NFC Forum – ISO/IEC 14443 Analog Parameter Comparison and Alignment

Methodology, Procedures and Results

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Contents

Table 1: Applicable Documents or References

References	
[ISO14443-1]	ISO/IEC 14443-1:2008 Identification cards — Contactless integrated circuit cards — Proximity cards —Part 1:Physical characteristics
[ISO14443-1:AMD1]	ISO/IEC 14443-1:2008 AMENDMENT 1: Additional PICC classes
[ISO14443-2]	ISO/IEC 14443-2:2010 Identification cards — Contactless integrated circuit cards — Proximity cards —Part 2: Radio frequency power and signal interface
[ISO14443-2:AMD1]	ISO/IEC 14443-2:2010 AMENDMENT 1: Limits of electromagnetic disturbance levels parasitically generated by the PICC
[ISO14443-2:AMD2]	ISO/IEC 14443-2:2010 AMENDMENT 2: Additional PICC classes
[ISO14443-3]	ISO/IEC 14443-3:2011 Identification cards — Contactless integrated circuit cards — Proximity cards Part 3: Initialization and anticollision
[ISO14443-3:AMD1]	ISO/IEC 14443-3:2011 AMENDMENT 1: Electromagnetic disturbance handling and single-size unique identifier
[ISO10373-6]	ISO/IEC 10373-6:2011 Identification cards — Test methods —Part 6: Proximity cards
[ISO10373-6:AMD1]	ISO/IEC 10373-6:2011 AMENDMENT 1: Additional PICC classes
[ISO10373-6:AMD2]	ISO/IEC 10373-6:2011 AMENDMENT 2: Test methods for electromagnetic disturbance
[ISO10373-6:COR1]	ISO/IEC 10373-6:2011 TECHNICAL CORRIGENDUM 1: R2 value range, start of PICC transmission and program for EMD level measurement
[ISO18092]	ISO/IEC 18092:2013 Information technology — Telecommunications and information exchange between systems — Near Field Communication — Interface and Protocol (NFCIP-1)
[EMVCo_Book_D_v2_4]	EMV Contactless Specifications for Payment Systems Book D: EMV Contactless Communication Protocol Specification Version: 2.4
[NFC_ANA]	NFC Forum ANALOG Specification V1.0, 2012-07-11
[NFC_TC_ANA]	NFC Forum Test cases for Analog V1.0.03
[NFC_ACTIVITY]	NFC Forum Activity Specification v1.1
[NFC_DIGITAL]	NFC Forum Digital Specification v1.1
[CEN/TS 16794-1]	Public transport — Communication between contactless readers and fare media —Part 1: Implementation requirements for ISO/IEC 14443
[Mobile_Usecases]	Documentation of Use Cases for NFC Mobile Devices in Public Transport, "PT Mobile use cases v1.7.3"
[ConceptInteroperability]	140826 Concept_for_Interoperability_NFCF-ISO_V0.9.9
[NFC_Public_Transport]	Transforming_NFC_Public_Transport_Experience

Table 2 Abbreviations

Abbreviations	
DUT	Device Under Test
DUT P0	NFC Forum – Reference Poller 0 emulating the DUT
DUT P3	NFC Forum – Reference Poller 3 emulating the DUT
DUT P6	NFC Forum – Reference Poller 6 emulating the DUT

DUT L1	NFC Forum – Reference Listener 1 emulating the DUT
DUT L3	NFC Forum – Reference Listener 3 emulating the DUT
DUT L6	NFC Forum – Reference Listener 6 emulating the DUT
DUT PCD1	ISO Test PCD Assembly 1 emulating the DUT
DUT PCD2	ISO Test PCD Assembly 2 emulating the DUT
DUT PICC1	ISO Reference PICC 1 emulating the DUT
DUT PICC3	ISO Reference PICC 3 emulating the DUT
DUT PICC6	ISO Reference PICC 6 emulating the DUT
NFC OV	Operating volume as defined by NFC Forum
ISO OV	Operating volume associated to public transport needs (assumed to be identical with NFC OV for this study)

Table 3 ISO/IEC 14443 and NFC Forum Variable definition and comparison used in this document

Magnetic Field strength, Power Conditions			
ISO	**Comment**	**NFC Forum**	**Comment**
H	Equivalent homogenous magnetic field strength as measured by the calibration coil of the Test PCD Assembly (see [ISO10373-6]).	Poller: V_{OV}, Listener: $V_{S,OV}$	Voltage measured at NFC Forum Reference Listener J1 connector. The measured voltage relates to the field strength exposed to. The NFC Forum Reference Listener is configured to a defined load and resonance frequency. The voltage V_{OV} is the measured quantity when a Poller is the DUT. The voltage $V_{S,OV}$ is used whenever a certain field condition is setup to test a Listener.
V_{load}	DC voltage measured at Reference PICC CON3 connector (see [ISO10373-6]). The load resistor is adjusted such that V_{load} remains constant independent of field strength.	Not defined in NFC Forum	
Communication PCD to PICC			
ISO	**Comment**	**NFC Forum**	**Comment**
Type A	Communication Technology	NFC-A	Communication Technology
PCD: t_1, t_2, t_3, t_4 PICC: t_1, t_2, t_3, t_4	Timing parameters for waveform Type A. Defined with margin for PCD and PICC	Poller: t_1, t_2, t_3, t_4 Listener: $t_{S,1}$, $t_{S,2}$, $t_{S,3}$, $t_{S,4}$	Timing parameters for waveform NFC-A. Defined with margin for Poller and Listener
Overshoot	No explicit margin defined for PCD and PICC. In this document called OS_{MAX}	Poller: $V_{OU,A}$ Listener: $V_{S,OU,A}$	Overshoot parameter for waveform NFC-A. Defined with margin for Poller and Listener

Type B	Communication Technology	NFC-B	Communication Technology
PCD: t_r, t_f PICC: t_r, t_f	Rise and fall time parameters for waveform Type B. Defined with margin for PCD and PICC	Poller: $t_{r,B}$, $t_{f,B}$ Listener: $t_{S,r,B}$, $t_{S,f,B}$	Rise and fall time parameters for waveform NFC-B. Defined with margin for Poller and Listener
PCD: m PICC: m	Modulation Index parameter for waveform Type B. Defined with margin for PCD and PICC	Poller: $mod_{i,B}$ Listener: $mod_{S,i,B}$	Modulation Index parameter for waveform NFC-B. Defined with margin for Poller and Listener
PCD: h_r , h_f PICC: h_r , h_f	Overshoot parameter for waveform Type B. Defined with margin for PCD and PICC. In this document called OS_{MAX}	Poller: $V_{OU,B}$ Listener: $V_{S,OU,B}$	Overshoot parameter for waveform NFC-B. Defined with margin for Poller and Listener
--		NFC-F	Communication Technology. Not defined in ISO/IEC14443
Communication PICC to PCD			
ISO	**Comment**	**NFC Forum**	**Comment**
V_{LMA}	Load Modulation Amplitude. Defined with margin for PCD and PICC. In this document called LMA	Listener: V_{PP} Poller: $V_{S,PP}$	Load Modulation Amplitude. Defined with margin for Poller and Listener

1 Introduction

1.1 Motivation and Objectives

The 13.56 MHz contactless interface enables the communication between a Reader and a Card in close proximity of a distance up to 10 cm. Due to the properties of this interface it is well suited for applications like payment, public transport, fare collection, ticketing and access control. Traditionally these applications have been well separated and used in its own closed ecosystem. For each of the above mentioned applications different standardization bodies emerged and defined requirements. ISO/IEC 14443 standard series defines the 13.56 MHz interface for applications like access control, fare collection and ticketing. EMVCo defines the 13.56 MHz radio for payment applications. ISO/IEC 18092 standard the first time defined requirements for the communication between mobile devices, known as peer to peer communication, using 13.56 MHz contactless interface. NFC Forum, an industry association, defined requirements to combine peer to peer, reader and card functionality in a single device. Therefore NFC Forum defined requirements for this interface for use within a mobile device. All these developments resulted in an application dependent fragmentation of the 13.56MHz contactless interface standards.

Over the last years the NFC interface became a standard interface in most smart phones which can be used for all above mentioned applications and many more. Due to this fact the application dependent closed ecosystem approach is no longer valid. As a consequence the mobile device has to be able to interact with readers and/or cards from the above ecosystems. However, each of them is defining separate requirements for the contactless interface which are similar but not identical. This fact causes potential interoperability problems which are not in the interest for this technology and hampers a seamless introduction of mobile use cases into legacy infrastructure. [Mobile_Usecases] documents relevant mobile use cases in the context of public transport. For this reason NFC Forum and EMVCo started the harmonization work on digital matters in 2009. In 2014 the scope was extended to the analog parameter gap analysis and harmonization. In parallel NFC Forum started an initiative of harmonization to ISO/IEC 14443 analog parameters as joint activity with Public transport organizations, GSMA and ISO JTC1 SC17 WG8 (see also [NFC_Public_Transport]). WG8 working group defines and maintains amongst others, the ISO/IEC 14443 standards series.

This document contains a generic comparison of selected analog parameters between NFC Forum and ISO/IEC 14443. Since the Public Transport use case has a special attention in this work the application profile defined in [CEN/TS 16794-1] has been taken into account whenever appropriate. The goal of this work was to define a generic methodology to compare analog parameter limit values defined by NFC Forum and ISO/IEC 14443. Once parameter limit differences have been identified concepts and approaches to resolve these differences have been evaluated with the goal to achieve interoperability.

1.2 Purpose

This document contains the methodology how analog parameters limits between NFC Forum and ISO/IEC 14443 have been compared. This study takes into account the parameter limits analysis mapped from NFC Forum to ISO/IEC 14443. For each parameter limit an associated procedure has

been defined. Each procedure is written in such a way that an experienced engineer can repeat the procedure and will measure similar results. For parameter limits which resulted in a difference between NFC Forum and ISO/IEC 14443 an approach for harmonization has been developed. Once a harmonization solution has been identified, this solution or the resulting candidate parameter limits have been validated.

1.3 Public Transport Collaborations

This white paper "NFC Forum – ISO/IEC 14443 Analog Parameter Comparison and Alignment" documents the methodology, procedures and results that have been developed to ensure that Forum-conformant mobile devices will be interoperable with ISO/IEC14443- and ISO/IEC18092-conformant public transport readers and objects.

In order to address the needs of the public transport market, NFC Forum's Transport SIG, in ollaboration with GSMA, East Japan Railways, CEN TC278 WG3 and the Smart Ticketing Alliance have identified high level requirements that would need to be fulfilled in order to achieve interoperability between NFC mobile devices and public transport fare management infrastructures on a wider scale.

The technical solution addressing these requirements, the "concept for interoperability", subsequently has been aligned through a formal liaison between the NFC Forum and CEN TC278 WG3 for ISO/IEC 14443-conformant public transport infrastructures and with East Japan Railways for ISO/IEC 18092-conformant public transport infrastructures.

As basis for the specification work, the NFC Forum's Technical Committee then developed the methodology and procedures for the analog comparison of NFC Forum and ISO/IEC 14443 specifications and discussed the results with CEN TC278 WG3, GSMA, East Japan Railways and Smart Ticketing Alliance's experts at the Joint Public Transport Workshops. The result is documented in this white paper "NFC Forum – ISO/IEC 14443 Analog Parameter Comparison and Alignment".

Based on these agreed methods and procedures, the NFC Forum developed version 2.0 of the Analog Specification which shall be applied to NFC mobile devices which are used for public transport services. CEN TC278 WG3 generated the 2nd edition of CEN/TS 16794 for public transport contactless readers and objects. This 2nd edition was enhanced to support interoperability with NFC mobile devices. Both specifications are synchronized and hence enable contactless interoperability between NFC mobile devices conformant to NFC Forum's new Analog 2.0 (or later) specification and existing Activity and Digital specifications, and public transport readers and objects conformant to the 2nd edition of CEN/TS 16794.

The concept for interoperability and its technical foundation which is documented in this white paper "NFC Forum – ISO/IEC 14443 Analog Parameter Comparison and Alignment" are formally endorsed by CEN TC278 WG3.The NFC Forum, ISO/IEC JTC1/SC17/WG8 and CEN TC278 WG3 intend to continue their technical cooperation in order to provide synchronized updates of their specifications as required.

1.4 Outline of This Document

Section 2 of this document defines the boundary conditions, the methodology approach used for the harmonization work and the selected analog parameters. In section 3 the actual parameter limit comparison is performed. Thus, this part defines the procedures for each selected parameter limit and the according measurement results. The measurement results provide evidence on potential limit differences. For parameter limits with identified limit differences the subsequently following section 4 describes the detail way for harmonization. Afterwards the validation of the harmonization result is presented. Section 5 defines a way forward how to introduce the analog EMD requirement in a harmonized manner in NFC Forum. Finally for easy cross reference Annex A and Annex B contain the relevant requirements defined by ISO/IEC 14443 used for this harmonization.

2 Boundary Conditions and Methodology for Analog Parameter Comparison

NFC Forum defines different roles for a mobile device, which are:

- Peer: A role either equal to the role of an Initiator (Poller) or to the role of a Target (Listener).The Peer role covers the peer to peer (P2P) communication between Initiator and Target.
- Reader: NFC Forum Device in Poll Mode when it has gone through a number of Activities. The Reader covers the communication to Tags and legacy PICCs
- Card Emulator (CE): NFC Forum Device in Listen Mode when it has gone through a number of states. CE covers the communication to legacy infrastructure (Readers or PCDs)

The document [Mobile_Usecases] performs an analysis of mobile use cases in Public Transport. This analysis shows that the Reader and the Card Emulator role are essential and therefore have to be supported.

2.1 Interoperability Versus Conformance

At the start of this harmonization activity an analysis was performed if interoperability or conformance is the goal to be achieved for this project. In order to answer this question a common understanding of the two terms had been developed. Therefore the following definitions are valid for interoperability and conformance/compliance in the context of this harmonization work when comparing requirements between NFC Forum and ISO/IEC 14443.

- **Conformance/Compliance:** An NFC Forum Device implementing a certain set of requirements which are tested according to NFC Forum would automatically also fulfill the requirements as defined and tested by ISO/IEC 14443 and [ISO10373-6]. This results in a perfect match of the requirement and resulting operating range (minimum and maximum limit of a parameter) including testing and test equipment as defined by both organizations.
  Example: An NFC Forum Device in Reader role tested for load modulation amplitude reception requirement according to NFC Forum will implicitly fulfill the related PCD requirement and test according to ISO/IEC 14443 and [ISO10373-6], respectively.
- **Interoperability:** An NFC Forum Device in a certain role (e.g., Reader) implementing a certain set of requirements which are tested according to NFC Forum would be able to communicate with the counterpart (e.g., Card) as defined by ISO/IEC 14443. This counterpart (e.g., Card) implements the requirements as defined and tested by ISO/IEC 14443 and [ISO10373-6].
  Example: An NFC Forum Device in Reader role implementing and tested for load modulation amplitude requirement according to NFC Forum will be able to communicate with a PICC implementing the requirement and test according to ISO/IEC 14443.

NOTE Additionally this interoperability definition includes an assessment on relevance for interoperability in the field. This covers the case of differences on parameter limits which are declared to be non-critical or irrelevant for interoperability in the field or due to non-

applicability for the defined use cases in [Mobile_Usecases]. Therefore these differences will be given low priority, if at all, and are rated as theoretical differences.

The above definition of conformance and interoperability leaded to the conclusion that for this work interoperability is the primary target to ensure interoperability between NFC Forum conformant devices and public transport certified reader or media in the field. Nevertheless it was decided that the parameter limit comparison will address both, interoperability and conformance.

2.2 Boundary Conditions

In order to achieve a valid assessment for parameter limit comparison and their harmonization some boundary conditions have been defined. The following boundary conditions have been agreed between NFC Forum Technical Experts, Transport SIG and PT Experts:

1. Operating Volume (OV):
   In contrast to NFC Forum, ISO/IEC 14443 standard series do not specify absolute values for an operating volume (OV). ISO/IEC14443 defines the OV for each PICC class as the positions where the corresponding Reference PICC shows PCD compliance with all requirements of this part of ISO/IEC14443. For simplicity the OV as defined by NFC Forum is assumed to represent the ISO/IEC 14443 and PT OV. This OV definition will be used throughout this harmonization work. A definition of the OV can be found in [NFC_ANA]. Thus the same OV is valid for the ISO/IEC 14443 as well as the NFC Forum perspective of requirements.
   There is one additional Listening side requirement on the operating distance in [CEN/TS 16794-1] on NFC Forum perspective. The Load Modulation Amplitude (LMA) for NFC Forum Devices in Listen Mode is required to be valid up to 2 cm in z-direction. Since the distance aspect is inherently covered by the requirement defined by [ISO14443-2] and its associated test methods [ISO10373-6] it does not require special analysis.
2. PICC Antenna classes:
   A detailed analysis has to be performed in order to carry out a boundary condition definition on the PICC antenna classes for this harmonization work. [ISO14443-1:AMD1], sec. 5.2.2 defines as mandatory requirement for PCD compliance to support PICCs of "Class 1", "Class 2" and "Class 3". This requirement is also defined for the public transport use case in [CEN/TS 16794-1] and described in [Mobile_Usecases]. In order to achieve interoperability between a mobile device and PT reader or media, an NFC Forum Device in Reader role has to support the requirements for PICCs of "Class 1", "Class 2" and "Class 3" and a NFC Forum Device in CE role must behave independently on its antenna size at least as a PICC of "Class 3". With this analysis we can derive the following antenna class dependent boundary conditions:
   a. An NFC Forum Polling Device claiming ISO compliance has to be compliant to:
   - Mandatory: Class 1-3 compliance
   - Optional: Class 1-3 and 6 compliance
   - Optional: Class 6 only compliance (only for information purposes, not relevant for use cases)

   b. NFC Forum Listening Device claiming ISO compliance has to fulfill the following requirements:
   - Optional: Compliance to the particular antenna class

- Mandatory: Compliance to either of Class 1 to 3

2.2.1 Generic Considerations on the Antenna Size and Its Impact on Communication Stability

The 13.56 MHz radio performs communication and/or power transfer using magnetic coupling. Generally, the ratio of the Reader to Card antenna size as well as their relative distance determines the coupling. This has a huge impact on both, communication stability and power transfer.

One can mainly distinguish between the two extreme cases of coupling:

- Low coupling and high coupling cases:
  - Low coupling is encountered in cases of large antenna size differences or at large distance between Reader and Card antennas.
  - High coupling situations are met in case of almost equal antenna sizes of Reader and Card and at small distances between the antennas.

As described in the introduction, in the past Readers and Cards have been primary designed for single applications used in a closed ecosystem. Public transport and Payment clearly belong to these applications and implemented systems mainly based on the low coupling case. In contrast access systems and the communication between mobile phones are mainly designed for the high coupling case. Due to the increasing mobile phone multi-application usage covering public transport as well as payment the mobile use case faces new challenges. It has to support both, low and high coupling cases which finally will impact all, Readers, Cards and mobile devices.

2.3 Methodology

For the analog limit comparison between EMVCo and NFC Forum a methodology was developed. This methodology will be equally followed in this work.

Parameter limits comparison can be carried out either from NFC Forum to ISO/IEC 14443 or from ISO/IEC 14443 to NFC Forum. The term NFC Forum perspective denotes the parameter comparison from NFC Forum to ISO/IEC 14443 and ISO/IEC perspective denotes the comparison from ISO/IEC 14443 to NFC Forum. Depending on the mentioned perspective the Device under Test (DUT) is emulated by the according reference equipment. This study considers only the NFC Forum perspective.

1. ISO/IEC perspective, PCD and PICC requirements:
   - Test PCD Assembly 1 and 2 [ISO10373-6], [ISO10373-6:AMD1] are used to emulate the PCD Device Under Test (DUT)
   - ISO/IEC Reference PICC 1, 2, 3 and 6 are used to emulate the DUT PICCs
2. NFC Forum perspective, Poller and Listener requirements:
   - NFC Forum – Reference Pollers 0, 3 and 6 are used to emulate the DUT Poller
   - NFC Forum – Reference Listeners 1, 3 and 6 are used to emulate the DUT Listener

Once the setup for a certain test condition has been performed these DUTs can be evaluated in the environment of interest. Compliance and interoperability between the standards is tested by the following fundamental principle:

Is a DUT (e.g. Poller) compliant to the requirement XX (e.g., LMA_{min}) of NFC Forum Analog specification also compliant or interoperable to the PCD or PICC requirement YY (e.g., LMA_{min}) of ISO/IEC 14443?

Example Procedure: NFC Forum Perspective, Requirement for Polling Device: Minimum field strength

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.1.2.1: When the NFC Forum – Reference Listening Device is located within the Operating Volume of the Polling Device, under the conditions described in the specification context above, it SHALL generate an output voltage V_{OV} at J1 of the NFC Forum – Reference Listening Device. The average value over a small period of time (>10µs) at a fixed location of the voltage V_{OV} SHALL be characterized.
Implicit Requirement	Minimum power
Question	Is an NFC Forum Device in Poll mode which is compliant for the minimum of the above power requirement also compliant corresponding ISO PCD Requirement or interoperable to the corresponding ISO PICC Requirement?
PROCEDURE	
Step	**SETUP**
1	Setup of a compliant NFC Forum DUT Polling Device *Setup the DUT Poller to be on the limit for the requirement in at least one position of the NFC OV. All other positions have a value equal to or higher than the min requirement. The requirement has to be fulfilled by all 3 NFC Forum – Reference Listeners.*
Step	**VERIFICATION**
1	Setup the ISO/IEC reference equipment
2	Perform the test for minimum field strength as defined in ISO/IEC 10373-6 in the whole defined operating volume using the ISO Reference PICC of Class 1
EXPECTED OUTCOME	
Step	**COMPLIANCE**
1	Compliance is given if the minimum PCD requirement is met
Step	**INTEROPERABILITY**
1	Interoperability is given if the minimum PICC requirement is met
RESULT	
CONCLUSION / DISCUSSION	

2.4 Analog Parameters Selected for Comparison

For this harmonization work NFC Forum Technical Experts, Transport SIG and PT Experts have selected the analog parameters identified as essential for interoperability in the field. These selected parameters are listed below and are also well covered in [ConceptInteroperability]:

1. Bit rates considered:
   - ISO/IEC 14443 – NFC Forum: 106 kbps (Type A and Type B), for both communication directions
   - ISO/IEC 18092 – NFC Forum (passive communication mode only):
     For analog parameter and its limit ISO/IEC 18092 references to ISO/IEC 14443.
     - NFC-A: 106 kbps, for both communication directions (covered by ISO/IEC 14443 – NFC Forum)
     - NFC-F: 212 and 424 kbps, for both communication directions (covered by ISO/IEC 14443 – NFC Forum)
       - Poller - Listener communication direction: analog parameter are covered by NFC-B Technology analysis
       - Listener – Poller communication direction: analog parameter are covered by generic LMA analysis
2. Magnetic field strength:
   - Minimum and maximum magnetic field strength
   - Maximum alternating field strength according to [ISO14443-1]
3. Electromagnetic disturbance
4. Maximum loading effect / Influence on the field
5. Resetting the operating field ($V_{OV,RESET}$)
6. Waveform transmission/reception (PCD-PICC / Poller-Listener)
7. Load modulation transmission/reception (PICC-PCD / Listener-Poller)

3 NFC Forum to ISO/IEC 14443 Comparison (NFC Forum Perspective)

This section contains the analog parameter comparison procedures defined for each parameter limit. Below each procedure description, the measurement results are presented. Generally, results are shown once to address the compliance aspect and once the interoperability aspect. Following the measurement results a verdict assessment is performed. First the status quo assessment for the Polling Device is carried out

3.1 Polling Device Requirements

This section contains the procedure and comparison results for the following parameter limits:

- Power Transfer from Polling Device to Listening Device (Polling Device Transmission)
  - Minimum field strength
  - Maximum field strength
- Listening Device Reset (Polling Device Transmission)
- Polling Device RF Collision Avoidance before Carrier Generation
- Modulation Polling Device to Listening Device – NFC-A (Polling Device Transmission)
  - Waveform Analysis
  - Overshoot and Undershoot analysis
- Modulation Polling Device to Listening Device – NFC-B (Polling Device Transmission)
- Modulation Listening Device to Polling Device (Polling Device Reception)
  - Minimum load modulation amplitude
  - Maximum load modulation amplitude

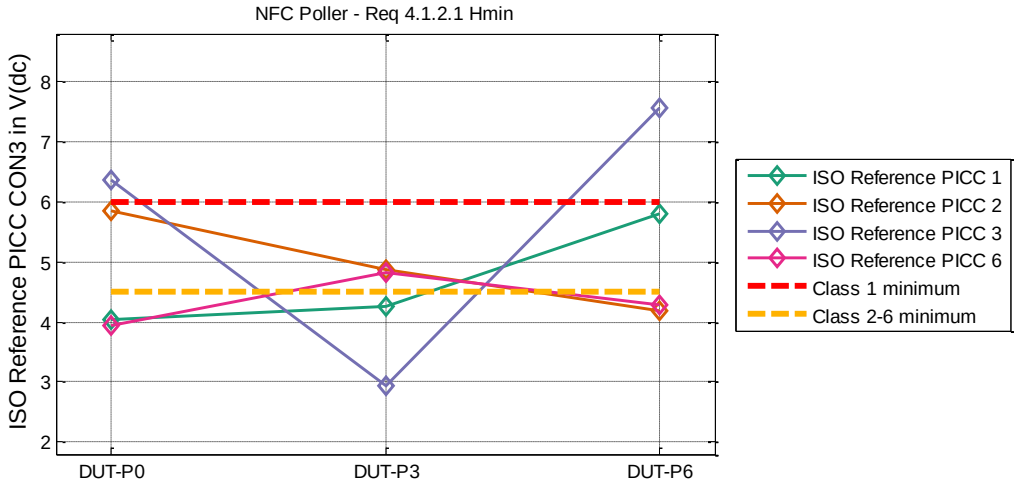
3.1.1 Requirement 4.1.2.1: Power Transfer from Polling Device to Listening Device (Polling Device Transmission)

a. Minimum field strength

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.1.2.1: When the NFC Forum – Reference Listening Device is located within the Operating Volume of the Polling Device, under the conditions described in the specification context above, it SHALL generate an output voltage V_{OV} at J1 of the NFC Forum – Reference Listening Device. The average value over a small period of time (>10µs) at a fixed location of the voltage V_{OV} SHALL be characterized.
Implicit Requirement	Minimum power
Question	Is an NFC Forum Device in Poll mode which is compliant for the minimum of the above power requirement also compliant or interoperable to the corresponding ISO PCD Requirement?

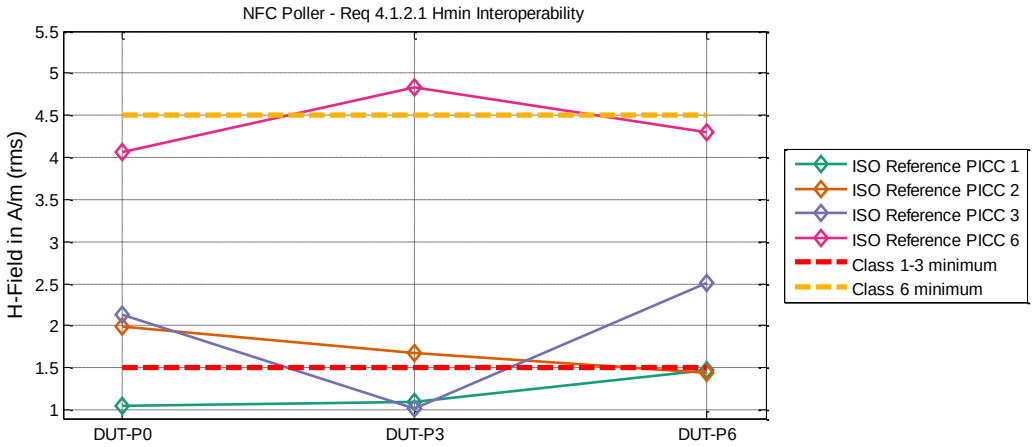
<table>
<tr><th colspan="2">PROCEDURE</th></tr>
<tr><td>Step</td><td>SETUP</td></tr>
<tr><td>1 NFC SETUP</td><td>Setup DUT P0 in order to get Poller minimum field strength value when measured with NFC Forum – Reference Listener 1 on at least one position of the NFC OV. Other positions shall give a field strength above or equal to the minimum of the NFC Forum specification.
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th>RL</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th><th>Ω</th></tr>
<tr><td>Power transfer: Poller→Listener</td><td>VOV</td><td>Listener-1</td><td>4.10</td><td>820</td><td>V</td></tr>
</table></td></tr>
<tr><td>2</td><td>Measure V_{DC} output of the NFC Forum – Reference Listener 3 in the whole NFC Forum OV of the DUT P0 and note the lowest value measured.
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th>RL</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th><th>Ω</th></tr>
<tr><td>Power transfer: Poller→Listener</td><td>VOV</td><td>Listener-3</td><td>3.14</td><td>820</td><td>V</td></tr>
</table>
If the value measured is less than 3.14 V, increase the field strength to 3.14 V at this position.</td></tr>
<tr><td>3</td><td>Measure V_{DC} output of the NFC Forum – Reference Listener 6 in the whole NFC OV of the DUT P0 and note the lowest value measured.
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th>RL</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th><th>Ω</th></tr>
<tr><td>Power transfer: Poller→Listener</td><td>VOV</td><td>Listener-6</td><td>3.79</td><td>820</td><td>V</td></tr>
</table>
If the value measured is less than 3.79 V, increase the field strength to 3.79 V at this position.</td></tr>
<tr><td>4 ISO SETUP</td><td>Tune each of the Reference PICCs 1, 2 and 3 and 6 to 13,56 MHz</td></tr>
<tr><td>5</td><td>For each Reference PICC, place the Reference PICC into the DUT position on the Test PCD assembly producing the H_{min} (see Table 22) operating condition on the calibration coil. Measure V_{load} as defined in Table 21 at connector CON3. The operating field condition shall be verified by monitoring the voltage on the calibration coil and adjusted if necessary.</td></tr>
<tr><td>Step</td><td>VERIFICATION</td></tr>
<tr><td>1</td><td>Measure V_{DC} output of each of the ISO Reference PICC 1, 2, 3 and 6 in the whole ISO OV of the DUT P0 and note the lowest value measured.</td></tr>
<tr><td>2</td><td>Place each of the ISO Reference PICCs on the respective Test PCD assembly and readjust the operating field such that at CON3 the same lowest DC voltage is measured as in the previous step. Record the field strength as measured at the calibration coil.</td></tr>
<tr><td>3</td><td>Repeat the SETUP and VERIFICATION procedure with DUT P3 and DUT P6.</td></tr>
</table>

EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	For compliance the DC voltage as measured at CON3 for R2 must be equal to or larger than the value defined for each ISO Reference PICC in Table 21. *Note: Compliancy is split into three subtasks: 1) Mandatory compliance to class 1-3, 2) Optional compliance to class 1-3 & 6, and 3) compliance to ISO class 6 only.*
Step	**INTEROPERABILITY**
1	Compare the minimum field strength for each ISO Reference PICC as measured in VERIFICATION step 2 to the minimum field strength an ISO compliant PICC still has to work. The minimum field strength is defined in [ISO14443-2]. *Note: Interoperability is split into three subtasks: 1) Mandatory to class 1-3, 2) Optionally to class 1-3 & 6, and 3) only to ISO class 6.*
RESULT	
	COMPLIANCY:



Overall compliancy verdict	DUT-P0	DUT-P3	DUT-P6
Subtask 1: Mandatory compliance to ISO class 1-3	KO	KO	KO
Subtask 2: Optional compliance to ISO class 1-3 & 6	KO	KO	KO
Subtask 3: Compliance to ISO class 6 only	KO	OK	KO

INTEROPERABILITY:



Overall compliancy verdict	DUT-P0	DUT-P3	DUT-P6
Subtask 1: Mandatory interoperability with ISO PICC 1-3	KO	KO	KO
Subtask 2: Optional interoperability with ISO PICC 1-3 & 6	KO	KO	KO
Subtask 3: Interoperability with ISO PICC 6 only	KO	OK	KO

CONCLUSION / DISCUSSION

See 3.1.10

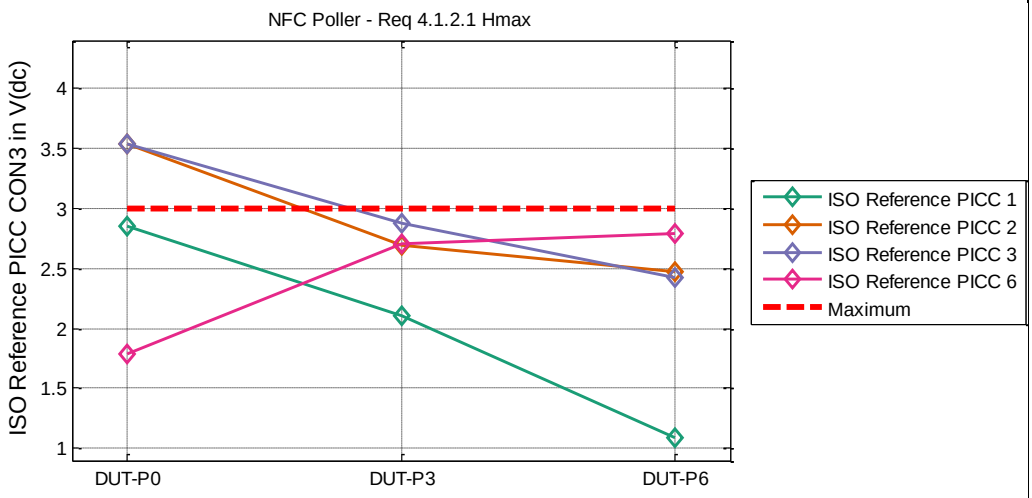
b. Maximum field strength

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.1.2.1: When the NFC Forum – Reference Listening Device is located within the Operating Volume of the Polling Device, under the conditions described in the specification context above, it SHALL generate an output voltage VOV at J1 of the NFC Forum – Reference Listening Device. The average value over a small period of time (>10µs) at a fixed location of the voltage VOV SHALL be characterized.
Implicit Requirement	Maximum power
Question	Is an NFC Forum Device in Poll mode which is compliant for the maximum of the above power requirement also compliant or interoperable to the corresponding ISO PCD Requirement?

PROCEDURE	
Step	**SETUP**
1 NFC Setup	Setup DUT P0 in order to get Poller maximum field strength value when measured with NFC Forum – Reference Listener 1 on at least one position of the NFC OV. Other positions shall give field strength below or equal to the maximum of the NFC Forum specification.

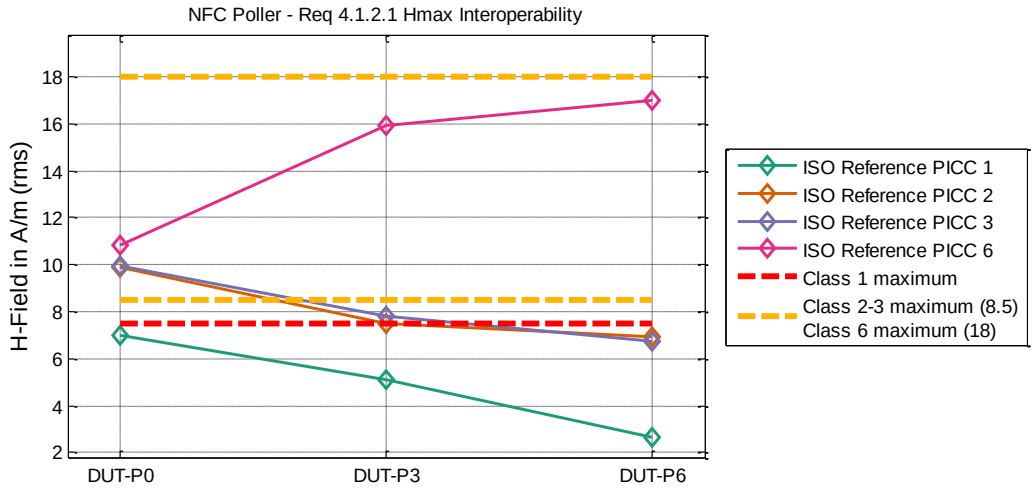
		Topic	**Parameter**	**Coil**	**Value** Max	**R_L** Ω	**Units**
		Power transfer: Poller→Listener	V_{OV}	Listener-1	2.85	82	V
2	Measure V_{DC} output of the NFC Forum – Reference Listener 3 in the whole NFC OV of the DUT P0 and note the highest value measured. **Topic** / **Parameter** / **Coil** / **Value** Max / **R_L** Ω / **Units** Power transfer: Poller→Listener / V_{OV} / Listener-3 / 2.30 / 82 / V If the value measured is more than 2.30 V, decrease the field strength to 2.30 V at this position.						
3	Measure V_{DC} output of the NFC Forum – Reference Listener 6 in the whole NFC OV of the DUT P0 and note the highest value measured. **Topic** / **Parameter** / **Coil** / **Value** Max / **R_L** Ω / **Units** Power transfer: Poller→Listener / V_{OV} / Listener-6 / 2.23 / 82 / V If the value measured is more than 2.23 V, decrease the field strength to 2.23 V at this position.						
4	Repeat above SETUP procedure with DUT P3 and DUT P6						
5 ISO Setup	Tune f_{res} of each of the ISO Reference PICC 1, 2, 3 and 6 to 19 MHz.						
6	Calibrate the ISO Test PCD assembly to produce the H_{max} (see Table 22) operating condition on the calibration coil.						
7	Place each ISO Reference PICC into the DUT position on the Test PCD assembly. Adjust R2 to obtain a DC voltage of 3 V measured at connector CON3. The operating field condition shall be verified by monitoring the voltage on the calibration coil and adjusted if necessary.						
Step	**VERIFICATION**						
1	Measure V_{DC} output of each ISO Reference PICC in the whole ISO OV of the DUT P0 and note the highest value measured.						
2	Place each of the ISO Reference PICCs on the respective Test PCD assembly and readjust the operating field such that at CON3 the same highest DC voltage is measured as in the previous step. Record the field strength as measure at the calibration coil.						
3	Repeat above VERIFICATION procedure with DUT P3 and DUT P6.						
EXPECTED OUTCOME							
Step	**COMPLIANCY**						
1	Compare the highest DC voltage measure in VERIFICATION step 1 to ISO/IEC maximum limit as defined in Table 22. The test is PASS if the						

	measured DC voltage of VERIFICATION step 1 is lower than the value in Table 22. *Note: Compliancy is split into three subtasks: 1) Mandatory compliance to class 1-3, and 2) Optional compliance to class 1-3 & 6 3) compliance to ISO class 6.*
Step	**INTEROPERABILITY**
1	Compare the maximum measured H-field strength of VERIFICATION step 2 to the limit an ISO compliant PICC must be able to be functional (see Annex 0, clause 0, [ISO14443-2]). *Note: Interoperability is split into three subtasks: 1) Mandatory to class 1-3, and 2) Optionally to class 1-3 & 6 3) only to ISO class 6.*
RESULT	
	COMPLIANCY: Verdict assessment: PASS if below the ISO/IEC 14443 defined limit curve.



Overall compliancy verdict	DUT-P0	DUT-P3	DUT-P6
Subtask 1: Mandatory compliance to ISO class 1-3	KO	OK	OK
Subtask 2: Optional compliance to ISO class 1-3 & 6	KO	OK	OK
Subtask 3: Compliance to ISO class 6 only	OK	OK	OK

INTEROPERABILITY:
Verdict assessment: PASS if below the ISO/IEC 14443 defined limit curve.



Overall interoperability verdict	DUT-P0	DUT-P3	DUT-P6
Subtask 1: Mandatory interoperability with ISO PICC 1-3	KO	OK	OK
Subtask 2: Optional interoperability with ISO PICC 1-3 & 6	KO	OK	OK
Subtask 3: Interoperability with ISO PICC 6 only	OK	OK	OK

CONCLUSION / DISCUSSION

See 3.1.10

c. Minimum and Maximum Field Strength results

In this section the field strength operating range in its entirety is analysed. This step is taken to assess the overlap of the field strength range depending on the Polling Device antenna size.

NFC Forum Poller 0 emulates a Device under Test (circular: diameter: 66mm)

The NFC Forum Poller 0 (DUT P0) is emulating a DUT with the largest considered antenna size. Below in the first subsection comparison results for Class 1-3 and in the second subsection comparison results for Class 6 are provided.

NFC Polling Device Power Transmission - class 1-3

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical. Compliance/ interoperability is observed if the operating range as indicated by the blue lines for each Reference PICC in Figure 1 is between the ISO defined limits. The limits are antenna class dependent and are depicted as vertical lines in Figure 1. For Class 1 compliance/interoperability assessment the blue line must remain within the borders of the red and orange dashed vertical lines. For Class 2 and 3 the limit lines are defined by the red and yellow dashed vertical lines. From the result shown one can see that DUT P0 for all 3 analyzed classes shows a significant overlap if compared to the limit range defined by ISO/IEC 14443. For example for Class 1 the overlap is 92%. However, one can also see that DUT P0 does not emit the minimum required field for Class 1 according to ISO/IEC 14443. This difference is seen as critical since typically PICCs (e.g., PT media) are powered by the PCD emitted field and if the PCD's field is too low, the PICC is not fully

powered and therefore no communication is possible. In contrast, for Class 2 and 3 the maximum power requirement is exceeded. This difference has been rated as insignificant for the following reasons:

- Mobile Phones are battery powered and therefore do not emit a field close to the maximum.
- The field in both cases is below the maximum alternating field strength defined in [ISO14443-1] and [ISO14443-1:AMD1] a PICC has to permanently survive if exposed to.
- For the maximum field strength the Reference PICCs are configured to the lowest load possible. Any known PICC deployed in the field has a loading higher than the Reference PICC and this would result in a lower field strength observed by the PICC.

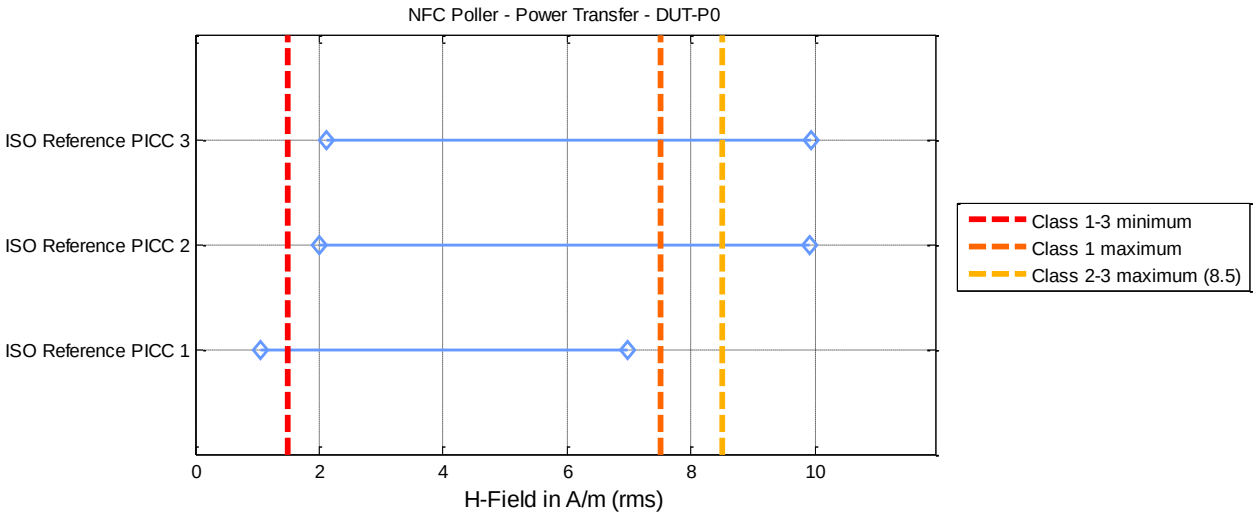


Figure 1: DUT Poller 0 field strength parameter comparison for Class 1-3 compliance/interoperability assessment.

NFC Polling Device Power Transmission - class 6

Figure 2 shows the field strength comparison results for DUT P0 and Class 6. Also in this figure the measurement results are shown as blue line and the ISO/IEC 14443 defined limits are depicted as vertical dashed lines. Similarly to the Class 1- 3 analysis above, compliance/interoperability is given if the DUT P0 min and max field remains within the limits of ISO/IEC 14443. For this DUT antenna size the maximum field is by far not reached. In contrast the minimum field strength requirement for this Class is not fulfilled. Therefore, interoperability is not given due to NFC Forum requirement.

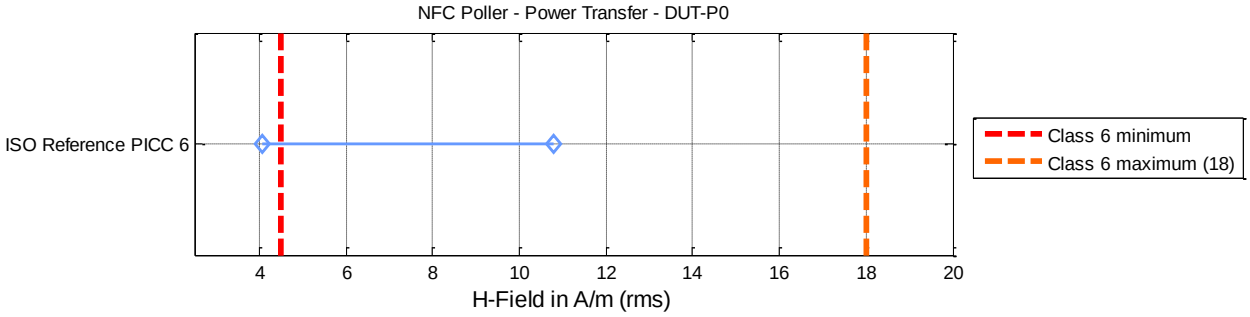


Figure 2: DUT Poller 0 field strength parameter comparison for Class 6 compliance/interoperability assessment.

NFC Forum Poller 3 emulates a Device under Test (size: 44 x 30mm^2)

The NFC Forum Poller 3 (DUT P3) is emulating a DUT with an average antenna size. This antenna size range is commonly used within mobile devices. In the first subsection below comparison results for Class 1-3 and in the second subsection comparison results for Class 6 are provided.

NFC Polling Device Power Transmission - class 1-3

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical. Compliance/ interoperability is observed if the operating range as indicated by the blue lines for each Reference PICC in Figure 3 is between the ISO defined limits. The limits are antenna class dependent and are depicted as vertical lines in Figure 3. For Class 1 compliance/interoperability assessment, the blue line must remain within the borders of the red and orange dashed vertical lines. For Class 2 and 3 the limit lines are defined by the red and yellow dashed vertical lines. From the result shown one can see that DUT P3 for all 3 analyzed classes shows a significant overlap if compared to the limit range defined by ISO/IEC 14443. For Class 2 the overlap is close to perfect. However, one can also see that DUT P3 does not emit the minimum required field for Class 1 and Class 3 according to ISO/IEC 14443. This difference is seen as critical since typically PICCs (e.g., PT media) are powered by the PCD emitted field and if the PCD field is too low the PICC is not fully powered and therefore no communication is possible.

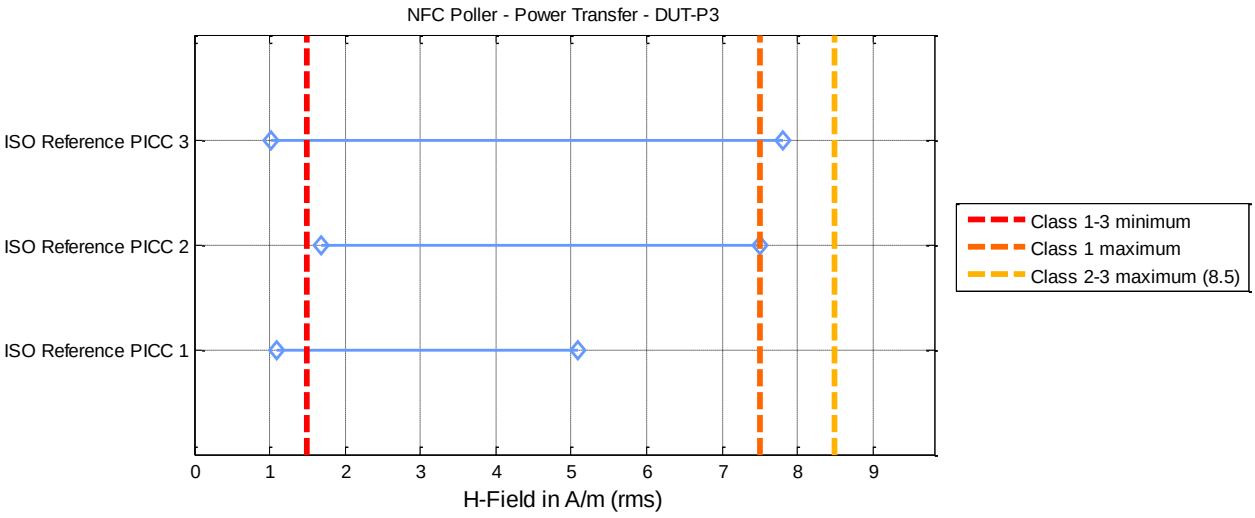


Figure 3: DUT Poller 3 field strength parameter comparison for Class 1-3 compliance/interoperability assessment.

NFC Polling Device Power Transmission - class 6

Figure 4 shows the field strength comparison results for DUT P3 and Class 6. In this figure the measurement results are shown as blue line and the ISO/IEC 14443 defined limits are depicted as vertical dashed lines. Similarly to the Class 1- 3 analysis above, compliance/interoperability is given if the DUT P3 min and max field remains within the limits of ISO/IEC 14443. For this DUT antenna size the maximum field as defined by ISO/IEC 14443 is not reached. The minimum field strength requirement for this Class is slightly exceeded. Therefore, full interoperability is given for this antenna size combination and field strength parameter due to NFC Forum requirement.

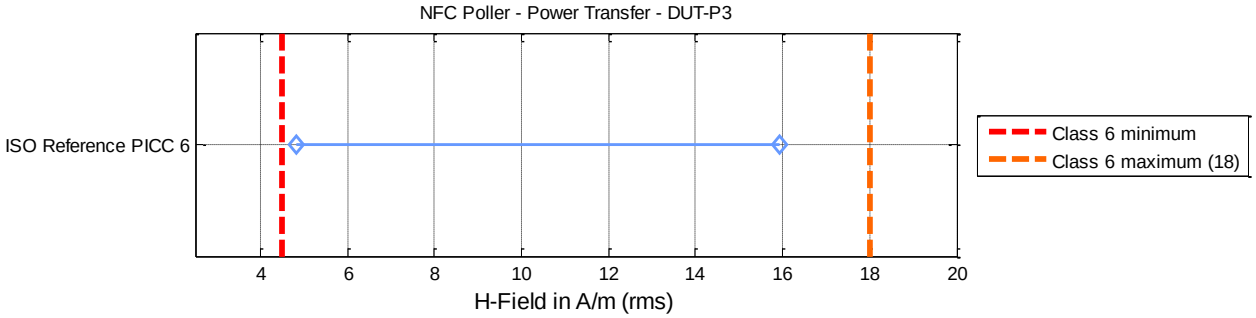


Figure 4: DUT Poller 3 field strength parameter comparison for Class 6 compliance/interoperability assessment.

NFC Forum Poller 6 emulates a Device under Test (size: 20.5 x 15.5mm^2)

The NFC Forum Poller 6 (DUT P6) is emulating a DUT with the smallest considered antenna size. In the first subsection below the comparison results for Class 1-3 and in the second subsection the comparison results for Class 6 are provided.

NFC Polling Device Power Transmission - class 1-3

Compliance/ interoperability is observed if the operating range as indicated by the blue lines for each Reference PICC in Figure 5 is between the ISO defined limits. The limits are antenna class dependent and are depicted as vertical lines in Figure 5. For Class 1 compliance/interoperability assessment the blue line must remain within the borders of the red and orange dashed vertical lines. For Class 2 and 3 the limit lines are defined by the red and yellow dashed vertical lines. From the result shown one can see that DUT P6 for all 3 analyzed classes shows a good overlap if compared to the limit range defined by ISO/IEC 14443. For Class 1 and 2 the minimum limit is met if we consider a small amount of measurement uncertainties. In contrast, the minimum field strength requirement is clearly exceeded for Class 3. Due to the small antenna size of DUT P6 the maximum field strength limit as defined by ISO/IEC 14443 is never reached by Class 1 -3. Summing, a DUT P6 antenna size device is emitting a sufficiently high field to power a PICC in the NFC OV.

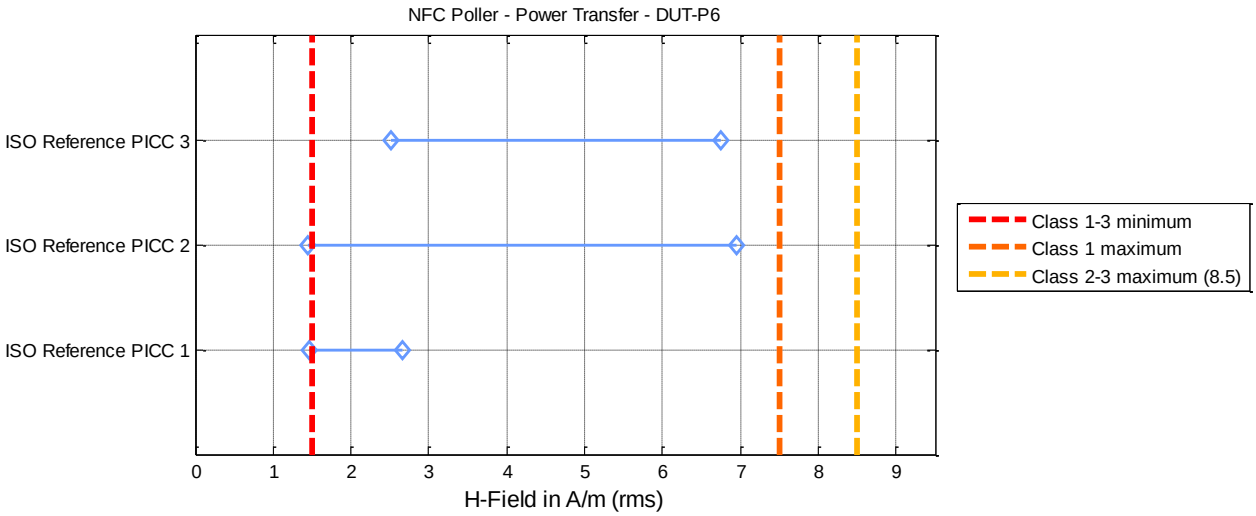


Figure 5: DUT Poller 6 field strength parameter comparison for Class 1-3 compliance/interoperability assessment.

NFC Polling Device Power Transmission - class 6

Figure 6 shows the field strength comparison results for DUT P6 and Class 6. In this figure the measurement results are shown as blue line and the ISO/IEC 14443 defined limits are depicted as

vertical dashed lines. Similarly to the Class 1- 3 analysis above, compliance/interoperability is given if the DUT P6 min and max field remains within the limits of ISO/IEC 14443. For this DUT antenna size the maximum field as defined by ISO/IEC 14443 is not exceeded. The minimum field strength requirement for this Class is not completely reached. [ISO14443-2:AMD1] defines a minimum field strength of 4.5A/m(rms) for Class 6. DUT P6 emits a minimum field strength of approximately 4.3A/m(rms) in at least one position of the NFC OV.

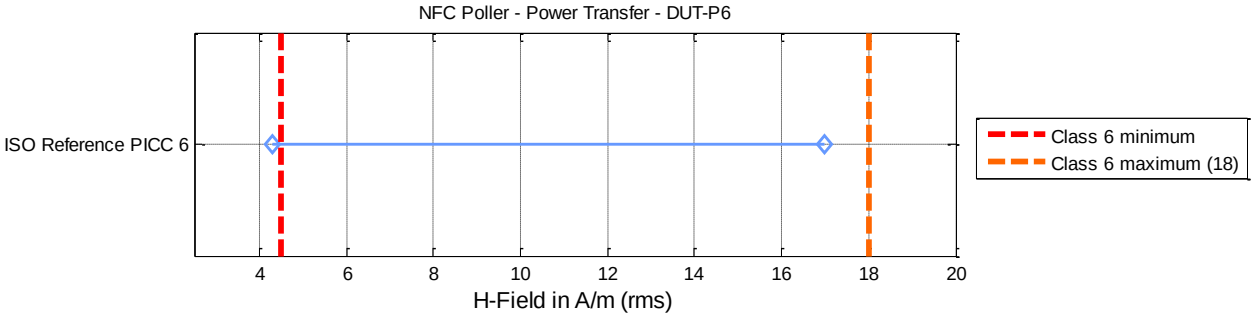


Figure 6: DUT Poller 6 field strength parameter comparison for Class 6 compliance/interoperability assessment.

Summary

The NFC Forum Reference Polling Devices have been chosen to emulate the relevant antenna size range observed in the field for NFC Devices. The comparison of the minimum and maximum limit of the field strength parameter between NFC Forum and ISO/IEC 14443 results in the following observations.

- The comparison has unveiled a good overlap between NFC Forum and ISO/IEC 14443 on the field strength parameter for a Polling Device independently of antenna size.
- The H_{min} and H_{max} limits as defined by both, NFC Forum and ISO/IEC 14443, permit to design an NFC Polling Device compliant to both specifications.
- NFC Forum cannot claim compliance and/or interoperability for the field strength parameter H_{min}.
- In particular the minimum limit of the field strength parameter for Class 1 - 3 is not always met antenna size independent by an NFC Forum Polling Device.

3.1.2 Requirement 4.4.2.1: Carrier Frequency fc (Polling Device Transmission)

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.4.2.1: The frequency of the Operating Field (carrier frequency) generated by the Polling Device SHALL be within the range of Min and Max values of fC. .
Implicit Requirement	Carrier Frequency Generation
Question	Is an NFC Forum Device in Poll mode which is compliant for the above Carrier Frequency requirement also compliant or interoperable to the corresponding ISO Requirement?
CONCLUSION / DISCUSSION	

	• For a comparison on specification level refer to Annex 0) ISO/IEC 14443-2 PCD Requirement for Carrier Frequency fc • No difference for this parameter on specification level • No experimental measurement needed.

3.1.3 Requirement 4.7.2.1: Listening Device Reset (Polling Device Transmission)

a. t_{FIELD_OFF}

CONTEXT	
Reference	[NFC_ACTIVITY]
Requirement	6.1.1.1 When the NFC Forum Device in Poll Mode sets the Operating Field to the Operating Field Off condition (carrier off, as defined in [ANALOG]) other than for NFC-A modulation purposes, then the Operating Field SHALL be set to Operating Field Off condition for a time of at least t_{FIELD_OFF}.
Implicit Requirement	Duration of Field Off
Question	Is an NFC Forum Device in Poll mode which is compliant for the above t_{FIELD_OFF} requirement also compliant or interoperable to the corresponding ISO Requirement?
CONCLUSION / DISCUSSION	
	This is not a parameter which is directly related to Analog. For an analysis on specification level refer to Annex 0 0)a. Timing and Duration $_{of}$ Reset No experimental measurement needed.

b. $V_{OV,RESET}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.7.2.1: When the NFC Forum – Reference Listening Device is within the Operating Volume of the Polling Device and the Polling Device resets the Operating Field, it SHALL generate a voltage less than or equal to Max $V_{0V,RESET}$ (rms) for a time t_{FIELD_OFF} defined by [ACTIVITY], characterized at the output of the sense coil on J4 of the NFC Forum – Reference Listening Device.
Implicit Requirement	Resetting the field
Question	Is an NFC Forum Device in Poll mode which is compliant for the maximum of the above power requirement also compliant or interoperable to the corresponding ISO PCD Requirement?
CONCLUSION / DISCUSSION	
	There is no equivalent parameter defined in ISO/IEC14443 No experimental measurement needed.

3.1.4 Requirement 4.9.2.1: Polling Device RF Collision Avoidance Before Carrier Generation

ISO/IEC18092 defines $H_{Threshold}$ = 0,1875A/m in order to distinguish between "Remote Field Present" and "No Remote Field". NFC Forum uses the $V_{s,thresh\ RF\ Collision\ Avoidance}$ for this purpose. This value is already aligned as stated in [NFC_ANA]. This means, $H_{Threshold}$ was setup using the Test PCD Assembly 1 and then measured with the NFC Forum Reference Listening Device. This measured value is used by NFC Forum for this parameter. Recently, the measurement methodology for the parameter and the Listening Device test case has been adapted to be performed in dependence of the actual Listening Device load.

Conclusion: No experimental measurement needed.

3.1.5 Requirements 5.1.2.1 to 5.1.2.7: Modulation Polling Device to Listening Device – NFC-A (Polling Device Transmission)

a. Waveform analysis

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[NFC_ANA]</td></tr>
<tr><td>Requirement</td><td>5.1.2.1-5.1.2.7:
When measured as described in the specification context above the Polling Device SHALL modulate the Operating Field in the Operating Volume in such a way that the signal monitored at the output J4 of the sense coil of the NFC Forum – Reference Listening Device or by means of an 8-shaped sensing coil as described in Appendix D has the following characteristics:
5.1.2.1 The time between V_4 of the falling edge and V_2 of the rising edge SHALL be t_1.
5.1.2.2 If V does not decrease monotonically with time from V_4 to V_2, the time between a local maximum and the time of passing the same value before the local maximum SHALL be t_5. This SHALL only apply if the local maximum is greater than V_2.
5.1.2.3 Ringing following the falling edge SHALL remain below $V_{OU,A}$ x V_1.
5.1.2.4 V SHALL remain less than V_2 for a time t_2.
5.1.2.5 V SHALL increase monotonically with time from V_2 to V_3 in a time t_4.
5.1.2.6 V SHALL increase monotonically with time from V_2 to V_4 in a time t_3.
5.1.2.7 Overshoots immediately following the rising edge SHALL remain within $(1\pm V_{OU,A})$ x V_1.
<table>
<tr><td rowspan="5">Modulation Poller→Listener (NFC-A)</td><td>t_1 (106kbps)</td><td></td><td>2.06</td><td>2.99</td><td rowspan="5">330 & 820</td><td>µs</td></tr>
<tr><td>t_2 (106kbps)</td><td></td><td>0.52</td><td>t_1</td><td>µs</td></tr>
<tr><td>t_3 (106kbps)</td><td></td><td>1.5 x t_4</td><td>1.18</td><td>µs</td></tr>
<tr><td>t_4 (106kbps)</td><td></td><td>0</td><td>0.44</td><td>µs</td></tr>
<tr><td>t_5 (106kbps)</td><td></td><td>0</td><td>0.50</td><td>µs</td></tr>
</table>
</td></tr>
<tr><td>Implicit Requirement</td><td>NFC-A Wave shape generation</td></tr>
</table>

Question	Is an NFC Forum Device in Poll mode which is compliant for the above NFC-A wave shape transmission requirement also compliant or interoperable to the corresponding ISO PCD Requirement?

CONCLUSION / DISCUSSION

For a comparison on specification level refer to Annex 0 0) a. Waveform analysis

Table 4: Conversion of NFC-A timing requirements from µs to 1/fc

Topic	Parameter	Value		R_L	Unit
		min	Max	Ω	
Modulation Poller→Listener (NFC-A)	t_1 (106kbps)	27.934	40.545	330 & 820	*1/fc*
	t_2 (106kbps)	7.050	t_1		
	t_3 (106kbps)	1.5 x t_4	16.001		
	t_4 (106kbps)	0	5.966		
	t_5 (106kbps)	0	6.780		

- ISO $t_{2,min}$ is defined in dependency of t_1. Not in NFC Forum
- NFC Forum has no symmetry requirement between the falling and rising edge of the modulation like ISO.

Generic observations:

- The Antenna size geometry and layout of NFC Forum and ISO/IEC 14443 Reference Equipment are identical.
- NFC Forum defines a fixed load for the Reference Listener versus ISO/IEC 14443 defines a field strength dependent load
- NFC Forum uses a single resonance frequency of 13.56MHz for the Reference Listeners. ISO/IEC 14443 defines different resonance frequencies dependent on the PCD test case. For the modulation index and waveform test case as defined in [ISO10373-6] the Reference PICC has to be tuned to 16.5 MHz. Additionally it is recommended to also test with resonance frequencies of 13.56 MHz and 15 MHz.

ISO/IEC 14443 adds a symmetry requirement for falling and rising edge of the modulation pulse as well as a requirement on the $t_{2,min}$ parameter as a function of t_1. Both requirements are not defined by neither NFC Forum nor EMVCo (Book D v2.6).

These definitions are considered to be of rather theoretical nature, which have no relevance for interoperability in the field. Based on the above analysis no substantial differences in the waveform measurement between NFC Forum and ISO/IEC 14443 are expected.

Conclusion: No experimental measurement needed.

b. Overshoot and Undershoot analysis

CONTEXT

Reference	[NFC_ANA]
Requirement	5.1.2.1-5.1.2.7: When measured as described in the specification context above the Polling Device SHALL modulate the Operating Field in the Operating Volume in such a way that the

<table>
<tr><td></td><td>signal monitored at the output J4 of the sense coil of the NFC Forum – Reference Listening Device or by means of an 8-shaped sensing coil as described in Appendix D has the following characteristics:
5.1.2.1 The time between V_4 of the falling edge and V_2 of the rising edge SHALL be t_1.
5.1.2.2 If V does not decrease monotonically with time from V_4 to V_2, the time between a local maximum and the time of passing the same value before the local maximum SHALL be t_5. This SHALL only apply if the local maximum is greater than V_2.
5.1.2.3 Ringing following the falling edge SHALL remain below $V_{OU,A}$ x V_1.
5.1.2.4 V SHALL remain less than V_2 for a time t_2.
5.1.2.5 V SHALL increase monotonically with time from V_2 to V_3 in a time t_4.
5.1.2.6 V SHALL increase monotonically with time from V_2 to V_4 in a time t_3.
5.1.2.7 Overshoots immediately following the rising edge SHALL remain within (1±$V_{OU,A}$) x V_1.
<table>
<tr><th>Topic</th><th>Parameter</th><th>Coil</th><th colspan="2">Value</th><th>R_L Ω</th><th>Units</th></tr>
<tr><th></th><th></th><th></th><th>Min</th><th>Max</th><th></th><th></th></tr>
<tr><td></td><td>$V_{OU,A}$ (106kbps)</td><td></td><td>0</td><td>$0 \le t_3 \le \frac{3}{f_c}$
$\Rightarrow \left(1-\frac{t_3}{2 \cdot t_{3\_max}}\right) \cdot 0.39$
$\frac{3}{f_c} \le t_3 \le \frac{6}{f_c}$
$\Rightarrow \frac{-y_1+y_2}{3/f_c} \cdot t_3 + 2y_1 - y_2$
$\frac{6}{f_c} \le t_3 \le t_{3\_max}$
$\Rightarrow \left(1-\frac{t_3}{2 \cdot t_{3\_max}}\right) \cdot 0.1$
with
$y_1 = \left(1-\frac{3/f_c}{2 \cdot t_{3\_max}}\right) \cdot 0.39$
$y_2 = \left(1-\frac{6/f_c}{2 \cdot t_{3\_max}}\right) \cdot 0.1$</td><td>330 & 820</td><td>-</td></tr>
</table>
<u>Maximum of overshoots:</u>
• t_3 = 0: OS_{max} = 39%
• t_3 = 3/fc: OS_{max} = 35.3%
• t_3 = 6/fc: OS_{max} = 8.1%
• t_3 = 16/fc: OS_{max} = 5%</td></tr>
<tr><td>Implicit Requirement</td><td>NFC-A Wave shape generation</td></tr>
<tr><td>Question</td><td>Is an NFC Forum Device in Poll mode which is compliant for the above NFC-A wave shape transmission requirement also compliant or interoperable to the corresponding ISO PCD Requirement?</td></tr>
<tr><td colspan="2">CONCLUSION / DISCUSSION</td></tr>
<tr><td></td><td>For a comparison on specification level refer to Annex 0 0) b. Overshoot and Undershoot analysis
NFC Forum pursues efforts on the OS/US limits definition for harmonization. The reason is a change in capturing the waveform with the 8-shaped coil instead of the sense coil of the NFC Forum Reference Listeners.
Conclusion: No experimental measurement needed.
See 3.1.5) 0) for further considerations including test equipment and test case.</td></tr>
</table>

3.1.6 Requirements 5.3.2.1 to 5.3.2.6: Modulation Polling Device to Listening Device – NFC-B (Polling Device Transmission)

a. Waveform analysis

CONTEXT	
Reference	[NFC_ANA]
Requirement	5.3.2.1 - 5.3.2.16: When measured as described in the specification context above, the Polling Device SHALL modulate the Operating Field in the Operating Volume in such a way that the signal measured at the output J4 of the sense coil of the NFC Forum – Reference Listening Device or by means of an 8-shaped sensing coil as described in Appendix D has the following characteristics: 5.3.2.1 The modulation index (mi) of the signal SHALL be $mod_{i,B}$. 5.3.2.2 V SHALL decrease from V_3 to V_4 (i.e., the falling edge) in a time $t_{f,B}$. 5.3.2.3 V SHALL increase from V_4 to V_3 (i.e., the rising edge) in a time $t_{r,B}$. 5.3.2.4 The rising and falling edges of the modulation SHALL be monotonic with time. 5.3.2.5 Overshoots and undershoots following the falling edge (hf) SHALL be less than $V_{OU,B}$ x (V_a-V_b). 5.3.2.6 Overshoots and undershoots following the rising edge (hr) SHALL be less than $V_{OU,B}$ x (V_a-V_b).

Modulation Poller→Listener (NFC-B)	$mod_{i,B}$ (106kbps)		8	15	330 & 820	%
	$t_{f,B}$ (106kbps)		0	1.18		µs
	$t_{r,B}$ (106kbps)		Maximum of 0 and $t_{f,B}$-0.59	Minimum of 1.18 and 0.59+$t_{f,B}$		µs

Implicit Requirement	NFC-B Wave shape generation
Question	Is an NFC Forum Device in Poll mode which is compliant for the above NFC-B wave shape transmission requirement also compliant or interoperable to the corresponding ISO PCD Requirement?
CONCLUSION / DISCUSSION	
	For a comparison on specification level refer to 0 0) a. Waveform analysis Conclusion: No experimental measurement needed. See 3.1.5) 0) for further considerations including test equipment and test case.

b. Overshoot and Undershoot analysis

CONTEXT	
Reference	[NFC_ANA]
Requirement	5.3.2.1 - 5.3.2.16: When measured as described in the specification context above, the Polling Device SHALL modulate the Operating Field in the Operating Volume in such a way that the signal measured at the output J4 of the sense coil of the NFC Forum – Reference Listening Device or by means of an 8-shaped sensing coil as described in Appendix D has the following characteristics: 5.3.2.1 The modulation index (mi) of the signal SHALL be $mod_{i,B}$.

5.3.2.2 V SHALL decrease from V_3 to V_4 (i.e., the falling edge) in a time $t_{f,B}$.
5.3.2.3 V SHALL increase from V_4 to V_3 (i.e., the rising edge) in a time $t_{r,B}$.
5.3.2.4 The rising and falling edges of the modulation SHALL be monotonic with time.
5.3.2.5 Overshoots and undershoots following the falling edge (hf) SHALL be less than $V_{OU,B}$ x (V_a-V_b).
5.3.2.6 Overshoots and undershoots following the rising edge (hr) SHALL be less than $V_{OU,B}$ x (V_a-V_b).
Values:

Topic	Parameter	Coil	Value		RL	Units
			Min	Max	Ω	
Modulation: Poller→Listener	$V_{OU,B}$ (106kbps)		0	$0 \le t_{r,B} \le \frac{3}{f_c} \Rightarrow \left(1-\frac{t_{r,B}}{2 \cdot t_{r,B\_max}}\right) \cdot 0.39$ $\frac{3}{f_c} \le t_{r,B} \le \frac{6}{f_c} \Rightarrow \frac{-y_1+y_2}{3/f_C} \cdot t_{r,B} + 2y_1 - y_2$ $\frac{6}{f_c} \le t_{r,B} \le t_{r,B\_max} \Rightarrow \left(1-\frac{t_{r,B}}{2 \cdot t_{r,B\_max}}\right) \cdot 0.1$ Or $0 \le t_{f,B} \le \frac{3}{f_c} \Rightarrow \left(1-\frac{t_{f,B}}{2 \cdot t_{f,B\_max}}\right) \cdot 0.39$ $\frac{3}{f_c} \le t_{f,B} \le \frac{6}{f_c} \Rightarrow \frac{-y_1+y_2}{3/f_C} \cdot t_{f,B} + 2y_1 - y_2$ $\frac{6}{f_c} \le t_{f,B} \le t_{f,B\_max} \Rightarrow \left(1-\frac{t_{f,B}}{2 \cdot t_{f,B\_max}}\right) \cdot 0.1$ With $y_1 = \left(1-\frac{3/f_C}{2 \cdot t_{r/f,B\_max}}\right) \cdot 0.39$ $y_2 = \left(1-\frac{6/f_C}{2 \cdot t_{r/f,B\_max}}\right) \cdot 0.1$	330 & 820	V

<u>Maximum of overshoots:</u>

- $t_{f/r}$ = 0: OS_{max} = 39%
- $t_{f/r}$ = 3/fc: OS_{max} = 35.3%
- $t_{f/r}$ = 6/fc: OS_{max} = 8.1%
- $t_{f/r}$ = 16/fc: OS_{max} = 5%

Implicit Requirement	NFC-B Wave shape generation
Question	Is an NFC Forum Device in Poll mode which is compliant for the above NFC-B wave shape transmission requirement also compliant or interoperable to the corresponding ISO PCD Requirement?

CONCLUSION / DISCUSSION

For a comparison on specification level refer to Annex 0 0) b. Overshoot and Undershoot analysis.
Conclusion: No experimental measurement needed.
See 3.1.5) 0) for further considerations including test equipment and test case.
NFC Forum pursues efforts on the OS/US limits definition for harmonization.
The reason is a change in capturing the waveform with the 8-shaped coil instead of the sense coil of the NFC Forum Reference Listeners.

3.1.7 Requirements 5.5.2.1 to 5.5.2.6: Modulation Polling Device to Listening Device – NFC-F (Polling Device Transmission)

No experimental measurement needed. Covered by NFC-B analysis.

3.1.8 Requirement 6.5.2.1: Modulation Listening Device to Polling Device (Polling Device Reception)

a. $V_{PP,min}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.5.2.1: For NFC-A, NFC-B, and NFC-F, the Polling Device SHALL function properly with the NFC Forum – Reference Listening Device placed in its Operating Volume, provided the NFC Forum – Reference Listening Device has been set up as described in the specification context above.
Implicit Requirement	Minimum load modulation amplitude
Question	Is an NFC Forum Device in Poll mode which is compliant for the above minimum load modulation requirement also compliant or interoperable to the corresponding minimum ISO PCD Requirement?

PROCEDURE	
Step	**SETUP**
NFC Setup 1	Setup the DUT P0 power to exactly ISO H_{min} when measured in the whole ISO OV (H_{min} must be measured in exactly one point of the OV. All other positions shall have the same or a higher value). The NFC max power shall not be exceeded in the whole NFC OV using NFC Forum – Reference Listeners. Record the measured V_{OV} in the whole NFC OV with each NFC Forum – Reference Listener set to 820 Ω (min power setup). *Note 1: NFC Forum max power has to be measured with NFC Forum – Reference Listeners 1, 3, 6. The ISO min field strength is split into 3 experiments: In the first the setup is done with ISO Reference PICC 1, 2, 3. In the second setup is done only with ISO Reference PICC 1, 2, 3 and 6 and in the third setup is done with ISO Reference PICC 6.*
2	Place the NFC Forum – Reference Listener 1 (820 Ω) in NFC OV – 100 of the NFC Forum – Reference Poller 0 and setup the minimum measured V_{OV} as recorded in step 1. Set NFC Forum – Reference Listener 1 to transmit min LMA ($V_{S,PP,min}$) with 330Ω loading at (100-NFC OV) of NFC Forum – Reference Poller 0. *Note: min LMA for L1, L3 and L6 is always setup with NFC Forum – Reference Poller 0*

		Topic	Parameter	Coil	Value Min	RL Ω	Units
		Load Modulation (NFC-A, NFC-B, NFC-F)	$V_{s,pp}$ with Poller 0	**Listener-1**	18	330	mV_{pp}
				Listener-3	26	330	mV_{pp}
				Listener-6	26	330	mV_{pp}
3	Move the NFC Forum – Reference Listener 1 in whole NFC OV of DUT P0 and measure the LMA at J2 of DUT P0. Record the measured V_{OV} (Listener with 330Ω load), the minimum LMA and the position.						
4	Repeat steps 2) and 3) for NFC Forum – Reference Listener 3 and 6.						
4b	Search the minimum LMA of the DUT Poller amongst all NFC Forum – Reference Listener. *Note: It is assumed that the DUT Poller sensitivity is the value of the global min LMA independent on the Reference Listener antenna size and field strength seen by the Reference Listener.*						
5	Repeat steps 1) – 4) setting up the DUT Poller to the $V_{OV,max}$ in step 1. *Note: Care should be taken to be within H_{min} and H_{max} of ISO for a) classes 1-3, b) class 1-3 and class 6 and c) Class 6 only.*						
6	Repeat steps 1) - 5) for DUT P3 and DUT P6.						
8 ISO SETUP:	Tune the resonance frequency of each of the ISO Reference PICC 1, 2, 3 and 6 to 13,56 MHz.						
Step	**VERIFICATION**						
1	For each position of the ISO OV perform the steps below: Place the ISO Reference PICC 1 in each position of the complete ISO OV of the DUT P0 and adjust the load so that the voltage measured at CON3 matches the V_{load} value defined in Table 21.						
2	Increase the amplitude of the load modulation of the ISO Reference PICC 1 until the min value for the position (see setup step 4b) measured by the DUT P0 J2 output is reached.						
3	Place the ISO Reference PICC 1 in the DUT position of the respective Test PCD assembly and adjust the field strength until the value defined in Table 21 is measured at CON3.						
4	Read the field strength measured at the calibration coil.						
5	Measure the load modulation amplitude.						
6	Repeat the VERIFICATION steps 1-5 for ISO Reference PICC 2, 3 and 6.						
7	Repeat VERIFICATION steps 1-6 for DUT P3 and DUT P6.						
8	Repeat VERIFICATION procedure step 1-7 for each of the Reference PICCs 1, 2, 3 and 6 tuned to 15 MHz resonance frequency.						
EXPECTED OUTCOME							
Step	**COMPLIANCY**						
1	Compare the measured LMA and field strengths of VERIFICATION step 4 and 5 to the ISO PCD limits of Table 24.						
Step	**INTEROPERABILITY**						
1	Compare the measured LMA and field strengths of VERIFICATION step 4 and 5 to the ISO PICC limits of [ISO14443-2].						

NFC Forum Poller 0 as DUT: Load modulation reception

This section contains the result for a DUT P0 emulating a DUT with the largest considered antenna size if claiming compliance to ISO/IEC 14443 on load modulation reception and LMA_{min} ($V_{PP,\,min}$). The LMA parameter and Polling device reception comparison to ISO/IEC 14443 can be mainly divided into three parts. The first part is the determination of the minimum load modulation amplitude a DUT Poller must be able to receive if tested according to NFC Forum. NFC Forum measures only the AM component of the load modulation signal. In the second step the ISO Reference PICCs are each placed in the OV of the DUT. For each position the load is adjusted and the load modulation amplitude is set to the minimum limit value defined by NFC Forum. Finally in the third step, the field strength condition is re-established on the Test PCD Assembly and the LMA measured using the DFT method. The measured LMA value is compared to the field strength dependent defined PCD limit value.

For each DUT Polling Device the compliance comparison is performed to Class 1-3 and afterwards to Class 6.

DUT-P0 load modulation reception and compliance to PICC class 1 – 3

Figure 7 shows the compliance results to Class 1 - 3 for the LMA_{min} for DUT P0. Results are plotted as side band amplitudes, which is basically the LMA, versus field strength. The limit curves as defined by ISO/IEC 14443 are plotted as: The EMD limit is depicted in orange colour and a dashed line with plus signs. The Class1 PCD limit is shown in red dashed line with diamond and the Class 2 – 3 limit curve is shown as rose dashed line with plus signs. The LMA_{min} or Poller sensitivity is Reference PICC dependent. Figure 7 plots the results for each Reference PICC in different colours:

- black colour: Reference PICC 1 and 13.56 MHz resonance frequency (f_{RES})
- dark blue colour: Reference PICC 1 and f_{RES} of 15.00 MHz
- violet colour: Reference PICC 2 and f_{RES} of 13.56 MHz
- grey colour: Reference PICC 2 and f_{RES} of 15.00 MHz
- light blue colour: Reference PICC 3 and f_{RES} of 13.56 MHz
- green colour: Reference PICC 3 and f_{RES} of 15.00 MHz

Lower side band (LSB) amplitude results are marked with crosses and upper side band (USB) amplitude results with diamonds.

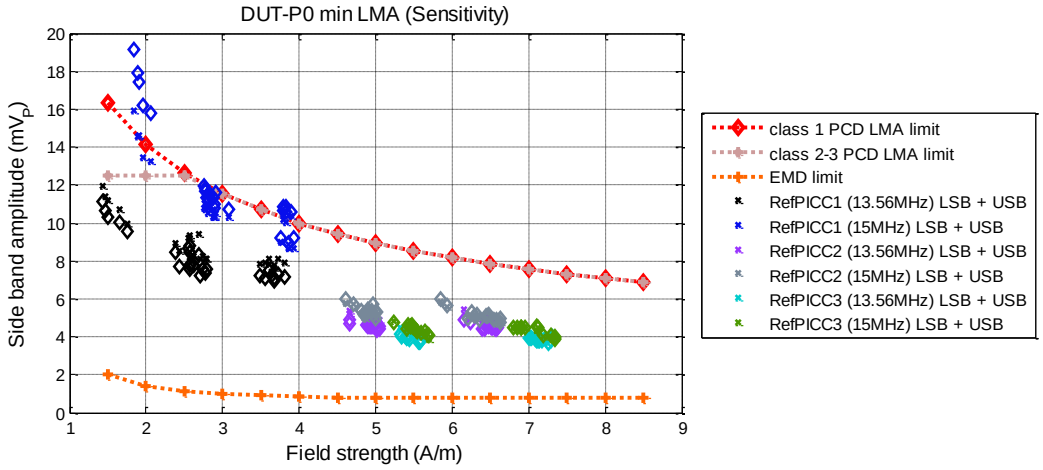


Figure 7: DUT-Poller 0 compliance to PICC class 1 – 3

Compliance is given for DUT P0 in case that all results are equal to or lower than the Class 1 -3 PCD limit curves and higher than the EMD limit curve. This condition is mostly fulfilled, except for Reference PICC 1 tuned to 15 MHz and Class 1 and Class 2-3 limit curves at low field strengths. The main reason for this shortcoming is seen in the LMA AM measurement of NFC Forum during the adjustment phase of Verification Step 2 above. For a resonance frequency tuning to 15MHz a higher amount of LMA signal information is contained in the phase component, therefore the LMA input drive has to be increased extraordinary in order to reach the minimum AM level. This is confirmed by the Reference PICC 1 with a resonance frequency of 13.56MHz. The results for this Reference equipment at similar field strength are well below the limit curve.

DUT-P0 load modulation reception and compliance to PICC class 6

Figure 8 shows the results if claiming compliance to Class 6 and LMA_{min}. In contrast to Class 1 – 3, Class 6 results are measured on the Test PCD Assembly 2 [ISO10373-6:AMD1]. Also in this plot the limit curve for this class is plotted in red and the EMD limit in orange colour. Reference PICC 6 results for 13.56 MHz resonance frequency tuning are plotted in black colour and results for the 15 MHz tuning are shown in dark blue colour. Lower side band (LSB) amplitude results are marked with crosses and upper side band (USB) amplitude results with diamonds.

The same conclusions as presented in the last section (Class 1 - 3) are also valid for this section.

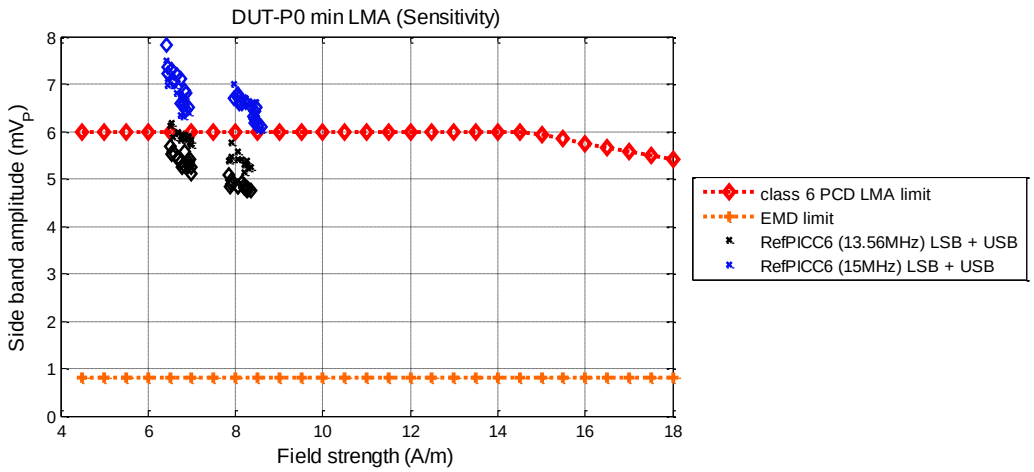


Figure 8: DUT-Poller 0 compliance to PICC class 6

NFC Forum Poller 3 as DUT: Load modulation reception

This section contains the result for a DUT P3 emulating a DUT with a medium antenna size if claiming compliance to ISO/IEC 14443 on load modulation reception and LMA_{min}.

For each DUT Polling Device the compliance comparison is performed to Class 1-3 and afterwards to Class 6.

DUT-P3 load modulation reception and compliance to PICC class 1 – 3

Results as presented in Figure 9 follow the same principle and colour coding as described in the result section above for DUT P0 and Figure 7. Moreover, also compliance assessment is identical. The same interpretations on the result verdict as for DUT P0 are applicable for DUT P3. The majority of results are equal to or below the PCD limit curve as defined for Class 1 and Class2-3, respectively. Again for Reference PICC 1 tuned to 15 MHz the PCD limit curve at low field strength

is exceeded. The main reason for this behaviour is due to the LMA measurement method difference between NFC Forum and ISO/IEC 14443.

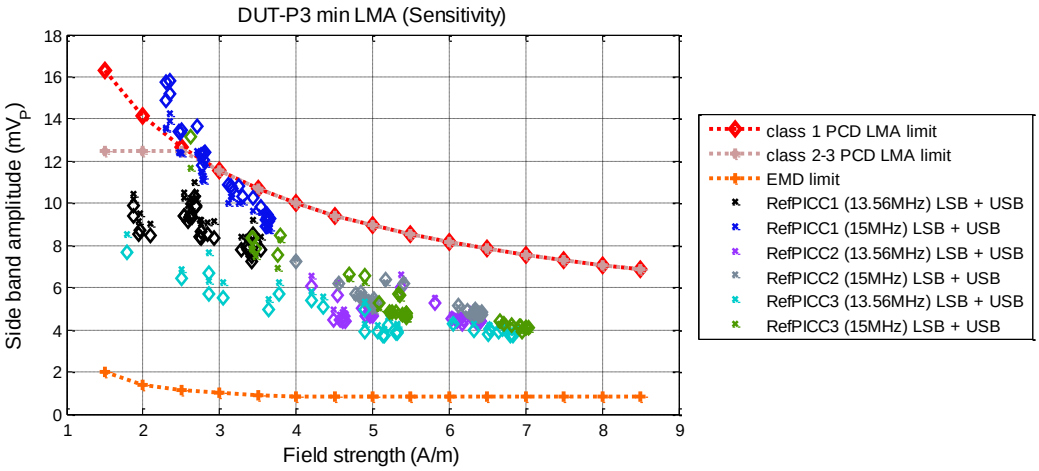


Figure 9: DUT-Poller 3 compliance to PICC class 1 – 3

DUT-P3 load modulation reception and compliance to PICC class 6

Figure 10 shows the results if claiming compliance to Class 6. In contrast to Class 1 – 3, Class 6 results are measured on Test PCD Assembly 2. Also in this plot the limit curve for this class is plotted in red and the EMD limit in orange colour. Reference PICC 6 results for 13.56 MHz resonance frequency tuning are plotted in black colour and results for the 15 MHz tuning are shown in dark blue colour. Lower side band (LSB) amplitude results are marked with crosses and upper side band (USB) amplitude results with diamonds.

All results are below the PCD limit curve and above the EMD limit curve. Compliance can be claimed.

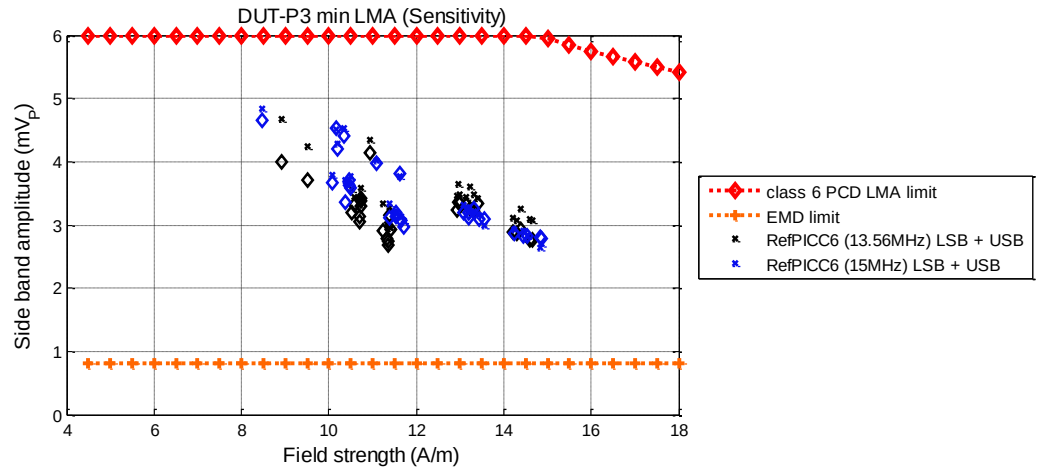


Figure 10: DUT-Poller 3 compliance to PICC class 6

NFC Forum Poller 6 as DUT: Load modulation reception

This section contains the result for a DUT P6 is emulating a DUT with a small antenna size if claiming compliance to ISO/IEC 14443 on load modulation reception.

For each DUT Polling Device the compliance comparison is performed to Class 1-3 and afterwards to Class 6.

DUT-P6 load modulation reception and compliance to PICC class 1 – 3

Results as presented in Figure 11 follow the same principle and colour coding as described in the result section above for DUT P0 and Figure 7. Moreover, also compliance assessment is identical. The same interpretations on the result verdict as for DUT P0 are applicable for DUT P6. The majority of results are equal to or below the PCD limit curve as defined for Class 1 and Class2-3, respectively. Again for Reference PICC 1 tuned to 15 MHz the PCD limit curve at low field strength is exceeded. The main reason for this behaviour is due to the LMA measurement method difference between NFC Forum and ISO/IEC 14443. This is evident if comparing to the Reference PICC 1 results when tuned to 13.56 MHz.

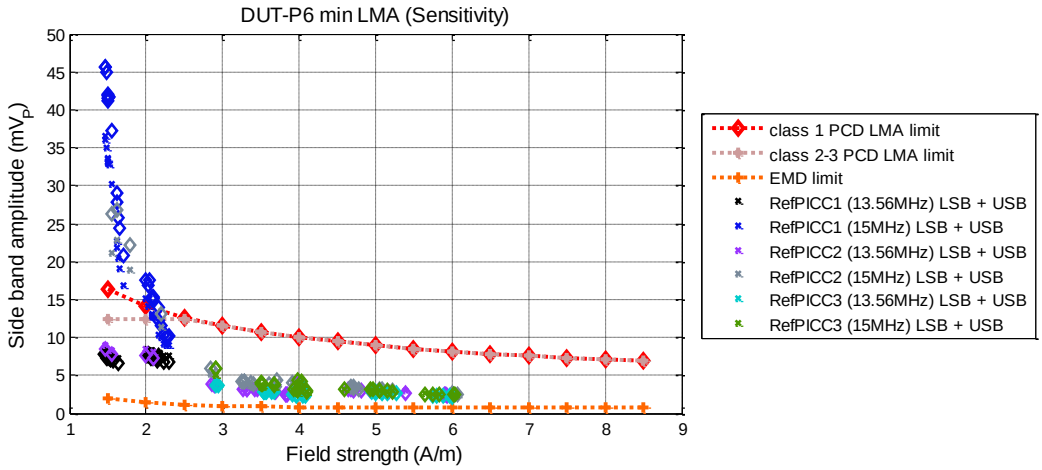


Figure 11:DUT-Poller 6 compliance to PICC class 1 – 3

DUT-P6 load modulation reception and compliance to PICC class 6

Figure 12 shows the results if claiming compliance to Class 6. In contrast to Class 1 – 3, Class 6 results are measured on Test PCD Assembly 2. Also in this plot the limit curve for this class is plotted in red and the EMD limit in orange colour. Reference PICC 6 results for 13.56 MHz resonance frequency tuning are plotted in black colour and results for the 15 MHz tuning are shown in dark blue colour. Lower side band (LSB) amplitude results are marked with crosses and upper side band (USB) amplitude results with diamonds.

All results are below the PCD limit curve and above the EMD limit curve. Compliance can be claimed.

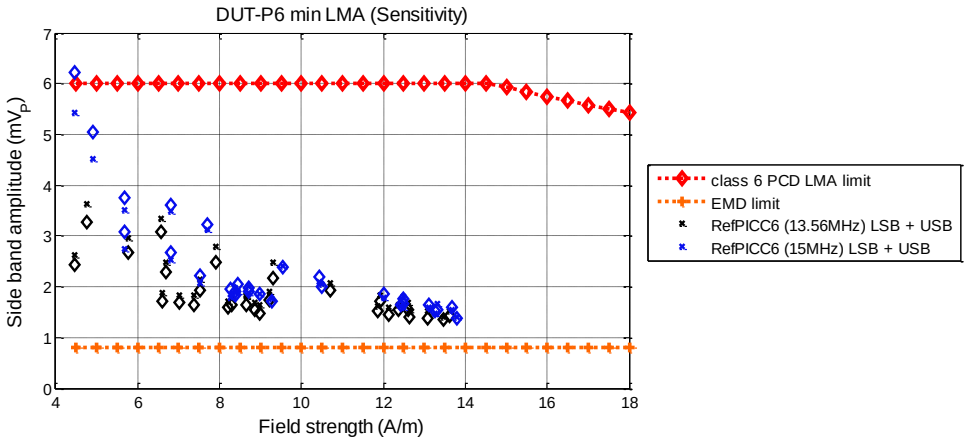


Figure 12: DUT-Poller 6 compliance to PICC class 6

Summary on Compliance

This section provides a summary on a DUT Poller claiming compliance to ISO/IEC 14443 on load modulation reception for LMA_{min}. A high level verdict summary on compliance is presented in Table 5. This table contains for each DUT Poller and each Reference PICC and resonance frequency tuning a compliance verdict. In general the results have shown that NFC Forum requires a higher sensitivity from a Polling device compared to ISO/IEC 14443. A strict analysis of the results shows that compliance for the resonance frequency of 15 MHz and mainly Reference PICC 1 at low field strength is not met. However, a more detailed analyses shows that the root cause for this result mainly comes from the different methods for measuring the LMA in NFC Forum and ISO/IEC 14443. Additionally the sensitivity level at low field strength for the Reference PICC 1 and a tuning to 13.56MHz has shown a sensitivity level below the PCD limit curve as defined by [ISO14443-2]. For this reason the common understanding of the group is that interoperability can be claimed for LMA_{min} and Polling Device reception. ISO WG8 is currently working on an improvement on requirements and test methods for PICC transmission and PCD reception, which is not covered by this harmonization work and will be covered by future alignment work.

Table 5: Summary: DUT Poller and Load modulation reception compliance on LMA_{min}

	Reference PICC		DUT-P0	DUT-P3	DUT-P6
	-	f_{res}(MHz)			
Compliance	1	13.56	YES	YES	YES
		15.00	NO	NO	NO
	2	13.56	YES	YES	YES
		15.00	YES	YES	NO
	3	13.56	YES	YES	YES
		15.00	YES	YES	YES
	6	13.56	YES	YES	YES
		15.00	NO	YES	YES

b. $V_{PP,max}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.5.2.1: For NFC-A, NFC-B, and NFC-F, the Polling Device SHALL function properly with the NFC Forum – Reference Listening Device placed in its Operating Volume, provided the NFC Forum – Reference Listening Device has been set up as described in the specification context above.
Implicit Requirement	Maximum load modulation amplitude
Question	Is an NFC Forum Device in Poll mode which is compliant for the above maximum load modulation requirement also compliant or interoperable to the corresponding maximum ISO PCD Requirement?

PROCEDURE

Step	SETUP
NFC Setup 1	Setup the DUT P0 power to exactly ISO H_{min} when measured in the whole ISO OV (H_{min} must be measured in exactly one point of the OV. All other positions shall have the same or higher value). The NFC max power shall not be exceeded in the whole NFC OV using NFC Forum – Reference Listeners. Record the measured V_{OV} in the whole NFC OV with each NFC Forum – Reference Listener set to 820 Ω (min power setup). *Note 1: NFC Forum max power has to be measured with NFC Forum – Reference Listeners 1, 3, 6. The ISO min field strength is split into 3 experiments: In the first the setup is done with ISO Reference PICC 1, 2, 3. In the second setup is done only with ISO Reference PICC 1, 2, 3 and 6 and in the third setup is done with ISO Reference PICC 6.*
2	Place the NFC Forum – Reference Listener 1 (820 Ω) in NFC OV – 100 of the NFC Forum – Reference Poller and setup to the maximum V_{OV} as recorded in step 1. Setup the NFC Forum – Reference Listener 1 to transmit max LMA with 330Ω loading at (100-NFC OV) on the respective NFC Forum – Reference Poller. *Note: for max LMA setup the following Reference Equipment configurations are used: P0-L1, P3-L3, P6-L6*
3	Move NFC Forum – Listener 1 in whole NFC OV of DUT P0 and measure the LMA at J2 of DUT P0. Record the measured V_{OV} (Listener with 330Ω load), the maximum LMA and the position.
4	Repeat steps 2) and 3) for NFC Forum – Reference Listener 3 and 6. *Note: In step 2) the according NFC Forum – Reference Poller has to be used.*
5	Search the maximum LMA of the DUT Poller amongst all NFC Forum – Reference Listener.

Topic	Parameter	Coil	Value Max	RL Ω	Units
Load Modulation (NFC-A, NFC-B, NFC-F)	$V_{S,pp}$	Poller0 with Listener-1	114	330	mV_{pp}
		Poller3 with Listener-3	54		
		Poller6 with Listener-6	90		

	Note: It is assumed that the DUT Poller maximum is the value of the global max LMA independent on the Reference Listener antenna size and field strength seen by the Reference Listener.
6	Repeat steps 1) – 4) setting up the DUT Poller to the $V_{OV,max}$ in step 1. *Note: Care should be taken to be within H_{min} and H_{max} of ISO for a) classes 1-3, b) class 1-3 and class 6 and c) Class 6 only.*
7	Repeat steps 1) - 6) for DUT P3 and DUT P6.
8 ISO SETUP	Tune the resonance frequency of each of the ISO Reference PICC 1, 2, 3 and 6 to 13,56 MHz.
Step	**VERIFICATION**
1	For each position of the ISO OV perform the steps below: Place the ISO Reference PICC 1 in each position of the compete ISO OV of the DUT P0 and adjust the load measured at CON3 to the value defined in Table 21.
2	Increase the amplitude of the load modulation of the ISO Reference PICC 1 until the max value measured by the DUT P0 J2 output for this position (see setup step 5) is reached.
3	Place the ISO Reference PICC 1 in the DUT position of the respective Test PCD assembly and adjust the field strength until the value defined in Table 21 is measured at CON3.
4	Read the field strength measured at the calibration coil.
5	Measure the load modulation amplitude.
6	Repeat the VERIFICATION steps for ISO Reference PICC 2, 3 and 6.
7	Repeat VERIFICATION steps 1-6 for DUT P3 and DUT P6.
8	Repeat VERIFICATION procedure 1-7 for each of the Reference PICCs 1, 2, 3 and 6 tuned to 15 MHz resonance frequency.

EXPECTED OUTCOME		
Step	**COMPLIANCY**	
1	n.a.	
Step	**INTEROPERABILITY**	
1	n.a.	
RESULT		
	n.a.	**Verdict** **Interoperability** / **Compliancy**
CONCLUSION / DISCUSSION		
	[ISO14443-2] does not define maximum LMA limit. Thus this procedure is seen as an input for further discussions.	

3.2 Listening Device Requirements

This section contains the procedure and comparison results for the following parameter limits:

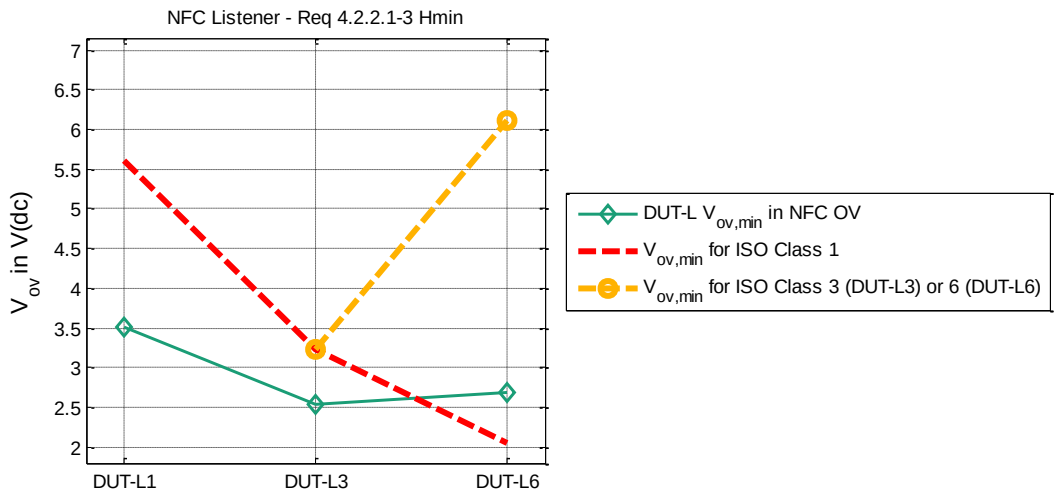
- Power Transfer from Polling Device to Listening Device (Listening Device Reception)
  - Minimum field strength
  - Maximum field strength
- Influence of the Listening Device on the Operating Field
- Listening Device Reset (Listening Device Reception)
- Modulation Polling Device to Listening Device – NFC-A (Listening Device Reception)
  - Waveform Analysis
  - Overshoot and Undershoot analysis
- Modulation Polling Device to Listening Device – NFC-B (Listening Device Reception)
  - Waveform Analysis
  - Overshoot and Undershoot analysis
- Modulation Listening Device to Polling Device (Listening Device Transmission)
  - Minimum load modulation amplitude
  - Maximum load modulation amplitude

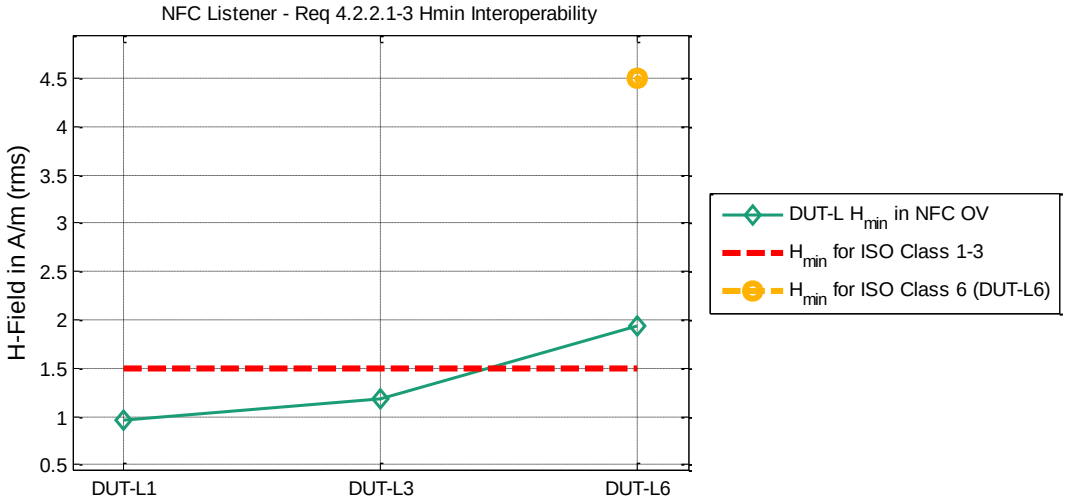
3.2.1 Requirements 4.2.2.1 & 4.2.2.2 & 4.2.2.3: Power Transfer from Polling Device to Listening Device (Listening Device Reception)

a. Minimum field strength

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.2.2.1-4.2.2.3: 4.2.2.1 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-A. See Section 3.4 for definition of “function properly”. 4.2.2.2 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-B. 4.2.2.3 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-F.
Implicit Requirement	Minimum power reception
Question	Is an NFC Forum Device in Listen mode which is compliant for the above minimum power reception requirement also compliant or interoperable to the corresponding minimum ISO PICC Requirement?

PROCEDURE	
Step	SETUP
1 NFC Setup:	Setup the 3 NFC Forum – Reference Pollers to generate listener minimum field strength with NFC Forum – Reference Listener 1 at (100 – NFC OV).

		Topic	Param	Coil	Value Min	RL Ω	Units	
		Power transfer: Poller→Listener	$V_{S,OV}$ Set up using Listener-1	Poller-0	4.70	820	V	
				Poller-3	4.24		V	
				Poller-6	3.73		V	
2	Measure V_{DC} output of the DUT L1, DUT L3 and DUT L6 (820 Ω) in the whole NFC OV of each of the 3 NFC Forum – Reference Pollers and note the lowest value found for each DUT Listener.							
3 ISO Setup:	Adjust the RF power delivered by the signal generator to the ISO test PCD antenna to the H_{min} (see Table 25) as measured by the calibration coil. *Note: Use the according Test PCD Assembly as defined for the PICC Class.*							
4	Place each of the DUT L1, DUT L3 and DUT L6 (820 Ω) in the DUT position of the ISO Test PCD Assembly. If necessary readjust the H-field to H_{min} (see Table 25) as measured by the calibration coil.							
Step	**VERIFICATION**							
1	Measure V_{DC} output of each DUT L1, DUT L3 and DUT L6 and note the values.							
EXPECTED OUTCOME								
Step	**COMPLIANCY**							
1	Compare the lowest values found in VERIFICATION on the ISO Test PCD Assembly to the lowest value found in SETUP step 2) on the 3 NFC Forum Reference Pollers for each NFC Forum Reference Listener.							
Step	**INTEROPERABILITY**							
1	Interoperability is compliance. No margin defined between PCD and PICC in ISO/IEC 14443.							
RESULT								
	Compliance:  Verdict: DUT-L is compliant if equal to or below the red/yellow (Class dependent) dotted line.							

	Interoperability:  Verdict: DUT-L is interoperable if equal to or below the red/yellow (Class dependent) dotted line.

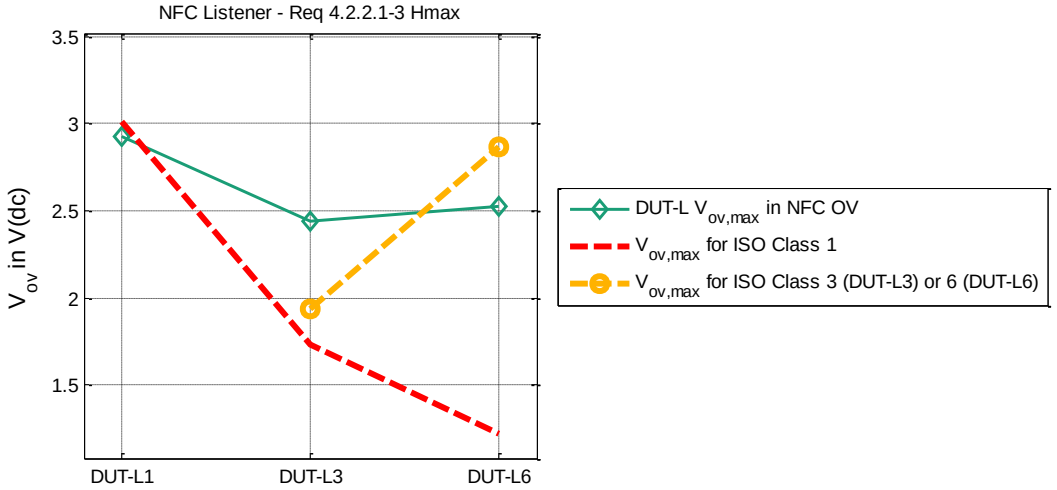
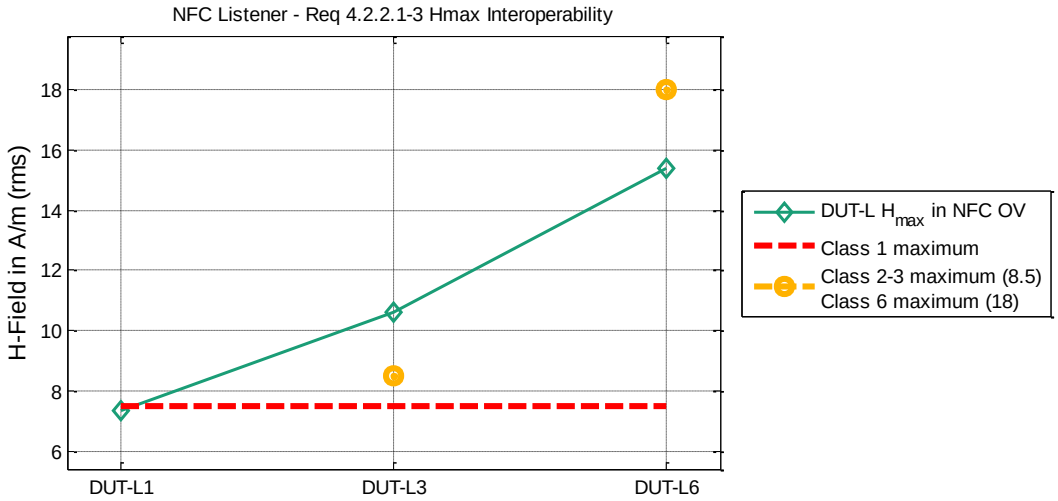
Overall verdict	DUT-L1	DUT-L3	DUT-L6
DUT can claim ISO Class 1 compliance	OK	OK	KO
DUT can claim ISO Class 3 compliance	n/a	OK	n/a
DUT can claim ISO Class 6 compliance	n/a	n/a	OK

CONCLUSION / DISCUSSION	
	Conclusions are discussed in section 3.2.1 0).

b. Maximum field strength

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.2.2.1-4.2.2.3: 4.2.2.1 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-A. See Section 3.4 for definition of “function properly”. 4.2.2.2 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-B. 4.2.2.3 A Listening Device SHALL function properly within the Operating Volume of the NFC Forum – Reference Polling Device when the operating conditions have been established as described in the specification context above for NFC-F.
Implicit Requirement	Maximum power reception
Question	Is an NFC Forum Device in Listen mode which is compliant for the above maximum power reception requirement also compliant or interoperable to the corresponding maximum ISO PICC Requirement?

<table>
<tr><th colspan="2">PROCEDURE</th></tr>
<tr><td>Step</td><td>SETUP</td></tr>
<tr><td>1 NFC Setup</td><td>Setup each of the 3 NFC Forum – Reference Pollers to generate listener maximum field strength with the respective NFC Forum – Reference Listener at (100 – NFC OV).
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th>RL</th><th rowspan="2">Units</th></tr>
<tr><th>Max</th><th>Ω</th></tr>
<tr><td rowspan="3">Power transfer: Poller→Listener</td><td rowspan="3">$V_{S,OV}$</td><td>Listener-1</td><td>2.84</td><td rowspan="3">82</td><td>V</td></tr>
<tr><td>Listener-3</td><td>2.22</td><td>V</td></tr>
<tr><td>Listener-6</td><td>1.82</td><td>V</td></tr>
</table></td></tr>
<tr><td>2</td><td>Measure V_{DC} output of the 3 NFC Forum – Reference Listeners (82 Ω load) in the whole NFC OV of each of the 3 NFC Forum – Reference Pollers and note the highest value found for each NFC Forum – Reference Listener.</td></tr>
<tr><td>3 ISO Setup:</td><td>Adjust the RF power delivered by the signal generator to the ISO Test PCD Assembly to the H_{max} (see Table 25) as measured by the calibration coil with the DUT in the field.
Note: Use the according Test PCD Assembly as defined for the PICC Class.
Note: This test assumes that the maximum loading test was PASS.</td></tr>
<tr><td>4</td><td>Place each of the DUT L1, DUT L3 and DUT L6 (82 Ω) in the DUT position of the ISO Test PCD Assembly. If necessary readjust the H-field to H_{max} (see Table 25) as measured by the calibration coil.
Note: Perform this step for DUT L6 with both, Test PCD Assembly 1 and 2.</td></tr>
<tr><td>Step</td><td>VERIFICATION</td></tr>
<tr><td>1</td><td>Measure V_{DC} output of each DUT L1, DUT L3 and DUT L6 (82 Ω loading) and note the values.</td></tr>
<tr><th colspan="2">EXPECTED OUTCOME</th></tr>
<tr><td>Step</td><td>COMPLIANCY</td></tr>
<tr><td>1</td><td>Compare the highest value found in VERIFICATION on the ISO Test PCD Assembly to the highest value found in SETUP step 2) on the 3 NFC Forum Reference Pollers for each NFC Forum Reference Listener.</td></tr>
<tr><td>Step</td><td>INTEROPERABILITY</td></tr>
<tr><td>1</td><td>Interoperability is compliance. No margin defined between PCD and PICC in ISO/IEC 14443.</td></tr>
</table>

RESULT	
	Compliance:  Verdict: DUT-L is compliant if equal to or above the red/yellow (Class dependent) dotted line. **Interoperability:**  Verdict: DUT-L is interoperable if equal to or above the red/yellow (Class dependent) dotted line. **Overall verdict** / **DUT-L1** / **DUT-L3** / **DUT-L6** *DUT can claim ISO Class 1 compliance* / KO / OK / OK *DUT can claim ISO Class 3 compliance* / n/a / OK / n/a *DUT can claim ISO Class 6 compliance* / n/a / n/a / KO
CONCLUSION / DISCUSSION	
	Conclusions are discussed in the next section

c. Minimum and Maximum Field strength results

In this section the field strength operating range in its entirety is analysed. This step is taken to assess the overlap of the field strength range depending on the Listening Device antenna size. Depending on the actual antenna size a DUT PICC in ISO/IEC14443 can claim to meet requirements of a particular Class or alternatively can claim compliance to no particular Class. If the PICC does not claim compliance to a particular class the requirements defined for Class1 have to be

met. Regarding the H_{min} limit parameter there is no difference between Class 1 to Class 3. In order to ensure interoperability it is sufficient to be in line with Class 1 or Class 2 or Class 3 requirements since a compliant PCD mandatorily has to support these 3 classes. Whenever a DUT Listener claim compliance to no particular Class ("No Class") either Class 1, Class 2 or Class 3 defined requirements will be met. Compliance/ interoperability for the DUT Listener against the ISO/IEC 14443 selected Class can be claimed if:

1) the minimum value of V_{OV} measured with the DUT Listener in the NFC OV on the Reference Pollers P0, P3 and P6 setup to minimum power condition is equal to or below the value of V_{OV} measured on the Test PCD Assembly (1 or 2) adjusted to the minimum field strength condition for the selected Class as defined in Table 25 using the according ISO Reference PICC.
2) the maximum value of V_{OV} measured with the DUT Listener in the NFC OV on the Reference Pollers P0, P3 and P6 setup to maximum power condition is equal to or above the value of V_{OV} measured on the Test PCD Assembly (1 or 2) adjusted to the maximum field strength condition for the selected Class as defined in Table 25 using the according ISO Reference PICC.

NFC Forum Listener 1 emulates a DUT (rectangular:71,6 x 41,5mm)

The NFC Forum Listener 1 (DUT L1) is emulating a DUT with the largest antenna size. In the subsection below comparison results for Class 1 is provided. Compliance against other Classes is not applicable.

NFC Listening Device Power Reception - Class 1

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical.

Compliance/interoperability for the DUT L1 against Class 1 can be claimed for the minimum value of V_{OV}, but not for the maximum V_{OV} value. As the difference for the maximum is insignificant, the group of experts concluded not to take any further action.

NFC Forum Listener 3 emulates a DUT (rectangular:46 x 32mm)

The NFC Forum Listener 3 (DUT L3) is emulating a DUT with a medium antenna size. This antenna size range is commonly used in mobile devices. In the first subsection below comparison results for Class 1 and in the second subsection comparison results for Class 3 are provided.

NFC Listening Device Power Reception - Class 1

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical.

Compliance/interoperability for the DUT L3 against Class 1 is given for the minimum value of V_{OV}, and for the maximum value.

NFC Listening Device Power Reception - Class 3

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical.

Compliance/ interoperability for the DUT L3 against Class 3 is given for the minimum value of V_{OV}, and for the maximum value.

NFC Forum Listener 6 emulates a DUT (rectangular:24,7 x 19,7mm)

The NFC Forum Listener 6 (DUT L6) is emulating a DUT with a small antenna size. This antenna size range is commonly used in mobile devices. In the first subsection below comparison results for Class 1 and in the second subsection comparison results for Class 6 are provided. Compliance for Class 3 is not applicable.

NFC Listening Device Power Reception - Class 1

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical.

Compliance/ interoperability for the DUT L6 against Class 1 is not given for the minimum value of V_{OV}, but for the maximum value. Taking into account the PT specific requirement for PCDs on H_{min} as defined in [CEN/TS 16794-1] interoperability can be claimed for a NFC Device using an antenna size of Class 6. [CEN TS16794-1] requires an H_{min} of at least 2 A/m(rms) if measured with a Reference PICC 3. An NFC Device of Class 6 is tested at a minimum field strength of 1.9 A/m(rms).

NFC Listening Device Power Reception – Class 6

[ISO14443-2] does not apply the margin principle for PCD and PICC limit values for the field strength parameter. For this reason compliance and interoperability verdicts are identical.

Compliance/ interoperability for the DUT L6 against Class 6 is given for the minimum value of V_{OV}, but not for the maximum value.

Summary and Recommendations

The NFC Forum Reference Listening Devices have been chosen to emulate the relevant antenna size range observed in the field for NFC Devices. The most relevant use cases as defined in [Mobile_Usecases] are relying on compliance or at least interoperability to Class 1 - 3.The comparison of the minimum and maximum limit of the field strength parameter between NFC Forum and ISO/IEC 14443 results in the following observations.

- The comparison has unveiled a good overlap between NFC Forum and ISO/IEC 14443 on the field strength parameter for a Listening Device independently of antenna size. Generally NFC Forum requires a Listening Device to work at a lower H_{min} compared to ISO/IEC 14443.
- NFC Forum Devices in Listen mode using an antenna size of Class 1 or Class 3 can claim compliance to ISO/IEC 14443 and the H_{min} parameter for "Class 1" and "Class 3", respectively.
- NFC Forum Devices in Listen mode using an antenna size of Class 6 can claim interoperability to PCDs compliant to [CEN/TS 16794-1] and the H_{min} parameter for Class 3.
- NFC Forum Devices in Listen mode using an antenna size Class 1, Class 3 or Class 6 can claim compliance to ISO/IEC 14443 and the H_{max} parameter for Class 1.

No further actions are taken

3.2.2 Requirements 4.3.2.1: Influence of the Listening Device on the Operating Field

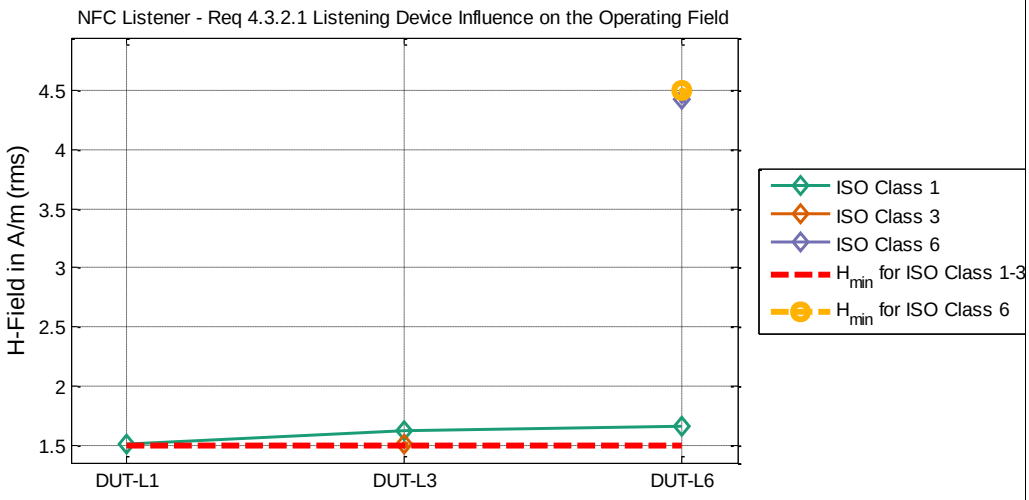
CONTEXT	
Reference	[NFC_ANA]
Requirement	*4.3.2.1 ➔ Expected to be updated in the NFC Forum ANALOG specification!* *When placed in the Operating Volume of the NFC Forum – Reference Polling Device, the loading caused by the Listening Device SHALL result in a maximum voltage drop of ΔV_{OV} as detected across the sense resistor via J2 of the NFC Forum – Reference Polling Device.* *The definition of the voltage drop is the difference in peak to peak voltage level before ($V_{OV,FREE\ AIR}$) and after ($V_{OV,Listening\ Device}$) the Listening Device is placed in the Operating Volume of the NFC Forum Reference Polling Device.* *$\Delta V_{OV,DUT} = V_{OV,FREE\ AIR} - V_{OV,Listening\ Device}$ detected at J2 of the NFC Forum Reference Polling Device.* *$\Delta V_{OV,ratioP0} = \Delta V_{OV,DUT} / \Delta V_{OV,P0\text{-}L1(000)}$, $\Delta V_{OV,ratioP3} = \Delta V_{OV,DUT} / \Delta V_{OV,P3\text{-}L3(000)}$,* *$\Delta V_{OV,ratioP6} = \Delta V_{OV,DUT} / \Delta V_{OV,P6\text{-}L6(000)}$, where $\Delta V_{OV,PX\text{-}LX(000)}$ is measured with the respective NFC Forum reference equipment*
Implicit Requirement	Maximum card loading
Question	Is an NFC Forum Device in Listen mode which is compliant for the above maximum card loading requirement also compliant or interoperable to the corresponding maximum ISO PICC Requirement?

PROCEDURE	
Step	**SETUP**
1	Tune the selected ISO Reference PICC to a f_{RES} of 13,56 MHz.
2	Calibrate the Test PCD assembly to produce H_{min} (see Table 25) operating condition on the calibration coil with the selected ISO Reference PICC in the DUT position of the Test PCD Assembly. *Note: Use the according Test PCD Assembly as defined for the PICC Class.*
Step	**VERIFICATION**
1	Place each of DUT L1, DUT L3 and DUT L6 in the DUT position of the Test PCD Assembly.
2	Read the H-field measured at the calibration coil.

EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compliance is given if the measured H-field in VERIFICATION step 2 is equal to or greater than H_{min} (see Table 25).
Step	**INTEROPERABILITY**
1	INTEROPERABILITY equals COMPLIANCY.

RESULT

Compliance and Interoperability:



Verdict: Compliance can be claimed if DUT-L result is equal to or larger than the red/yellow limit value.

Overall verdict	DUT-L1	DUT-L3	DUT-L6
DUT can claim ISO Class 1 compliance	OK	OK	OK
DUT can claim ISO Class 3 compliance	n/a	OK	n/a
DUT can claim ISO Class 6 compliance	n/a	n/a	KO

The below sub-sections investigate the Influence on the Field parameter, also known as maximum loading, comparison results between NFC Forum and ISO/IEC 14443.

NFC Forum Listener 1 emulates a DUT (rectangular:71,6 x 41,5mm)

The NFC Forum Listener 1 (DUT L1) is emulating a DUT with a large antenna size and claims compliance to Class 1 for this parameter. Comparing the DUT L1 and the Reference PICC 1 properties one can observe that the antenna size of DUT L1 and the Reference PICC 1 as well as the resonance frequency are identical. Additionally, the load configured is quite similar at H_{min} between the 2 devices. Therefore compliance can be claimed for this parameter by DUT L1 for this parameter and Class 1.

NFC Forum Listener 3 emulates a DUT (rectangular:46 x 32mm)

The NFC Forum Listener 3 (DUT L3) is emulating a DUT with a medium antenna size. This antenna size range is commonly used in mobile devices. In the first subsection below comparison results for Class 1 and in the second subsection comparison results for Class 3 are provided.

NFC Listening Device Influence on the Field - Class 1

Since the definition of the antenna size for NFC Forum Reference Listener 3 which is used as a DUT is smaller than the antenna size of the Reference PICC 1 defined in ISO/IEC 14443 while the resonance frequency and the load configured is quite similar it is obvious that compliance for a DUT L3 against Class 1 is achieved.

NFC Listening Device Influence on the Field - Class 3

The definition of the antenna size for NFC Forum Reference Listener 3, emulating DUT Listener 3, equals the antenna size of the Reference PICC 3 defined in [ISO10373-6] and [ISO10373-6:AMD1]. Additionally the resonance frequency is equal and the configured load is quite similar. Therefore compliance for a DUT L3 against Class 3 can be claimed.

NFC Forum Listener 6 emulates a DUT (rectangular:24,7 x 19,7mm)

The NFC Forum Listener 6 (DUT L6) is emulating a DUT with a small antenna size. This antenna size range is commonly used within mobile devices. In the first subsection below comparison results for Class 1 and in the second subsection comparison results for Class 6 are provided.

NFC Listening Device Influence on the Field - Class 1

Since the definition of the antenna size for NFC Forum Reference Listener 6 which is used as a DUT is smaller than the antenna size of the Reference PICC 1 defined in ISO/IEC 14443 while the resonance frequency and the load configured is quite similar compliance for a DUT L6 against Class 1 can be claimed.

NFC Listening Device Influence on the Field - Class 6

The definition of the antenna size for NFC Forum Reference Listener 6, emulating DUT L6, equals the antenna size of the Reference PICC 6 defined in [ISO10373-6] and [ISO10373-6:AMD1]. Additionally the resonance frequency settings are equal and the configured load is quite similar. The measurement results show a difference for this parameter and a slightly higher loading of DUT Listener 6 compared to the loading of the Reference PICC 6. Since this difference is very low it can be considered as measurement uncertainty. Therefore compliance for a DUT L6 against Class 6 can be claimed.

Summary and Recommendations

Compliance can be claimed for all considered sizes of DUT antennas according to NFC Forum against the Class 1 (including "no Class") as defined by ISO/IEC 14443 additionally to the compliance to the claimed Class. No further actions required.

3.2.3 Requirement 4.5.2.1: Carrier Frequency fc (Listening Device Reception)

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.5.2.1 When placed in the Operating Volume of the NFC Forum – Reference Polling Device, the Listening Device SHALL function properly with a carrier frequency between the Min and Max values of $\mathbf{f}_{s,c}$ as defined in Appendix B.3, being generated by the NFC Forum – Reference Polling Device
Implicit Requirement	Carrier Frequency Generation
Question	Is an NFC Forum Device in Listen mode which is compliant for the above Carrier Frequency requirement also compliant or interoperable to the corresponding ISO Requirement?
CONCLUSION / DISCUSSION	
	For a comparison on specification level refer to 0) B.4. ISO/IEC 14443-2 PICC Requirement for the Carrier Frequency fc

	No experimental measurement needed.

3.2.4 Requirement 4.6.2.1: Power On (Listening Device Reception)

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.6.2.1 If a Listening Device in NO_REMOTE_FIELD state is placed in the Operating Volume of the NFC Forum – Reference Polling Device set-up to be between the Min and Max power levels of Operating Field that may be provided by a Polling Device, it SHALL enter the IDLE state within a time GT_A, GT_B, and GT_F. Refer to [DIGITAL] for the values of GT_A, GT_B and GT_F. Refer to [ACTIVITY] for details on the NO_REMOTE_FIELD and IDLE states.
Implicit Requirement	Startup Time for a Listener to enter IDLE State
Question	Is an NFC Forum Device in Listen mode which is compliant for the above requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	This parameter is defined in [NFC_ACTIVITY] and therefore is not of relevance for this analog parameter comparison. No experimental measurements needed.

3.2.5 Requirements 4.8.2.1: Listening Device Reset (Listening Device Reception)

a. $t_{FIELD\ OFF}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.7.2.1 When the NFC Forum - Reference Listening Device is within the Operating Volume of the Polling Device and the Polling Device resets the Operating Field, it SHALL generate a voltage less than or equal to Max $V_{0V,RESET}$ (rms) for a time t_{FIELD_OFF} defined by [ACTIVITY], characterized at the output of the sense coil on J4 of the NFC Forum - Reference Listening Device.
Implicit Requirement	Time for a Listener to enter NO_REMOTE_FIELD State
Question	Is an NFC Forum Device in Listen mode which is compliant for the above requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	This parameter is defined in [NFC_ACTIVITY] and therefore of no relevance for this analog parameter comparison. No experimental measurements needed.

b. $V_{OV,RESET}$

CONTEXT

Reference	[NFC_ANA]
Requirement	4.8.2.1 When the Operating Field is switched off as simulated by the signal generator level being reduced from $V_{GEN,MINIMUM}$ to $V_{GEN,RESET}$ for a time t_{FIELD_OFF} defined by [ACTIVITY], a Listening Device SHALL enter NO_REMOTE_FIELD state as defined by [ACTIVITY]. After the signal level is restored back to $V_{GEN,MINIMUM}$, the Listening Device MUST be in IDLE state after a time GT_A, GT_B and GT_F.
Implicit Requirement	Residual amplitude verification
Question	Is an NFC Forum Device in Listen mode which is compliant for the above maximum reset voltage reception requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	There is no such Requirement in [ISO14443-2] . No experimental Measurements needed.

3.2.6 Requirement 5.2.2.1: Modulation Polling Device to Listening Device – NFC-A (Listening Device Reception)

CONTEXT	
Reference	[NFC_ANA]
Requirement	5.2.2.1: When placed in the Operating Volume of the NFC Forum – Reference Polling Device, a Listening Device of NFC-A SHALL function properly when the NFC Forum – Reference Polling Device has been set up as described in the specification context above.
Implicit Requirement	NFC-A Listener wave shape reception
Question	Is an NFC Forum Device in Listen mode which is compliant for the above NFC-A wave shape reception requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	See section 3.1.5 for further information

3.2.7 Requirement 5.4.2.1: Modulation Polling Device to Listening Device – NFC-B (Listening Device Reception)

CONTEXT	
Reference	[NFC_ANA]
Requirement	5.4.2.1: When placed in the Operating Volume of the NFC Forum – Reference Polling Device, a Listening Device of NFC-B SHALL function properly when the NFC Forum – Reference Polling Device has been set up as described in the specification context above.
Implicit Requirement	NFC-A Listener wave shape reception

Question	Is an NFC Forum Device in Listen mode which is compliant for the above NFC-B wave shape reception requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	See section 3.1.6 for further information

3.2.8 Requirement 5.6.2.1: Modulation Polling Device to Listening Device – NFC-F (Listening Device Reception)

No experimental measurement needed.

3.2.9 Requirement 6.1.2.1 & 6.1.2.2 & 6.2.3.3: Load Modulation Characteristics – Generic (Listening Device Transmission)

a. Subcarrier Frequency

No experimental measurement needed.

b. $V_{PP,min}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.1.2.1-6.1.2.3: When put in the Operating Volume of the NFC Forum – Reference Polling Device that has been set up as described in the specification context above, the Listening Device SHALL modulate the Operating Field in such a way that the signal monitored at J2 of the NFC Forum – Reference Polling Device has the following characteristics: 6.1.2.1 The subcarrier frequency fs of the modulation signal SHALL be fc/16 for NFC-A and NFC-B. 6.1.2.2 For NFC-F, the frequency fs of the modulation signal during the preamble SHALL be fc/32 or fc/64 and SHALL be fc/32, fc/64 or fc/128 (see note 1) at other times. 6.1.2.3 The amplitude (V_{pp}) of the modulation signal at J2 of the NFC Forum – Reference Polling Device SHALL be V_{pp} (peak to peak). (Choosing a measurement position avoiding all transient effects, e.g., the first change from 0 to 1 for NFC-A, the TR1 zone for NFC-B and the zero coding preamble before the Sync code for NFC-F).
Implicit Requirement	Minimum load modulation amplitude transmission
Question	Is an NFC Forum Device in Listen mode which is compliant for the above minimum load modulation transmission requirement also compliant or interoperable to the corresponding minimum ISO PICC Requirement?

PROCEDURE	
Step	**SETUP**
1	Setup the NFC Forum – Reference Poller 0 to nominal field strength ($V_{S,OV,nom}$).
2	Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 0.

<table>
<tr><td></td><td>
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th></tr>
<tr><td>Load Modulation
Poller←Listener</td><td>V_{pp}</td><td>Poller-0</td><td>20</td><td>mV_{pp}</td></tr>
</table>
Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
</td></tr>
<tr><td>3</td><td>Setup the NFC Forum – Reference Poller 3 to nominal field strength ($V_{S,OV,nom}$).</td></tr>
<tr><td>4</td><td>Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 3.
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th></tr>
<tr><td>Load Modulation
Poller←Listener</td><td>V_{pp}</td><td>Poller-3</td><td>9.5</td><td>mV_{pp}</td></tr>
</table>
Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.</td></tr>
<tr><td>5</td><td>Setup the NFC Forum – Reference Poller 6 to nominal field strength.</td></tr>
<tr><td>6</td><td>Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 6.
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th>Value</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th></tr>
<tr><td>Load Modulation
Poller←Listener</td><td>V_{pp}</td><td>Poller-6</td><td>7</td><td>mV_{pp}</td></tr>
</table>
Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.</td></tr>
<tr><td>7</td><td>Repeat the procedure above with DUT L3 and DUT L6.</td></tr>
<tr><td>Step</td><td>VERIFICATION</td></tr>
<tr><td>1</td><td>Place DUT L1 in the DUT position of the respective Test PCD Assembly.</td></tr>
<tr><td>2</td><td>Readjust the field strength until the V_{OV} as measured at DUT L1 in each of the NFC Forum – Reference Poller test positions is reached.</td></tr>
<tr><td>3</td><td>Set the load modulator input voltage for the position (SETUP Steps 2), 4) and 6)) and measure the load modulation amplitude.</td></tr>
<tr><td>4</td><td>Repeat the VERIFICATION steps with DUT L3 and DUT L6.</td></tr>
<tr><td>5</td><td>Repeat the complete SETUP and VERIFICATION steps with max $V_{S,OV}$ in SETUP steps 1, 3 and 5.
Note: This analysis assumes the NFC Forum Analog specification defines the Load modulation amplitude limits independent of position within the NFC OV and field strength.</td></tr>
</table>

EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PICC minimum load modulation amplitude (see Table 27).
Step	**INTEROPERABILITY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PCD minimum load modulation amplitude (see Table 24).

The below sub-sections analyze the minimum load modulation amplitude parameter comparison results, between NFC Forum and ISO/IEC 14443.

Compliance and interoperability evaluation are performed for Class 1, Class 2 and Class 3 as defined by ISO/IEC 14443. Since the support of these classes is mandatory for PCDs compliant to [CEN/TS 16794-1] and [ISO14443-2] interoperability to one of these classes is the goal. For DUT L6 compliance and interoperability is verified additionally for Class 6.

NFC Forum Listener 1 emulates a DUT (rectangular:71,6 x 41,5mm)

The NFC Forum Listener 1 (DUT L1) is emulating a DUT with the largest considered antenna size. In the subsection below comparison results for compliance/interoperability to Class 1-3 is given. Compliance to other classes is not applicable.

DUT L1 min LMA ($V_{PP,\,min}$) and PICC class 1 compliance and interoperability

Figure 13 shows the field strength versus side band amplitude graph. Each black pair of points (* and Diamond) corresponds to one measurement position of DUT L1 on Reference P0, P3 and P6, transformed to equivalent field strength on the ISO Test PCD Assembly 1 with its related sideband amplitude. The red dashed line denotes the minimum PICC limit, relevant for compliance, while the red dotted line depicts the minimum PCD limit, relevant for interoperability for this parameter. For interoperability the side band amplitude level for each field strength should be equal to or above the PCD limit curve, for compliance equal to or above the PICC limit curve.

Compliance/Interoperability of DUT L1 against Class 1 Class 2 and Class 3 can only be claimed for a field strength higher than 4,5A/m.

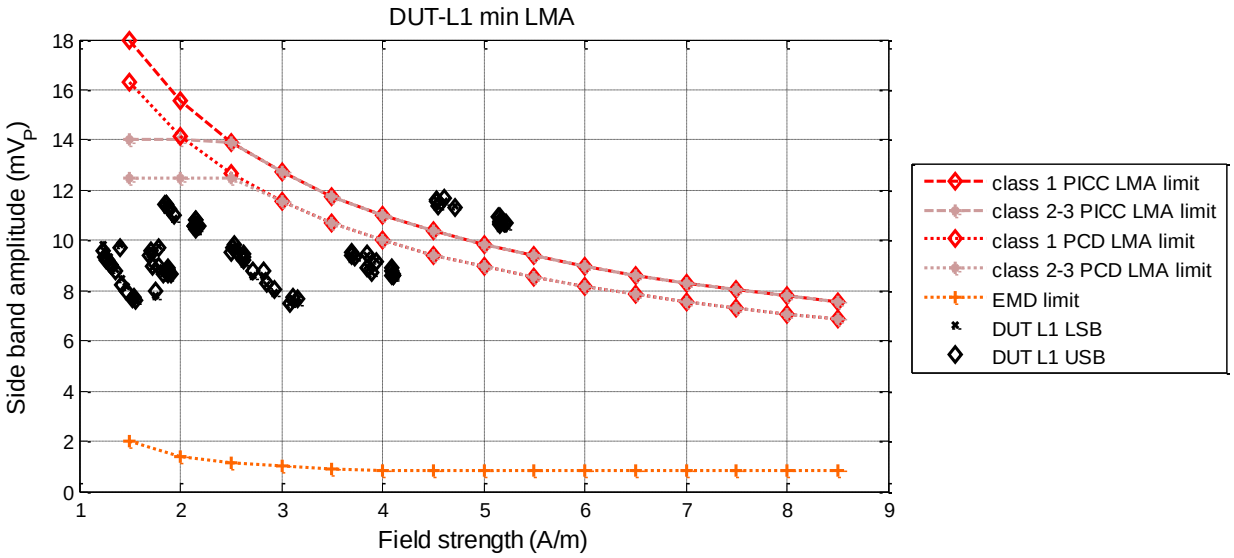


Figure 13: DUT L1 compliance and interoperability assessment to class 1

NFC Forum Listener 3 emulates a DUT (rectangular: 46 x 32mm)

The NFC Forum Listener 3 (DUT L3) is emulating a DUT with a medium antenna size. In the subsection below comparison results for compliance/interoperability to Class 1-3 is given. Compliance to other classes is not applicable.

DUT L3 min LMA ($V_{PP,\,min}$) and PICC class 1 – 3 compliance and interoperability

Figure 14 shows the field strength versus side band amplitude graph. Each black pair of points (* and Diamond) corresponds to one measurement position of DUT L1 on Reference P0, P3 and P6, transformed to equivalent field strength on the ISO Test PCD Assembly 1 with its related sideband amplitude. The red dashed line denotes the minimum PICC limit, relevant for compliance, while the red dotted line depicts the minimum PCD limit, relevant for interoperability for this parameter. For interoperability the side band amplitude level for each field strength should be equal to or above the PCD limit curve, for compliance equal to or above the PICC limit curve.

Compliance/Interoperability of DUT L3 cannot be claimed.

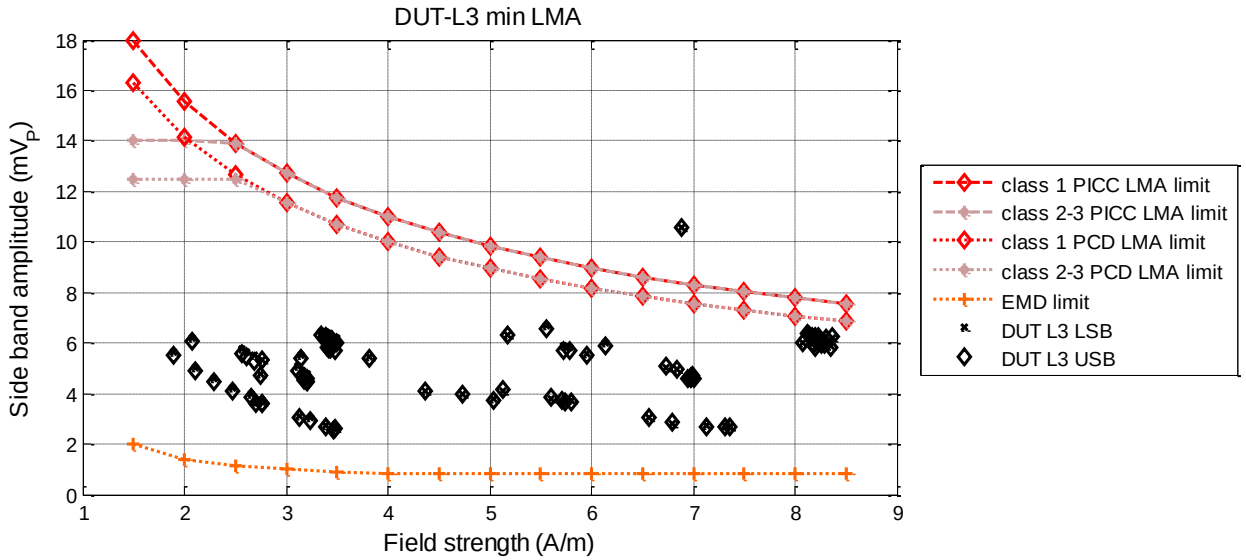


Figure 14: DUT L3 and compliance assessment to class 1-3

NFC Forum Listener 6 emulates a DUT (rectangular: 24,7 x 19,7mm)

The NFC Forum Listener 6 (DUT L6) is emulating a DUT with a small antenna size. In the first subsection below comparison results for compliance/interoperability to Class 1-3 is given. The second subsection shows results for compliance/interoperability to Class 6

DUT L6 min LMA ($V_{PP, min}$) and PICC class 1 – 3 and 6 compliance and interoperability

Figure 15 shows the field strength versus side band amplitude graph. Each black pair of points (* and Diamond) corresponds to one measurement position of DUT L1 on Reference P0, P3 and P6, transformed to equivalent field strength on the ISO Test PCD Assembly 1 with its related sideband amplitude. The red dashed line denotes the minimum PICC limit, relevant for compliance, while the red dotted line depicts the minimum PCD limit, relevant for interoperability for this parameter. For interoperability the side band amplitude level for each field strength should be equal to or above the PCD limit curve, for compliance equal to or above the PICC limit curve.

Neither compliance nor interoperability of DUT L6 can be claimed to Class 1-3.

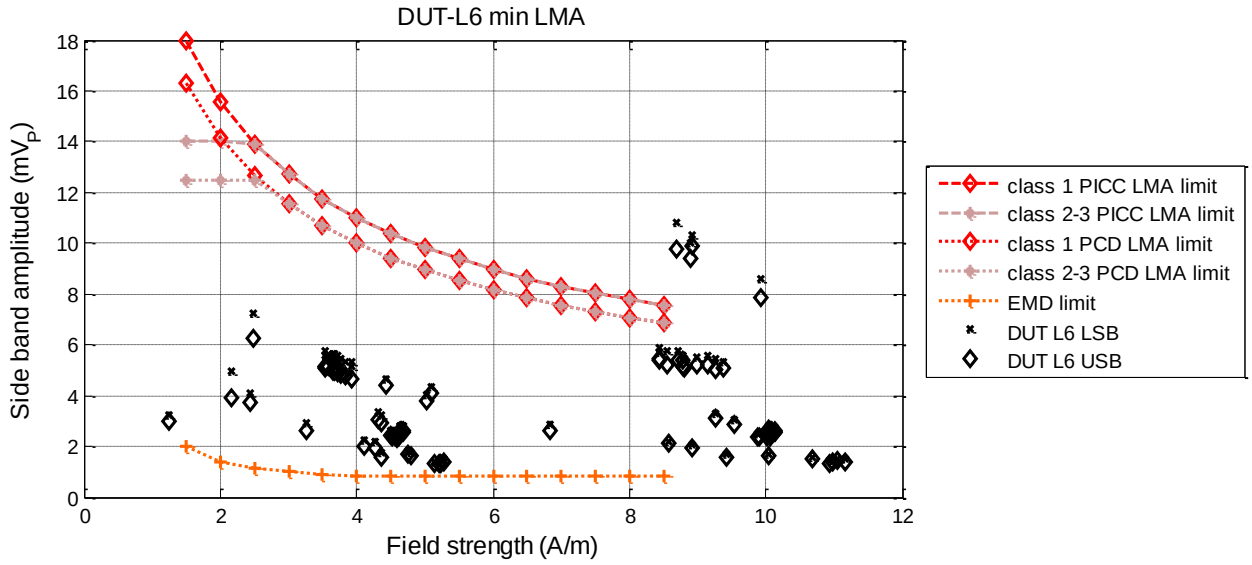


Figure 15: DUT L6 and compliance assessment to class 1-3

Figure 16 contains the results for claiming compliance and interoperability to Class 6. For Class 6 measurements have been performed using the Test PCD Assembly 2. The graph otherwise is identical to Figure 15.

Neither compliance nor interoperability of DUT L6 can be claimed to Class 6.

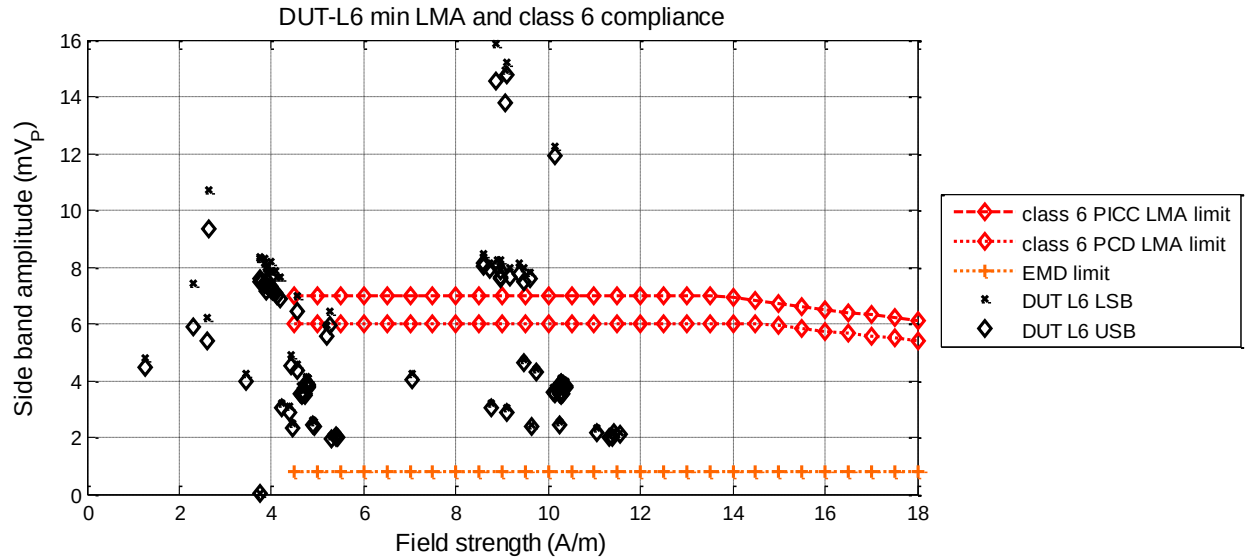


Figure 16: DUT L6 and compliance assessment to class 6

Summary

This section provides a summary on a DUT Listener claiming compliance to ISO/IEC 14443 on load modulation reception for LMA_{min}. A high level verdict summary is presented in Table 6. This table contains for each DUT Listener a compliance/interoperable verdict if applicable. In general the results have shown that NFC Forum requires a Device in Listen Mode to emit less Side Band Amplitude compared to ISO/IEC 14443. The results show that neither compliancy nor interoperability to ISO/IEC 14443 is guaranteed by NFC Forum testing of Load Modulation Amplitude.

Table 6: Summary: DUT Listener and Load Modulation Transmission LMA_{min}

	ISO PICC class	DUT-L1	DUT-L3	DUT-L6
Compliance/Interoperable	1	NO/NO	NO/NO	NO/NO
	3	N/A	NO/NO	N/A
	6	N/A	N/A	NO/NO

LMA_{min} result presentation as measured on each Reference Polling Device

Figure 17 to Figure 19 visualize the rearranged results of Figure 13 to Figure 15. Each black point represents an equivalent field strength versus side band amplitude of one position of the DUT L1 in the NFC OV on Reference Poller 0. There are two clouds of black points visible: the minimum power condition and the maximum power condition the P0 is setup when testing load modulation amplitude in NFC Forum. The same is true for the blue points: these are representing DUT L3 on Reference Poller 0, while the pink ones represent DUT L6 on Reference Poller 0.

This clearly gives recommendations for alignment to increase limit values for DUT Listeners as defined for each Reference Poller.

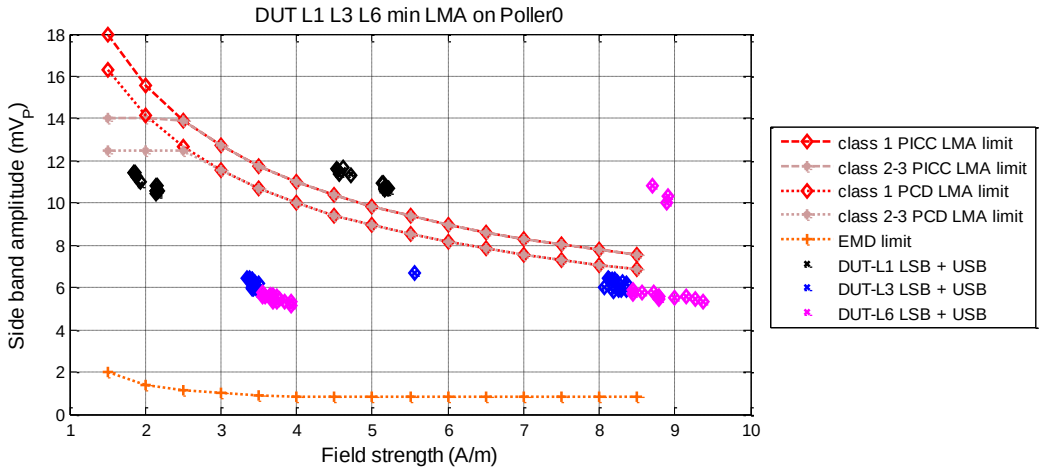


Figure 17: LMA_{MIN} results of L1, L3 and L6 on Reference Poller 0

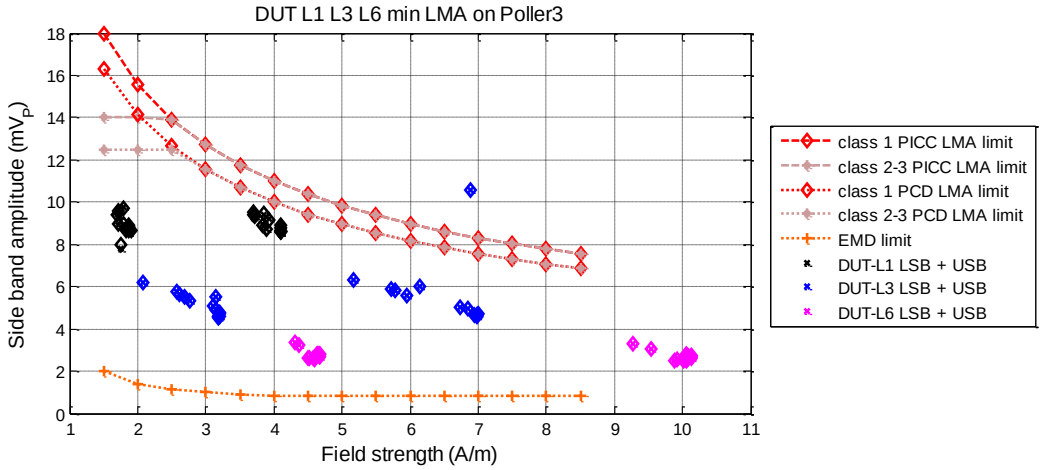


Figure 18: LMA_{MIN} results of L1, L3 and L6 on Reference Poller 3

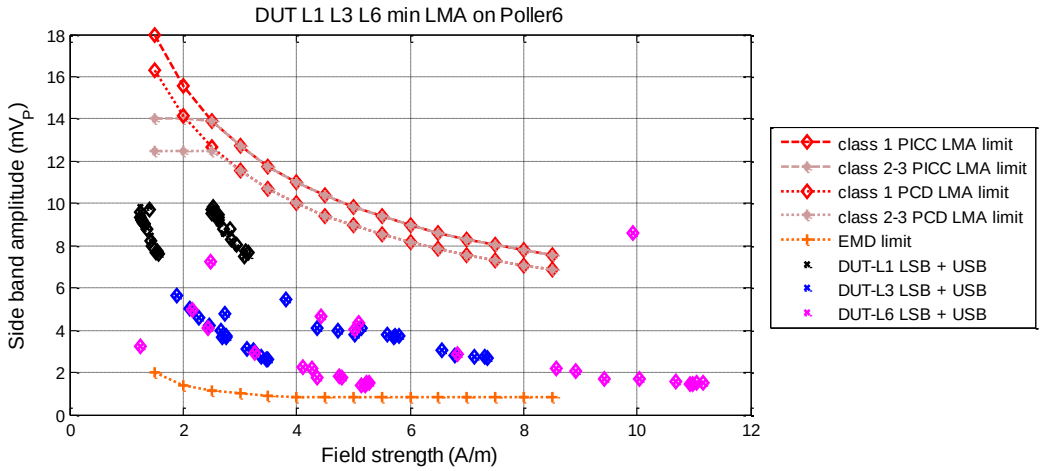


Figure 19: LMA_{MIN} results of L1, L3 and L6 on Reference Poller 6

c. $V_{PP,max}$

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.1.2.1-6.1.2.3: When put in the Operating Volume of the NFC Forum – Reference Polling Device that has been set up as described in the specification context above, the Listening Device SHALL modulate the Operating Field in such a way that the signal monitored at J2 of the NFC Forum – Reference Polling Device has the following characteristics: 6.1.2.1 The subcarrier frequency fs of the modulation signal SHALL be fc/16 for NFC-A and NFC-B. 6.1.2.2 For NFC-F, the frequency fs of the modulation signal during the preamble SHALL be fc/32 or fc/64 and SHALL be fc/32, fc/64 or fc/128 (see note 1) at other times. 6.1.2.3 The amplitude (V_{pp}) of the modulation signal at J2 of the NFC Forum – Reference Polling Device SHALL be V_{pp} (peak to peak). (Choosing a measurement position avoiding all transient effects, e.g., the first change from 0 to 1 for NFC-A, the TR1 zone for NFC-B and the zero coding preamble before the Sync code for NFC-F).

Implicit Requirement	Maximum load modulation amplitude transmission
Question	Is an NFC Forum Device in Listen mode which is compliant for the above maximum load modulation transmission requirement also compliant or interoperable to the corresponding maximum PICC V_{LMA} Requirement?

PROCEDURE

Step	SETUP
1	Setup the NFC Forum – Reference Poller 0 to nominal field strength ($V_{S,OV,nom}$).
2	Setup the DUT L1 (loading 330Ω) in order to get listener maximum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 0. Topic: Load Modulation Poller←Listener; Parameter: V_{PP}; Coil: Poller-0; Value Max: 110; Units: mVpp Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
3	Setup NFC Forum – Reference Poller 3 to nominal field strength.
4	Setup the DUT L1 (loading 330Ω) in order to get listener maximum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 3. Topic: Load Modulation Poller←Listener; Parameter: V_{PP}; Coil: Poller-3; Value Max: 53; Units: mVpp Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
5	Setup NFC Forum – Reference Poller 6 to nominal field strength.
6	Setup the DUT L1 (loading 330Ω) in order to get listener maximum load modulation value in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 6. **Topic**: Load Modulation Poller←Listener; **Parameter**: V_{PP}; **Coil**: Poller-6; **Value Min**: 90; **Units**: mV_{pp} Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
7	Repeat the above SETUP procedure with DUT L3 and DUT L6.
Step	**VERIFICATION**
1	Place DUT L1 in the DUT position of the Test PCD Assembly.
2	Readjust the field strength until the V_{OV} as measured at DUT L1 in each of the NFC Forum – Reference Poller test positions is reached.
3	Set the load modulator input voltage for the position (SETUP Steps 2), 4) and 6)) and measure the load modulation amplitude.
4	Repeat the VERIFICATION steps with DUT L3 and DUT L6.

5	**Repeat the complete SETUP and VERIFICATION steps with max $V_{S,OV}$ in SETUP steps 1, 3 and 5.** *Note: This analysis assumes the NFC Forum Analog specification defines the Load modulation amplitude limits independent of position within the NFC OV and field strength.*
EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PICC maximum load modulation amplitude (see 00)c. $V_{PP,max}$ *in process in WG8*).
Step	**INTEROPERABILITY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PCD maximum load modulation amplitude (see 0 0)b. $V_{PP,max}$ *in process in WG8*).

3.2.10 Requirements 6.2.1.1 & 6.2.1.2: Load Modulation Characteristics – NFC-A (Listening Device Transmission)

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.2.1.1 A Listening Device of NFC-A SHALL modulate the subcarrier using On-Off Keying (OOK). 6.2.1.2 When modulating the subcarrier, a Listening Device of NFC-A SHALL only start the bit period on the rising or falling edge of the subcarrier so that the modulation starts with a defined phase relationship to the subcarrier.
Implicit Requirement	NFC-A subcarrier Load Modulation Characteristics
Question	Is an NFC Forum Device in Listen mode which is compliant for the above NFC-A load modulation characteristics requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	No Difference from specification point of view No experimental measurement needed.

3.2.11 Requirements 6.3.1.1 & 6.3.1.3: Load Modulation Characteristics – NFC-B (Listening Device Transmission)

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.3.1.1 A Listening Device of NFC-B SHALL modulate the subcarrier using BPSK. 6.3.1.2 A Listening Device of NFC-B SHALL generate a subcarrier only when data is to be transmitted. 6.3.1.3 Phase shifts SHALL only occur at nominal positions of rising or falling edges of the subcarrier.
Implicit Requirement	NFC-B subcarrier Load Modulation Characteristics

Question	Is an NFC Forum Device in Listen mode which is compliant for the above NFC-B load modulation characteristics requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	No Difference from specification point of view No experimental measurement needed.

3.2.12 Requirement 6.4.1.1: Load Modulation Characteristics – NFC-F (Listening Device Transmission)

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.4.1.1 A Listening Device of NFC-F SHALL load modulate the carrier using Amplitude Shift Keying (ASK).
Implicit Requirement	NFC-F subcarrier Load Modulation Characteristics
Question	Is an NFC Forum Device in Listen mode which is compliant for the above NFC-B load modulation characteristics requirement also compliant or interoperable to the corresponding ISO PICC Requirement?
CONCLUSION / DISCUSSION	
	No difference from specification point of view No experimental measurement needed.

4 Limit Harmonization and Validation

In the previous section a generic status quo assessment for analogue parameter limits between NFC Forum and ISO/IEC 14443 has been performed taking into account the Public Transport application profile is defined in [CEN/TS 16794-1]. The comparison of results in combination with an interpretation, as well as a relevance analysis, finally led to the identification of parameter limits differences with potential interoperability risks. For these identified parameter limits, this section discusses options for harmonization. For the selected option harmonization proposals are developed and proposed. Once a solution for harmonization was found. e.g. a new limit value has been determined, an adequate validation is performed.

Amongst the analysed parameter limits the following resulted in differences which are relevant for interoperability of mobile devices in legacy infrastructures and with legacy PICCs:

- Polling Device minimum power requirement $V_{OV,\,min}$ versus ISO/IEC PCD requirement for H_{min}
- Listening Device LMA_{min} requirement $V_{PP,\,min}$ versus ISO/IEC PICC requirement for LMA_{min} ($V_{LMA,\,PICC}$)

4.1 NFC Forum Polling Device $V_{OV,min}$ Harmonization and Validation

For the harmonization of the minimum field strength parameter the following process was followed. First an evaluation of different options for harmonization was performed. Second, for the selected option the methodology and procedure have been defined. Third, the measurements have been performed and reviewed accordingly. In case a suitability analysis was passed successfully the validation of the new candidate limit was performed.

The following options to align the minimum field strength requirement between NFC Forum and ISIO/IEC 14443 (with PT focus) have been discussed between the experts:

(1) Increase minimum field strength requirement defined by NFC Forum
(2) Decrease the H_{min} requirement as defined in ISO/IEC 14443. This however, would need the support of ISO WG 8
(3) Indirect increase of field strength requirement by increasing the operating volume in NFC Forum
(4) Addition of a certification track with increased H_{min} power requirements in NFC Forum.
(5) any combination of above listed options

All experts involved in the decision process clearly preferred the harmonization option (1), that NFC Forum should increase the minimum field strength requirement. This step would globally improve interoperability to all standards bodies defining the 13.56 MHz radio.

The harmonization for H_{min} was split into two distinct analysis. The first harmonization approach performs harmonization based on a homogenous field condition. This is achieved by performing the harmonization on the Test PCD Assembly as defined in [ISO10373-6]. In contrast, the second harmonization approach performs harmonization looking at the real situation in the field. This is well reflected by the Polling Device power transmission and PCD field strength test cases defined

by each body, respectively. The condition is called heterogeneous field condition and is seen as more relevant to achieve harmonization.

4.1.1 Minimum Field Strength – HarmonizationPpart 1: Homogenous Field Condition

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.1.2.1: When the NFC Forum – Reference Listening Device is located within the Operating Volume of the Polling Device, under the conditions described in the specification context above, it SHALL generate an output voltage V_{OV} at J1 of the NFC Forum – Reference Listening Device. The average value over a small period of time (>10µs) at a fixed location of the voltage V_{OV} SHALL be characterized.
Implicit Requirement	Minimum power harmonization
Question	What are the new V_{OV} limit values for each listener if the requirement is aligned with ISO H_{min} classes 1 – 3 and class 6?

PROCEDURE	
Step	
1	Configure NFC Forum – Listener 1, 3 and 6 to a load of 820 Ω.
2	Tune Reference PICCs 1, 3, and 6 to 13,56 MHz resonance frequency.
3	Place the Reference PICC 1 in the DUT position of the ISO Test PCD Assembly 1.
4	Calibrate the Test PCD assembly 1 to produce the H_{min} operating condition on the calibration coil (see Table 22).
5	Adjust the load of the Reference PICC 1 as measured at CON3 to the value defined in Table 21 for the class. The operating field condition shall be verified by monitoring the voltage on the calibration coil and adjusted if necessary.
6	Do not change the field and remove the Reference PICC 1 from the DUT position of the Test PCD Assembly 1.
7	Place the NFC Forum – Reference Listener 1 in the DUT position of the ISO Test PCD Assembly 1 and measure the V_{OV} at J1.
8	Readjust the filed strength to the value in step 4) and measure the V_{OV} at J1 of Reference Listener 1.
9	Repeat steps 3) – 8) for the pairs of Reference PICC 3 – Reference Listener 3 and Reference PICC 6 – Reference Listener 6. For the pair Reference PICC 6 – Reference Listener 6 the Test PCD Assembly 2 shall be used.
Step	**Verification**
1	Place the NFC Forum – Reference Listener 1 in the DUT position of the ISO Test PCD Assembly 1 and adjust the field strength until $V_{OV,min}$ is measured at J1.
2	Note V(rms) as measured by the calibration coil.

3	Repeat above Verification steps 1) – 2) for NFC Forum – Reference Listener 3 and 6. For NFC Forum – Reference Listener 6 use Test PCD Assembly 2.

Results part 1: homogenous field condition

Table 7 presents the results of the homogenous field condition harmonization. The table provides information on the selected Reference Listening Device as well as the load adjusted and the used Test PCD Assembly. Each NFC Forum Reference Listening Device was setup to the $V_{OV,\,min}$ defined by NFC Forum and afterwards the corresponding field strength as measured by the calibration coil was recorded. In a second step the H_{min} according to ISO/IEC 14443 was setup and the V_{OV} as measured by the Reference Listening Device was recorded. The results contained in Table 7 show that for Reference Listener 1 and 6, $V_{OV,min}$ for Polling Device power transmission has to be increased in order to meet the H_{min} required by ISO/IEC 14443.

Table 7: homogenous field condition results

Ref. Device	Load	V_{OV}	CalCoil	H-field	Test PCD Assembly
	Ω	V(dc)	V(rms)	A/m(rms)	
Listener 1	820	***4.100***	0.372	1.166	1
		5.375	0.477	***1.500***	
Listener 3	820	***3.140***		1.541	
		3.115	0.477	***1.500***	
Listener 6	820	***3.790***	0.350	2.991	2
		6.034	0.532	***4.500***	
		1.975	0.477	***1.500***	1

4.1.2 Minimum Field Strength – Harmonization Part 2: Heterogeneous Field Condition

CONTEXT	
Reference	[NFC_ANA]
Requirement	4.1.2.1: When the NFC Forum – Reference Listening Device is located within the Operating Volume of the Polling Device, under the conditions described in the specification context above, it SHALL generate an output voltage V_{OV} at J1 of the NFC Forum – Reference Listening Device. The average value over a small period of time (>10µs) at a fixed location of the voltage V_{OV} SHALL be characterized.
Implicit Requirement	Minimum power harmonization
Question	What are the new V_{OV} limit values for each listener if the requirement is aligned with ISO H_{min}?
PROCEDURE	
Step	**SETUP**
ISO SETUP 1	Tune Reference PICCs 1, 2, 3, and 6 to 13,56 MHz resonance frequency.

ISO SETUP 2	Place the Reference PICC into the DUT position of the Test PCD assembly 1 producing the H_{min} (see Table 22) operating condition on the calibration coil. Measure V_{load} as defined in Table 21 at connector CON3. The operating field condition shall be verified by monitoring the voltage on the calibration coil and adjusted if necessary.
ISO SETUP 3	Repeat steps 2) – 4) for Reference PICCs 2, 3, and 6. Use Test PCD Assembly 2 for Reference PICC 6.
NFC SETUP 4	Setup DUT P0 in order to get Poller minimum field strength value measured with the Reference PICC 1, i.e., the measured CON3 value shall be equal to or larger than the value defined in Table 21 for the class, on at least one position of the NFC OV. Other positions shall give field strengths equal to or above the minimum defined for Reference PICC 1.
5	Measure the CON3 voltage V(dc) of Reference PICC 2 in the whole NFC OV of the DUT P0 and note the lowest value. If the value measured is less than the value defined in Table 21 for the class, increase the field strength to the value defined in Table 21 for this class, at this position.
6	Repeat Step 5 for Reference PICC 3 and 6.
Step	**VERIFICATION**
1	Measure V_{DC} output of each of the NFC Forum Reference Listening Devices in the whole NFC OV of the DUT P0 and note the lowest value measured.
2	Repeat this procedure with DUT P3 and DUT P6.

4.1.2.1 SETUP and VERIFICATION harmonization part 2: heterogeneous field condition

This section contains the results of the measurements performed according to the heterogeneous field condition described in section 4.1.2. Table 8 contains the V_{OV} [V(dc)] values as measured at J1 of the Reference Listening Devices for each DUT Polling device if setup is performed to be compliant to exactly the H_{min} limit defined by ISO/IEC 14443 for Class 1 - 3 and Class 6, i.e. measured with Reference PICCs 1, 2, 3 and 6. This means for the setup using the Reference PICCs at least in one position the minimum value V_{load} (see Table 21) is achieved and in all other positions of the OV the same value or a value higher is measured. For DUT Poller 0 the worst case counterpart was Reference PICC 1. For DUT Poller 3 the worst case counterpart was Reference PICC 3. Finally, for DUT Poller 6 the worst case counterpart was Reference PICC 1. In order to ensure interoperability on this parameter limit the minimum $V_{OV, J1}$ value as measured by each Listener on each DUT Poller in the OV is relevant. Therefore amongst the minimum $V_{OV, J1}$ additionally the position information where this value was measured is provided. The position information is encoded according to the NFC Forum definition (see [NFC_ANA], [NFC_TC_ANA]) except that the rotation index digit is not shown because constant. This minimum will be automatically a candidate for new limits which achieves interoperability. In NFC Forum a DUT Polling Device is required to pass the test cases using all 3 Reference Listening Devices.

Typically NFC Forum requirements and test cases are defined in such a way that each antenna size of the Reference Equipment establishes the worst case for a DUT antenna size group. In case of the $V_{OV, min}$ parameter, the best matching antenna size of the Reference Listener represent the worst case situation for a DUT Poller or PCD. An analysis of the results contained in Table 8 show that

Reference Listener 1, 3 and 6 establish the worst case for medium and small Polling Device antenna sizes emulated by Poller 3 and Poller 6. Additionally one can observe that Reference Listener 1 establishes the worst case for a small antenna size of a Polling Device. For the minimum V_{OV} limit therefore the rule of the best matching device establish the worst case is broken. Accepting the result as shown would end up in a potential interoperability risk for Polling Devices with an antenna size larger than Class 3. The alternative option to select the Listener 1 smallest measured value on Poller 0 (red coloured), would increase the minimum requirement for Polling devices of small antenna sizes unnecessarily high. In order to meet the Reference PICC 6 H_{min} a $V_{OV,\,J1}$ of 4.04 V(dc) measured with Listener 6 would be sufficient. This would be a $V_{OV,\,J1}$ of 5.34 V(dc) on Listener 1 and not 6.15 V(dc). Additionally any solution overstressing NFC Forum Devices would in contrast lead to a compliance issue for ISO/IEC 14443 compliant PCDs if tested according to NFC Forum on this parameter. After this analysis the group agreed to review the problem in detail in order to identify the root cause. For more details see section 4.1.2.3.

Table 8: Verification results part 2: heterogeneous field condition

	Poller 0		Poller 3		Poller 6	
	Position	$V_{OV,J1}$	Position	$V_{OV,J1}$	Position	$V_{OV,J1}$
	(z,r,φ)	V(dc)	(z,r,φ)	V(dc)	(z,r,φ)	V(dc)
Listener 1	**000**	**6.15**	013	6.26	**122**	**5.34**
Listener 3	011	7.69	**000**	**4.68**	122	5.59
Listener 6	000	6.42	012	6.27	**000**	**4.04**

4.1.2.2 Summary H-field reference value assessment

Table 9 provides an overview summary on the results for the validation procedures of the homogenous and heterogeneous field condition. The outcome of these validation results can be directly used for derivation of candidate limits of minimum power limits $V_{OV,\,min}$ for DUT Pollers measured with Reference Listener 1, 3 and 6. For reference also the existing NFC Forum limit values are shown. A comparison of the homogenous and heterogeneous field condition based candidate limits show a clear difference in the values. Also one can observe that the limit values are higher than the currently defined limit values by NFC Forum. As stated already at the beginning of this section the heterogeneous field condition is more relevant to achieve an interoperability solution of NFC Devices in Poll mode because this condition is actually following the test case procedure which must be successfully passed. Unfortunately this condition did not result in a unique solution but instead resulted in an interoperability problem for Polling Devices with larger antenna sizes and a violation of the NFC Forum testing methodology. This problem will be addressed in the next section.

Table 9: Summary of H-field validation for homogenous and heterogeneous field condition

	candidate limit values		existing limits
	Homogenous Part: V_{OV} (V_{DC})	Heterogeneous Part: V_{OV} (V_{DC})	$V_{OV,min}$ (V_{DC})
Listener 1	5.35	5.34/6.15	4.1
Listener 3	3.115	4.68	3.14
Listener 6	6.034	4.04	3.79

4.1.2.3 Problem Analysis

The heterogeneous field condition procedure can be mainly split into 2 parts, the setup and the verification part. In the previous section the verification part was carefully analysed and for this reason this section starts with the analysis of the setup part using the ISO reference equipment. Before doing so a summary on the NFC Forum Reference Listener properties with respect to this parameter is given and compared to ISO Reference PICCs whenever possible:

- Listeners have shown by current limits that NFC Forum testing methodology is valid
- Antenna size, design, layout, pitch track, windings: no difference between NFC Forum Listener 1, 3 and 6 and Reference PICC 1, 3 and 6
- Circuit and components (rectifier Diodes, Zener Diode, …): no difference between NFC Forum Listener 1, 3 and 6 and Reference PICC 1, 3 and 6
- Resonance frequency: 13.56 MHz; no difference between NFC Forum Listener 1, 3 and 6 and Reference PICC 1, 3 and 6
- Loading:
    - NFC Forum defines a static loading of 820 Ω for Listener 1, 3 and 6
    - difference between NFC Forum Listener 1, 3 and 6 and Reference PICC 1, 3 and 6
    - [ISO10373-6] and [ISO10373-6:AMD1] define field strength dependent load

From this analysis one can conclude that the only parameter which may cause the difference must be in the different definition of the loading between NFC Forum and [ISO10373-6]. Indeed [ISO10373-6:AMD1] defines a specific load for each Reference PICC. This load is configured by changing the resistance of R2 in order to measure a dc voltage V_{load} as depicted in Table 10 (see also [ISO10373-6:AMD1], or Table 21). Considering the actual V_{load} value definitions for each Reference PICC in Table 10 one observes that all are the same except for Reference PICC 1. Examining the setup summary of section 4.1.2.1 we note that Reference PICC 1 already during setup established the worst case for DUT Poller 0 and DUT Poller 6. After this analysis the experts of NFC Forum followed the recommendation provided in the note below Table 3 of [ISO10373-6:AMD1] which says:

"NOTE V_{load} may be harmonized to 4,5 V for all classes in future revisions of ISO/IEC 10373-6."

In order to prove the hypothesis the heterogeneous field condition procedure (see section 4.1.2) was repeated and during setup for Reference PCC 1 a V_{load} of 4.5 V(dc) was used instead of 6 V(dc).

Table 10: ISO/IEC 10373-6 Class dependent load definition for Reference PICCs (source: [ISO10373-6:AMD1], Table 3)

Class	Reference PICC	V_{load}	$R2_{min}$	$R2_{max}$	Test PCD Assembly
1	1	6,0 V(dc)	870 Ω	1070 Ω	Test PCD Assembly 1
2	2	4,5 V(dc)	1030 Ω	1260 Ω	
3	3	4,5 V(dc)	1080 Ω	1320 Ω	
4	4	4,5 V(dc)	990 Ω	1210 Ω	Test PCD Assembly 2
5	5	4,5 V(dc)	960 Ω	1170 Ω	
6	6	4,5 V(dc)	700 Ω	900 Ω	

4.1.2.4 Validation – SETUP

This section repeats the procedure for the heterogeneous field condition defined in section 4.1.2 using a V_{load} of 4.5 V(dc) for Reference PICC 1. The analysis provided in the previous section proposes this step in order to resolve the problems in the limit harmonization attempt. Table 11 - Table 14 show the measurement results on each DUT Poller for the setup procedural steps for Reference PICC 1, 2, 3 and 6. The position information is encoded according to NFC Forum definition ([NFC_ANA], [NFC_TC_ANA]) except that the rotation index digit is not shown because constant. Experience has shown that the best matching antenna size in position (0 0 0) establishes the critical condition on minimum field strength for the respective DUT Poller. Therefore, as a starting condition DUT Poller 0 was setup with Reference PICC 1, DUT Poller 3was setup using Reference PICC 3 and DUT Poller 6 was setup using Reference PICC 6. Table 11 contains the measurement results for all 3 DUT Poller when measured with Reference PICC 1. The minimum measured voltage at connector CON3 of Reference PICC 1 across all positions and DUT Poller is the position used for setup. This is highlighted in yellow colour. So indeed the change of V_{load} to 4.5 V(dc) resolved the problems faced in the first place.

Table 11: Reference PICC 1 Setup

	Poller-0		Poller-3		Poller-6	
Power loading device	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*
Ref PICC 1	000	4.51	000	6.46	000	6.57
	010	4.57	010	6.59	010	6.86
	011	4.81	011	6.40	011	6.55
	012	4.52	012	6.61	012	6.89
	013	4.66	013	6.33	013	6.63
	100	5.62	100	7.68	100	6.08
	110	5.68	110	7.86	110	6.13
	111	5.74	111	7.70	111	6.04
	112	5.67	112	7.88	112	6.13
	113	5.68	113	7.60	113	6.20
	120	5.84	120	8.27	120	5.99
	121	5.93	121	7.76	121	6.04
	122	5.77	122	8.31	122	6.09
	123	5.88	123	7.51	123	6.37

Table 12 contains all measurement result using Reference PICC 2 and all DUT Poller. For this reference device the lowest value is measure at an outside position in the z equal to 5mm plane of DUT Poller 6. The minimum V_{load} is achieved for Reference PICC 2. This is highlighted in green colour

Table 12: Reference PICC 2 Setup

	Poller-0		Poller-3		Poller-6	
Power loading device	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*
Ref PICC 2	000	7.28	000	7.57	000	8.26
	010	7.34	010	7.23	010	8.68
	011	7.54	011	7.55	011	8.35
	012	7.26	012	7.42	012	8.66
	013	7.35	013	7.44	013	8.18
	100	8.09	100	8.79	100	8.36
	110	8.09	110	8.89	110	7.63
	111	8.12	111	8.80	111	8.29
	112	8.10	112	8.85	112	7.64
	113	8.11	113	8.69	113	8.46
	120	8.12	120	9.15	120	4.64
	121	8.11	121	8.85	121	8.21
	122	8.12	122	9.03	122	4.50
	123	8.14	123	8.60	123	8.53

Table 13 shows the measurement results of the CON3 voltage measured using Reference PICC 3 for all DUT Pollers and positions. Also for Reference PICC 3 the minimum measured CON3 voltage

across all positions and DUT Pollers is the position used for setup. In this case position (0 0 0) of DUT Poller 3. This is highlighted in yellow colour.

Table 13: Reference PICC 3 Setup

	Poller-0		Poller-3		Poller-6	
Power loading device	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*
Ref PICC 3	000	8.01	000	4.51	000	9.17
	010	7.83	010	5.91	010	9.05
	011	7.78	011	5.43	011	9.16
	012	7.92	012	5.76	012	9.03
	013	7.89	013	5.33	013	9.12
	100	8.34	100	7.69	100	8.93
	110	8.36	110	8.32	110	8.80
	111	8.36	111	8.16	111	8.89
	112	8.35	112	8.32	112	8.81
	113	8.37	113	8.02	113	9.01
	120	8.33	120	9.28	120	7.89
	121	8.38	121	8.88	121	8.74
	122	8.34	122	9.31	122	7.84
	123	8.40	123	8.71	123	8.96

Table 14 shows the measurement results of the CON3 voltage measured using Reference PICC 6 for all DUT Pollers and positions. Also for Reference PICC 6 the minimum measured CON3 voltage across all positions and DUT Pollers is the position used for setup. In this case position (0 0 0) of DUT Poller 6. This is highlighted in yellow colour.

Table 14: Reference PICC 6 Setup

	Poller-0		Poller-3		Poller-6	
Power loading device	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*	**Position** (x,r,ϕ)	CON3 *V(dc)*
Ref PICC 6	000	5.26	000	7.71	000	4.55
	010	5.39	010	7.58	010	6.53
	011	5.28	011	7.68	011	6.27
	012	5.32	012	7.50	012	6.57
	013	5.38	013	7.67	013	5.91
	100	5.05	100	7.74	100	7.49
	110	5.11	110	7.70	110	7.31
	111	5.08	111	7.74	111	7.35
	112	5.12	112	7.70	112	7.31
	113	5.09	113	7.77	113	7.44
	120	5.31	120	7.30	120	5.22
	121	5.28	121	7.71	121	6.17
	122	5.17	122	7.03	122	4.96
	123	5.21	123	7.75	123	6.68

4.1.2.5 Validation – VERIFICATION

The setup analysis of the previous section indicates that the verification result will not show any conflicts for Reference Listeners or DUT Poller antenna size. Table 15 depicts the measurement results performing the verification according to the procedure. One can clearly see that the worst case, i.e., the minimum measured value of each Reference Listener is measured on that DUT Poller antenna having the most congruent size and is different for every Reference Listener. This means the NFC Forum testing methodology requirement is fulfilled and re-established due to the Reference PICC 1 V_{load} change from 6 V(dc) to 4.5 V(dc). This change of V_{load} to 4.5V(dc) is supported by ISO JTC1 SC17 WG8 group and is being integrated into the text of the 4th Edition of ISO/IEC 10373-6. The green highlighted values in Table 15 represent already the candidate limit values for NFC Forum minimum power parameter $V_{OV,\,min}$. Moreover no validation of these candidate limit values is necessary since directly derived from DUT Poller setup to exactly fulfill the H_{min} requirement of ISO/IEC 14443.

Table 15: Final measurement results containing also the candidate limit values for Reference Listening Devices (shown in green colour).

	Poller 0		Poller 3		Poller 6	
	Position	$V_{OV,\,J1}$	Position	$V_{OV,\,J1}$	Position	$V_{OV,\,J1}$
	(x,r,ϕ)	V(dc)	(x,r,ϕ)	V(dc)	(x,r,ϕ)	V(dc)
Listener 1	**000**	**4.98**	013	6.26	122	5.34
Listener 3	011	6.35	**000**	**4.68**	122	5.59
Listener 6	000	5.33	012	6.27	**000**	**4.04**

4.2 NFC Forum Listener Minimum Load Modulation Amplitude ($V_{PP, min}$) Harmonization

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.1.2.1-6.1.2.3: When put in the Operating Volume of the NFC Forum – Reference Polling Device that has been set up as described in the specification context above, the Listening Device SHALL modulate the Operating Field in such a way that the signal monitored at J2 of the NFC Forum – Reference Polling Device has the following characteristics: 6.1.2.1 The subcarrier frequency fs of the modulation signal SHALL be fc/16 for NFC-A and NFC-B. 6.1.2.2 For NFC-F, the frequency fs of the modulation signal during the preamble SHALL be fc/32 or fc/64 and SHALL be fc/32, fc/64 or fc/128 (see note 1) at other times. 6.1.2.3 The amplitude (V_{pp}) of the modulation signal at J2 of the NFC Forum – Reference Polling Device SHALL be V_{pp} (peak to peak). (Choosing a measurement position avoiding all transient effects, e.g., the first change from 0 to 1 for NFC-A, the TR1 zone for NFC-B and the zero coding preamble before the Sync code for NFC-F).
Implicit Requirement	Minimum load modulation amplitude transmission
Question	How to harmonize the LMA min limits between NFC Forum and ISO/IEC 14443?

PROCEDURE	
Step	**SETUP**
ISO Setup 1:	Tune the resonance frequency of each of the ISO Reference PICC 1, 2, 3 and 6 to 13,56 MHz and 15MHz (DUT PICCs).
NFC Forum Setup measurements	
NFC Step 2:	Setup the NFC Forum – Reference Poller 0 to nominal field strength ($V_{S,OV,nom}$).
3	Place DUT L1 (loading 330Ω) in the NFC OV and measure the V_{OV} in the whole NFC OV of NFC Forum – Reference Poller 0.
4	Repeat step 3 for DUT L3 and DUT L6.
5	For each position of the NFC OV perform the steps below: Place the DUT PICC 1 in each position of the complete NFC OV of the NFC Forum – Reference Poller 0 and adjust the load measured at CON3 to the value defined in Table 21 by changing the CON2 DC voltage. Record this V(dc) value.
6	Repeat step 5 for DUT PICC 2, 3 and 6.
7	Repeat steps 2) – 6) with NFC Forum – Reference Poller 3 and 6.
8	Repeat steps 2) – 7) for maximum setup field strength ($V_{S,OV,max}$).
ISO/IEC Setup measurements	
9	Place the DUT PICC 1 in the DUT position on the Test PCD Assembly 1.

	Note: This procedure is defined to meet PICC CLASS1-3 requirements only, independent on antenna form factor.
10	Set the load changing voltage (CON2 of DUT PICC) to the value measured in step 5 and increase the field strength until the value defined in Table 21 is measured. Read the calibration coil voltage.
11	Increase the LMA input signal until the CLASS1 PCD minimum LMA value defined for this field strength is achieved (as defined in Table 24) and record the load modulator input voltage. Additionally, measure the LMA signal using the NFC Forum method for load modulation amplitude measurement.
12	Increase the LMA input signal until the CLASS1 PICC minimum LMA value defined for this field strength is achieved (as defined in Table 27) and record the load modulator input voltage. Additionally, measure the LMA using the NFC Forum method for load modulation amplitude measurement.
13	Repeat steps 10) – 12) for each position of the NFC OV.
14	Repeat Steps 9) – 13) for DUT PICC 2, 3 and 6.
15	Place the DUT L1 (330R) in the DUT position of the Test PCD Assembly 1.
16	Set the field strength such that the V_{OV} value measured in step 3 is achieved.
17	Increase the LMA input signal until the CLASS1 PCD minimum LMA value defined for this field strength is achieved (as defined in Table 24) and record the load modulator input voltage. Additionally, measure the LMA using the NFC Forum method for load modulation amplitude measurement.
18	Increase the LMA input signal until the CLASS1 PICC minimum LMA value defined for this field strength is achieved (as defined in Table 27) and record the load modulator input voltage. Additionally, measure the LMA using the NFC Forum method for load modulation amplitude measurement.
19	Repeat steps 16) – 18) for each position of the NFC OV.
20	Repeat Steps 15) – 19) for DUT L3 and DUT L6.
NFC Forum Verification measurements	
21	Setup the NFC Forum – Reference Poller 0 to nominal field strength ($V_{S,OV,nom}$).
22	Place DUT L1 (loading 330Ω) in the NFC OV and configure the PCD limit load modulation input amplitude to the value measured in step 17 for this field strength/position of the NFC Forum – Reference Poller 0.
23	Measure the LMA using the ISO DFT method as well as the NFC Forum method.
24	Repeat Step 22) – 23) for the PICC limit load modulation input amplitude of step 18.
25	Perform steps 22) – 24) for all position of the NFC OV.
26	Repeat steps 22) – 25) for DUT L3 and DUT L6.
27	For each position of the NFC OV perform the steps below:

	Place the DUT PICC1 in each position of the complete NFC OV of the NFC Forum – Reference Poller 0 and set DC voltage of CON2 of the DUT PICC1 to the value measured in step 5 and configure the load modulation input amplitude to the value measured in step 11 (PCD LMA limit) for this field strength/position of the NFC Forum – Reference Poller 0.
28	Measure the LMA using the ISO DFT method as well as the NFC Forum method.
29	Repeat Step 27) – 28) for the load modulation input amplitude of step 12 (PICC LMA limit).
30	Repeat steps 27) – 29) for DUT PICC 2, 3 and 6.
31	Repeat steps 21) – 30) with NFC Forum – Reference Poller 3 and 6.
32	Repeat steps 21) – 31) for maximum setup field strength ($V_{S,OV,max}$).

The subsequent sections contain the measurement results for the harmonization of the Listener minimum load modulation amplitude parameter. The expected outcome carrying out the procedure are candidate limit value for LMA_{min} in NFC Forum which achieve interoperability or compliance to ISO/IEC 14443 when measure on Reference Poller 0, 3 and 6. As DUT Listeners to following devices have been selected:

- Listener 1, 3 and 6 each configured to 330 Ω loading
- Reference PICC 1, 2, 3 and 6 tuned to a resonance frequency of 13.56 MHz
- Reference PICC 1, 2, 3 and 6 tuned to a resonance frequency of 15 MHz

In order to allow full flexibility the below results do not follow the above described procedure step by step but instead follow a slightly different strategy with the same result. The above procedure can be split into 3 main steps:

1. NFC Forum Setup: Measure field strength on Reference Poller 0, 3 and 6 with DUT Listeners (Listener 1, 3,6 and Reference PICC 1,2,3 and 6)
2. ISO Setup – Test PCD Assembly: For each measured field strength setup the LMA_{min} as defined for PICC and PCD of each DUT Listener
3. NFC Forum Setup: For position with field strength as measured in step 1 adjust the LMA_{min} output to the value as determined in step 2 and measure LMA according the NFC Forum.

The below followed procedure merged step 1 and 2 as shown above. This is achieved as follows:

1. ISO Setup – Test PCD Assembly:
    a. Perform an H-field sweep from below H_{min} to a value exceeding H_{max}. The step size for this sweep was set to 50mA/m(rms).
    b. For each field strength value setup the LMA_{min} as defined for this field strength (PCD ($V_{LMA,\ PCD}$) and PICC ($V_{LMA,\ PICC}$) limit). If the field strength is below H_{min} take the LMA_{min} limit value defined for H_{min}). If the field strength is above H_{max} take the LMA_{min} limit value defined for H_{max}.
2. NFC Forum Setup:
    a. For each position in the NFC Forum measure the V(dc) in case of DUT Listeners or adjust V_{load} and measure the needed CON2 V(dc) in case of DUT PICC.

b. For measured values in 2)a) search the corresponding LMA output amplitude in 1)b). In case the measured field strength is between 2 measurement points of 1) use linear interpolation. This approach is valid due to the continuous run of LMA over field strength.

4.2.1 Part1: H-field Versus LMA_{min} Versus V(dc) Versus AWG LMA Output

This section contains the result for each selected DUT Listener when measured on the Test PCD Assembly 1 according to the adapted procedure described in previous section 4.2. For each DUT placed on the Test PCD Assembly the field strength is set to the target value. The measured V(dc) or V(dc) required to achieve the target V_{load} are recorded. Afterwards the LMA is adjusted to the $V_{LMA, PCD}$ or $V_{LMA, PICC}$ limit value defined for the field strength. The needed load modulation drive level to achieve the LMA_{min} limit from an Arbitrary Waveform Generator (AWG) is noted. Repeating these steps for the entire field strength range results in a so called mapping table. This mapping table provides information on the required AWG drive level for a given field strength in order to achieve an LMA of exactly the LMA_{min} limit defined for either PCD or PICC ($V_{LMA, PCD}$ or $V_{LMA, PICC}$).

4.2.1.1 NFC Forum Reference Listening Devices as DUT

Figure 20 visualizes the mapping table for DUT L1 and a loading of 330 Ω. The Figure consists of 3 subplots. Each subplot depicts another parameter over field strength. The top subplot shows the measured LMA setup to the limit value over field strength. In red colour with a left triangle the PICC limit and with a right triangle the PCD limit over field strength are plotted. The middle plot additionally provides results on the measured AM LMA in mV_{PP} as defined by NFC Forum if measured on the Test PCD Assembly. Finally the bottom subplot contains 2 parameters. In blue colour the DUT measured V(dc) which is linearly increasing with increasing field strength. In orange colour with an x-mark at every measurement point the AWG drive level in order to achieve the PCD LMA_{min} limit and with a diamond at each measurement point the AWG drive level in order to achieve the PICC LMA_{min} limit is depicted. The vertical red line indicates the lowest field strength for which the DUT still can be setup to achieve the limit values. This point is marked as "valid range for load modulation". Consequently, for any field strength higher than the minimum field strength of approximately 0.9 A/m(rms) this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. For a measured field strength below this point this is not the case therefore such a field strength has to be excluded.

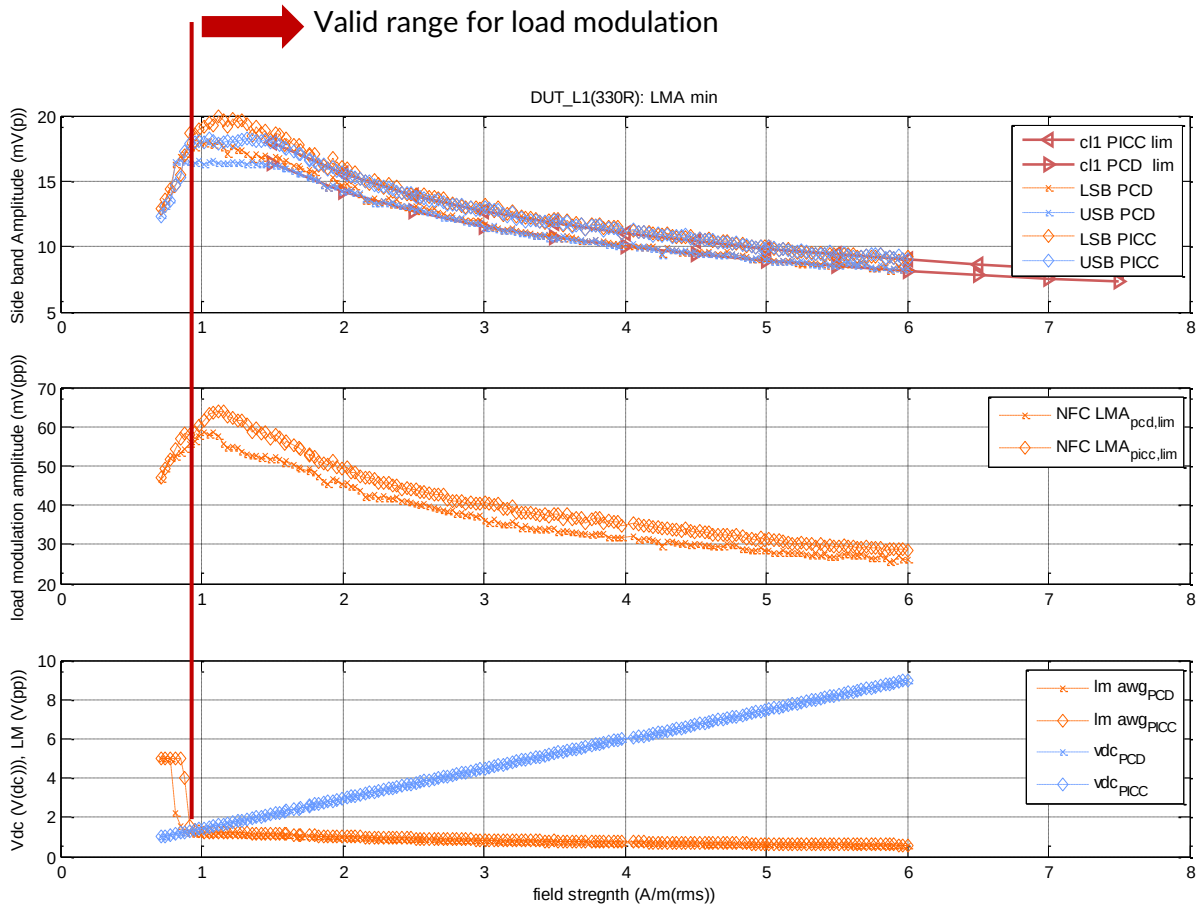


Figure 20: DUT L1(330R) mapping table for LMA harmonization

Figure 21 visualizes the mapping table for DUT L3 and a loading of 330 Ω. The description of Figure 20 similarly applies for this Figure. The lower bound of valid operation marked as "valid range for load modulation" for DUT L3 is approximately 2.3 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. Any measured field strength below this point is invalid and therefore has to be excluded.

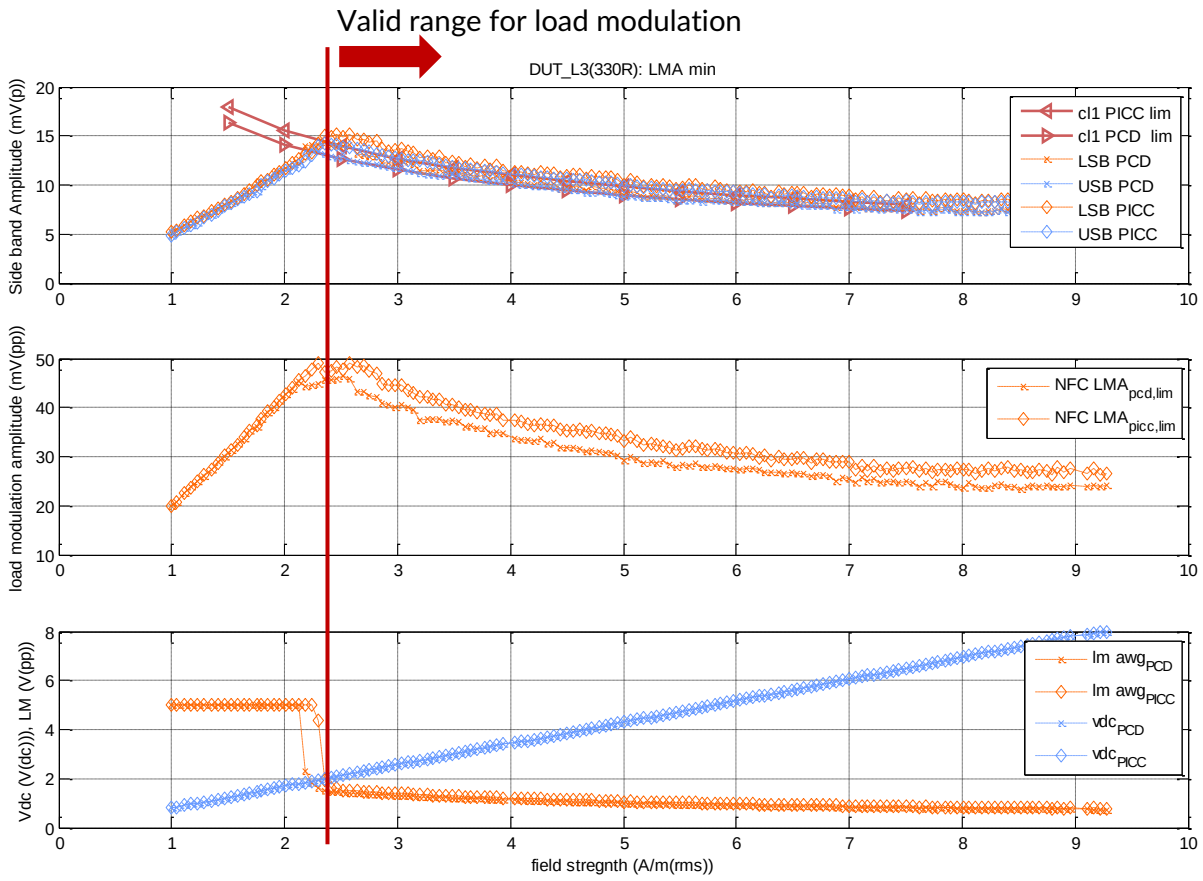


Figure 21: DUT L3(330R) mapping table for LMA harmonization

Figure 22 visualizes the mapping table for DUT L6 and a loading of 330 Ω. The description of Figure 20 similarly applies for this Figure. The lower bound of valid operation marked as "valid range for load modulation" for DUT L6 is approximately 4 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. Any measured field strength below this point is invalid and therefore has to be excluded.

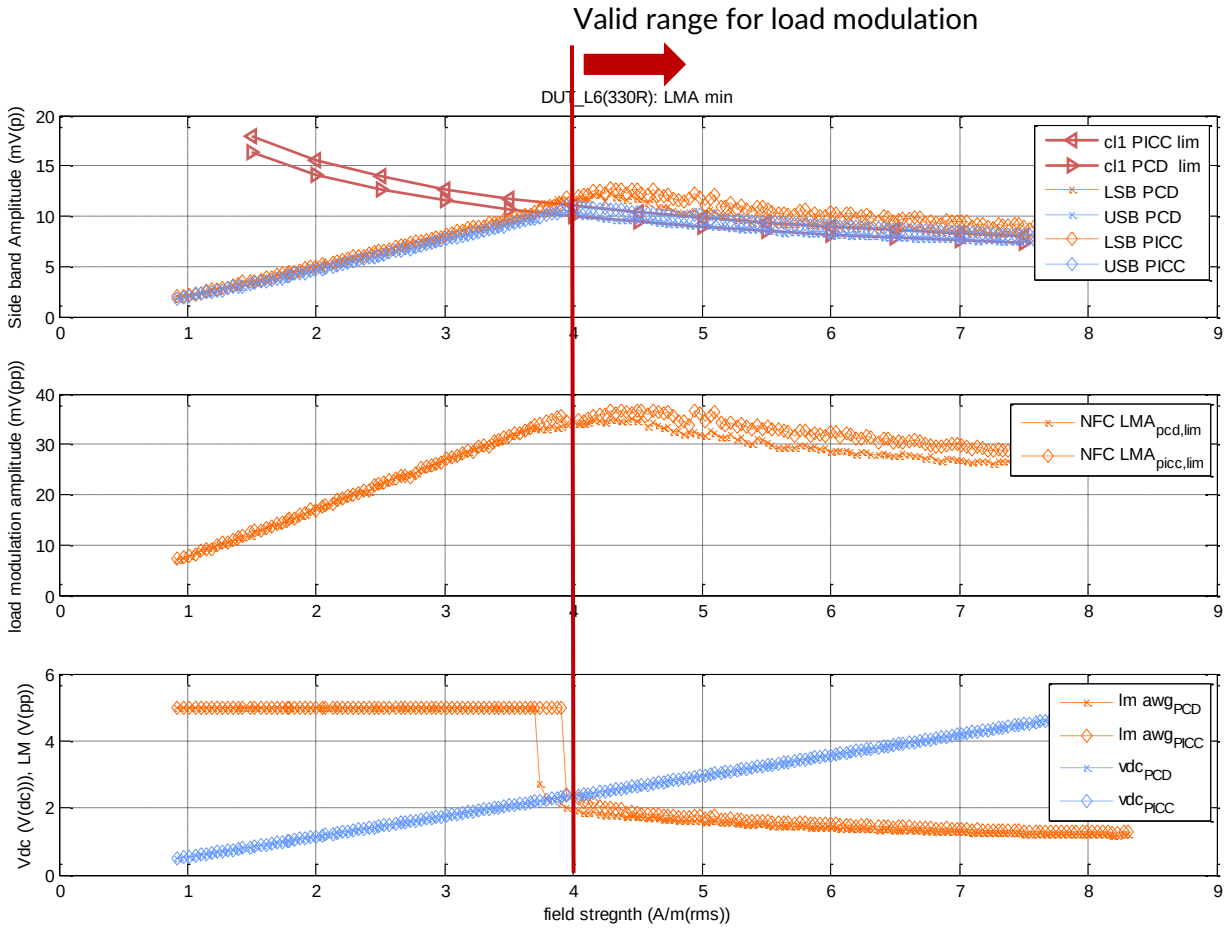


Figure 22: DUT L6(330R) mapping table for LMA harmonization

4.2.1.2 ISO Reference PICCs as DUT

Figure 23 contains 2 mapping table results. On the left hand side the mapping table for Reference PICC 1 and a resonance frequency of 13.56 MHz and on the right hand side the mapping table of Reference PICC 1 and a resonance frequency of 15 MHz. Each Subfigure consists of 3 subplots. Each subplot depicts another parameter over field strength. The top subplot shows the measured LMA setup to the limit value over field strength. In red colour with a left triangle the PICC limit and with a right triangle the PCD limit over field strength are plotted. The middle plot additionally provides results on the measured AM LMA in mV_{PP} as defined by NFC Forum if measured on the Test PCD Assembly. Finally the bottom subplot contains 2 parameters. In blue colour the DUT measured V_{load} in V(dc) which is constant within the ISO defined field strength range. Below H_{min}, the load is not further changed in order to achieve the target V_{load} defined for the Reference PICC. Instead the maximum loading is kept constant. In orange colour with an x-mark at every measurement point the AWG drive level in order to achieve the PCD LMA_{min} limit and with a diamond at each measurement point the AWG drive level in order to achieve the PICC LMA_{min} limit is depicted. The lower bound of valid operation for DUT Reference PICC 1 is approximately 0.5 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. For a measured field strength below this point this is not the case therefore such a field strength has to be excluded.

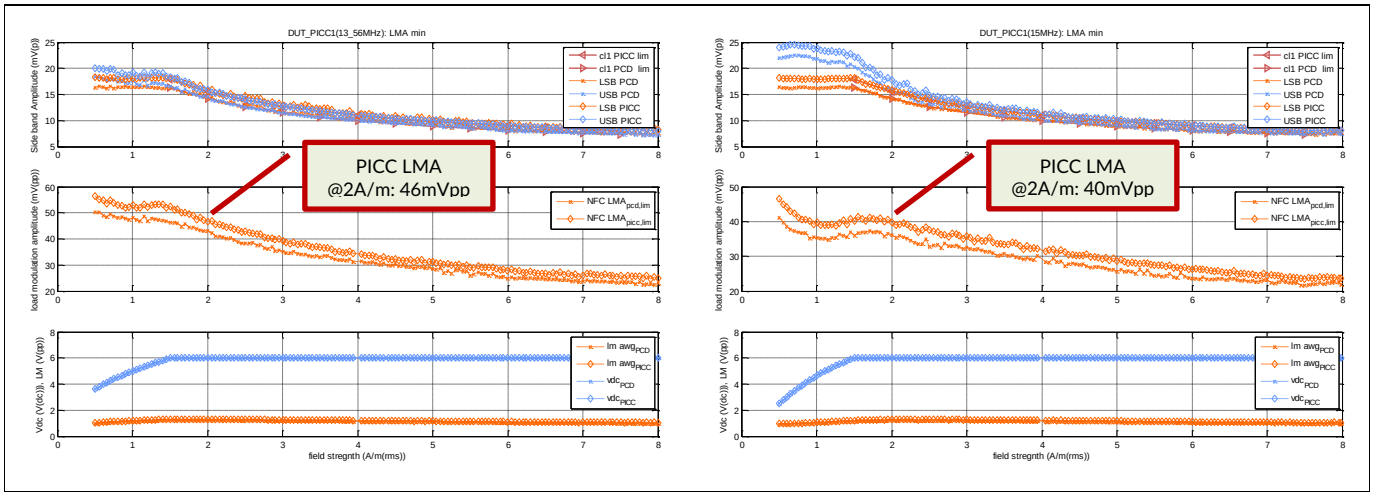


Figure 23: DUT PICC 1 mapping table for LMA harmonization. Left hand side: f_{res} = 13,56MHz; Right hand side: f_{res} = 15MHz

Figure 24 visualizes the mapping table for DUT Reference PICC 2. The description of Figure 23 similarly applies for this Figure. The lower bound of valid operation for DUT Reference PICC 2 is approximately 0.8 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. Any measured field strength below this point is invalid and therefore has to be excluded.

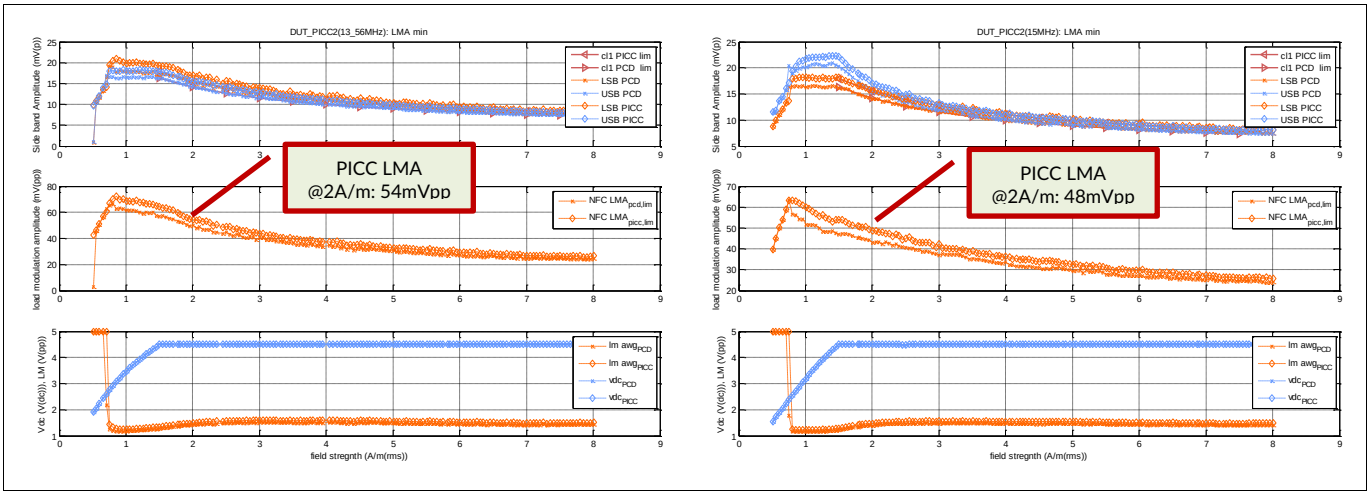


Figure 24: DUT PICC 2 mapping table for LMA harmonization. Left hand side: fres = 13,56MHz; Right hand side: fres = 15MHz

Figure 25 visualizes the mapping table for DUT Reference PICC 3. The description of Figure 23 similarly applies for this Figure. The lower bound of valid operation for DUT Reference PICC 3 is approximately 0.8 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. Any measured field strength below this point is invalid and therefore has to be excluded.

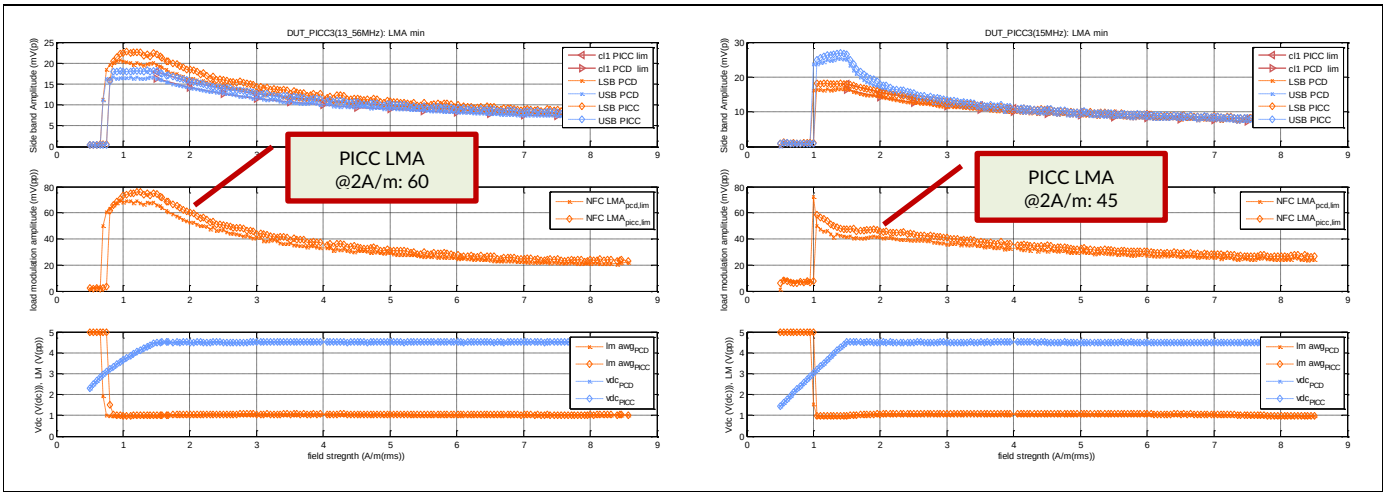


Figure 25: DUT PICC 3 mapping table for LMA harmonization. Left hand side: fres = 13,56MHz; Right hand side: fres = 15MHz

Figure 26 visualizes the mapping table for DUT Reference PICC 6. The description of Figure 23 similarly applies for this Figure. The lower bound of valid operation for DUT Reference PICC 6 is approximately 3.5 A/m(rms). Consequently, for any field strength higher than this minimum field strength this DUT can be setup to transmit an LMA at the limit for PICC or PCD, respectively. Any measured field strength below this point is invalid and therefore has to be excluded.

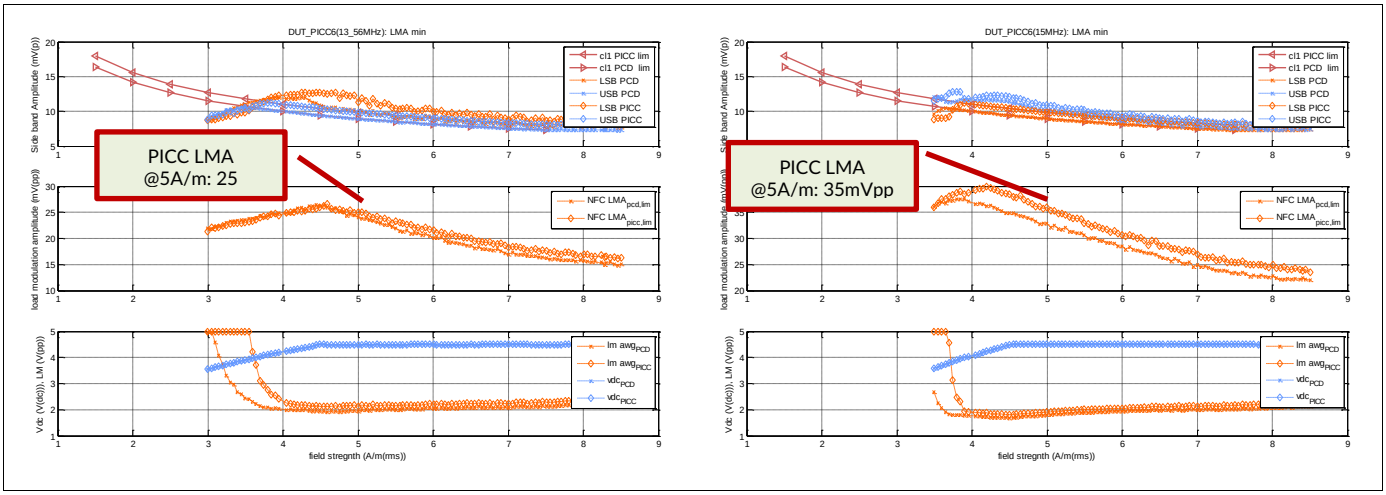


Figure 26: DUT PICC 6 mapping table for LMA harmonization. Left hand side: fres = 13,56MHz; Right hand side: fres = 15MHz

4.2.2 Part 2: Verification of LMA_{min} Harmonization

This section presents the LMA result of the ISO/IEC 14443 PICC and PCD limit values if transformed to NFC Forum. In particular, section 4.2.2.1 contains the transformed limits if measured according to the LMA definition in NFC Forum, namely the AM LMA. Section 4.2.2.2 presents the transformed limits if using the ISO defined DFT method measuring the upper and lower side band amplitudes on NFC Forum Reference Poller.

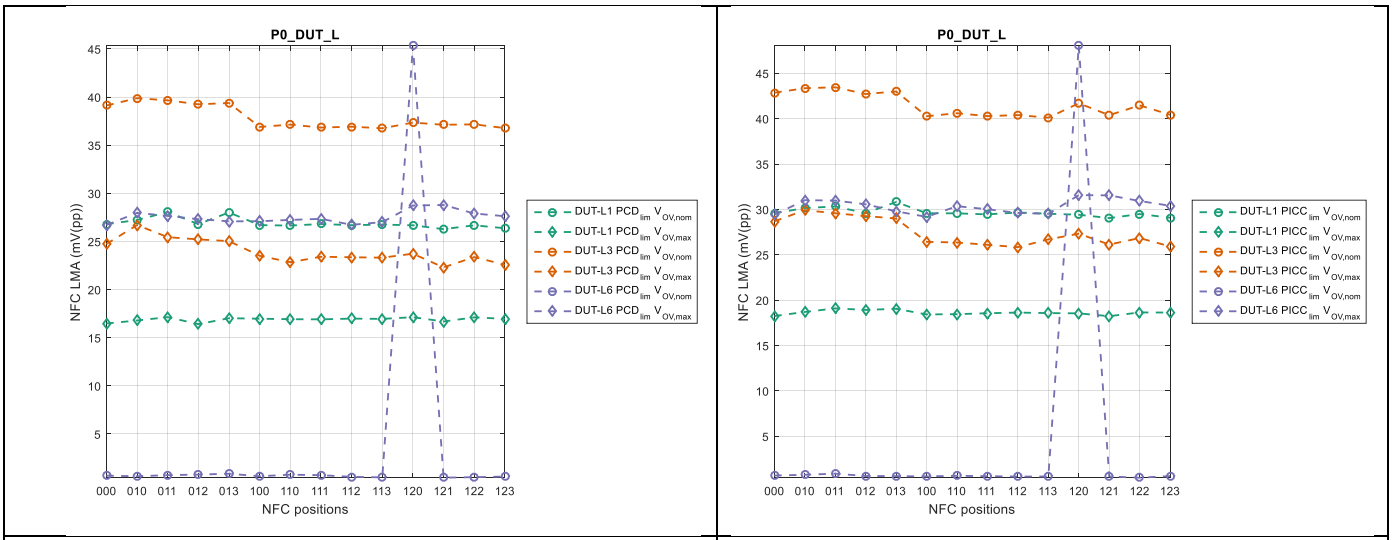
4.2.2.1 NFC LMA Signal Analysis Results: PCD and PICC limit

This section contains the LMA AM measurement result as received by the NFC Forum Reference Poller for DUT Listeners and DUT PICCs transmitting an LMA exactly on the PCD and PICC limit defined by ISO/IEC 14443. The first section contains the results on each Reference Poller for DUT Listeners and the subsequent section the LMA AM results for DUT PICCs configured to different resonance frequencies (f_{RES}). For each position of the NFC Forum operating volume the LMA is

measured. Therefore each result plot shows the LMA as a function of NFC position. The position index is following the NFC Forum convention except that the last digit encoding the DUT rotation is removed because only the nominal rotation is used (see [NFC_ANA], [NFC_TC_ANA]).

DUT Listener (330Ω) LMA (AM) results for all Poller

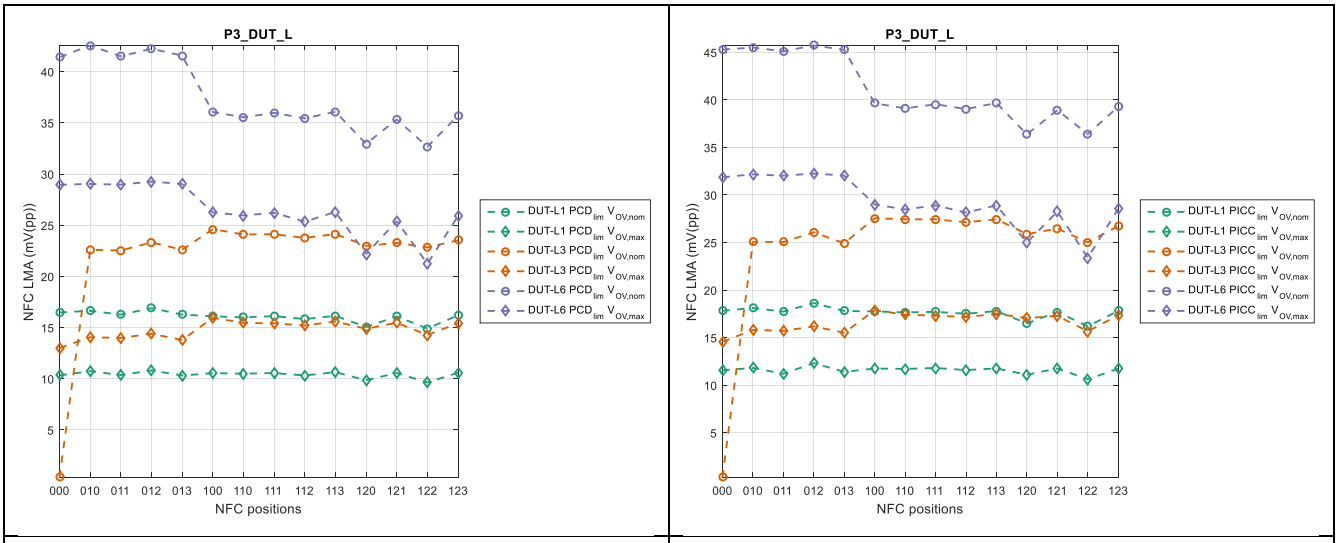
Figure 27 depicts the LMA AM (mV_{PP}) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT Listeners transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT Listeners transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT Listener. For each DUT Listener two sets of measurement results are included, one for the nominal ($V_{S,OV,nom}$) and one for the maximum ($V_{S,OV,max}$) power condition. For DUT Listener 6 and the nominal power condition only for one position the minimum required field strength in order to deliver a valid result is observed. For all other positions the minimum field strength required to deliver valid results was not met and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 27: LMA_{min} AM: DUT Listeners on Reference Poller 0

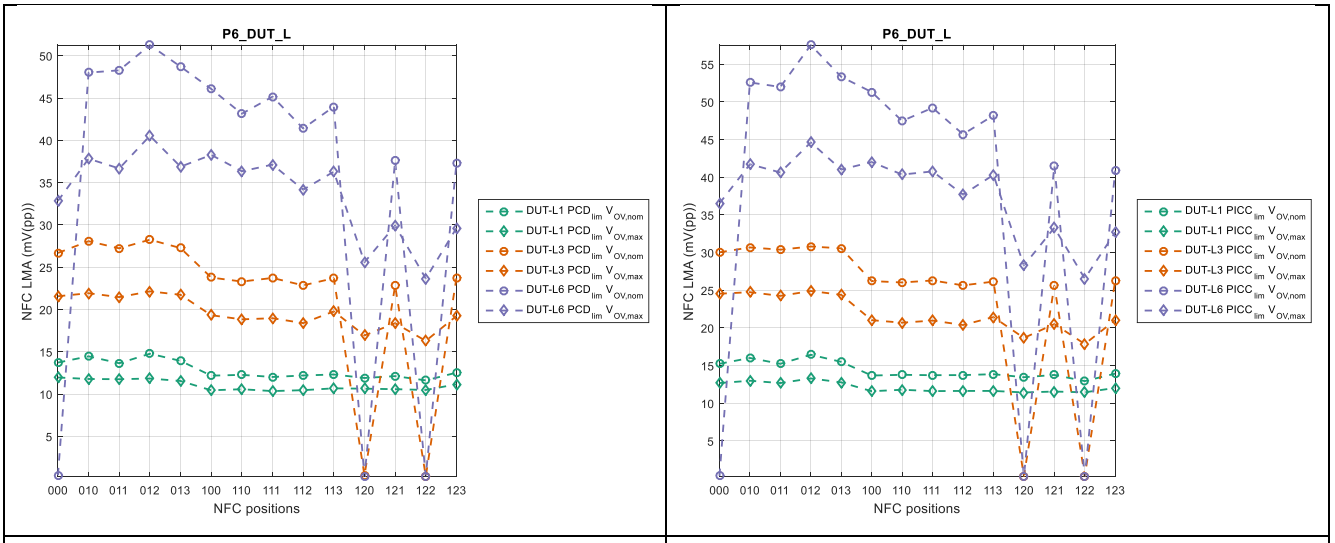
Figure 28 depicts the LMA AM (mV_{PP}) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 27. For DUT Listener 3 and the nominal power condition and position NFC OV (0 0 0) the minimum required field strength required to deliver valid results was not met and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 28: LMA$_{min}$ AM: DUT Listeners on Reference Poller 3

Figure 29 depicts the LMA AM (mV$_{PP}$) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 27. For DUT Listener 1, 3 and the nominal power condition 2 positions did not observe the minimum required field strength in order to deliver a valid result and therefore had been set to zero.

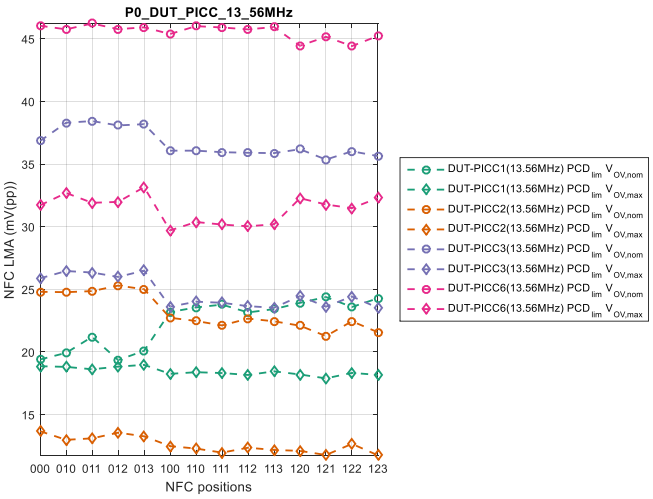


PCD limit harmonization	PICC limit harmonization

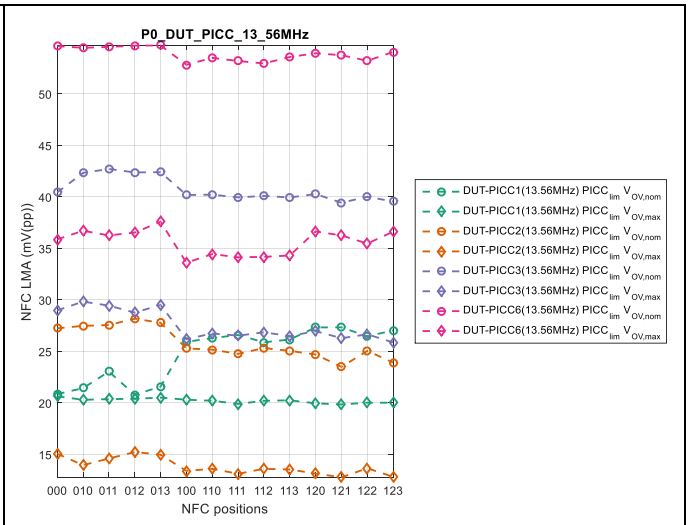
Figure 29: LMA$_{min}$ AM: DUT Listeners on Reference Poller 6

DUT PICC(13,56MHz) LMA (AM) results for all Poller

Figure 30 depicts the LMA AM (mV$_{PP}$) results for all DUT PICCs for a f_{RES} of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT PICCs transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT PICCs transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT PICC. For each DUT PICC two sets of measurement results are included, one for the nominal ($V_{S,OV,nom}$) and one for the maximum ($V_{S,OV,max}$) power condition.



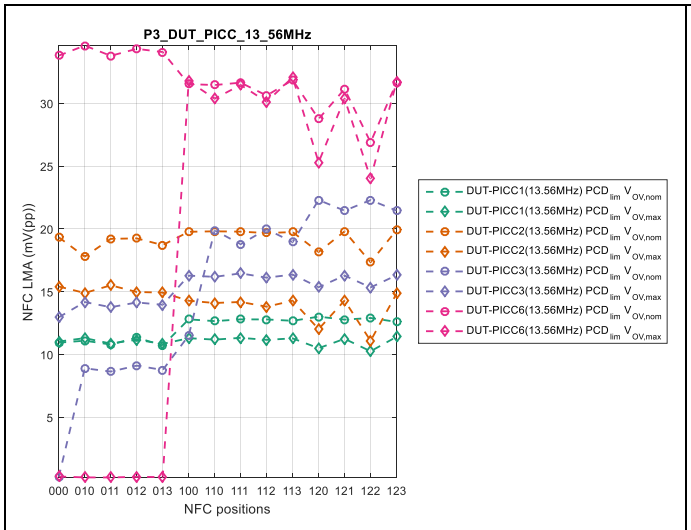
PCD limit harmonization



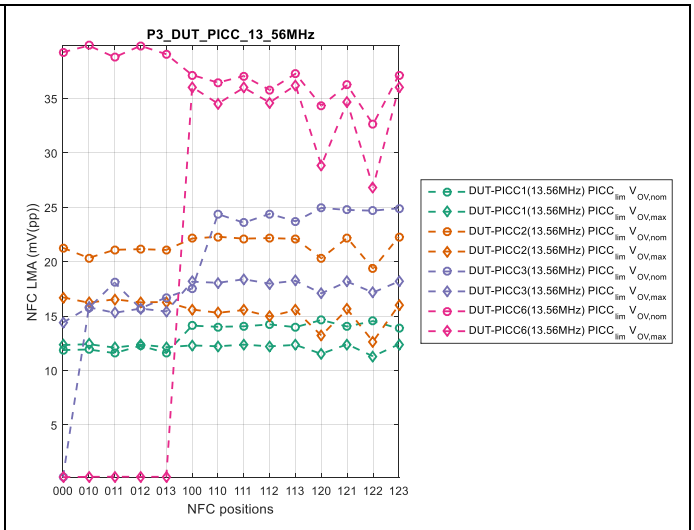
PICC limit harmonization

Figure 30: LMA$_{min}$ AM: DUT PICCs f_{res} = 13,56MHz on Reference Poller 0

Figure 31 depicts the LMA AM (mV_{PP}) results for all DUT PICCs for a f_{RES} of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 30. For DUT PICC 6 and the maximum power condition and positions in the zero plane the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



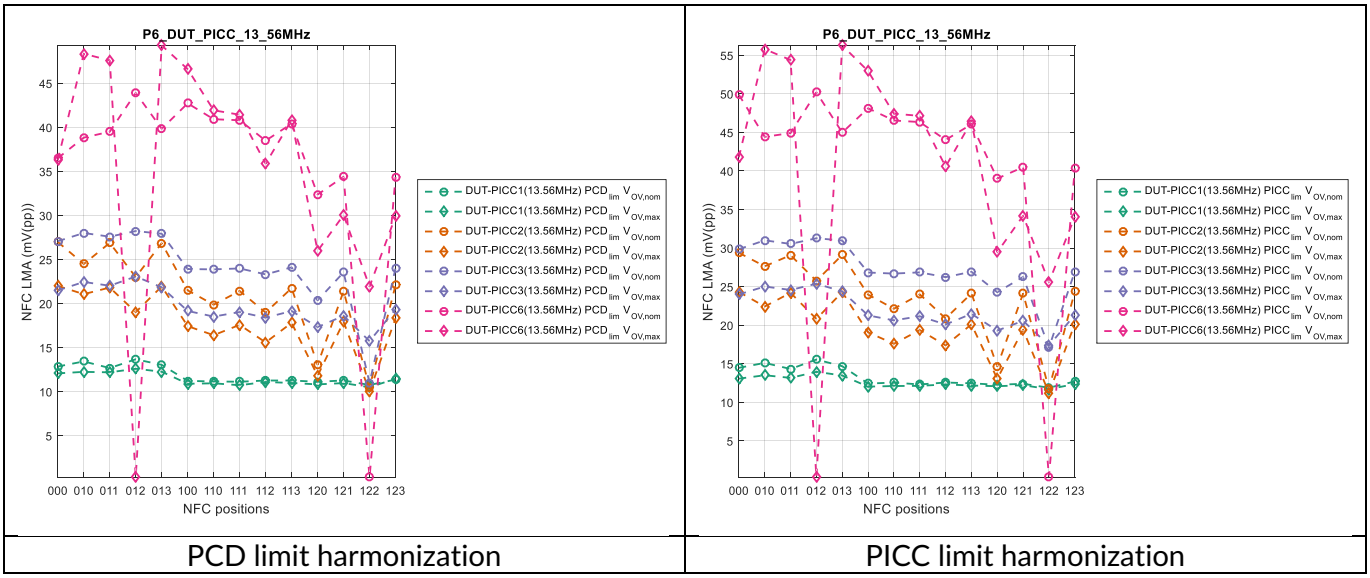
PCD limit harmonization



PICC limit harmonization

Figure 31: LMA$_{min}$ AM: DUT PICCs f_{res} = 13,56MHz on Reference Poller 3

Figure 32 depicts the LMA AM (mV_{PP}) results for all DUT PICCs for a f_{RES} of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 30. For DUT PICC 6 and the maximum power condition in two positions the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.

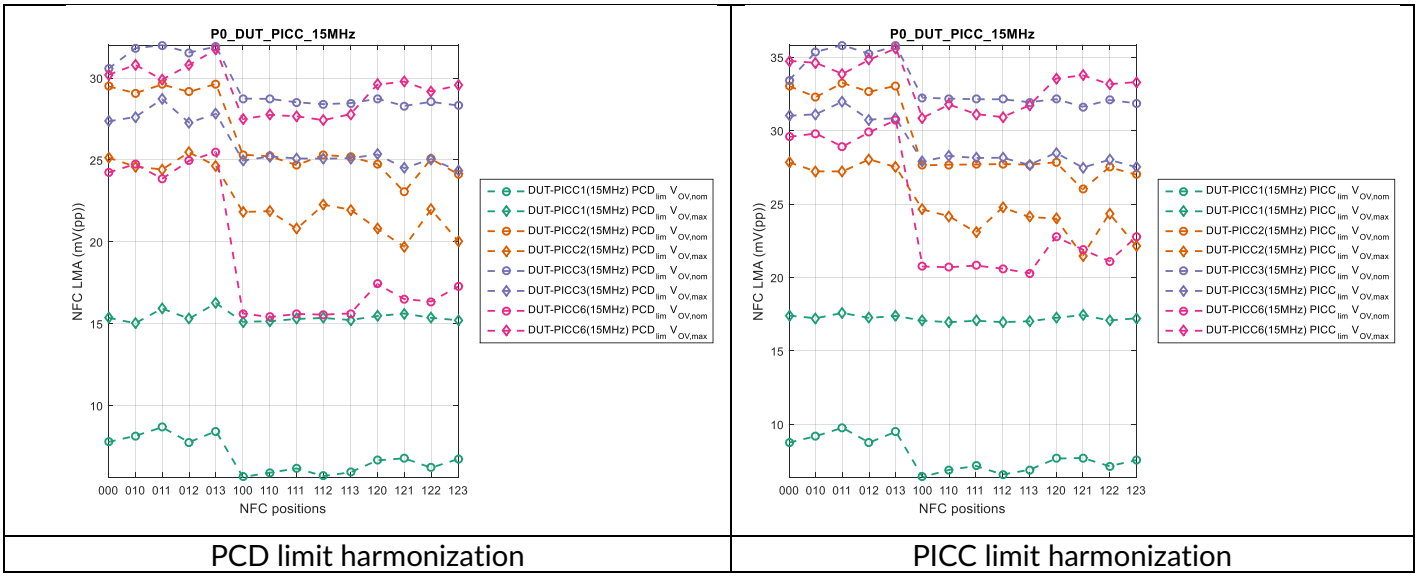


PCD limit harmonization	PICC limit harmonization

Figure 32: LMA$_{min}$ AM: DUT PICCs f_{res} = 13,56MHz on Reference Poller 6

DUT PICC(15MHz) LMA (AM) results for all Poller

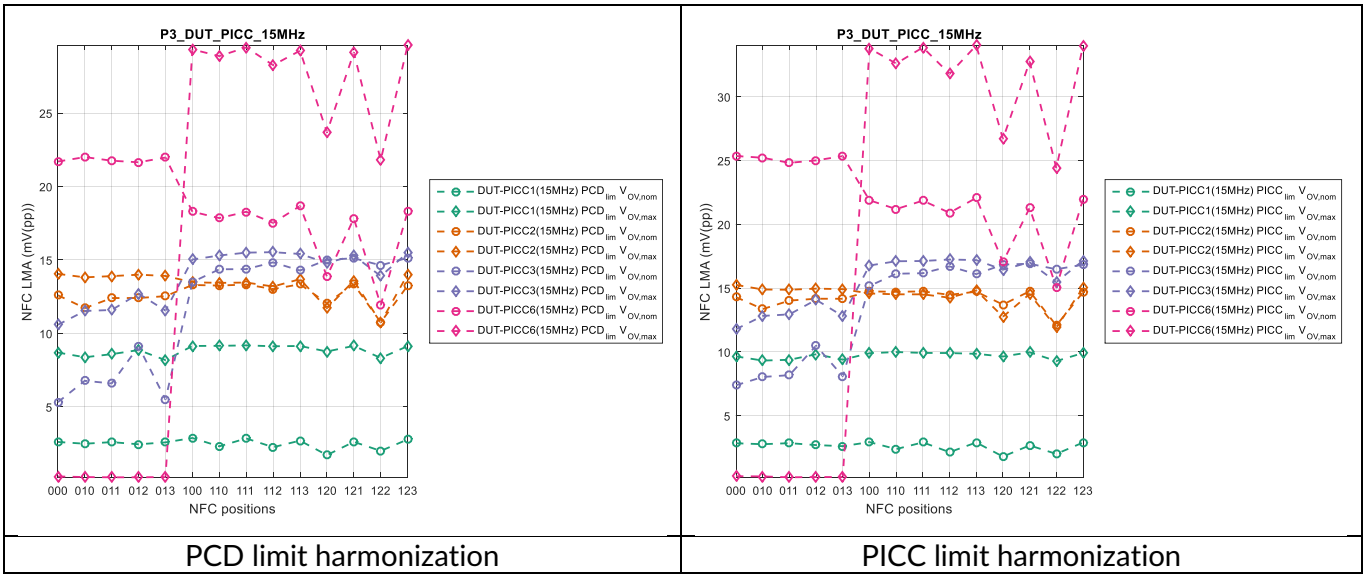
Figure 33 depicts the LMA AM (mV_{PP}) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT PICCs transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT PICCs transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT PICC. For each DUT PICC two sets of measurement results are included, one for the nominal ($V_{S,OV,nom}$) and one for the maximum ($V_{S,OV,max}$) power condition.



PCD limit harmonization	PICC limit harmonization

Figure 33: LMA$_{min}$ AM: DUT PICCs f_{res} = 15 MHz on Reference Poller 0

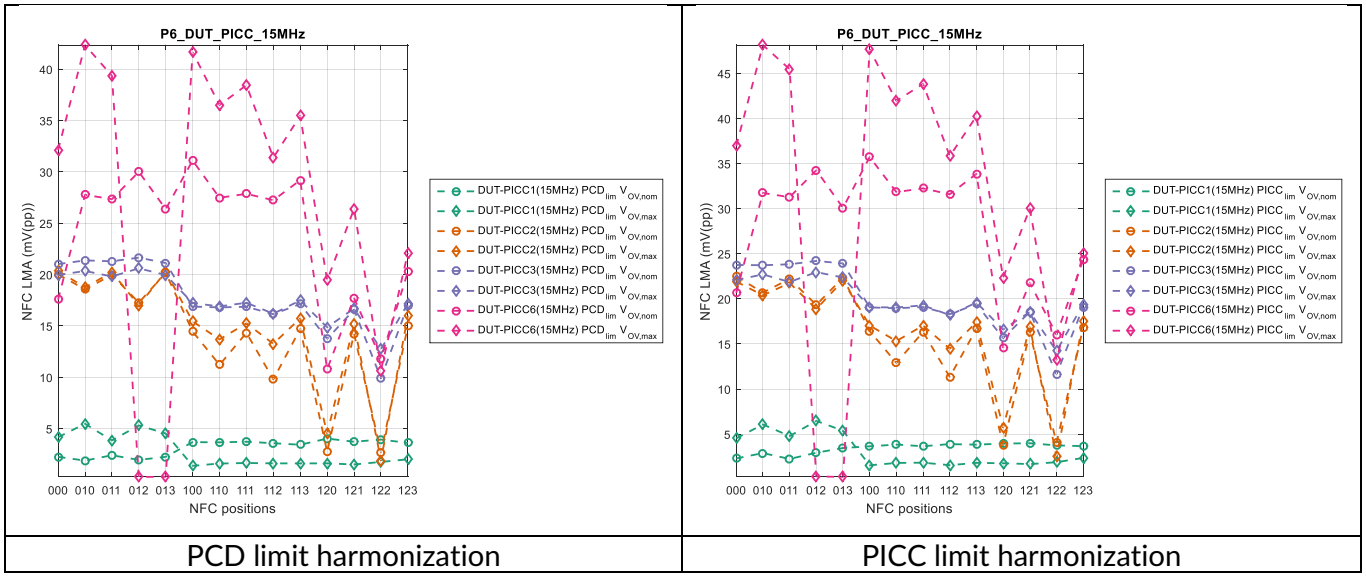
Figure 34 depicts the LMA AM (mV_{PP}) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 33. For DUT PICC 6 and the maximum power condition and positions in the zero plane the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 34: LMA$_{min}$ AM: DUT PICCs f_{res} = 15 MHz on Reference Poller 3

Figure 35 depicts the LMA AM (mV_{PP}) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 33. For DUT PICC 6 and the maximum power condition in two positions the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 35: LMA$_{min}$ AM: DUT PICCs f_{res} = 15 MHz on Reference Poller 6

Summary NFC LMA – PICC / PCD limit harmonization

The evaluation of the results contained in Figure 27 to Figure 35 allow to draw the following general conclusions:

- For a given power condition the LMA of each DUT is quite constant across all position of the operating volume.
- The Reference Poller received LMA value is different for different power conditions.
- The required LMA$_{min}$ is higher for DUT antenna sizes of Class 1 and nominal power condition compared to maximum power condition.

- DUTs of small antenna size cause a significant change to the existing NFC Forum limit values compared to just analyzing Class 1 antenna size.

In the current version of the specifications NFC Forum does not define limit values in dependence of field strength or DUT antenna size. Therefore the summery targets to maintain this situation and to analyse its impact. The measurement results as contained in the Figure 27 to Figure 35 can be used to determine candidate limits for Listener transmission in NFC Forum. For example Table 16, contains the maximum LMA value across DUT L1- DUT L6 and all positions as received at Reference Poller 0 for ISO/IEC 14443 PCD and PICC limit respectively. The same result for DUT PICC with f_{RES} of 13.56 and 15 MHz are shown. This means this summary table covers all relevant antenna sizes for mobile devices. Finally by selecting the DUT L1 maxima candidate limits independent on the field strength and DUT antenna size can be defined. Note, actually the maximum value for each column would result in compliance or interoperability to ISO/IEC 14443. This however would results in a too large change compared to the existing limits, which are added in the last row of Table 16 for better comparison.

Table 16: Candidate Limits for Listener min LMA harmonization for NMD of class 1, 2, 3 & 6

DUT	NFC Ref Poller 0		NFC Ref Poller 3		NFC Ref Poller 6	
	PCD lim	PICC lim	PCD lim	PICC lim	PCD lim	PICC lim
max. L1 – L6 mV(pp)	45	47	43	45	49	52
max. PICC1-PICC6 (13.56MHz) mV(pp)	46	52	34	37	47	55
max. PICC1-PICC6 (15MHz) mV(pp)	33	35	30	35	43	47
Resulting candidate limit mV(pp):	45	47	43	45	49	52
Existing limits mV(pp):	20		9.5		7	

In case one would take into account only DUT Listener/PICC antenna sizes of Class 1 to 3 the change in limit values compared to the existing limit values would be significantly lower. This is summarized in Table 17.

Table 17: Candidate Limits for Listener min LMA harmonization for NMD of class 1, 2 and 3

DUT	NFC Ref Poller 0		NFC Ref Poller 3		NFC Ref Poller 6	
	PCD lim	PICC lim	PCD lim	PICC lim	PCD lim	PICC lim
max. L1 – L3 mV(pp)	39	43	24	28	27	30
max. PICC1-PICC3 (13.56MHz) mV(pp)	38	43	22	25	28	31
max. PICC1-PICC3 (15MHz) mV(pp)	33	35	15	17	22	24
Resulting candidate limit mV(pp):	39	43	24	28	28	31
Existing limits mV(pp):	20		9.5		7	

The candidate limits as contained in Table 16 for any Listener antenna size are exceeding the possibilities of NFC Forum by margins. It would result in too high requirements for Class 1, 2 and 3

antenna sized Listeners and would result that Listeners with Class 6 antenna size barely achieve the minimum required LMA. On the other hand the candidate limits shown in Table 17 are much lower compared to Table 16 with the drawback to cover only antenna sizes of Class 1 to 3.

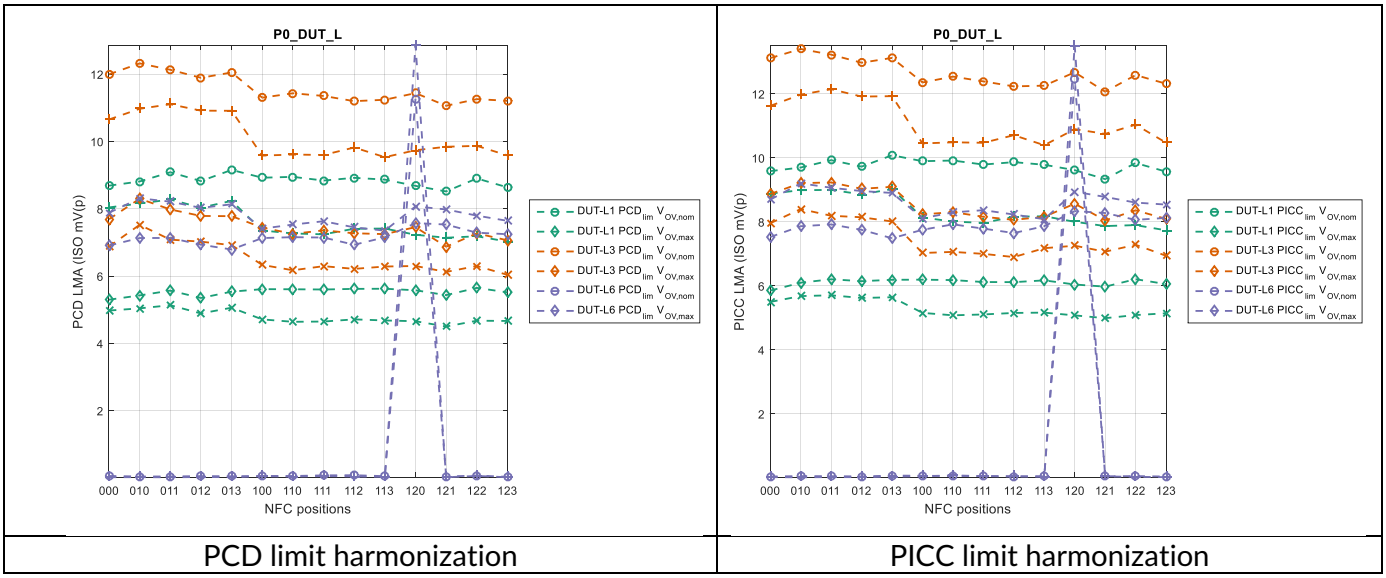
Therefore one can conclude that a good alignment on this parameter limit to ISO/IEC 14443 which is valid in both directions, from NFC Forum to ISO/IEC 14443 and vice versa, can only be achieved by taking into account both, power conditions and antenna size.

4.2.2.2 DFT LMA Signal Analysis Results: PCD and PICC Limit

This section performs the same analysis then the previous section 4.2.2.1 but instead of evaluating the LMA AM as defined by NFC Forum the DFT method is used. The main difference in the LMA measurement method is that the LMA AM method does not take into account the phase information contained in the LMA signal. The first section below contains the results on each Reference Poller for DUT Listeners and the subsequent section the LMA DFT results for DUT PICCs configured to different resonance frequencies. Both, the upper and lower side band amplitudes (SBA) are depicted in the result figures. For each position of the NFC Forum operating volume the LMA is measured. Therefore each result plot shows the LMA as a function of NFC position. The position index is following the NFC Forum convention except that the last digit encoding the DUT rotation is removed because only the nominal rotation is used (see [NFC_ANA], [NFC_TC_ANA]).

DUT Listener DFT LMA results for all Reference Poller

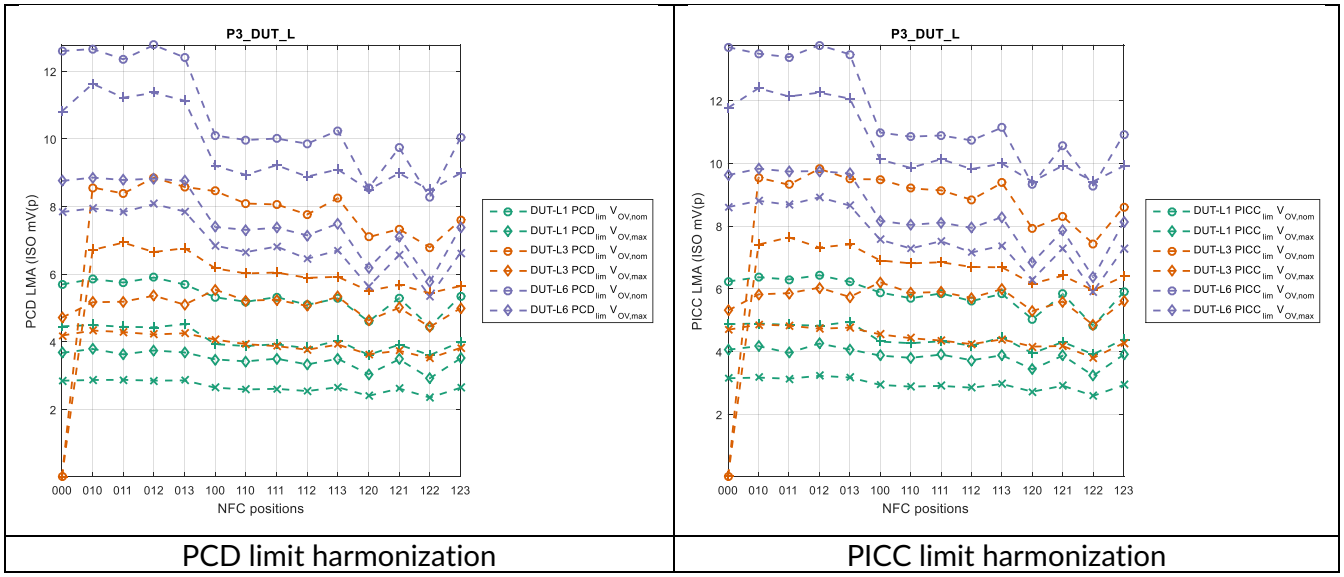
Figure 36 depicts the LMA DFT (mV_P) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT Listeners transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT Listeners transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT Listener. For each DUT Listener two sets of measurement results are included, one for the nominal ($V_{S,OV,nom}$) and one for the maximum ($V_{S,OV,max}$) power condition. The upper side band amplitude (USB) results are indicated by the respective symbols in the legend of the figures. The lower side band amplitudes (LSB) are indicated by plus signs. For DUT Listener 6 and the nominal power condition only for one position the minimum required field strength in order to deliver a valid result is observed. For all other positions the minimum required field strength required to deliver valid results was not met and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 36: LMA$_{min}$ SBA: DUT Listeners on Reference Poller 0

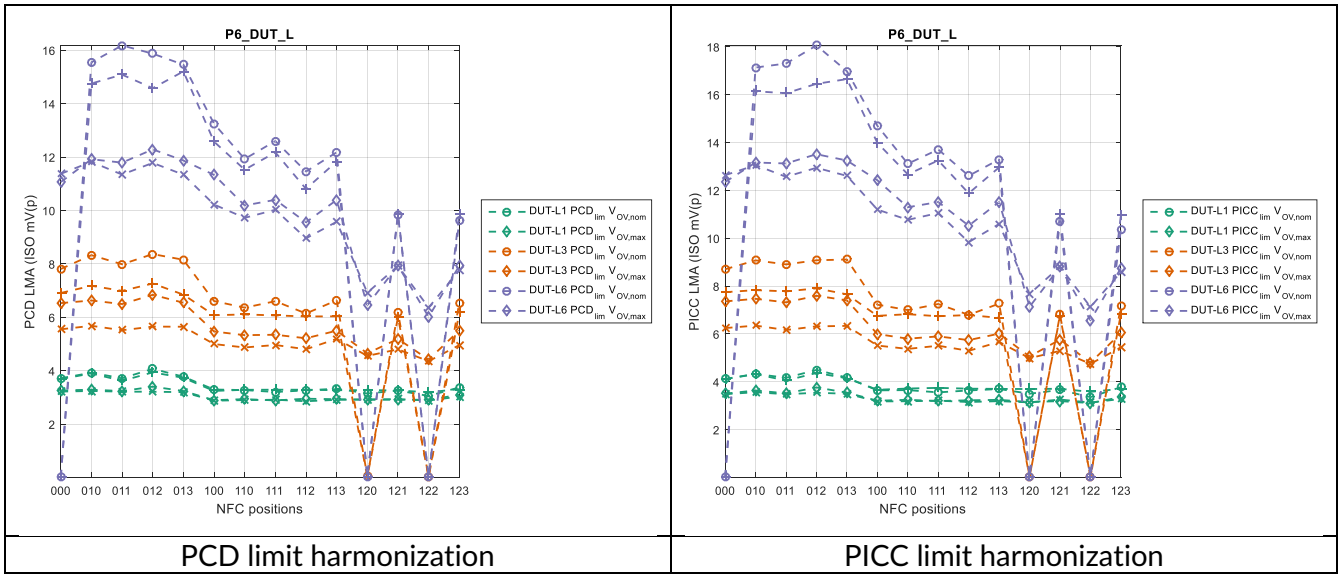
Figure 37 depicts the LMA DFT (mV$_P$) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 36. For DUT Listener 3 and the nominal power condition and position NFC OV (0 0 0) the minimum required field strength required to deliver valid results was not met and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 37: LMA$_{min}$ SBA: DUT Listeners on Reference Poller 3

Figure 38 depicts the LMA DFT (mV$_P$) results for all DUT Listeners and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 36. For DUT Listener 1, 3 and the nominal power condition 2 positions did not observe the minimum required field strength in order to deliver a valid result and therefore had been set to zero.

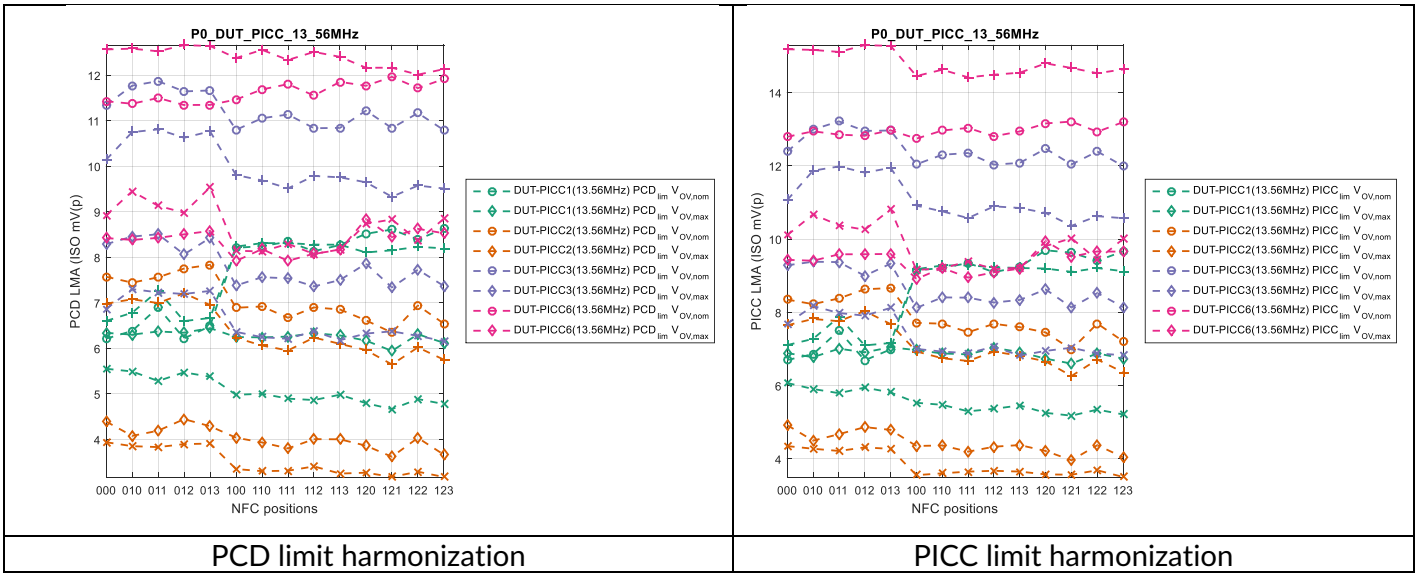


PCD limit harmonization | PICC limit harmonization

Figure 38: LMA$_{min}$ SBA: DUT Listeners on Reference Poller 6

DUT PICC (13.56 MHz) DFT LMA results for all Poller

Figure 39 depicts the LMA DFT (mV$_P$) results for all DUT PICCs for a f$_{RES}$ of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT PICCs transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT PICCs transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT PICC. For each DUT PICC two sets of measurement results are included, one for the nominal (V$_{S,OV,nom}$) and one for the maximum (V$_{S,OV,max}$) power condition. The upper side band amplitude (USB) results are indicated by the respective symbols in the legend of the figures. The lower side band amplitudes (LSB) are indicated by plus signs.

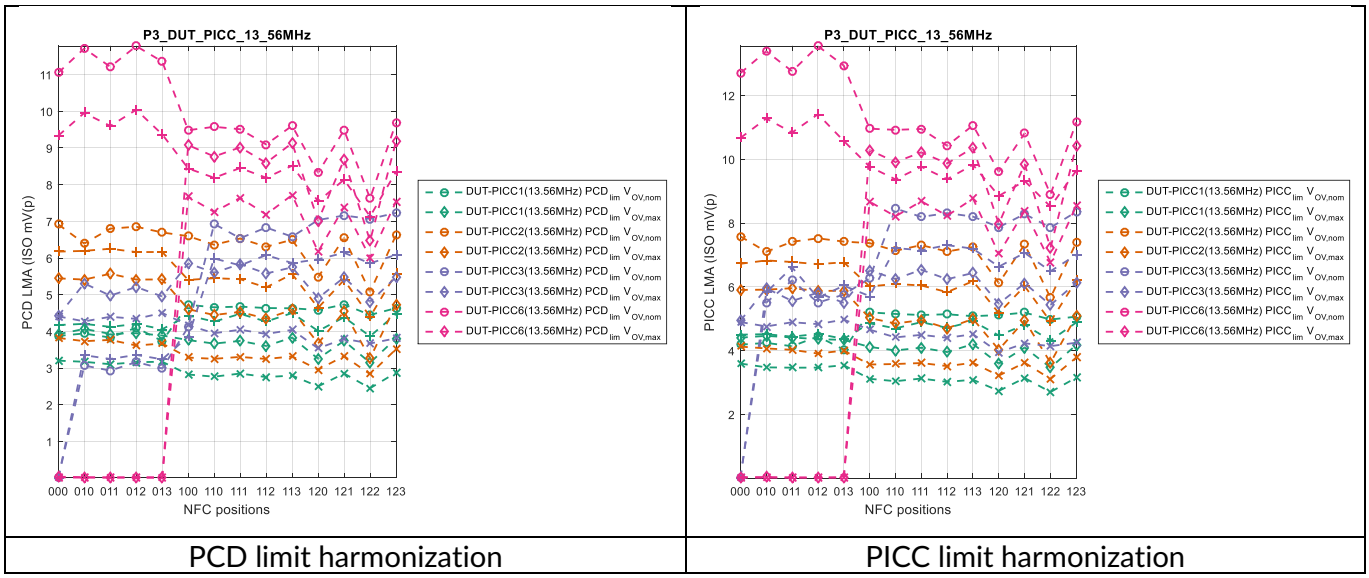


PCD limit harmonization | PICC limit harmonization

Figure 39: LMA$_{min}$ SBA: DUT PICCs f$_{res}$ = 13,56 MHz on Reference Poller 0

Figure 40 depicts the LMA DFT (mV$_P$) results for all DUT PICCs for a f$_{RES}$ of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 39. For DUT PICC 6 and the maximum power condition and positions in the zero plane the

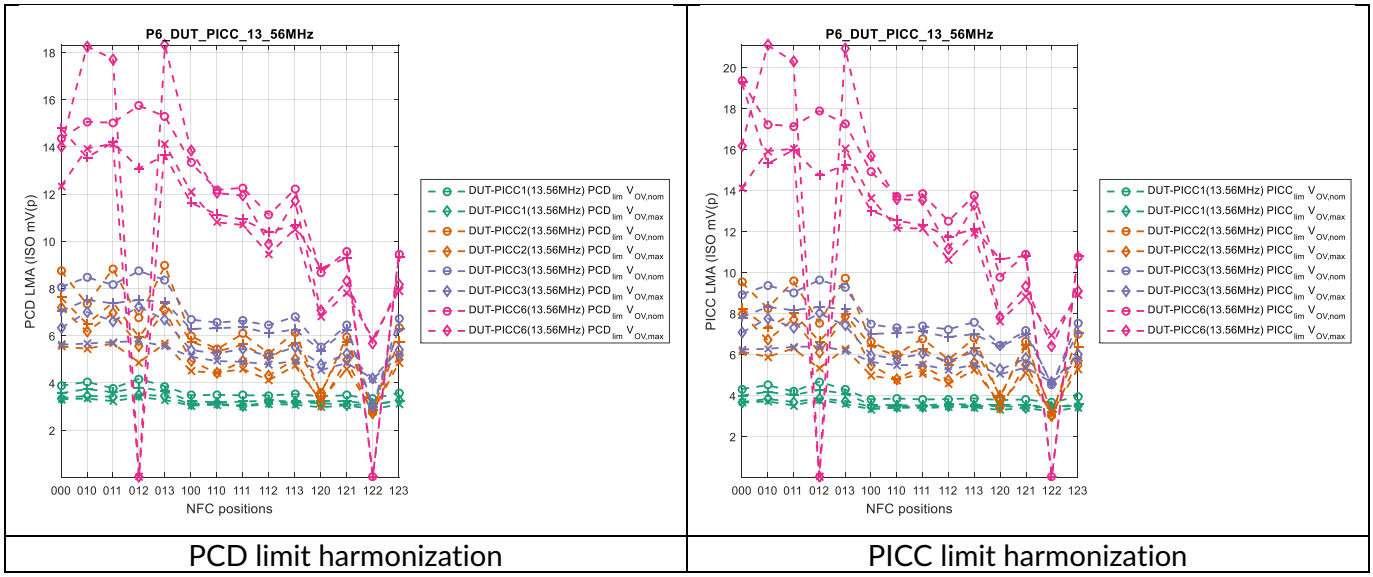
maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



PCD limit harmonization	PICC limit harmonization

Figure 40: LMA$_{min}$ SBA: DUT PICCs f_{res} = 13,56 MHz on Reference Poller 3

Figure 41 depicts the LMA DFT (mV$_P$) results for all DUT PICCs for a f_{RES} of 13.56 MHz and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 39. For DUT PICC 6 and the maximum power condition in two positions the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



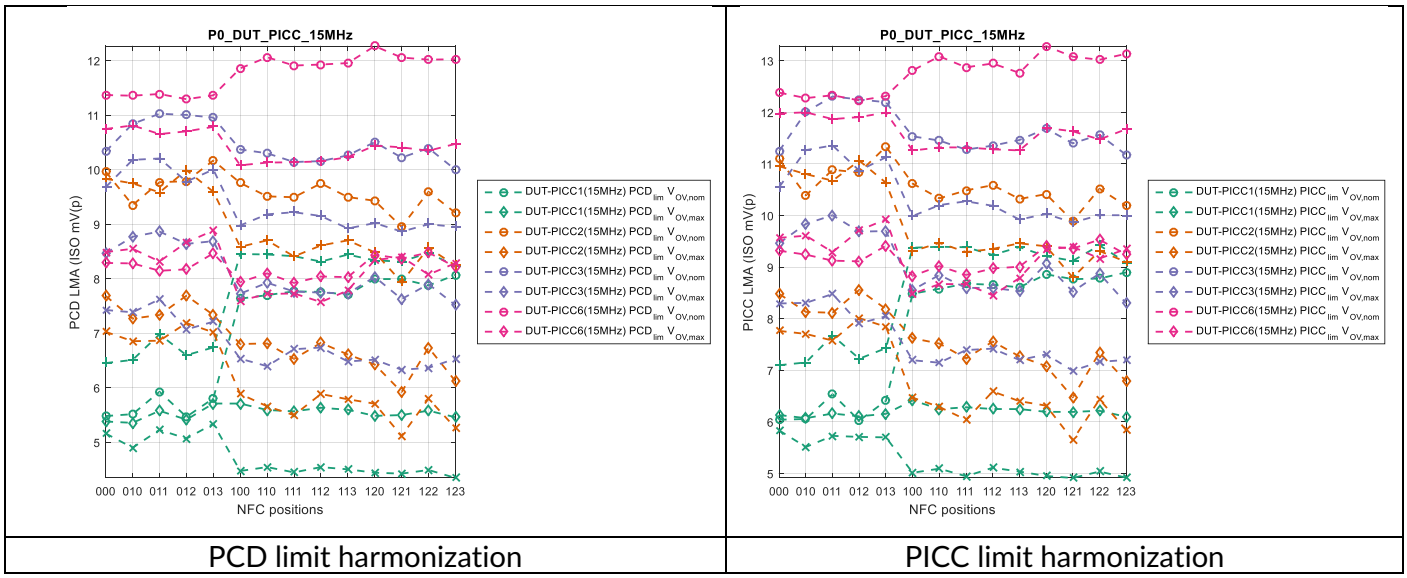
PCD limit harmonization	PICC limit harmonization

Figure 41: LMA$_{min}$ SBA: DUT PICCs f_{res} = 13,56 MHz on Reference Poller 6

DUT PICC (15 MHz) DFT LMA results for all Poller

Figure 42 depicts the LMA DFT (mV$_P$) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 0. The left hand side figure contains the results for DUT PICCs transmitting the LMA of the PCD limit for the field strength observed. The right hand side figure accordingly contains the results for DUT PICCs transmitting the LMA of the PICC limit for the field strength observed. Each color identifies the used DUT PICC. For each DUT PICC two

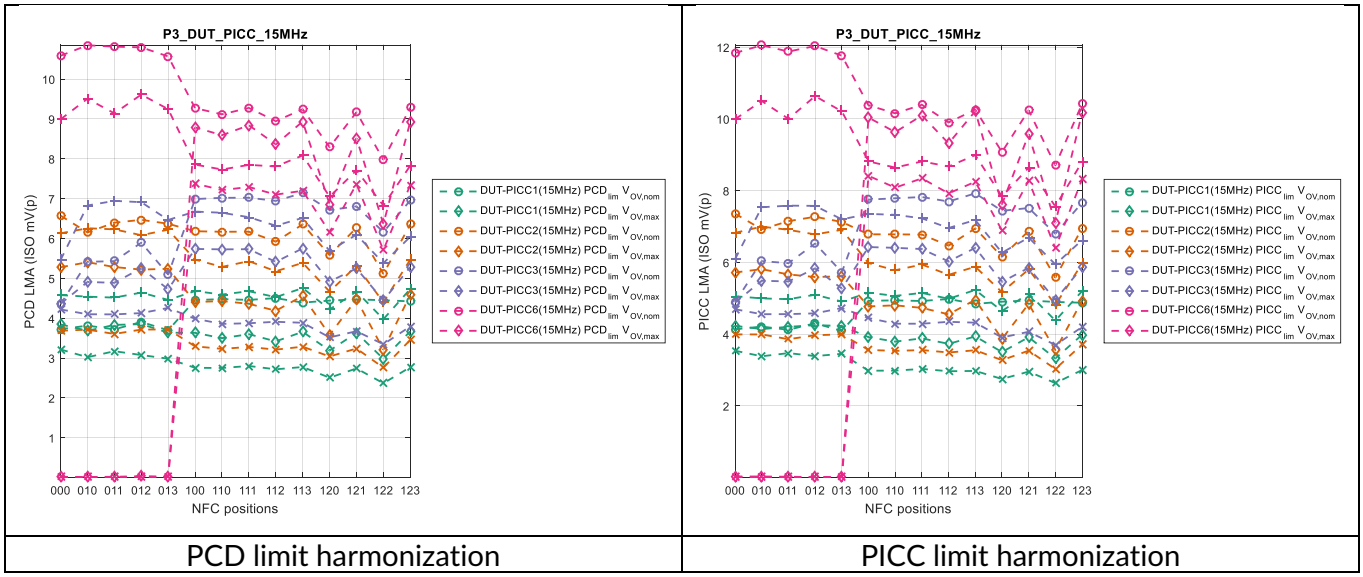
sets of measurement results are included, one for the nominal ($V_{S,OV,nom}$) and one for the maximum ($V_{S,OV,max}$) power condition. The upper side band amplitude (USB) results are indicated by the respective symbols in the legend of the figures. The lower side band amplitudes (LSB) are indicated by plus signs.



PCD limit harmonization | PICC limit harmonization

Figure 42: LMA$_{min}$ SBA: DUT PICCs f_{res} = 15 MHz on Reference Poller 0

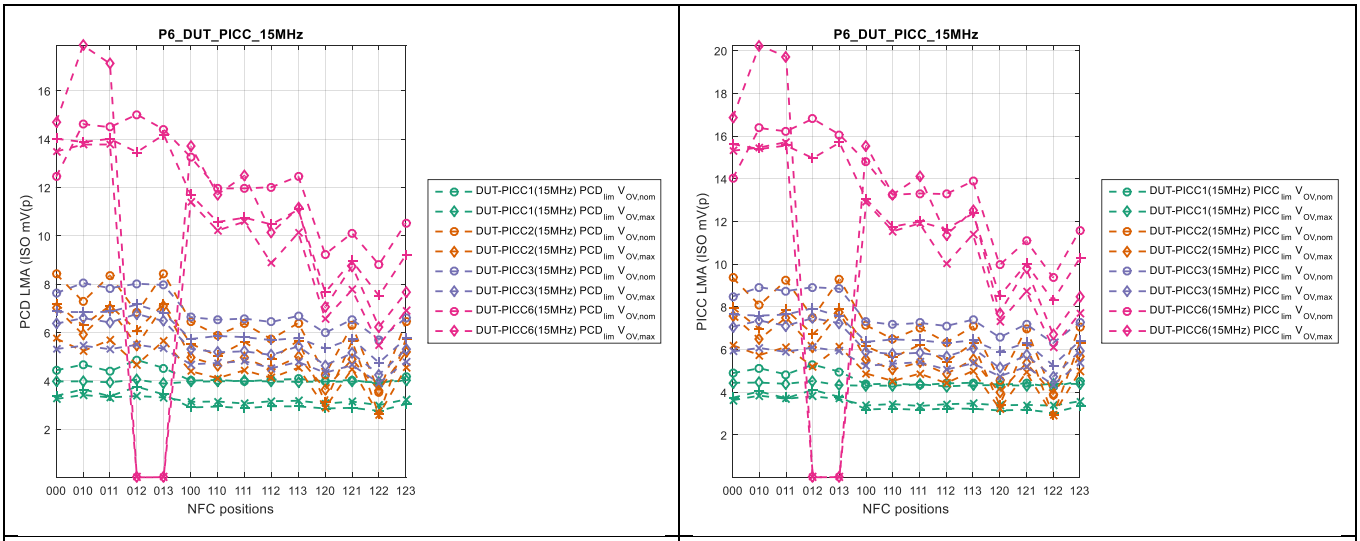
Figure 43 depicts the LMA DFT (mV$_P$) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 3. Result visualization is in analogy to Figure 42. For DUT PICC 6 and the maximum power condition and positions in the zero plane the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



PCD limit harmonization | PICC limit harmonization

Figure 43: LMA$_{min}$ SBA: DUT PICCs f_{res} = 15 MHz on Reference Poller 3

Figure 44 depicts the LMA AM (mV$_P$) results for all DUT PICCs for a f_{RES} of 15 MHz and positions as measured by the NFC Forum Reference Poller 6. Result visualization is in analogy to Figure 42. For DUT PICC 6 and the maximum power condition in two positions the maximum observed field strength exceeds the mapping table field strength range and therefore had been set to zero.



PCD limit harmonization | PICC limit harmonization

Figure 44: LMA_{min} SBA: DUT PICCs f_{res} = 15 MHz on Reference Poller 6

Summary DFT LMA – PICC / PCD limit harmonization

The candidate limit derivation for the measurement results contained in Figure 36 to Figure 44 are contained for all antenna sizes in Table 18 and for Class 1-3 antenna size in Table 19. Basically the same observations and conclusions are valid for the LMA DFT based limit transformation from ISO/IEC 14443 to NFC Forum as presented for the LMA AM based limit transformation as contained in the summary part of section 4.2.2.1.

Finally, one has to address the difference in LMA measurement method between NFC Forum and [ISO10373-6]. NFC Forum evaluates only the AM component of the load modulation signal whereas ISO computes the amplitude of upper and lower side band using the DFT method. Consequently, both, AM and PM signal components are taken into account. This difference in measurement method leads to an unwanted interoperability problem between NFC Forum and ISO conformant devices. LMA AM analysis only is typically over constraining the Listeners transmit side. A reliable Poller (in the field) will always analyze AM and PM LMA signal components to ensure robust operation. Due to changing coupling situation the Listening device LMA signal will always contain a larger or smaller PM component. For this reason also the measurement method should be incorporated into consideration for harmonization.

Table 18: Candidate Limits for min LMA and SBA analysis harmonization for class 1, 2, 3 & 6

DUT	NFC Ref Poller 0		NFC Ref Poller 3		NFC Ref Poller 6	
	PCD lim	PICC lim	PCD lim	PICC lim	PCD lim	PICC lim
max. L1 – L6 mV(p)	12	13	13	14	15	16
max. PICC1-PICC6 (13.56MHz) mV(p)	12	13	8	9	14	16
max. PICC1-PICC6 (15MHz) mV(p)	11	12	9	10	14	16
Resulting candidate limit:	12	13	13	14	15	16

Table 19: Candidate Limits for min LMA and SBA analysis harmonization for class 1, 2 & 3

DUT	NFC Ref Poller 0		NFC Ref Poller 3		NFC Ref Poller 6	
	PCD lim	PICC lim	PCD lim	PICC lim	PCD lim	PICC lim
max. L1 – L3 mV(p)	11	12	7	7.5	7	8
max. PICC1-PICC3 (13.56MHz) mV(p)	10.5	12	6.5	7	7.5	8
max. PICC1-PICC3 (15MHz) mV(p)	10	11.5	7	7.5	7	8
Resulting candidate limit:	11	12	7	7.5	7	8

4.2.3 Harmonization Result Proposal

The goal of NFC Forum is to achieve harmonization for Listening Devices on the LMA transmission minimum limit to ISO/IEC 14443 PCD limits ($V_{LMA, PCD}$) as defined for class 1 – 3 in order to achieve interoperability. Based on the achieved harmonization measurements and conclusions drawn in section 4.2 the NFC Forum approach to define one limit independent on field strength and antenna size is unsustainable.

As a consequence the TC EMVCo Alignment TF by consensus recommended the following changes to the LMA parameter to achieve alignment/interoperability to ISO/IEC 14443:

(1) Load modulation signal analysis: Both, amplitude and phase components should be analysed from NFC Forum perspective (NFC Forum so far analysed only the amplitude). Therefore it is recommended to use the DFT algorithm similarly as defined by [ISO10373-6] in order to achieve equal comparison.
(2) Listening Device load modulation amplitude test:
    a. It is recommended to define distinct LMA_{min} limits ($V_{PP,MIN}$) for the setup power conditions $V_{S,OV,NOM}$ and $V_{S,OV,MAX}$ during the Listener load modulation transmission test.
(3) Recommended limit values:
    a. In the future NFC Forum plans to define specifications and test requirements for NFC Tag Devices. Since the NFC Tag use case is limited to the interaction with an NFC Reader Device it is no target to apply the LMA_{min} harmonization to NFC Tags. NFC Tags for e.g., consumer electronics (cameras, headsets, speakers, …) typically require a very small antenna. Therefore, it is recommended:
        i. To define separate LMA_{min} limit values for NFC Devices as Listener or in CEM and for NFC Tag Devices.
        ii. To not change the NFC Poller LMA_{min} (reception limits)
    b. Limit recommendation:
        i. It was observed that depending on the antenna size of the NFC Device (Listener/CEM) the limit values resulting in harmonization are different. Consequently a single limit value would either result in overstressing NFC Devices with larger antenna size or result in no harmonization and therefore no interoperability for NFC Devices with small antenna sizes.
        ii. Based on aforementioned observation, it is recommended to define separate limit values depending on the NFC Device antenna size. 3 categories of antenna size are sufficient to establish a harmonization for all relevant antenna sizes.
        iii. This requires the manufacturer to declare the antenna size (antenna category), like already done for the positioning (center and orientation) in the NFC Forum IXIT

(Implementation eXtra Information for Testing) document required for analog certification.

The recommended changes are summarized as follows:

- Usage of DFT for LMA analysis: Compute PASS/FAIL verdict by calculating the average of upper and lower side band
- Define separate LMA_{min} limit values for NFC Devices as Listener or in CEM and NFC Tag Devices.
- Define antenna size dependent LMA_{min} limit values for NFC Devices: 3 categories are proposed
- Separate Listener limits LMA_{min} ($V_{PP,min}$) for power conditions $V_{S,OV,NOM}$ and $V_{S,OV,MAX}$
- Unchanged LMA_{min} limit values for Polling Device reception tests

In contrast to ISO/IEC 10373-6 NFC Forum does not compute the LMA as the minimum of USB and LSB but instead computes the average of USB and LSB. Main reason for this difference is the difference in measurement equipment used for testing. ISO/IEC 10373-6 uses the Test PCD Assembly to measure the PICC LMA. In particular the sense coils capture the PICC transmission. The sense coils are wide band in frequency and therefore have no or only a negligible influence on the signal. Additionally, the sense coils are arranged in a way that they perform a spatial filtering and thus mainly capture the PICC transmission. In contrast NFC Forum measurement methodology is closer to the real case seen in the field. NFC Forum receives the PICC transmission directly via the Reference Poller antenna. In particular the voltage drop across the quality damping resistor is measured. This means the observed PICC transmission is shaped by the Reference Poller transfer function of the receive path. This transfer function is changing as a function of the coupling and f_{RES} of the DUT Listener or DUT PICC. For this reason the absolute value of LSB and USB has not the same meaning compared to ISO/IEC 14443 since the levels of USB and LSB are shifting in dependence of coupling and the DUT Listener f_{RES}. The average of USB and LSB was shown to be a good candidate to resolve the level shifting between USB and LSB. In case an ISO compliant PCD uses a single side band receiver or amplifies one side band a reduction of the operating distance may be observed. Future harmonization work will address the side band amplitude to V_{LMA} (LMA_{min}) computation difference. The recommended LMA_{min} candidate limit values using the DFT method (mV_P) are shown in Table 20. For the NFC Forum Devices 3 antenna categories (CAT) are introduced and shown on the right hand side of Table 20. CAT A covers Class 1antenna sizes, CAT B covers antenna sizes smaller than class 1 and equal to or larger than Class 3. CAT C is defined for all antenna size smaller than Class 3 and is represented by a Class 6 antenna size. Moreover, any antenna size which does not fit into CAT A or B belongs to CAT C.

Table 20: Listener Minimum LMA limits - harmonization proposal

Reference Poller	field strength setting	existing limits (translated to DFT)	Tag Device	NFC Forum Device		
				CAT C, default category	CAT B	CAT A
	$V_{S,OV}$ V(DC)	mV(p)	mV(p)	mV(p)	mV(p)	mV(p)
Poller 0	nom	5.8	5.8	12	12	9
	max			8	8	7
Poller 3	nom	2.8	2.8	13	8	5
	max			8	5	3
Poller 6	nom	2	2	15	8	4
	max			12	6.5	3.5

A detailed description on the antenna category selection criteria can be found in NFC Forum's Analog Specification v2.0 or in Annex 0.

All above recommendation are included in NFC Forum's Analog Specification v2.0.

4.2.4 NFC Forum Listener Minimum Load Modulation Amplitude ($V_{PP,min}$) Validation

This section validates the minimum limit values $V_{PP,min}$ for Load Modulation Amplitude of Listening Devices found and proposed in the previous chapter. As stated the goal is to achieve interoperability to the PCD limit ($V_{LMA, PCD}$) as defined in ISO/IEC 14443-2. The procedure shown in section 4.2.4.1 was defined using NFC Forum Reference Listeners and ISO Reference PICCs as DUTs. Finally the results are validated.

4.2.4.1 Procedure

CONTEXT	
Reference	[NFC_ANA]
Requirement	6.1.2.1-6.1.2.4: When it is placed in the Operating Volume of the NFC Forum – Reference Polling Device that has been set up as described in the specification context above, the Listening Device SHALL modulate the Operating Field in such a way that the signal monitored at J2 of the NFC Forum – Reference Polling Device has the following characteristics: 6.1.2.1 The subcarrier frequency fS of the modulation signal SHALL be fC /16 for NFC-A and NFC-B. 6.1.2.2 For NFC-F the frequency fS of the modulation signal during the preamble SHALL be fC /32 or fC /64. 6.1.2.3 The subcarrier frequency fS of the modulation signal SHALL be fC /32 for NFC-V 6.1.2.4 The average amplitude of the two sidebands (fC + fS and fC - fS), calculated from the modulation signal at J2 of the NFC Forum – Reference Polling Device using the DFT method, SHALL be VLMA. (Choosing a measurement position that avoids all transient effects, e.g., the first change from 0 to 1 for NFC-A, the TR1 zone for NFC-B and NFC-F, and the pattern I for NFC-V, as defined in [DIGITAL].)

	Refer to Appendix B.2 for the value of VLMA and to Appendix B.4 for the definition of antenna category.
Implicit Requirement	Minimum load modulation amplitude harmonization result validation
Question	Is an NFC Forum Device in Listen mode which is compliant for the above minimum load modulation transmission requirement also compliant or interoperable to the corresponding minimum ISO PICC Requirement?

PROCEDURE	
Step	**SETUP**
1	Setup the NFC Forum – Reference Poller 0 to nominal field strength ($V_{S,OV,nom}$).
2	Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value (see Table 20 – CAT A) in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 0. Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
3	Setup the NFC Forum – Reference Poller 3 to nominal field strength ($V_{S,OV,nom}$).
4	Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value (see Table 20 – CAT A) in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 3. Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
5	Setup the NFC Forum – Reference Poller 6 to nominal field strength.
6	Setup the DUT L1 (loading 330Ω) in order to get listener minimum load modulation value (see Table 20 – CAT A) in each position of the NFC OV when measured at the J2 output of the NFC Forum – Reference Poller 6. Record V_{OV} (loading 330Ω) and the load modulator input voltage for each position of the NFC OV.
7	Repeat the procedure above with: • DUT L1 (CAT A, 820 Ω), • DUT L3 (CAT B, 330 Ω and 820 Ω), • DUT L6 (CAT C, 330 Ω and 820 Ω), • DUT PICC 1 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT A, • DUT PICC 2 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT B, • DUT PICC 3 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT B, • DUT PICC 6 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT C.
Step	**VERIFICATION**
1	Place DUT L1 (820 Ω) in the DUT position of the respective Test PCD Assembly.
2	Readjust the field strength until the V_{OV} as measured at respective DUTListener/ DUT PICC in each of the NFC Forum – Reference Poller test positions is reached.

3	Set the load modulator input voltage for the position (SETUP Steps 2) , 4) and 6)) and measure the load modulation amplitude.
4	• Repeat the VERIFICATION steps with:DUT L1 (330 Ω) • DUT L3 (330 Ω and 820 Ω) • DUT L6 (330 Ω and 820 Ω) • DUT PICC 1 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT A, • DUT PICC 2 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT B, • DUT PICC 3 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT B, • DUT PICC 6 (f_{RES} of 13.56, 15 and 16.5 MHz) for CAT C.
5	**Repeat the complete SETUP and VERIFICATION steps with $V_{S,OV,MAX}$ in SETUP steps 1, 3 and 5.** *Note: This analysis assumes the NFC Forum Analog specification defines the Load modulation amplitude limits independent of position within the NFC OV and field strength.*
EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PICC minimum load modulation amplitude (see Table 27).
Step	**INTEROPERABILITY**
1	Compare the measured load modulation amplitude of VERIFICATION step 3 to the ISO PCD minimum load modulation amplitude (see Table 24).
CONCLUSION / DISCUSSION	
	Results are presented in section 4.2.4.2 and a discussion is performed in section 4.2.5.

4.2.4.2 Validation Results

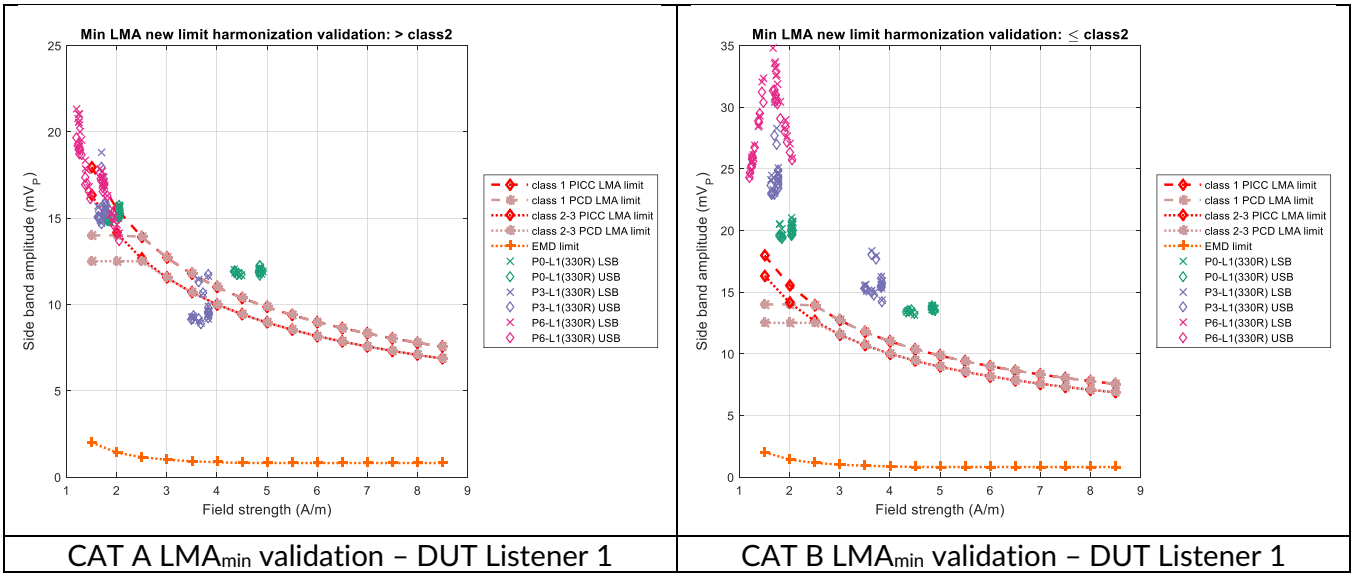
Validation results are presented using the following Reference Equipment and configurations emulating DUTs:

- NFC Forum Reference Listener 1, 3 and 6 with loading 330Ω
- NFC Forum Reference Listener 1, 3 and 6 with loading 820Ω
- Reference PICCs 1 – 3 and 6 and resonance frequency 13,56MHz
- Reference PICCs 1 – 3 and 6 and resonance frequency 15MHz
- Reference PICCs 1 – 3 and 6 and resonance frequency 16,5MHz

The DUT configurations used for validation represent a real DUT Listener and DUT PICCs in the field. The analysis considered a representative range of antenna sizes with different loadings and resonance frequencies. The validation results contained in Figure 45 - Figure 64 are all depicted as side band amplitude using the DFT method versus field strength. All result plots contain the LMA_{min} PCD ($V_{LMA,\,PCD}$) and PICC ($V_{LMA,\,PICC}$) limits versus field strength for Class 1 and Class 2-3 as defined in [ISO14443-2]and [ISO14443-2:AMD2] (see also Table 24 and Table 27). Also the EMD limit versus field strength is indicated in orange colour (see [ISO14443-2:AMD1] and section 0 for a definition). Additionally, DUTs of Class 6 results are provided when measured with Test PCD Assembly 2 as required for Class 6 (see [ISO14443-2:AMD2] and [ISO10373-6:AMD1]).

NFC Forum Reference Listener 1, 3 and 6 (DUT L1, L§ and L6) with loading 330Ω

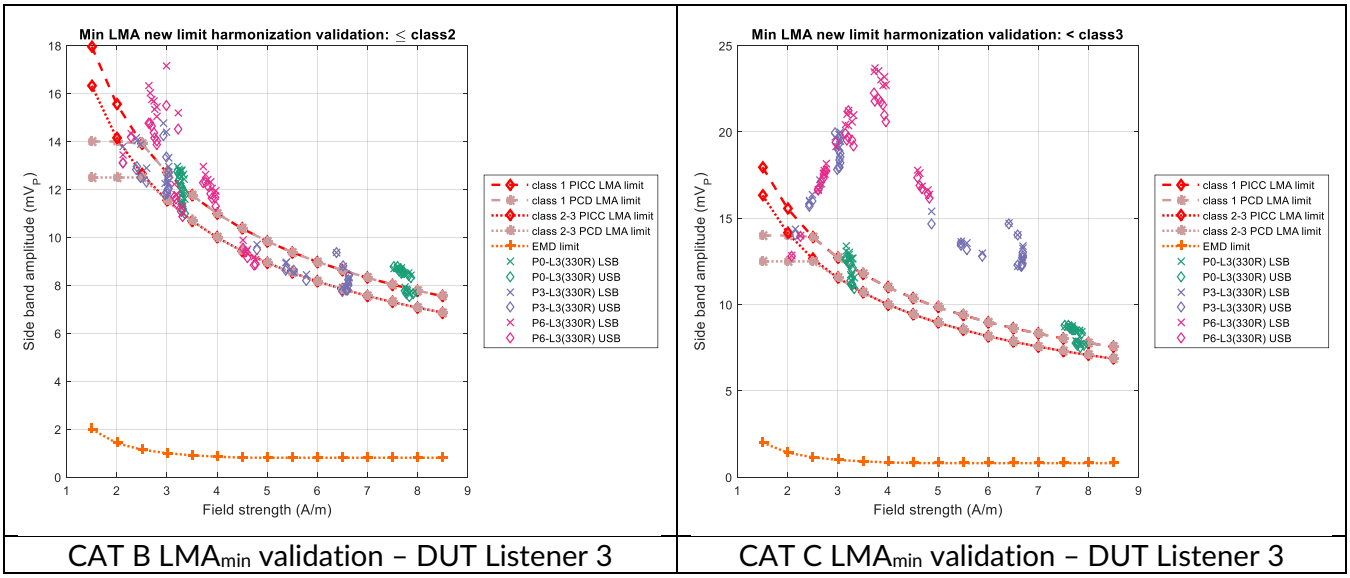
Figure 45 shows the validation results for DUT L1 complying either with CAT A (left hand side) or CAT B (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT A was defined for antenna sizes of Class 1 which is also used by DUT L1. Therefore one can observe that the limit of CAT A conforms well to the ISO/IEC 14443 defined Class 1 limit curve. Around 3 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The right hand side graph illustrates the behaviour of a Class 1 antenna size complying with CAT B. These results are exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT L1 with a loading of 330 Ω is approximately from 1.1 A/m(rms) to 5 A/m(rms). A DUT L1 device can claim interoperability to ISO/IEC 14443 Class 1 - 3 when implementing the candidate limit values of CAT A as defined in Table 20 within the tested field strength range.



CAT A LMA_{min} validation – DUT Listener 1	CAT B LMA_{min} validation – DUT Listener 1

Figure 45: Listener 1 (330R) and CAT A limit validation

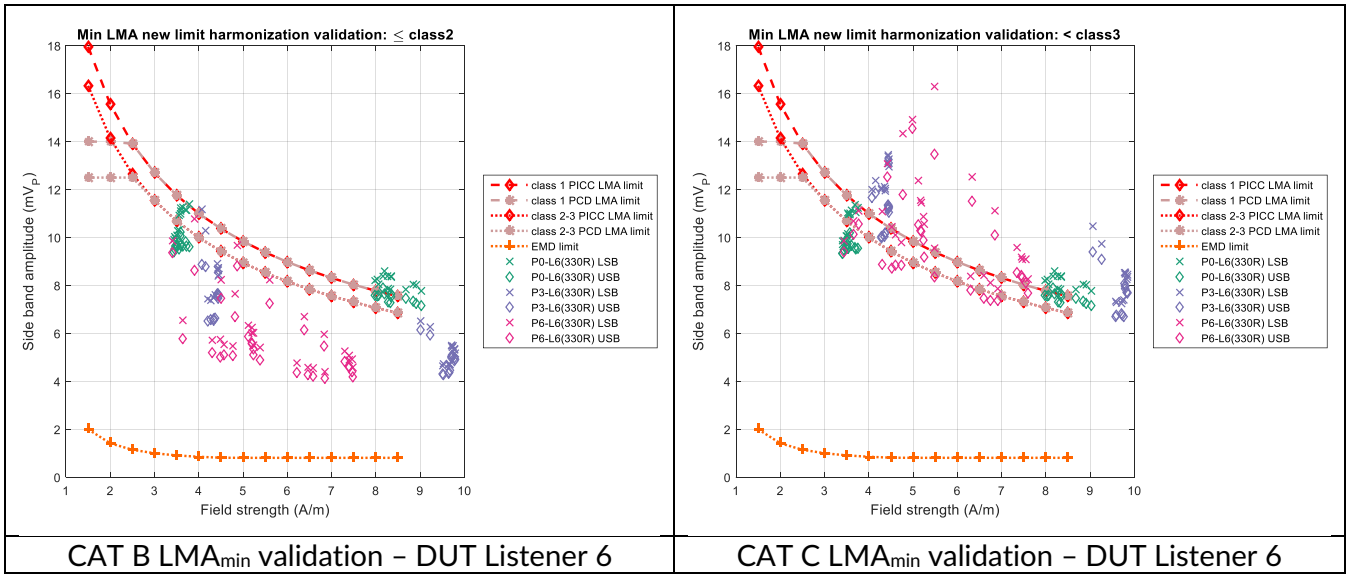
Figure 46 shows the validation results for DUT L3 complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT B was defined for antenna sizes of Class 3 which is also used by DUT L3. Therefore one can observe that the limit values of CAT B conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The right hand side graph illustrates the behaviour of a Class 3 antenna size complying with CAT C. These results are exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT L3 with a loading of 330 Ω is from approximately 2 A/m(rms) to 8 A/m(rms). A DUT L3 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.



CAT B LMA$_{min}$ validation – DUT Listener 3 | CAT C LMA$_{min}$ validation – DUT Listener 3

Figure 46: Listener 3 (330R) and CAT B limit validation

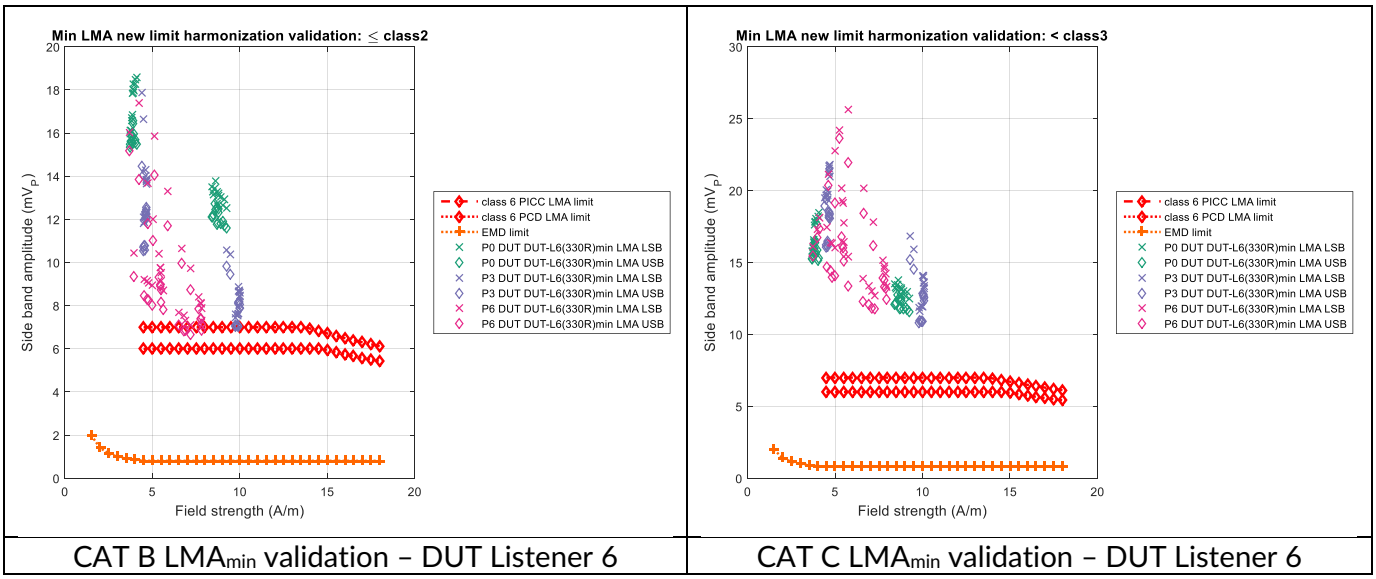
Figure 47 shows the validation results for DUT L6 complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 1. CAT C was defined for antenna sizes of Class 6 which is also used by DUT L6. Therefore one can observe that the limit of CAT C conforms well to the ISO/IEC 14443 defined Class 3 limit curve. Around 3 - 5 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The left hand side graph illustrates the behaviour of a Class 6 antenna size complying with CAT B. These results do not fulfil the requirement on LMA$_{min}$ for Class 1 - 3 as defined by ISO/IEC 14443. The field strength range coverage for DUT L6 with a loading of 330 Ω is approximately from 3.5 A/m(rms) to 10 A/m(rms). A DUT L6 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT C as defined in Table 20 within the tested field strength range.



CAT B LMA$_{min}$ validation – DUT Listener 6 | CAT C LMA$_{min}$ validation – DUT Listener 6

Figure 47: Listener 6 (330R) and CAT C limit validation using ISO Test PCD Assembly 1

Figure 48 shows the validation results for DUT L6 complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 2. CAT C was defined for antenna sizes as small as Class 6 which is also used by DUT L6. CAT C limits have been selected to align to ISO/IEC 143443 Class 3. Therefore one can observe that the results exceed the ISO/IEC 14443 defined Class 6 limit curve for both CAT B and CAT C. The field strength range coverage for DUT L6 with a loading of 330 Ω is approximately from 3.5 A/m(rms) to 10 A/m(rms). A DUT L6 device can claim compliance and interoperability to ISO/IEC 14443 Class 6 when implementing the candidate limits of CAT B and C as defined in Table 20 within the tested field strength range.

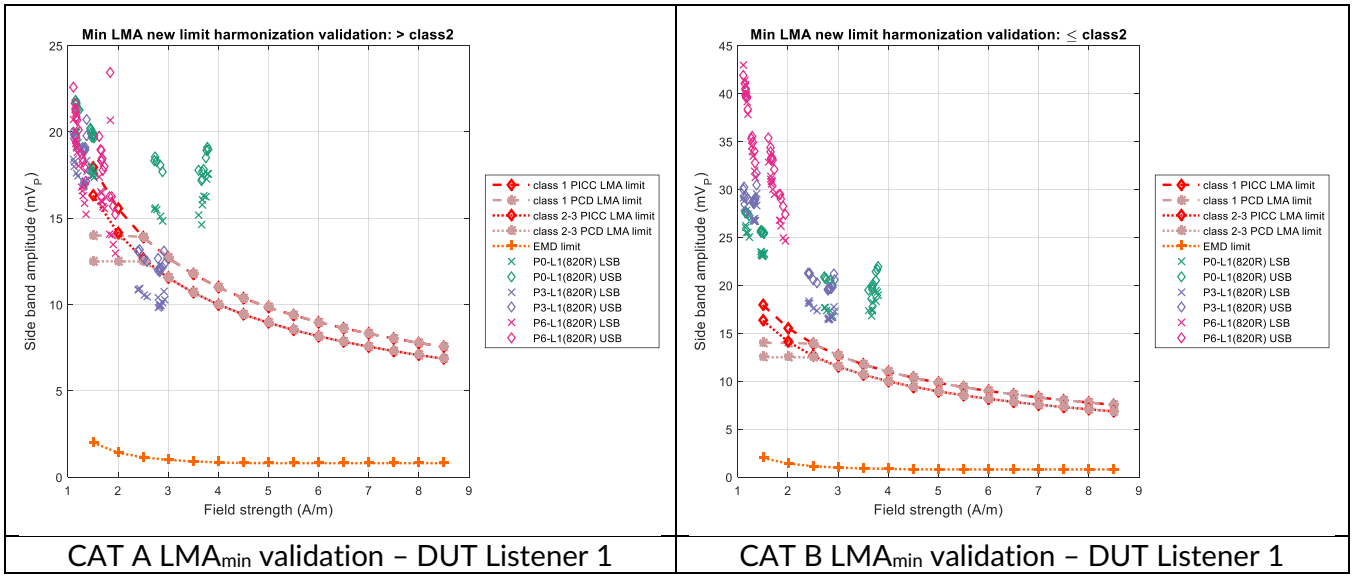


CAT B LMA_{min} validation – DUT Listener 6	CAT C LMA_{min} validation – DUT Listener 6

Figure 48: Listener 6 (330R) and CAT C limit validation using ISO Test PCD Assembly 2

NFC Forum Reference Listener 1, 3 and 6 (DUT L1, L3 and L6) with loading 820Ω

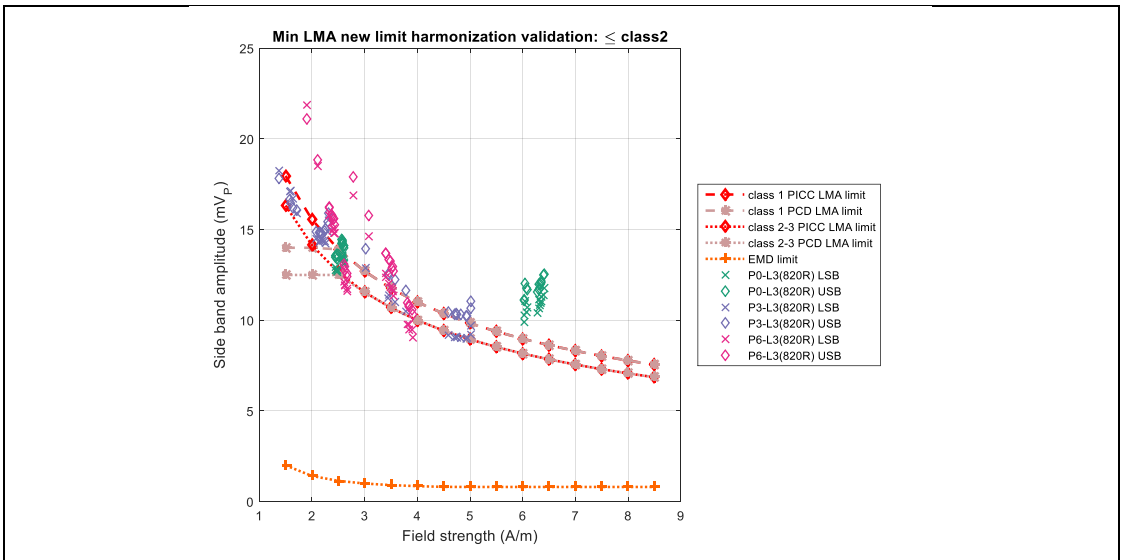
Figure 49 shows the validation results for DUT L1 and 820 Ω loading complying either with CAT A (left hand side) or CAT B (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT A was defined for antenna sizes of Class 1 which is also used by DUT L1. Therefore one can observe that the limit of CAT A conforms well to the ISO/IEC 14443 defined Class 1 limit curve. Around 2.5 to 3 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The right hand side graph illustrates the behaviour of a Class 1 antenna size complying with CAT B. These results are exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT L1 with a loading of 820 Ω is approximately from 1 A/m(rms) to 4 A/m(rms). A DUT L1 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT A as defined in Table 20 within the tested field strength range.



CAT A LMA_{min} validation – DUT Listener 1 | CAT B LMA_{min} validation – DUT Listener 1

Figure 49: Listener 1 (820R) and CAT A limit validation

Figure 50 shows the validation results for DUT L3 and 820 Ω loading complying either with CAT B limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT B was defined for antenna sizes of Class 3 which is also used by DUT L3. Therefore one can observe that the limit of CAT B conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The field strength range coverage for DUT L3 with a loading of 820 Ω is approximately from 1.5 A/m(rms) to 6.5 A/m(rms). A DUT L3 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.

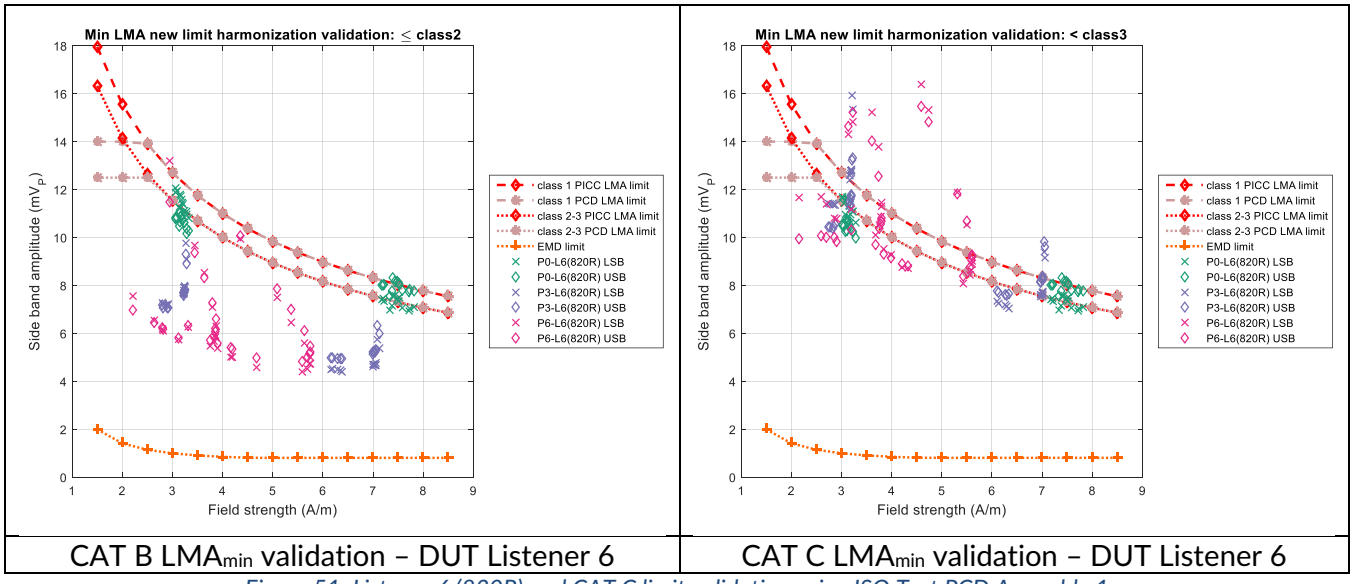


CAT B LMA_{min} validation – DUT Listener 3

Figure 50: Listener 3 (820R) and CAT B limit validation

Figure 51 shows the validation results for DUT L6 and 820 Ω loading complying either to CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 1. CAT C was defined for antenna sizes of Class 6 which is also used by DUT L6. Therefore one can observe that the limit of CAT C conforms to the ISO/IEC 14443 defined Class 3 limit curve. Around 2.5 – 4.5 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since

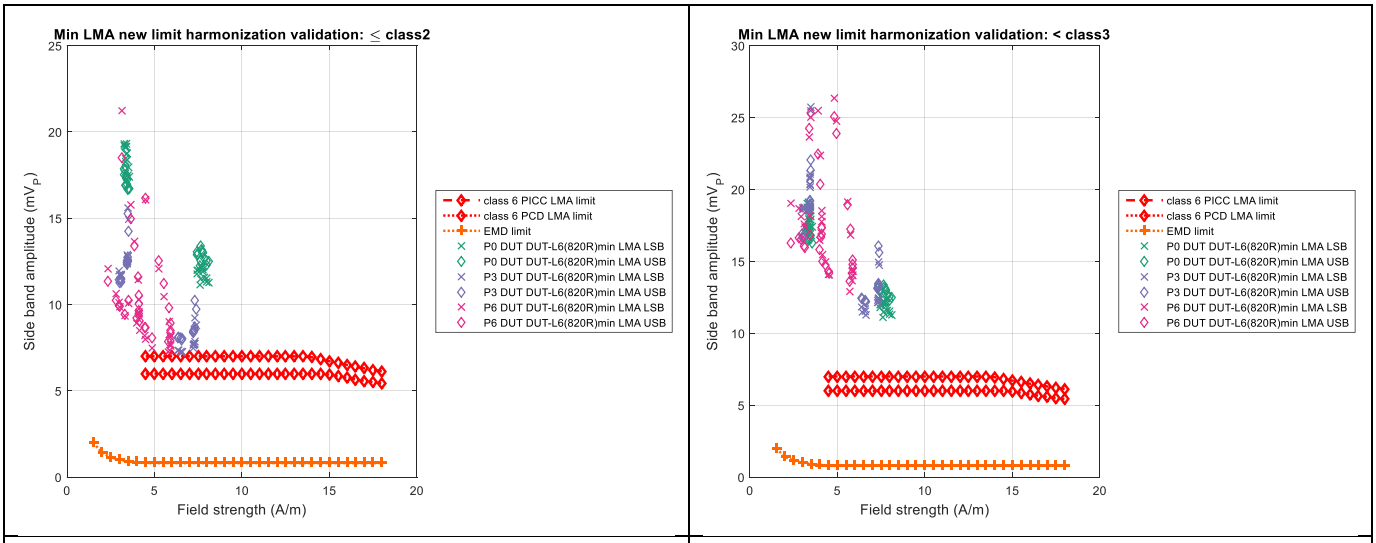
measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The left hand side graph illustrates the behaviour of a Class 6 antenna size complying with CAT B. These results do not fulfil the requirement on LMA_{min} for Class 1 - 3 as defined by ISO/IEC 14443. The field strength range coverage for DUT L6 with a loading of 820 Ω is from approximately 2 A/m(rms) to 8 A/m(rms). A DUT L6 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT C as defined in Table 20 within the tested field strength range.



CAT B LMA_{min} validation – DUT Listener 6 | CAT C LMA_{min} validation – DUT Listener 6

Figure 51: Listener 6 (820R) and CAT C limit validation using ISO Test PCD Assembly 1

Figure 52 shows the validation results for DUT L6 and 820 Ω loading complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 2. CAT C was defined for antenna sizes of as small as Class 6 which is also used by DUT L6. CAT C limits have been selected to align to ISO/IEC 143443 Class 3. Therefore one can observe that the limit of CAT C exceeds the ISO/IEC 14443 defined Class 6 limit curve for both CAT B and CAT C. The field strength range coverage for DUT L6 with a loading of 820 Ω is from approximately 2.5 A/m(rms) to 8 A/m(rms). A DUT L6 device can claim compliance and interoperability to ISO/IEC 14443 Class 6 when implementing the candidate limits of CAT B or CAT C as defined in Table 20 within the tested field strength range.

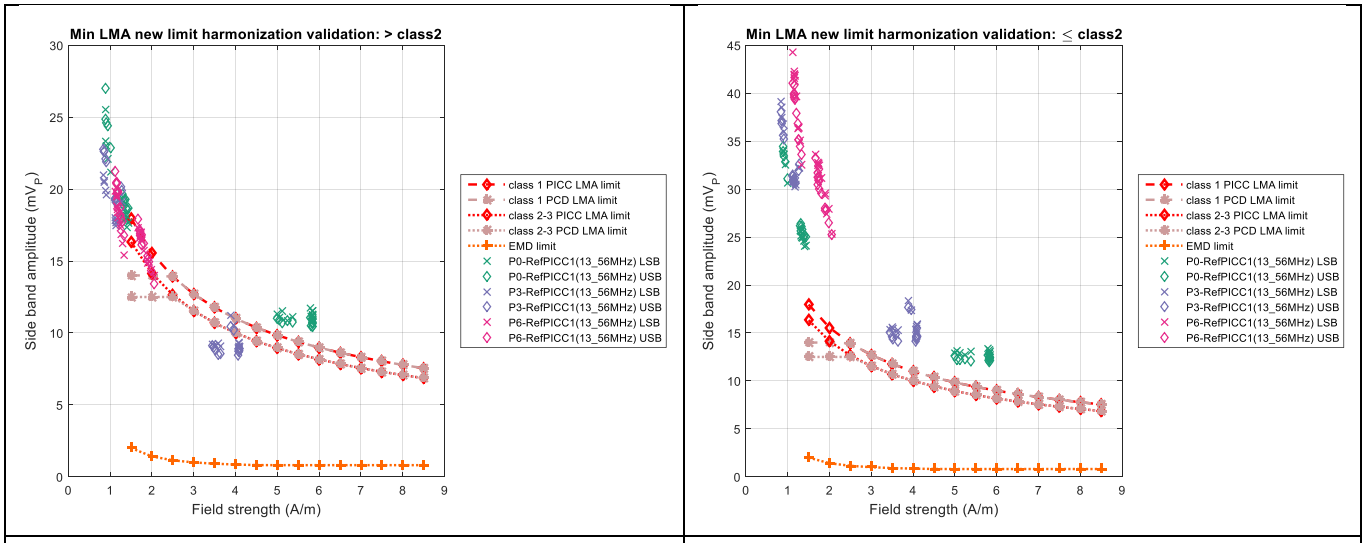


CAT B LMA_{min} validation – DUT Listener 6	CAT C LMA_{min} validation – DUT Listener 6

Figure 52: Listener 6 (820R) and CAT C limit validation using ISO Test PCD Assembly 2

Reference PICCs 1 – 3 and 6 (DUT PICC 1-3 and 6) and resonance frequency 13.56MHz

Figure 53 shows the validation results for DUT PICC 1 and f_{RES} of 13.56 MHz complying either with CAT A (left hand side) or CAT B (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT A was defined for antenna sizes of Class 1 which is also used by DUT PICC 1. Therefore one can observe that the limit of CAT A conforms well to the ISO/IEC 14443 defined Class 1 limit curve. Around 4 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The right hand side graph illustrates the behaviour of a Class 1 antenna size complying with CAT B. The results are exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 1 and f_{RES} of 13.56 MHz is approximately from 0.9 A/m(rms) to 6 A/m(rms). A DUT PICC 1 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT A as defined in Table 20 within the tested field strength range.



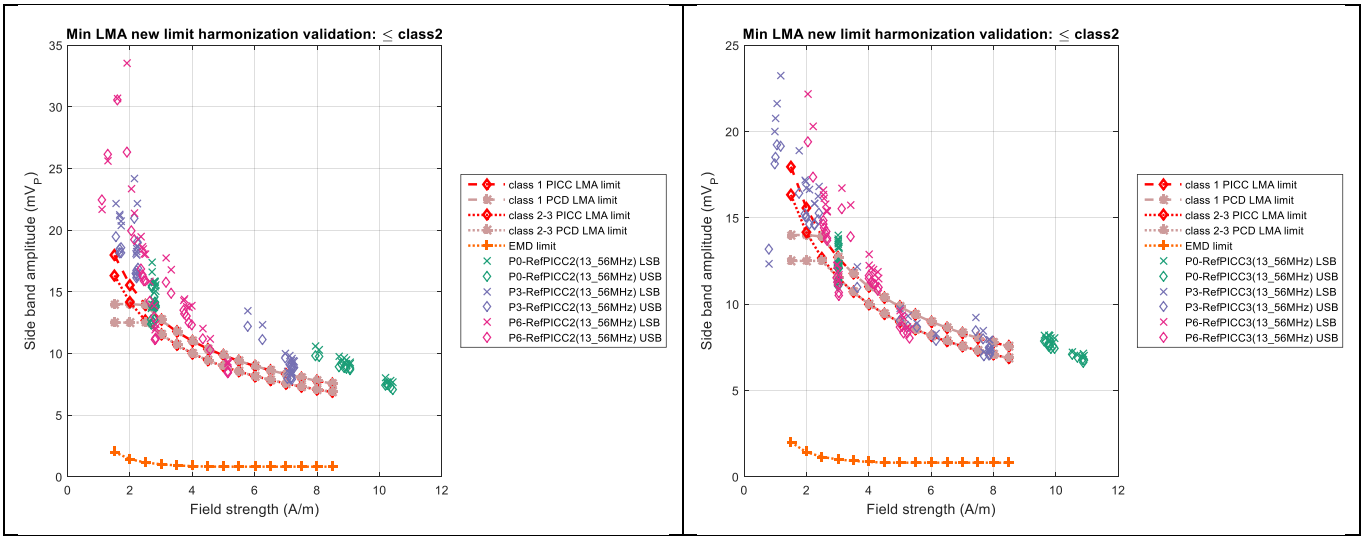
CAT A LMA_{min} validation – DUT PICC 1	CAT B LMA_{min} validation – DUT PICC 1

Figure 53: Reference PICC 1 f_{RES} = 13.56 MHz and CAT A limit validation

Figure 54 shows the validation results for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 13.56 MHz complying with CAT B limit values as defined in Table 20 when measured according to the definition in [ISO10373-6]. CAT B was defined for antenna sizes of Class 2 and Class 3 which is also used by DUT PICC 2 and DUT PICC 3, respectively. Therefore one can observe that the limit of CAT B conforms well with the ISO/IEC 14443 defined Class 3 limit curve. The field strength range coverage for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 13.56 MHz is:

- DUT PICC 2 (13.56 MHz): approximately from 1.3 A/m(rms) to 10.5 A/m(rms).
- DUT PICC 3 (13.56 MHz): approximately from 0.9 A/m(rms) to 11 A/m(rms).

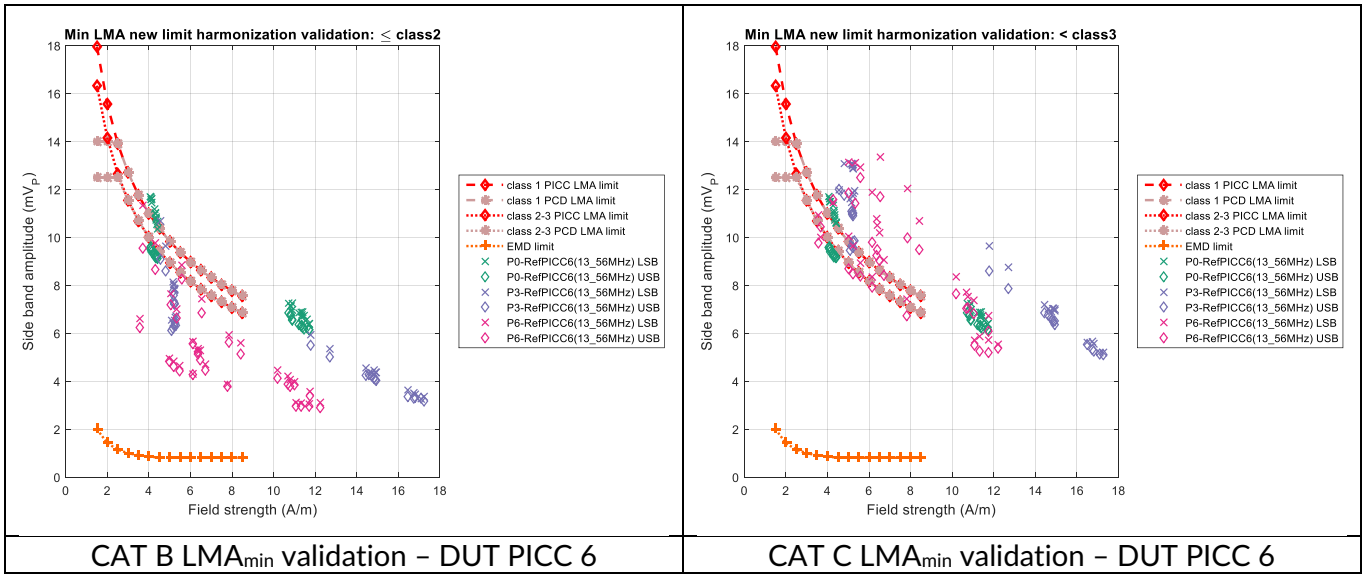
Both, DUT PICC 2 (13.56 MHz) and DUT PICC 3 (13.56 MHz) devices can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.



CAT B LMA_{min} validation – DUT PICC 2	CAT B LMA_{min} validation – DUT PICC 3

Figure 54: Reference PICC 2 and Reference PICC 3 f_{RES} = 13.56 MHz and CAT B limit validation

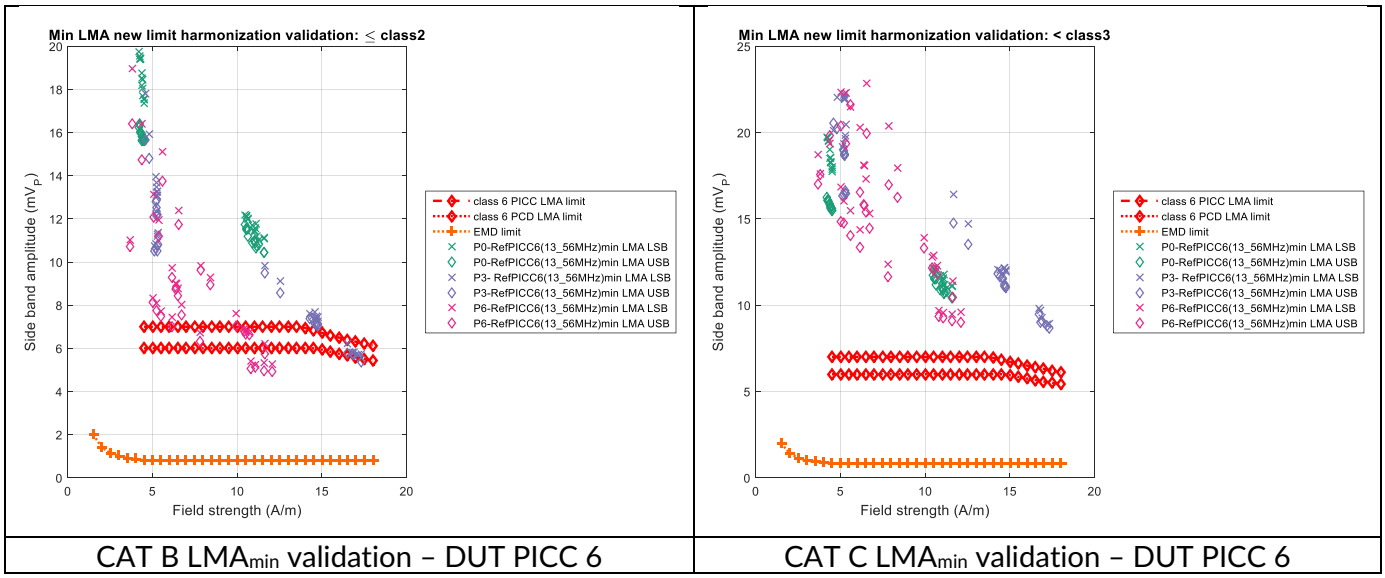
Figure 55 shows the validation results for DUT PICC 6 and f_{RES} of 13.56 MHz complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 1. CAT C was defined for antenna sizes of Class 6 which is also used by DUT PICC 6. Therefore one can observe that the limit of CAT C conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The left hand side graph illustrates the behaviour of a Class 6 antenna size complying with CAT B. These results do not fulfil the requirement on LMA_{min} for Class 1 - 3 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 6 and f_{RES} of 13.56 MHz is approximately from 3.5 A/m(rms) to 17.5 A/m(rms). A DUT L6 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT C as defined in Table 20 within the tested field strength range.



CAT B LMA_{min} validation – DUT PICC 6	CAT C LMA_{min} validation – DUT PICC 6

Figure 55: Reference PICC 6 f_{RES} = 13.56 MHz and CAT C limit validation using ISO Test PCD Assembly 1

Figure 56 shows the validation results for DUT PICC 6 and f_{RES} of 13.56 MHz complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition in [ISO10373-6] using Test PCD Assembly 2. CAT C was defined for antenna sizes of as small as Class 6 which is also used by DUT L6. CAT C limits have been selected to align to ISO/IEC 14443 Class 3. Therefore one can observe that the limit of CAT C exceeds the ISO/IEC 14443 defined Class 6 limit curve. The field strength range coverage for DUT PICC 6 and f_{RES} of 13.56 MHz is approximately from 3.5 A/m(rms) to 17 A/m(rms). A DUT PICC 6 device can claim compliance and interoperability to ISO/IEC 14443 Class 6 when implementing the candidate limits of CAT C and interoperability when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.



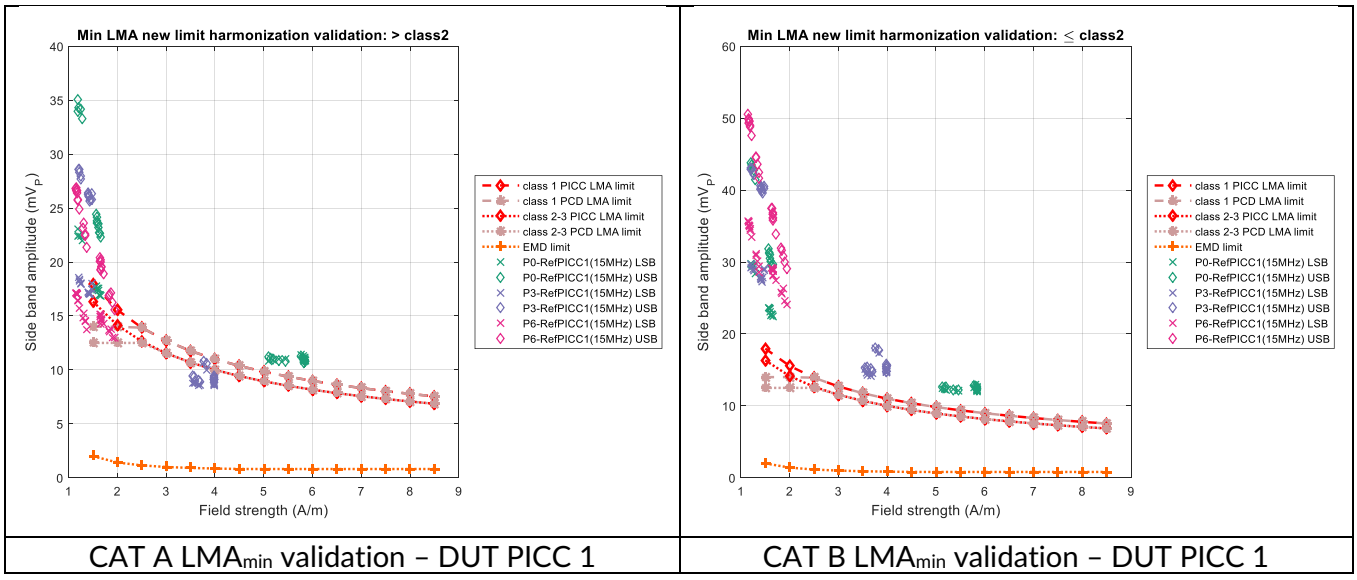
CAT B LMA_{min} validation – DUT PICC 6	CAT C LMA_{min} validation – DUT PICC 6

Figure 56: Reference PICC 6 f_{RES} = 13.56 MHz and CAT C limit validation using ISO Test PCD Assembly 2

Reference PICCs 1 – 3 and 6 (DUT PICC 1-3 and 6) and resonance frequency 15MHz

Figure 57 shows the validation results for DUT PICC 1 and f_{RES} of 15 MHz complying either with CAT A (left hand side) or CAT B (right hand side) limit values as defined in Table 20 when measured according to the definition of [ISO10373-6]. CAT A was defined for antenna sizes of Class 1 which

is also used by DUT PICC 1. Therefore one can observe that the limit of CAT A conforms well to the ISO/IEC 14443 defined Class 1 limit curve. Around 4 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The right hand side graph illustrates the behaviour of a Class 1 antenna size complying with CAT B. This results in exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 1 and f_{RES} of 15 MHz is approximately from 1.1 A/m(rms) to 6 A/m(rms). A DUT PICC 1 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT A as defined in Table 20 within the tested field strength range.



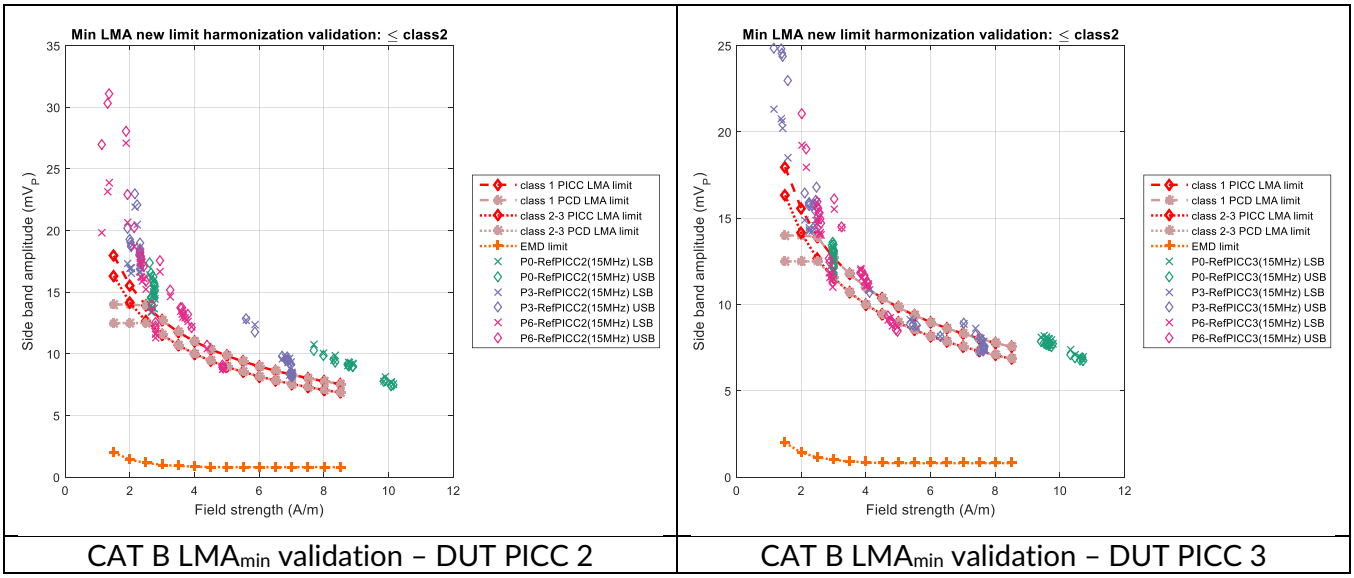
CAT A LMA_{min} validation – DUT PICC 1	CAT B LMA_{min} validation – DUT PICC 1

Figure 57: Reference PICC 1 f_{RES} = 15 MHz and CAT A limit validation

Figure 58 shows the validation results for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 15 MHz complying with CAT B limit values as defined in Table 20 when measured according to the definition of [ISO10373-6]. CAT B was defined for antenna sizes of Class 2 and Class 3 which is also used by DUT PICC 2 and DUT PICC 3, respectively. Therefore one can observe that the limit of CAT B conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The field strength range coverage for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 15 MHz is:

- DUT PICC 2 (15 MHz): approximately from 1.3 A/m(rms) to 10.5 A/m(rms).
- DUT PICC 3 (15 MHz): approximately from 1.3 A/m(rms) to 11 A/m(rms).

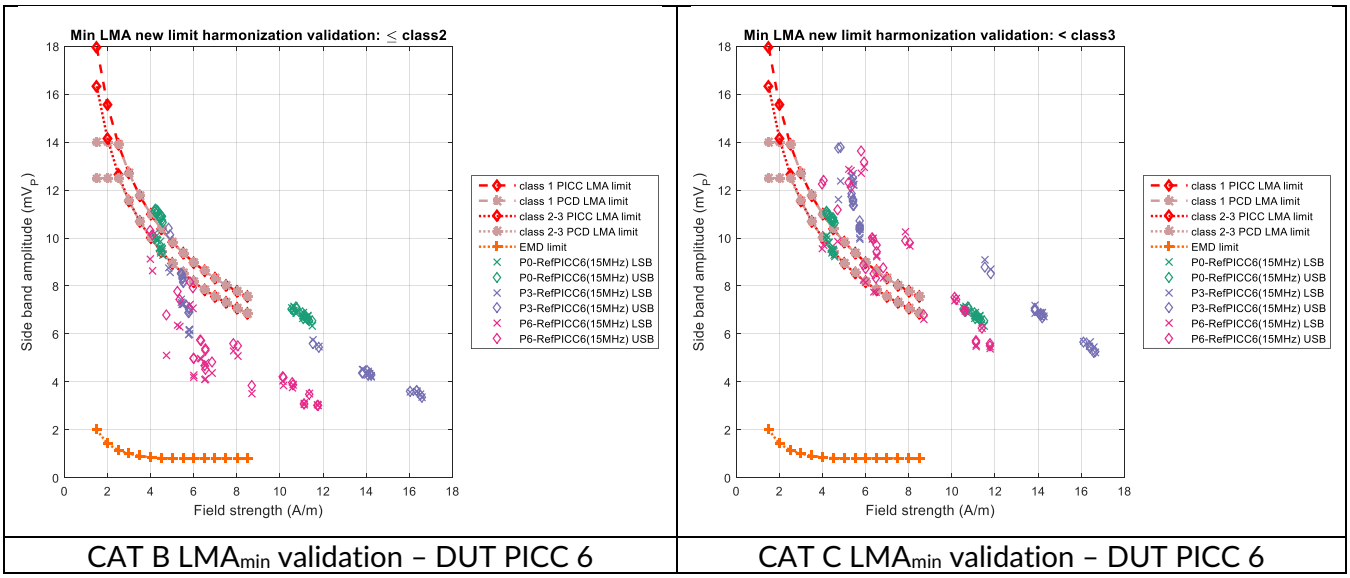
Both, DUT PICC 2 (15 MHz) and DUT PICC 3 (15 MHz) devices can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.



CAT B LMA$_{min}$ validation – DUT PICC 2	CAT B LMA$_{min}$ validation – DUT PICC 3

Figure 58: Reference PICC 2 and Reference PICC 3 f_{RES} = 15 MHz and CAT B limit validation

Figure 59 shows the validation results for DUT PICC 6 and f_{RES} of 15 MHz complying either to CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition of [ISO10373-6] using Test PCD Assembly 1. CAT C was defined for antenna sizes of Class 6 which is also used by DUT PICC 6. Therefore one can observe that the limit of CAT C conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The left hand side graph illustrates the behaviour of a Class 6 antenna size complying with CAT B. These results do not fulfil the requirement on LMA$_{min}$ for Class 1 - 3 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 6 and f_{RES} of 15 MHz is approximately from 4 A/m(rms) to 17 A/m(rms). A DUT PICC 6device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT C as defined in Table 20 within the tested field strength range.

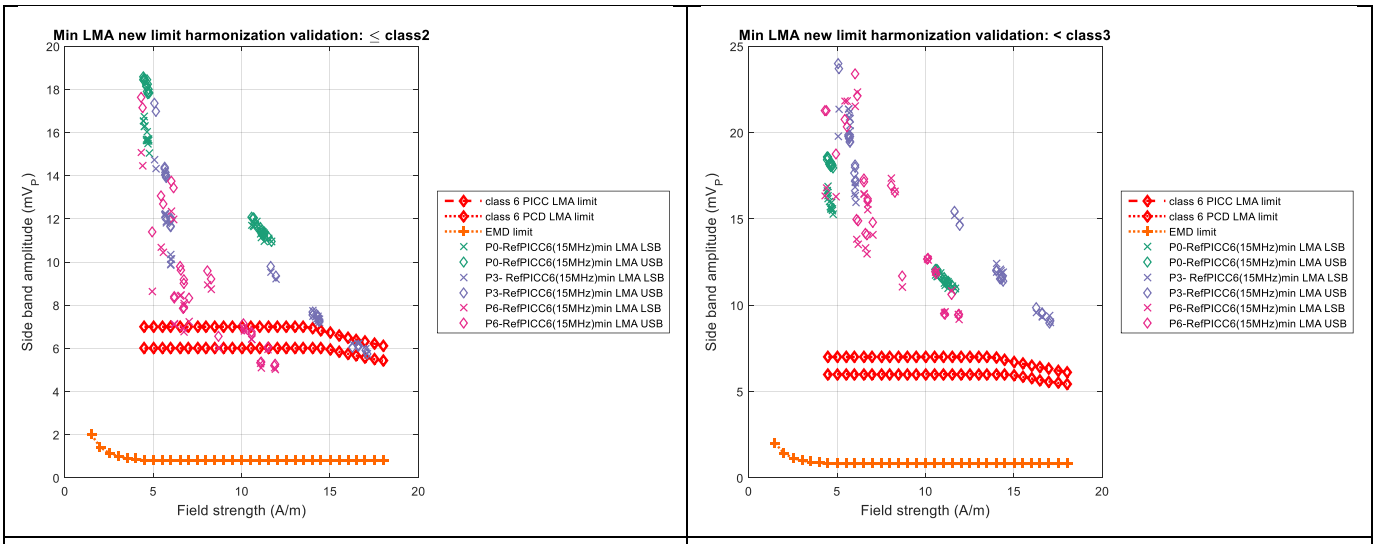


CAT B LMA$_{min}$ validation – DUT PICC 6	CAT C LMA$_{min}$ validation – DUT PICC 6

Figure 59: Reference PICC 6 f_{RES} = 15 MHz and CAT C limit validation using ISO Test PCD Assembly 1

Figure 60 shows the validation results for DUT PICC 6 and f_{RES} of 15 MHz complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition of [ISO10373-6] using Test PCD Assembly 2. CAT C was defined for antenna sizes of as small as Class 6 which is also used by DUT PICC 6. CAT C limits have been

selected to align to ISO/IEC 14443 Class 3. Therefore one can observe that the limit of CAT C exceeds the ISO/IEC 14443 defined Class 6 limit curve. The field strength range coverage for DUT PICC 6 and f_{RES} of 15 MHz is approximately from 4 A/m(rms) to 17 A/m(rms). A DUT PICC 6 device can claim compliance and interoperability to ISO/IEC 14443 Class 6 when implementing the candidate limits of CAT C and interoperability when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.

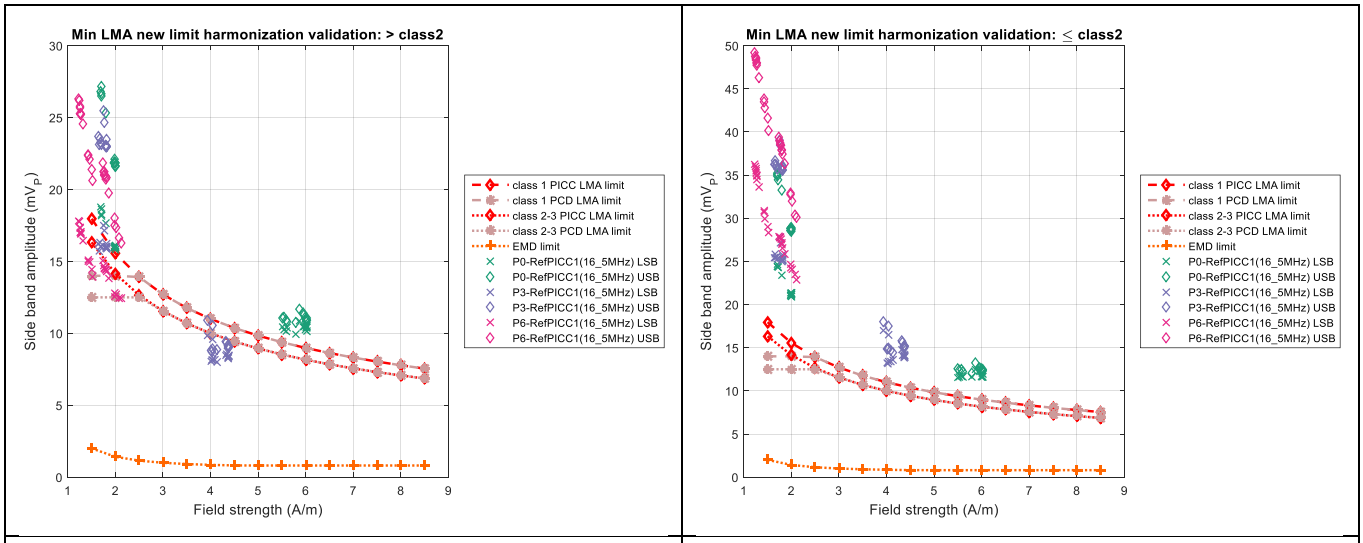


CAT B LMA_{min} validation – DUT PICC 6	CAT C LMA_{min} validation – DUT PICC 6

Figure 60: Reference PICC 6 f_{RES} = 15 MHz and CAT C limit validation using ISO Test PCD Assembly 2

Reference PICCs 1 – 3 and 6 (DUT PICC 1-3 and 6) and resonance frequency 16.5MHz

Figure 61 shows the validation results for DUT PICC 1 and f_{RES} of 16.5 MHz complying either with CAT A (left hand side) or CAT B (right hand side) limit values as defined in Table 20 when measured according to the definition of [ISO10373-6]. CAT A was defined for antenna sizes of Class 1 which is also used by DUT PICC 1. Therefore one can observe that the limit of CAT A conforms well to the ISO/IEC 14443 defined Class 1 limit curve. Around 4 A/m(rms) one can observe some measurement points which are slightly below the PCD limit curve. Since measurement points at the same field strength exist, exceeding the PCD limit, no further action is required. The right hand side graph illustrates the behaviour of a Class 1 antenna size complying with CAT B. This results in exceeding the requirement on LMA_{min} for Class 1 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 1 and f_{RES} of 16.5 MHz is approximately from 1.1 A/m(rms) to 6 A/m(rms). A DUT PICC 1 device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT A as defined in Table 20 within the tested field strength range.



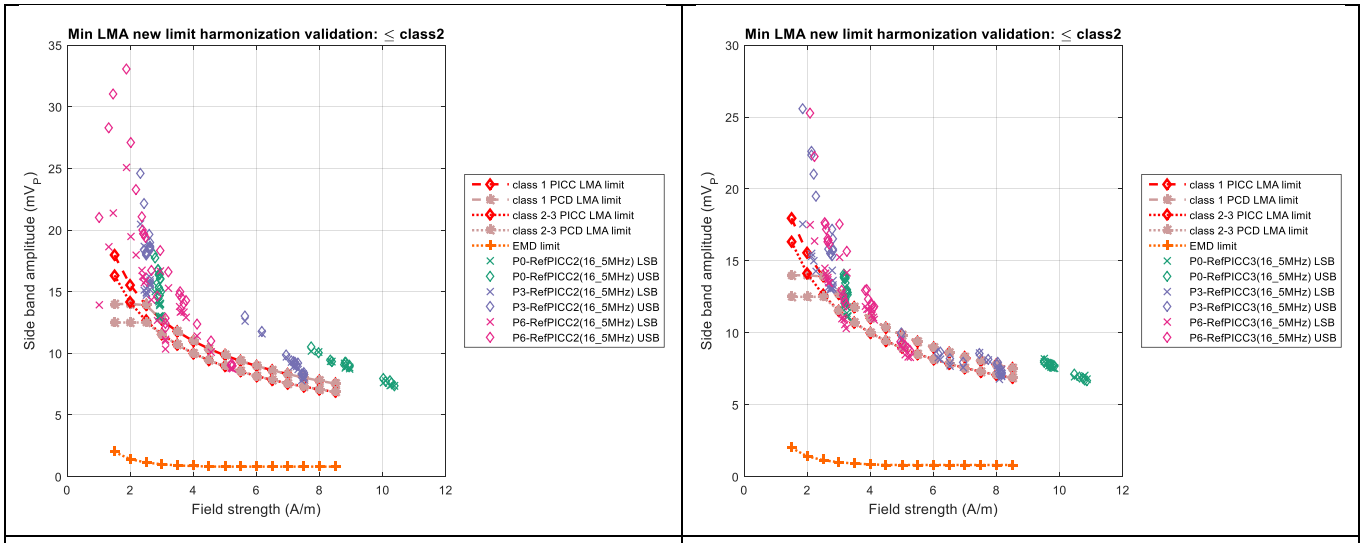
CAT A LMA$_{min}$ validation – DUT PICC 1	CAT B LMA$_{min}$ validation – DUT PICC 1

Figure 61: Reference PICC 1 f_{RES} = 16.5 MHz and CAT A limit validation

Figure 62 shows the validation results for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 16.5 MHz complying with CAT B limit values as defined in Table 20 when measured according to the definition of [ISO10373-6]. CAT B was defined for antenna sizes of Class 2 and Class 3 which is also used by DUT PICC 2 and DUT PICC 3, respectively. Therefore one can observe that the limit of CAT B conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The field strength range coverage for DUT PICC 2 and DUT PICC 3 both having a f_{RES} of 16.5 MHz is:

- DUT PICC 2 (16.5 MHz): approximately from 1.3 A/m(rms) to 10.5 A/m(rms).
- DUT PICC 3 (16.5 MHz): approximately from 1.7 A/m(rms) to 11 A/m(rms).

Both, DUT PICC 2 (16.5 MHz) and DUT PICC 3 (16.5 MHz) devices can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.

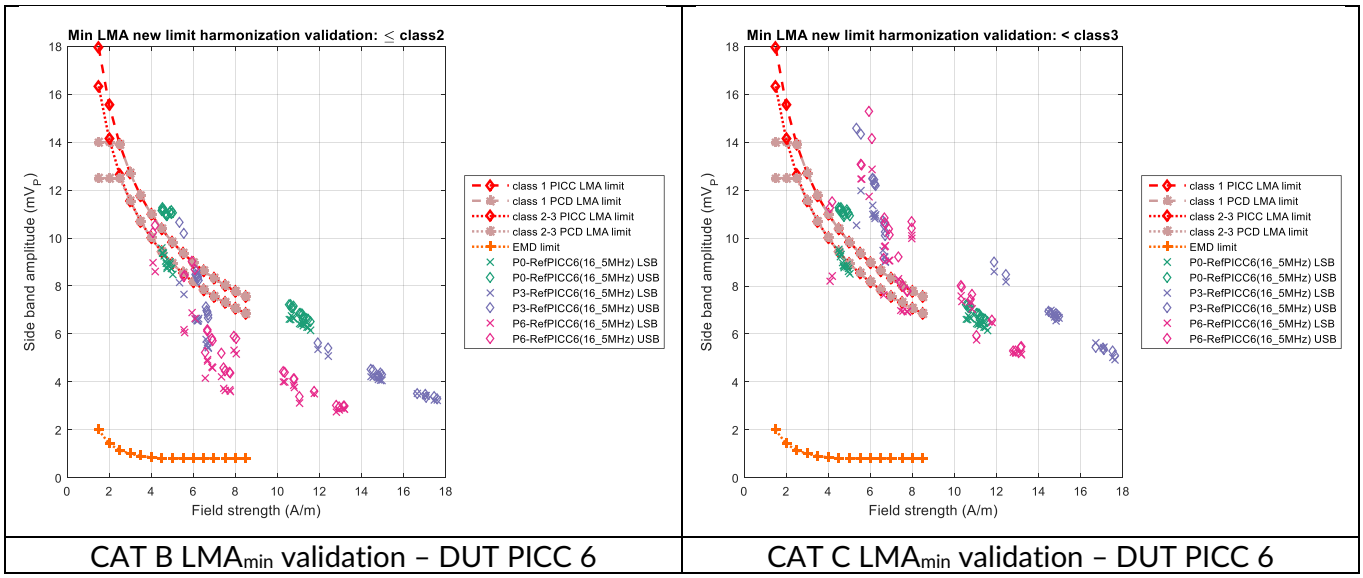


CAT B LMA$_{min}$ validation – DUT PICC 2	CAT B LMA$_{min}$ validation – DUT PICC 3

Figure 62: Reference PICC 2 and Reference PICC 3 f_{RES} = 16.5 MHz and CAT B limit validation

Figure 63 shows the validation results for DUT PICC 6 and f_{RES} of 16.5 MHz complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured

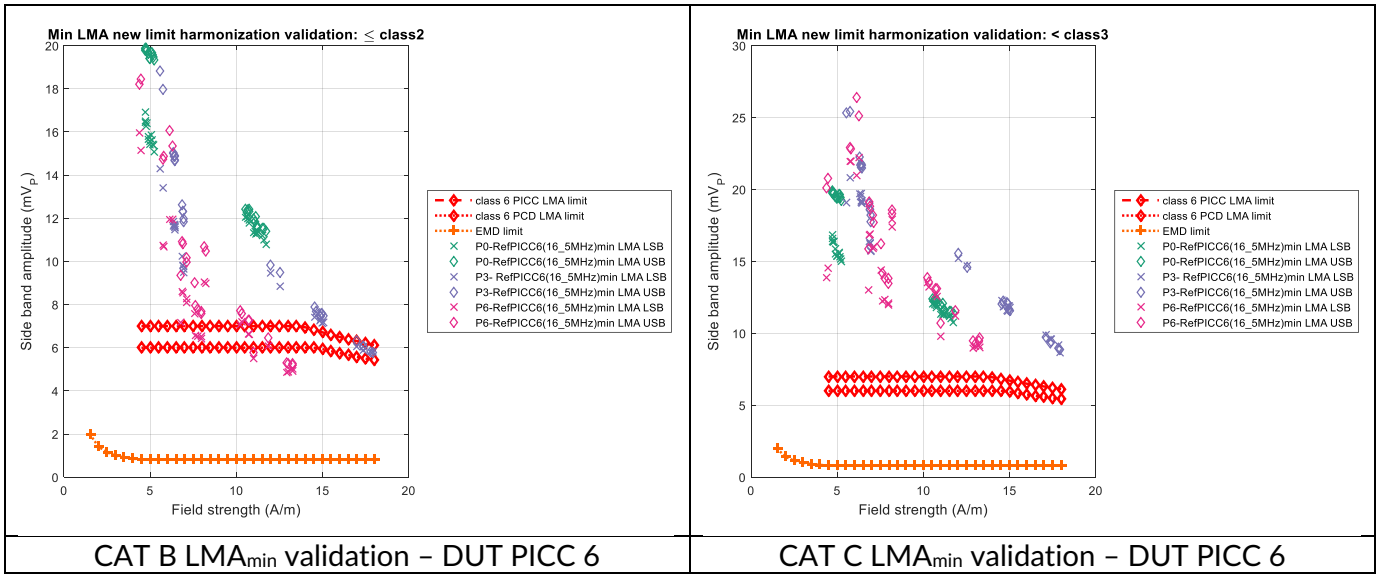
according to the definition of [ISO10373-6] using Test PCD Assembly 1. CAT C was defined for antenna sizes of Class 6 which is also used by DUT PICC 6. Therefore one can observe that the limit of CAT C conforms well to the ISO/IEC 14443 defined Class 3 limit curve. The left hand side graph illustrates the behaviour of a Class 6 antenna size complying with CAT B. These results do not fulfil the requirement on LMA_{min} for Class 1 - 3 as defined by ISO/IEC 14443. The field strength range coverage for DUT PICC 6 and f_{RES} of 16.5 MHz is approximately from 4 A/m(rms) to 18 A/m(rms). A DUT PICC 6device can claim interoperability to ISO/IEC 14443 Class 1-3 when implementing the candidate limits of CAT C as defined in Table 20 within the tested field strength range.



CAT B LMA_{min} validation – DUT PICC 6	CAT C LMA_{min} validation – DUT PICC 6

Figure 63: Reference PICC 6 f_{RES} = 16.5 MHz and CAT C limit validation using ISO Test PCD Assembly 1

Figure 64 shows the validation results for DUT PICC 6 and f_{RES} of 16.5 MHz complying either with CAT B (left hand side) or CAT C (right hand side) limit values as defined in Table 20 when measured according to the definition of [ISO10373-6] using Test PCD Assembly 2. CAT C was defined for antenna sizes of as small as Class 6 which is also used by DUT PICC6. CAT C limits have been selected to align to ISO/IEC 14443 Class 3. Therefore one can observe that the limit of CAT C exceeds the ISO/IEC 14443 defined Class 6 limit curve. The field strength range coverage for DUT PICC 6 and f_{RES} of 16.5 MHz is approximately from 4 A/m(rms) to 18 A/m(rms). A DUT PICC 6 device can claim compliance and interoperability to ISO/IEC 14443 Class 6 when implementing the candidate limits of CAT C and interoperability when implementing the candidate limits of CAT B as defined in Table 20 within the tested field strength range.



CAT B LMA_{min} validation – DUT PICC 6	CAT C LMA_{min} validation – DUT PICC 6

Figure 64: Reference PICC 6 f_{RES} = 16.5 MHz and CAT C limit validation using ISO Test PCD Assembly 2

4.2.5 Summary

The below listed points summarize the Listener LMA_{min} interoperability solution of section 4.2.3 and the validation of section 4.2.4 by comparing to the ISO/IEC 14443 PCD and PICC limits in dependency of the antenna class:

- Harmonization solution has been presented
- All relevant parameters have been included in the validation:
  - Antenna size
  - Loadings
  - Resonance frequencies
- Harmonization to ISO/IEC 14443 PCD Class 1-3 LMA_{MIN} ($V_{LMA, PCD}$) limits have been successfully demonstrated
- NFC Forum LMA_{MIN} limits have been defined in order to be as close as possible to ISO/IEC 14443 PCD/PICC LMA_{MIN} limits
- NFC Forum Listening Device can claim interoperability to ISO/IEC 14443 conformant PCDs and the application profile for public transport defined in [CEN/TS 16794-1].

The validation results presented in section 4.2.4.2 cover well the points listed above. However, for some antenna sizes, the ISO/IEC 14443 defined field strength range defined for PICCs of Class 1 -3 is not fully covered. Specifically, the maximum field strength for Class 1 antenna sizes and the minimum field strength for Class 6 devices as defined by ISO/IEC 14443 Class 1 -3 are not fully covered. The subsection below analyses the NFC Forum testing methodology and compares it to the methodology defined in [ISO10373-6] and [ISO10373-6:AMD1]. Subsequently the maximum field strength for CAT A devices is analysed. Finally, the minimum field strength coverage for CAT C devices is discussed.

a. Testing methodology difference analysis

NFC Forum testing methodology basically follows the methodology of EMVCo for Listener/PICC test cases. For this reason the Reference Poller are setup to a specific power condition using the Reference Listening Devices in a specific position in the operating volume. For minimum power

setup the maximum loading configuration of 820 Ω and for maximum power setup the minimum loading configuration of 82 Ω of the Reference Listening Device is used. As a result the Reference Polling Device is setup to emit an H-field covering the valid range between H_{min} and H_{max} (plus a small margin) when measured with Reference Listeners loading as defined for H_{min} and H_{max} in the whole operating volume. During testing the field strength observed by the DUT finally depends of its own loading. For DUT Poller Devices power emission test case the same measurement principle is applied. Thus, the power test cases for DUT Poller and DUT Listener in NFC Forum match.

In contrast [ISO10373-6] uses a specific test setup called Test PCD Assembly to test PICCs. In this setup no operating volume tests are performed, instead the DUT PICC is placed at a fixed position and the field strength is varied within the range of H_{min} and H_{max}. The adjustment of the field strength is performed with the DUT in the field. Therefore, the DUT loading is compensated and the field strength is always readjusted to the target value. The [ISO10373-6] PCD field strength test is performed with Reference PICCs. In order the verify the minimum field strength of the DUT PCD the Reference PICCs are configured to the highest load at a f_{RES} of 13.56 MHz (see Annex 0 and [ISO10373-6], [ISO10373-6:AMD1]). To verify the maximum field strength of the DUT PCD the Reference PICCs are configured to the lowest load at a f_{RES} of 19 MHz (see Annex 0 and [ISO10373-6], [ISO10373-6:AMD1]). Thus PCD testing methodology of NFC Forum and ISO/IEC 14443 are equivalent on this parameter.

b. Maximum field strength – class 1 antenna size

Considering the field strength ranges for DUTs of Class 1 antenna size the LMA_{min} validation does not include the field strength range up to H_{max} of 7.5A/m(rms) as defined by [ISO14443-2]. Taking into account the worst case loading emulated by a DUT L1 of 820 Ω, the DUT observed maximum field strength is approximately 4 A/m(rms).

The Listener LMA test is performed up to a maximum field strength which depends on the Listening Device load and may not reach H_{max} defined in ISO/IEC 14443-2 for a Listening Device under test with a load higher than the Reference Listening Device configured to 82 Ω loading.

NFC Forum Reference Listener 1 (Class 1) was used for the validation of the minimum LMA limits and CAT A. This device can be configured to different loadings. 820 Ω loading is the worst case loading which also is aligned to ISO Ref PICC1 at 1.5 A/m(rms). This configuration usage is best at low field strength values and remains constant independent on field strength. This device is perfectly suited for low field strength (H_{min}) tests but at higher field strength it is not at all emulating a real PICC or NFC Device. At 7.5 A/m(rms) the DC voltage induced is higher than 22V(dc). As a result, a typical integrated device would be destroyed by such high voltages. Thus every real device (PICC or Listener) would decrease its own/inherent loading (change of antenna quality factor or similar) in order to reduce the received voltage (voltage regulation to protect the device). Consequently a real NFC Device will always observe a field strength significantly higher than a Listener 1 (820Ω) observes.

The minimum loading defined by NFC Forum is emulated by the Reference Listening Device configured to 82Ω loading. Figure 65 contains the LMA_{min} validation results as a function of field strength. Due to the changed load of the DUT the observed field strength is 7.5 A/m(rms) plus a small margin.

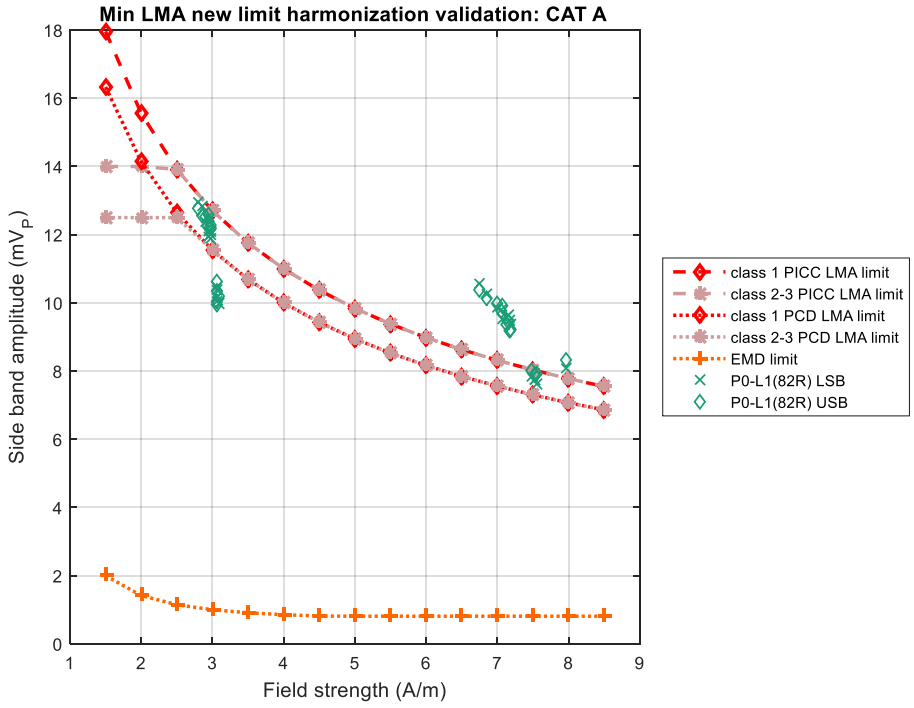


Figure 65: LMA$_{min}$ validation for DUT Listener 1 with 82 Ω loading on Reference Poller 0

NFC Forum Listening Device excessive field strength test

NFC Forum introduced a high field strength test in which the Listening Device under test is exposed to field strengths of 10 and 12 A/m(rms), similar to the maximum alternating field strength test defined in ISO/IEC 14443-1. For this test NFC Forum made efforts to expose the DUT at the target field strength independent on the DUT loading. Therefore, the field observed in this test is well defined from the DUT perspective. The actual H-field exposure for each category is as follows:

1. CAT A (class 1): 10 A/m(rms) and 12 A/m(rms)
2. CAT B (class 2-3) and CAT C (class 6) : ~11,3 A/m(rms) and 13,6 A/m(rms)

NFC Forum is not measuring the LMA during this test. Since this test is a survival test, no communication is performed during the high field exposure.

c. CAT C and minimum field strength

Considering the field strength ranges for DUTs of Class 6, the LMA$_{min}$ validation does not include the field strength range starting at H_{min} of 1.5A/m(rms) as defined by [ISO14443-2] for Class 1 - 3. The DUT observed minimum field strength is in the lowest case approximately 3 A/m(rms). NFC Forum Reference Poller emitted power and the field distribution induces a field higher than 1.5 A/m(rms) in a Class 6 device but a field lower than the H_{min} of 4.5A/m(rms) as required by [ISO14443-2:AMD2] and Class 6. As described in section 4.2.5) 0) the DUT observed field strength depends on the DUT position and loading. The Reference Poller emits a field between H_{min} and H_{max}..

CAT C, default category, results have been validated using a Class 6 antenna size, emulating the smallest antenna size considered. The Public Transport specific application profile [CEN/TS 16794-1] requires a minimum field strength for PCDs of 2 A/m(rms) (see [CEN/TS 16794-1], Requirement Rdr 3) for antenna sizes of Class 3. Consequently, any antenna size smaller than Class 3 will observe an H-field equal to or larger than 2 A/m(rms). Therefore it can be concluded that it is sufficient to additional perform an LMA$_{min}$ validation for CAT C at a field strength of 2 A/m(rms) using a DUT L6

with a Class 6 antenna size. For this additional validation the procedure defined in section 4.2.4.1 was used. The power setup was slightly adapted in order to achieve a $V_{S,OV}$ aligned to 2 A/m(rms). Figure 66 depicts the results when measured according to the definition of [ISO10373-6] using Test PCD Assembly 1. One can observe that the limit of CAT C just meets the ISO/IEC 14443 PCD limit defined for Class 3 at 2 A/m(rms). Actually, the LSB is slightly above and the USB is slightly below the PCD limit. On average a good match to the PCD limit is achieved. Interoperability can be claimed in case a PCD does not mainly rely on the USB in combination with a sensitivity exactly on the PCD limit and its field strength for a PICC Class 6 antenna is close to 2 A/m(rms).

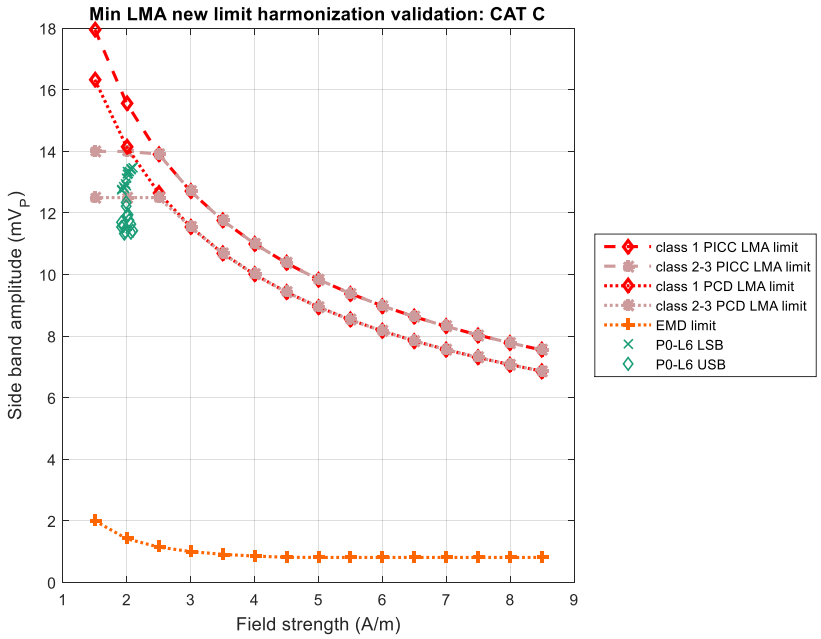


Figure 66: LMA_{min} validation at 2 A/m(rms) for DUT Listener 6 with 820 Ω loading on Reference Poller 0

4.2.6 Conclusion

The validation results presented in the previous sections as well as the detailed analysis provided in section 4.2.5 demonstrated that the proposed harmonization solution indeed enables interoperability between NFC Devices in Listen mode and PCDs implemented according to ISO/IEC 14443 and [CEN/TS 16794-1] application profile. As a consequence, NFC Forum integrated the solution on LMA_{min} proposed in section 4.2.3 into the Analog v2.0 specification.

5 Electromagnetic Disturbance (EMD)

Electromagnetic disturbances (EMD) occurring in the frequency band of communication can impact the Card to Reader communication stability. In order to mitigate the risk of communication instabilities due to EMD, ISO/IEC 14443, EMVCo and NFC Forum defined requirements on EMD. The below points compare the EMD requirements as defined by each standardization body for Poller/PCD and Listener/PICC:

- Poller EMD handling rules of NFC Forum [NFC_DIGITAL] are aligned with [EMVCo_Book_D_v2_4] and [ISO14443-3:AMD1] PCD EMD requirements.
- Timing requirements regarding EMD for Poller/PCD are aligned between NFC Forum [NFC_DIGITAL] and [EMVCo_Book_D_v2_4] and are similar to [ISO14443-3:AMD1].
- Timing requirements regarding EMD for Listener/PICC are aligned between [NFC_DIGITAL], [EMVCo_Book_D_v2_4] and [ISO14443-3:AMD1].
- Analog PCD and PICC EMD requirements defined in ISO/IEC 14443 are not defined by both, NFC Forum and EMVCo.

Section 5.1 evaluates the impact of the analog EMD requirement on interoperability for NFC Forum.

5.1 EMD Impact Analysis

This section performs an analysis on the benefits for NFC Forum to introduce analog EMD requirements. The benefits are assessed in terms of an interoperability analysis between NFC Forum Devices and the communication to legacy infrastructure and PICCs. Firstly, the NFC Forum Device in Poll or Reader role and afterwards the NFC Forum Device in Listen or CE role are analysed.

- NFC Forum Device in Poll or Reader role:
  - Communication with an ISO-conformant PICC should be supported.
  - PICC dynamic current consumption during command execution may result in arbitrary load changes. This load change affects the magnetic field.
  - Conclusion: For NFC Forum Devices in Poll or Reader role, **Analog EMD is required.**
- NFC Forum Device in Listen or CE role:
  - An NFC Forum Device is battery powered therefore no load change will affect the magnetic field.
  - No EMD due to command execution and/or crypto processing
  - Conclusion: For NFC Forum Devices in Listen or CE role, **Analog EMD requirement is rated as low priority.**

Based on the provided analysis NFC Forum will consider to introduce requirements and test cases for the analog EMD parameter and for NFC Forum Polling Devices in a future version of the Analog Specification and according test cases document.

ANNEX A: ISO/IEC 14443 PCD Requirement References

A.1. General PCD Requirements for Compliance

CONTEXT	
Reference	[ISO14443-2], [ISO14443-2:AMD1]
Requirement	**3.6 operating volume** for each PICC class, the positions where the corresponding Reference PICC shows PCD compliance with all requirements of this International Standard for this class **5.2.2 PCD compliance** The PCD shall comply with all mandatory requirements of this International Standard and may support optional requirements (bit rate, support of PICCs of optional classes…). The PCD — shall support PICCs of “Class 1”, “Class 2” and “Class 3”, — may optionally support PICCs of “Class 4”, — may optionally support PICCs of “Class 5”, — and may optionally support PICCs of “Class 6”. PCD requirements measured with Reference PICCs 1, 2 and 3 are mandatory for all PCDs. PCD requirements measured with Reference PICC 4 are only mandatory for PCDs supporting operation with “Class 4” PICCs. PCD requirements measured with Reference PICC 5 are only mandatory for PCDs supporting operation with “Class 5” PICCs. PCD requirements measured with Reference PICC 6 are only mandatory for PCDs supporting operation with “Class 6” PICCs. For each supported PICC class, the PCD manufacturer shall indicate the operating volume within which the PCD fulfils all requirements of this International Standard. *NOTE As an indication of each operating volume, the manufacturer may give the operating range (e.g. 0 to X cm with PCD and PICC relative positions, e.g. PCD and PICC antennas parallel and concentric).* **5.2.2.1 PCD supporting PICCs of particular class(es)** If a PCD is expected to operate with PICCs of only particular class(es), it is not mandatory for this PCD to support PICCs of other classes. This PCD shall comply with all other relevant clauses of this International Standard. The PCD manufacturer shall clearly state which class(es) are supported. *NOTE A PCD which does not support one of the mandatory classes 1, 2 and 3 is not fully compliant with 14443-2. It may be advertised as “supporting “Class X” PICCs only” or “compliant with Class(es) X requirements only”.* **7.1 PCD Tests** All the PCD tests described below will be done in the operating volumes as defined by the PCD manufacturer for each supported class. All PCD tests of ISO/IEC 14443-2 parameters shall be performed using Reference PICCs 1, 2 and 3 and optionally other Reference PICCs corresponding to the optional classes supported by the PCD, with the relevant parameters and test PCD assembly as defined in Table 21.

Table 21: Classes Parameter ([ISO10373-6:AMD1], Section 7.1, Table 3)

Class	Reference PICC	V_{load}	$R2_{min}$	$R2_{max}$	Test PCD Assembly
1	1	6 V	870 Ω	1070 Ω	Test PCD Assembly 1
2	2	4,5 V	1030 Ω	1260 Ω	
3	3	4,5 V	1080 Ω	1320 Ω	
4	4	4,5 V	990 Ω	1210 Ω	Test PCD Assembly 2
5	5	4,5 V	960 Ω	1170 Ω	
6	6	4,5 V	700 Ω	900 Ω	

A.2. 14443-1 PCD Requirements for Alternating Magnetic Field

CONTEXT	
Reference	[ISO14443-1], [ISO14443-1:AMD1], [ISO14443-2:AMD1], [ISO10373-6]
Requirement	Reg. Section 6.2 of [ISO14443-2:AMD1]: The PCD shall not generate a field strength higher than the average and maximum levels specified for all mandatory and optional classes in ISO/IEC 14443-1:2008/Amd.1:2012, 4.4 (alternating magnetic field) in any possible PICC position and orientation, measured with the associated Reference PICCs. Test methods for the PCD operating field are defined in ISO/IEC 10373-6 and use a dedicated Reference PICC for each class. Reg. Section: 4.4, Test-Reg. Section: 6.1 If the PICC meets the requirements of one particular class as specified in Annex A, then the PICC, whichever form the PICC has according to 4.1, shall continue to operate as intended after continuous exposure to a magnetic field of an average level of 4/3 times H_{max} at 13,56 MHz as specified in ISO/IEC 14443-2:2010/Amd.2:—1), 6.2 for this class. The averaging time is 30 seconds and the maximum level of the magnetic field is limited to 8/5 times H_{max}. If the PICC does not claim to meet the requirements of one particular class as specified in Annex A, then the PICC, whichever form the PICC has according to 4.1, shall continue to operate as intended after continuous exposure to a magnetic field of an average level of 10 A/m (rms) at 13,56 MHz. The averaging time is 30 seconds and the maximum level of the magnetic field is limited to 12 A/m (rms).

A.3. 14443-2 Requirement on PCD Field Strength

a. Minimum Field Strength

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO14443-2:AMD1], [ISO10373-6], [ISO10373-6:AMD1]</td></tr>
<tr><td>Requirement</td><td>Req. Section: 6.2, Test-Req. Section: 7.1.1
Within the manufacturer specified operating volumes, the PCD shall generate a field strength of at least H_{min} and not exceeding H_{max} under unmodulated conditions.
The PCD
— shall support PICCs of “Class 1”, “Class 2” and “Class 3”,
— may optionally support PICCs of “Class 4”,
— may optionally support PICCs of “Class 5”,
— and may optionally support PICCs of “Class 6”.
PCD requirements measured with Reference PICCs 1, 2 and 3 are mandatory for all PCDs.
PCD requirements measured with Reference PICC 4 are only mandatory for PCDs supporting operation with “Class 4” PICCs.
PCD requirements measured with Reference PICC 5 are only mandatory for PCDs supporting operation with “Class 5” PICCs.
PCD requirements measured with Reference PICC 6 are only mandatory for PCDs supporting operation with “Class 6” PICCs.
Table 22: PCD Minimum and Maximum Field Strength – Classes ([ISO14443-2:AMD2], Sec. 6.2, Table 1)
<table>
<tr><th></th><th colspan="2">PCD</th></tr>
<tr><th></th><th>H_{min}
A/m (rms)</th><th>H_{max}
A/m (rms)</th></tr>
<tr><td>Measured with Reference PICC 1</td><td>1,5</td><td>7,5</td></tr>
<tr><td>Measured with Reference PICC 2</td><td>1,5</td><td>8,5</td></tr>
<tr><td>Measured with Reference PICC 3</td><td>1,5</td><td>8,5</td></tr>
<tr><td>Measured with Reference PICC 4 (optional)</td><td>2,0</td><td>12</td></tr>
<tr><td>Measured with Reference PICC 5 (optional)</td><td>2,5</td><td>14</td></tr>
<tr><td>Measured with Reference PICC 6 (optional)</td><td>4,5</td><td>18</td></tr>
</table>
The PCD shall not generate a field strength higher than the value specified in [ISO14443-1] and [ISO14443-1:AMD1], 4.4 (alternating magnetic field) in any possible PICC position and orientation. Test methods for the PCD operating field strength are defined in ISO/IEC 10373-6.
Test methods for the PCD operating field are defined in ISO/IEC 10373-6 and use a dedicated Reference PICC for each class.</td></tr>
</table>

b. Maximum Field Strength

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO10373-6]</td></tr>
<tr><td>Requirement</td><td>Req. Section: 6.2, Test-Req.Section: 7.1.1
See above Requirement of 0) a. Minimum Field Strength.</td></tr>
<tr><td>Implicit Requirement</td><td></td></tr>
</table>

A.4. ISO/IEC 14443-2 PCD Requirement for Carrier Frequency fc

CONTEXT	
Reference	[ISO14443-2]
Requirement	Reg. Section: 6.1 Frequency The frequency fc of the RF operating field shall be 13.56 MHz ± 7 kHz.
NFC Forum Reference	[NFC_ANA]
Requirement	4.4.2.1 The frequency of the Operating Field (carrier frequency) generated by the Polling Device SHALL be within the range of Min and Max values of f_C Refer to Appendix B.2 for the Min and Max range values of f_C

Power ON/OFF	$V_{OV,RESET}$					rms
Carrier Frequency	f_c		13.553	13.567	820	MHz
Modulation	t_{μ}		2.06	2.99	330	µs

RESULT	
	The Requirements are equal from the specification point of view
CONCLUSION / DISCUSSION	
	n.a.

[ISO14443-2] Req-Section: 6.1: No experimental measurement needed.

A.5. ISO/IEC 14443-2 EMD PCD Requirement

CONTEXT	
Reference	[ISO14443-2:AMD1]
Requirement	Req. Section: 10.1, Test-Req. Section: 7.1.6, 7.1.7 The PCD shall not detect any load modulation amplitude below $V_{E,PCD}$ at a field strength H [A/m (rms)], when measured as specified in ISO/IEC 10373 - 6:2011/Amd.2. $V_{E,PCD}$ is: • $2/3 + 3/H^2$ [mV (peak)] for $H_{min} \leq H \leq 4.5$ A/m (rms) • 0,81 mV (peak) for 4.5 A/m (rms) $\leq H \leq H_{max}$ *WARNING — This limit is referenced to "Class 1" only and may be detrimental to communication with PICCs of the other classes. Values for other classes will be specified in the future.* ***Note: EMD limit for PCD and PICC are identical. No margin is applied.***

A.6. ISO/IEC 14443-2 PCD Requirement for Resetting the Operating Field

a. Timing and Duration of Reset

CONTEXT	
Reference	[ISO14443-3]
Requirement	5.2.4 Transition to POWER-OFF state The PICC shall be in the POWER-OFF state no later than 5 ms after the operating field is switched off
NFC Forum Reference	[NFC_ACTIVITY]
Requirement	6.1.1.1 When the NFC Forum Device in Poll Mode sets the Operating Field to the Operating Field Off condition (carrier off, as defined in [ANALOG]) other than for NFC-A modulation purposes, then the Operating Field SHALL be set to Operating Field Off condition for a time of at least t_{FIELD_OFF}.
RESULT	
	ISO/IEC14443 does implicitly require the PCD to switch off the field for a time longer than 5ms, which is reflected by the Poller value of t_{FIELD_OFF} in NFC Forum. The Requirements are considered to be equal from the specification point of view.

No experimental measurement needed.

b. $V_{OV,reset}$

There is no amplitude value defined in [ISO14443-2] or [ISO14443-3] similarly to $V_{OV,RESET}$ in NFC Forum. ISO/IEC14443 actually requires to turn-off the field long enough to allow the PICC to enter POWER-OFF state (see above) for $t_{FIELD,OFF}$.

A.7. ISO/IEC 14443-2 PCD Requirements for Power-off of the Operating Field

No Requirement available.

A.8. ISO/IEC 14443-2 PCD Requirements for Modulation PCD to PICC – Type A

a. Waveform analysis

CONTEXT	
Reference – ISO	[ISO14443-2], [ISO10373-6]
Requirement-ISO	Req.Section: 8.1.2.1 Modulation for a bit rate of fc/128 Communication from PCD to PICC for a bit rate of fc/128 shall use the modulation principle of ASK 100 % of the RF operating field to create a PauseA as shown in Figure 3. The envelope of the PCD field shall decrease monotonically to less than 5 % of its initial value $H_{INITIAL}$ and remain less than 5 % for more than t_2. This envelope shall comply with Figure 3. If the envelope of the PCD field does not decrease monotonically, the time between a local maximum and the time of passing the same value before the local maximum shall not exceed 0,5 µs. This shall only apply if the local maximum is greater than 5 % of $H_{INITIAL}$. The PauseA length t_1 is the time between 90 % of the falling edge and 5 % of the rising edge of the H-field signal envelope. In case of an overshoot the field shall remain within 90 % of $H_{INITIAL}$ and 110 % of $H_{INITIAL}$.

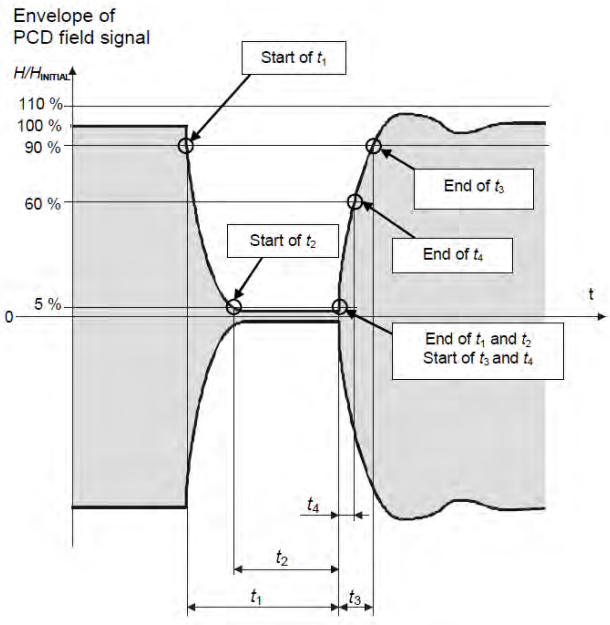


Figure 3 — PauseA for a bit rate of *fc*/128

The PCD shall generate a PauseA with timing parameters defined in Table 23.

Table 23: PCD transmission: PausA timing parameters for a bit rate of fc/128.

Parameter	Condition	Min	Max
t_1		28/*fc*	40,5/*fc*
t_2	t_1 > 34/*fc*	7/*fc*	t_1
	t_1 ≤ 34/*fc*	10/*fc*	
t_3		1,5 × t_4	16/*fc*

	<table><tr><td>t_4</td><td></td><td>0</td><td>6/*fc*</td></tr></table> NOTE 1 PCD implementations may be restricted to generate a PauseA with values of t_1 = n/*fc* (n = integer). Therefore measurement of t_1 should be rounded to the closest n in the unit 1/*fc*. NOTE 2 The maximum value of t_2 is a function of the measured value of t_1. NOTE 3 The minimum value of t_3 is a function of the measured value of t_4. For a bit rate of *fc*/128 the PCD shall generate a PauseA with a rise time t_3 – greater than both 0/*fc* and (t_1 – t_2) – 24.5/*fc*, – and less than both (t_1 – t_2) + 7/*fc* and 16/*fc*.

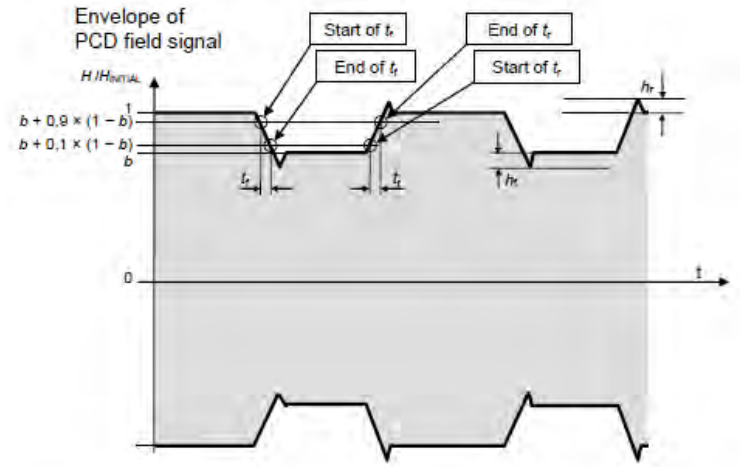
b. Overshoot and Undershoot analysis

CONTEXT	
Reference	[ISO14443-2]
Requirement	Req.Section: 8.1.2.1 Modulation for a bit rate of fc/128 In case of an overshoot the field shall remain within 90 % of $H_{INITIAL}$ and 110 % of $H_{INITIAL}$. <u>Maximum of overshoots:</u> OS_{max} = 10%

A.9. ISO/IEC 14443-2 PCD Requirements for Modulation PCD to PICC – Type B

a. Waveform analysis

CONTEXT	
Reference	[ISO14443-2]
Requirement	Req-Section 9.1.2 Communication from PCD to PICC shall use the modulation principle of ASK 10 % of the RF operating field. The modulation waveform shall comply with Figure 12. The rising and falling edges of the modulation shall be monotonic. The rise and fall times (tr, tf) shall be measured between 10 % and 90 % of the actual modulation step.



For all supported bit rates the PCD shall generate a modulation waveform with a modulation index m between
8 % and 14 %.
The overshoot and undershoot of the PCD modulation waveform shall remain within limits specified in Table 8.
Table 8 — PCD transmission: Overshoot and undershoot for bit rates of fc/128, fc/64, fc/32 and fc/16

Parameter	Min	Max
h_f	0	$(1-t_f /(2 \times t_{f,max,PCD})) \times 0.1*(1-b)$
h_r	0	$(1-t_r /(2 \times t_{r,max,PCD})) \times 0.1*(1-b)$

For a bit rate of *fc*/128 the PCD shall generate a modulation waveform with
– a fall time t_f between 0/*fc* and $t_{f, max, PCD}$ = 16/*fc*,
– and a rise time t_r
– greater than both 0/*fc* and t_f – 8/*fc*,
– and less than both t_f + 8/*fc* and $t_{r, max, PCD}$ = 16/$_{fc}$.

b. Overshoot and Undershoot analysis

CONTEXT	
Reference	[ISO14443-2]
Requirement	Req-Section 9.1.2 The overshoot and undershoot of the PCD modulation waveform shall remain within limits specified in Table 8.

Table 8 — PCD transmission: Overshoot and undershoot for bit rates of fc/128, fc/64, fc/32 and fc/16

Parameter	Min	Max
h_f	0	$(1-t_f /(2 \times t_{f,max,PCD})) \times 0.1*(1-b)$
h_r	0	$(1-t_r /(2 \times t_{r,max,PCD})) \times 0.1*(1-b)$

Maximum of overshoots/undershoots:

- t_f / t_r = 0: OS_{max} = 10%
- t_f / t_r = 3/fc: OS_{max} = 9.06%
- t_f / t_r = 6/fc: OS_{max} = 8.13%
- t_f / t_r = 16/fc: OS_{max} = 5%

A.10. ISO/IEC 14443-2 PCD Requirements for Modulation PICC to PCD

a. $V_{PP,min}$

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2]</td></tr>
<tr><td>Requirement</td><td>Reg. Section: 8.2.2:
The PCD shall be able to receive a V_{LMA} of at least $V_{LMA,\ PCD}$ when measured as described in ISO/IEC 10373-6, using test PCD assembly 1, with Reference PICCs 1, 2 and 3, where H is the value of magnetic field strength in A/m (rms).
If the PCD supports operation with “Class 4” PICCs, it shall be able to receive a V_{LMA} of at least $V_{LMA,\ PCD}$ when measured as described in ISO/IEC 10373-6, using test PCD assembly 2, with Reference PICC 4, where H is the value of magnetic field strength in A/m (rms).
If the PCD supports operation with “Class 5” PICCs, it shall be able to receive a V_{LMA} of at least $V_{LMA,\ PCD}$ when measured as described in ISO/IEC 10373-6, using test PCD assembly 2, with Reference PICC 5, where H is the value of magnetic field strength in A/m (rms).
If the PCD supports operation with “Class 6” PICCs, it shall be able to receive a V_{LMA} of at least $V_{LMA,\ PCD}$ when measured as described in ISO/IEC 10373-6, using test PCD assembly 2, with Reference PICC 6, where H is the value of magnetic field strength in A/m (rms).
Table 9 specifies for each Reference PICC both the load modulation reception limit $V_{LMA,\ PCD}$ and the test PCD assembly to use to measure the PCD sensitivity.
Table 24: PCD minimum load modulation ([ISO14443-2:AMD2], Section 8.2.2, Table 9)
<table>
<tr><th></th><th colspan="2">PCD</th></tr>
<tr><th></th><th>$V_{LMA,PCD}$
mV (peak)</th><th>Test PCD assembly</th></tr>
<tr><td>Measured with Reference PICC 1</td><td>$20/H^{0,5}$</td><td rowspan="3">Test PCD assembly 1</td></tr>
<tr><td>Measured with Reference PICC 2</td><td>$Min(12,5; 20/H^{0,5})$</td></tr>
<tr><td>Measured with Reference PICC 3</td><td>$Min(12,5; 20/H^{0,5})$</td></tr>
<tr><td>Measured with Reference PICC 4 (optional)</td><td>$Min(16; 36/H^{0,5})$</td><td rowspan="3">Test PCD assembly 2</td></tr>
<tr><td>Measured with Reference PICC 5 (optional)</td><td>$Min(13; 31/H^{0,5})$</td></tr>
<tr><td>Measured with Reference PICC 6 (optional)</td><td>$Min(6; 23/H^{0,5})$</td></tr>
</table>
</td></tr>
</table>

b. $V_{PP,max}$

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2]</td></tr>
<tr><td>Requirement</td><td>No maximum load modulation amplitude ($V_{LMA,max}$) defined in any published ISO/IEC 14443 related standard
Note: At the moment SC17/WG8 works on the topic in the amendment ISO/IEC14443-2:2008 PDAM1_2. In this document a maximum $V_{LMA,PCD}$ of 110 mV(peak) is proposed.</td></tr>
</table>

ANNEX B: ISO/IEC 14443 PICC Requirements

B.1. 14443-1 PICC Requirements for Alternating Magnetic Field

CONTEXT	
Reference	[ISO14443-1], [ISO14443-1:AMD1], [ISO10373-6]
Requirement	Req.Section: 4.4, TestReq.Section: 6.2 If the PICC meets the requirements of one particular class as specified in Annex A, then the PICC, whichever form the PICC has according to 4.1, shall continue to operate as intended after continuous exposure to a magnetic field of an average level of 4/3 times H_{max} at 13.56 MHz as specified in ISO/IEC 14443-2:2010/Amd.2:—1), 6.2 for this class. The averaging time is 30 seconds and the maximum level of the magnetic field is limited to 8/5 times H_{max}. If the PICC does not claim to meet the requirements of one particular class as specified in Annex A, then the PICC, whichever form the PICC has according to 4.1, shall continue to operate as intended after continuous exposure to a magnetic field of an average level of 10 A/m (rms) at 13.56 MHz. The averaging time is 30 seconds and the maximum level of the magnetic field is limited to 12 A/m (rms).

B.2. ISO/IEC 14443-2 Power Transfer PCD to PICC (PICC Reception)

a. Minimum Field Strength

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO14443-2:AMD2], [ISO10373-6]</td></tr>
<tr><td>Requirement</td><td>Reg. Section: 6.2, Test-Reg. Section: 7.1.1
If the PICC meets the requirements of one particular class as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then the PICC shall operate as intended continuously between H_{min} and H_{max} defined for its class; this includes all PICC requirements defined in this International Standard and processing of the manufacturer specified set of commands.
If the PICC does not claim to meet the requirements of one particular class as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then:
— if the PICC antenna fits within the external rectangle defined in “Class 2” as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then:
— the PICC shall operate as intended continuously between H_{min} and H_{max} defined for “Class 2”,
— the PICC shall pass the loading effect test defined for “Class 2”;
— if the PICC antenna fits within the external rectangle or external circle defined in “Class 3” as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then:
— the PICC shall operate as intended continuously between H_{min} and H_{max} defined for “Class 3”,
— the PICC shall pass the loading effect test defined for “Class 3”;
— if the PICC antenna does not claim to fit within the external rectangle or external circle defined in “Class 2” or “Class 3” as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then:
— the PICC shall operate as intended continuously between H_{min} and H_{max} defined for “Class 1”,
— the PICC shall pass the loading effect test defined for “Class 1”.
NOTE 2 If the PICC does not claim to meet the requirements of one particular class then the requirements defined above may not be sufficient to guarantee proper operation and interoperability with PCDs.
Table 25: PICC Minimum and Maximum Field Strength – Classes ([ISO14443-2:AMD2], Sec. 6.2, Table 2)
<table>
<tr><th rowspan="2"></th><th colspan="2">PICC</th></tr>
<tr><th>H_{min}
A/m (rms)</th><th>H_{max}
A/m (rms)</th></tr>
<tr><td>“Class 1“ PICC</td><td>1,5</td><td>7,5</td></tr>
<tr><td>“Class 2“ PICC</td><td>1,5</td><td>8,5</td></tr>
<tr><td>“Class 3“ PICC</td><td>1,5</td><td>8,5</td></tr>
<tr><td>“Class 4“ PICC</td><td>2,0</td><td>12</td></tr>
<tr><td>“Class 5“ PICC</td><td>2,5</td><td>14</td></tr>
<tr><td>“Class 6“ PICC</td><td>4,5</td><td>18</td></tr>
</table>
</td></tr>
</table>

b. Maximum Field Strength

CONTEXT	
Reference	[ISO14443-2], [ISO14443-2:AMD1], [ISO10373-6]

Requirement	Req. Section: 6.2, Test-Req. Section: 7.1.1 See above Requirement of 0) a. Minimum field strength.

B.3. ISO/IEC 14443-2 PICC Maximum Loading

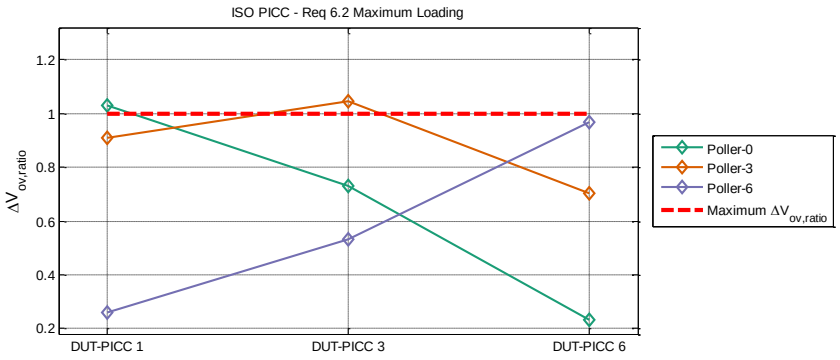
CONTEXT	
Reference	[ISO14443-1:AMD1], [ISO10373-6], [ISO10373-6:AMD1]
Requirement	Req. Section: A 1.2, A 2.2, A 3.2, A 4.2, A 5.2 and A 6.2; Test-Req. Section: 7.2.4 Req: **Electrical requirement** The "Class X" PICC shall also pass the PICC maximum loading effect test defined in [ISO10373-6:AMD1], 7.2.4. Test-Req: The PICC loading effect at H_{min} shall be measured using the Test PCD assembly. It shall not exceed the loading effect of the selected Reference PICC tuned to 13.56 MHz and calibrated to obtain V_{load} at CON3 at H_{min}.
Implicit Requirement	Maximum loading Effect, Influence on the field
Question	Is an ISO compliant PICC on the maximum loading effect also NFC Forum compliant?

PROCEDURE	
Step-NFC	**SETUP**
1	Setup each of the NFC Forum Reference – Poller to $V_{S,OV,MIN}$ using the NFC Forum – Reference Listener 1.
2	Measure $V_{OV,free\ air}$ at the J2 output of each of the NFC Forum Reference – Poller without a Listening Device in the field.
3	Place the respective NFC Forum – Reference Listener in the NFC OV of the respective NFC Forum Reference – Poller (i.e., Poller 0 – Listener 1, Poller 3 – Listener 3, Poller 6 – Listener 6).
4	Measure $V_{OV,\ Listening\ Device}$ in the (000 – NFC OV).
5	Compute ΔV_{OV} for each Polling Device.
Setup – ISO 6	Tune each of the Reference PICCs 1, 3 and 6 to 13,56 MHz.
7	Place the Reference PICC into the DUT position on the respective Test PCD assembly producing the H_{min} (see Table 22) operating condition on the calibration coil. Adjust R2 or the voltage at CON2 to measure V_{load} as defined in Table 21 at connector CON3. The operating field condition shall be verified by monitoring the voltage on the calibration coil and adjusted if necessary.
Step	**VERIFICATION**
1	Place DUT PICC1 in the NFC OV of the NFC Forum – Reference Poller 0 and measure $V_{OV,loaded}$ at the J2 output of the NFC Forum – Reference Poller 0 in the complete NFC OV. *Note: If V_{load} of DUT PICC1 is lower than the defined value in Table 21, no readjustment shall be performed. If V_{load} of DUT PICC1 is higher than the defined value in Table 21, V_{load} must be readjusted to V_{load} of Table 21.*
2	Repeat VERIFICATION Step 1 with DUT PICC3 and DUT PICC6.
3	Repeat VERIFICATION Step 1-2 with NFC Forum – Reference Poller 3 and 6.

4	Compute ΔV_{OV} for each DUT PICC on each NFC Forum – Reference Polling Device.
5	Compute $\Delta V_{OV,\ ratio}$ using the results of VERIFICATION Step 4 and SETUP Step 5.

EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	The test is PASS if $\Delta V_{OV,\ ratio}$ is ≤ 1.
Step	**INTEROPERABILITY**
1	N.A

RESULT



Verdict	
DUT PICC 1	DUT PICC 1
DUT PICC 2	DUT PICC 2
DUT PICC 3	DUT PICC 3
DUT PICC 6	DUT PICC 6
Interoperability	Compliancy

CONCLUSION / DISCUSSION	
	For detailed discussion refer to section 3.2.2

B.4. ISO/IEC 14443-2 PICC Requirement for the Carrier Frequency fc

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO10373-6]</td></tr>
<tr><td>Requirement</td><td>Req. Section: 6.1 Frequency
The frequency fc of the RF operating field shall be 13.56 MHz ± 7 kHz.</td></tr>
<tr><td>NFC Forum Reference</td><td>[NFC_ANA]</td></tr>
<tr><td>Requirement</td><td>4.5.2.1
When placed in the Operating Volume of the NFC Forum – Reference Polling Device, the Listening Device SHALL function properly with a carrier frequency between the Min and Max values of $f_{s,c}$ as defined in Appendix B.3, being generated by the NFC Forum – Reference Polling Device.
Table 6: Parameters for Setting-up of Reference Equipment
<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Parameter</th><th rowspan="2">Coil</th><th colspan="3">Setup Values to establish....</th><th>$R_{s,L}$</th><th rowspan="2">Units</th></tr>
<tr><th>Min</th><th>Nominal</th><th>Max</th><th>Ω</th></tr>
<tr><td>Carrier Frequency</td><td>$f_{s,c}$</td><td></td><td>13.55</td><td>13.56</td><td>13.57</td><td></td><td>MHz</td></tr>
</table>
</td></tr>
<tr><th colspan="2">RESULT</th></tr>
<tr><td></td><td>The Requirements are providing a small difference from the specification point of view</td></tr>
<tr><th colspan="2">CONCLUSION / DISCUSSION</th></tr>
<tr><td></td><td>No experimental measurement needed.</td></tr>
</table>

B.5. ISO/IEC 14443-2 EMD PICC Requirement

CONTEXT	
Reference	[ISO14443-2:AMD1]
Requirement	Req. Section: 10.2, Test-Req. Section: 7.2.2 This EMD requirement is applicable for "Class 1" PICC only. *WARNING – Requirements for the classes other than "Class 1" will be specified in the future. However, the PICC limit for "Class 1" may ultimately be applied to "Class 2" and "Class 3" PICCs.* The EMD level before PICC data transmission shall be below $V_{E,PICC}$ at a field strength H [A/m (rms)], for at least the duration of the low EMD time $t_{E,PICC}$, when measured as specified in ISO/IEC 10373-6:2011/Amd.2. $V_{E,PICC}$ for "Class 1" PICC is: • $2/3 + 3/H^2$ [mV (peak)] for $H_{min} \leq H \leq 4,5$ A/m (rms) • 0,81 mV (peak) for 4,5 A/m(rms) ≤ H ≤ H_{max} During this low EMD time, the EMD level may exceed VE,PICC for no more than two short periods of 16/fc if: • it never exceeds 4 x $V_{E,PICC}$ and • in case of two periods, the time between the two periods is greater than 1 etu. Figure 18 shows an illustration of such allowed EMD spikes. *NOTE The low EMD time $t_{E,PICC}$ is defined in ISO/IEC 14443-3:2011/Amd.1.* *WARNING – This limit is referenced to "Class 1" only and values for the other classes may be specified in the future.* ***Note: EMD limit for PCD and PICC are identical. No margin is applied.***

B.6. ISO/IEC 14443-2 PICC Requirements for Transition to POWER-OFF / IDLE State

a. Duration of Transition to POWER-OFF/IDLE state

No experimental measurement needed.

b. $V_{OV,RESET}$

There is no amplitude value defined in [ISO14443-2]or [ISO14443-3] similarly to $V_{OV,RESET}$ in NFC Forum.

B.7. ISO/IEC 14443-2 PICC Requirements for Modulation PCD to PICC – Type A

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO10373-6]</td></tr>
<tr><td>Requirement</td><td>Req. 8.1.2.
The PICC shall be able to receive a PauseA with timing parameters defined in Table 26.
Table 26: PICC reception: PauseA timing parameters for a bit rate of fc/128
<table>
<tr><th>Parameter</th><th>Condition</th><th>Min</th><th>Max</th></tr>
<tr><td>t_1</td><td></td><td>27,5/fc</td><td>41/fc</td></tr>
<tr><td rowspan="2">t_2</td><td>$t_1 > 34/fc$</td><td>6/fc</td><td rowspan="2">t_1</td></tr>
<tr><td>$t_1 \leq 34/fc$</td><td>9/fc</td></tr>
<tr><td>t_3</td><td></td><td>1,5 × t_4</td><td>17/fc</td></tr>
<tr><td>t_4</td><td></td><td>0</td><td>7/fc</td></tr>
</table>
NOTE 4 The maximum value of t_2 is a function of the set value of t_1.
NOTE 5 The minimum value of t_3 is a function of the set value of t_4.

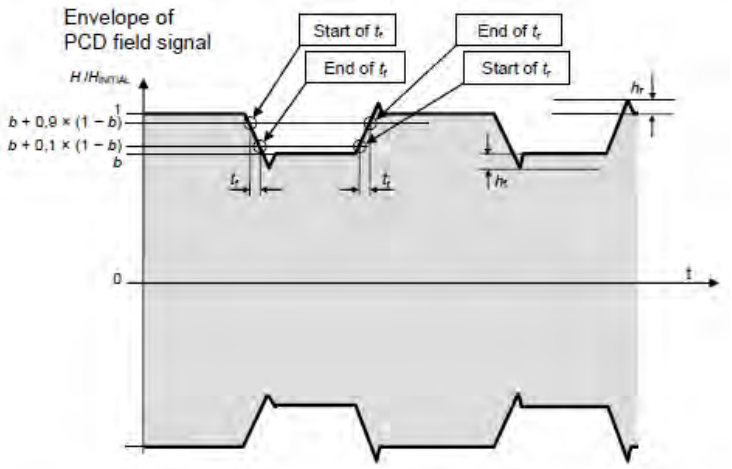
For a bit rate of fc/128 the PCD shall generate a PauseA with a rise time t_3
• greater than both 0/fc and ($t_1 - t_2$) – 24.5/fc,
• and less than both ($t_1 - t_2$) + 7/fc and 16/fc.
For a bit rate of fc/128 the PICC shall be able to receive a PauseA with a rise time t_3
• greater than both 0/fc and ($t_1 - t_2$) – 26/fc,
• and less than both ($t_1 - t_2$) + 8/fc and 17/fc.
NOTE 6 Minimum and maximum values of ($t_1 - t_2$) are derived from minimum and maximum values of t_1 and t_2 defined in Table 23 and Table 26.

The PICC shall detect the end of PauseA after the field exceeds 5 % of $H_{INITIAL}$ and before it exceeds 60 % of $H_{INITIAL}$. Figure 5 shows the definition of the end of PauseA. This definition applies to all modulation envelope timings.</td></tr>
<tr><td>Implicit Requirement</td><td></td></tr>
<tr><td>Question</td><td>Is a PICC compliant to the above waveform reception requirement also NFC Forum compliant?</td></tr>
</table>

PROCEDURE	
Step	**SETUP**
NFC Forum setup: 1	Setup NFC Forum – Reference Poller 0 to nominal power.
2	Place NFC Forum – Reference Listener 1 in Setup position (820 Ω loading).
3	Setup waveform condition 3 and 4 (see Annex C of [NFC_TC_ANA]).
4	Repeat Steps 2 and 3 with NFC Forum – Reference Listener 1 and 330 Ω load. *Note: Since the 820 Ω loading impacts the wave form more than a loading of 330 Ω this step can be skipped. For details also see the input document of EMVCo to ANALOG WG.*
5	Repeat Steps 1-4 with NFC Forum – Poller 3 and 6 with respectively NFC Forum – Listener 3and 6.
ISO Setup: 1	Setup ISO Reference PICC 1, 3 and 6 to 16.5MHz.

Step	VERIFICATION
1	Place each ISO Reference PICC 1, 3 and 6 in the complete NFC OV of the NFC Forum – Reference Poller 0 and adjust the load according to Table 21. Note: The R2 has to be re-adjusted for every NFC OV position.
2	Measure to waveform of the pick-up coil of the respective ISO Reference PICC.
3	Repeat Verification procedure steps 1-2 for NFC Forum – Reference Poller 3 and 6.
EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compare the measured waveform parameter values of VERIFICATION Step 2 to the limits defined in [ISO14443-2]. The test is PASS if the measured waveform parameter values do not exceed the limits defined for the respective parameter.
Step	**INTEROPERABILITY**
CONCLUSION / DISCUSSION	
	Due to similar Reference Equipment used for PCD / Poller waveform measurement only a limit comparison is required. See Section 3.1.5 0) for a discussion.

B.8. ISO/IEC 14443-2 PICC Requirements for Modulation PCD to PICC – Type B

<table>
<tr><th colspan="2">CONTEXT</th></tr>
<tr><td>Reference</td><td>[ISO14443-2], [ISO10373-6]</td></tr>
<tr><td>Requirement</td><td>
Req-Section 9.1.2
Communication from PCD to PICC shall use the modulation principle of ASK 10 % of the RF operating field. The modulation waveform shall comply with Figure 12. The rising and falling edges of the modulation shall be monotonic. The rise and fall times (tr, tf) shall be measured between 10 % and 90 % of the actual modulation step.


The PICC shall be able to receive for any bit combination a modulation waveform with a modulation index, m
— greater than
— both (9,5 – 1,5H/H_{min}) % and 7 % for bit rates of fc/128, fc/64, fc/32 and fc/16,
— 8 % for bit rates of fc/8, fc/4 and fc/2;
— and less than
— 15 % for bit rates of fc/128, fc/64, fc/32 and fc/16,
— 21 % for bit rates of fc/8, fc/4, and fc/2.
The PICC shall be able to receive a modulation waveform with overshoot and undershoot defined in Table 12.
Table 12 — PICC reception: Overshoot and undershoot for all supported bit rates
<table>
<tr><th>Parameter</th><th>Min</th><th>Max</th></tr>
<tr><td>h_f</td><td>0</td><td>$(1-t_f /(2 \times t_{f,max,PCD})) \times 0.11*(1-b)$</td></tr>
<tr><td>h_r</td><td>0</td><td>$(1-t_r /(2 \times t_{r,max,PCD})) \times 0.11*(1-b)$</td></tr>
</table>
For a bit rate of fc/128 the PCD shall generate a modulation waveform with
– a fall time t_f between 0/fc and $t_{f, max, PCD}$ = 17/fc,
– and a rise time t_r
– greater than both 0/fc and t_f – 9/fc,
– and less than both t_f + 9/fc and and $t_{r, max, PCD}$ = 17/$_{fc}$.
</td></tr>
<tr><td>Implicit Requirement</td><td></td></tr>
</table>

Question	Is a PICC compliant to the above waveform reception requirement also NFC Forum compliant?
PROCEDURE	
Step	**SETUP**
NFC Forum setup: 1	Setup NFC Forum – Reference Poller 0 to nominal power.
2	Place NFC Forum – Reference Listener 1 in Setup position (820 Ω loading).
3	Setup waveform condition 3 and 4 (see Annex C of [NFC_TC_ANA]).
4	Repeat Steps 2 and 3 with NFC Forum – Reference Listener 1 and 330 Ω load. *Note: Since the 820 Ω loading impacts the wave form more than a loading of 330 Ω this step can be skipped. For details also see the input document of EMVCo to ANALOG WG.*
5	Repeat Steps 1-4 with NFC Forum – Poller 3 and 6 with respectively NFC Forum – Listener 3and 6.
ISO Setup: 1	Setup ISO Reference PICC 1, 3 and 6 to 16.5MHz.
Step	**VERIFICATION**
1	Place each ISO Reference PICC 1, 3 and 6 in the complete NFC OV of the NFC Forum – Reference Poller 0 and adjust the load according to Table 21. Note: The R2 has to be re-adjusted for every NFC OV position.
2	Measure to waveform of the pick-up coil of the respective ISO Reference PICC.
3	Repeat Verification procedure steps 1-2 for NFC Forum – Reference Poller 3 and 6.
EXPECTED OUTCOME	
Step	**COMPLIANCY**
1	Compare the measured waveform parameter values of VERIFICATION Step 2 to the limits defined in [ISO14443-2]. The test is PASS if the measured waveform parameter values do not exceed the limits defined for the respective parameter.
Step	**INTEROPERABILITY**
CONCLUSION / DISCUSSION	
	Due to similar Reference Equipment used for PCD / Poller waveform measurement only a limit comparison is required. See Section 3.1.6 0) for a discussion.

B.9. ISO/IEC 14443-2 PICC Requirements for Load Modulation

a. Subcarrier Frequency

No experimental measurement needed.

b. $V_{PP,min}$

CONTEXT	
Reference	[ISO14443-2]
Requirement	Req. Section: 8.2.2: The PICC shall be capable of communication to the PCD via an inductive coupling area where the carrier frequency is loaded to generate a subcarrier with frequency fs. The subcarrier shall be generated by switching a load in the PICC. If the PICC meets the requirements of one particular class as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then the load modulation amplitude V_{LMA} of the PICC shall be at least $V_{LMA, PICC}$ specified for its class when measured as described in ISO/IEC 10373-6, using the test PCD assembly defined for its class, where H is the value of magnetic field strength in A/m (rms). If the PICC does not claim to meet the requirements of one particular class as specified in ISO/IEC 14443-1:2008/Amd.1:2012, then the load modulation amplitude V_{LMA} of the PICC shall be at least $V_{LMA, PICC}$ specified for "Class 1" when measured as described in ISO/IEC 10373-6, using the test PCD assembly defined for "Class 1", where H is the value of magnetic field strength in A/m (rms). Table 8 specifies for each PICC class both the load modulation amplitude limit $V_{LMA, PICC}$ and the relevant test PCD assembly to measure the PICC load modulation amplitude V_{LMA}.

Table 27: PICC minimum load modulation ([ISO14443-2:AMD2], Section 8.2.2, Table 8)

	PICC	
	$V_{LMA,PICC}$ mV (peak)	Test PCD assembly
"Class 1" PICC	$22/H^{0,5}$	Test PCD assembly 1
"Class 2" PICC	$Min(14; 22/H^{0,5})$	
"Class 3" PICC	$Min(14; 22/H^{0,5})$	
"Class 4" PICC	$Min(18; 40/H^{0,5})$	Test PCD assembly 2
"Class 5" PICC	$Min(14; 34/H^{0,5})$	
"Class 6" PICC	$Min(7; 26/H^{0,5})$	

c. $V_{PP,max}$

CONTEXT	
Reference	[ISO14443-2]
Requirement	No maximum load modulation amplitude ($V_{LMA,max}$) defined in any published ISO/IEC 14443 related standard *Note: At the moment SC17/WG8 work on the topic in the amendment ISO/IEC14443-2:2008 PDAM1_2. In this document a maximum $V_{LMA, PICC}$ of 100 mV(peak) is proposed.*

B.10. ISO/IEC 14443-2 PICC Requirements for Subcarrier Modulation – Type A

No experimental measurement needed.

B.11. ISO/IEC 14443-2 PICC Requirements for Subcarrier Modulation – Type B

No experimental measurement needed.

ANNEX C: NFC Forum Analog References

C.1. NFC Forum Listening Devices Antenna Category Definitions (copy from ANALOG v2.0 Annex B.4)

In order to ensure interoperability of an NFC Forum Listening Device to ISO/IEC 14443 based systems, NFC Forum defines different load modulation amplitude limit values depending on the antenna size of the NFC Forum Listening Device. Only the active antenna size used for load modulation is affected by this definition. This section defines the rules how to select the correct antenna size category. If none of the category selection criteria apply for the Listening Device antenna size, the default category SHALL be used. The category selection is based on the outer and inner area enclosed by the antenna:

- The outer area is defined as the area enclosed by the outer most conductor of the antenna.
- The inner area is defined as the area enclosed by the inner most conductor of the antenna (enclosed by the antenna).

The 3 categories are defined as below and summarized in Table 28:

- **Category A (CAT A):** The Antenna encloses at least an inner area of 2180 mm^2, except for connections. If not designed as a circle, an aspect ratio of 19:10 for the inner area SHALL not be exceeded.
- **Category B (CAT B):** The Antenna encloses at least an inner area of 840 mm^2 but does not exceed an outer area of 2180 mm^2, except for connections. If not designed as a circle, an aspect ratio of 3:2 for the inner area SHALL not be exceeded.
- **Category C (CAT C), default category:** The antenna area does not exceed an outer area of 840 mm^2, except for connections, or does not fit into **Category A** or **Category B**.

Table 28: NFC Forum Listening Device antenna size definition

Antenna size	Category A	Category B	Category C, default category
Outer area (maximum)	-	2180 mm2	840 mm2
Inner area (minimum)	2180 mm2	840 mm2	-