
**Wake-up mode for
ST25R3916, ST25R3916B, ST25R3917 and ST25R3920 devices**

Introduction

This document describes the Wake-up mode of the ST25R3916, ST25R3916B, ST25R3917 and ST25R3920 devices, which feature different low-power modes to detect the presence of a card.

Three wake-up sources are available, namely capacitive sensing, amplitude measurement and phase measurement. Each source is individually configurable and can generate an interrupt to the MCU.

The document is based on the ST25R3916 device, but its content applies to ST25R3916B, ST25R3917 and ST25R3920 as well.

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1 Terms and acronyms

Table 1. Terms and acronyms

Acronym	Description
AAT	Automatic antenna tuning
ADC	Analog to digital converter
CSO	Capacitance sense output
CSI	Capacitance sense input
DAC	Digital to analog converter
EMC	Electromagnetic compatibility
HW	Hardware
IRQ	Interrupt request
MCU	Microcontroller
PCB	Printed circuit board
RC	Resistive-capacitive
RF	Radio frequency
SW	Software

2 Wake-up mode

The Wake-up mode is used to perform the low-power detection of card presence. It is implemented on the devices addressed in this document according to [Table 2](#).

Table 2. Wake-up mode capability

Device	Capacitive sensing (see Section 2.3)	Amplitude sensing (see Section 2.4)	Phase sensing (see Section 2.5)
ST25R3916	Yes	Yes	Yes
ST25R3916B	No	Yes	Yes
ST25R3917	No	Yes	Yes
ST25R3920	Yes	Yes	Yes

Usually the card detection is performed by a polling loop, which requires the device to periodically turn its field on, wait for a certain period to fulfill the card 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 family offers a low-power Wake-up mode.

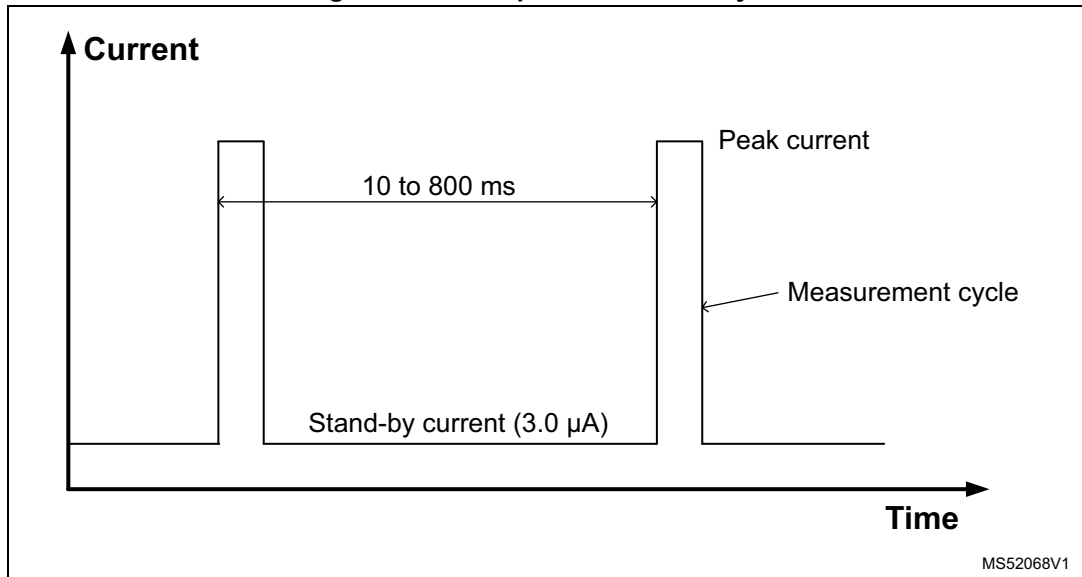
Once in this mode, the devices operate on an internal low-power RC oscillator while performing measurements. The periodically measured values are internally compared against those preset by the user, and trigger an interrupt if the measured value is outside the limits. This allows the MCU to sleep while the device autonomously detects approaching tags. The MCU can then be woken up by the interrupt pin and start normal polling for cards.

2.1 Low-power wake-up generator

The low-power wake-up generator is always active, the device consumes typically 3.0 μ A in this mode.

The wake-up generator can be programmed in 16 steps between 10 and 800 ms to trigger a measurement and compare it to the preset limits.

Figure 1. Wake-up measurement cycle



2.2 Auto averaging

The auto averaging is a method to dynamically adapt the reference value on slow varying environment conditions (e.g temperature, voltage) using a weighted moving average.

The higher the weight, the longer the reference takes to adapt, as more measurements are required. The values for the weight are 4, 8, 16 and 32.

Each time a new ADC value is measured, the weighted difference between the new and the stored value is added to the stored value:

$$\text{NewAverage} = \text{OldAverage} + ((\text{MeasuredValue} - \text{OldAverage}) / \text{Weight})$$

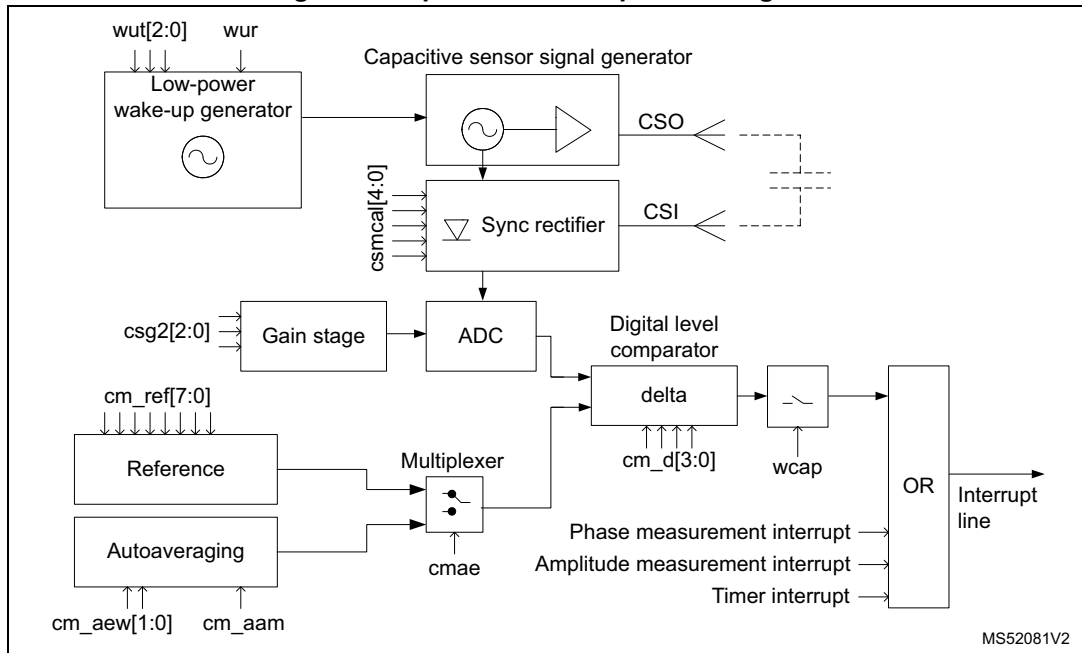
When the auto averaging is enabled, the reference evolves automatically to adapt to the new environment conditions. This reference is stored internally and it persists even if the Wake-up mode is exited and then restarted. The direct command Set default will reset the stored reference.

2.3 Capacitive sensing

[Figure 2](#) shows the capacitive wake-up system, composed by two electrodes, a 500 kHz signal generator, a synchronous rectifier with the calibration unit and the ADC of the device.

The capacitive wake-up is achieved using a different procedure, explained in the next section.

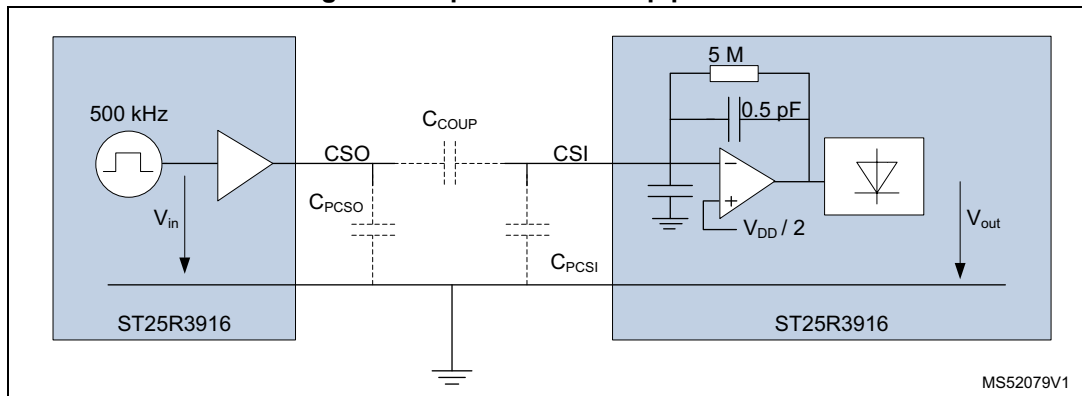
Figure 2. Capacitive wake-up block diagram



2.3.1 Measurement principle

The system includes two electrodes, CSO and CSI. Each pin is connected to an electrode, which is made out of a solid area on the PCB. On the CSO output, a 500 kHz rectangular carrier voltage is applied for a short period (300 μ s) and coupled via the parasitic capacitance C_{COUP} to the electrode on the CSI input.

Figure 3. Capacitive wake-up parasitics



Each electrode has a parasitic capacitance to ground. Assuming a strong driver and low parasitic capacitance between CSO and ground, the voltage on CSO pin is not significantly impacted by C_{PSO} .

The CSI input comprises a charge to voltage amplifier. This amplifier keeps the voltage on CSI input constant by using an internal feedback capacitor. As the voltage on CSI is constant, the parasitic capacitance C_{PSI} does not have an effect.

When an object approaches the electrical field of the electrodes two things can happen:

- If the object is conductive and not grounded, C_{COUP} increases as the object gets influenced by the emitting electrode, and the receiving electrode sees a higher electrical field.
- If the object is conductive and grounded (or has high capacitance to ground) it acts as a shield between the emitting and receiving electrode, thus reducing C_{COUP} and the receiving electrode sees a lower electrical field.

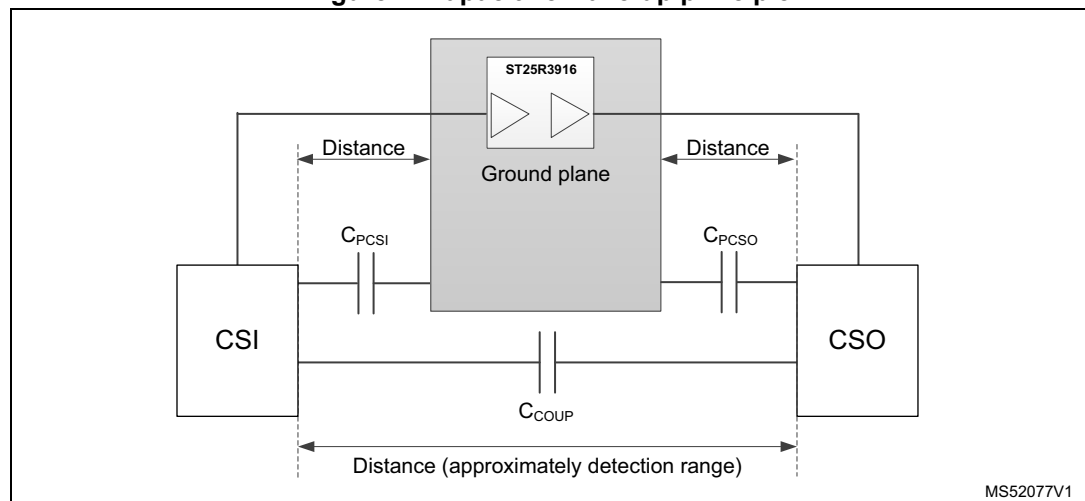
In both cases there is a change of the C_{COUP} capacitance from CSO to CSI, and this change is detected by the device.

2.3.2 Optimization layout for C_{COUP}

The parasitic capacitance to ground has to be as small as possible. This can be done by moving the capacitive plates away from any GND reference or GND plane.

To increase the measurement range or measurement precision the device can perform an offset calibration of the capacitance sensor. The capacitance measurement offset value can be chosen manually (up to 3.1 pF) or determined by the device with a built-in self-calibration procedure. To get some margin on the self-calibration it is recommended to use a coupling capacitor up to 2.7 pF.

Figure 4. Capacitive wake-up principle



2.3.3 Influence of materials

The normal use case is card carried by a human hand. The hand contains water, which changes the field propagation. The measurements show a reduction of the capacitance when a human hand is in proximity of the reader.

2.3.4 Shape of the electrodes

The shaping can be done either with a solid plane, a grid plane or stripped lines.

A solid plane gives the best area / capacitance ratio, but must be not too close to the RFID antenna since eddy currents generated in the wake-up electrode dampen the field.

The distance between the RF antenna and the electrodes has to be at least 5 mm.

2.3.5 Setup of the wake-up system

The minimum resolution of the capacitive measurement is 1.2 fF. In order to configure the capacitance wake-up, the device provides a calibration system that suppresses the initial capacitance caused by pin pads, and also has a configurable threshold level at which the change of capacitance is reported to the microcontroller. The calibration procedure is described in [Section 4.1](#).

2.3.6 Digital capacitor sensing unit

The capacitive sensor system consists of a frequency generator, which delivers a signal onto an electrode (CSO pin). The signal is received across the coupling capacitance on the input electrode (CSI pin).

To minimize the noise in the system an embedded synchronous rectifier generates a DC signal. To reject the effect of parasitic capacitances, calibration bits `cs_mcal` adjusts the DC voltage. The resulting DC signal is then amplified in a programmable gain stage (bit `cs_g` configures the gain) and fed to the ADC. The ADC converts the DC value into the digital domain and delivers a digital value to the level comparator.

The level comparator has two inputs, one from the ADC and another from the reference.

There are two options to set the reference:

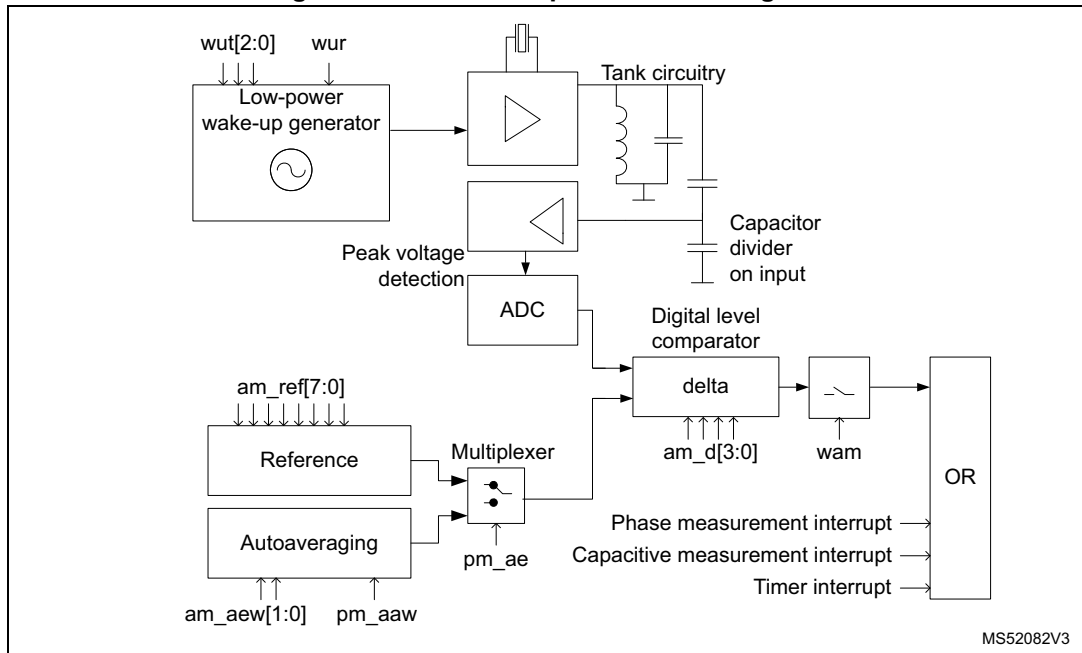
- fixed value inside a register
- floating average generated by a digital averaging circuitry.

2.4 Amplitude sensing

Inductive wake-up uses the detuning of the antenna caused by an approaching tag. This method requires a running crystal oscillator and an RF field, hence the average current consumption is higher compared to the capacitive wake-up. To decrease the current during transmission, the driver output resistance can be changed to a higher value using the RFO normal level definition register.

The measurement and interrupt trigger procedure is similar to that of the capacitive wake-up, the difference lies in the generation of the ADC value.

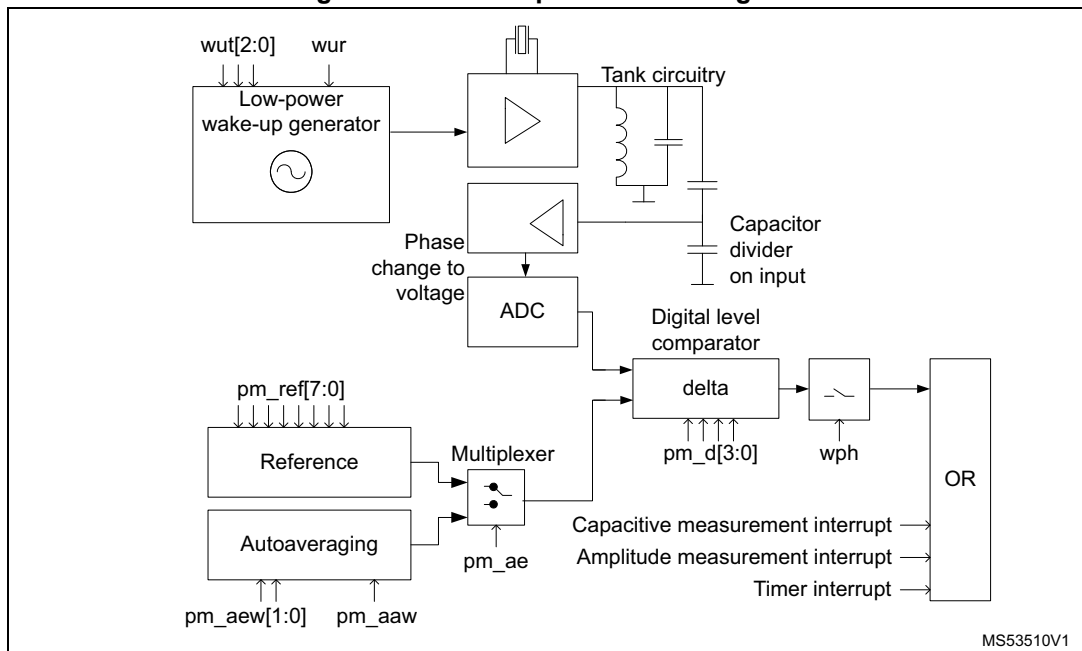
Figure 5. Inductive amplitude block diagram



2.5 Phase sensing

The inductive wake-up with a phase change is similar to the inductive wake-up with amplitude change, but the measurement value is taken from the phase measurement.

Figure 6. Inductive phase block diagram



3 Wake-up configuration

The Wake-up mode can be configured to perform either capacitive or inductive measurements. The amplitude measurement can be combined with phase measurement if desired for the wake-up, but the capacitive measurement must always be configured without any other.

Table 3. Relevant registers for Wake-up mode

Address (hex)	Name	Description
02	Operation control	Wake-up mode enable
32	Wake-up timer control	Wake-up configuration
33	Amplitude measurement configuration	Amplitude measurement configuration and display
34	Amplitude measurement reference	
35	Amplitude measurement auto-averaging display	
36	Amplitude measurement display	
37	Phase measurement configuration	Phase measurement configuration and display
38	Phase measurement reference	
39	Phase measurement auto-averaging display	
3A	Phase measurement display	
3B	Capacitance measurement configuration	Capacitance measurement configuration and display
3C	Capacitance measurement reference	
3D	Capacitance measurement auto-averaging display	
3E	Capacitance measurement display	

To set up the Wake-up mode a common configuration needs to be applied together with measurement specific configuration.

3.1 Common configuration

Register 32h contains the generic configuration for the Wake-up mode with the following bits:

- wur and wut configure the interval at which the Wake-up mode performs the defined measurement(s)
- wto defines whether the host controller will get an interrupt upon every timeout (regardless from the detection of a card)
- wam, wph and wcap specify which measurements are performed periodically.

3.2 Measurement specific configuration

Each type of measurement has its own set of registers, which configure the behavior of the individual measurement. The available configurations are identical for the three measurements.

For simplicity purposes, similar bits for the individual measurement are explained together.

For this reason, the letter x is used instead of a, p or c for amplitude, phase and capacitance, respectively.

Measurement configuration registers (33h, 37h and 3Bh) configure the individual measurement specifics with the following bits

- `xm_d` sets the difference from the reference value to the measured one, which will trigger a wake-up interrupt when reached.
- `xm_aam` makes it possible to include or exclude the measurement that caused the IRQ when using auto-averaging feature. When included the auto-averaging reference evolves into the new environment conditions after signaling the IRQ. When it is excluded the auto-average reference stays at the old value continuing to signal IRQs.
- `xm_ae` enables or disables the auto-averaging feature.

[Figure 7](#) and [Figure 8](#) show how bit `xm_aam` causes the reference (blue line) to evolve or not, and how it affects the wake-up interrupts (red dots) triggered.

Figure 7. Auto-averaging with `xm_aam` enabled

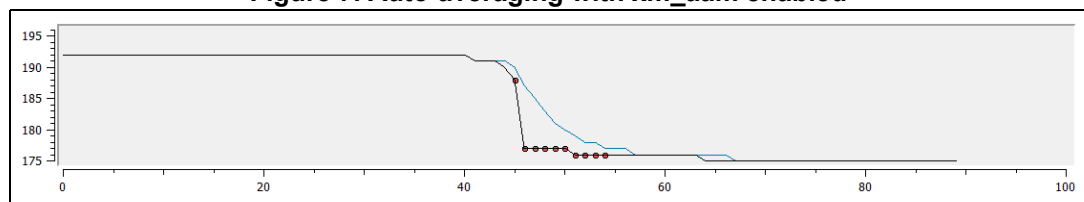
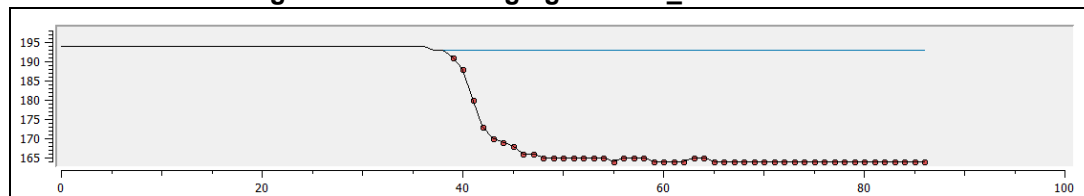


Figure 8. Auto-averaging with `xm_aam` disabled



Measurement reference registers (34h, 38h and 3Ch) define the reference value for each individual measurement. These reference values are compared periodically against the measured ones, and a difference greater or equal than `xm_d` triggers a wake-up interrupt.

Measurement auto-averaging display registers (35h, 39h and 3Dh) show the current reference when the auto-averaging feature is enabled.

Measurement display registers (36h, 3Ah and 3Eh) show the result of the last performed measurement.

4 Wake-up flow

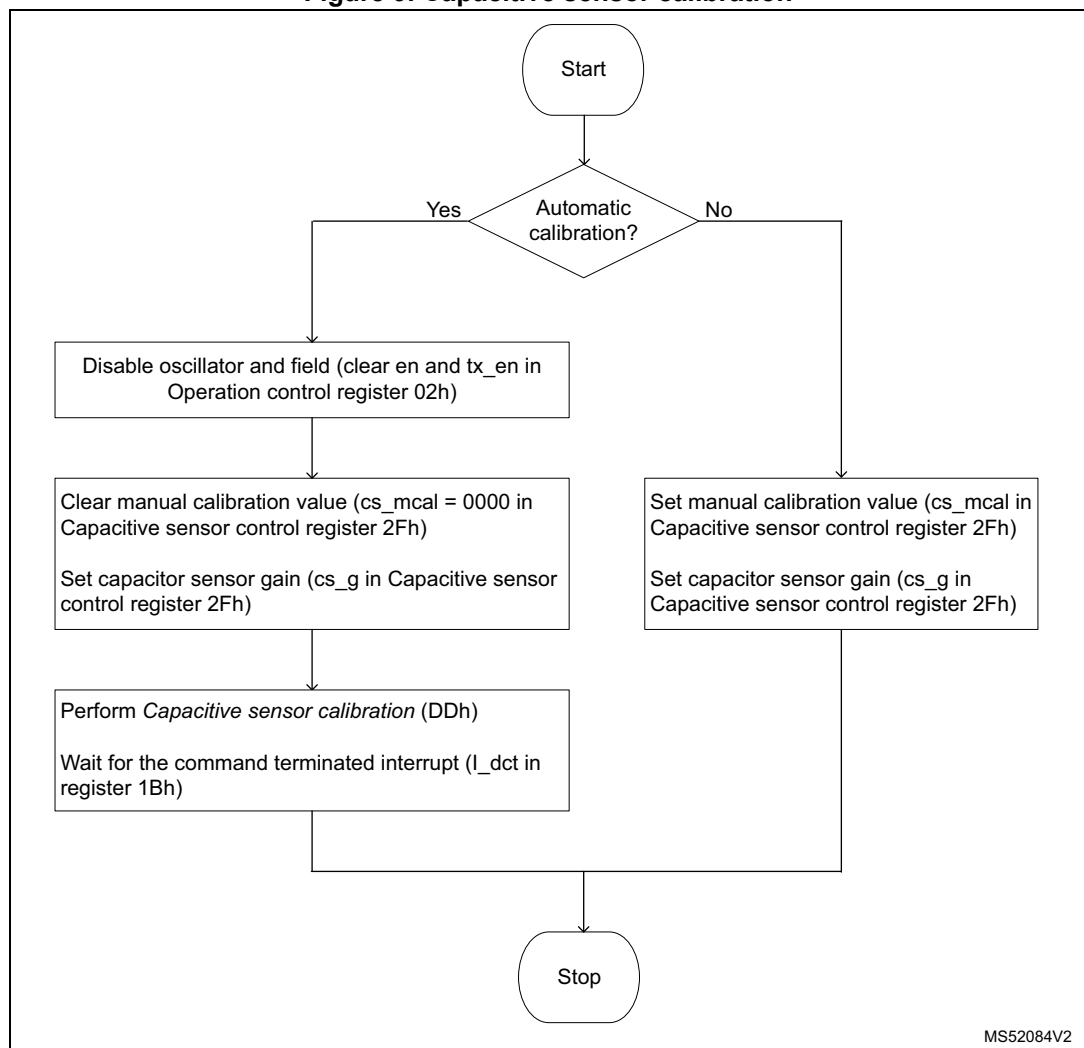
A specific sequence must be executed to enter and exit the Wake-up mode.

The procedure is similar for each wake-up measurement, with one additional step if the capacitance measurement is used (requires up-front calibration).

4.1 Capacitive sensor calibration

Two options are available to calibrate the capacitive sensor namely manual or automatic calibration, they are detailed in [Figure 9](#).

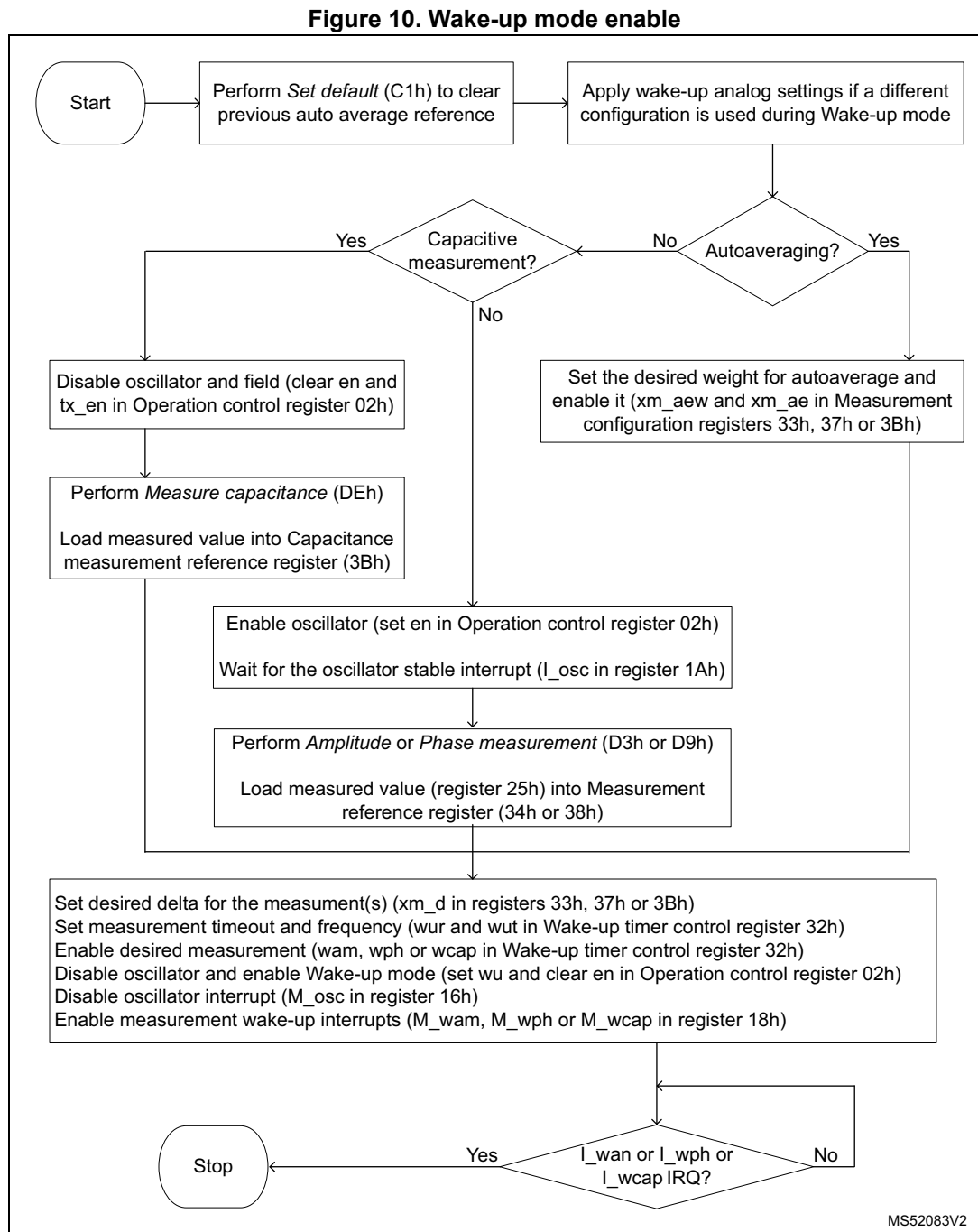
Figure 9. Capacitive sensor calibration



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4.2 Entering Wake-up mode

Figure 10 illustrates the sequence to properly configure and enable the Wake-up mode.



Initially, execute a Set default command to reset the auto-averaging reference value. The Set default is required only when the auto-averaging is used, but it is anyhow recommendable to run it, as it ensures a defined state.

After setting the default values on the device, a known good analog setting for wake-up must be applied.

Some systems require to have different analog settings for Wake-up and normal modes, to optimize power consumption and maximize range.

If the auto-averaging feature has to be used, it must be configured and enabled for each measurement.

Without auto-averaging a reference measurement must be obtained by executing the corresponding measurement command. Afterwards, the measured value needs to be set as a reference for each measurement type used.

There is a difference between performing capacitive or inductive (phase and amplitude) measurements:

- for capacitive measurements the sensor has to be calibrated (as described before) and the device must be in Power-down mode (field and oscillator disabled) to avoid interference
- for inductive measurements the oscillator has to be enabled and stable to perform the reference measurements.

Once the reference measurement is complete the value must be loaded into the corresponding measurement reference register(s).

At this stage it is important to ensure that the measured value is within an expected valid range.

Unexpected / invalid values indicate that something is wrong with the measurement, typically a mis-configured antenna or a measurement triggered without waiting for a stable oscillator.

Values close to the edges can lead to a configuration that never wakes-up the system, so, if delta is the difference that triggers an interrupt, the reference value must always satisfy the following conditions:

- $\text{reference} - \text{delta} > 0$
- $\text{reference} + \text{delta} < 255$.

Afterwards the wake-up can be configured by defining the measurement(s) interval, the measurement(s) to be performed, and then placing the device in Wake-up mode.

Note: It is known that having the field enabled for long periods may increase the temperature of the matching components, such as wire wound EMC inductors.

While entering the Wake-up mode a reference measurement is taken, and it has been observed in some systems that the increased temperature of the matching components leads to a deviated reference value. This situation causes the device to trigger a wake-up IRQ as soon as the components cool down.

The reference measurement has to be carried out in conditions similar to those where the Wake-up mode will run. Therefore, in some system designs it is recommended to ensure a certain period of time with field off before executing the Wake-up mode enable procedure, allowing the components to get back to the environment temperature.

4.3 Exiting Wake-up mode

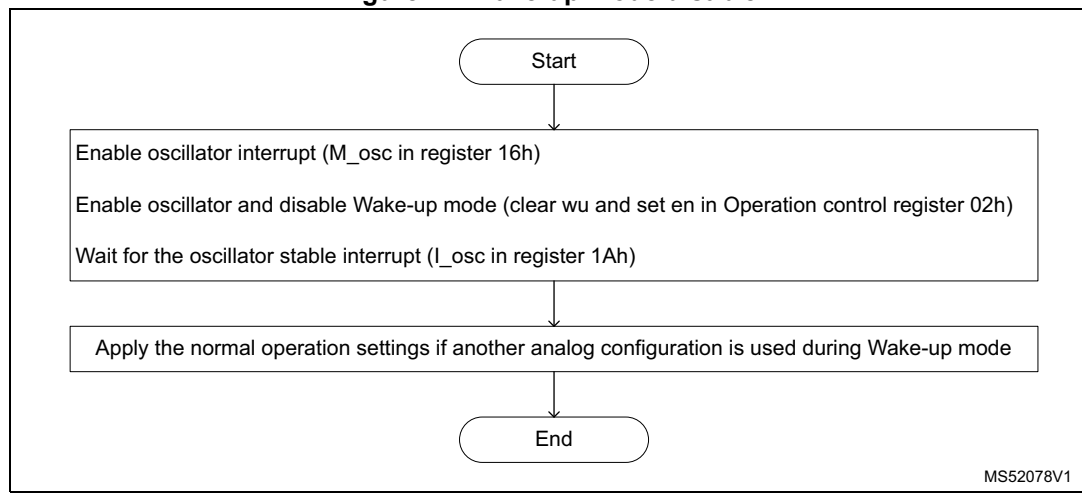
Once the Wake-up mode is enabled the host MCU can go to low-power mode to minimize power consumption.

As soon as the device detects a change on the measured value bigger than the defined difference it will trigger an IRQ.

The host MCU then reacts by disabling the ST25R3916 Wake-up mode, and executing the normal polling cycle.

Figure 11 shows the sequence to exit from the Wake-up mode.

Figure 11. Wake-up mode disable



To return to normal mode, the Wake-up mode must be disabled and the oscillator enabled. If a different analog setting is used during Wake-up mode, the normal operation setting has to be applied.

5 Wake-up mode power calculation

While in Wake-up mode, the ST25R3916 performs the enabled measurements (inductive and/or capacitive), more frequent measurements result in higher power consumption.

Unlike the capacitive measurement, the power consumption of the inductive measurements is dependent on the target matching impedance.

Each measurement has a different duration and therefore different power consumption. The duration of each measurement type is shown in the following figures, where yellow is for the RF field and green for V_{SP_RF} .

Figure 12. Amplitude measurement

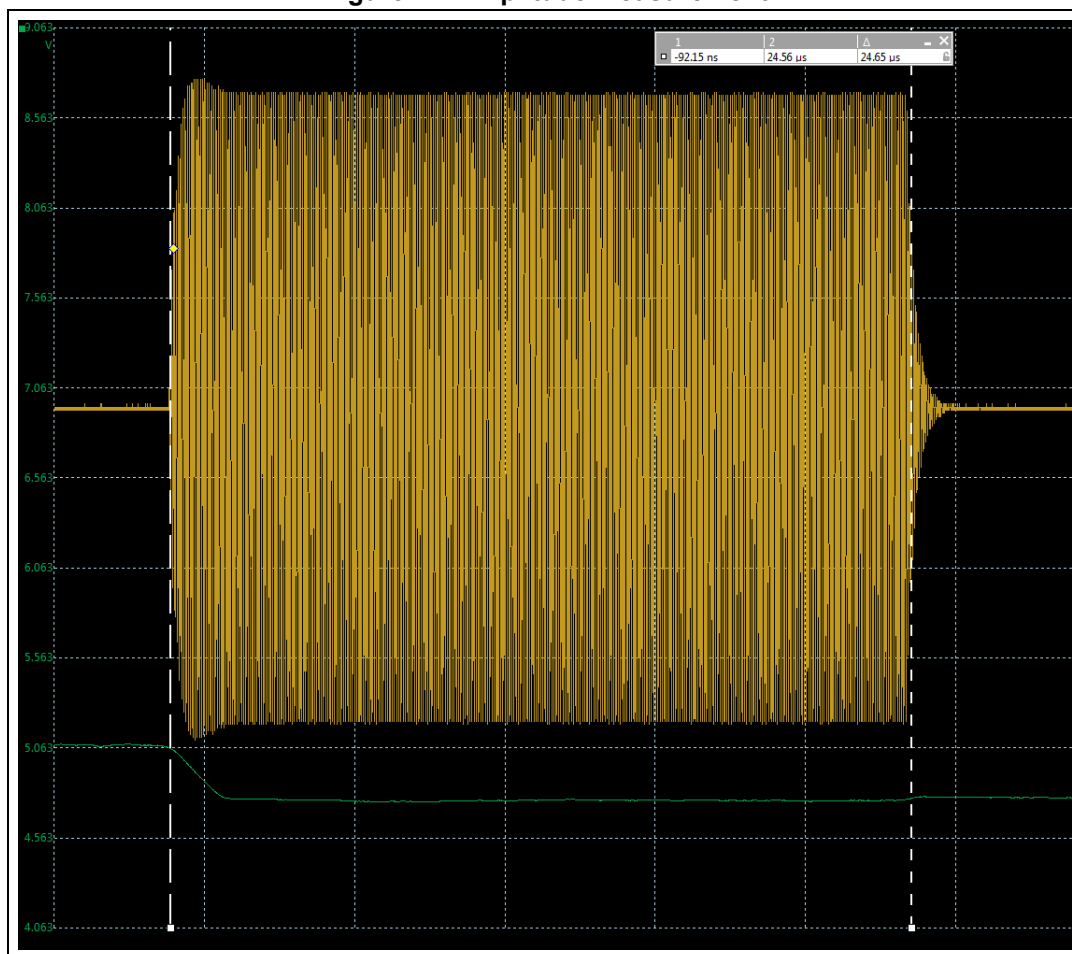


Figure 13. Phase measurement

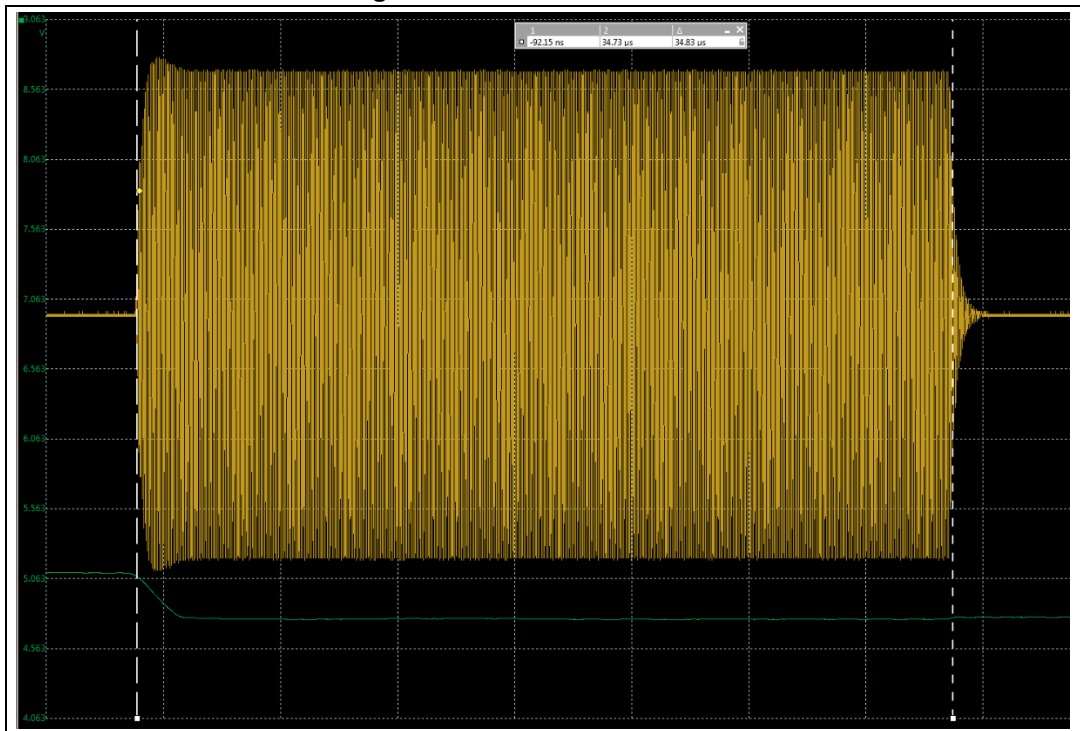
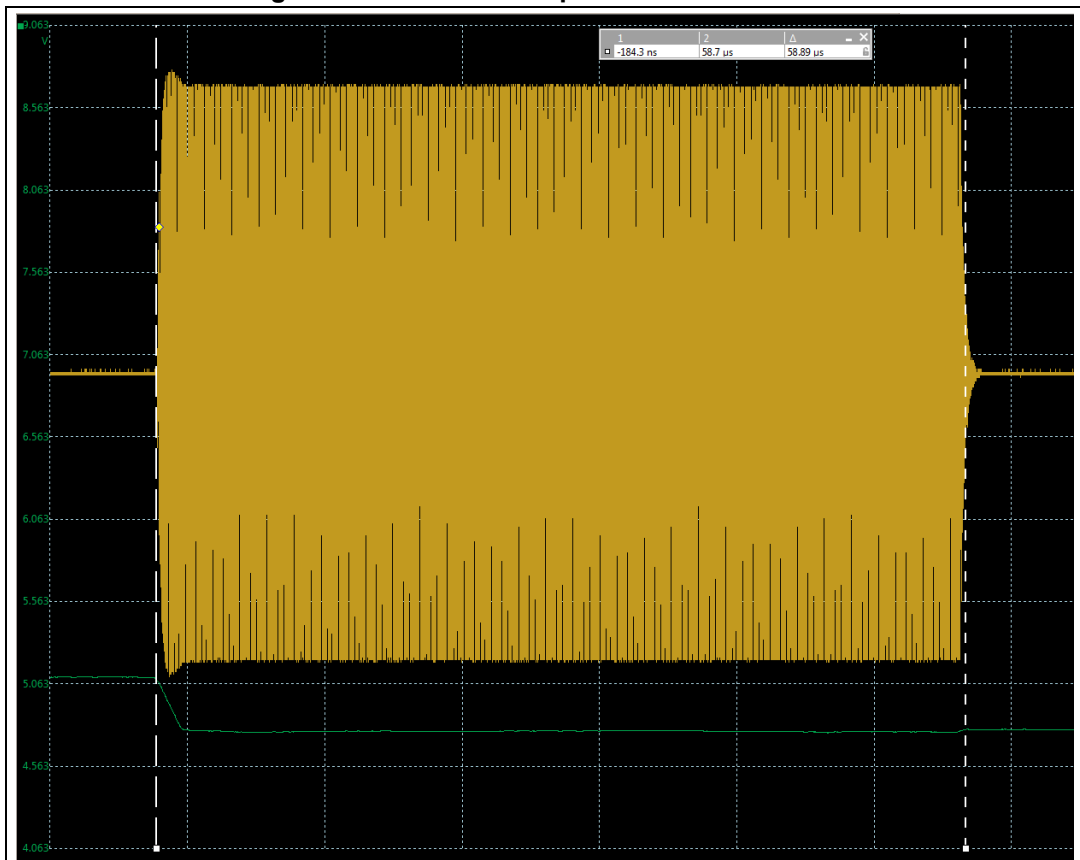


Figure 14. Phase and amplitude measurements



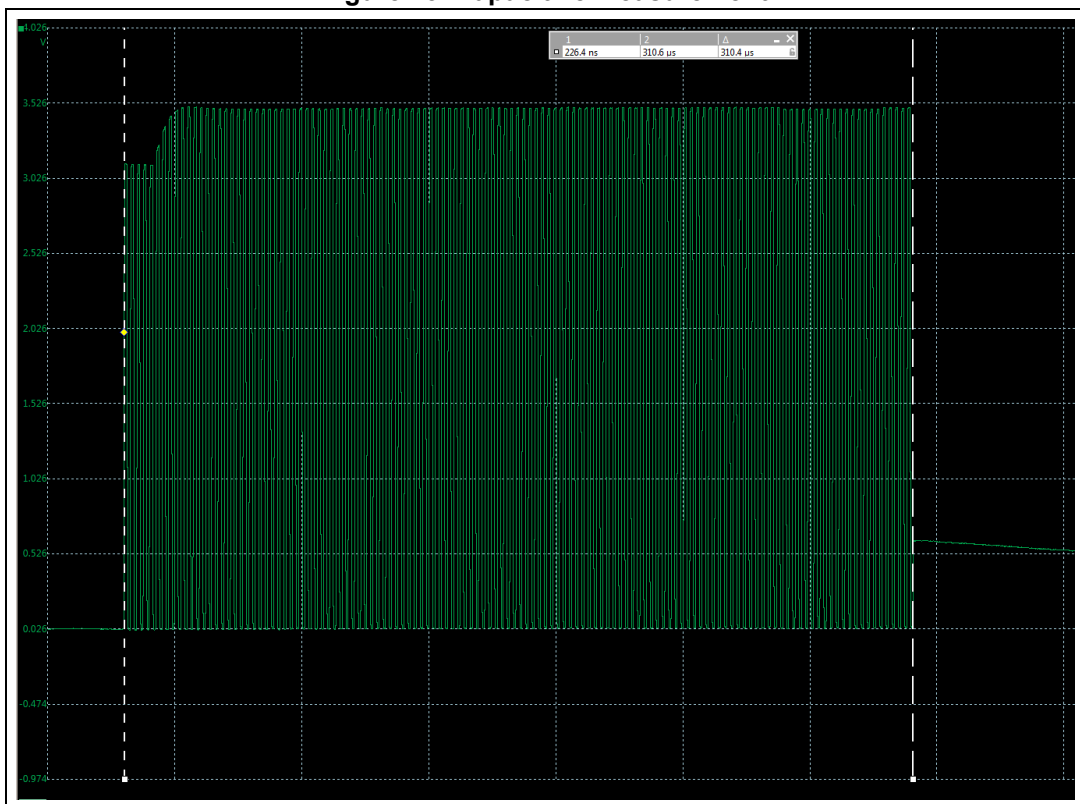
As shown in [Figure 12](#) and [Figure 13](#) the amplitude measurement (T_{AWU}) and the phase measurement (T_{PWU}) have a duration of, respectively, $\sim 24 \mu s$ and $\sim 35 \mu s$.

When both inductive measurements are combined (as in [Figure 14](#)) the total duration of the measurement phase is $\sim 59 \mu s$.

Additionally, the voltage drop of V_{SP_RF} can be observed. The voltage drops from V_{DD} and settles at the defined V_{SP_RF} voltage. This is an expected behavior and shows that after reaching the estimated V_{SP_RF} value the voltage stays constant. Oscillations or voltage drops in V_{SP_RF} indicate a problem with the supply voltage and disclose the reason for an unstable measurement during Wake-up mode.

[Figure 15](#) shows the CSO signal in green (RF field channel not shown): the capacitive measurement has a duration (T_{CWU}) of $\sim 310 \mu s$.

Figure 15. Capacitive measurement



The following calculation shows how to estimate the average power consumption in Wake-up mode.

The duration of each measurement is approximately

- $T_{AWU} = 25 \mu s$
- $T_{PWU} = 35 \mu s$
- $T_{CWU} = 310 \mu s$

The typical consumption values of supply current in Wake-up mode, which can be found on ST25R3916 datasheet, are

- $I_{CS} = 1.1 \text{ mA}$
- $I_{WU} = 3.0 \text{ } \mu\text{A}$
- $I_{RD} = 4.5 \text{ mA}$

The current during an inductive measurement ($I_{IP} = I_{IA}$) depends upon the matching impedance, therefore it varies with each system, typically between 150 and 200 mA.

The timeout / interval (T_{out}) between each measurement stage is configurable.

For an estimate of the current consumption I_{AVG} it is required to calculate the current consumption for each individual measurement ($I_{C,AVG}$, $I_{IP,AVG}$ and $I_{IA,AVG}$), using the following equations

- $I_{C,AVG} = (I_{CS} - I_{WU}) (T_{CWU} / T_{OUT})$
- $I_{IP,AVG} = (I_{IP} - I_{WU}) (T_{PWU} / T_{OUT})$
- $I_{IA,AVG} = (I_{IA} - I_{WU}) (T_{AWU} / T_{OUT})$

When an inductive measurement (amplitude and/or phase) is used there is an additional contribution (while enabling the oscillator) that must be taken into account

$$I_{OSC,AVG} = (I_{RD} - I_{WU}) (T_{OSC} / T_{OUT})$$

Then, the total current consumption I_{AVG} is

$$I_{AVG} = I_{C,AVG} + I_{IP,AVG} + I_{IA,AVG} + I_{OSC,AVG} + I_{WU}$$

For example, assuming that for a particular system $I_{IP,AVG} = 200 \text{ mA}$, $T_{OSC} = 0.7 \text{ ms}$ and $T_{OUT} = 200 \text{ ms}$, the estimated current consumption with inductive amplitude measurement during the Wake-Up mode, can be estimated as

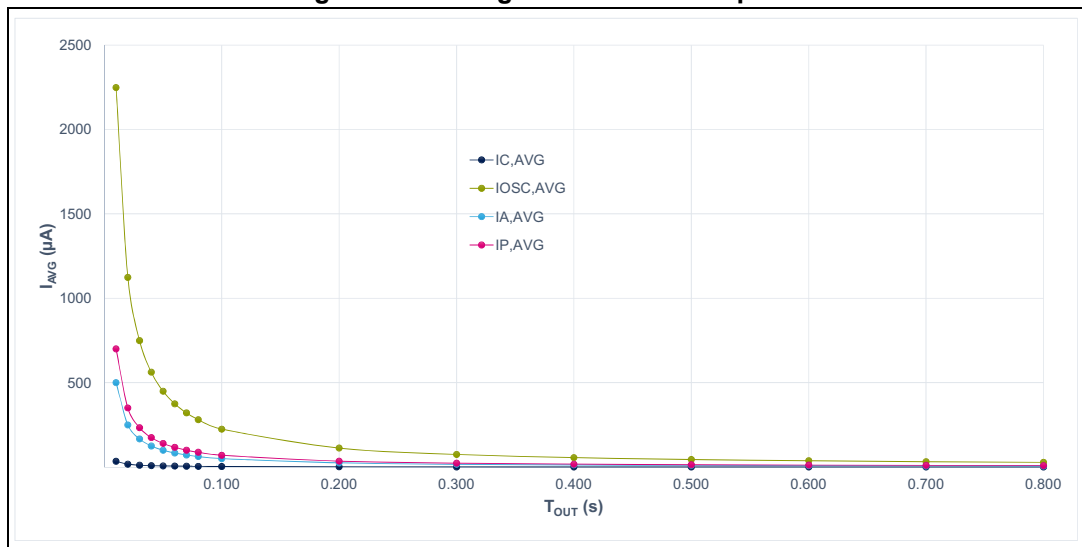
- $I_{C,AVG} = 0$
- $I_{IP,AVG} = 0$
- $I_{IA,AVG} = (200 \times 10^{-3} - 3.0 \times 10^{-6}) \times (25 \times 10^{-6} / 200 \times 10^{-3}) = 25.00 \text{ } \mu\text{A}$
- $I_{OSC,AVG} = (4.5 \times 10^{-3} - 3.0 \times 10^{-6}) \times (0.7 \times 10^{-3} / 200 \times 10^{-3}) = 15.74 \text{ } \mu\text{A}$.

The total current consumption of this system (using capacitive and inductive amplitude measurements during the Wake-up mode) can be estimated as

$$I_{AVG} = I_{C,AVG} + I_{IP,AVG} + I_{IA,AVG} + I_{WU} = 0 + 0 + 25 + 15.74 + 3.0 = 43.74 \text{ } \mu\text{A}$$

In [Figure 16](#) it is possible to see how each average current consumption relates to the different timeout / period configurations ($I_{IP} = I_{IA} = 200 \text{ mA}$).

Figure 16. Average current consumption



6 Wake-up mode with AAT

The ST25R3916 gives the possibility to have designs with fixed matching, or to use a variable tuning by means of the AAT technique, detailed in *ST25R3916 automatic antenna tuning (AAT)* (AN5322), available on www.st.com.

The ST25R3916 AAT is achieved by two DAC outputs driving voltage controlled capacitors (varicaps), which make possible to dynamically change the serial and parallel capacitance of the matching.

Due to power consumption efficiency, these DAC outputs are not enabled when the device is put in Power-down mode and the AAT_A / AAT_B pins are in undefined / floating state.

Once the Wake-up timeout occurs the DAC outputs are enabled to the defined voltage, and as soon as the oscillator is stable the inductive measurement is performed. The varicaps can still be settling to the new control voltage, this can lead to a different antenna matching during normal operation and in Wake-up mode. As a consequence the reference value obtained in Ready mode can differ from the one acquired in Wake-up mode, causing the system to be woken-up.

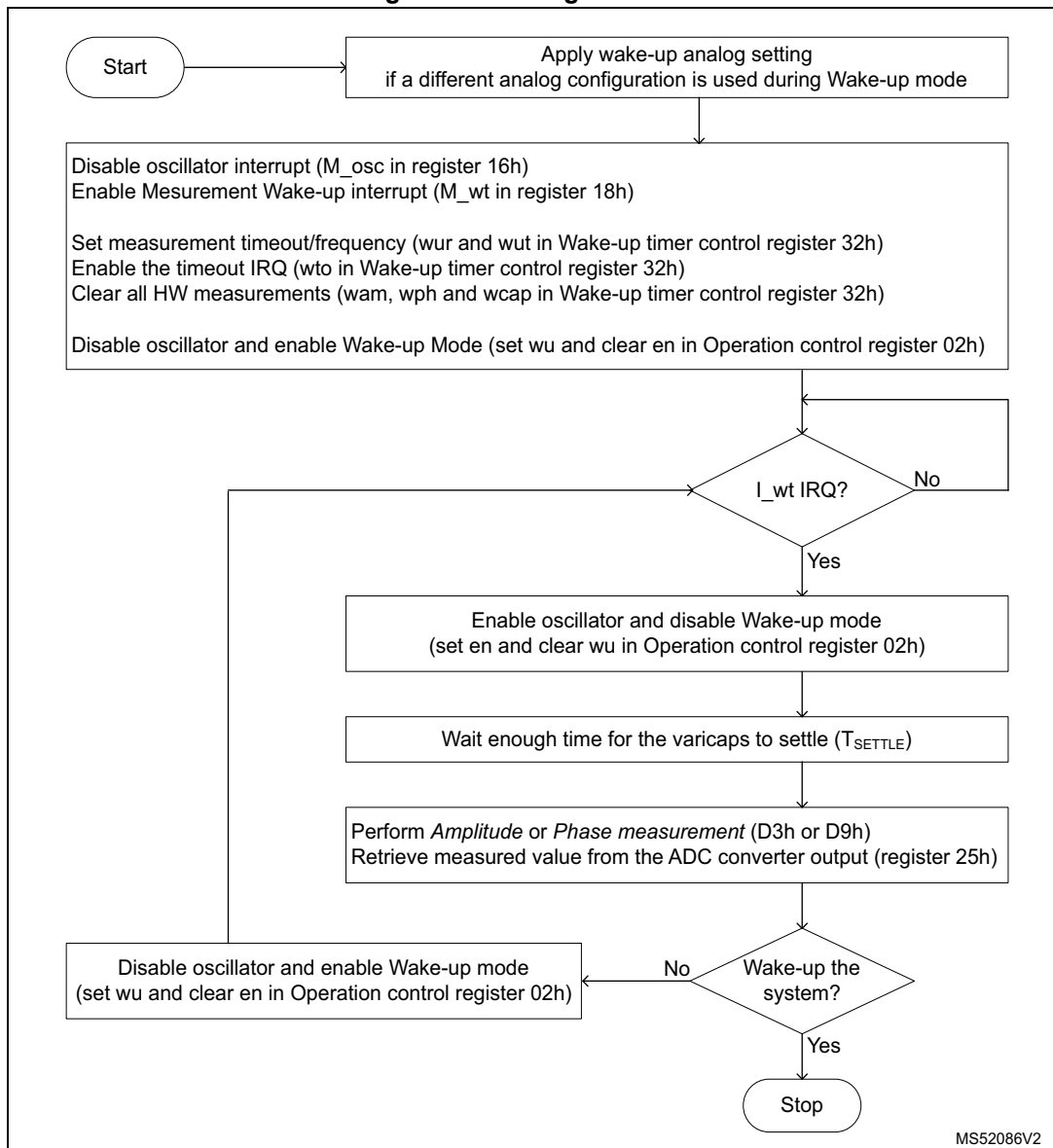
To minimize such effects two techniques are available, SW tag detection and measurement delay, described in the next subsections.

6.1 SW tag detection

In this case (see [Figure 17](#)) the ST25R3916 is put in Power-down mode, where the power consumption is minimal, and the Wake-up timer is used to wake / trigger the host MCU to periodically perform measures.

The host MCU can be also placed in a low-power mode during this procedure. Periodically, when it receives the external IRQ from the device, the host puts it in Ready mode, and performs the required measurement(s) after the appropriate varicap settling time (they reach their final capacitance value after T_{SETTLE} , the amount of time to delay the measurement pulse until the varicaps have reached their final capacitance value). Then, it evaluates the difference from previous samples, and decides whether the system must poll for NFC devices, or go back to Low-power mode.

Figure 17. SW tag detection



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To terminate the SW tag detection execute the sequence described in [Section 4.3: Exiting Wake-up mode](#).

To improve the robustness of the SW tag detection different wake-up methods can be applied, such as a moving reference (similarly to the procedure described in [Section 2.2: Auto averaging](#)), or a fractional delta concept.

The main difference between the SW tag detection and the Wake-up mode is that the host must be periodically woken-up to execute the measurement(s), and the device is kept in Ready mode for at least T_{SETTLE} each period, with an impact on the overall power consumption and system responsiveness.

With SW tag detection T_{SETTLE} significantly influences the power consumption. Based on calculations described in [Section 5](#), and assuming that $T_{OSC} < T_{SETTLE}$, the average power consumption of the ST25R3916 alone can be estimated as

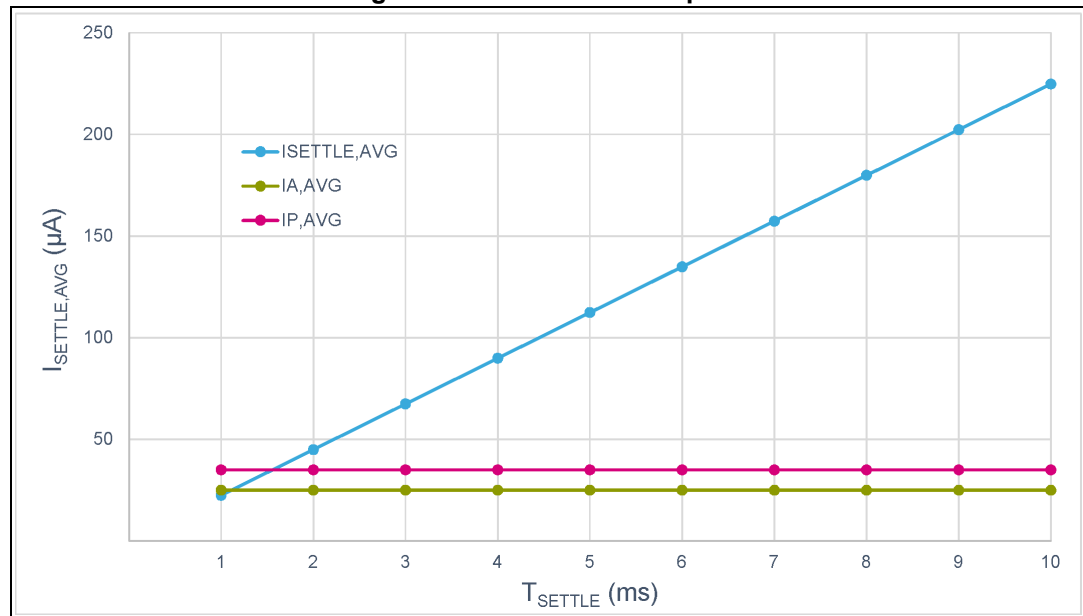
- $I_{AVG} = I_{C,AVG} + I_{IP,AVG} + I_{IA,AVG} + I_{SETTLE,AVG} + I_{WU}$
- $I_{SETTLE,AVG} = (I_{RD} - I_{WU}) T_{SETTLE} / T_{OUT}$

Using the example presented in [Section 5](#) ($I_{IP} = I_{IA} = 200$ mA, $T_{out} = 200$ ms) and with $T_{SETTLE} = 5$ ms the power can be calculated as

- $I_{SETTLE,AVG} = (I_{RD} - I_{WU}) T_{SETTLE} / T_{OUT} = (4.5 \times 10^{-3} - 3.0 \times 10^{-6}) \times (5 \times 10^{-3} / 200 \times 10^{-3}) = 112.43 \mu A$
- $I_{AVG} = I_{C,AVG} + I_{IP,AVG} + I_{IA,AVG} + I_{SETTLE,AVG} + I_{WU} = 0 + 0 + 25 + 112.43 + 3.0 = 140.43 \mu A$

[Figure 18](#) shows how $I_{SETTLE,AVG}$ increases linearly with T_{SETTLE} , thus impacting the overall power consumption.

Figure 18. Current consumption



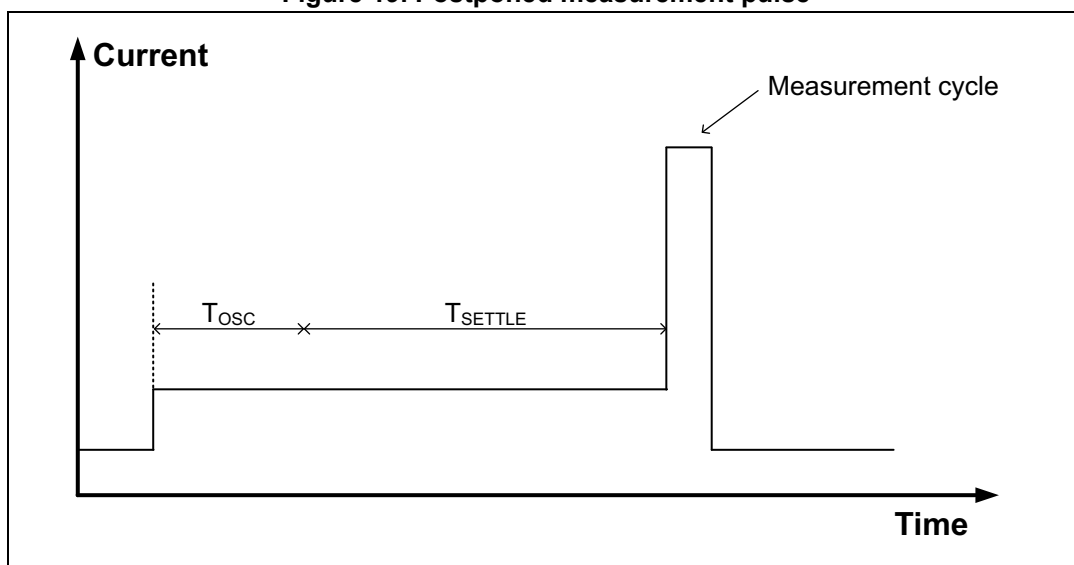
6.2 Measurement delay

This solution is available only on the ST25R3916B device.

It is possible to complete T_{SETTLE} ahead of the measurement pulse, thus enabling the wake-up mode together with AAT, without the need for SW tag detection. The timing can be adjusted via `meas_tx_del` bits (in combination with `wur` and `wut` bits) within a range from 0 to 12 ms. For detailed information refer to the datasheet, available on www.st.com.

As shown in [Figure 19](#), once the wake-up timer triggers, the device moves into Ready mode, and postpones the inductive measurement pulse by T_{SETTLE} , depending on the configuration.

Figure 19. Postponed measurement pulse



7 Conclusion

The low-power Wake-up mode available on ST25R3916, ST25R3916B, ST25R3917 and ST25R3920 devices allows the user to implement an optimized card detection, operating in complete autonomy from the microcontroller.

Thanks to this feature the overall system current consumption is kept at a minimum, while still being reactive to cards approaching the NFC reader device.

The availability of amplitude, phase, and capacitive wake-up sources results in a wide flexibility for customer design.

8 Revision history

Table 4. Document revision history

Date	Revision	Changes
09-May-2019	1	Initial release.
09-Jul-2019	2	Updated Section 2.1: Low-power wake-up generator , Section 5: Wake-up mode power calculation and Section 6: Wake-up mode with AAT .
06-Feb-2020	3	Updated Section 5: Wake-up mode power calculation and Section 6: Wake-up mode with AAT . Updated Figure 2: Capacitive wake-up block diagram , Figure 5: Inductive amplitude block diagram , Figure 6: Inductive phase block diagram , Figure 9: Capacitive sensor calibration , Figure 10: Wake-up mode enable and Figure 17: SW tag detection . Added Figure 18: Current consumption . Minor text edits across the whole document.
14-Aug-2020	4	Document scope extended to ST25R3917 and ST25R3920. Updated document title, Introduction , Section 2: Wake-up mode and Section 6: Wake-up mode with AAT . Added Table 2: Wake-up mode capability .
17-Dec-2021	5	Document scope extended to ST25R3916B. Updated document title, Introduction , Section 6: Wake-up mode with AAT and Section 7: Conclusion . Updated Table 2: Wake-up mode capability . Added Section 6.1: SW tag detection and Section 6.2: Measurement delay .

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