Wake-up mode for the ST25R300, ST25R500, ST25R501 and ST25R210

Introduction

The ST25R300 brings the convenience of contactless interaction to a variety of end applications. This document describes the wake-up mode of the ST25R300, 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 ST25R300, but also applies to the ST25R500, ST25R501 and ST25R210. For further information, refer to the datasheets (DS14655 and DS14593).

For the creation of this application note, the STEVAL-25R300KA and its associate software were used. The GUI is STSW-ST25R023, and the firmware is STSW-ST25R022.

1 Acronyms and definitions

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

Table 1. **Acronyms list**

Acronyms	Definitions
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 Reference documents

Table 2. **Reference documents**

Document reference	Document description
DS14655	*NFC reader for payment, consumer and industrial applications*, ST25R300 datasheet, STMicroelectronics
DS14593	*Automotive high performance NFC reader for CCC digital key and car center console*, ST25R500 datasheet, STMicroelectronics
DS15081	*NFC reader for industrial and consumer applications*, ST25R210 datasheet, STMicroelectronics

3 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 ST25R300, ST25R500, ST25R501 and ST25R210 wake-up modes are used to perform low-power card detection (LPCD) to wake-up and inform 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 MCU/host. The MCU/host can then perform the regular 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 thresholds 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 displayed on two registers as 8-bit signed values, using two complement representation, ranging from -128 to 127.

ST25R300, ST25R500, ST25R501 and ST25R210 enable the configuration of the conditions for sending a wake-up IRQ to the host, offering flexibility in using the WU mode.

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

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

3.1 Wake-up period

In WU mode, the RC oscillator is running while the IC is in power down mode, spending most of the time in this state where power consumption is at a minimum (refer to IWU in DS14655).

Once the defined period elapses, the ST25R300, ST25R500, ST25R501 and ST25R210 are temporally set in ready mode and a WU measurement is performed.

Several wake-up periods are available and are defined by wut bits, as detailed below:

Table 3. **Wake-up timer period**

wut<3:0>	WU periods (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

wut<3:0>	WU periods (ms)
0xF	Infinity

Figure 1 shows one complete pulse interval. The bit wut is set to 0x4, which is a wake-up interval of 100 ms and the bit `tagdet_len[CC1]` is set to 0x3. `Tagdet_len = 0x3` is used to extend the measurement pulse to 61.4 µs. Further information about `tagdet_len` can be found in Section 3.2: Measurement pulse duration.

Figure 1. **Wake-up interval 100 ms**

Measurement	Current	Mean	Min	Max	Range (Max-Min)	Std Dev	Count
① Burst period(1)	100.088320 ms	99.9416180 ms	99.7429800 ms	100.168280 ms	425.30000 µs	142.150033 µs	51
② Burst width(1)	60.36000 µs	60.318627 µs	60.22000 µs	60.40000 µs	180.00 ns	70.036 ns	102

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The yellow channel shows the magnetic RF field captured via a pick-up coil. It illustrates the emitted measurement pulse. The red channel shows the current consumption of the VDD and VDD_TX supply during the wake-up cycle. The small current peak at - 2.5 ms is further explained in Section 4.3: Weak discharge.

The burst period measurement shows the interval between the measurement pulses. The burst width measurement shows the field on duration captured via the pick-up coil. Since the signal is captured via a pick-up coil and due to the AWS, the measured pulse-length is not the same as outputted via the RFO pins.

3.2 Measurement pulse duration

As shown in Figure 5, the RF field is turned on during the I/Q measurement automatically. After the measurement is performed, the field is turned off again. The field on period is defined by the selected measurement time `td_mt`. The table below shows the measurement time dependent on the `td_mt` and `td_mf` setting.

Table 4. **I/Q measurement duration**

td_mt	td_mf	Measurement pulse µs
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

ST25R300, ST25R500, ST25R501 and ST25R210 offer the possibility to turn on the RF in advance of the actual I/Q measurement. This allows the power supply to react on the load change which can improve the wake-up stability. Figure 6 illustrates the RF pulse extension. For example, it would be possible to turn on the RF field for 61.4 µs when choosing `tagdet_len = 0x3`. The measurement could then be performed in the last 10.6 µs of the field on when `td_mt = 0x0` and `td_mf = 0x1`. This gives the external PMU approximately 50 µs to react on the load change when turning on the RF field.

Figure 2. **RF pulse extension**

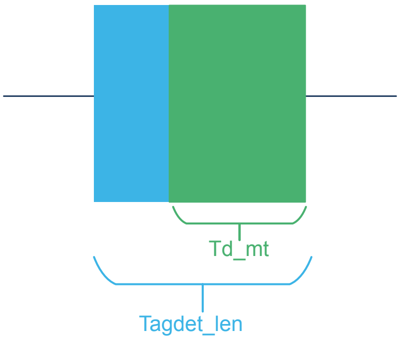


Table 6 shows the possible RF pulse extension. When `tagdet_len = 0x0`, the RF pulse length is defined by the setting of `td_mt` and `td_mf` without any further pulse extension.

Table 5. **Possible RF pulse extension**

Tagdet_len<1:0>	RF pulse duration [µs]	`td_mt` / `td_mf`
0	`td_mt` / `td_mf`	-
1	42.5	Any
2	51.9	Any
3	61.4	Any

3.3 Wake-up mechanism

When the 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 3. **WU trigger boundaries**

Once the WU is calibrated (see Section 4.4: Wake-up timer calibration for more information), a reference value for the WU is automatically set either by the ST25R300, the ST25R500, ST25R501 and ST25R210 or manually by the host. To set the reference manually, use the WU measurement command:

- The value `iq_aaref = 0` is selected when automatic averaging should not be used. 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 4: Wake-up setup. In this mode, automatic averaging is enabled. Automatic averaging is used to compensate for slow changes of the measurement result. It is used to overcome temperature changes, which are much slower compared to an approaching card. For further information, refer to Section 3.6: Wake-up auto averaging.

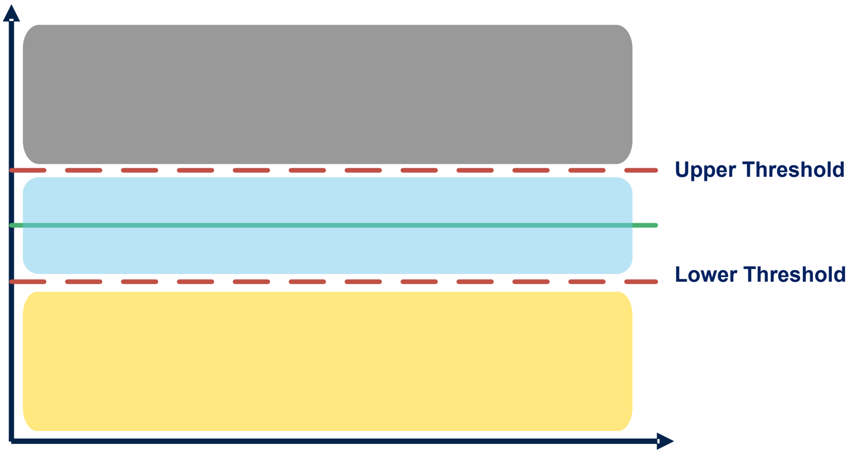
3.4 Wake-up trigger conditions

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.

The conditions are configured through ST25R300, ST25R500, ST25R501 and ST25R210 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 4. WU trigger intervals



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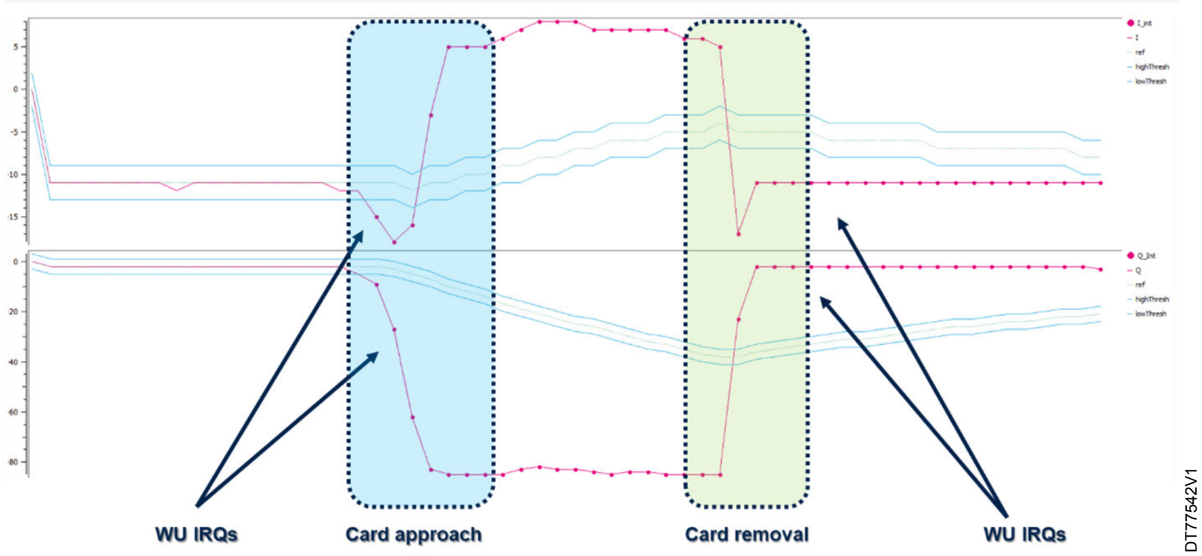
Using these configurable trigger conditions, the systems have more flexibility to cover use cases specific to their application.

3.5 Variation detection

Typically, after activating wake-up mode and enabling low-power mode on the MCU/host, 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 5. **WU variation detection**



In this example, once the measured value is outside the upper and lower limits, IRQs are periodically sent to the host. The positive or negative change of I and Q channel when a card is approaching is dependent on reader antenna matching and card resonance. This behavior cannot be generalized. One card can trigger a positive change on the I channel when approaching, another type of card can trigger a negative change.

3.5.1 Card approach only

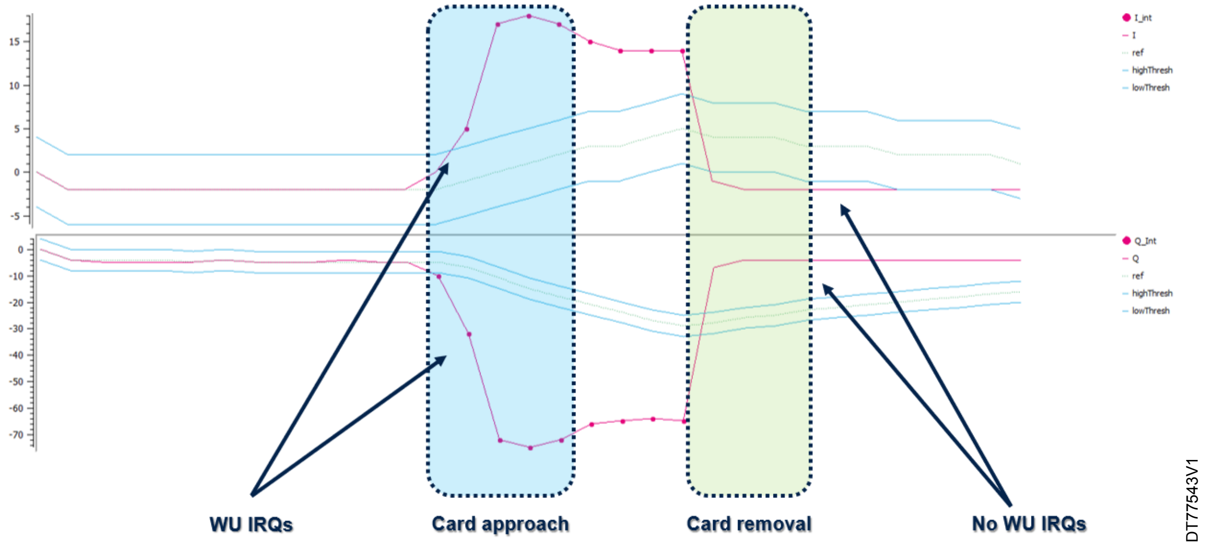
System are woken up when a card or a listener is approached to carry out NFC transactions.

The system then returns to the WU mode. 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. The dots denote the WU IRQs.

Figure 6. WU card approach



Note: Examples in Figure 5 and Figure 6 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

With this setting, the ST25R300, ST25R500, ST25R501 and ST25R210 WU modes inform 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).

3.6 Wake-up auto averaging

Auto averaging is a method for the reference value to adapt dynamically to 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, 32, 64, 100 and 128, 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:

$$newreference = \mathrm{oldreference} \quad - \quad \frac{\mathrm{oldreference} \quad - \quad \mathrm{measuredvalue}}{\mathrm{weight}}$$

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

Bits `i_iirqm` and `q_iirqm` define whether a measurement that causes an interrupt is taken into account for the average value calculation. Typically, the first interrupt notifies the MCU/host to stop the wake-up mechanism and poll for a card.

4 Wake-up setup

4.1 Wake-up measurement procedure

ST25R300, ST25R500, ST25R501 and ST25R210 enable automatic calibration and obtaining 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 6. Wake-up settings

Setting	Description
`skip_recal`	Enables/disables automatic re-calibration.
`skip_cal`	Enables/disables automatic calibration at startup.
`skip_twcal`	If enabled, it disables calibration delay at startup.
`skip_twref`	If enabled, it disables reference delay at startup.
`iq_aaref`	Enables/disables automatic averaging feature. When enabled, the reference is obtained automatically at startup.

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

4.1.1 Calibration and auto averaging enabled

The precondition for the figures below are:

- `Skip_recal = 0`
- `Skip_cal = 0`
- `iq_aaref = 1`

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

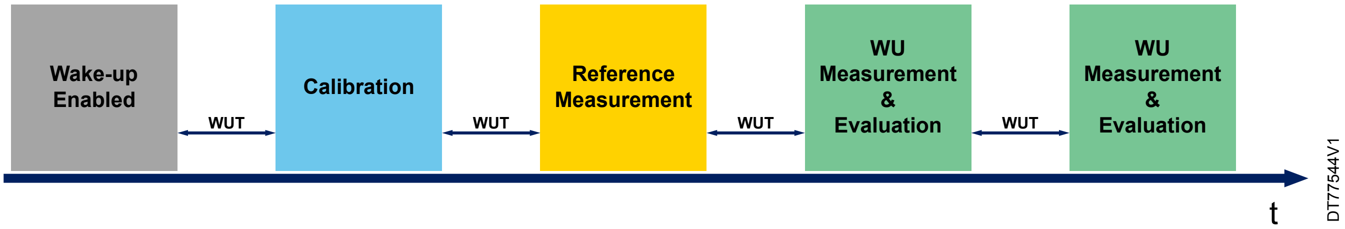


Figure 8. WU startup: skip_twcal = 0 and skip_twref = 1

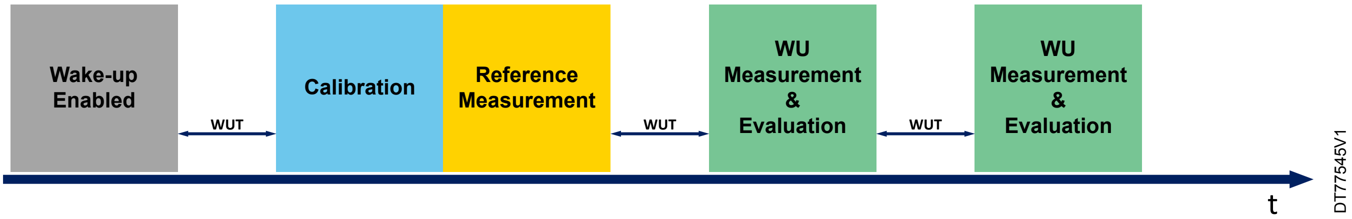


Figure 9. WU startup: skip_twcal = 1 and skip_twref = 0

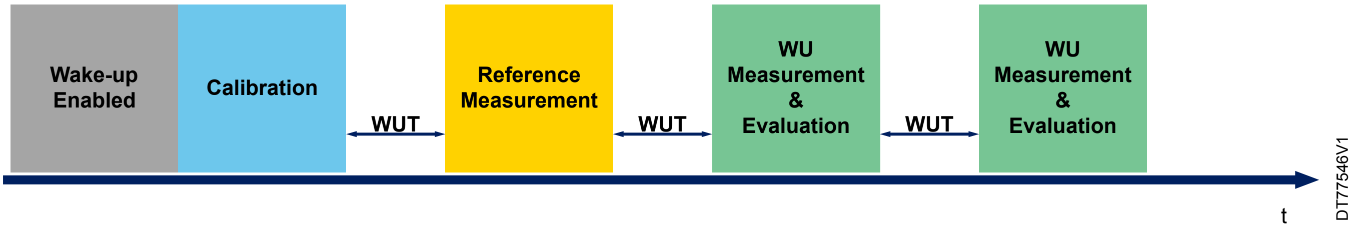
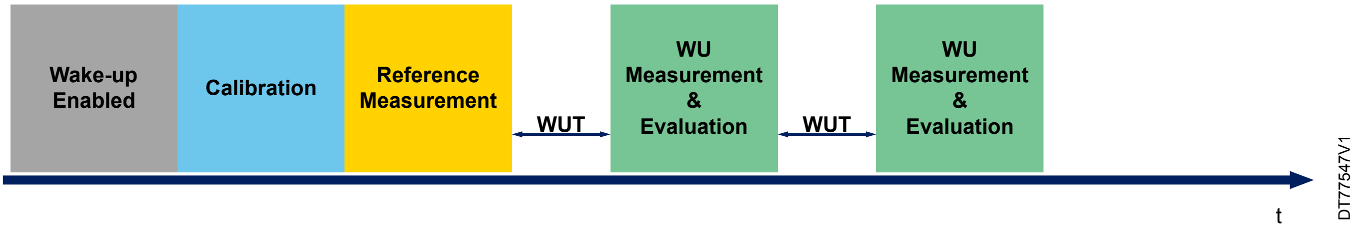


Figure 10. WU startup: skip_twcal = 1 and skip_twref = 1



4.1.2 Calibration disabled and auto averaging enabled

The precondition for the figures below are:

- `Skip_recal = 1`
- `Skip_cal = 1`
- `iq_aaref = 1`

Figure 11. WU startup: skip_twref = 0

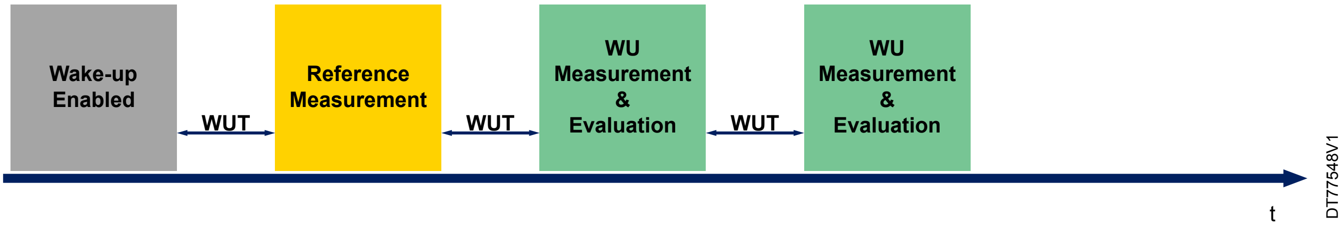
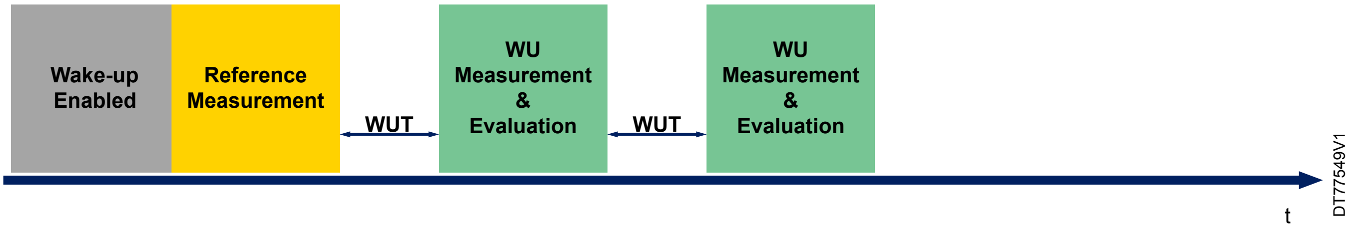


Figure 12. WU startup: skip_twref = 1

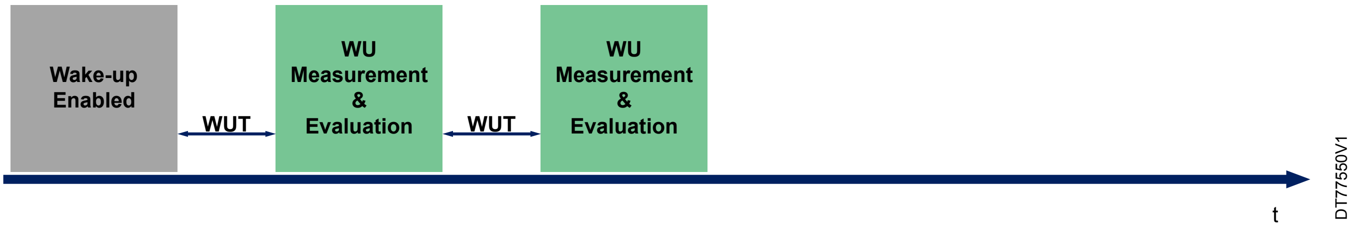


4.1.3 Calibration and auto averaging disabled

The precondition for the below figures are:

- `Skip_recal = 1`
- `Skip_cal = 1`
- `iq_aaref = 0`

Figure 13. **WU startup**



In this configuration, the calibration must be executed manually.

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 as shown in Figure 7.

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.

To achieve the highest sensitivity and system stability, the approach shown in Figure 7 is recommended. The wake-up method shown in Figure 7 ensures the highest stability and sensitivity at the cost of setup time.

4.2 Wake-up recalibration

The WU modes on ST25R300, ST25R500, ST25R501 and ST25R210 require a calibration step before performing the WU measurements. It can be executed manually, via a direct command (calibrate WU measurement), or automatically after enabling wake-up mode.

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

ST25R300, ST25R500, ST25R501 and ST25R210 are 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. The recalibration centers the measurement signal to the center of the ADC.

This autonomous mechanism aims to compensate for any slow system drift. For instance, due to temperature changes throughout the day.

Figure 14. **WU system recalibration**

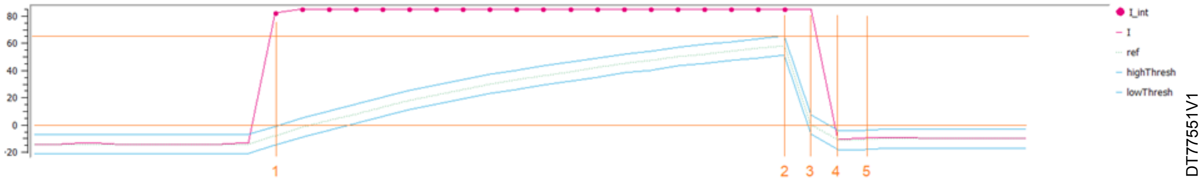


Figure 14 demonstrates which steps occur during the recalibration process.

Since the ADC value is outside of *i_ref +/- i_diff*, the MCU is notified at step 1 and stops the wake-up mode. Nevertheless, to show how the recalibration is behaving, the wake-up mechanism is not interrupted. In a real application, the drift would be slowly within *i_ref +/- i_diff* so that no wake-up event is being triggered.

At step 1, the reader antenna is being detuned by a tag. The wake-up mechanism is not stopped, and the reference is converging slowly to the current `I_ADC` value.

At step 2, the *i_ref + i_diff* is exceeding the *+/-63*. At the next expiration, which is step 3 of the wake-up timer, the recalibration is being executed.

In step 3 and step 4, the ADC value is not being processed to generate a wake-up event.

At step 4, a new reference measurement is being executed. An I and Q channel measurement is performed, and the ADC result is automatically taken as a new reference value. The wake-up system cannot detect changes during step 3 and 4.

At step 5, the normal wake-up measurement is continued. Due to the calibration, the reference and measurement value are centered again around “0”.

The recalibration of the Q channel happens in a same manner. Once one channel triggers a recalibration, both channels are calibrated.

To achieve the highest sensitivity and stability, it is recommended to keep the bits `skip_recal`, `skip_cal`, `skip_twcal` and `skip_twref` at 0.

4.3 Weak discharge

During power down mode, all supplies of the ST25R300, ST25R500, ST25R501 and ST25R210 are brought to a default level. This means that decoupling capacitors of AGD, VDD_A are discharged to 0 V when entering power down mode. During wake-up operation the IC passes several states.

- State 1: The wake-up timer expires and starts the transition from power-down mode to ready mode. The clock source of the wake-up timer is the internal RC oscillator.
- State 2: When entering ready mode, all internal blocks required for wake-up operation are activated. The most important blocks in this state are: VDD_A and VDD_DR regulator, AGD regulator, oscillator, which are used during wake-up measurement.
- State 3: During this state, VDD_A, VDD_DR, and AGD voltages settle to their final value and the oscillator ramps up.
- State 4: The driver and receiver are now active. The driver generates the RF pulse and the receiver performs the I and Q measurement. The internal logic evaluates the measurement result and issues an interrupt to the MCU when the thresholds are exceeded.
- State 5: ST25R300, ST25R500, ST25R501 and ST25R210 transition from ready mode to power down mode again and start the wake-up timer with the configured wake-up timer period.
  The figure below shows the five states and the current consumption on the VDD and VDD_TX supply.

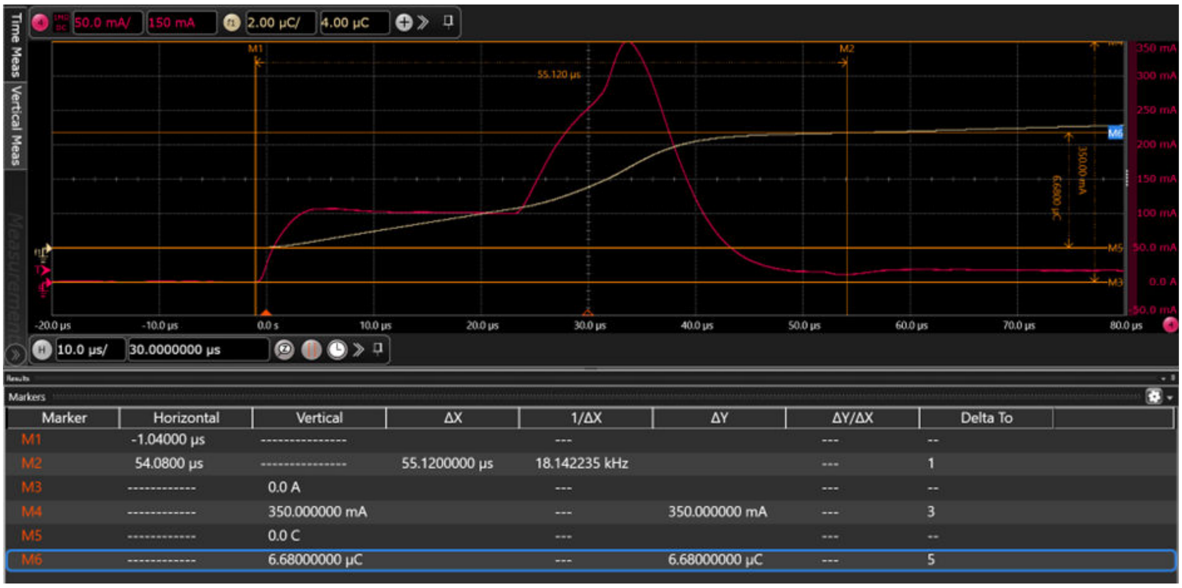
Figure 15. **Wake-up current consumption**

After the transition from power down to ready mode, a significant inrush current can be measured. It is the result of charging the VDD_A and AGD capacitors from 0 V to their final level. The bit `weak_disch` is influencing the current consumption during state 2.

When setting `weak_disch` to 1, the VDD_A and AGD capacitors are not discharged to 0 V in low-power mode. The capacitors discharge based on their parasitic parameters. A higher wake-up timer interval results in higher inrush current since the capacitors discharge to a lower voltage level.

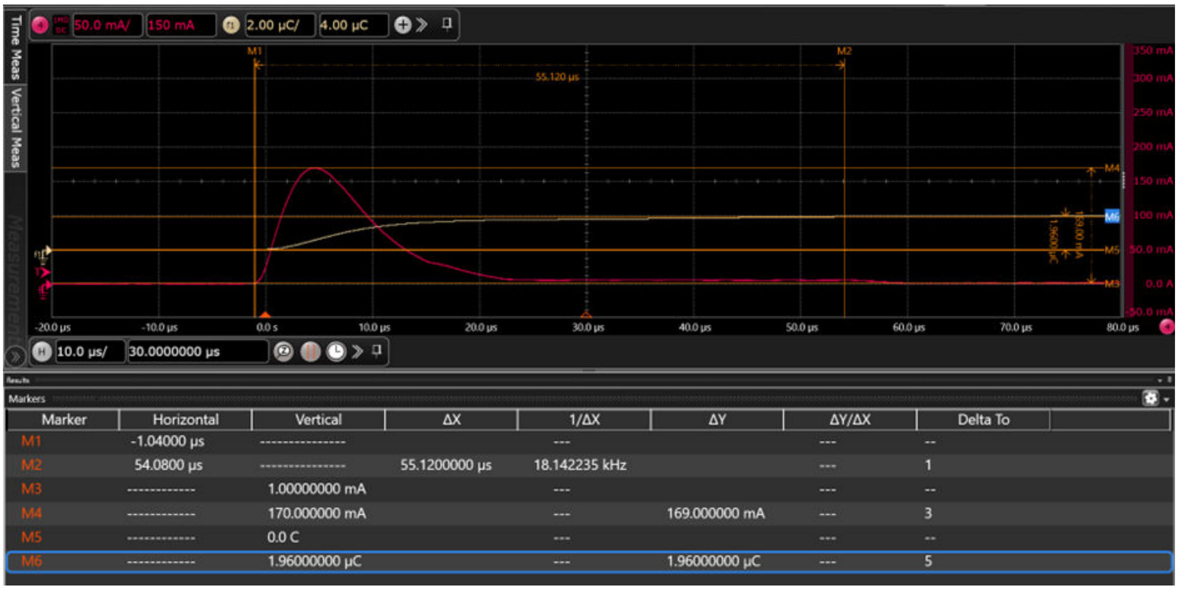
The figures below show the comparison of state 2, between `weak_disch = 0` which is shown in Figure 16. Current consumption using weak_disch = 0 and `weak_disch = 1` which is shown in Figure 17. Current consumption using weak_disch = 1.

Figure 16. **Current consumption using weak_disch = 0**



Marker	Horizontal	Vertical	ΔX	1/ΔX	ΔY	ΔY/ΔX	Delta To
M1	-1.04000 µs	---------------		---		---	--
M2	54.0800 µs	---------------	55.1200000 µs	18.142235 kHz		---	1
M3	------------	0.0 A		---		---	--
M4	------------	350.000000 mA		---	350.000000 mA	---	3
M5	------------	0.0 C		---		---	--
M6	------------	6.68000000 µC		---	6.68000000 µC	---	5

Figure 17. **Current consumption using weak_disch = 1**



Marker	Horizontal	Vertical	ΔX	1/ΔX	ΔY	ΔY/ΔX	Delta To
M1	-1.04000 µs	---------------		---		---	--
M2	54.0800 µs	---------------	55.1200000 µs	18.142235 kHz		---	1
M3	------------	1.00000000 mA		---		---	--
M4	------------	170.000000 mA		---	169.000000 mA	---	3
M5	------------	0.0 C		---		---	--
M6	------------	1.96000000 µC		---	1.96000000 µC	---	5

During state 2, the peak current flowing into the IC is around 350 mA when `weak_disch` is set to 0 at a 5 V supply. The peak current when having `weak_disch` set to 1 is around 170 mA and therefore significantly lower. The charge required during this phase is 6.68 uC vs. 1.96 uC which means that approximately 3.4 times more charge is required during startup.

`Weak_disch` set to 1 can be used to reduce power consumption during wake-up mode. `Weak_disch` set to 0 puts all voltages to a defined level when the IC is in low and wake-up power mode ensuring a defined startup procedure.

4.4 Wake-up timer calibration

The wake-up timer 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 wake-up timer bits. A wake-up timer duration of 100 ms +/-5 ms can only be guaranteed with enabled wake-up timer calibration.

In applications where an accurate WU period is required, a calibration mechanism can be enabled to minimize the RC variations. The wake-up timer calibration shall not be used on a wake-up timer period < 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.

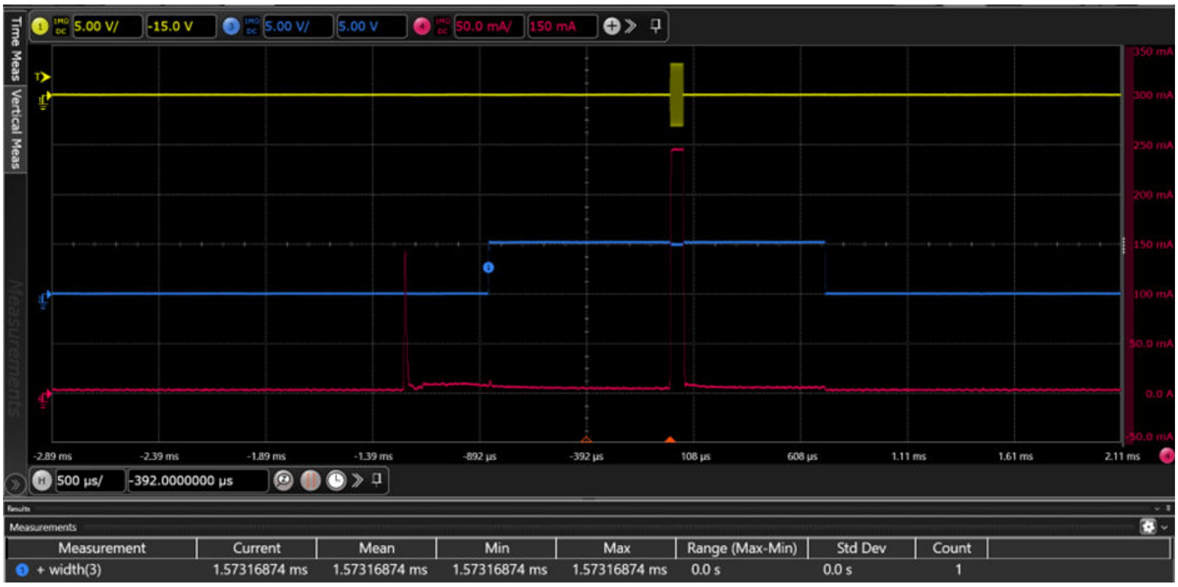
Therefore, the crystal oscillator is kept enabled for a certain calibration duration. The calibration is executed in wake-up mode whenever the wake-up timer expires and the chip transitions from PD to RD mode. A longer calibration duration results in increased accuracy of the WUT period. The table below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

Table 7. **Wake-up timer calibration duration**

Wut_cal_len	Calibration duration [ms]	Target accuracy [%]
0x0	0.781	3.33
0x1	1.562	1.67
0x2	3.125	0.83
0x3	6.248	0.43

The wake-up timer calibration is started once the oscillator is stable and the `I_osc` interrupt is issued. The figure below shows the current consumption with enabled `wut_cal`. After the oscillator is stable, the wake-up calibration is started. In this phase, the RC oscillator is calibrated based on the precision of the quartz oscillator. This is indicated by the rising edge of the blue channel. The falling edge of the blue channel indicates that the wake-up timer calibration is finished, and the oscillator is turned off. The yellow channel shows the generated magnetic RF field captured via a pick-up coil. It shows the wake-up measurement pulse. The red channel shows the current flowing in the VDD and VDD_TX pin.

Figure 18. **Wake-up measurement with enabled wake-up timer calibration**



Measurements

Measurement	Current	Mean	Min	Max	Range (Max-Min)	Std Dev	Count
+ width(3)	1.57316874 ms	1.57316874 ms	1.57316874 ms	1.57316874 ms	0.0 s	0.0 s	1

The figure above shows that when the `wut_cal = 1` bits and the `wut_cal_len=0x1` bits, the oscillator is active beyond the generation of the wake-up pulse. At the following edge of the blue channel, the current consumption reduces from I_{RD} to I_{WU}. The oscillator is active for approximately 1.57 ms which corresponds to a `wut_cal_len` setting of 0x1.

5 Wake-up measurement

ST25R300, ST25R500, ST25R501 and ST25R210 enable the configuration of the WU measurement pulse duration.

The shorter the time 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.

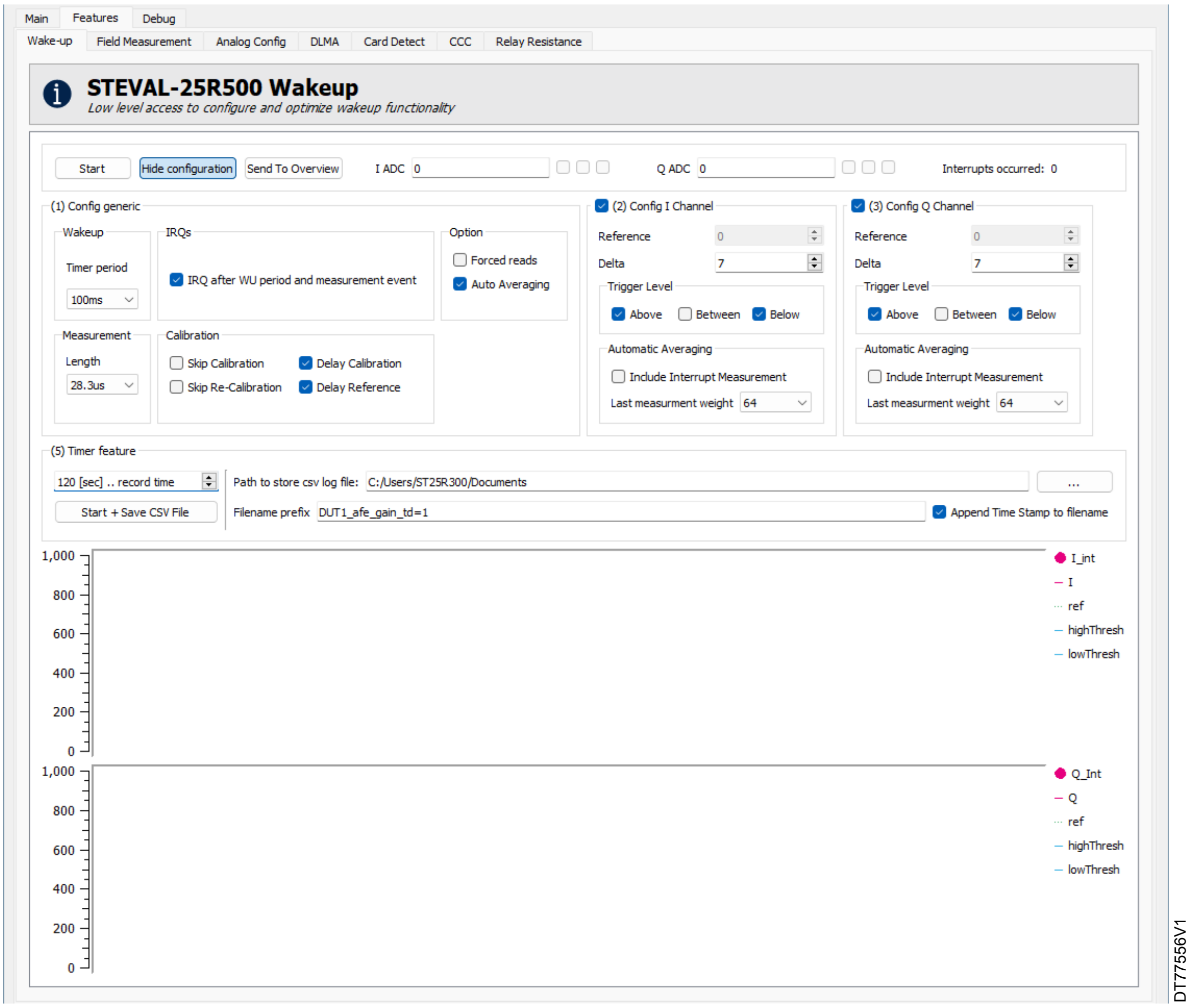
Several WU measurement pulse durations are available and are defined by the `td_mf` and `td_mt` bits, as illustrated in Section 3.2: Measurement pulse duration.

5.1 Selecting delta and afe_gain_td

In wake-up mode, ST25R300, ST25R500, ST25R501 and ST25R210 emit a short pulse and measure the I and Q signal using the receiver chain. Since the receiver is used to perform these m measurements, the receiver gain has an impact on the sensitivity of the measurement. The higher the receiver gain, the more sensitive the system is against detuning of the antenna. The receiver gain can be adjusted by setting the gain reduction in the bits `afe_gain_td`. A higher gain also results in more noise coming from the power supply or external influence. Thus, the delta for I and Q channel must be chosen bigger for less `afe_gain_td` gain reduction. Since external noise sources also affect the noise measured in the wake-up system, higher external noises (for example, coming from the power supply) cause higher delta values. The highest wake-up sensitivity can only be achieved when the external noise is reduced to a minimum.

The selection of the delta for I and Q channel can be based on the standard deviation of the unloaded reader. Therefore, the STEVAL-25R300 provides a timer feature in the wake-up tab:

Figure 19. STEVAL-25R300 GUI - Timer feature



STEVAL-25R500 Wakeup

Low level access to configure and optimize wakeup functionality

I ADC 0 ☐ ☐ ☐ Q ADC 0 ☐ ☐ ☐ Interrupts occurred: 0

(1) Config generic

Wakeup: Timer period 100ms

IRQs: ☑ IRQ after WU period and measurement event

Option: ☐ Forced reads ☑ Auto Averaging

Measurement: Length 28.3us

Calibration: ☐ Skip Calibration ☑ Delay Calibration ☐ Skip Re-Calibration ☑ Delay Reference

☑ (2) Config I Channel

Reference 0

Delta 7

Trigger Level: ☑ Above ☐ Between ☑ Below

Automatic Averaging: ☐ Include Interrupt Measurement; Last measurment weight 64

☑ (3) Config Q Channel

Reference 0

Delta 7

Trigger Level: ☑ Above ☐ Between ☑ Below

Automatic Averaging: ☐ Include Interrupt Measurement; Last measurment weight 64

(5) Timer feature

120 [sec] .. record time

Path to store csv log file: C:/Users/ST25R300/Documents

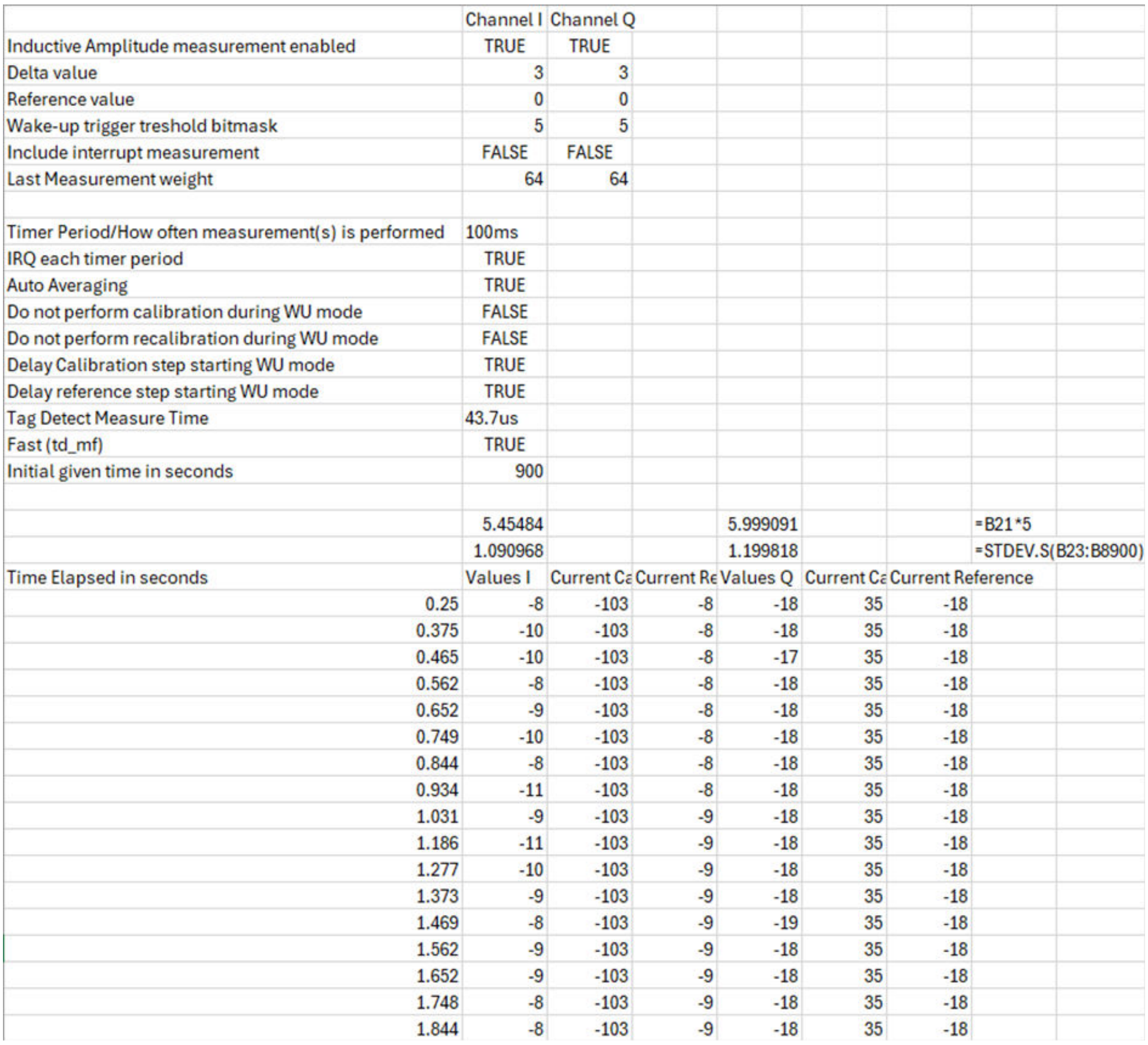
Filename prefix DUT1_afe_gain_td=1

☑ Append Time Stamp to filename

When pressing “Start + Save CSV file,” the wake-up feature is activated for a certain time and the I and Q values are plotted in a CSV file. A longer observation time results in more reliable results. Several DUTs should be observed.

The CSV provides an overview of the settings used and the measurement values. Figure 20 shows the settings and measurement values for `afe_gain_td` set to 0x1.

Figure 20. Standard deviation afe_gain_td = 0x1



	Channel I	Channel Q					
Inductive Amplitude measurement enabled	TRUE	TRUE					
Delta value	3	3					
Reference value	0	0					
Wake-up trigger treshold bitmask	5	5					
Include interrupt measurement	FALSE	FALSE					
Last Measurement weight	64	64					
Timer Period/How often measurement(s) is performed	100ms						
IRQ each timer period	TRUE						
Auto Averaging	TRUE						
Do not perform calibration during WU mode	FALSE						
Do not perform recalibration during WU mode	FALSE						
Delay Calibration step starting WU mode	TRUE						
Delay reference step starting WU mode	TRUE						
Tag Detect Measure Time	43.7us						
Fast (td_mf)	TRUE						
Initial given time in seconds	900						
	5.45484			5.999091			=B21*5
	1.090968			1.199818			=STDEV.S(B23:B8900)
Time Elapsed in seconds	Values I	Current Ca	Current Re	Values Q	Current Ca	Current Reference	
0.25	-8	-103	-8	-18	35	-18	
0.375	-10	-103	-8	-18	35	-18	
0.465	-10	-103	-8	-17	35	-18	
0.562	-8	-103	-8	-18	35	-18	
0.652	-9	-103	-8	-18	35	-18	
0.749	-10	-103	-8	-18	35	-18	
0.844	-8	-103	-8	-18	35	-18	
0.934	-11	-103	-8	-18	35	-18	
1.031	-9	-103	-9	-18	35	-18	
1.186	-11	-103	-9	-18	35	-18	
1.277	-10	-103	-9	-18	35	-18	
1.373	-9	-103	-9	-18	35	-18	
1.469	-8	-103	-9	-19	35	-18	
1.562	-9	-103	-9	-18	35	-18	
1.652	-9	-103	-9	-18	35	-18	
1.748	-8	-103	-9	-18	35	-18	
1.844	-8	-103	-9	-18	35	-18	

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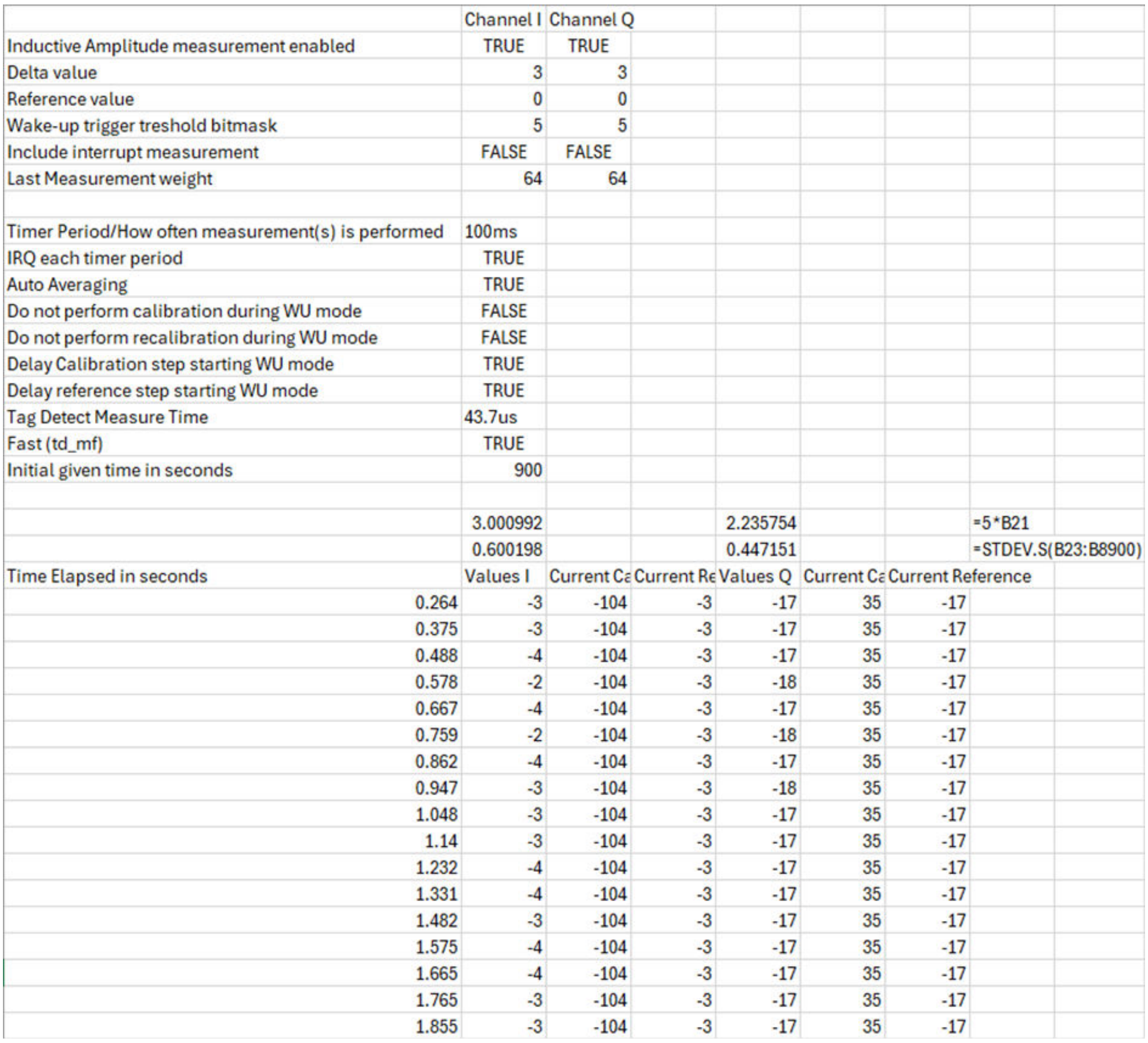
The standard deviation is calculated in Microsoft Excel by using the formular =STDEV.S(RANGE). In the example above, measurement values were collected over approximately 900 seconds. The same procedure has been executed for `afe_gain_td = 0x3`. In both cases, the `gain_boost` was set to 1.

Figure 21. **Standard deviation afe_gain_td = 0x3**



	Channel I	Channel Q					
Inductive Amplitude measurement enabled	TRUE	TRUE					
Delta value	3	3					
Reference value	0	0					
Wake-up trigger treshold bitmask	5	5					
Include interrupt measurement	FALSE	FALSE					
Last Measurement weight	64	64					
Timer Period/How often measurement(s) is performed	100ms						
IRQ each timer period	TRUE						
Auto Averaging	TRUE						
Do not perform calibration during WU mode	FALSE						
Do not perform recalibration during WU mode	FALSE						
Delay Calibration step starting WU mode	TRUE						
Delay reference step starting WU mode	TRUE						
Tag Detect Measure Time	43.7us						
Fast (td_mf)	TRUE						
Initial given time in seconds	900						
	3.000992			2.235754			=5*B21
	0.600198			0.447151			=STDEV.S(B23:B8900)
Time Elapsed in seconds	Values I	Current Ca	Current Re	Values Q	Current Ca	Current Reference	
0.264	-3	-104	-3	-17	35	-17	
0.375	-3	-104	-3	-17	35	-17	
0.488	-4	-104	-3	-17	35	-17	
0.578	-2	-104	-3	-18	35	-17	
0.667	-4	-104	-3	-17	35	-17	
0.759	-2	-104	-3	-18	35	-17	
0.862	-4	-104	-3	-17	35	-17	
0.947	-3	-104	-3	-18	35	-17	
1.048	-3	-104	-3	-17	35	-17	
1.14	-3	-104	-3	-17	35	-17	
1.232	-4	-104	-3	-17	35	-17	
1.331	-4	-104	-3	-17	35	-17	
1.482	-3	-104	-3	-17	35	-17	
1.575	-4	-104	-3	-17	35	-17	
1.665	-4	-104	-3	-17	35	-17	
1.765	-3	-104	-3	-17	35	-17	
1.855	-3	-104	-3	-17	35	-17	

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The table below summarizes the calculated standard deviation and delta values. When selecting a higher gain reduction, the noise and consequently the standard deviation in the I and Q channels decrease. It also results in a smaller delta for the I and Q channel. The delta is calculated based on the formulas mentioned in the last column.

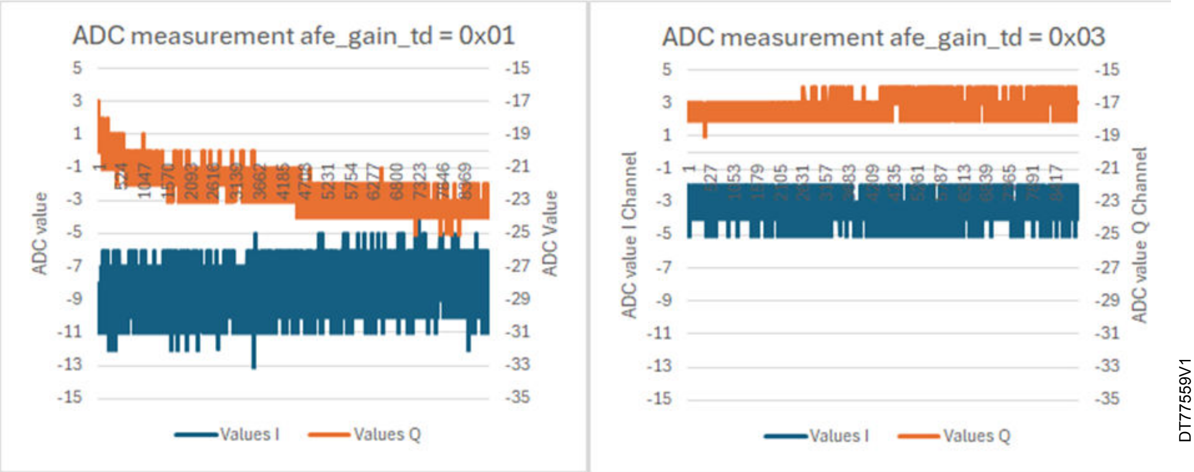
Table 8. **Summary standard deviation**

afe_gain_td	0x1	0x3
STDEV I	1.09	0.60
STDEV Q	1.20	0.45
Delta I	5.45	3.00
Delta Q	6.00	2.24
Selected delta I	6	3
Selected delta Q	6	3

As shown in Table 8, the noise in the measurement system is divided by two when a 6 dB gain reduction is applied. This directly translates to halving the delta window size. Fewer gain reduction results in a larger delta window.

Figure 22 shows a plot of the ADC values with different gain.

Figure 22. **ADC measurement comparison**



The comparison shows that at less gain reduction a settling is visible in the Q-channel. This settling is filtered out via the automatic averaging of the ST25R300, ST25R500, ST25R501 and ST25R210.

Figure 23. **Wake-up range comparison**

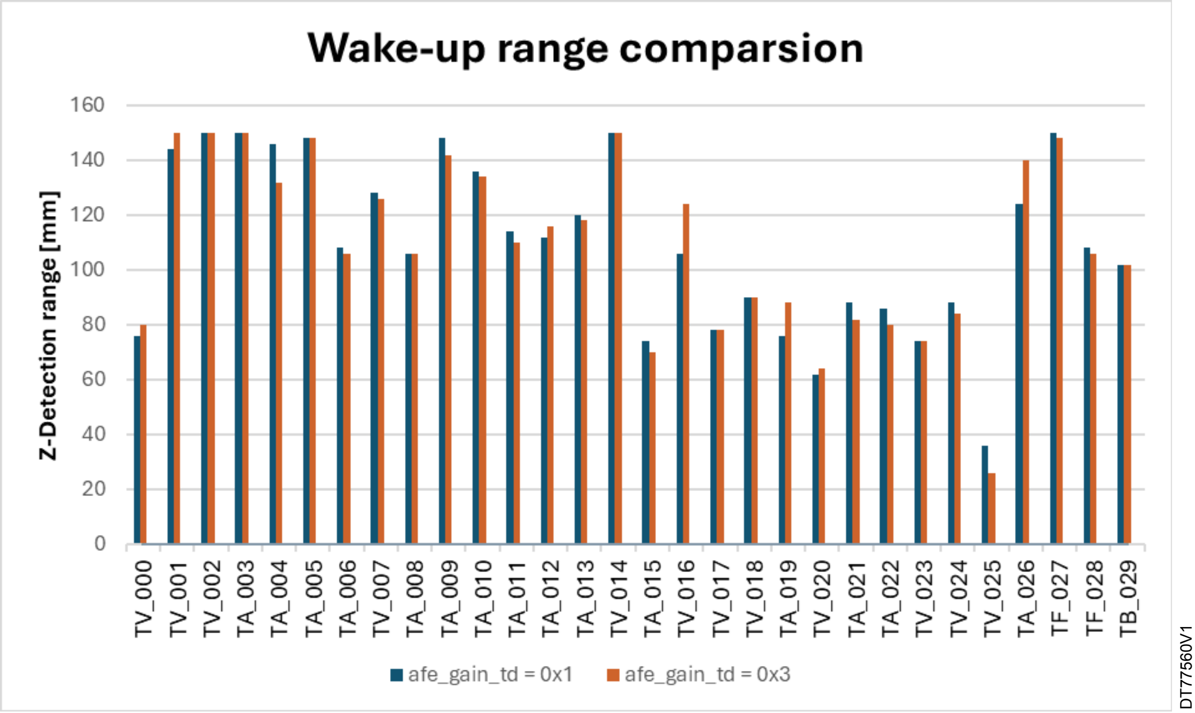


Figure 23 shows that with correct chosen delta limits, the detection range is almost the same. The settling can have a stronger impact when choosing a smaller gain reduction. Temperature drift may cause the wake-up mechanism to require more frequent recalibration. The `afe_gain_td` should be chosen in a way that the delta is not smaller than two or higher than 20. The selection of the delta is based on the standard deviation and gaussian distribution. A typical factor lies between 4 sigma and 6 sigma.

A battery-powered device, which should not wake-up too often without external event, may base its delta on 6 sigma. A device connected to an external supply allowing some unintended wake-ups may be based on 4 sigma. For the comparison illustrated in the following figure, a sigma of 5 has been chosen.

Table 9 shows the probability of unintended wake-ups versus the selected sigma value.

Note: *The `afe_gain_td` should be set to a value which causes the delta to be between 2 and 20. A too high delta can cause frequent recalibration of the wake-up system.*

Table 9. **Statistical probability of unintended wake-ups**

Sigma value	Unintended wake-ups (in ppm)	Usability
1	317300	Not recommended
2	45500	
3	2700	
4	64	recommended
5	6	
6	0.002	

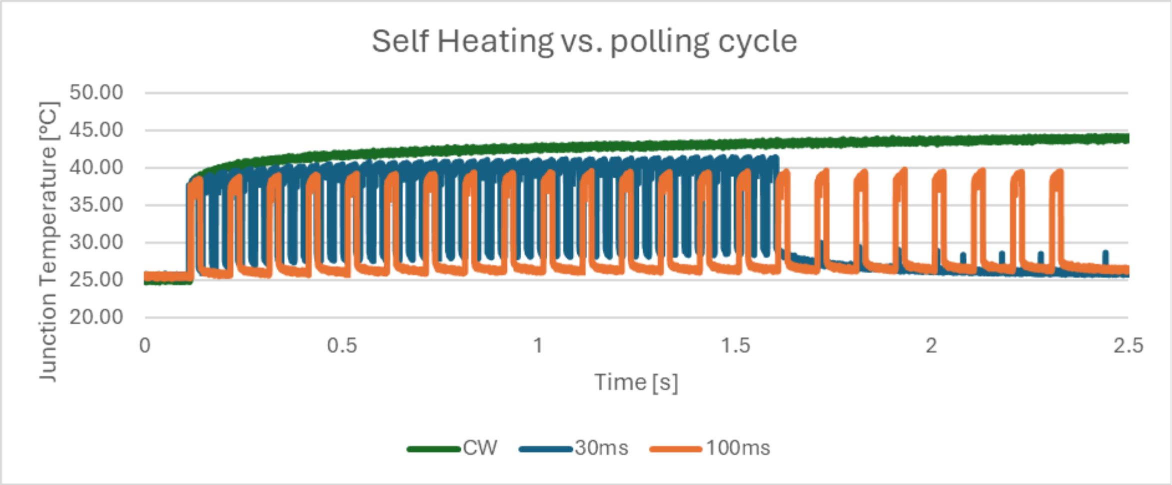
5.2 Settling and self-heating

During operation, ST25R300, ST25R500, ST25R501 and ST25R210 dissipate a certain amount of power. The most power is dissipated when the device is emitting a field. The dissipated power raises the junction temperature of the device and electrical parameters change. When the transistor in the driver heats up, its on-resistance increases slightly. The same effect can influence the matching components. The most affected components are the EMI inductors and damping resistors. When a current is flowing from the RFO to the antenna, the inductors and resistors heat up. It results in a resistance increase which causes a higher matching impedance and more damping. As a result, the field strength and measured voltage on the antenna decreases.

Dependent on the thermal characteristics of the PCB (size, number of cooper layers), the components heat faster or slower. Additionally, the temperature is not constant across the board as components have different thermal characteristics.

Figure 24 shows the self-heating of the same PCB using different polling cycles.

Figure 24. **Self-heating dependent on the polling cycle**



The figure above shows the self-heating with three different timings applied. The CW shows the self-heating when the field is being turned on without field off. The temperature of the junction raises from 25°C to approximately 43°C.

When a polling duration of 30 ms which includes 10 ms field off is used, the junction temperature rises to approximately 40°C. At this polling rate, the junction cannot cool down during the field off phase. When enabling the wake-up mode right after polling, the silicon is still cooling down. As a result, calibration, reference measurement, and the first wake-up measurement are performed at different temperatures. Dependent on this effect, settling effects might be visible which can lead to unstable wake-up conditions. This is due to heating up the PCB, which stores the temperature and delays the cooling down of the silicon. The same effect is acting on the EMC inductors and damping resistors.

When the 100 ms polling which includes an 80 ms field off is used, the maximum temperature raises to approximately 39°C. The initial temperature is already reached 80 ms after the field is turned off. This polling cycle enables the fastest system wake-up.

The measurement has been executed on a 70x25 mm PCB. At smaller the PCBs, the more it is impacted by self-heating, and the more the timings need to be relaxed.

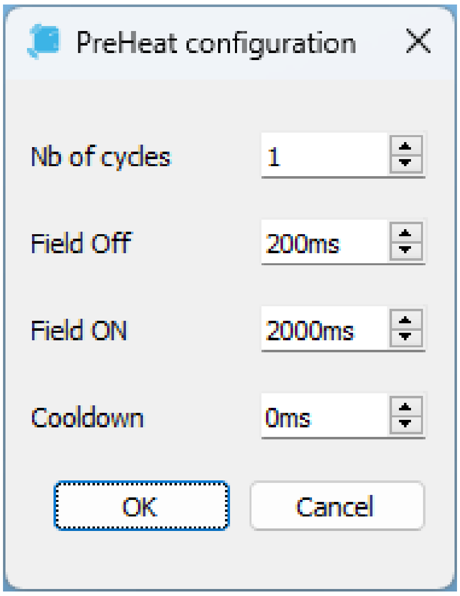
The conclusion is that although the maximum temperature is very similar (43°C versus 40°C versus 39°C) the cool-down time is significantly different. The polling cycle timings and the selected cool-down time have a significant impact on the self-heating and stability of the wake-up mechanism.

In the following, methods to cope with self-heating and settling are described from both the chip and software perspectives.

In the ST25R300, ST25R500, ST25R501 and ST25R210 Evaluation GUIs, these effects can be observed on the Wake-up tab. For the experiments shown, a load (such as another reader board, a field detector, or a tag with an antenna size similar to the reader) was used in order to obtain a pronounced effect on the board.

Before starting the wake-up, preheat settings were applied as shown in Figure 25. With these settings, false wake-up events were observed on the I channel, as illustrated in Figure 26.

Figure 25. **Preheat settings**



PreHeat configuration

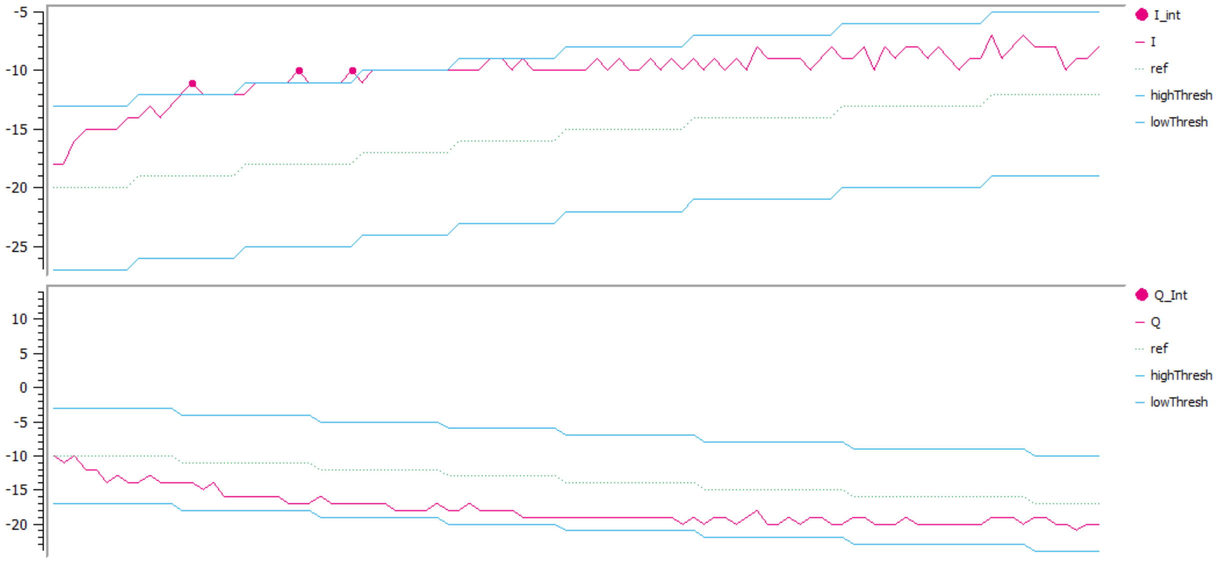
Nb of cycles: 1

Field Off: 200ms

Field ON: 2000ms

Cooldown: 0ms

Figure 26. **Preheat_default**

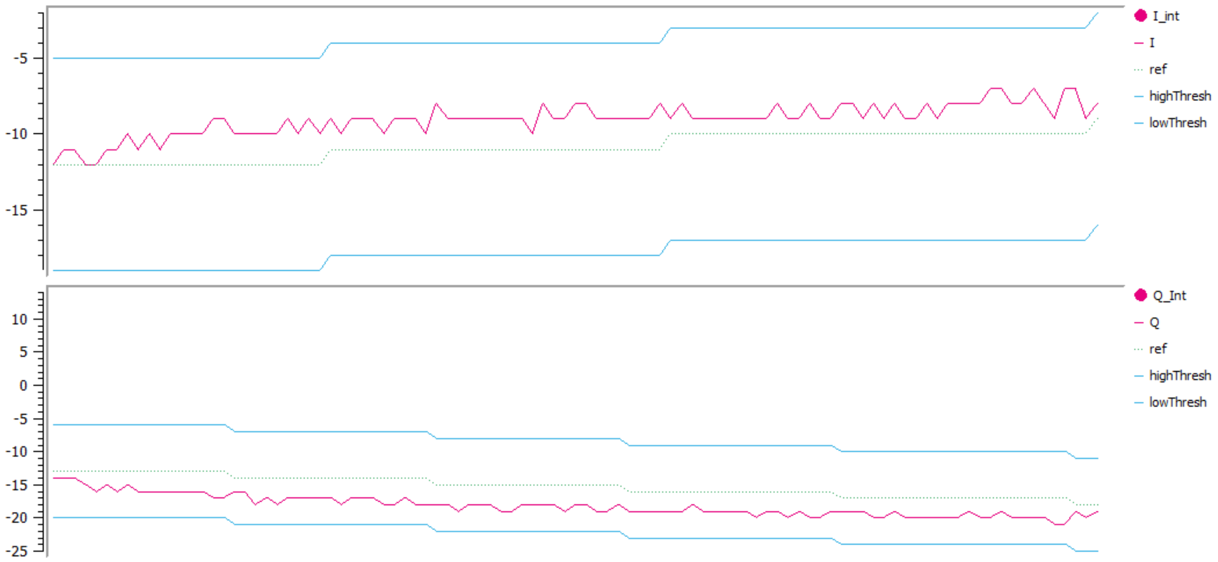


The options to mitigate such unwanted effects are described in the following sections.

5.2.1 Cooldown

Cooldown times can be applied by actively waiting after the end of communication or after switching the field off. In the example shown in Figure 27, an additional delay of 1 s was introduced before starting the wake-up.

Figure 27. **Preheat_cooldown1s**

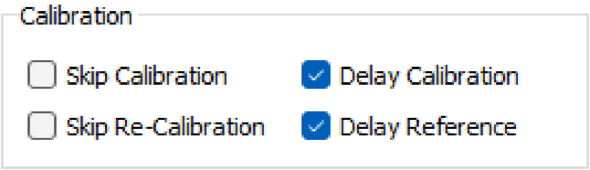


Other parameters that influence the cooldown behavior are:

- The configured WUT (Wake-Up Timer) period
- The skip_* options described in Section 4.1.1: Calibration and auto averaging enabled

These options are available and visible in the evaluation GUIs, as shown in Figure 28.

Figure 28. **Calibration**



Calibration

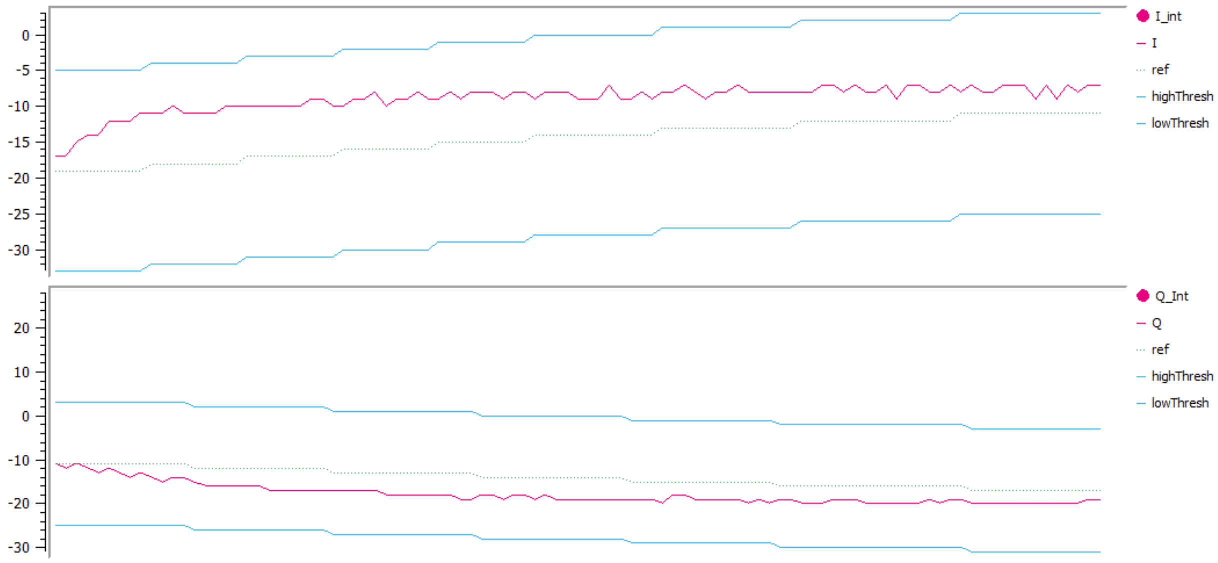
☐ Skip Calibration
☑ Delay Calibration
☐ Skip Re-Calibration
☑ Delay Reference

5.2.2 Delta/Diff

Increasing the delta (difference) thresholds (see Section 3.4: Wake-up trigger conditions) also helps to avoid issues related to settling. However, this approach comes at the cost of a reduced wake-up range.

An example of this trade-off is shown in Figure 29.

Figure 29. Preheat_delta14

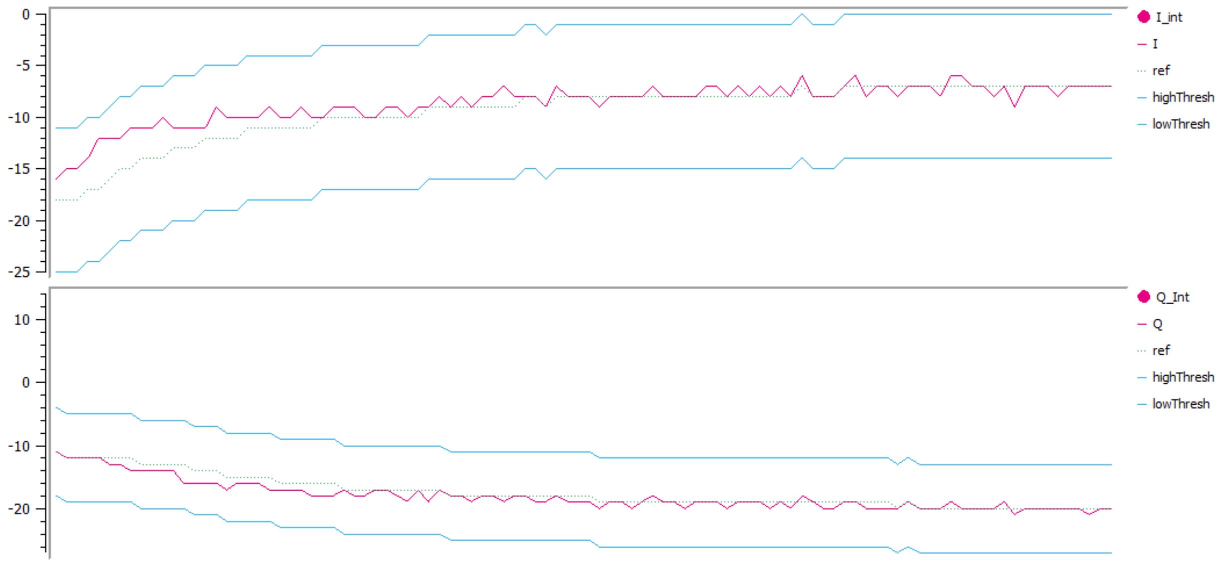


5.2.3 Weight

The auto averaging mechanism (see Section 3.6: Wake-up auto averaging) is specifically designed to cope with a changing environment and with settling effects.

By decreasing the averaging weight denominator from the Evaluation GUI default of 64 down to 8, the reference value can more closely follow the settling behavior, as shown in Figure 30.

Figure 30. Preheat_weight8



- The sensitivity for fast-moving loads is not expected to change significantly.
- The sensitivity can, however, be affected when loads move slowly, because the weaker averaging (lower denominator) can closely follow the moving load.

5.2.4 Dynamic weight

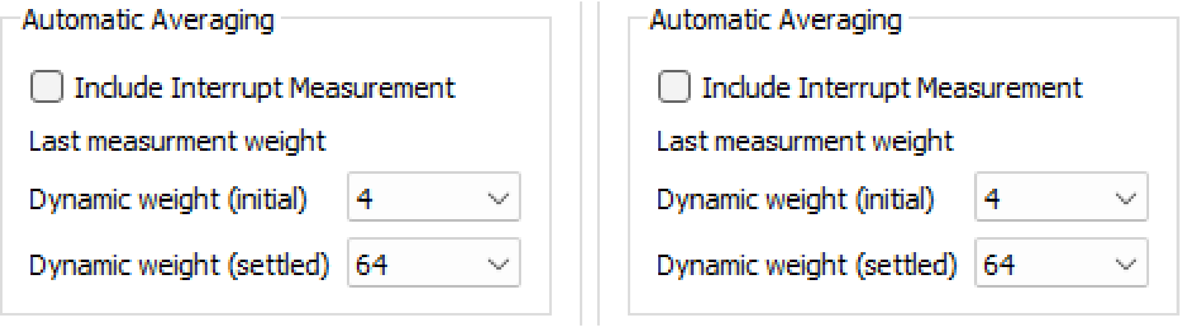
To compensate for the reduced range when slowly moving objects are present, it can be beneficial not to use a static low weight denominator (such as 4) permanently.

Instead, the software can be designed to:

1. Start with a low denominator (e.g. 4) so that the reference quickly adapts to settling and slow changes.
2. After a fixed time interval, switch to a higher denominator (e.g. 64) to restore a higher detection sensitivity.

In the example shown, the weight denominator is changed from 4 to 64 after 2 seconds. The used weight configuration is depicted in Figure 31, and the resulting behavior in Figure 32.

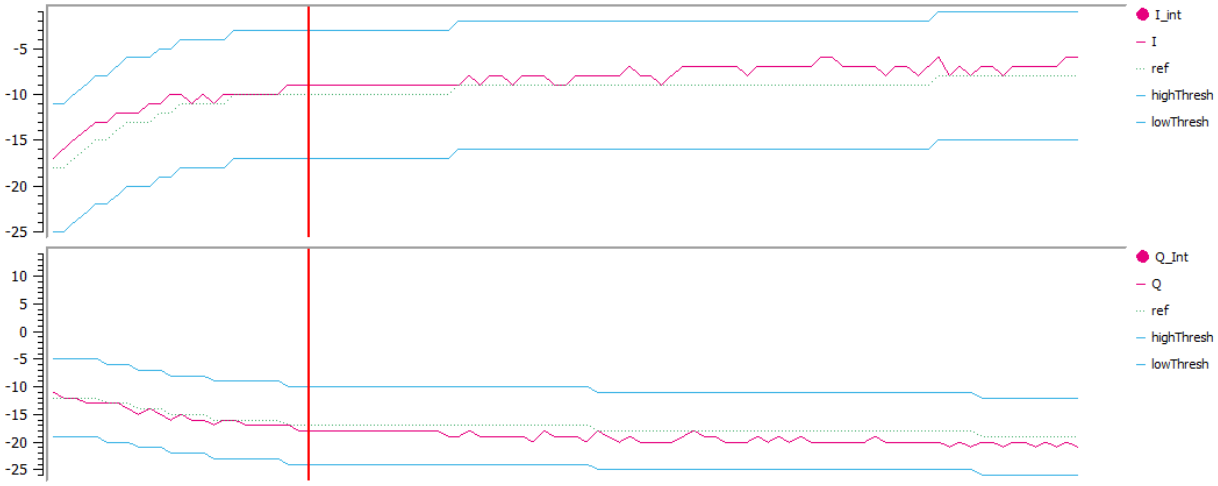
Figure 31. Weights



Automatic Averaging
☐ Include Interrupt Measurement
Last measurment weight
Dynamic weight (initial): 4
Dynamic weight (settled): 64

Automatic Averaging
☐ Include Interrupt Measurement
Last measurment weight
Dynamic weight (initial): 4
Dynamic weight (settled): 64

Figure 32. Preheat dyn weight 4 - 2 s - 64



When using RFAL in source code, this can be implemented by calling the following code fragment a few seconds after rfalNfcDiscover(&discParam):

```
rfalNfcDeactivate( RFAL_NFC_DEACTIVATE_IDLE );
discParam.wakeupConfig.I.aaWeight = RFAL_WUM_AA_WEIGHT_64;
discParam.wakeupConfig.Q.aaWeight = RFAL_WUM_AA_WEIGHT_64;
rfalNfcDiscover( &discParam );
```

This sequence deactivates the NFC discovery, updates the auto-averaging weight for both I and Q channels, and restarts discovery with the new configuration.

6 Wake-up mode power estimation

6.1 Power calculations

In wake-up mode, more frequent measurements lead to higher average power consumptions.

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

Additionally, longer measurement pulses spend more time emitting the RF carrier, which also increases power consumption.

Therefore, the average power consumption is estimated based on these variables/configurations and the characteristics of ST25R300, ST25R500, ST25R501 and ST25R210, as 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 current during an inductive measurement (I_M) depends upon the matching impedance, therefore it varies with each system, typically between 150 mA and 350 mA but can reach 500 mA.

For an estimate of the current consumption of the I_{AVG}, the current consumption for the measurement $_{M,AVG}$ must be calculated using the following formulas:

$$I_{M,\,AVG} = (I_M - I_{WU})\,\frac{T_{MEAS}}{T_{out}}$$

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

$$I_{OSC,\,AVG} = (I_{RD} - I_{WU})\,\frac{T_{OSC}}{T_{out}}$$

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, if for a particular system I_M = 250 mA; T_{OSC} = 1.2 ms and it sets T_{out} = 100 ms; T_{MEAS} = 43.7 µs, the current consumption during the WU mode, can be estimated as:

- I_{WU} = 2.86 µA
- I_{RD} = 2.95 mA
- T_{MEAS} = 43.7 µs
- T_{out} = 100 ms
- I_M = 250 mA

$$I_{M,\,AVG} = (I_M - I_{WU})\,\frac{T_{MEAS}}{T_{out}} = \left(250\times10^{-3}\times 2.86\times10^{-6}\right) - \frac{43.7\times10^{-6}}{100\times10^{-3}} = 109.25\ \mu A$$

$$I_{OSC,\,AVG} = (I_{RD} - I_{WU})\,\frac{T_{OSC}}{T_{out}} = \left(2.95\times10^{-3} - 2.86\times10^{-6}\right)\frac{1.2\times10^{-3}}{100\times10^{-3}} = 35.37\ \mu A$$

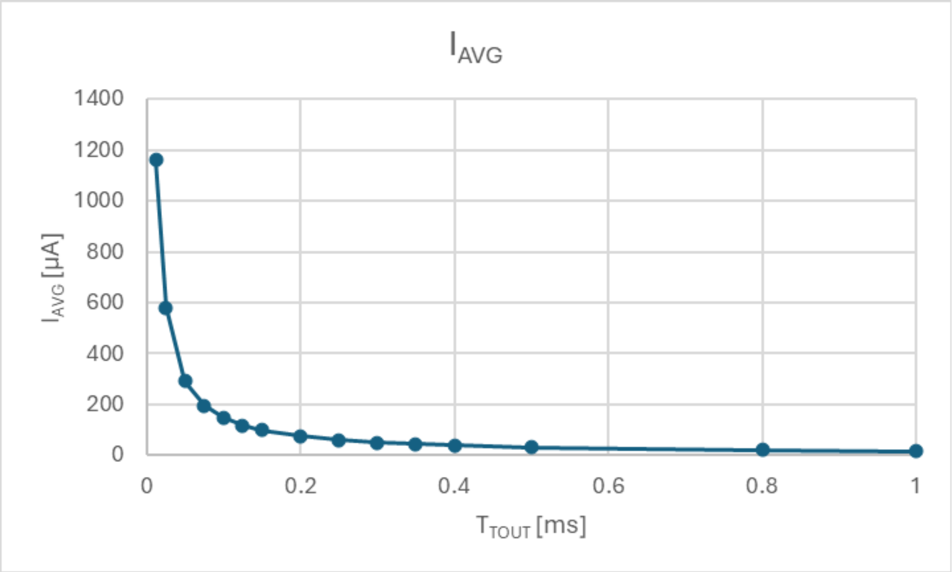
$$I_{AVG} = I_{M,\,AVG} + I_{OSC,\,AVG} + I_{WU} = 109.25\times10^{-6} + 35.37\times10^{-6} + 2.86\times10^{-6} = 147.5\ \mu A$$

The average current consumption during wake-up mode is around 147.5 µA. When the timer period is changed from 100 ms to 200 ms, the average current consumption drops to 75.17 µA. The main contributor to the current consumption in wake-up mode is the current during an inductive measurement (I_M) and the selected timeout interval (T_{out}).

The initial charging of the decoupling capacitors is not considered for this calculation.

In Figure 33, it is possible to see how the current consumption evolves as a function timeout/period configuration (I_M = 250 mA; T_{OSC} = 1.2 ms; T_{MEAS} = 43.7 µs).

Figure 33. I_{AVG} vs. T_{out}



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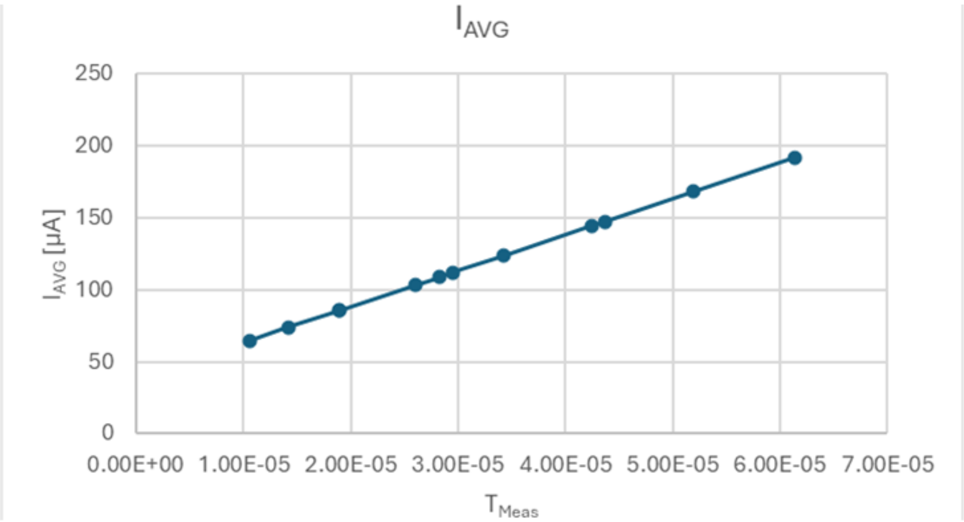
In Figure 34, it is possible to see how the current consumption evolves as a function timeout/period configuration (I_M = 250 mA; T_{OSC} = 1.2 ms; T_{OUT} = 100 ms).

Figure 34. I_{AVG} vs. T_{MEAS}



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T_{out} and T_{MEAS} timings have a significant impact on the power consumption during wake-up mode. T_{out} and T_{MEAS} have the most influence and can be chosen without direct impact on the detection range.

Revision history

Table 10. **Document revision history**

Date	Version	Changes
13-May-2025	1	Initial release.
03-Feb-2026	2	Added: • New product ST25R210 • New sections: Section 5.2.1: Cooldown, Section 5.2.2: Delta/Diff, Section 5.2.3: Weight, Section 5.2.4: Dynamic weight

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