AN12365

NTAG 5 - How to use energy harvesting

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Document information

Information	Content
Keywords	NTAG 5 switch, NTAG 5 link, NTAG 5 boost, energy harvesting, circuit, schematics, reference application
Abstract	Guidelines for designing applications using NTAG 5 energy harvesting capabilities.

Revision history

Rev	Date	Description
v.1.2	20200518	Updates on modes of operation, EH block, see Section 3.3 and Section 2.3, Figure 3 updated
v.1.1	20200304	General update
v.1.0	20200109	Initial version

1 Abbreviations

Table 1. Abbreviations

Acronym	Description
NFC	Near Field Communication
EH	Energy Harvesting
ALM	Active Load Modulation
VCD	Vicinity Coupling Device
VICC	Vicinity Integrated Circuit Card

2 Introduction

This document describes "energy harvesting" capabilities of NTAG 5 family ICs. NTAG 5 phrase in this document refers to all three IC variants: NTAG 5 switch, NTAG 5 link, NTAG 5 boost. To reduce complexity, NTAG 5 abbreviation is used through whole document for all three IC variants.

The NTAG 5 provides the capability to harvest energy from the RF field. This feature can be used to supply external circuits or devices (e.g., microcontrollers, sensors) with enough energy to operate.

NTAG 5 is the first IC with configurable regulated power output.

This document focuses on showing how much energy the NTAG 5 can deliver and under which conditions, how to design a circuitry to optimize energy harvesting capabilities.

It shall be considered that **ALM** (Active Load Modulation) functionality and **energy harvesting** are **not available at the same time**.

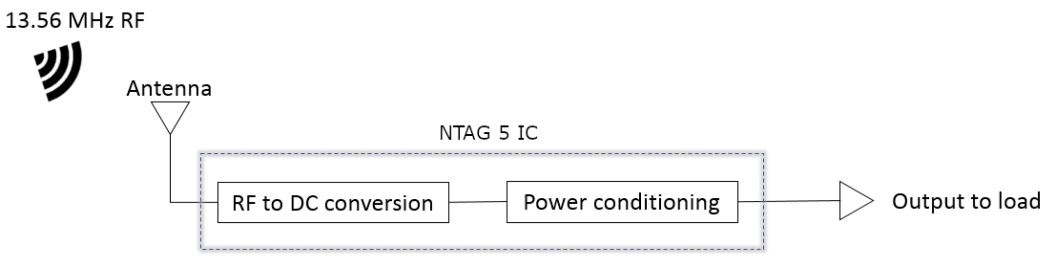

Figure 1. Harvesting ambient RF energy with NTAG 5 - concept

In the case energy harvesting is used to power NTAG 5 (when V_{CC} is not supplied externally), all harvested excess power (power not required to supply NTAG 5) is available to supply external circuits.

NTAG 5 consists of configurable current detection block. It allows triggering energy harvesting only when enough energy is retrieved from RF to provide expected current level.

2.1 Target applications

- Fully sealed devices
- Sensor Tags, Sensor tags with NTAG 5 in I^2C master mode (w/o MCU), reference [Application note]
- Maintenance of broken systems, in case of general power outage, reference [Application note]
- Especially for devices where power is an issue

2.2 Influencing factors on energy harvesting

Main factors influence the power NTAG 5 is able to harvest are the following:

- Antenna size: Larger is the NTAG 5 antenna higher is the level of energy collected by NTAG 5 from RF.

- Antenna turn count: Lower is the number of turns higher is the level of energy collected by NTAG 5 from RF.
- Antenna matching: In case of highly coupled systems (reader and NTAG 5 antennas size are the same, with small or even zero distance in between) the reader can be detuned from the tag. This can reduce amount of energy collected by NTAG 5.
- Field strength: Stronger is the field emitted by the RF reader higher is the level of energy collected by NTAG 5. Field strength dropping while distance between reader antenna and NTAG 5 antenna increase.

Note: In general, under the load V_{OUT} voltage drops if too much current is taken out of the NTAG 5 or if field strength gets weaker. In this condition (DISABLE_POWER_CHECK = 0b and field strength too weak to deliver configured output) NTAG 5 only responds to INVENTORY command and READ/WRITE CONFIGURATION to access session registers on NFC interface side.

For stable I^2C communication, the V_{CC} should not drop below recommended minimum V_{CC} (Electrical characteristics in [Datasheet]).

2.3 Modes of operation

There are two (2) modes which can be set for energy harvesting operation, with bits EH_MODE:

- Energy harvesting optimized for low field strength (default) - if expected VCDs have lower NFC field strength (e.g. NFC mobiles). The low field strength mode is optimized for high energy harvesting efficiency and can drive up to 20 mW output power.
- Energy harvesting optimized for high field strength - if expected VCDs be able to output more strong field (e.g. specially designed VCDs). The high field strength mode can drive higher power and also supports a VCD with 10 % modulation index next to the 100 % ASK modulation scheme.

Table 2. Modes of EH operation comparison

	Low Field Strength	High Field Strength
Energy harvesting efficiency	Best	10 % - 20 % reduced efficiency vs Low Field Strength Mode
Energy harvesting power	< 20 mW	> 20 mW (< 50 mW)
Modulation scheme	100 % ASK VCD Modulation	10 % and 100 % ASK VCD Modulation

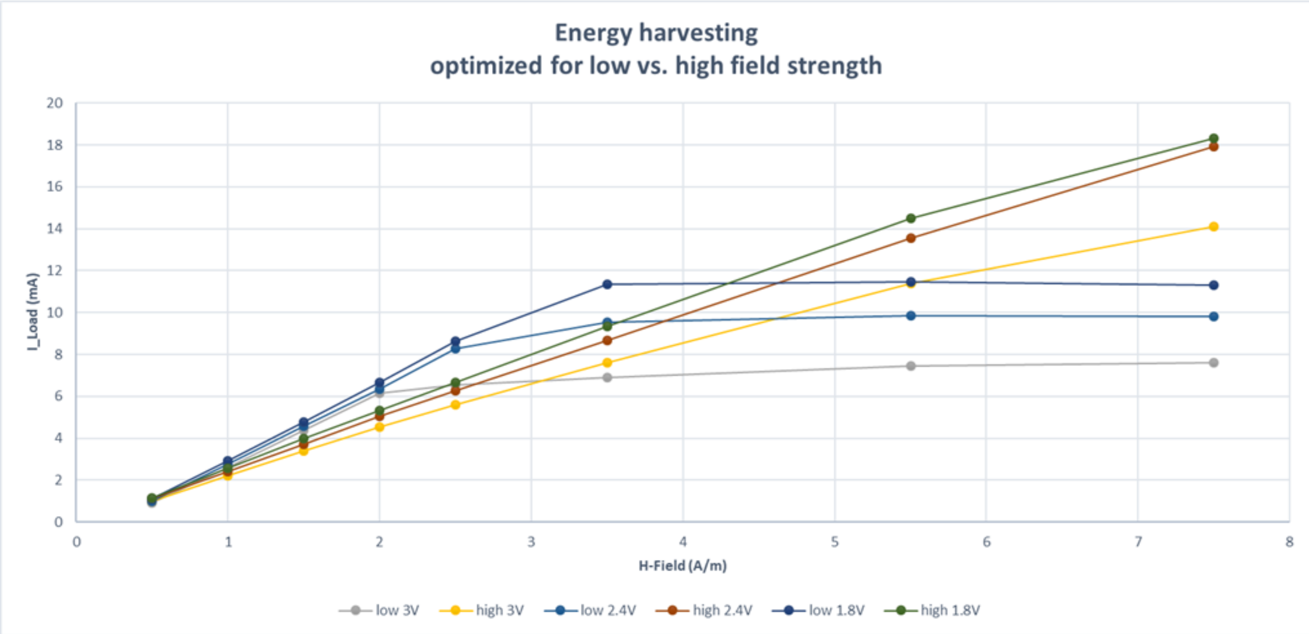

Figure 2. Current vs. Load vs. H field

3 Recommendations

To optimize energy harvesting as whole, following topics shall be considered: on system level and on components surrounding IC.

3.1 System level

- Minimize the current needed to be harvested. Energy supplied via EH, needs to be supplied by the reader, therefore reduces the read range of the NTAG 5.
- On MCU systems, clock down the MCU and also use the deep sleep modes to minimize the current consumption.
- The power requirements connected to the energy harvesting pin should be kept at minimum as needed by the external system. The larger the requirements are, the harder it is for the reader to wake up and supply the NTAG 5.
- Use optimum Vtx level on VCD

3.2 Application level

The external capacitor (C below) value must be chosen to prevent voltage drop below 100 mV during VCD modulation pauses.

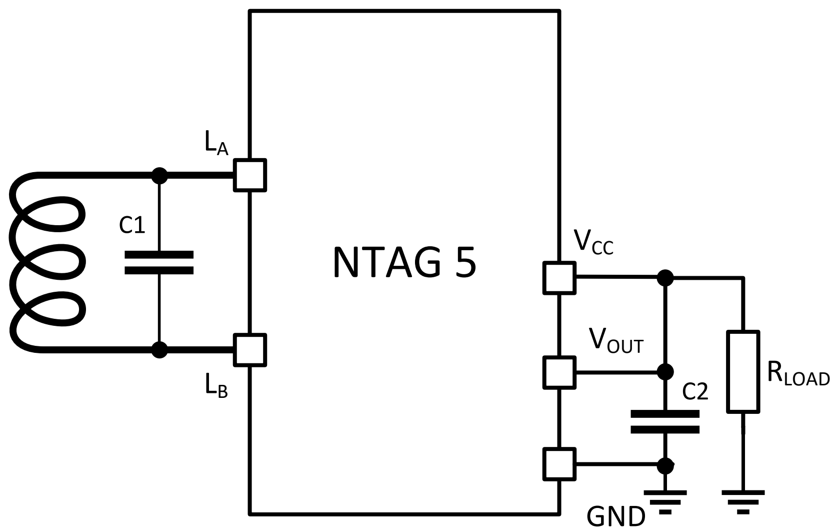

Figure 3. Example application circuit

Voltage drop during VCD pauses (miller modulation type) can be calculated following below formula, where V_{drop} is the voltage drop during VCD modulation pauses in volts, I_L is the load current in amps and t_{pause} is the modulation pause duration in seconds:

$$V_{drop} = \frac{I_L x t_{pause}}{C} \quad (1)$$

Additionally, the external capacitor value impacts the V_{OUT} ramp-up time according below formula, where t_{ramp} is the V_{OUT} ramp-up time in seconds and I_{field} is the configured output current in amps (refers to EH_VOUT_I_SEL):

$$t_{ramp} = \frac{V_{out} \times C}{I_{field} - I_L} \quad (2)$$

- V_{OUT} can also be used as an "NFC field detector" alternative (among ED pin[1])
- In case NTAG 5's V_{OUT} (harvested energy) also supplies I^2C bus, then V_{CC} must be connected to V_{OUT}, and pull-up resistors are required on the SCL and SDA lines. These pull-up resistors must be sized appropriately to limit the sink current when the lines are pulled low. Resistors value depends on the devices connected on the bus, recommendation is to start with value 4.7 kOhms and adjust it down if necessary.
- In case NTAG 5's V_{OUT} (harvested energy) also supplies ED pin (Event Detect pin [Application note]) in Pass-through mode [Application note], then the pull-up resistor on the Event Detect line must be sized appropriately to limit the sink current when pulled low by NTAG 5.

[1] When using ED pin functionality, NTAG 5 does not need to be VCC supplied.

3.3 Energy harvesting block operation

NTAG 5 includes a power check block, which offers a current detection mechanism and can be enabled or disabled through DISABLE_POWER_CHECK. Current detection mechanism will be operating (if enabled) ONLY when RF field is available. The current detection mechanism compares harvested current with a reference value and enables the output Vout only, when the harvested current is higher than the reference value.

Note: If the current detection is enabled and there is not enough field strength available to enable V_{OUT}, EEPROM access is disabled. NTAG 5 is then answering ONLY to INVENTORY command and READ/WRITE CONFIGURATION to access session registers on NFC interface.

The block „energy harvesting“ can operate in low or high field strength mode (Section 2.3) and it includes a shunt regulator which provides the configured regulated voltage (EH_VOUT_V_SEL) at Vout.

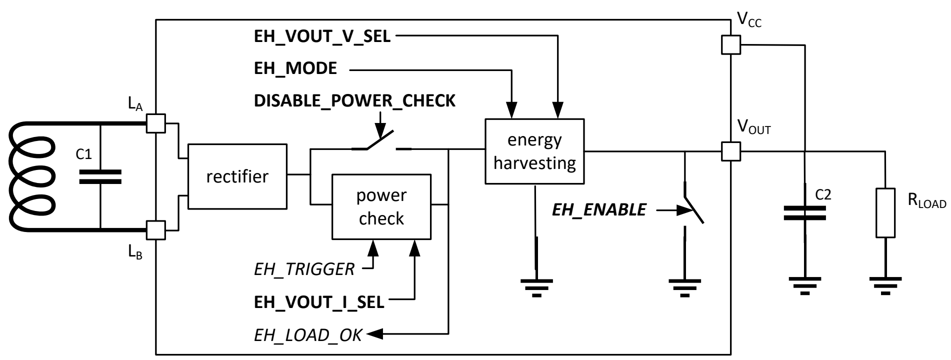

Figure 4. NTAG 5's energy harvesting block diagram

EH_LOAD_OK is a bit in session register that indicates if sufficient energy, harvested from RF, is available.

4 How to configure NTAG 5 for energy harvesting

Mode of energy harvesting feature can be configured by either of following bytes:

- EH_CONFIG_REG in session register (Block address from NFC:A7h, from I^2C:10A7h, Byte0) >> Current session
- EH_CONFIG in configuration memory (Block address from NFC:3Dh, from I^2C:103Dh, Byte0) >> Start-up behavior

As soon as energy harvesting is used, V_{OUT} and V_{CC} must be connected. Otherwise no EEPROM access is possible from NFC side and status registers reflect invalid information.

Detailed description of those parameters can be found in NTAG 5 [Datasheet].

The two different possible methods of enabling EH are described in next chapters:

1. Enabling EH by session registers (Recommended method) [Section 4.1]
2. EH enabled during boot [Section 4.2]

4.1 Enabling EH by session registers - the recommended method

This first method is the recommended one because it provides more reliable NFC communication (less time slot in which NFC communication cannot be fully achieved). However it requires dedicated scenario from the VCD side, therefore requiring specific application running on VCD.

Prerequisites:

- in EH_CONFIG (3Dh from NFC / 103Dh from I^2C):
  - Energy harvesting at startup must be disabled, setting bit EH_ENABLE to 0b, since it will on the fly be enable through session register
  - EH_VOUT_V_SEL and EH_VOUT_I_SEL must be set according to the requirement
  - DISABLE_POWER_CHECK has no effect, as EH_ENABLE is set to 0b
- In CONFIG (37h from NFC / 1037h from I^2C) desired energy harvesting mode must be chosen (optimized for low or high field strength - see Section 2.3)

Procedure:

1. VCD triggers current detection by by writing to EH_CONFIG_REG session register (A7h) → EH_TRIGGER (Bit3) set to 1b
2. VCD polls EH_CONFIG_REG (A7h) until the available field strength is sufficient → EH_LOAD_OK (Bit7) equal to 1b
3. VCD enables the energy harvesting by writing to EH_CONFIG_REG session register (A7h) → EH_ENABLE (Bit0) set to 1b and EH_TRIGGER (Bit3) set to 1b
4. VCD polls STATUS1_REG (A0h) until VCC ramps up → VCC_BOOT_OK (Bit7) equal to 1b

Note: If VCD directly enables EH (step 3) without checking if field strength is sufficient (step 1 and 2), risk is NTAG 5 may reset because of voltage drop (if not enough energy). EH will be disabled (since only valid for current NFC session).

Note: If EH_ARBITER_MODE_EN (CONFIG_1 register 37h from NFC / 1037h from I^2C) is set to 0 the ARBITER_MODE is selected via CONFIG_1_REG session register (A1h from NFC) since related setting from CONFIG_1 configuration register is ineffective.

Limitations:

- Until V_{OUT} gets generated and V_{CC} ramps up, the communication to memory is not possible. Only INVENTORY command and access to session registers are possible from NFC interface.
- Any NFC communication during V_{OUT} ramp up may be disturbed/corrupted.

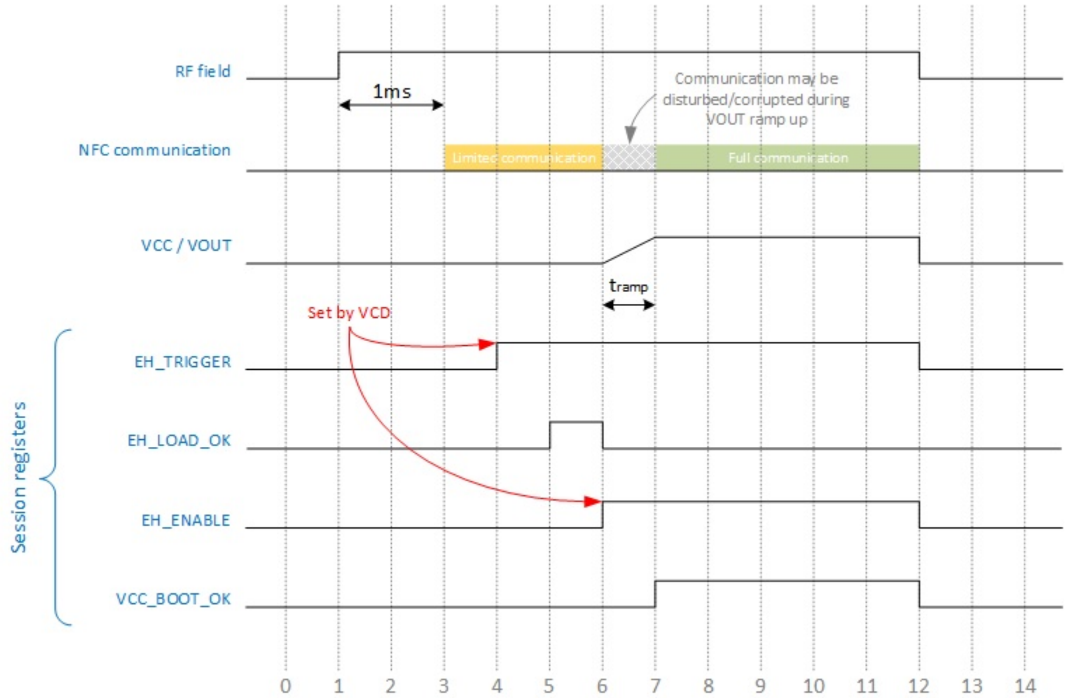

Figure 5. Enabling EH by session registers time state diagram

Timestamp	Description
1	RF field appears
3	NTAG 5 is ready for NFC activation from VCD
4	VCD writes to session register: EH_TRIGGER = 1b
4-5	VCD polls for EH_LOAD_OK status signal in session registers
6	VCD writes to session register EH_ENABLE = 1b and EH_TRIGGER = 1b V_{CC} boot starts. V_{CC} boot to be restarted if V_{CC} toggles between time 6 and 7
7	NFC and I^2C fully functional
7-12	If the RF field strength drops or Load current increases, the V_{OUT} will drop, consequently also V_{CC} drops If V_{CC} goes below 1.62 V, the system reset will be triggered and NTAG 5 will reboot
12	RF field disappears leading to V_{OUT} drop then NTAG 5 shutdown

Note: Writing to Session Registers to enable energy harvesting, will be treated as a "Write alike" command which means V_{CC} ramp can go up to 20 ms max. If V_{CC} supply does not come up until 20 ms, then the VCD needs to take a corrective action.

4.2 Energy harvesting enabled during boot

This second method is the only one which can be considered if there is no control to the VCD application.

Prerequisites

- in EH_CONFIG (3Dh from NFC / 103Dh from I^2C):
  - Energy harvesting at startup must be enabled, setting bit EH_ENABLE to 1b
  - EH_VOUT_V_SEL and EH_VOUT_I_SEL must be set according to the requirement
  - DISABLE_POWER_CHECK can be configured to use current detection monitor or not

Procedure:

- Depending on DISABLE_POWER_CHECK setting, energy harvesting will be directly enabled after boot or only when field strength becomes stronger enough to generate the required load

Limitations:

- Until V_{OUT} gets generated and V_{CC} ramps up, the communication to EEPROM is not possible. Only INVENTORY command and access to registers are possible from NFC interface.
- Any NFC communication during V_{OUT} ramp up may be disturbed/corrupted.

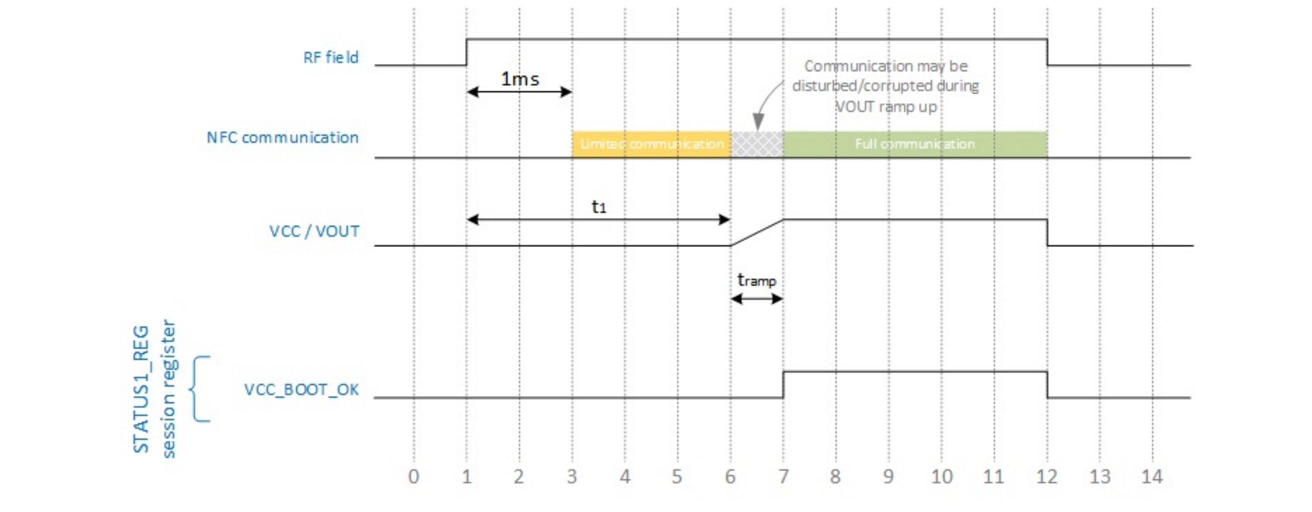

Figure 6. EH enabled by Configuration Bytes timing state diagram

Timestamp	Description
1	RF field appears
3	NTAG 5 is ready for NFC activation from VCD
3-6	VCD can activate NTAG 5 but cannot access memory (only access to registers is granted)
6	V_{CC} boot starts. V_{CC} boot to be restarted if V_{CC} toggles between time 6 and 7
7	NFC and I^2C fully functional
7-12	If the RF field strength drops or Load current increases, the V_{OUT} will drop, consequently also V_{CC} drops If V_{CC} goes below 1.62 V, the system reset will be triggered and NTAG 5 will reboot

Timestamp	Description
12	RF field disappears leading to V_{OUT} drop then NTAG 5 shutdown

The EH sequence will be retriggered after every boot.

Time between RF field appears and V_{CC} boot starts (timestamp 1 to timestamp 6) when EH is enabled at boot, indicated as t_1 on above diagram, is about 1.52 ms.

To check, if the NTAG 5 is powered and if EH is enabled or not, session register can be checked:

- STATUS0_REG (A0h from NFC / 10A0h from I^2C), bit VCC_SUPPLY_OK
- EH_CONFIG (A7h from NFC / 10A7h from I^2C), bit EH_ENABLE

5 Antenna design guidelines

Optimal energy transfer can be achieved by considering the following recommendations:

1. larger antenna size with lesser turns
2. antenna size close to a reader's antenna size (but not exact same size to avoid decoupling effect at low or zero distance)

To achieve most optimum configuration for RF performance (read range) and energy harvesting power yield, it is recommended to use a parallel capacitor for tuning and to lower antenna's inductance.

Example: For an antenna having total 1 µH inductance, parallel 82 pF tuning can be used.

More details on "How to design antenna for NTAG 5" can be found in [Application note].

6 Example measurements

6.1 Reference setup

The reference setup used for the measurement is the NTAG 5 demo board referenced as OM23510ARD featuring a 3 turns 54 mm x 27 mm antenna.

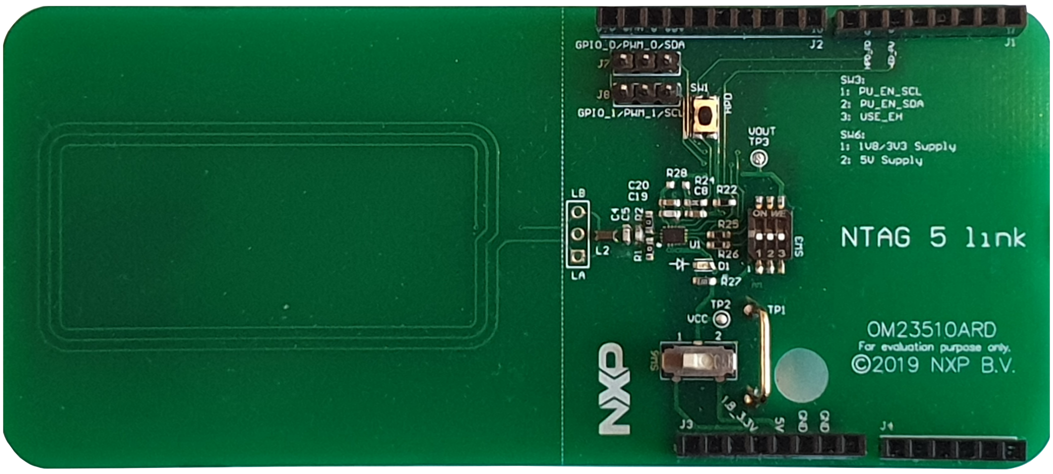

Figure 7. OM23510ARD NTAG 5 demo board

Following measurements are done using different devices, acting as Vicinity readers, to provide wide range of NTAG 5 energy harvesting capabilities.

Note: Minimum load allowing to run energy harvesting depends on the V_{OUT} configuration:

- for V_{OUT} configured to 3.0 V → minimum load is 430 Ω
- for V_{OUT} configured to 2.4 V → minimum load is 260 Ω
- for V_{OUT} configured to 1.8 V → minimum load is 160 Ω

6.1.1 CLRC663 plus demo board

Measurement with CLRC663 plus are performed using CLEV6630B demo board.

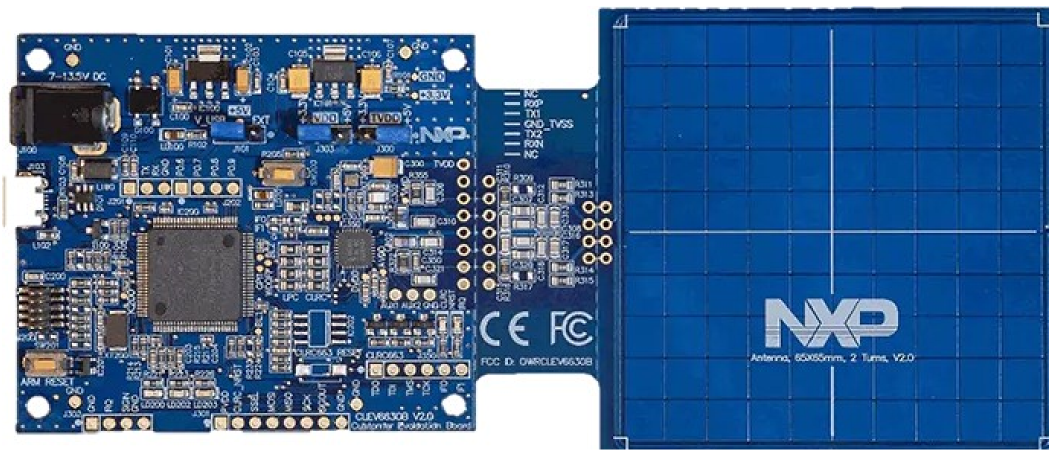

Figure 8. CLEV6630B CLRC663 plus demo board

See in below block diagram of the measurement setup.

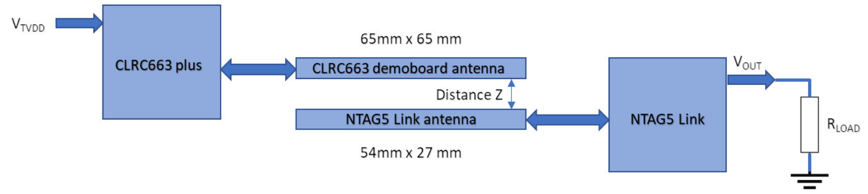

Figure 9. CLRC663 plus measurement setup

Below are measurement results for different values of R_{load} and V_{TVDD}, and different V_{OUT} configurations (EH_VOUT_V_SEL parameter).

Note: Measurements with CLRC663 plus are done with NTAG 5 set in energy harvesting mode optimized for high field strength (EH_MODE parameter).

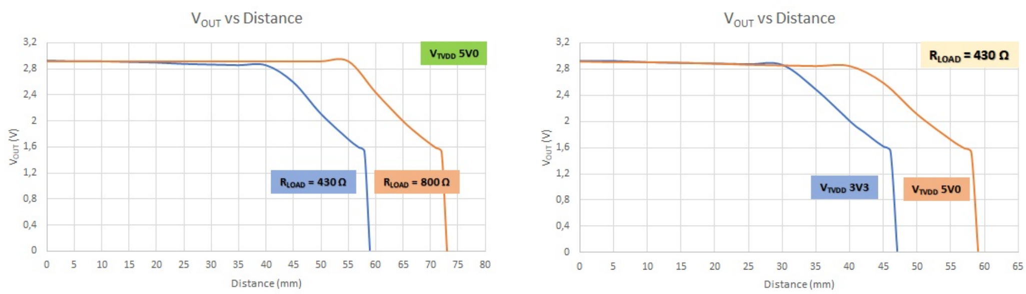

Figure 10. CLRC663 plus measurement results with V_{OUT} configured to 3.0 V

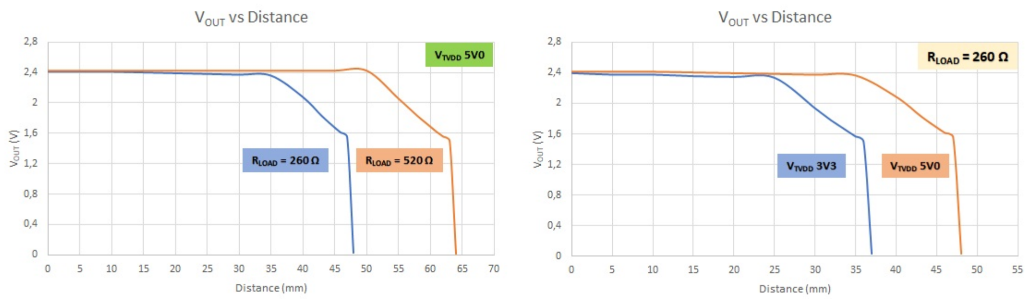

Figure 11. CLRC663 plus measurement results with V_{OUT} configured to 2.4 V

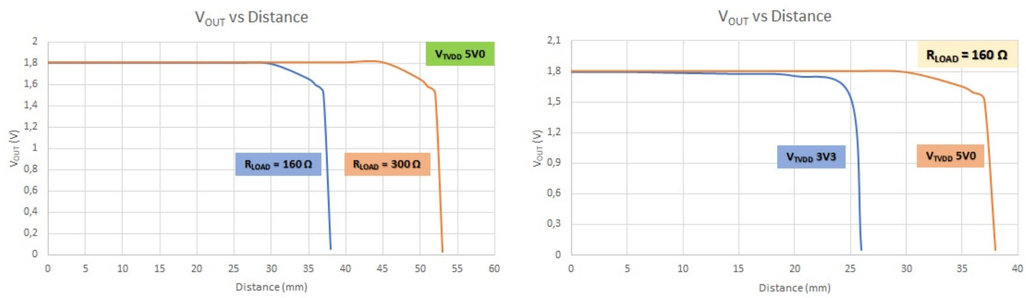

Figure 12. CLRC663 plus measurement results with V_{OUT} configured to 1.8 V

6.1.2 PN7462 demo board

Measurement with PN7462 is performed using PNEV7462C demo board.

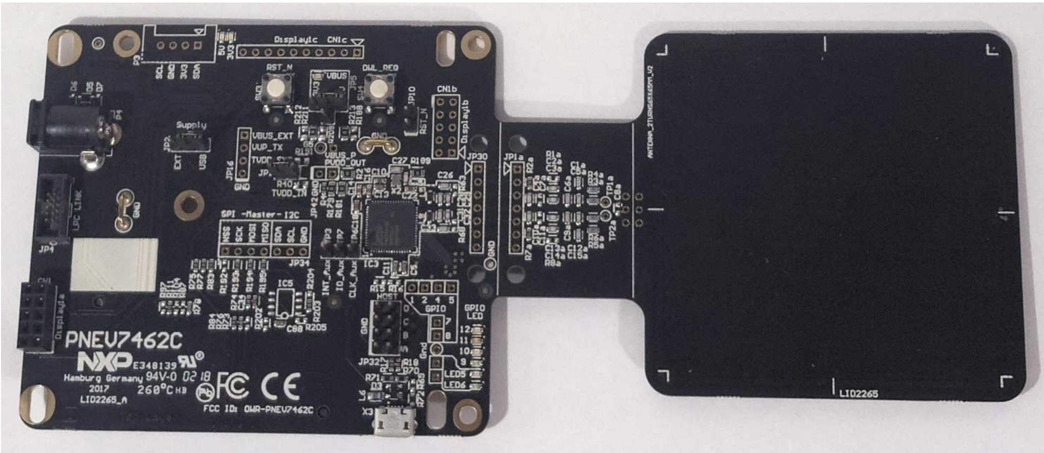

Figure 13. PNEV7462C PN7462 demo board

See in below block diagram of the measurement setup.

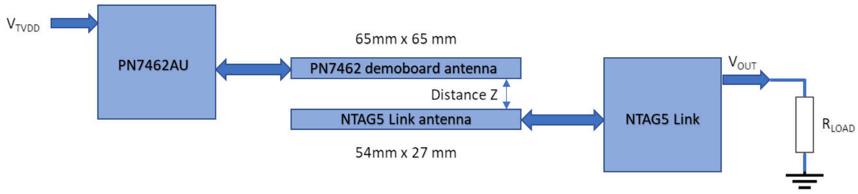

Figure 14. PN7462 measurement setup

Below are measurement results for different values of R_{load} and V_{TVDD}, and different V_{OUT} configurations (EH_VOUT_V_SEL parameter).

Note: Measurements with PN7462 are done with NTAG 5 set in energy harvesting mode optimized for high field strength (EH_MODE parameter).

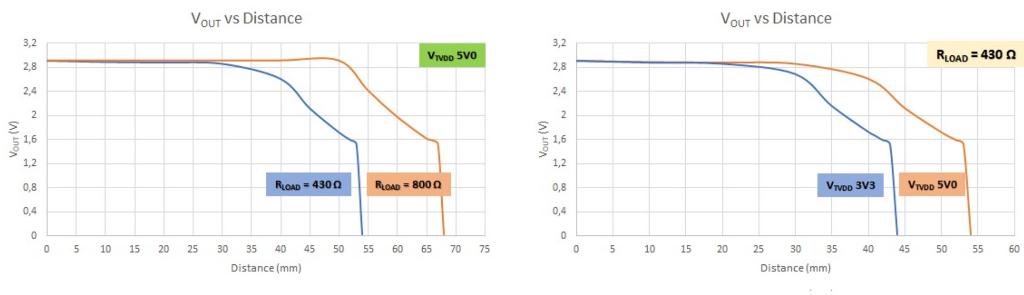

Figure 15. PN7462 measurement results with V_{OUT} configured to 3.0 V

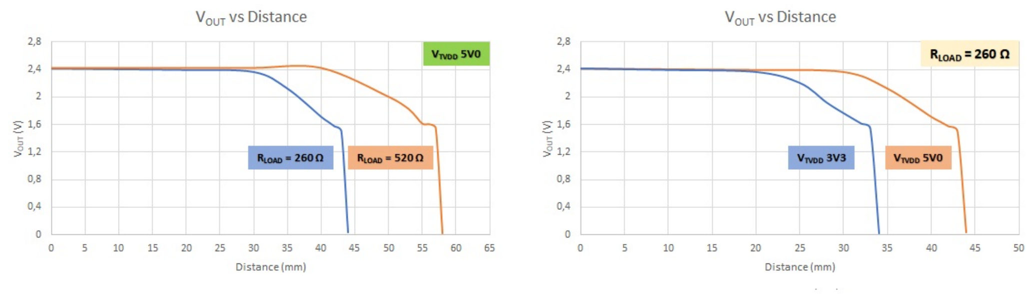

Figure 16. PN7462 measurement results with V_{OUT} configured to 2.4 V

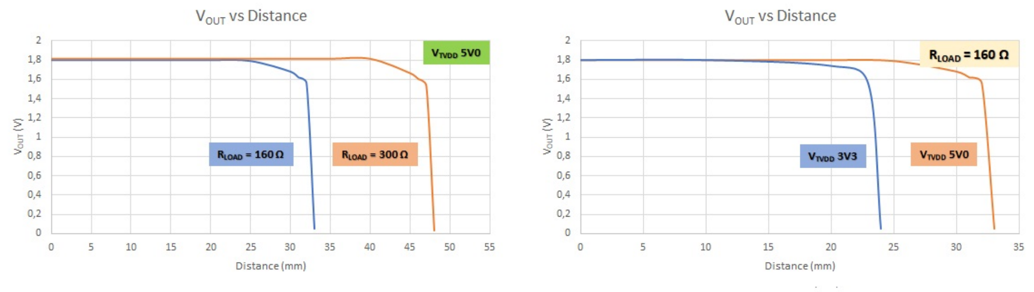

Figure 17. PN7462 measurement results with V_{OUT} configured to 1.8 V

6.1.3 NFC mobile phones

Measurement with mobile phones is performed using NFC mobile phones Google Pixel 3, Huawei P20 Pro and Apple iPhone 11.

Figure 18. NFC Mobile phones

See in below block diagram of the measurement setup.

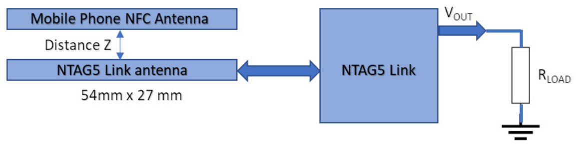

Figure 19. NFC mobile phones measurement setup

Below are measurement results for different values of R_{load} and different V_{OUT} configurations (EH_VOUT_V_SEL parameter).

Note: Measurements with NFC mobile phones are done with NTAG 5 set in energy harvesting mode optimized for low field strength (EH_MODE parameter).

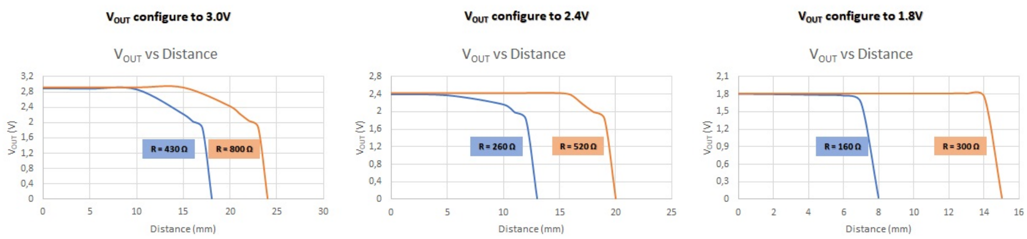

Figure 20. Google Pixel 3 NFC mobile phone measurement results

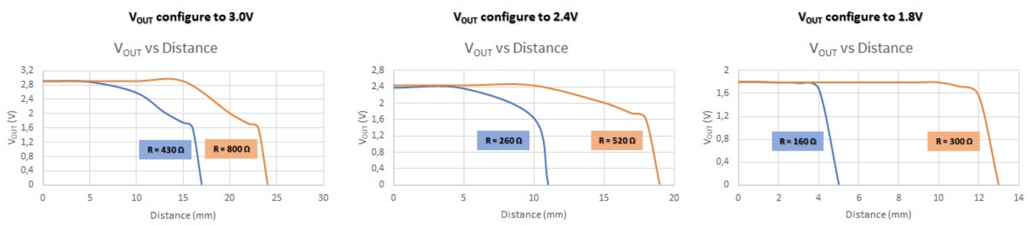

Figure 21. Huawei P20 Pro NFC mobile phone measurement results

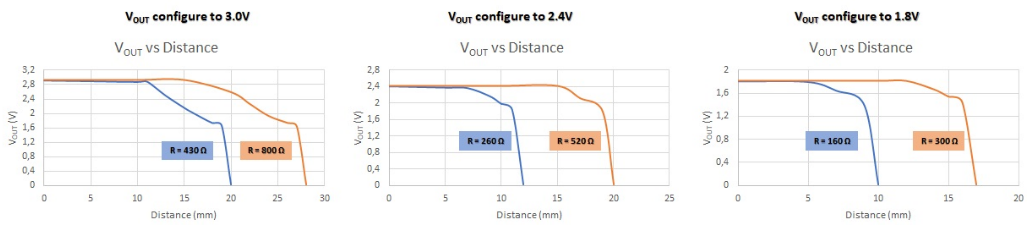

Figure 22. Apple iPhone 11 NFC mobile phone measurement results

6.2 Boot sequence example timings

Below is a diagram of a boot sequence example when EH is enabled by configuration registers (see Section 4.2).

It shows timing of RF field ON event and V_{OUT} signal ramp-up, until the start of a PWM (GPIO_PAD1 configured as PWM output).

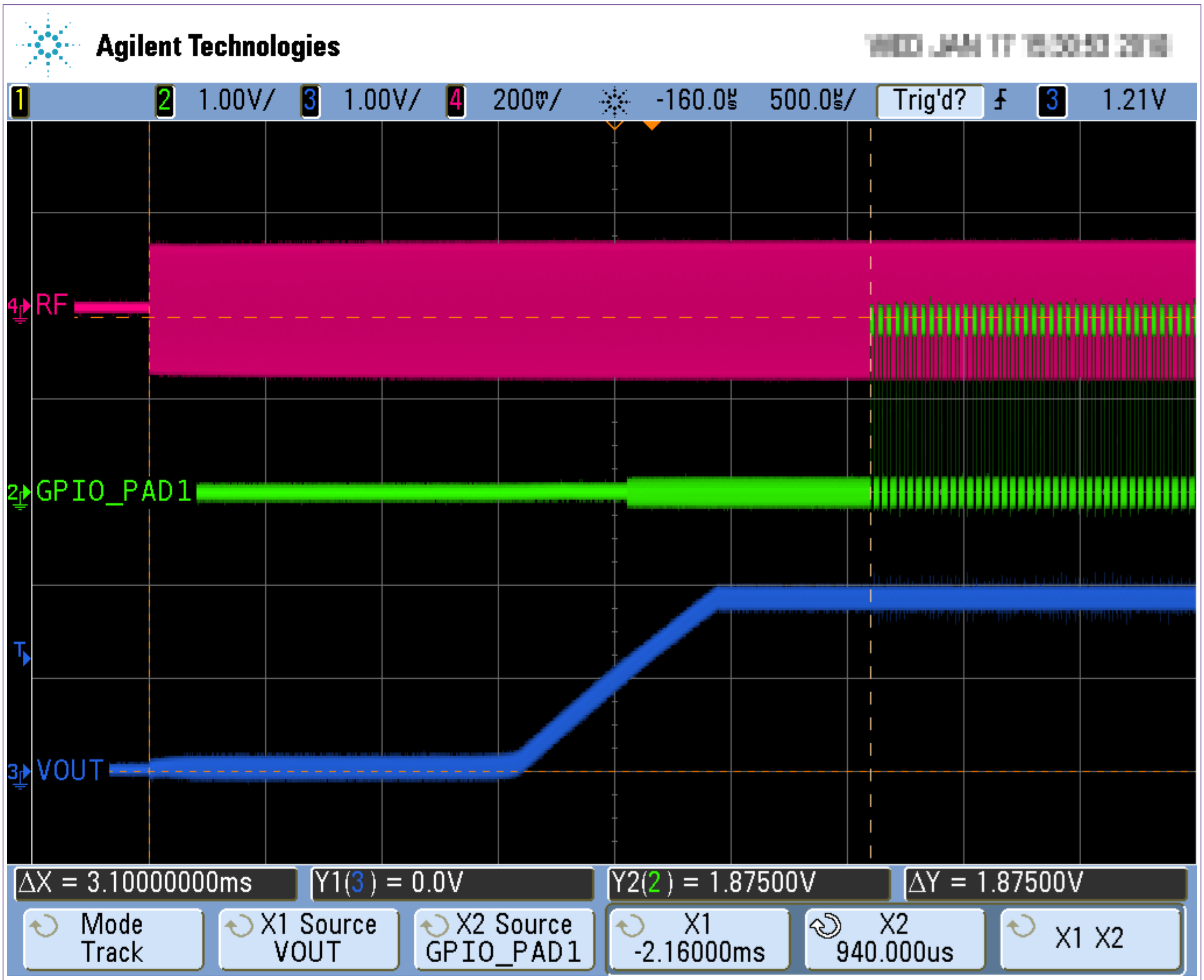

Figure 23. Enable EH by Config. bytes (Boot up behavior) - time/state diagram scope trace

7 References

[1] NTP5210 - NTAG 5 switch, NFC Forum-compliant PWM and GPIO bridge, doc.no. 5477xx
https://www.nxp.com/docs/en/data-sheet/NTP5210.pdf

[2] NTA5332 - NTAG 5 boost, NFC Forum-compliant I^2C bridge for tiny devices, doc.no. 5475xx
https://www.nxp.com/docs/en/data-sheet/NTA5332.pdf

[3] AN11203 - NTAG 5 Use of PWM, GPIO and Event detection, doc.no. 5302xx
https://www.nxp.com/docs/en/application-note/AN11203.pdf

[4] AN12364 - NTAG 5 Bidirectional data exchange, doc.no. 5303xx
https://www.nxp.com/docs/en/application-note/AN12364.pdf

[5] AN12368 - NTAG 5 Link I^2C Master mode, doc.no. 5306xx
https://www.nxp.com/docs/en/application-note/AN12368.pdf

[6] AN12339 - Antenna Design Guide for NTAG 5
https://www.nxp.com/docs/en/application-note/AN12339.pdf

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