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**Wake-up mode of the ST25R3911B/ST25R391x**

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**Introduction**

This document describes the ST25R3911B wake-up mode, which comprises different low-power modes that are used to detect the presence of a card.

Three wake-up sources are available:

- Capacitive sensing
- Amplitude measurement
- Phase measurement

Each source is individually configurable and can generate an interrupt to the MCU.

**Table 1. Device summary**

Reference	Part number
ST25R3911B	ST25R3911B
ST25R391x	ST25R3912 ST25R3913 ST25R3914 ST25R3915

This application note only mentions the ST25R3911B, but its content also applies to ST25R3912, ST25R3913, ST25R3914 and ST25R3915 devices.

# Contents

- 1      Wake-up mode ..... 5**
- 1.1    Low-power wake generator ..... 5
- 1.2    Auto averaging ..... 6
- 1.3    Capacitive sensing ..... 6
- 1.3.1    Measurement principle ..... 7
- 1.3.2    Optimization layout for CCOUP ..... 8
- 1.3.3    Influence of Material ..... 9
- 1.3.4    Shaping of electrodes ..... 9
- 1.3.5    Setup of the wake-up system ..... 9
- 1.3.6    Digital capacitor sensing unit ..... 9
- 1.4    Amplitude sensing ..... 10
- 1.5    Phase sensing ..... 11
- 1.6    Wake-up configuration ..... 12
- 1.7    Common configuration ..... 12
- 1.8    Measurement specific configuration ..... 13
  
- 2      Wake-up flow ..... 14**
- 2.1    Capacitive sensor calibration ..... 14
- 2.2    Entering wake-up mode ..... 15
- 2.3    Exiting from wake-up mode ..... 17
  
- 3      Wake-up mode power calculation ..... 18**
  
- 4      Glossary ..... 24**
  
- 5      Conclusion ..... 25**
  
- 6      Revision history ..... 26**

## List of tables

Table 1.	Device summary . . . . .	1
Table 2.	Wake-up types available per device . . . . .	5
Table 3.	Wake-up register . . . . .	12
Table 4.	List of terms and acronyms. . . . .	24
Table 5.	Document revision history . . . . .	26

# List of figures

Figure 1. Wake-up measurement cycle . . . . . 6  
Figure 2. Capacitive wake-up block diagram . . . . . 7  
Figure 3. Capacitive wake-up parasitics . . . . . 7  
Figure 4. Capacitive wake-up principle . . . . . 9  
Figure 5. Inductive amplitude block diagram . . . . . 10  
Figure 6. Inductive phase wake-up mode . . . . . 11  
Figure 7. Auto-averaging with xm aam enabled . . . . . 13  
Figure 8. Auto-averaging with xm aam disabled . . . . . 13  
Figure 9. Capacitive sensor calibration . . . . . 14  
Figure 10. Wake-up mode enable . . . . . 15  
Figure 11. Wake-up mode disable . . . . . 17  
Figure 12. Amplitude measurement. . . . . 18  
Figure 13. Phase measurement. . . . . 19  
Figure 14. Phase and amplitude measurement . . . . . 20  
Figure 15. Capacitive measurement . . . . . 21  
Figure 16. Average current consumption. . . . . 23

# 1 Wake-up mode

The ST25R3911B wake-up mode is used to perform low-power detection of card presence. It includes several possibilities of low-power card detection:

- Capacitive sensor
- Phase measurement
- Amplitude measurement.

Traditional card detection is done by a polling loop, which requires the device to periodically turn its field on, wait for a certain period to fulfill the card's Guard Time (typically 5-20 ms), and then send a poll request.

Since this procedure is inefficient in terms of power consumption and detection time, the ST25R family offers a low-power wake-up mode.

Once in low-power wake-up mode, the ST25R3911B operates on an internal low power RC oscillator while performing environmental measurements. The periodically measured values are internally compared against the user presets, and will trigger an interrupt if the current value is outside the limits. This allows the MCU to sleep while the ST25R3911B autonomously detects approaching tags. The MCU can then be woken up by the interrupt pin and start normal polling for cards.

[Table 2](#) shows the wake-up types available per device.

**Table 2. Wake-up types available per device**

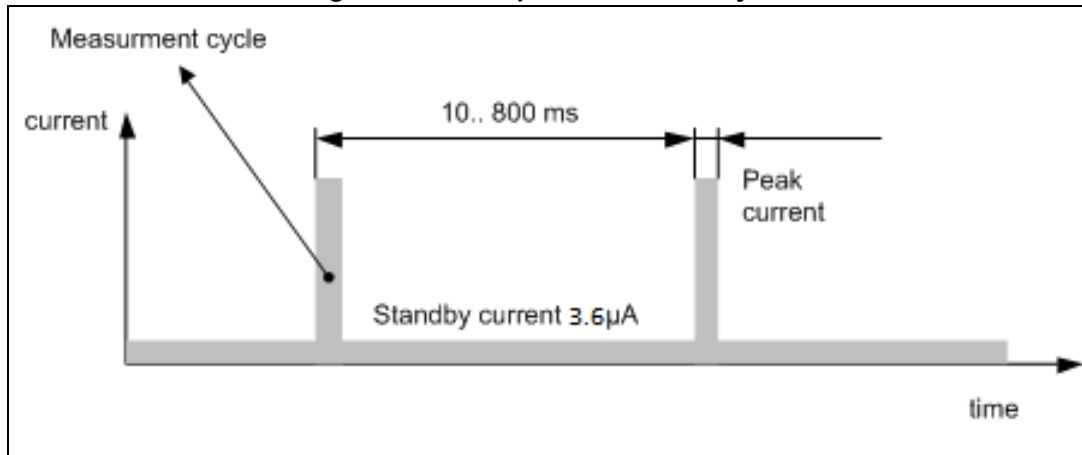
Part	Capacitive wake-up	Inductive wake-up (amplitude and phase)
ST25TR3911B	X	X
ST25TR3912	-	X
ST25TR3913	-	X
ST25TR3914	X	X
ST25TR3915	X	X

## 1.1 Low-power wake generator

The low-power wake generator will be always active, and the device consumes during the wake-up mode typically 3.6  $\mu$ A.

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

Figure 1. Wake-up measurement cycle



## 1.2 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 of the new value and the stored value is added to the stored value.

$$\text{NewReference} = \text{OldReference} + \left( \frac{\text{MeasuredValue} - \text{OldReference}}{\text{Weight}} \right)$$

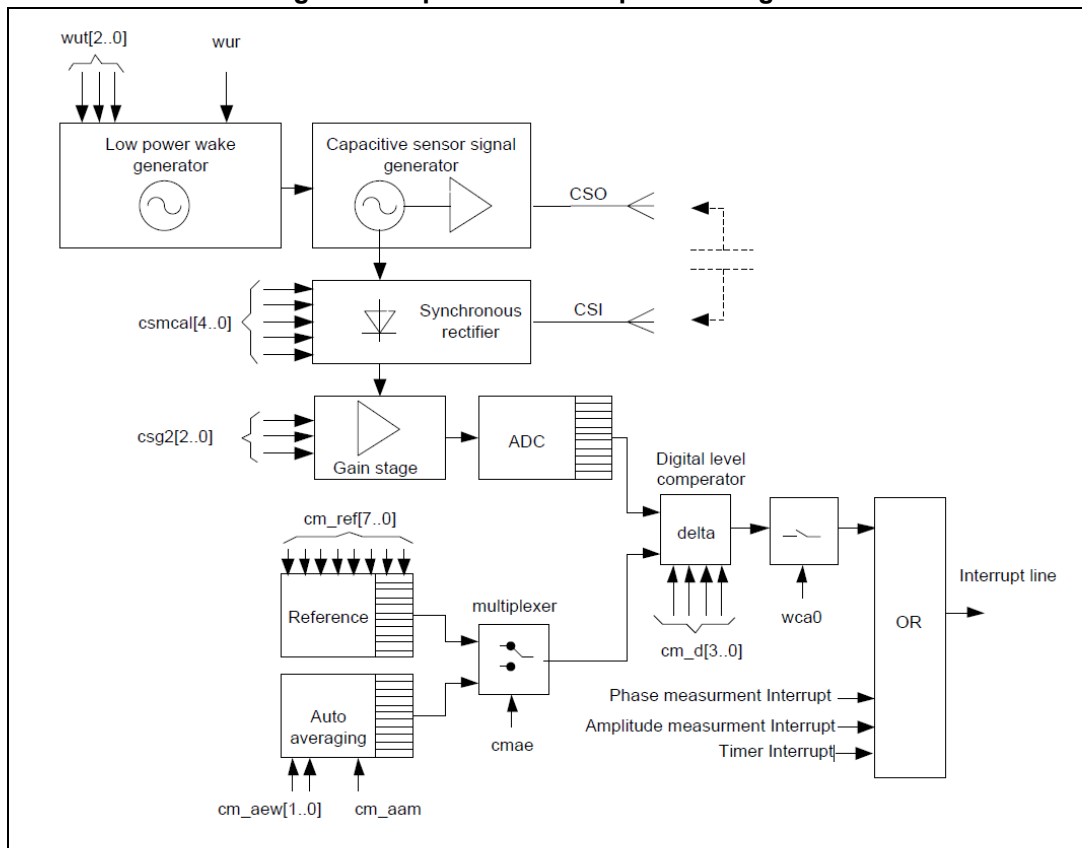
When the auto averaging is enabled, the reference evolves automatically to adapt to the new environment conditions. This reference is stored internally and it persists even if the wake-up mode is exited and then restarted. The direct command Set Default will reset the stored reference.

## 1.3 Capacitive sensing

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

The capacitive wake-up is achieved using a different procedures that is further explained on the next section.

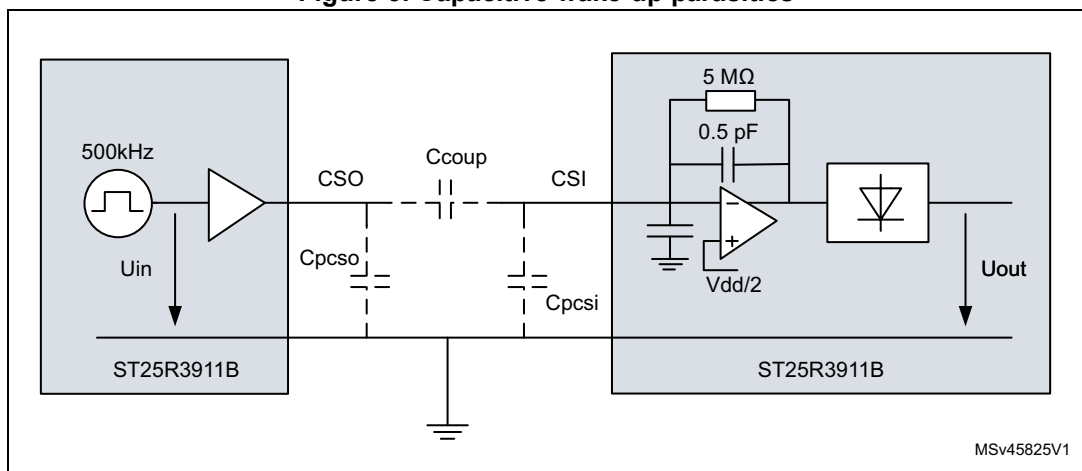
Figure 2. Capacitive wake-up block diagram



### 1.3.1 Measurement principle

The system includes two electrodes labeled CSO (Capacitance Sense Output) and CSI (Capacitance Sense Input). 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  $\mu$ s) and coupled via parasitic capacitance  $C_{COUP}$  to the electrode on the CSI input.

Figure 3. Capacitive wake-up parasitics



Each electrode also has a parasitic capacitance to ground.

Assuming a strong driver and low parasitic capacitance on CSO to ground, the voltage on the CSO pin is not jeopardized due to  $C_{PSO}$ .

The CSI input comprises a charge to voltage amplifier. This amplifier keeps the voltage on CSI input constant by using an internal feedback capacitor. Since on CSI the voltage is constant, the parasitic capacitance on CSI will not have an effect.

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

1. If the object is conductive and not grounded, the capacitance  $C_{COUP}$  will increase as the object gets influenced by the emitting electrode and the receiving electrode sees more of the electrical field.
2. If the object is conductive and grounded (or has high capacitance to ground) it will act as a shield between the emitting and receiving electrode, thus reducing the capacitance  $C_{COUP}$  and the receiving electrode sees less of the electrical field.

In both cases there will be a change of the capacitance  $C_{COUP}$  from CSO to CSI which is detected by the device.

### 1.3.2 Optimization layout for $C_{COUP}$

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

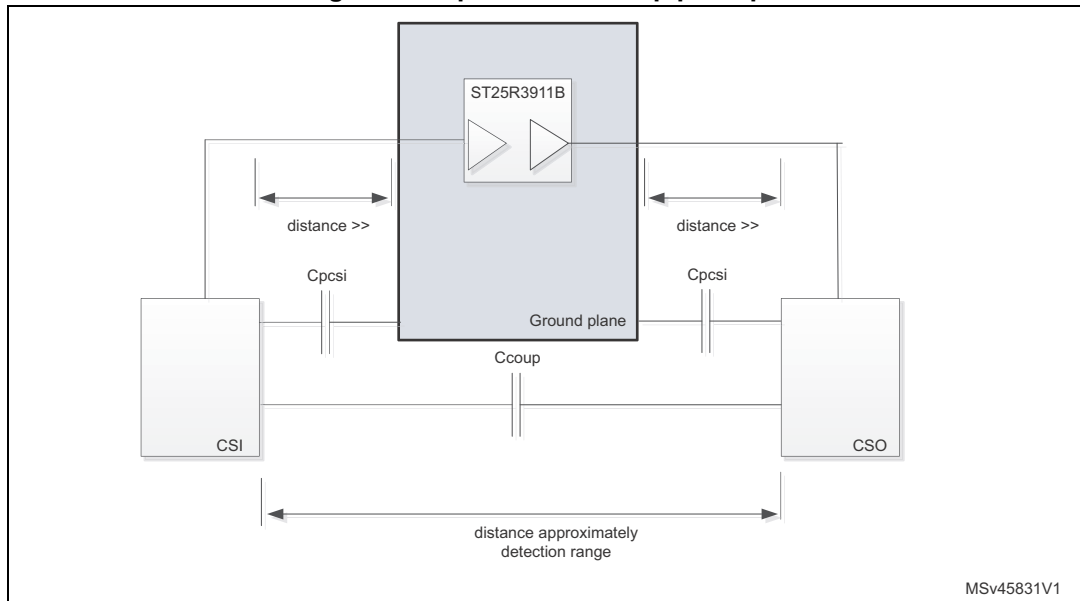
To increase the measurement range or measurement precision the ST25R3911B can perform an offset calibration of the capacitance sensor. The capacitance measurement offset value can either be chosen manually up to 3.1 pF or be determined by the ST25R3911B with a built-in self-calibration procedure.

To get some margin on the self-calibration, it is recommended to use a coupling capacitor up to 2.7 pF.

The size of the CSI and CSO electrodes should be made as large as possible, and both with similar size. The distance between the electrodes should be similar to the detection range.



Figure 4. Capacitive wake-up principle



### 1.3.3 Influence of Material

The normal use case will be a card carried by a human hand. The hand contains water which will change the field propagation. The measurements will show a reduction of the capacitance when a human hand is brought into proximity of the reader.

### 1.3.4 Shaping of 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, however a solid plane should not be used too close to the RFID antenna since eddy currents that are generated in the wake-up electrode will dampen the field.

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

### 1.3.5 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 ST25R3911B 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 2.1: Capacitive sensor calibration](#).

### 1.3.6 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, a synchronous rectifier is implemented that generates a DC signal. To reject the effect of parasitic capacitances, calibration bits `cs_mcal` will adjust the DC voltage. The resulting DC signal will then be amplified in a programmable gain stage

(bits `cs_g` configure 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:

1. One from the ADC
2. One from the Reference

There are two options to set the reference:

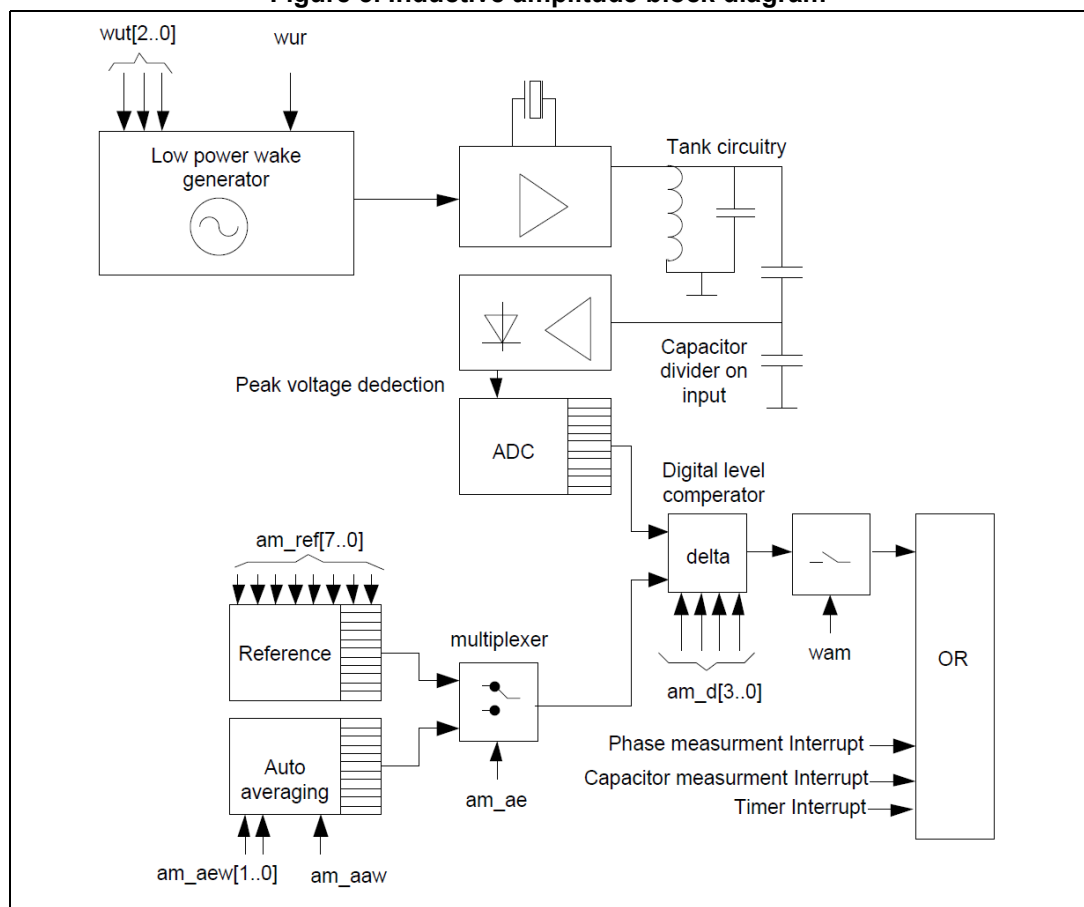
1. Fixed value inside a register
2. Floating average generated by a digital averaging circuitry.

## 1.4 Amplitude sensing

Inductive wake-up uses the detuning of the antenna caused by an approaching tag. Since that method requires a running crystal oscillator and an RF field, the average current consumption is higher compared to the capacitive wake-up. In order 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 analogue to the capacitive wake-up. The difference is the generation of the ADC value.

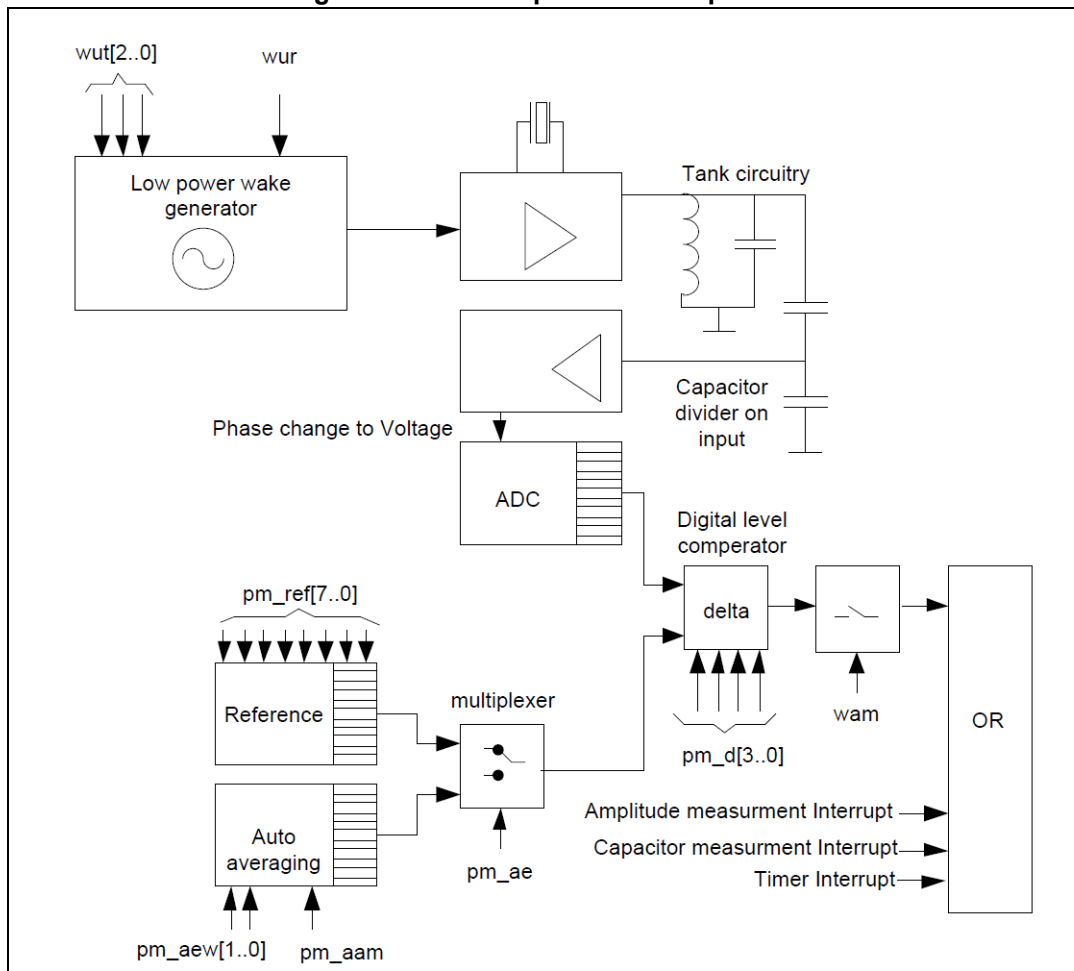
Figure 5. Inductive amplitude block diagram



### 1.5 Phase sensing

The inductive wake-up with a phase change is analogue to the inductive wake-up with amplitude change, the difference is that the measurement value is taken from the phase measurement.

Figure 6. Inductive phase wake-up mode



## 1.6 Wake-up configuration

The wake-up mode can be configured to perform either capacitive or inductive measurement(s). 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.

The relevant registers for the wake-up mode are the following:

**Table 3. Wake-up register**

Register address (hex)	Register name	Description
02	Operation Control	Wake-up mode enable
31	Wake-up Timer Control	Wake-up configuration
32	Amplitude Measurement Configuration	Amplitude measurement configuration and display
33	Amplitude Measurement Reference	
34	Amplitude Measurement Auto-Averaging Display	
35	Amplitude Measurement Display Register	
36	Phase Measurement Configuration	Phase measurement configuration and display
37	Phase Measurement Reference	
38	Phase Measurement Auto-Averaging Display	
39	Phase Measurement Display	
3A	Capacitance Measurement Configuration	Capacitance measurement configuration and display
3B	Capacitance Measurement Reference	
3C	Capacitance Measurement Auto-Averaging Display	
3D	Capacitance Measurement Display	

In order to set up the wake-up mode, a common configuration needs to be applied together with measurement specific configuration.

## 1.7 Common configuration

Register 31h contains the generic configuration for the wake-up mode with the following bits:

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

## 1.8 Measurement specific configuration

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

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

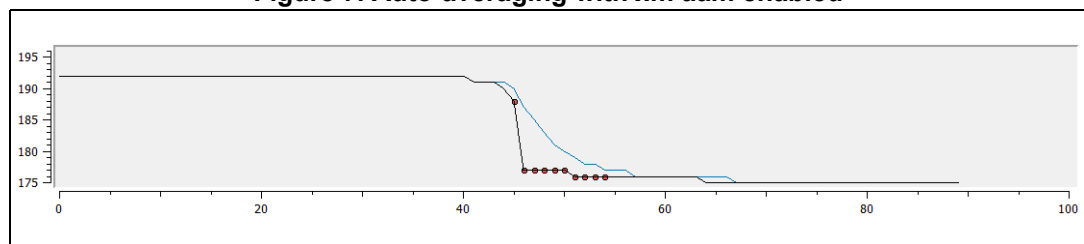
For this reason the letter x below is used instead of a, p or c as for Amplitude, Phase and Capacitance respectively.

Measurement Configuration registers (32h, 36h and 3Ah) configure the individual measurement specifics with the following bits:

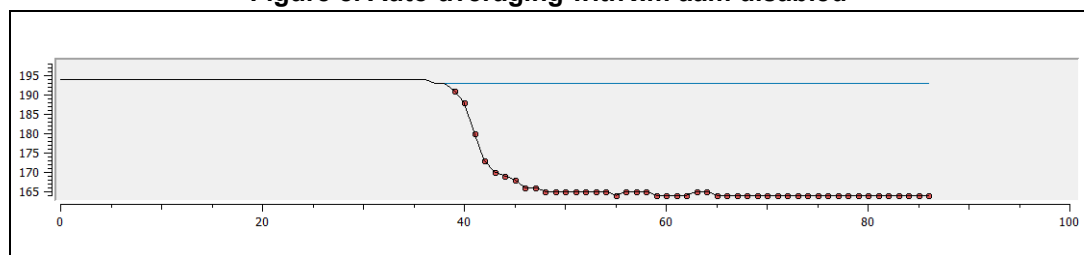
- `xm_d` sets the difference from the reference value to the measured one which will trigger a wake-up interrupt when reached.
- `xm_aam` allows to include or exclude the measurement that caused the IRQ when using auto-averaging feature. When included the auto-averaging reference will evolve into the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

[Figure 7](#) and [Figure 8](#) show how the `xm_aam` bit 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 (33h, 37h and 3Bh) define the reference value for each individual measurement. These reference values are compared periodically against the measured ones and if a difference greater or equal than `xm_d` will trigger a wake-up interrupt.

Measurement Auto-Averaging Display Registers (34h, 38h and 3Ch) shows the current reference when the auto-averaging feature is enabled.

Measurement Display Registers (35h, 39h and 3Dh) shows the result of the last measurement performed.

## 2 Wake-up flow

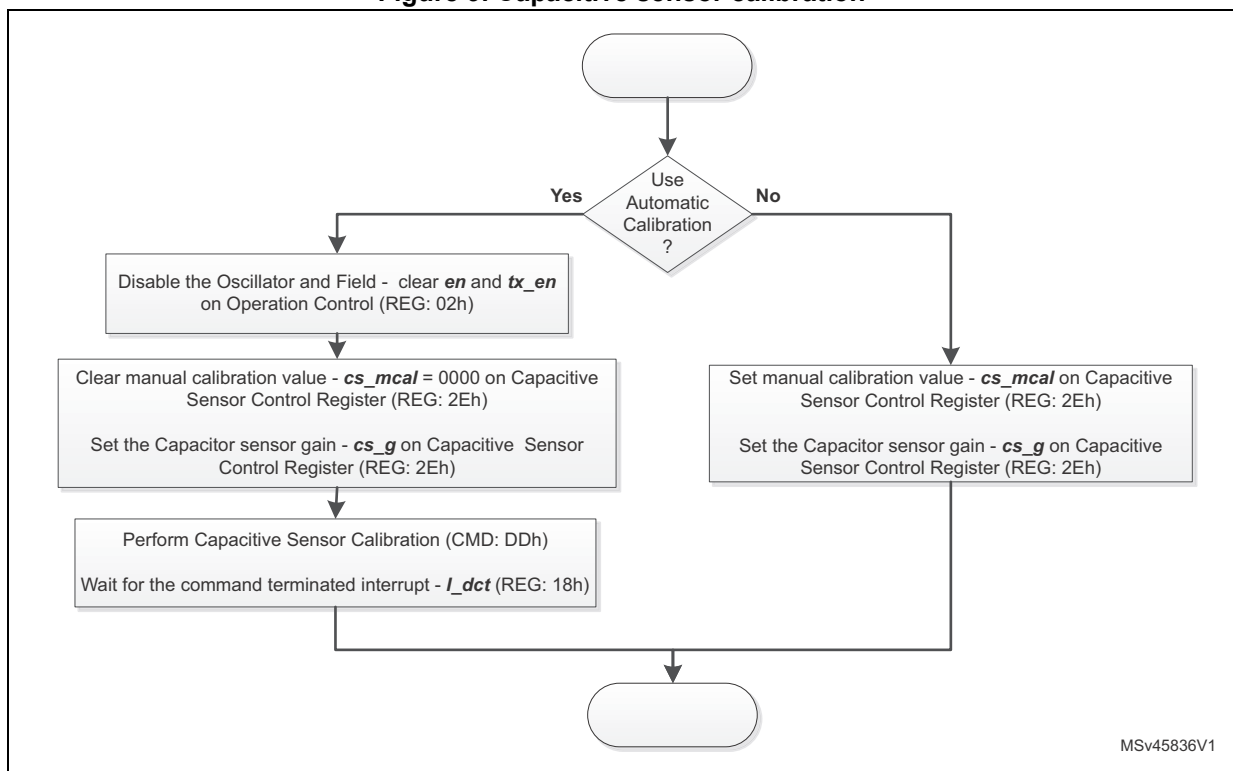
A specific sequence must be executed to enter and exit the wake-up mode.

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

### 2.1 Capacitive sensor calibration

In order to calibrate the capacitive sensor two options are available: manual or automatic calibration, as shown on Figure 9.

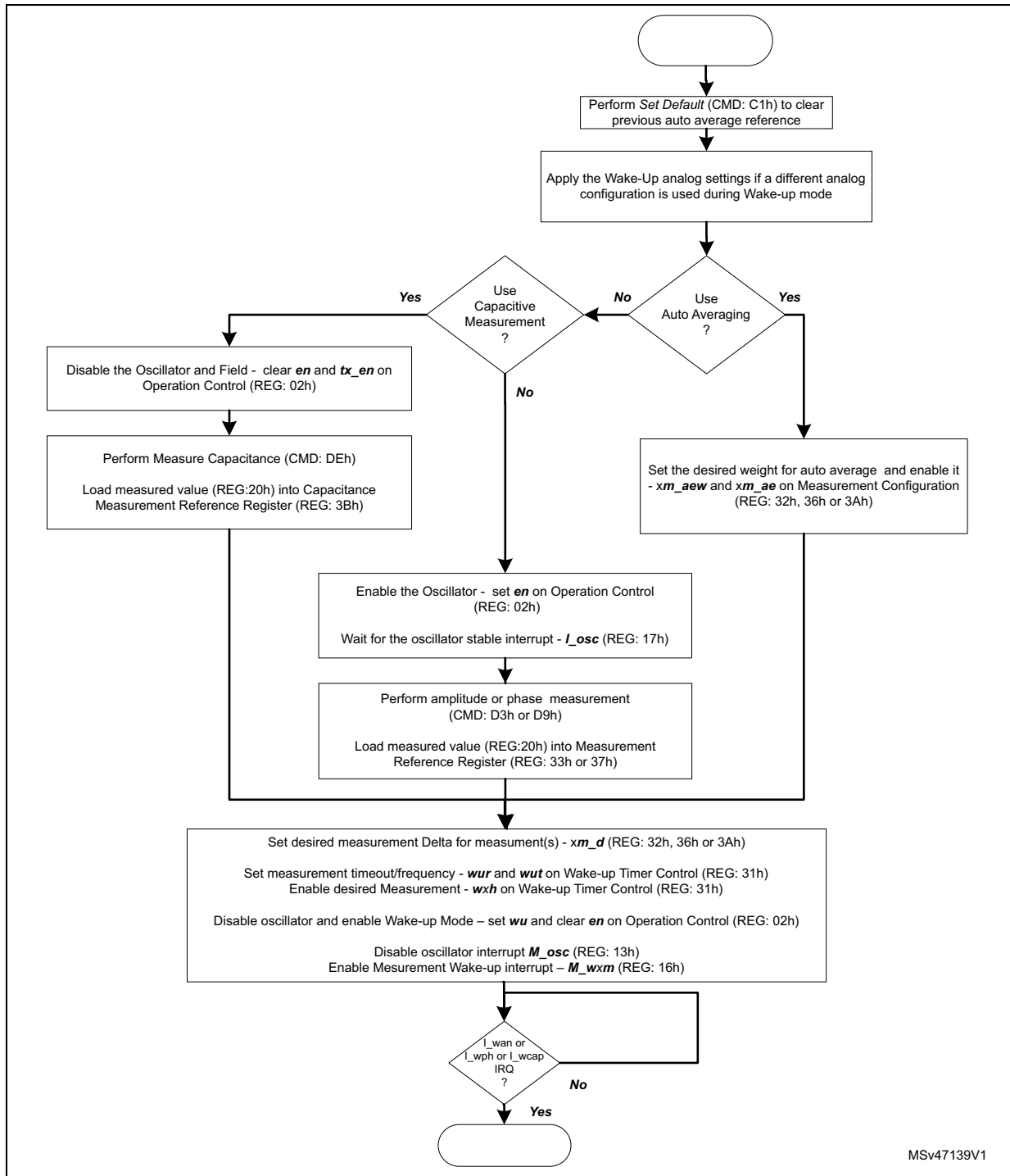
Figure 9. Capacitive sensor calibration



## 2.2 Entering wake-up mode

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

Figure 10. Wake-up mode enable



MSv47139V1

Initially a Set Default command shall be executed in order to reset the auto-averaging reference value. The Set Default is only required when the auto-averaging is to be used, but it's anyhow recommendable to do so as it ensures a defined state.

After setting the default values on the ST25R3911B, a known good analog settings for wake-up shall be applied.

Some systems require to have different analog settings for wake-up and normal mode in order to optimize power consumption and maximize range.

Afterwards, it depends whether the auto-averaging feature is going to be used. If so, it needs to be configured and enabled for each measurement used.

Without auto-averaging a reference measurement needs to 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's a difference between performing Capacitive or Inductive (Phase and Amplitude) measurements. For Capacitive the sensor needs to be calibrated (as described before) and the ST25R3911B shall be in power-down mode (field and oscillator disabled) in order to avoid interference.

For Inductive measurements the oscillator needs to be enabled and stable in order to perform the reference measurements.

Once the reference measurement is complete the value needs to be loaded into the corresponding Measurement Reference Register(s).

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

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

Values close to the edges could lead to a configuration which would never wake up the system, therefore the reference value must always be:

- $reference - delta > 0$
- $reference + delta < 255$

Afterwards the wake-up can be configured by defining the measurement(s) interval, which measurements are to be performed and then placing the ST25R3911B into wake-up mode.

**Note:** *It's 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 led to a deviated reference value. This situation causes the ST25R3911B to trigger a wake-up IRQ as soon as the components cool down.*

*The reference measurement should be obtained in condition as close as possible to 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 cool down to the environment temperature.*



### 2.3 Exiting from wake-up mode

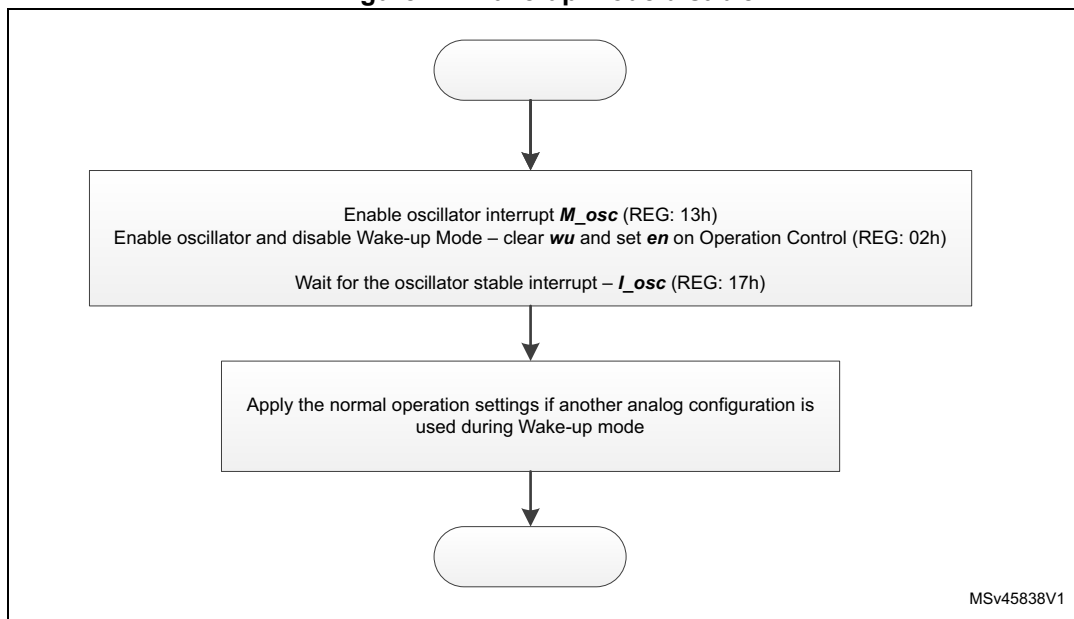
Once the wake-up mode is enabled the host MCU can go to low-power mode in order to minimize power consumptions.

As soon as ST25R3911B detects a change on the measured value bigger than the defined difference it will trigger an IRQ.

The host MCU shall then react by disabling the ST25R3911B's wake-up mode and perform a polling cycle.

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

Figure 11. Wake-up mode disable



In order to return to normal mode, the wake-up mode needs to be disabled and the oscillator enabled.

If a different analog setting is used during wake-up mode, the normal operation settings need to be applied.

### 3 Wake-up mode power calculation

While in wake-up mode the ST25R3911B performs the measurements that have been enabled (inductive and/or capacitive).

The more frequent the measurements are performed (short interval/period), the higher the power consumption will be over time.

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

Each measurement has a different duration and therefore power consumption. The duration of each measurement type can be observed on the following scope shots.

The signals below are:

- Yellow: RF Field
- Green: VSP\_RF

Figure 12. Amplitude measurement

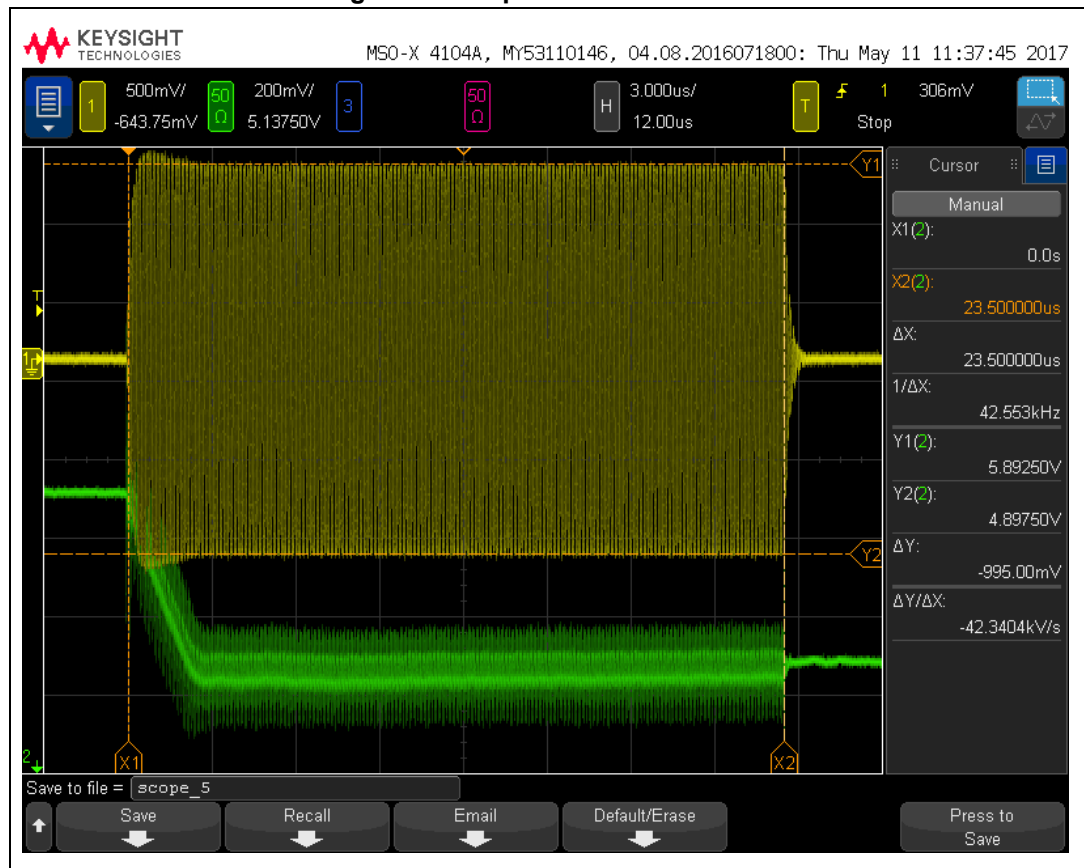


Figure 13. Phase measurement

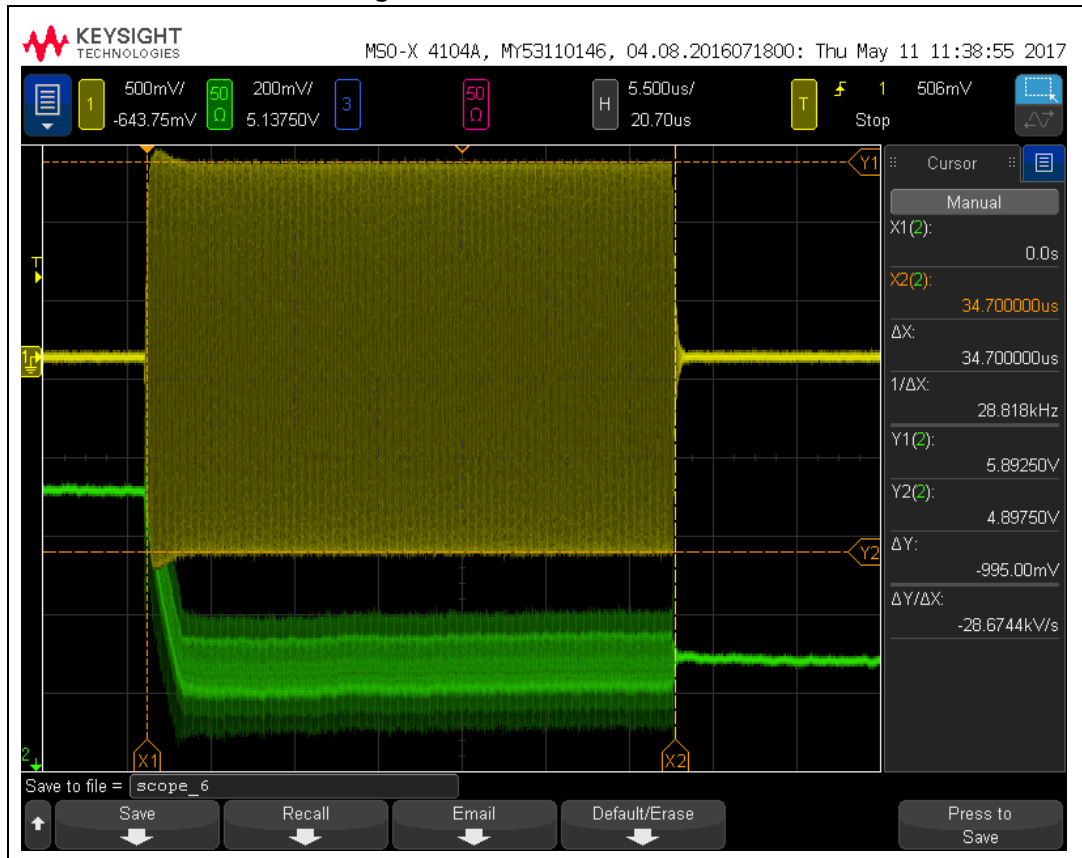
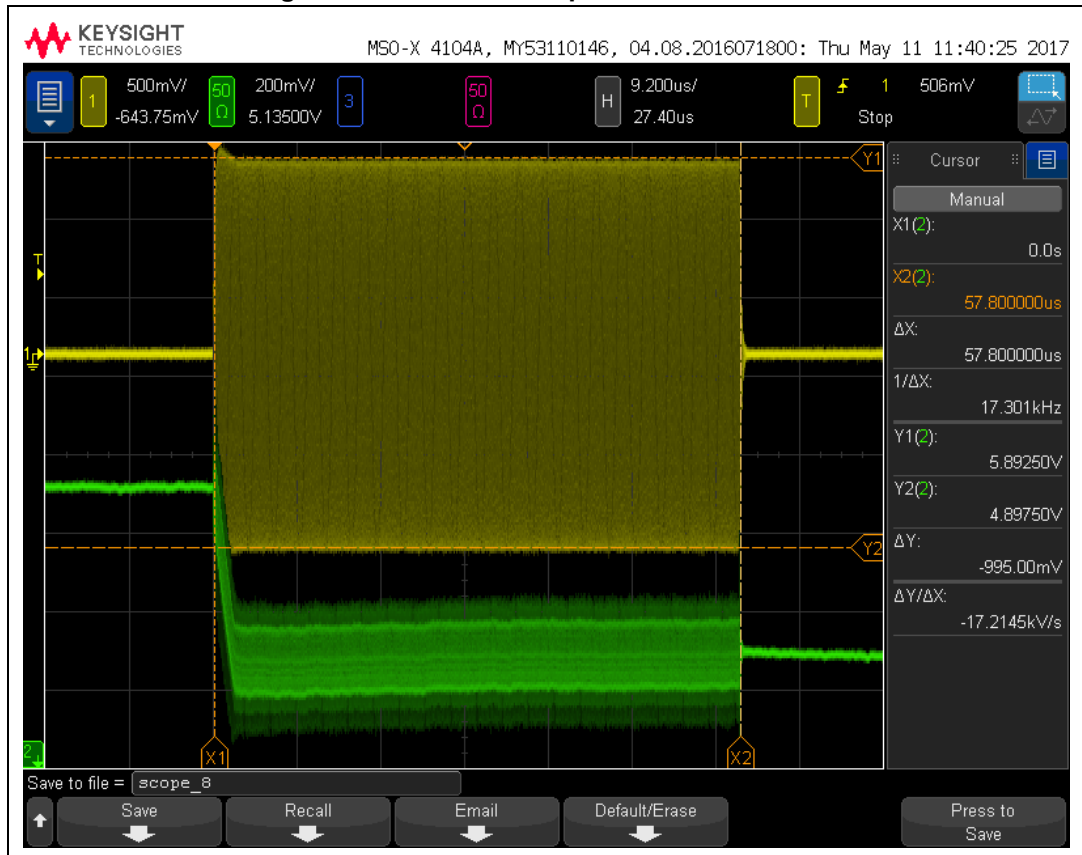


Figure 14. Phase and amplitude measurement



As shown on [Figure 12](#) and [Figure 13](#), the Amplitude measurement has a duration of  $\sim 24 \mu\text{s}$ , and a phase measurement of  $\sim 35 \mu\text{s}$ .

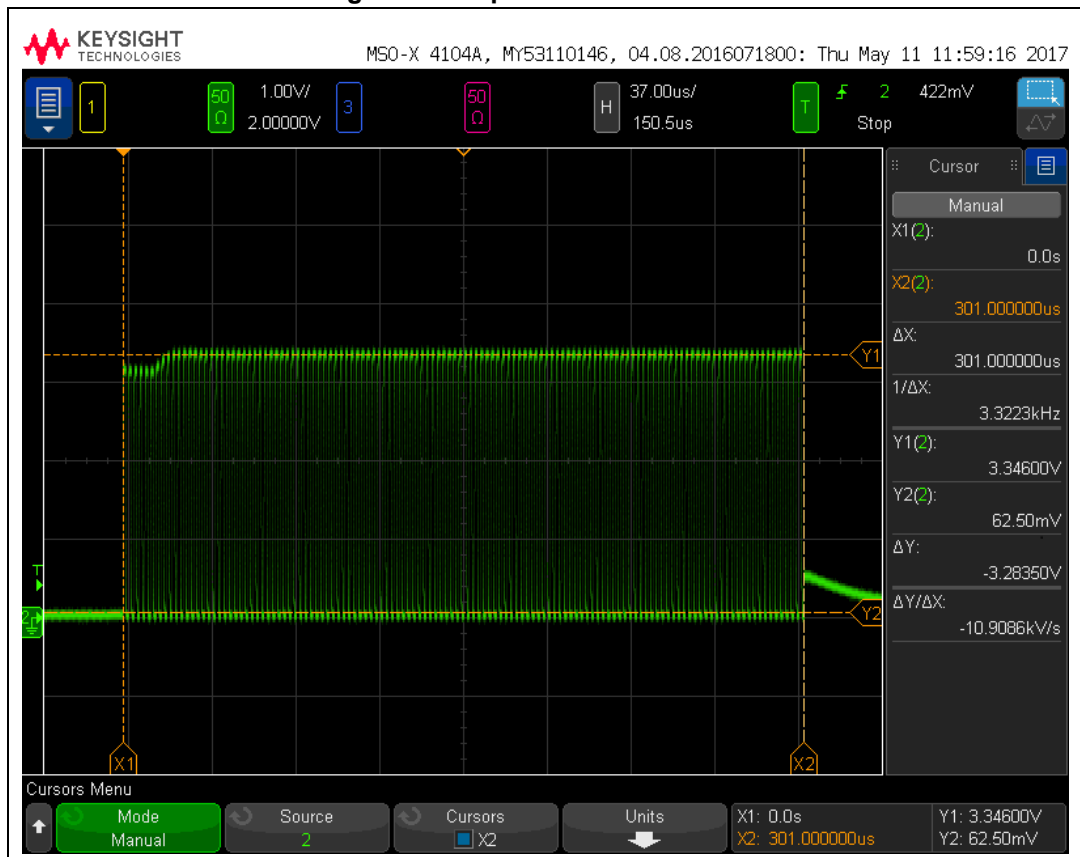
When both inductive measurements are combined as on [Figure 14](#), the total measurement duration is  $\sim 59 \mu\text{s}$ .

Additionally, the voltage drop of VSP\_RF can be observed. The voltage drops from VDD and settles at the defined VSP\_RF voltage. This is an expected behavior and shows that, after reaching the estimated VSP\_RF voltage, the voltage stays constant. Oscillations or voltage drops in VSP\_RF could indicate a problem with the supply voltage and disclose the reason for an unstable measurement during wake-up mode.

[Figure 15](#) shows the RF Field and CSO signal in different colors. In details:

- Yellow is used to represent the RF Field
- Green is used to represent the CSO

Figure 15. Capacitive measurement



As observed on [Figure 15](#), the capacitive measurement has a duration of  $\sim 300 \mu\text{s}$ .

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

The duration of each measurement must be:

- $T_{AWU} = 25 \mu\text{s}$
- $T_{PWU} = 35 \mu\text{s}$
- $T_{CWU} = 300 \mu\text{s}$

The typical consumption values of supply current in wake-up mode, which can be found on ST25R3911B datasheet, are:

- $I_{CS} = 1.1 \text{ mA}$
- $I_{WU} = 3.6 \mu\text{A}$
- $I_{RD} = 5.4 \mu\text{A}$

The current during an inductive measurement is dependent on the matching impedance therefore it varies with each system.

The timeout / interval between each measurement stage is configurable.

- $I_{IP} = I_{IA}$ : system dependent, typically between 150 and 200 mA
- $T_{out}$ : configurable

In order to calculate an estimation of the current consumption per second  $I_{AVG}$  it's required to calculate the current consumption for each individual measurement ( $I_{C,AVG}$ ,  $I_{IP,AVG}$  and  $I_{IA,AVG}$ ) as expressed in the following equations:

$$I_{C,AVG} = (I_{CS} - I_{WU}) \times \frac{T_{CWU}}{T_{OUT}}$$

$$I_{IP,AVG} = (I_{IP} - I_{WU}) \times \frac{T_{PWU}}{T_{OUT}}$$

$$I_{IA,AVG} = (I_{IA} - I_{WU}) \times \frac{T_{AWU}}{T_{OUT}}$$

Also, when an inductive measurement (Amplitude and/or Phase) is used there's an additional step while enabling the oscillator which must be taken into account.

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

Then, the total estimation of the current consumption  $I_{AVG}$  per second 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  $I_{IP} = I_{IA} = 200$  mA and the timeout/interval is  $T_{out} = 200$  ms, the estimated current consumption of this system which uses inductive amplitude measurement during the wake-up mode, can be estimated as:

$$I_{C,AVG} = 0 \mu A$$

$$I_{IP,AVG} = 0 mA$$

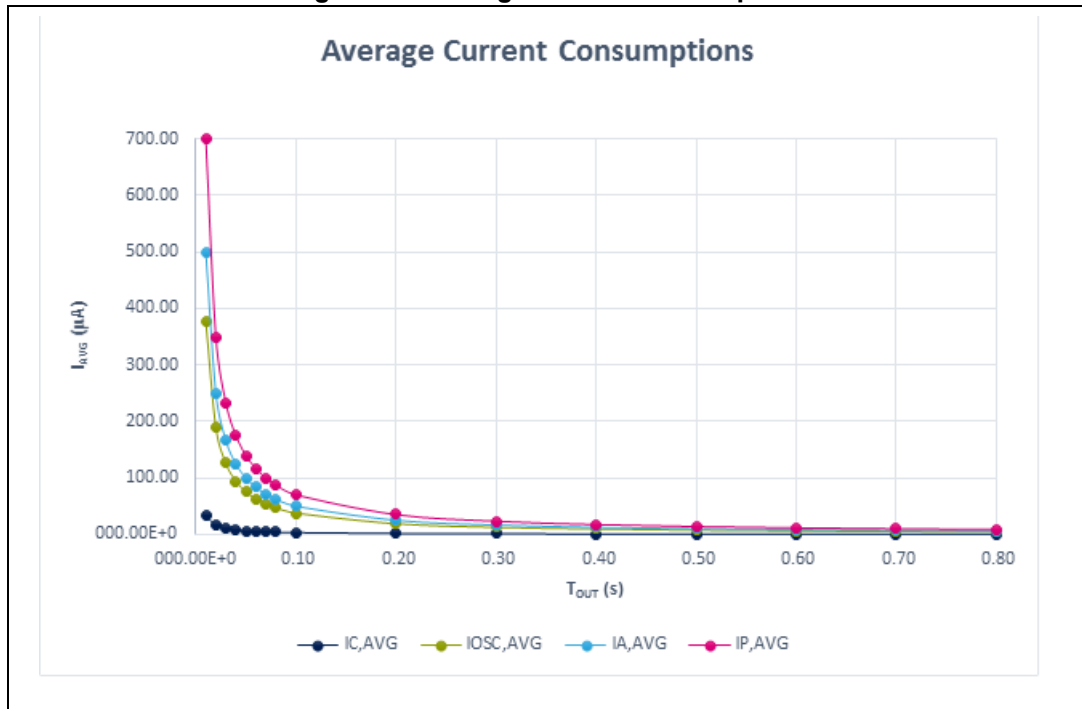
$$I_{IA,AVG} = (I_{IA} - I_{WU}) \times \frac{T_{AWU}}{T_{OUT}} = (200 \times 10^{-3} - 3.6 \times 10^{-6}) \times \frac{25 \times 10^{-6}}{200 \times 10^{-3}} = 25.00 \mu A$$

$$I_{IOSC,AVG} = (I_{RD} - I_{WU}) \times \frac{T_{OSC}}{T_{OUT}} = (5.4 \times 10^{-3} - 3.6 \times 10^{-6}) \times \frac{0.7 \times 10^{-6}}{200 \times 10^{-3}} = 18.89 \mu A$$

$$I_{AVG} = I_{C, AVG} + I_{IP, AVG} + I_{IA, AVG} + I_{WU} = 47.49\mu A$$

Figure 16 shows how each average current consumption relates to the different timeout/period configurations ( $I_{IP} = I_{IA} = 200 \text{ mA}$ ).

Figure 16. Average current consumption



## 4 Glossary

**Table 4. List of terms and acronyms**

<b>Terms and Acronyms</b>	<b>Description</b>
ADC	Analog to Digital Converter
CSO	Capacitance Sense Output
CSI	Capacitance Sense Input
EMC	Electromagnetic compatibility
IRQ	Interrupt Request
MCU	Microcontroller
PCB	Printed Circuit Board
RC	Resistive Capacitive
RF	Radio Frequency



## 5 Conclusion

The low-power wake-up mode of the ST25R3911B device allows the user to implement a power consumption optimized card detection which operates completely autonomously from the microcontroller. This allows the overall system current consumption to be kept at a minimum while being reactive to cards approaching the NFC reader device. The availability of amplitude, phase, and capacitive wake-up modes ensures that the best mode for a given customer design can be selected.

## 6 Revision history

Table 5. Document revision history

Date	Revision	Changes
24-Jul-2017	1	Initial release.

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