q_adc` to `i_ref/q_ref`.

When `iq_aaref = 1`, the reference is automatically obtained and set `on i_ref/q_ref` during the WU mode setup. For further information, refer to Section 3: Wake-up setup.

In this mode, autoaveraging is also enabled. For further information, refer to Section 2.5: Wake-up auto averaging.

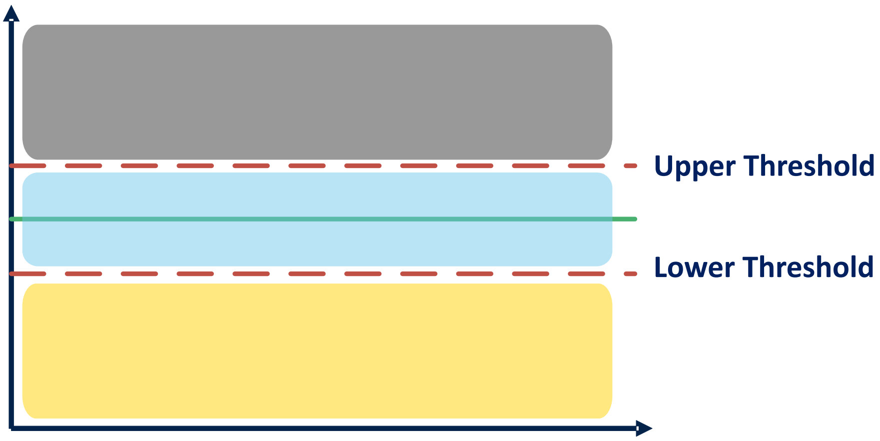
2.3 Wake-up trigger conditions

The current reference ± *diff* defines the upper and lower thresholds. After the measurement is performed at every WUT period, the device assesses the wake-up IRQ trigger conditions.

ST25R200 allows to configure the conditions when the wake-up IRQ must be sent, in the form of three intervals: above, between, lower.

- – IRQ when the latest measurement is above the upper limit: `i/q_adc > i/q_ref + i/q_diff`
  - IRQ when the latest measurement is in between the upper and lower limit: `i/q_ref - i/q_diff ≤ i/q_adc ≤ i/q_ref +i/q_diff`
  - IRQ when the latest measurement is below the lower limit: `i/q_adc < i/q_ref - i/q_diff`

Figure 2. WU trigger intervals



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Using these configurable trigger conditions, systems have more flexibility to cover use cases specific to their application.

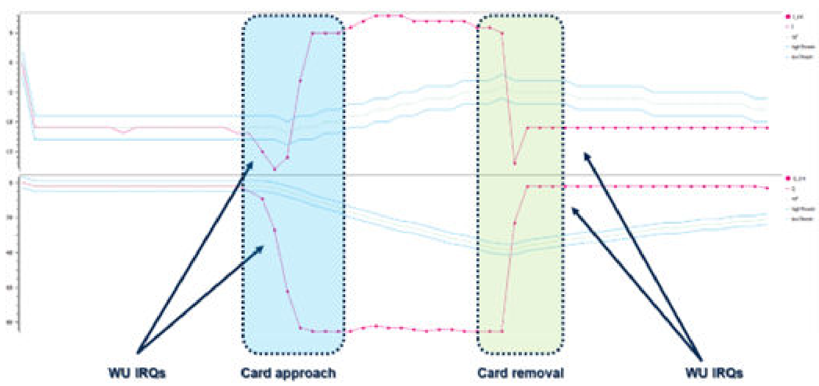
Note: The examples on Figure 3 and Figure 4 keep the WU mode running for illustration purposes. In a common application, the system host would likely react to the first IRQ and perform normal NFC polling/communication. Only then restart the WU mode with a new reference.

Variation detection

Typically, after going to sleep, the systems need to be informed/woken up when a variation is detected in the antenna vicinity. Therefore, any deviation detected on the I and/or Q channel must be notified to the host.

In this example, both I and Q channels are configured to trigger when above the upper limit and below the lower limit. Auto averaging is also enabled, so the reference evolves slowly towards the latest measurements. The dots on the magenta line denote WU IRQs.

Figure 3. WU variation detection



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In this example, once the measured value is outside the upper and lower limits, IRQs are periodically sent to the host.

Card approach only

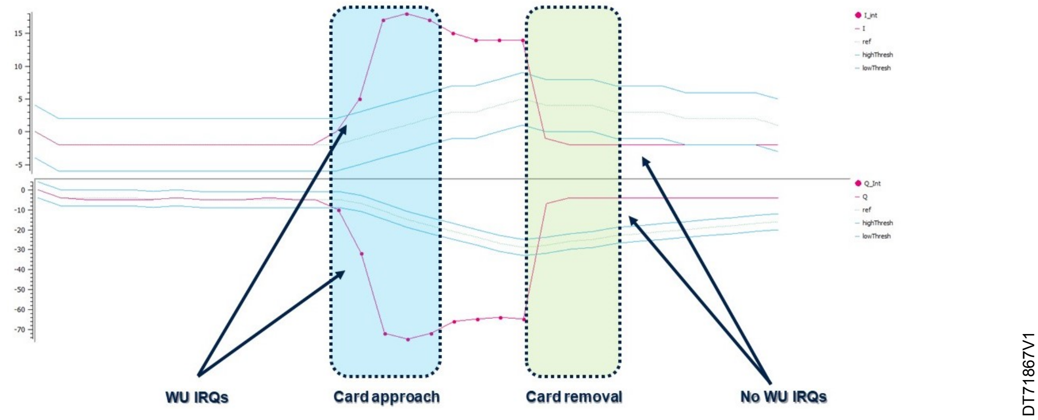
Often the systems need to be woken-up and perform a certain transaction via NFC upon a card or listener arrival.

The system returns afterwards to the WU mode and, as the card is removed from the reader antenna proximity, the system does not need to be woken up.

On the example below:

- I channel is configured to trigger only above the upper limit.
- Q channel is configured to trigger only below the lower limit.
- Autoaveraging is also enabled, so the reference evolves slowly towards the latest measurements.
- Magenta lines represent the measured value. Dots denote the WU IRQs.

Figure 4. WU card approach



With this setting, the ST25R200 WU modes informed when a card is approaching via WU IRQs, as shown in the blue area.

The measured value is above and below the limits on the I and Q channel, respectively.

As the card is removed, the measured values fall back to their initial values.

As the reference is still returning, the conditions below and above the limit on the I and Q channel, respectively, are satisfied. In this case, the host system is left in sleep state as the condition that the WU mode is perceiving is in the direction of a departing card.

Note: *Due to the various types of cards/listeners, it is not ensured that the detuning effect leads to the same increase/ decrease direction on I and Q channels. Such an example may suit better on closed systems where the NFC reader is expected to interact with a particular known card(s).*

2.4 Wake-up calibration

The WU mode on ST25R200 requires a calibration step before performing the WU measurements. It can be executed manually, via a direct command (Calibrate WU measurement), or automatically.

When starting the wake-up mode, if `skip_cal = 0`, a calibration step is performed automatically. A previous manual calibration is therefore not required.

The ST25R200 is also capable of performing recalibration autonomously. While the wake-up mode is running and `skip_recal = 0`, if the reference ± delta/diff is larger than 63, a recalibration step is performed.

This autonomous mechanism aims to compensate when the system conditions slowly drift. For instance, due to temperature changes throughout the day.

2.5 Wake-up auto averaging

Auto averaging is a method for the reference value to adapt dynamically on slow-varying environment conditions (such as temperature and voltage) using a weighted moving average.

The higher the weight, the longer the reference takes to adapt, as more measurements are required.

Auto average is enabled when iq_aaref=1 and the values for the weight are 4, 8, 16, and 32, defined by the i_aaw<1:0> and q_aaw<1:0> bits.

Every time a new WU measurement occurs, the weighted difference between the new and the stored value is added to the new reference:

$$new\_reference = \frac{\mathrm{old\_reference} - \mathrm{measured\_value}}{\mathrm{weight}}$$

The integer part of the current reference value is visible on the bits i_ref<7:0> and q_ref<7:0>. It gets cleared automatically every time the WU mode is restarted.

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

3 Wake-up setup

The ST25R200 allows to automatically calibrate and obtain a reference for the WU mode. It is possible to configure when these procedures take place.

The following settings influence the initial setup phase of the WU mode:

Table 3. Wake-up settings

Setting	Description
`skip_cal`	Enables/disables automatic calibration at startup
`iq_aaref`	Enables/disables autoaveraging feature. When enabled, the reference is obtained automatically as startup.
`skip_twcal`	If enabled, it disables calibration deferment at startup.
`skip_twref`	If enabled, it disables reference deferment at startup.

The following diagrams show how the different steps are executed along the startup phase, depending on the configuration.

Calibration and auto averaging enabled

Figure 5. WU startup: skip_twcal = 0 and skip_twref = 0

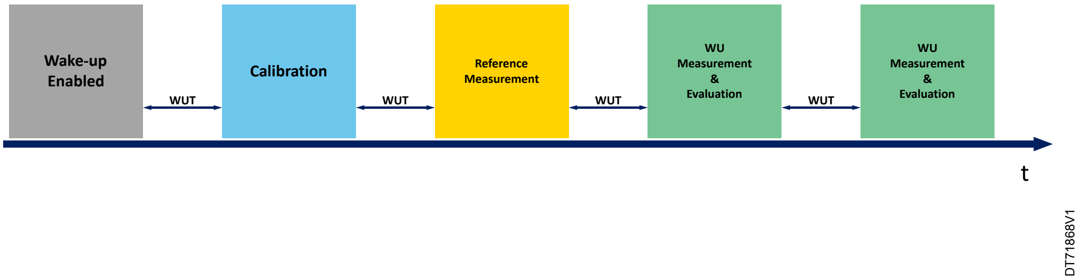


Figure 6. WU startup: skip_twcal = 0 and skip_twref = 1

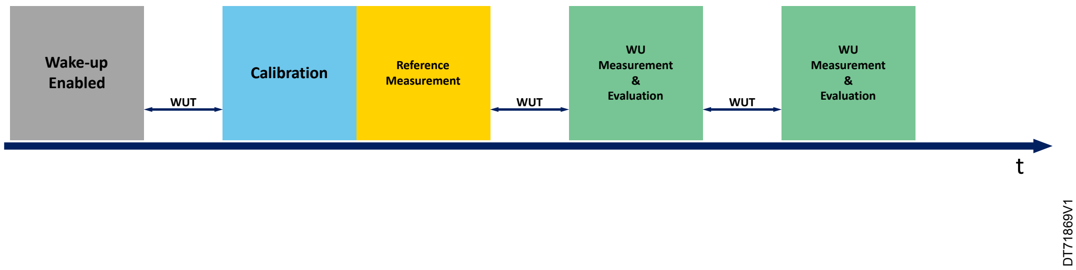


Figure 7. WU startup: skip_twcal = 1 and skip_twref = 0

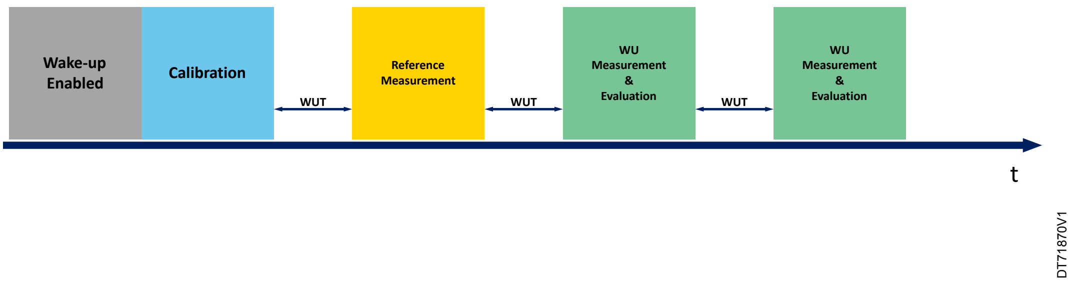
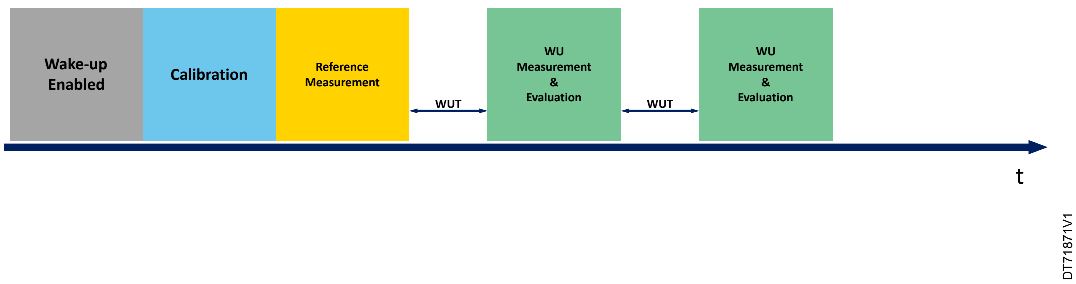


Figure 8. WU startup: skip_twcal = 1 and skip_twref = 1



Calibration disabled and auto averaging enabled

Figure 9. WU startup: skip_twref = 0

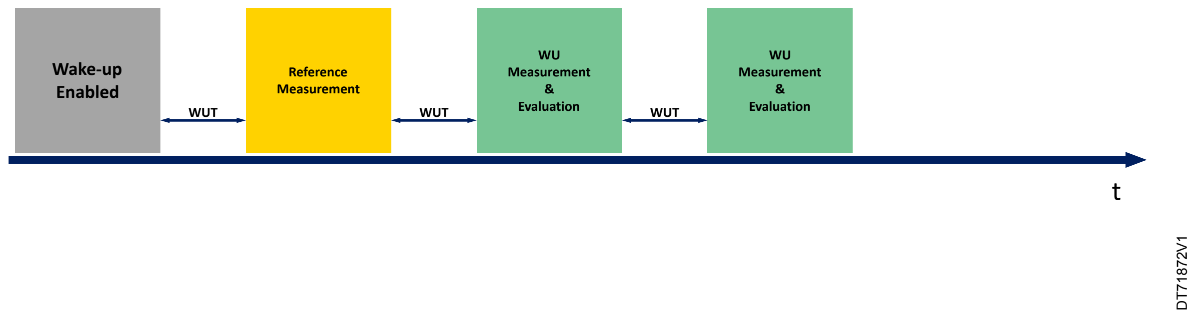
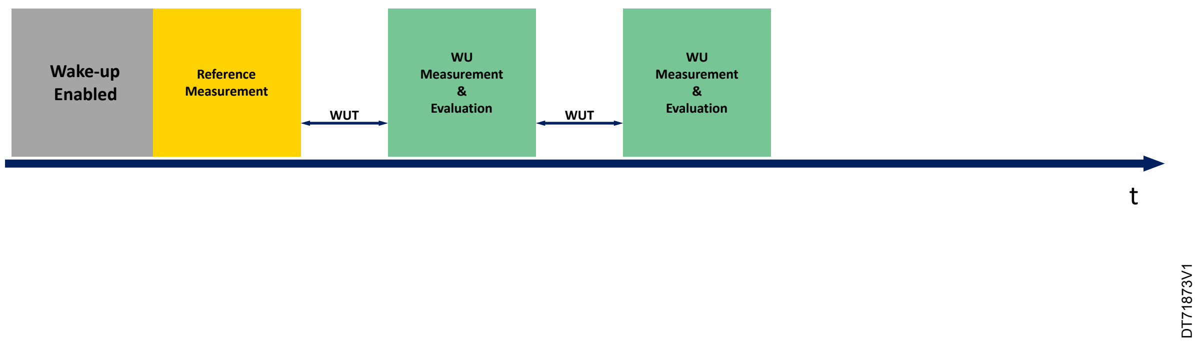
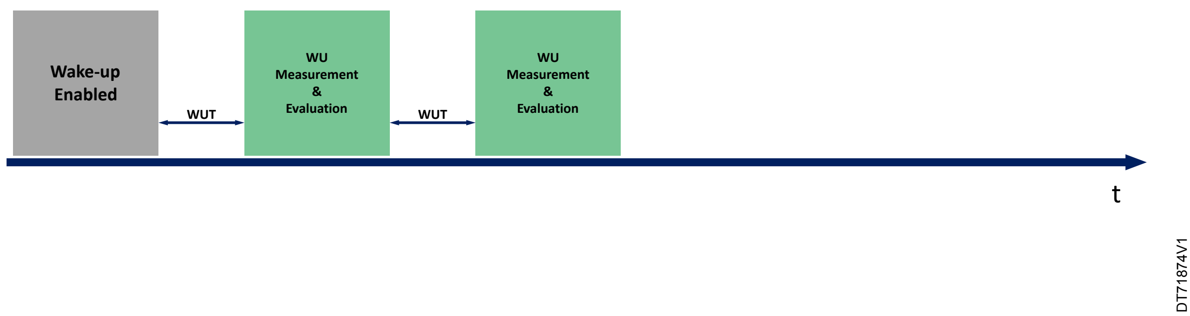


Figure 10. WU startup: skip_twref = 1



Calibration and auto averaging disabled

Figure 11. WU startup



The WU startup sequence behaves differently, depending on the settings used.

It is important to note that the first WU measurement and evaluation of the WU IRQ trigger conditions (in green) can take place at different moments. It may occur immediately after the first WUT expiration (WU period) or after three WUT periods (and two RF pulses emitted in between).

When automatic averaging is not enabled, the host must obtain and set the reference measurement to use during WU mode.

If not automatically retrieved, the reference measurement is often better to be obtained in an analogous condition as during the WU mode. That can be best replicated by executing the WU measurement command from the PD mode.

4 Wake-up measurement

The ST25R200 allows configurable WU measurement pulse duration.

The shorter the time where the device is emitting and measuring the inductive pulse, the lower the average power consumption. Longer measurement pulses can contribute to more stable and accurate measurements.

Several WU measurement pulse durations are available and are defined by the `td_mf` and `td_mt<1:0>` bits, as illustrated below.

Table 4. Measurement pulse length

td_mf	td_mt1	td_mt0	Measurement pulse (µs)
0	0	0	26.0
0	0	1	29.5
0	1	0	34.2
0	1	1	43.7
1	0	0	10.6
1	0	1	14.2
1	1	0	18.9
1	1	1	28.3

The ST25R200 performs the following steps:

1. Upon WUT expiration (an optional IRQ signal is available, `I_wut`), the device temporarily enables itself. It transits from WU to RD mode. Once the crystal oscillator becomes stable, an RF field is emitted and the received signal measured.
2. The new measurement is evaluated and an IRQ signal is produced, if the trigger conditions are satisfied.
3. Then the device returns to WU mode.
4. Upon the next WUT expiration, the same sequence occurs.

In detail, the ST25R200 measures the signal on the I and Q channels, and stores it into the corresponding registers.

The signal is handled internally, and it passes through an amplification stage controlled by `afe_gain_td<3:0>`. This setting improves the sensitivity of the measurement.

An increased sensitivity can lead to a less stable behavior, where WU IRQs are produced in the absence of a change in the antenna surroundings.

4.1 Channel variation

The received signal on RFI pins is decomposed into I and Q channels, which can show a different dynamic.

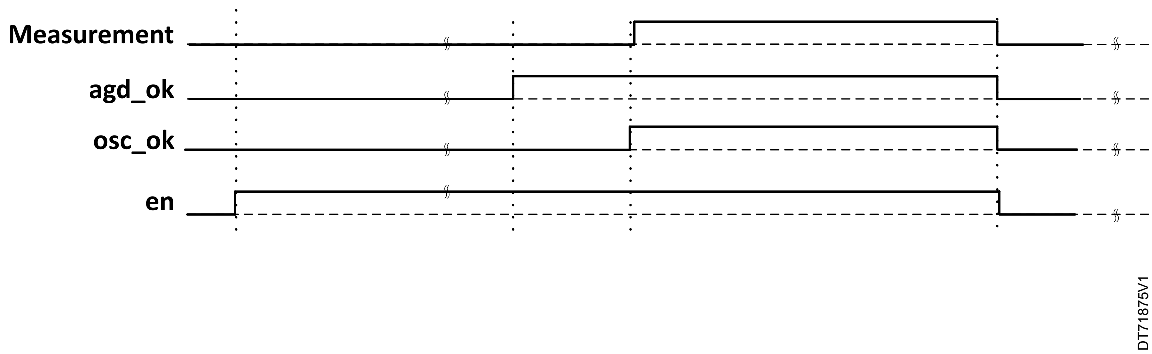
When a detuning element approaches, one of the channels (I or Q) can be more reactive than the other. Therefore, the delta/diff used during WU mode may not be symmetric between channels and must be thoroughly considered in each system, to have a good balance between stability and sensitivity.

4.2 Oscillator influence

When in WU mode, the device autonomously performs the periodic activities by temporarily enabling itself and triggering the measurement pulse. During the enable sequence, two conditions are required to obtain an accurate measurement:

- Oscillator stable (`osc_ok`)
- Analog reference stable (`agd_ok`)

Figure 12. **Temporary enable detail**



Typically, AGD becomes ready faster than the external XTAL oscillator. This is not ensured, and may happen that the external oscillator gets stable (osc_ok) faster than the analog reference. In this case, the measurement is performed when the AGD is still stabilizing, contributing to a certain variation within the measured values.

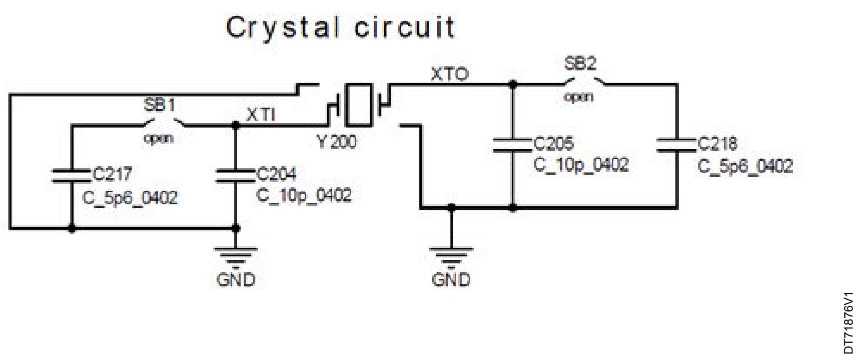
AGD stable (`agd_ok`) takes up to a max of 605 µs after enabling the device.

The oscillator stable (`osc_ok`) depends on external components, such as XTAL and assembled load capacitance.

There is no direct way to defer the osc_ok event within the device itself, but it is possible to adapt the XTAL load capacitance to ensure it always happens after agd_ok.

Note: To experiment with the added load capacitance and increased WU sensitivity (`afe_gain_td<3:0>`), additional load capacitance can be optionally added via SB1 and SB2 on X-NUCLEO-NFC09A1.

Figure 13. **X-NUCLEO-NFC09A1 XTAL circuit**



5 Wake-up mode power estimations

In the wake-up mode, the more frequent measurements are performed, the higher the average power consumption is.

The power consumption is directly dependent on the target matching impedance, which affects the driver current when the RF carrier is emitted.

Additionally, the longer the measurement pulse is, the more time is spent emitting the RF carrier, also leading to an increased power consumption.

Therefore, the average power consumption is estimated as a function of these variables/configurations and of the ST25R200 characteristics, obtained from the datasheet.

- I_{WU}: Supply current in wake-up mode
- I_{RD}: Supply current in ready mode
- I_M: Inductive measurement of current
- $T_{MEAS:}$ Measurement pulse length
- $T_{OUT:}$ Typical wake-up period/time
- $T_{OSC:}$ Oscillator startup time

The timeout interval (T_{OUT}) between each measurement stage is configurable by `wut<3:0>` bits.

The measurement pulse length is also configurable by `td_mf` ; `td_mt<1:0>` bits.

The oscillator ramp-up time is system dependent. It is typically below 1 ms.

The current during an inductive measurement (I_M) depends upon the matching impedance, therefore it varies with each system, typically between 150 mA and 200 mA.

For an estimate of the current consumption of the I_{AVG}, it is required to calculate the current consumption for the measurement ($I_{M,AVG}$), using the following equation:

$$I_{M,AVG} = (I_M - \mathrm{I}_{WU}) \left(\frac{T_{MEAS}}{T_{OUT}}\right)$$

An additional contribution from enabling of the oscillator must also be considered:

$$I_{OSC,AVG} = (I_{RD} - \mathrm{I}_{WU}) \left(\frac{T_{OSC}}{T_{OUT}}\right)$$

Then, the total current consumption of the I_{AVG} can be estimated as follows:

$$I_{AVG} = I_{M,AVG} + I_{OSC,AVG} + I_{WU}$$

For example, assuming that for a particular system I_M = 150 mA; T_{OSC} = 0.7 ms and it sets T_{OUT} = 212 ms; T_{MEAS} = 26 µs, the current consumption during the WU mode, can be estimated as:

- I_{WU} = 1.5 µA
- I_{RD} = 4.2 mA
- T_{MEAS} = 26 µs
- T_{OUT} = 212 ms
- I_M = 150 mA

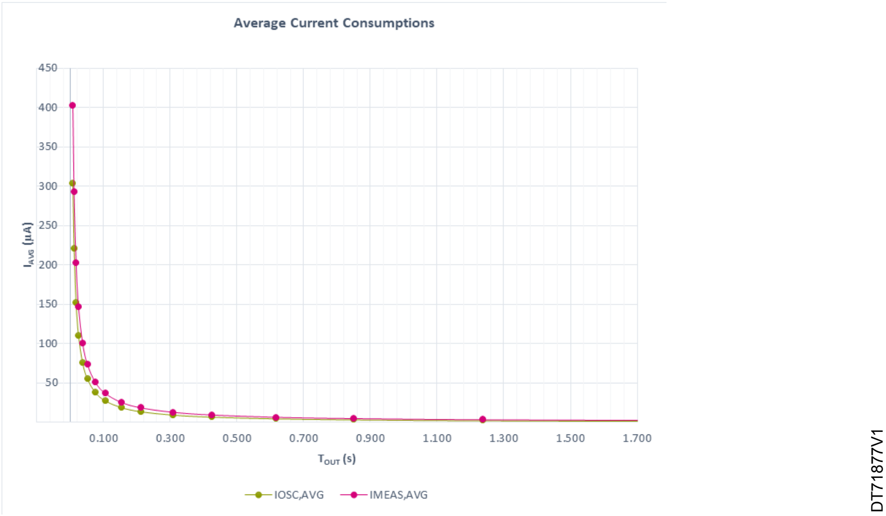
$$I_{M,AVG} = (I_M - I_{WU})\left(\frac{T_{MEAS}}{T_{OUT}}\right) = \left(150 \times 10^{-3} - 1.5 \times 10^{-6}\right)\left(\frac{26 \times 10^{-6}}{212 \times 10^{-3}}\right) = 18.3\mu A$$

$$I_{OSC,AVG} = \left(4.2 \times 10^{-3} - 1.5 \times 10^{-6}\right)\left(\frac{700 \times 10^{-6}}{212 \times 10^{-3}}\right) = 13.8\mu A$$

$$I_{AVG} = I_{M,AVG} + I_{OSC,AVG} + I_{WU} = 18.3\mu A + 13.8\mu A + 1.5\mu A = 33.65\mu A$$

In the figure below, it is possible to see how the current consumption evolves as a function timeout/period configuration (I_M = 250 mA; T_{OSC} = 0.7 ms; T_{MEAS} = 26 µs).

Figure 14. Average power consumption



Note: *To avoid leakage while in PD/WU mode, ST25R200 discharges the supplies V_{DD_A}, V_{DD_D} and AGD. These are then ramped up at every WUT period.*

Discharge of V_{DD_A} can optionally be disabled by setting bit0 on test register 09h. This configuration can only be used during WU mode and must be reverted once WU mode is terminated.

Revision history

Table 5. **Document revision history**

Date	Version	Changes
27-Sept-2023	1	Initial release.
27-Oct-2023	2	Updated the following: • Section 5: Wake-up mode power estimations
17-Nov-2023	3	Updated the following information: part number, reference documents.
03-Apr-2024	4	Changed the document scope from ST restricted to public.
20-Jun-2024	5	Updates: • Replaced device ST25R100 with ST25R200. • Minor text changes.

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