

AN13219

PN7160 antenna design and matching guide

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Application note

Document information

Information	Content
Keywords	NFC, PN7160, antenna design, antenna matching/tuning
Abstract	This application note provides guidelines to design an NFC antenna for PN7160, and explains how to match the antenna to PN7160. The document also covers standalone antenna performance evaluation and final RF system validation (PN7160 + tuning/matching network + NFC antenna).



1 Introduction

PN7160 is a highly integrated NFC transceiver IC for contactless communication at 13.56 MHz. This transceiver IC utilizes an outstanding modulation and demodulation concept completely integrated for different kinds of contactless communication methods and protocols at 13.56 MHz.

It is able to operate both in **reader mode (RM)** and in **card mode (CM)**.

PN7160 is intended to be connected to an external coil antenna through a specific matching/tuning network.

The purpose of this document is first to provide some guidelines regarding the design of an NFC antenna intended to be connected to PN7160 (recommended antenna characteristics).

It then depicts a measurement method to evaluate the performances of the antenna before it is connected to NXP NFC chips.

The next chapter explains how to determine the tuning/matching network to be placed between a given antenna and PN7160 (based on the antenna electrical equivalent circuit).

In this document, the main focus is **on the asymmetrical antenna tuning**. This tuning requires **the DPC (Dynamic Power Control) to be disabled**.

For the **DPC** enabled, the **symmetrical antenna tuning** should be used, refer to the dedicated application note [\[1\]](#).

The procedure for the **asymmetrical antenna tuning** described in this document is valid for the **symmetrical antenna tuning** as well. It differs only in cut-off frequency value of the EMC filter.

RF performance validation procedure is finally proposed.

2 Recommended NFC antenna characteristics

Antenna design is an essential part of NFC Readers implementation. Designing the right antenna for your application is crucial to get optimum read range and reliability with NFC in your products. Therefore, the recommendations described in this document shall be considered for a proper antenna design.

The NFC antennas are typically made of spiral loop (Figure 1). The outline dimensions, the number of turns, the copper track thickness, width, and spacing define the antenna electrical characteristics as the inductance, capacitance, resistance, self-resonance frequency, and Q-factor.



Figure 1. Standard coil antenna example

2.1 Standard coil antenna design

PN7160 was tested and validated with the below described loop antenna (40 mm x 40 mm). This antenna has been used as an example for the calculations and measurements described in the following chapters.

2.1.1 40 mm x 40 mm antenna

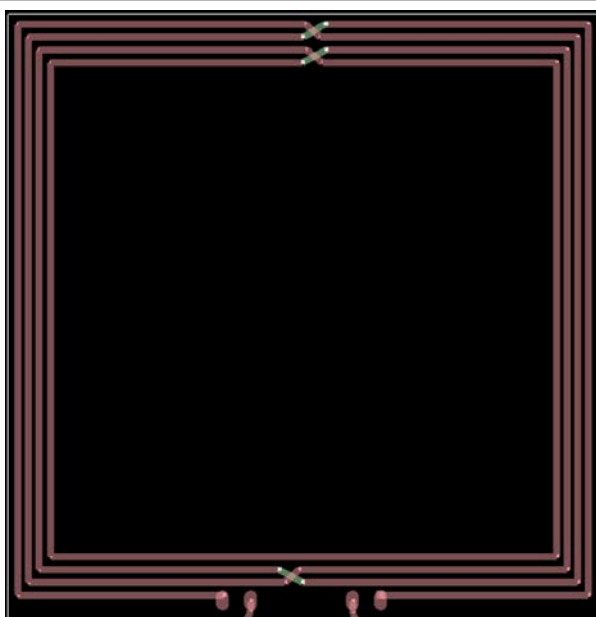


Figure 2. 40 mm x 40 mm antenna drawing

Table 1 provides the physical outlines of the antenna board.

Table 1. 40 mm x 40 mm antenna outlines

Description	Value	Unit
size	40 x 40	mm
# turns	4	
Track width	0.4	mm
Spacing	0.3	mm
Track thickness	35	µm

2.1.2 Recommended characteristics

In case one wants to design their own loop antenna for PN7160, it is recommended to fulfill the characteristics described below:

Table 2. Recommended standard coil antenna physical characteristics

Description	Min	Max
Size	800 mm²	5000 mm²
# turns	2	8
Track width	0.2 mm	2 mm
Spacing	0.2 mm	2 mm
Track thickness	20 µm	
Antenna inductance tolerance ^[1]		+/-3%

[1] Keep the antenna characteristics (inductance and parasitic) within a certain tolerance in production as they impact the system characteristics (i.e. esp. impedance matching) and thus performances.
Note that those characteristics can still be changed.

2.1.3 Antenna size

In general, the larger your antenna size, the longer the reading distance. Similarly, a smaller antenna provides a shorter read range. However, it is best to attempt to match the tag and the reader antenna geometries for maximum efficiency. A significant difference between the reader and tag antenna dimensions result in bad communication because of the small coupling factor.

2.1.4 Antenna system parameters

A standard NFC antenna is represented as an inductor with the following parameters:

- Inductance - L_{ANT}
- Capacitance - C_{ANT}
- Resistance - R_{ANT}
- Quality factor - Q
- Self-resonance frequency - f_{res}

The mechanical design of the antenna (outline dimensions, number of turns, copper track thickness, width, and spacing) define these parameters.

[Figure 3](#) illustrates the antenna model.

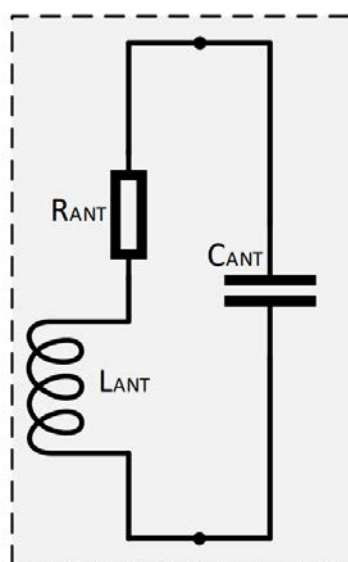


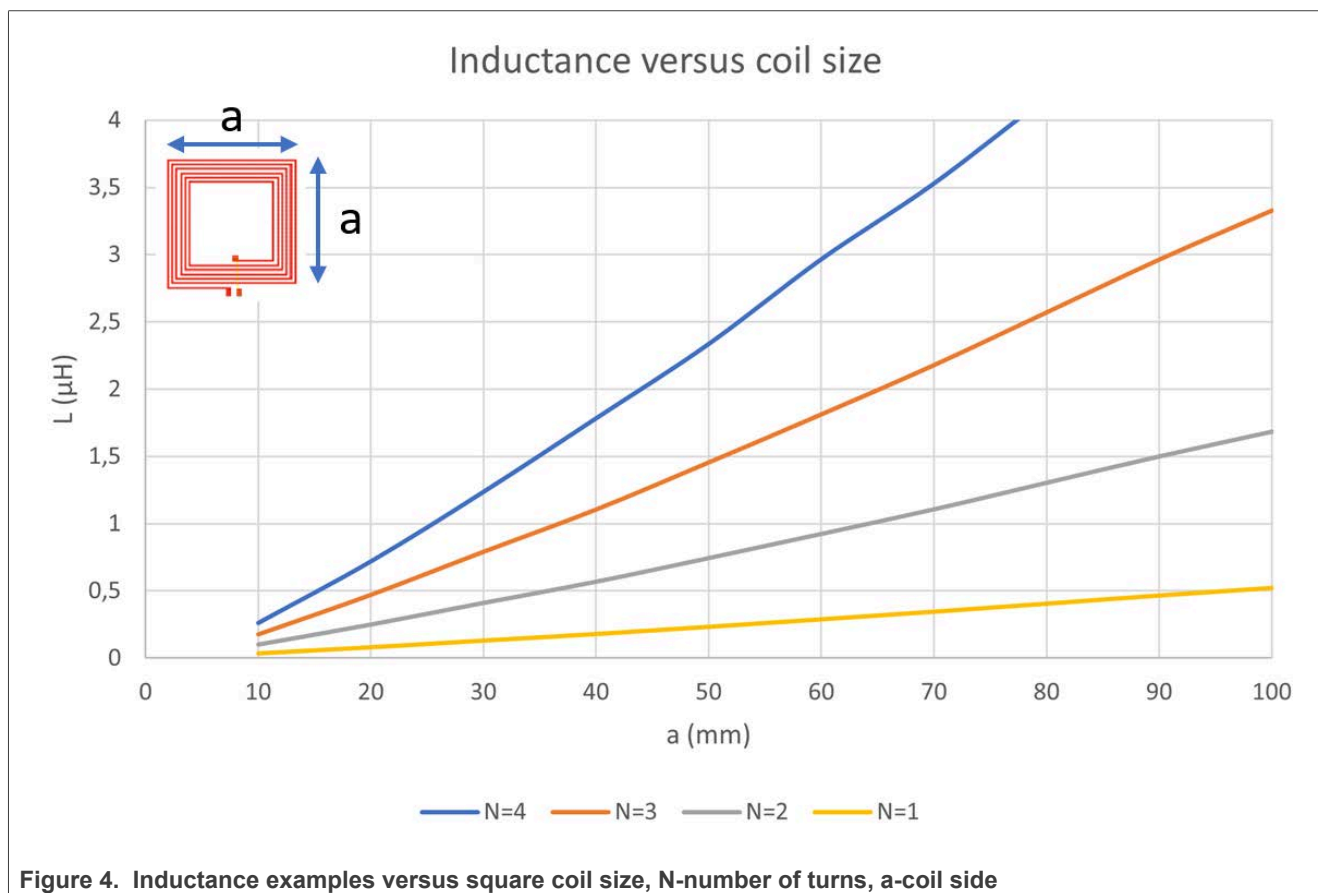
Figure 3. Antenna model for single frequency

2.1.4.1 Antenna inductance

Out of experience it turns out to be optimum to have an inductance around $L \approx 1 \mu\text{H}$ for a proper matching. But a wide range of $L \approx 300 \text{ nH}$ up to $L \approx 3 \mu\text{H}$ can be still matched properly. So typically 1 up to 4 turns in the normal range of antenna sizes are used.

Figure 4 shows the typical inductance values versus the square antenna coil size for 1, 2, 3 and 4 turns. These values are just examples, since the environment, the track width or wire thickness and some other parameters may influence the inductance.

The expected antenna inductance value is obtained as the output from the [NFC Antenna Design Hub](#) calculator.



2.1.4.2 Antenna capacitance

The antenna capacitance should be in the range of **1 pF - 30 pF**. If the antenna capacitance is too large, the antenna may not be tunable for 13.56 MHz.

The expected antenna capacitance is obtained as the output from the [NFC Antenna Design Hub](#) calculator.

2.1.4.3 Antenna resistance

The antenna resistance is a parasitic parameter that mostly depends on the track length, track width, and copper thickness. To minimize heat losses in the antenna, keep this parameter as small as possible. The antenna resistance is directly related to the antenna quality factor described below.

The expected antenna resistance is obtained as the output from the [NFC Antenna Design Hub](#) calculator.

2.1.4.4 Antenna quality factor

The quality factor declares the number of losses inside the inductor. For the NFC reader antennas, this parameter is not so strict. In practice, the Q-factor of the antenna itself should be higher than **20**. The antenna quality factor is typically adapted (reduced) during the impedance matching process to have a proper bandwidth.

The Q factor can be calculated over the following equation:

$$Q_a = \frac{\omega \cdot L_a}{R_a}$$

Where:

La - NFC Antenna Inductance

Ra - NFC Antenna Resistance

ω - Angular frequency ($2 \cdot \pi \cdot f$) where f is typically 13.56 MHz

2.1.4.5 Antenna self-resonance frequency

To tune the antenna comfortably, keep the self-resonance frequency higher than **25 MHz**.

The expected antenna self-resonance frequency is obtained as the output from the [NFC Antenna Design Hub](#) calculator.

3 Shielding and environment impact

3.1 Why shielding is important

The PN7160 and the associated NFC antenna are intended to be integrated into any kind of device.

Those devices could be composed of metallic parts such as batteries, the PCBs, electronic components and even sometimes a chassis.

If metal is placed close to the NFC antenna the alternating magnetic field generates some eddy currents in the metal. These eddy currents create a magnetic field in opposite direction, it absorbs power, and leads to detuning of the antenna due to a decreased inductance and quality factor. Therefore, it is necessary to shield the antenna with ferrite for proper operation in close metallic environment.

Adding a ferrite sheet allows to shield the antenna against the influence of metal.

The following figures are intended to highlight this phenomenon based on antenna field distribution simulation results. In order to simplify the simulation, results below are based on a circular antenna with a radius of 7.5 cm with 1 turn and a copper wire of 1 mm thickness. The right part shows the field distribution and the left part shows the magnitude of the field strength H over the distance d . The minimal field strength of $H_{\text{MIN}} = 1.5 \text{ A/m}$ defined by ISO 14443 is marked with dotted vertical line.

[Figure 5](#) shows the field distribution in an ideal environment without any metal near the antenna.

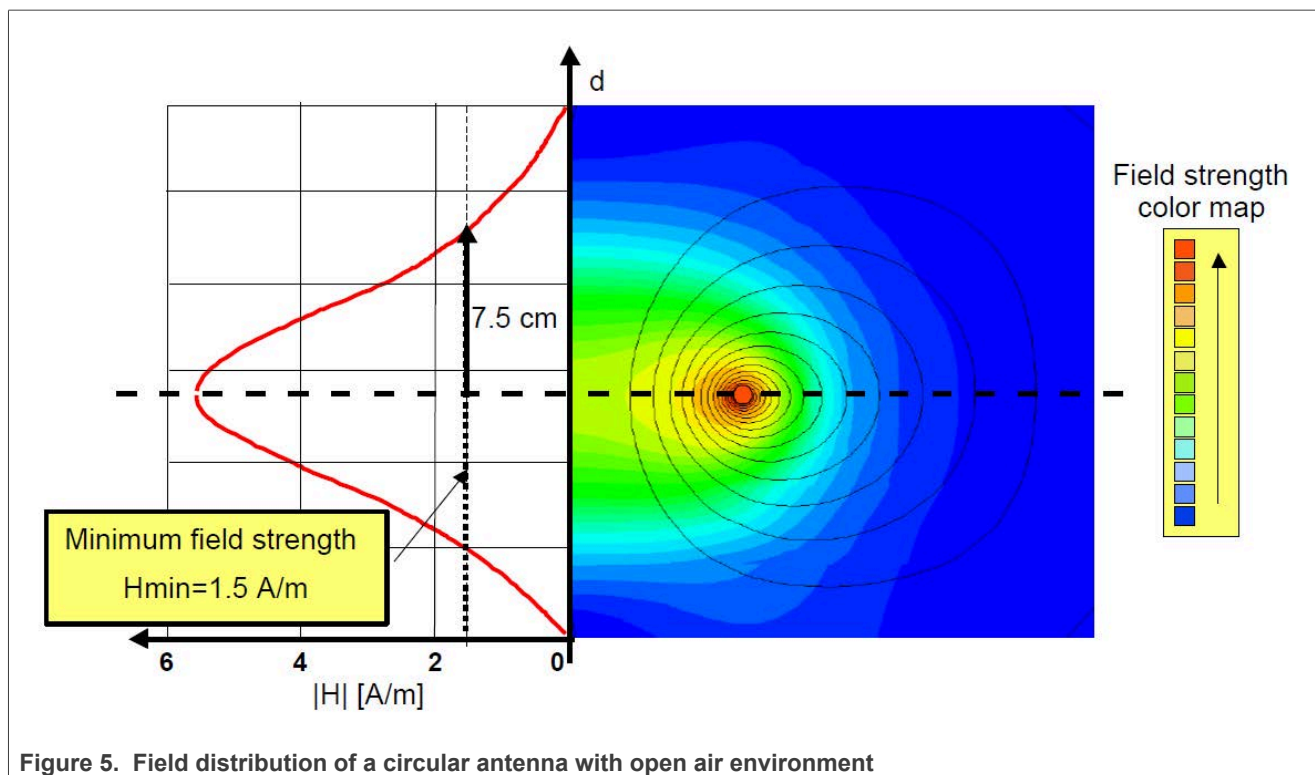


Figure 5. Field distribution of a circular antenna with open air environment

Figure 6 shows the field distribution of the same antenna but with a metal plane near to it. The magnitude of the field strength has significantly decreased compared to the open-air case which leads to a decreased operating distance.

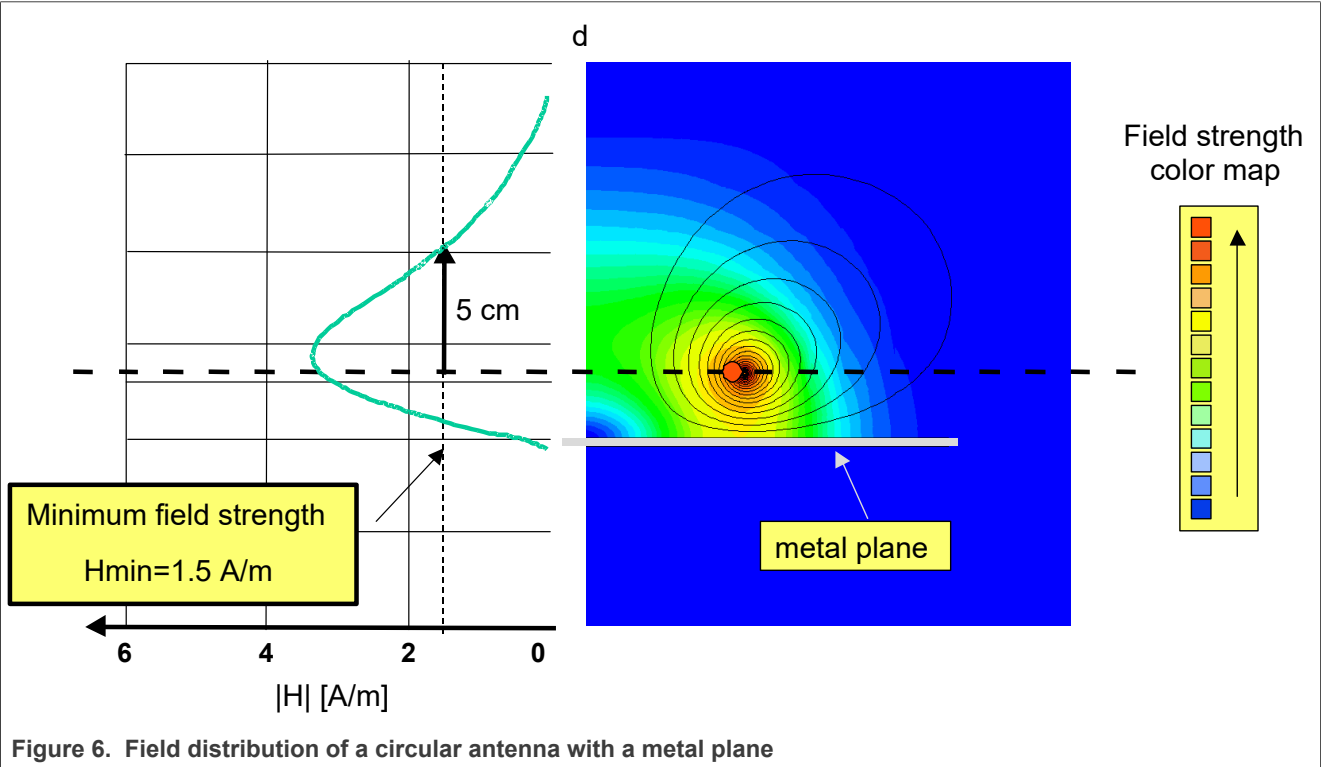
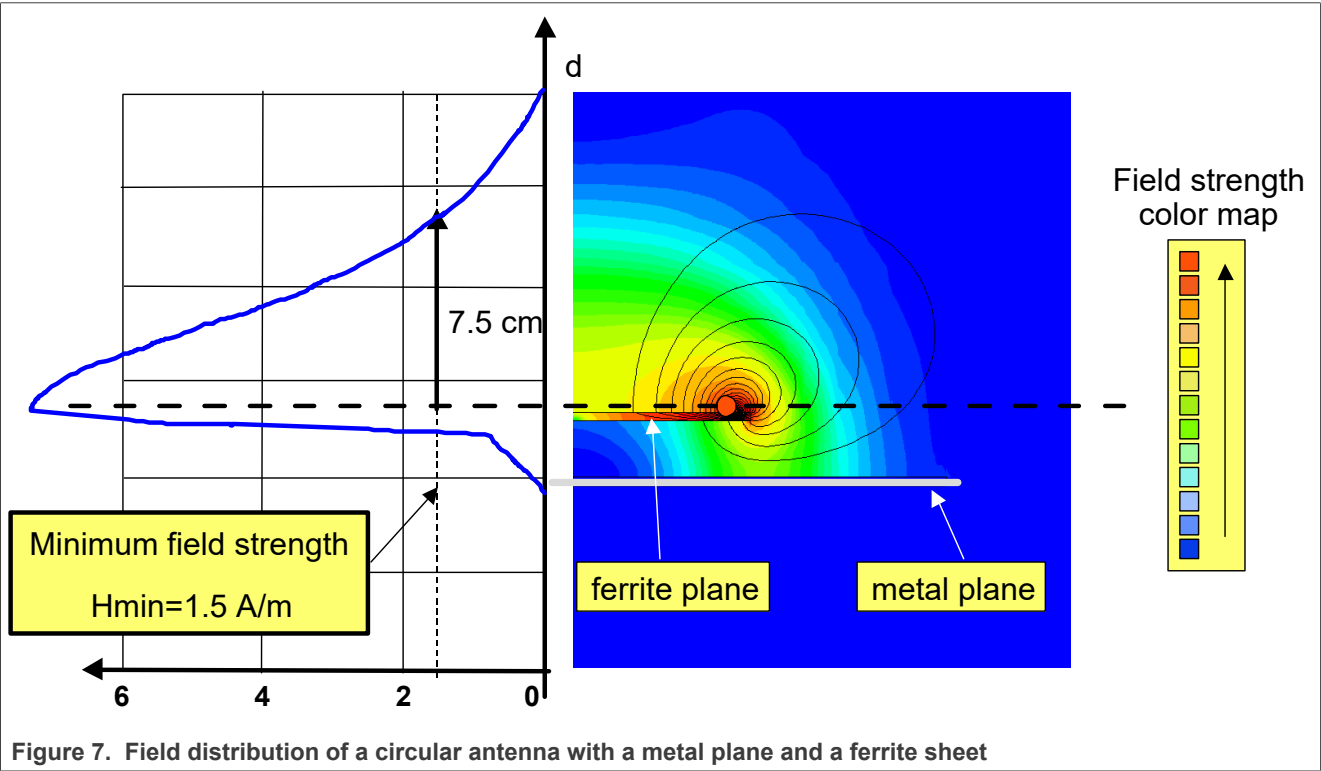


Figure 6. Field distribution of a circular antenna with a metal plane

Figure 7 shows the effect of adding a ferrite plane ($\mu_R=40$) between the metal plane and the antenna coil itself. The field distribution is still modified but the operating distance recovers its original open-air level.



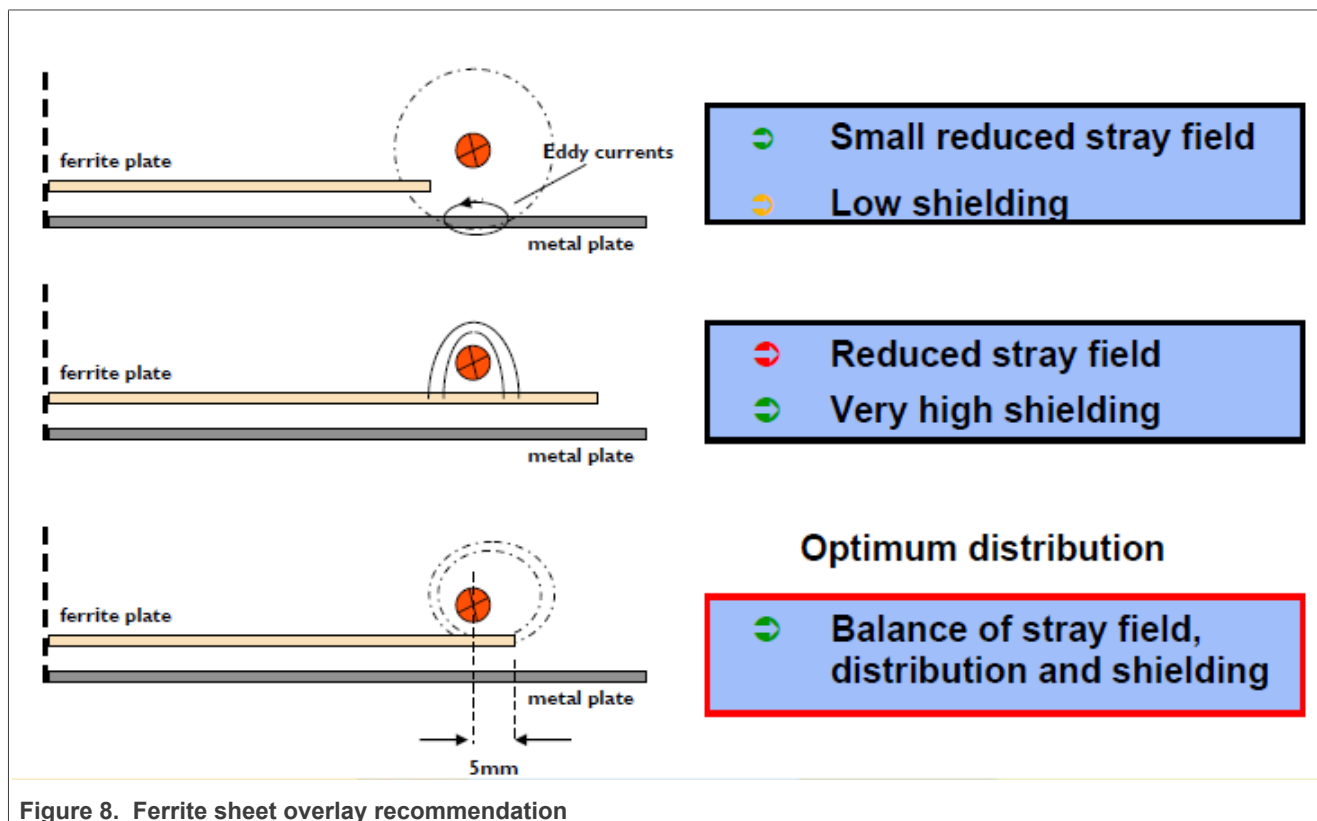
The simulation shows that the use of a ferrite reduces the generated eddy currents in a metal plane. The ferrite sheet changes the antenna environment characteristics, which result in a fixed detuning of the antenna itself. Shielding significantly impacts the antenna electrical equivalent model so it is key that when doing PN7160 tuning/matching network calculation, the antenna model is measured with the ferrite already in place (when applicable).

3.2 Ferrite shielding recommendation

The ferrite sheet must cover at least the entire surface of the antenna.

It is highly recommended to have an overlay but not too high otherwise it tends to reduce the stray field strength.

Figure 8 illustrates the trade-off.



The ferrite quality is also a key parameter which must be considered to assess the effectiveness of the shielding.

A high relative permeability is recommended because it contributes to a good shielding with a lower thickness.

The material must be specified for a high magnetic permeability in the frequency range that is involved in NFC operation, that is, 13.56 MHz.

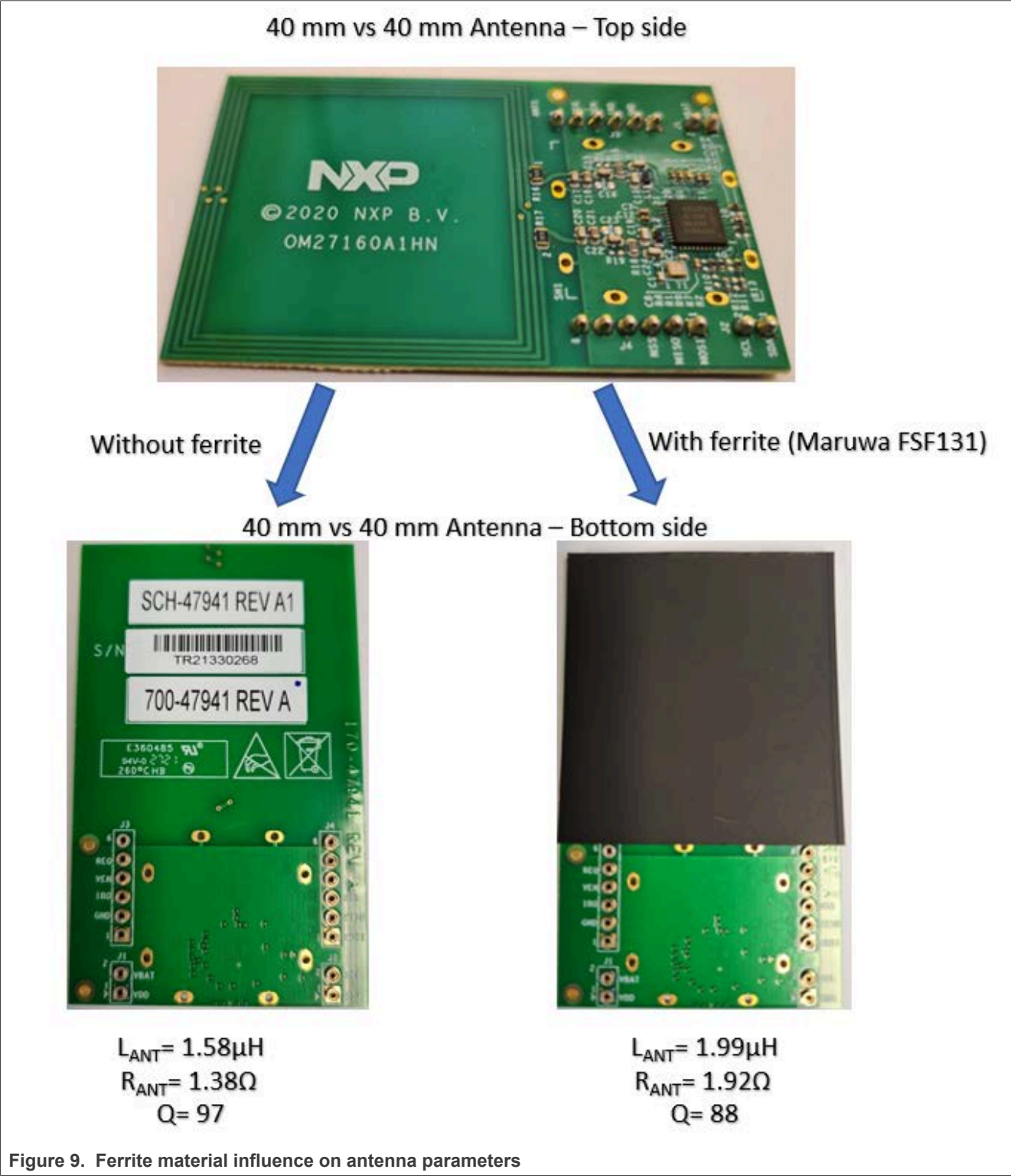
The relative magnetic permeability of a material is made of two parts: μ' is the real part of relative permeability and μ'' is the imaginary part. μ'' is reflecting the magnetic losses in the material.

Recommended values are:

- μ' between 40 and 150 at 13.56 MHz.
- μ'' as low as possible: < 3 at 13.56 MHz.

Note: The level of shielding not only depends on the material used but also on the thickness of the ferrite sheet. For a given permeability, the thickest sheet provides the strongest shielding.

The added ferrite sheet can increase the antenna inductance and resistance significantly and must be considered for the matching! (Figure 9).



4 Antenna tuning and matching to the PN7160

4.1 Antenna tuning/matching procedure overview

4.1.1 Step 1: Antenna calculation

When starting the antenna design, the [NFC Antenna Design Hub](#) (ref. [2]) tool is recommended ([Figure 10](#)).

As for the example of antenna matching, the data from [Table 1](#) (40 mm vs 40 mm antenna) has been used.

If an existing NFC antenna is already available, skip this section and start with [Section 4.1.2](#).

Note: If using a two-layer antenna (for example, 3+2 turns), the number (N) of turns is 5. The calculator is designed for 1-layer antennas only. Therefore, a slight mismatch between the calculated and measured results is expected. This mismatch can be compensated as described in [Section 4.1.3.3](#).

The screenshot shows the 'Readers' section of the NFC Antenna Design Hub Tool. It features a 'DOWNLOAD DATA' button at the top left. The interface is divided into two main columns. The left column contains input parameters with text boxes and units: Length (amax) 40 mm, Width (bmax) 40 mm, Track width (w) 400 μm, Gap between tracks (g) 300 μm, Additional Overlap Area (A) 0 mm², Track Thickness 35 μm, Number of Turns (N) 4, Turn exponent (E) 1.65, PCB Thickness 1.59 mm, and Er 4.3. The right column displays calculated output data: Inductance (Lant) 1485 nH, Lant min 1367 nH, Lant max 1933 nH, Capacitance (Cant) 1.9 pF, Resistance (Rant) 1.45 Ω, and Self resonance (Fres) 96 MHz. Below the input fields is a 3D visualization of a square antenna layout. At the bottom, there are 'RESET' and 'ANTENNA SYNTHESIS' buttons.

Figure 10. Antenna calculation using the NFC Antenna Hub Tool

The tool provides the following output data:

- Inductance 1485 nH
 - **Lant min** and **Lant max** represents the border positions depending on corner rounding
- Capacitance 1.9 pF
- Resistance 1.45 ohm
- Self-resonance 96 MHz

Once the calculated design complies with the criteria described in [Section 2.1.4](#), the prototype of the antenna can be built, measured and used as described in the following sections.

4.1.2 Step 2: Antenna model measurement

4.1.2.1 Electrical parameters overview

The antenna must be connected to a vector network analyzer (VNA) to measure the series and parallel components.

Note: *The antenna equivalent circuit must be determined under the final environmental conditions, especially when the antenna is operated in a metal environment, or when a ferrite sheet is used for shielding.*

For example, The OM27160 Development Kit for PN7160 is used with the Arduino or Raspberry Pi ([Figure 11](#)). Therefore, the antenna and impedance matching has to be done in the final environmental conditions.



Figure 11. OM27160 Development kit + Raspberry Pi connected

Figure 12 shows the modeling step used to get the L, R, C equivalent of the antenna.

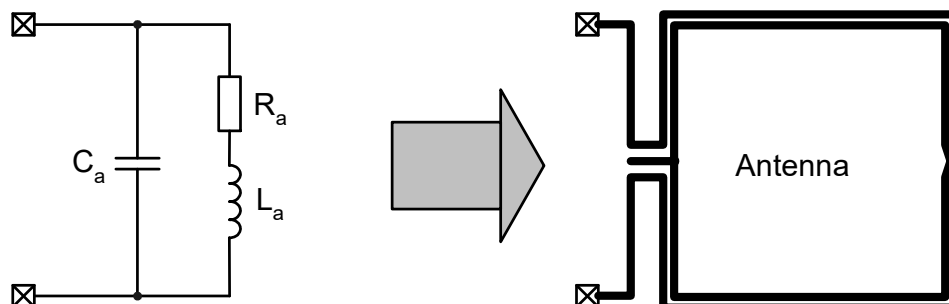


Figure 12. Series equivalent circuit

4.1.2.2 Measurement with vector network analyzer

The antenna must be positioned in its final housing to consider all parasitic effects like metal influence on quality factor, inductance, and extra capacitance (Figure 13).

Make sure that no matching components are placed during the antenna measurement.

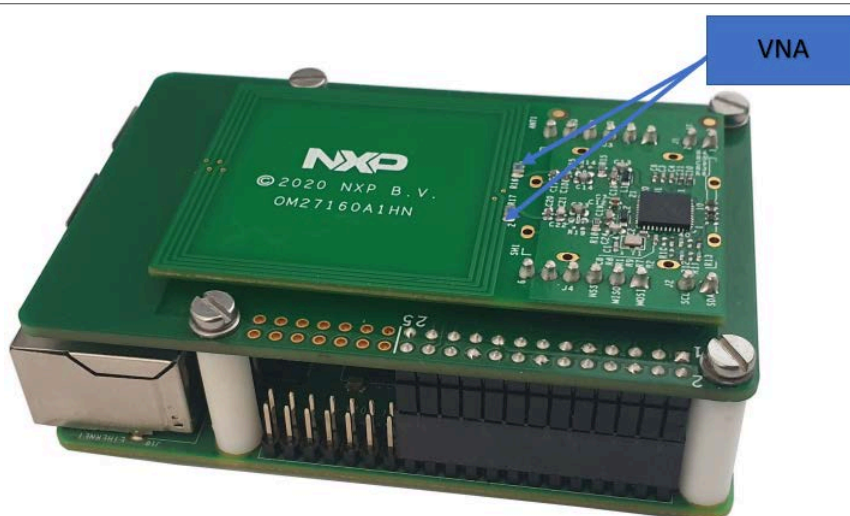


Figure 13. Antenna parameters - measurement point

To connect the antenna to the VNA, use a test fixture that does not influence any antenna parameters.

The analyzer must be calibrated (open, short, and load compensation at the calibration plane). And the test fixture—for example, extra wire length—must be compensated (open, short compensation at the connection points) before each measurement.

A high-end 50 Ω calibration kit for the used connector types (N-connector or SMA) does not help as the measurement must be made at the antenna terminals. Therefore, the calibration must be done as close as possible to these points. The best solution is to create a simple connection, that is, using a standard 2.54 mm pin row connector (male and female) to connect the VNA. This setup can be used to measure the antenna impedance at the correct points, and also to calibrate the VNA. [Figure 14](#) shows a simple and highly efficient homemade connector and tool.

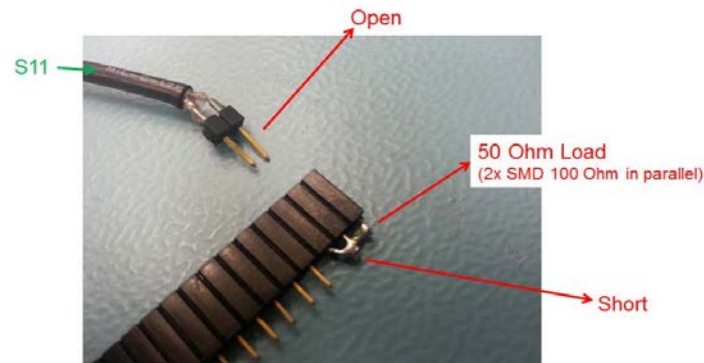


Figure 14. "Pin header" calibration kit

The VNA settings are the following:

- Settings: $|Z|$, Θ
- Start frequency: 5 MHz
- Stop frequency: 25 MHz
- Number of points 801
- Marker at 13.56 MHz

4.1.2.2.1 40 mm x 40 mm antenna measurement

The 40 mm vs 40 mm antenna has been measured in the final environmental conditions (see [Figure 13](#)).

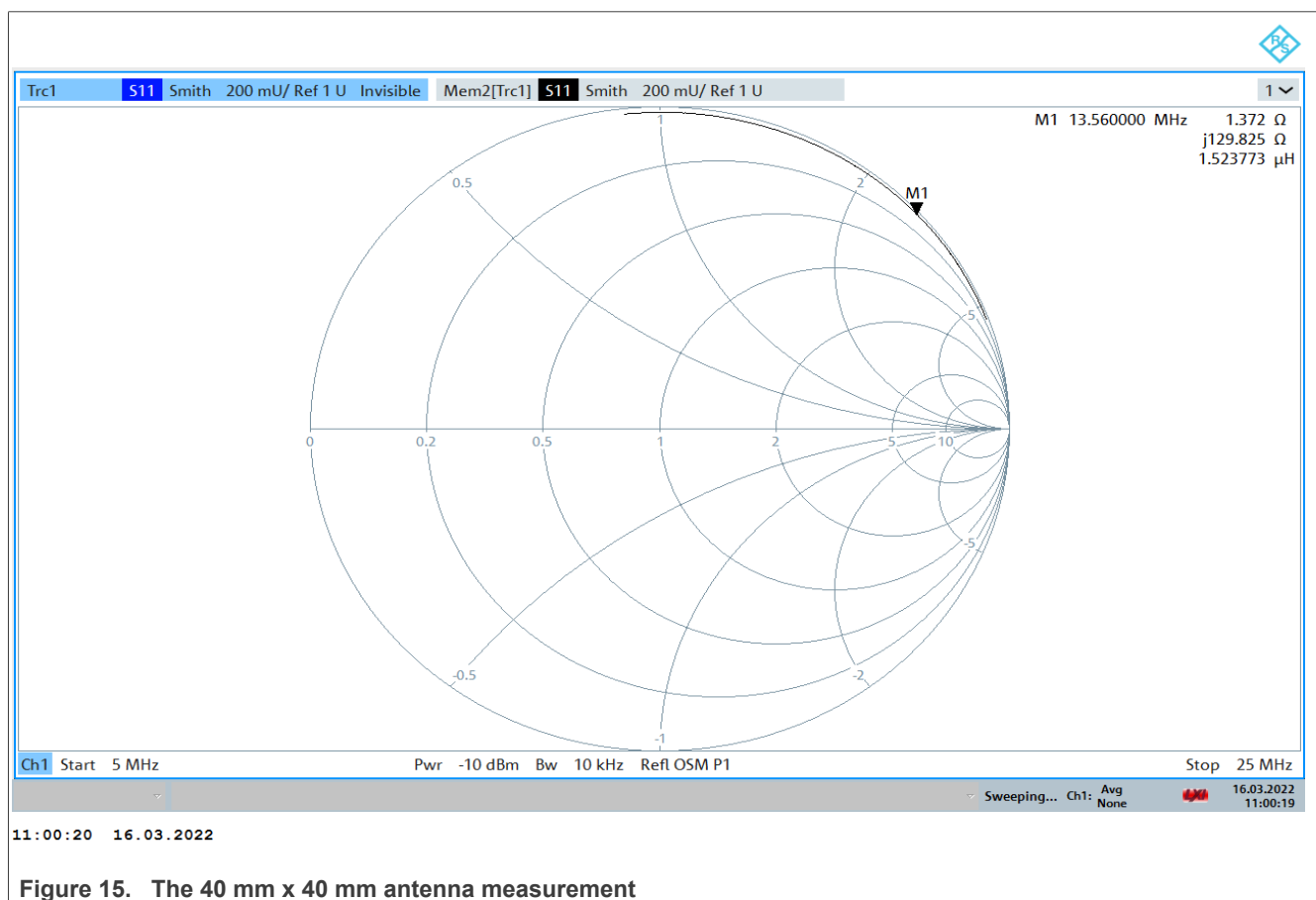
The measured values are:

- Antenna inductance - **1.52 μH**
- Antenna serial resistance - **1.37 Ω**

And the calculated values were:

- Antenna inductance - **1.46 μH**
- Antenna serial resistance - **1.45 Ω**

The difference is due to the manufacturing tolerances and the different antenna environment.

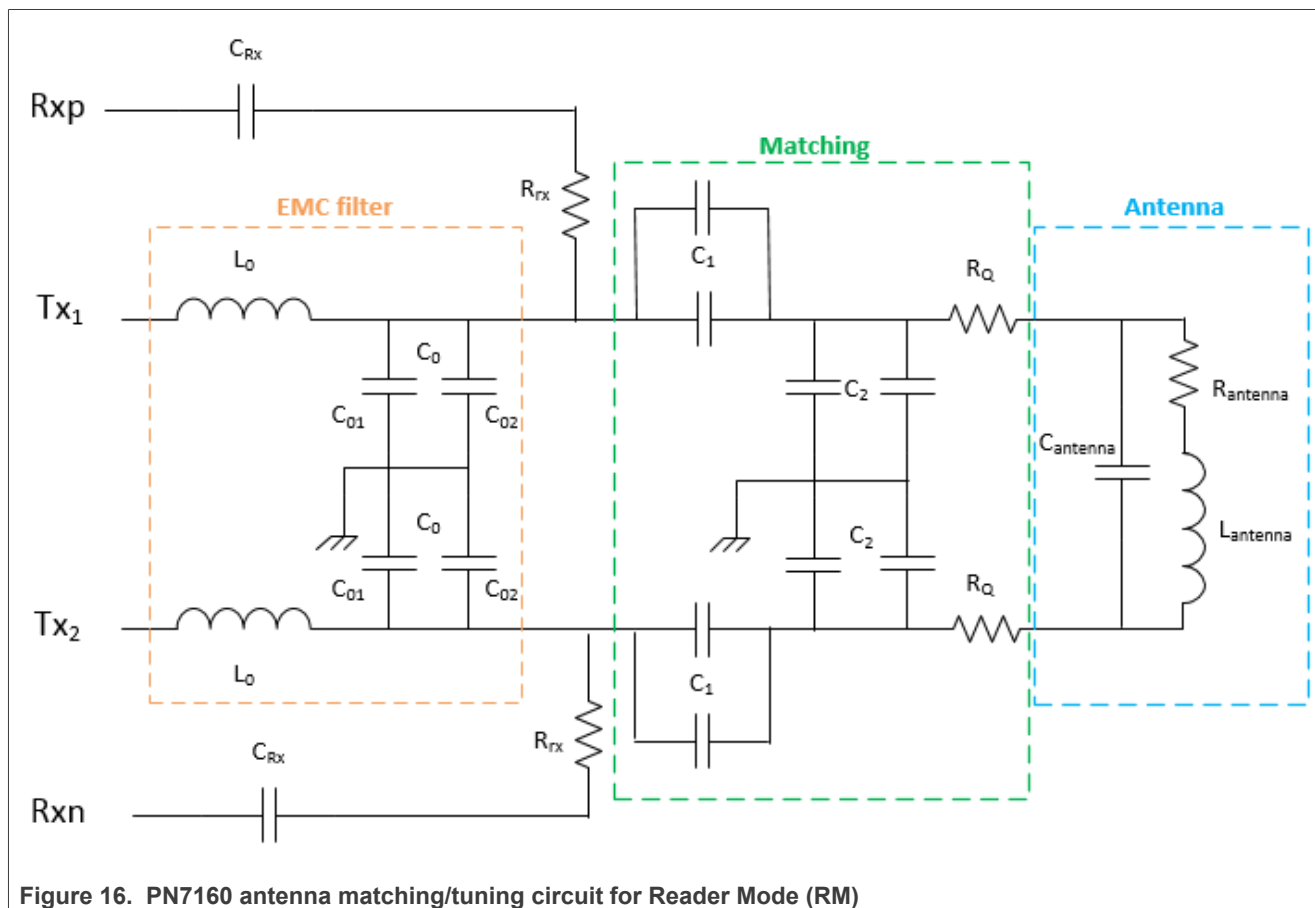


4.1.3 Step 3: Matching calculation and implementation for reader mode (RM)

The section describes antenna matching for reader mode.

4.1.3.1 Default configuration for reader mode (RM)

Figure 16 shows the default RF path configuration for reader mode of the PN7160. An asymmetrical or symmetrical transfer function (tuning) shall be considered according to the user case. See Section 4.1.3.2.



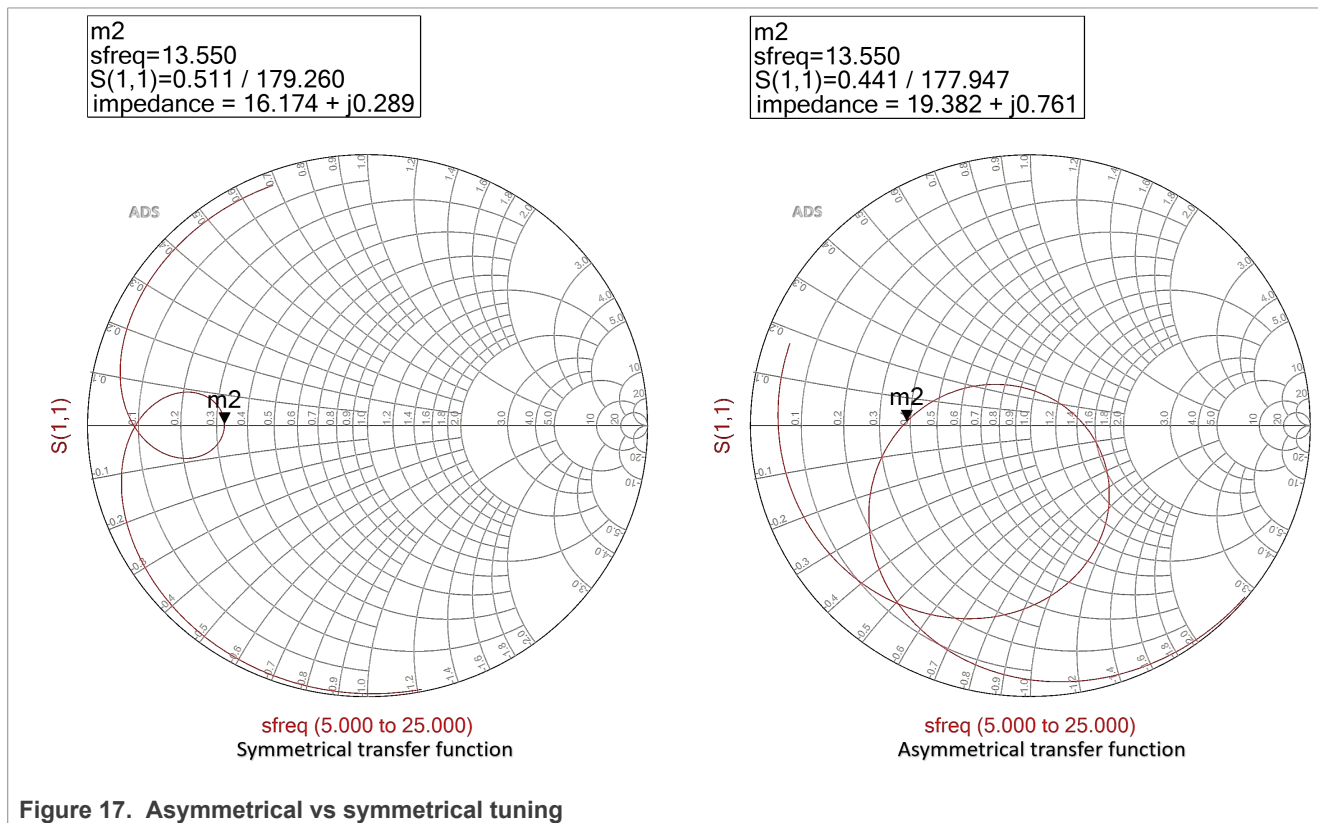
4.1.3.2 Asymmetrical versus symmetrical tuning

In the standard antenna design, the cut-off frequency of up to **22 MHz** provides the proper detuning and loading behavior of the antenna. This high cut-off frequency helps to meet the minimum and maximum field strength limits with normal antennas without using Dynamic Power Control. Also it keeps the I_{TVDD} current below the maximum limit. This case refers to **asymmetrical tuning**.

Once the cut-off frequency is changed to **14.4 MHz -14.7 MHz**, the impedance changes to a symmetrical impedance. This case refers to **symmetrical tuning**.

The problem with symmetrical tuning is the loading and detuning behavior. While the impedance in the case of asymmetrical tuning increases under detuning and loading conditions, the impedance in the case of symmetrical tuning always decreases. Without any specific control of the output power, the decreasing impedance increases the driver current. Therefore, the field strength may exceed the IC specification for the driver current I_{TVDD} , and the field strength limits.

Use the Dynamic Power Control (DPC) to compensate for the decreasing impedance and reduce the driver current automatically.



Asymmetrical tuning

- More robust against detuning and loading: tuning increases under detuning and loading conditions
- Cut off frequency $\approx 20 \text{ MHz} - 22 \text{ MHz}$
- No need to use DPC function
- Lower operating distance (potentially)
- Typically lower output power (Due to the higher target impedance, typically 20Ω)

Symmetrical tuning

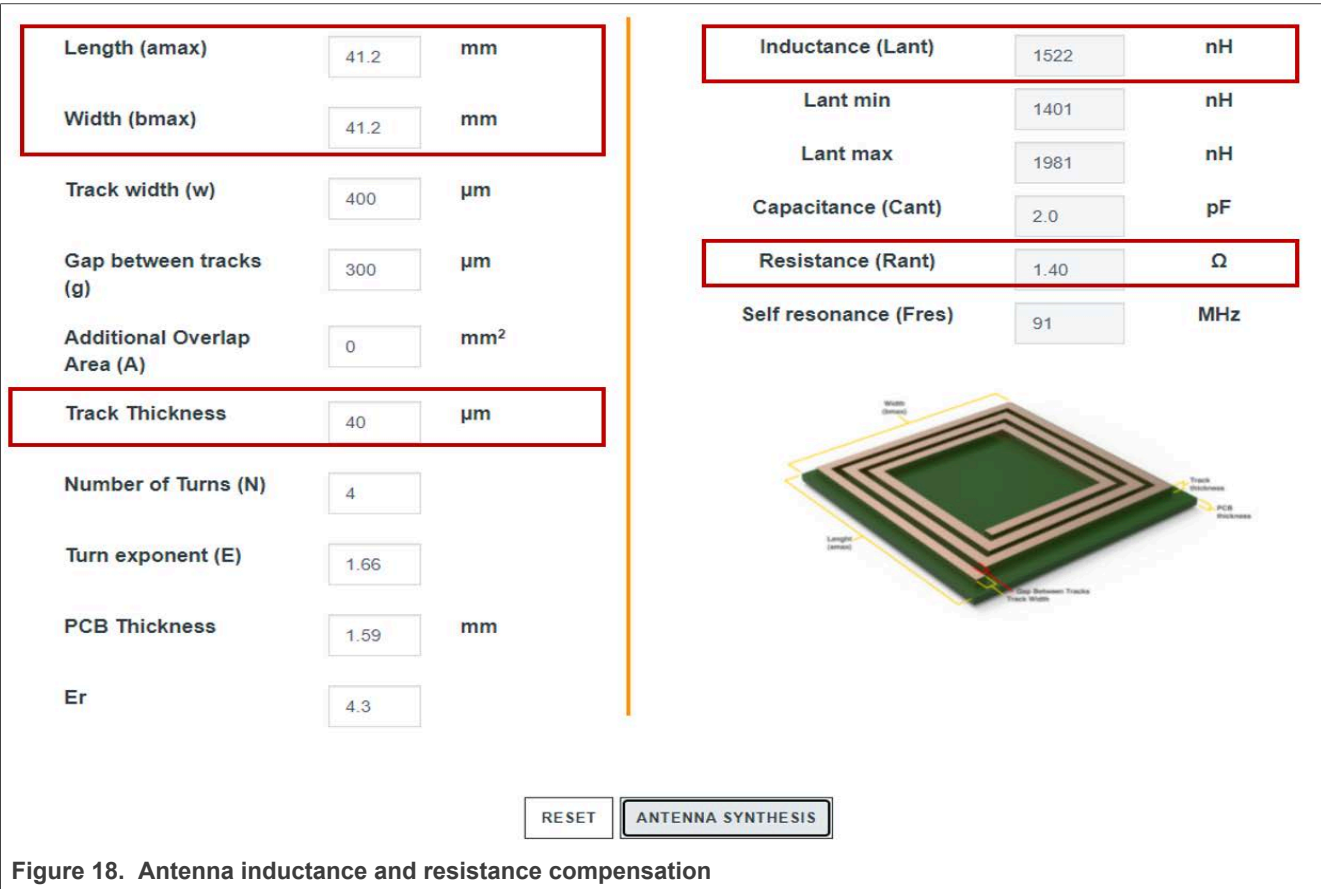
- More detuning and loading sensitive: tuning decreases under detuning and loading conditions
- Cut off frequency $\approx 14.4 \text{ MHz} - 14.7 \text{ MHz}$
- DPC function is required
- Increases the operating distance
- Supports smaller antennas
- Typically higher output power (Due to the lower target impedance, typically from 16Ω to 17Ω)

4.1.3.3 Antenna parameters compensation

The mismatch between the calculated and measured results can be due to the manufacturing tolerances (Section 4.1.2.2), and because of a different antenna environment (metal, ferrite sheet). The calculation tool considers only the air environment.

To get precise matching component values, implement the antenna inductance and resistance correction.

The recommended approach is to get approx. the same antenna inductance and resistance (Lant) by changing the **Length (amax)**, **Width (bmax)** and **Track Thickness** as measured in Section 4.1.2.2.1.



4.1.3.4 Input parameter: quality factor (bandwidth adjustment)

The antenna quality factor (Q) sets the reader bandwidth. A typical antenna quality factor value for the optimal bandwidth is between **15 and 20**. A high Q value can impact the signal shaping and system frequency bandwidth. If the measured antenna quality factor is larger than 20, use R_Q resistors in series to damp Q value. The NFC matching tool recommends the value for Q ([Figure 19](#)).

The recommended value for Q is **20**.

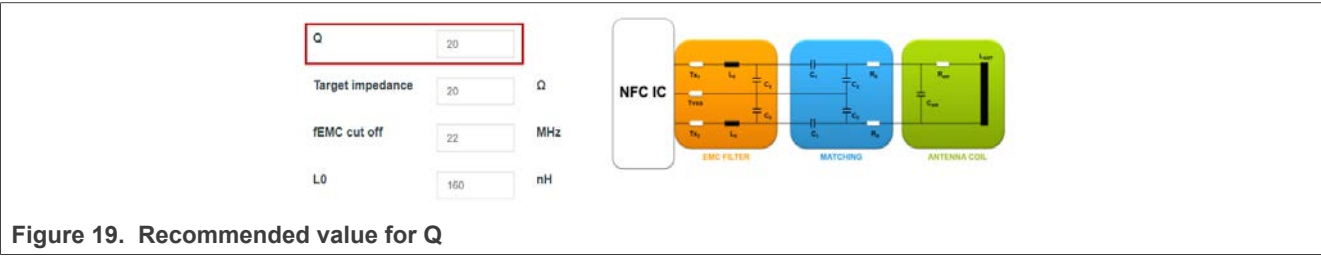


Figure 19. Recommended value for Q

4.1.3.5 Input parameter: target impedance

The target impedance of the circuit connected between TX1 and TX2 nodes defines the output power of the PN7160 IC RF transmitter.

The recommended value for most application using **asymmetrical tuning** function is **20 Ω**. for $V_{TVDD}=5\text{ V}$ respectively **13 Ω** for $V_{TVDD}=3.3\text{ V}$

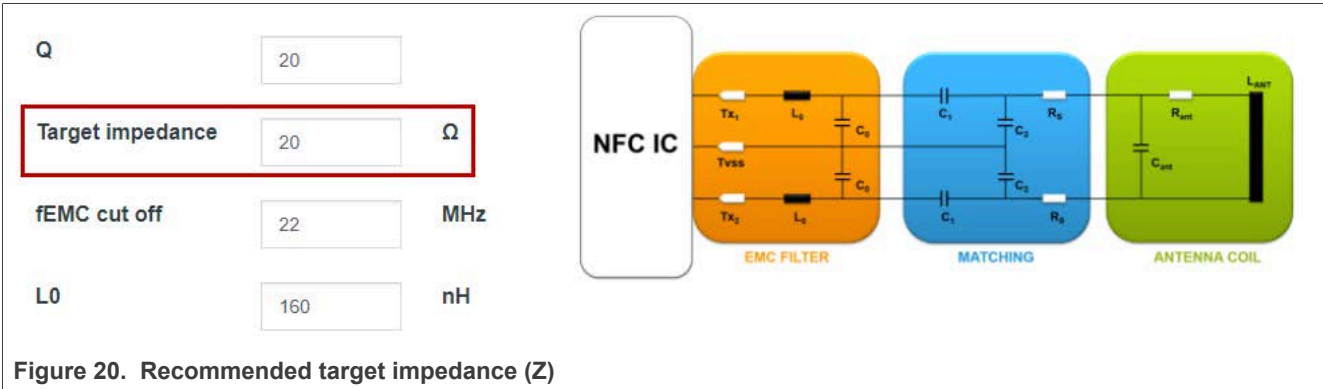
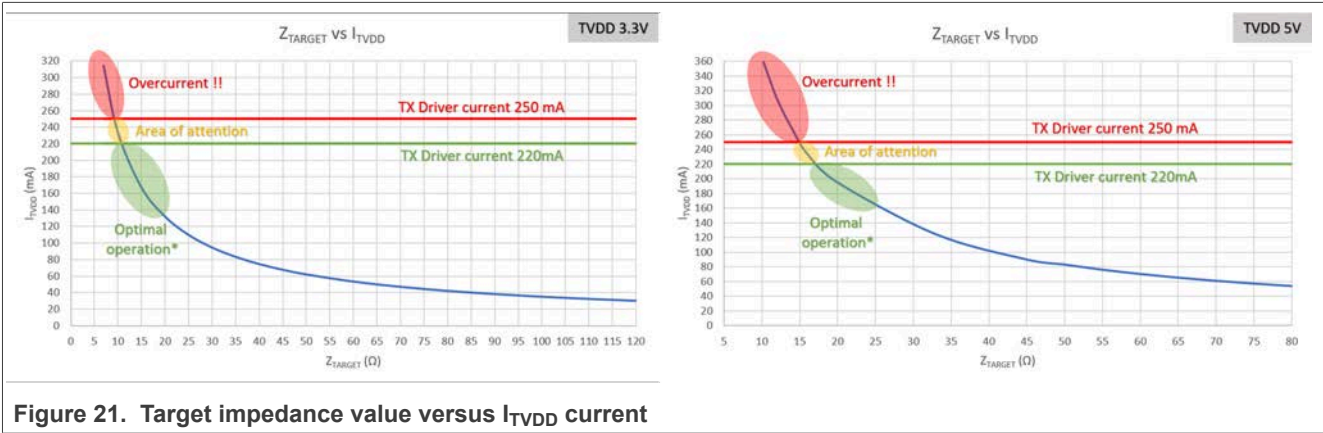


Figure 21 shows the TX driver current I_{TVDD} versus the target impedance.



- The green area shows the "optimal" operation of the NFC transmitter.
 - For symmetrical tuning, choose the target impedance corresponding to the TX Driver current **210 mA - 230 mA**.
 - For asymmetrical tuning, the target current of the TX driver is typically **160 mA - 180 mA**.

Tune the antenna to never exceed the 250 mA maximum current.

To use **symmetrical tuning** function + Dynamic Power Control (DPC), target the target impedance **16 Ω** for $V_{TVDD}=5\text{ V}$, and **11 Ω** for $V_{TVDD}=3.3\text{ V}$ respectively.

Table 3 shows the available TVDD voltage settings for TX drivers.

Table 3. TVDD voltage settings

	min										max
TXLDO voltages (Volts)	2.7	3	3.3	3.6	3.9	4.2	4.5	4.7	4.75	5	5.25

Figure 21 provides the target impedance values of the antenna versus TVDD.

Table 4. Target impedance

	TVDD ≤ 3.3 V	TVDD ≥ 3.6 V
Target impedance for asymmetrical tuning (typical)	13 Ω	20 Ω
Target impedance for symmetrical tuning + DPC enabled (typical)	11 Ω	16 Ω

4.1.3.6 Input parameter: EMC Filter cut-off frequency (fEMC cut off) and L0

The EMC filter contains an inductor (L0) and a capacitor (C0). The cut-off frequency defines the overall detuning behavior as well as the transfer function of the antenna circuit. The inductor L0 must be capable to drive the full power into the antenna without going into saturation. The Q-factor of the inductor should be as high as possible.

L0 and C0 value definition:

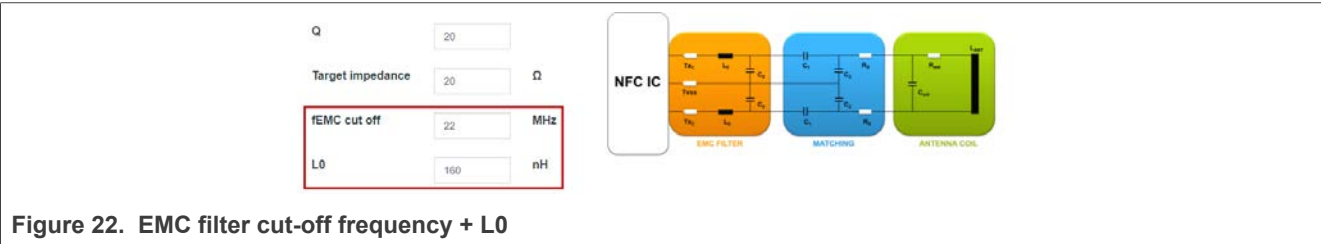
L0 = 160 nH – 560 nH

Filter resonance frequency f0 = 14.4 MHz to 22 MHz, => C0

The EMC filter resonance frequency f0 must be higher than the upper sideband frequency determined by the highest data rate (848 kHz sub carrier) in the system (that is 14.4 MHz).

The recommended values are **22 MHz for fEMC cut off** and **160 nH for L0**. This ensures an asymmetrical transfer function (asymmetrical matching).

For the symmetrical transfer function (symmetrical matching which required DPC function (see [1]), **14.6 MHz for fEMC cut off** and **160 nH for L0** can be chosen as a starting values.



4.1.3.7 Output parameters: C0, C1, C2, and Rs

NFC matching tool calculates the matching components.

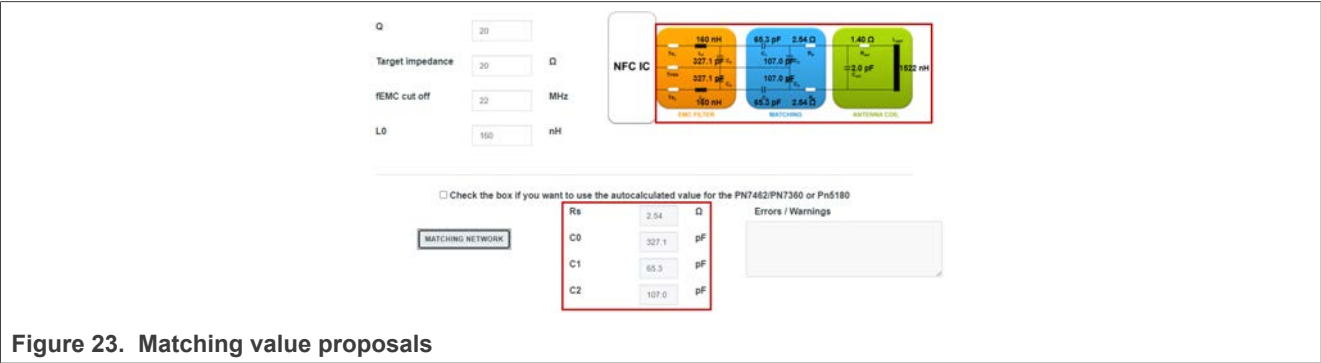


Figure 23. Matching value proposals

For the first matching iteration, the nearest component values within an E-series are recommended to use. In the case shown in [Figure 23](#):

- L0 = 160 nH
- C0 = 330 pF
- C1 = 68 pF
- C2 = 100 pF
- Rs = 2.7 Ω

TABLE lists the requirements for the matching components.

Table 5. Components characteristics

Component	Maximum tolerance	Type	Maximum rating
L ₀	5 %	Murata LQW18CNR (wire wound) TDK MLJ1608 (Multilayer Ferrite)	400 mA at least at 13.56 MHz
C ₀	2 %	NP0 - COG	16 V at least
C ₁	2 %	NP0 - COG	50 V or 25 V ^[1])
C ₂	2 %	NP0 - COG	50 V or 25 V ^[1]
R _q	5 %	N/A	N/A
RRX	5 %	N/A	N/A
C _{RX}	5 %	X7R	50 V or 25 V ^[1]
C _{VMID}	10 %	X7R	4 V at least
Antenna inductance	3 %	—	—

[1] The choice between 50 V and 25 V voltage depends on the antenna characteristics and operating conditions: the voltage at antenna terminals should be measured in the worst case conditions. For example, measurement in card mode using the [ISO10373-6 \[1\]](#) assembly PCD test bench to generate a field strength of 12 A/m.

The higher cut-off frequency of the EMC filter is due to a higher stability with close coupling devices in reader mode: less impact of detuning effect on power consumption increase.

4.1.3.8 Matching components calculation using the Excel calculator

If an existing NFC antenna is available and only the antenna parameters (La, Ra) are known based on measurement, the excel calculator (attachment of this document - *PN7160_matching_calculator.xls*) can be used. The measured antenna parameters as well as the required parameters such as the Bandwidth (defined by Q), Target impedance (Rmatch (Tx1-Tx2)), EMC filter cut-off frequency (calculated based on chosen C0 (330 pF for the asymmetrical matching)), and EMC inductor (L0) value can be directly inserted (Figure 24).

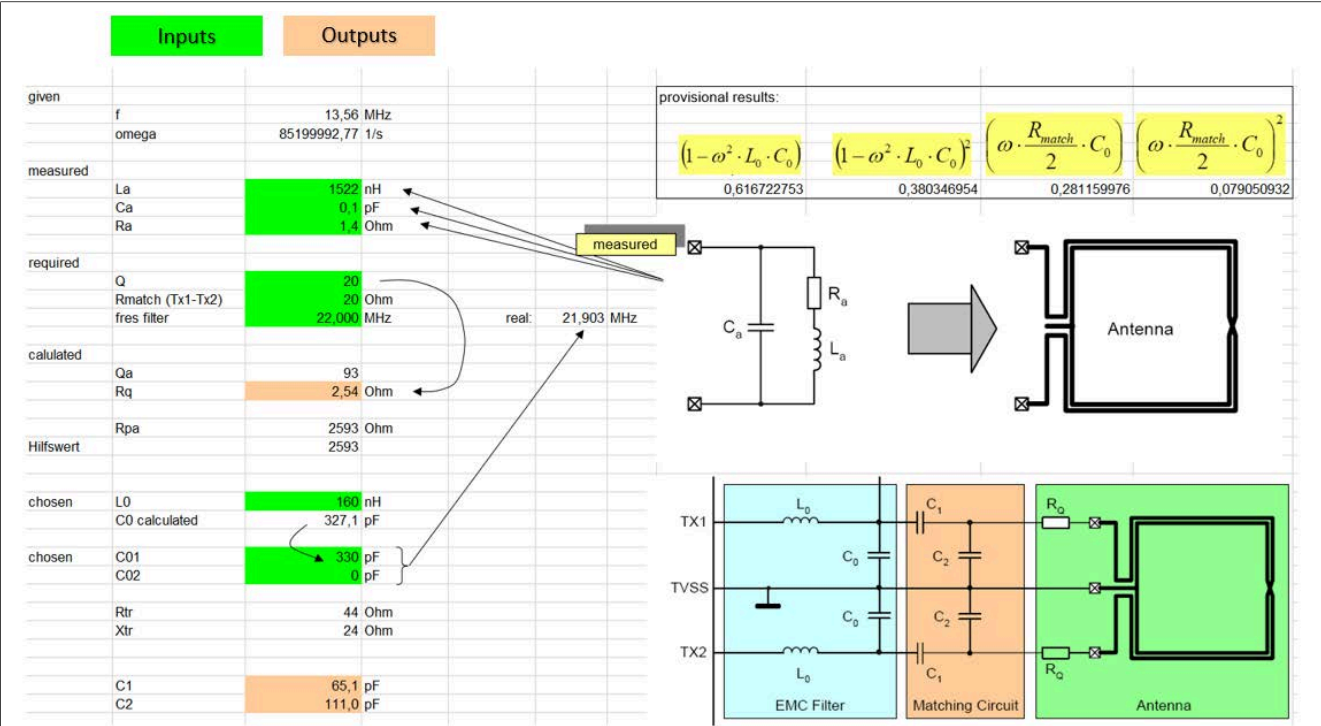


Figure 24. Example of matching component calculation with the Excel calculator

Note: The capacitance Ca can be chosen as 0.1 pF, as starting value.

4.1.3.9 Impedance matching measurement

Once the components have been calculated ([Section 4.1.3.8](#)), the matching impedance using the VNA can be measured.

The measurement is done in front of the EMC inductors as shown in [Figure 25](#).

During the antenna matching process, **the PN7160 IC must not be powered!**

The setting definitions and the calibration of the VNA are performed as described in [Section 4.1.2.2](#).



Figure 25. Impedance matching measurement

[Figure 26](#) shows the measured results.

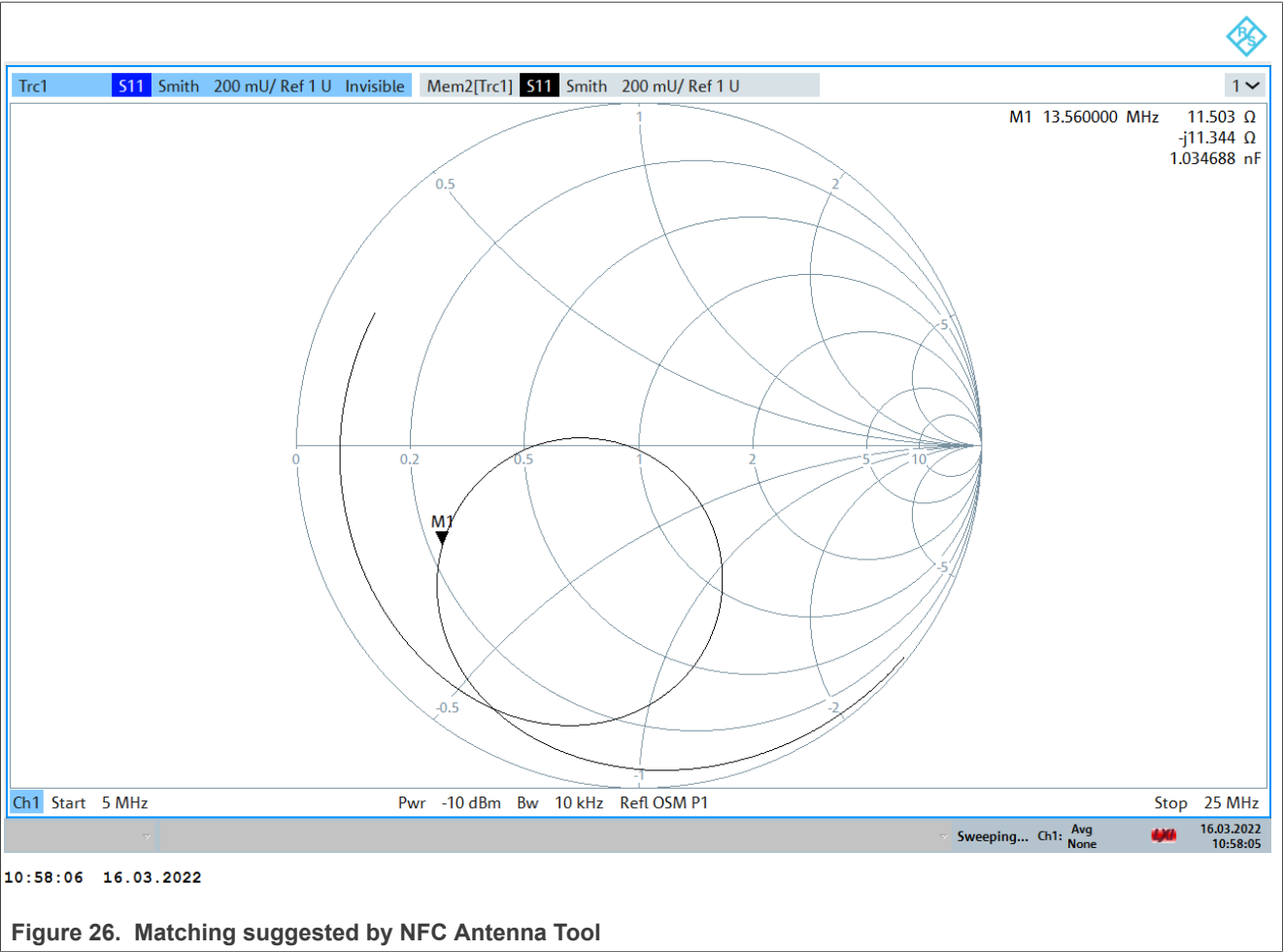
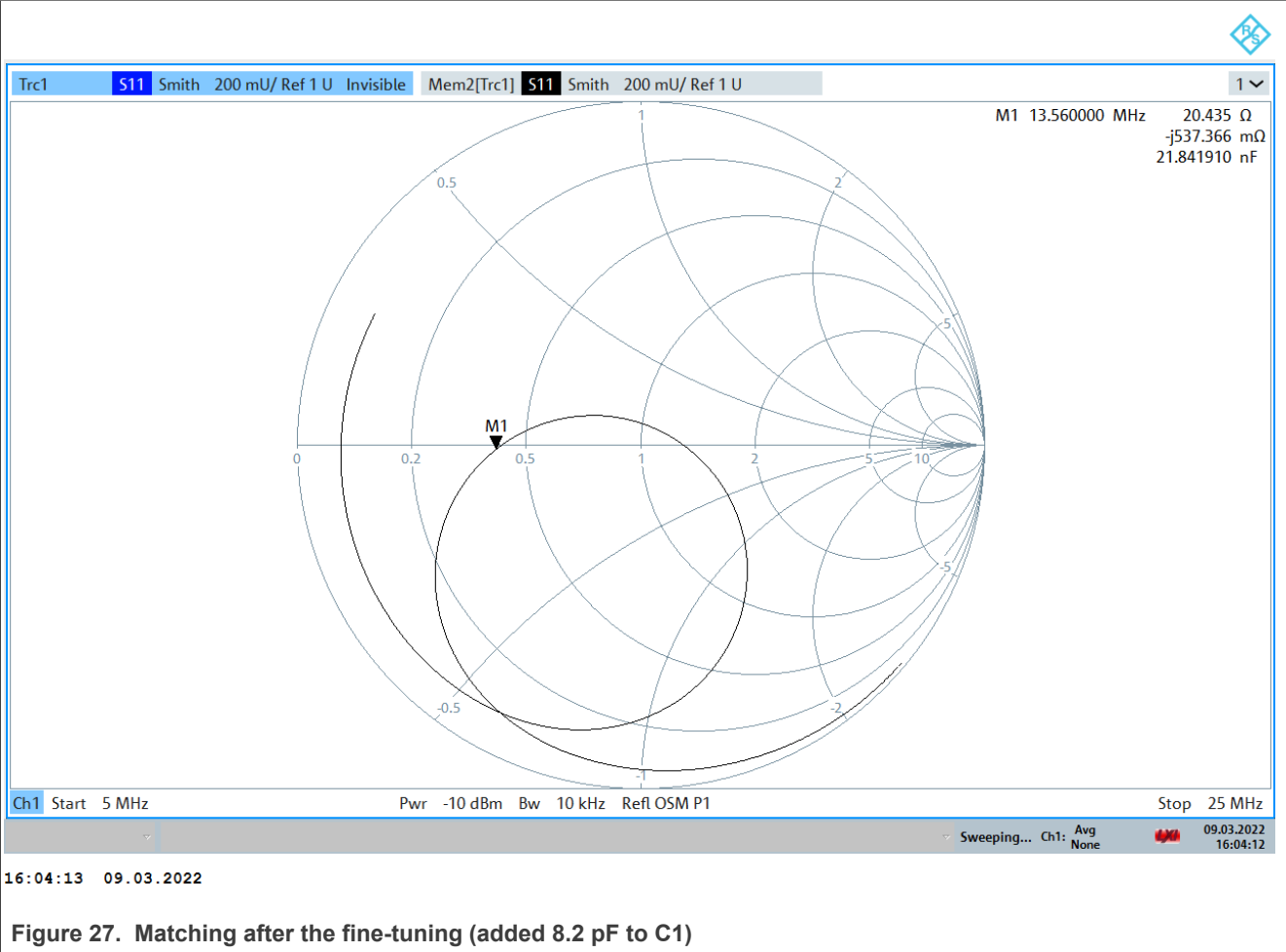


Figure 26. Matching suggested by NFC Antenna Tool

The matching already looks promising but a fine-tuning is required. The target is approximately 20 Ω . The fine-tuning uses the tips described in the [Section 5.1](#).



In this specific case, the Cs has been increased by 8.2 pF (overall 62 pF + 8.2 pF). This helped to achieve the target impedance of 20 Ω (Figure 27).

5 Matching/tuning guide

First, the antenna has first to be matched to PN7160 ([Section 4](#)). NFC matching tool provides the initial matching values. Second, the final matching is typically required.

This section describes how to fine-tune the antenna. During the antenna matching process, PN7160 IC is not powered.

5.1 Matching impedance tuning guide

Resonance of an NFC antenna is the condition where the antenna acts as resistive load. Resonance is achieved by adjusting the matching components as described below.

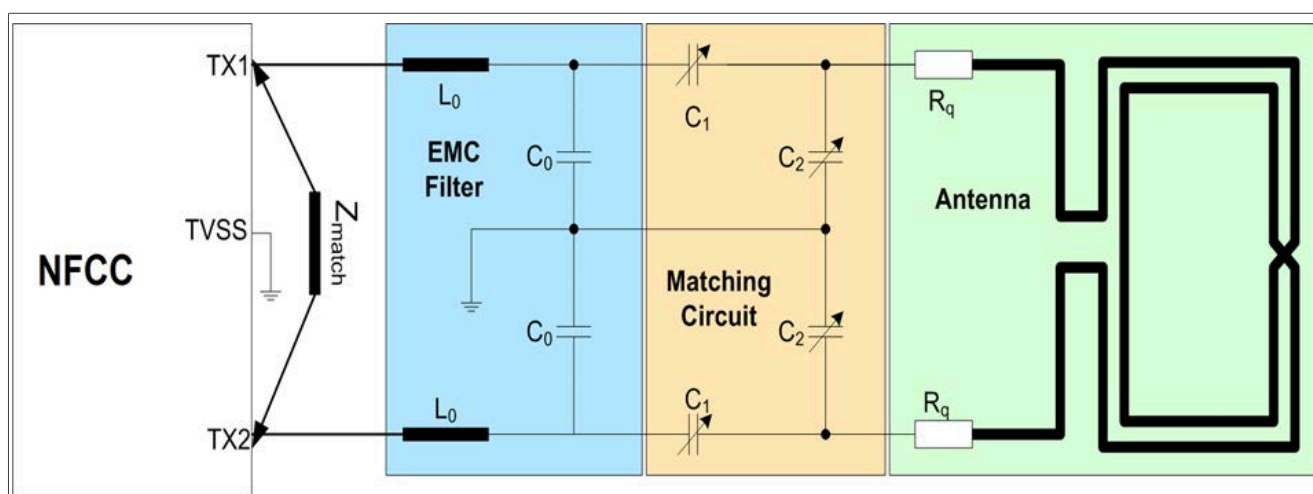


Figure 28. Measurement of the matching impedance

The value of C_1 changes the magnitude of the matching impedance. After changing C_1 , the imaginary part of Z_{match} must be compensated by adjusting C_2 .

C_2 changes mainly the imaginary part of Z_{match} .

C_0 value shifts the EMC filter resonance frequency.

Figure 29 to Figure 31 show behaviors that can be observed on the network analyzer while changing the values of C_1 , C_2 , and C_0 .

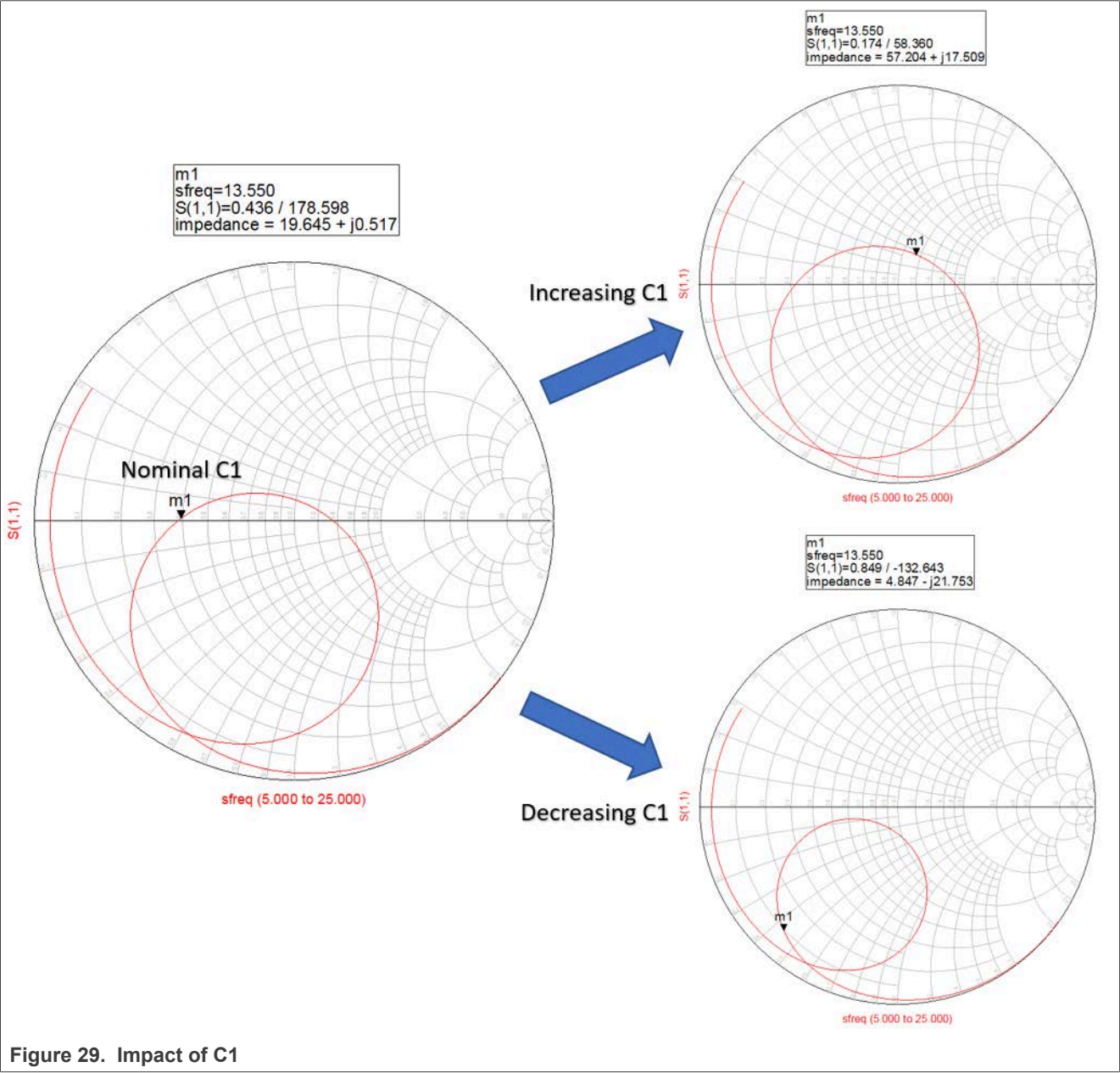
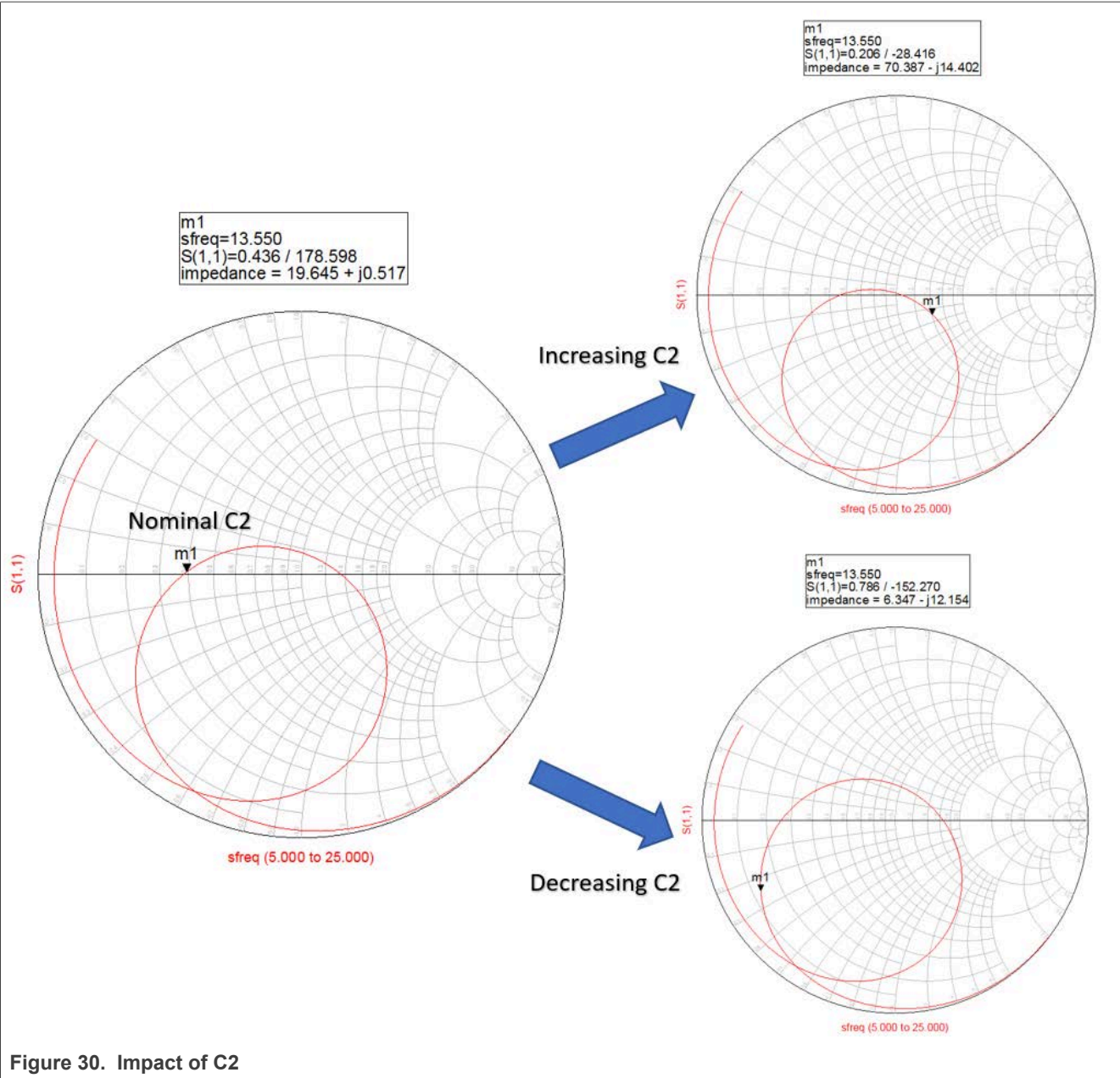
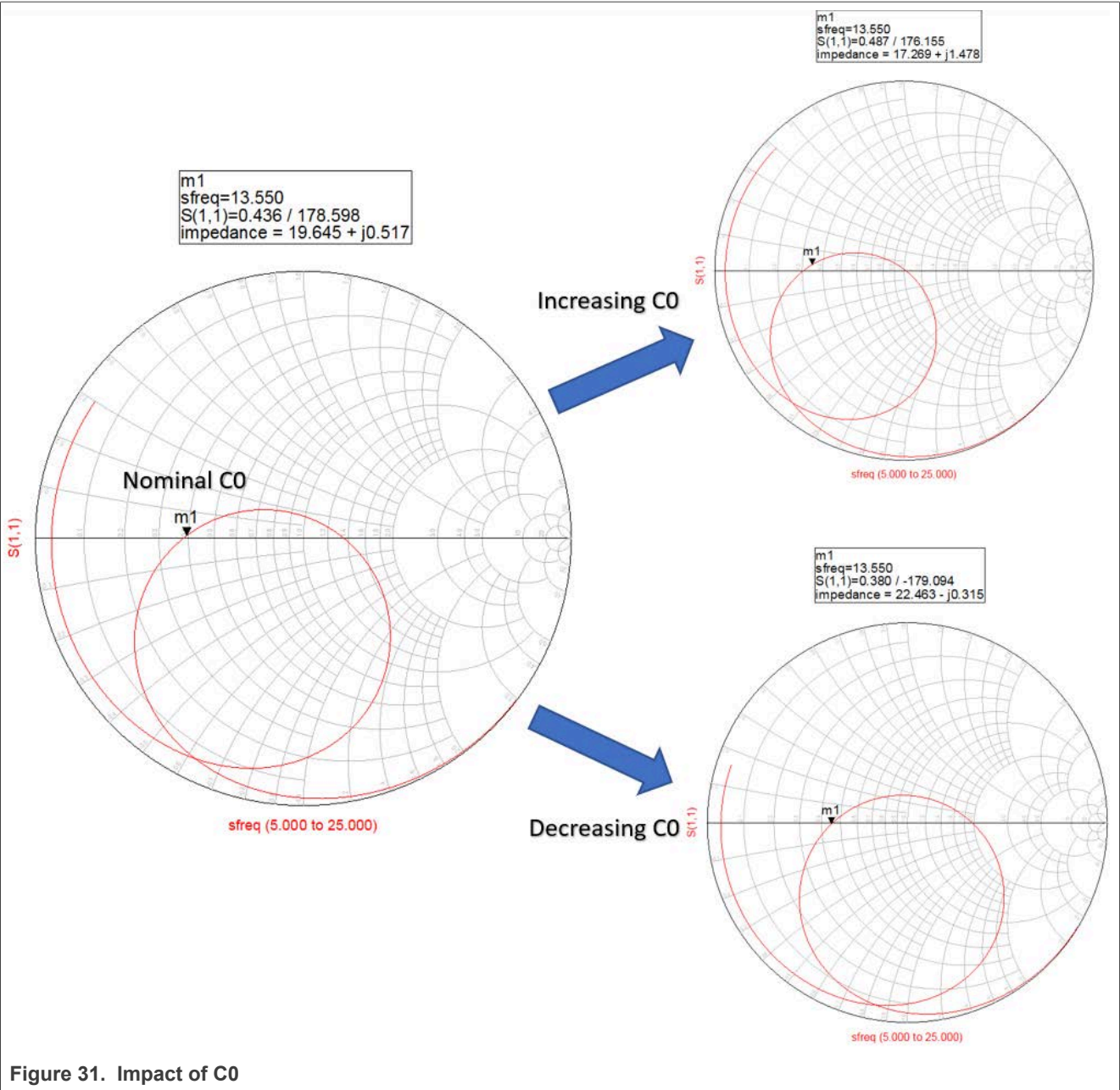


Figure 29. Impact of C_1



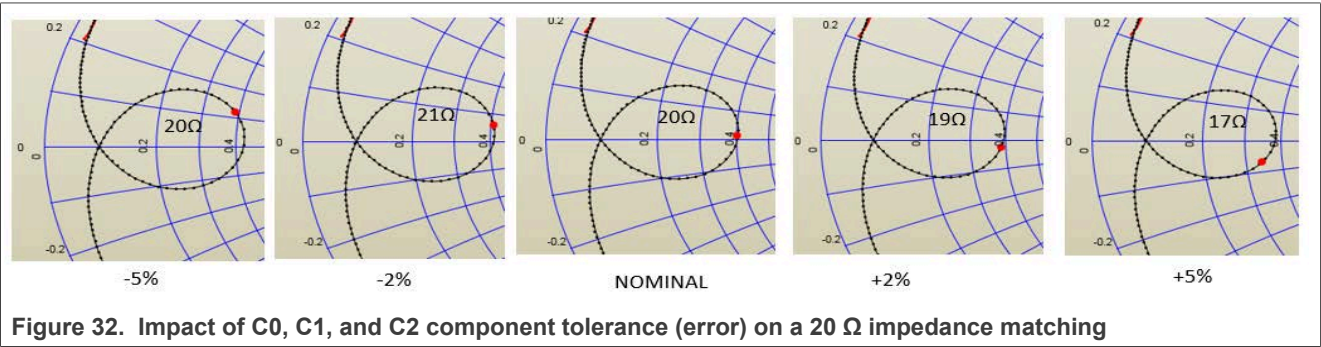


5.2 Matching components tolerance

It is highly recommended to use 2 % tolerance components for the matching. The impact of the matching component tolerance was simulated and the impedance shift is given in [Table 6](#).

Table 6. Impact of C0, C1, and C2 component errors on matching impedance

C1/C2 deviation	-5 %	-2 %	0 %	+2 %	+5 %
Impedance @13.56 MHz	20 Ω	21 Ω	20 Ω	19 Ω	17 Ω



Adding the tolerances of the antenna itself, the NFC performances can be significantly impacted.

5.3 Impedance matching simulation

The impedance matching can also be simulated using a suitable RF Tool. For instance, it can be ADS tool from Keysight (paid one) (ref. [9]) or the RFSim99 (ref. [10]) that is a freeware tool.

The matching structure including the 40 mm vs 40 mm antenna model has been simulated in ADS and RFSim99 as shown below.

Figure 33 shows the matching circuit with the component values obtained by the NFC Matching Tool.

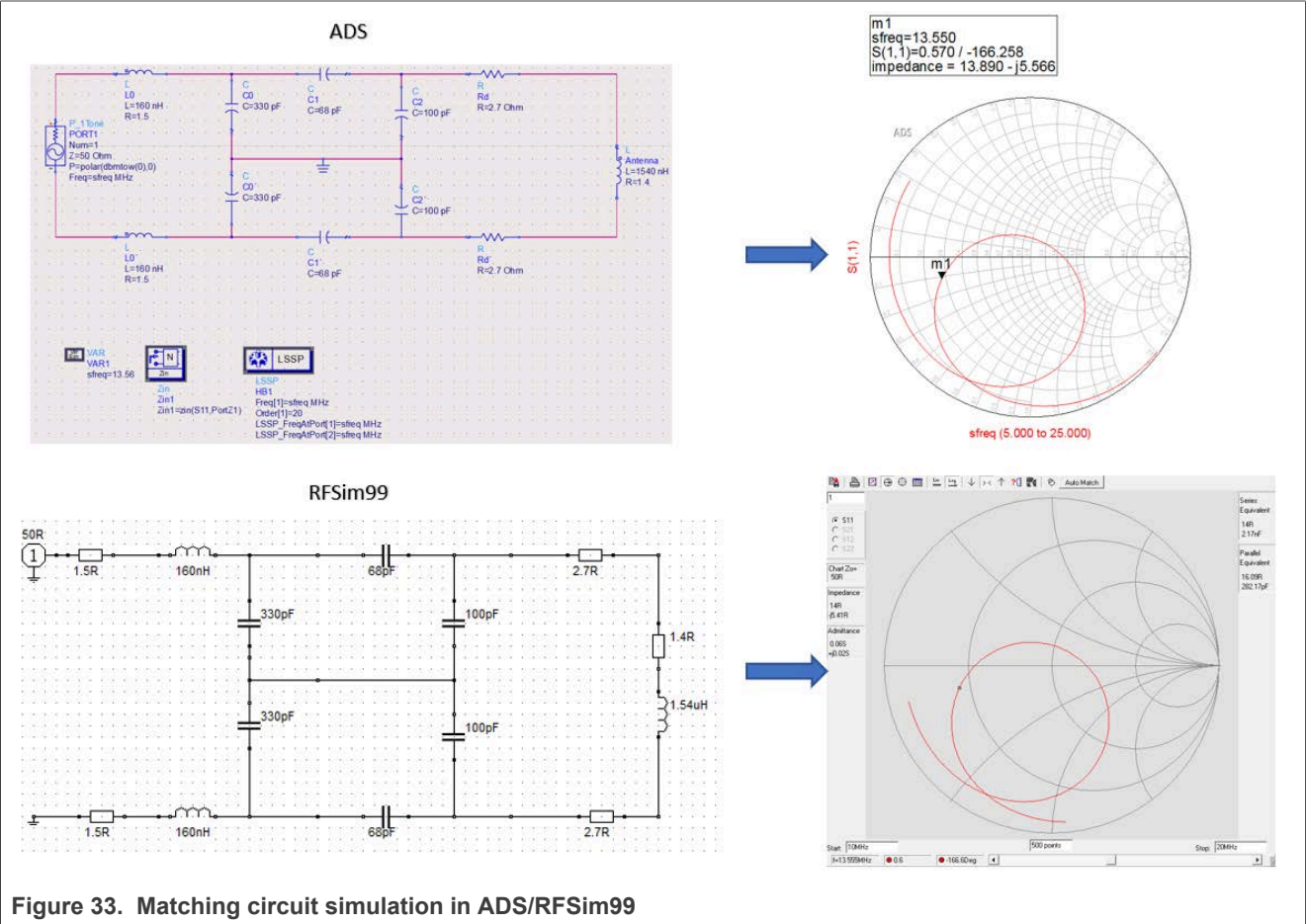
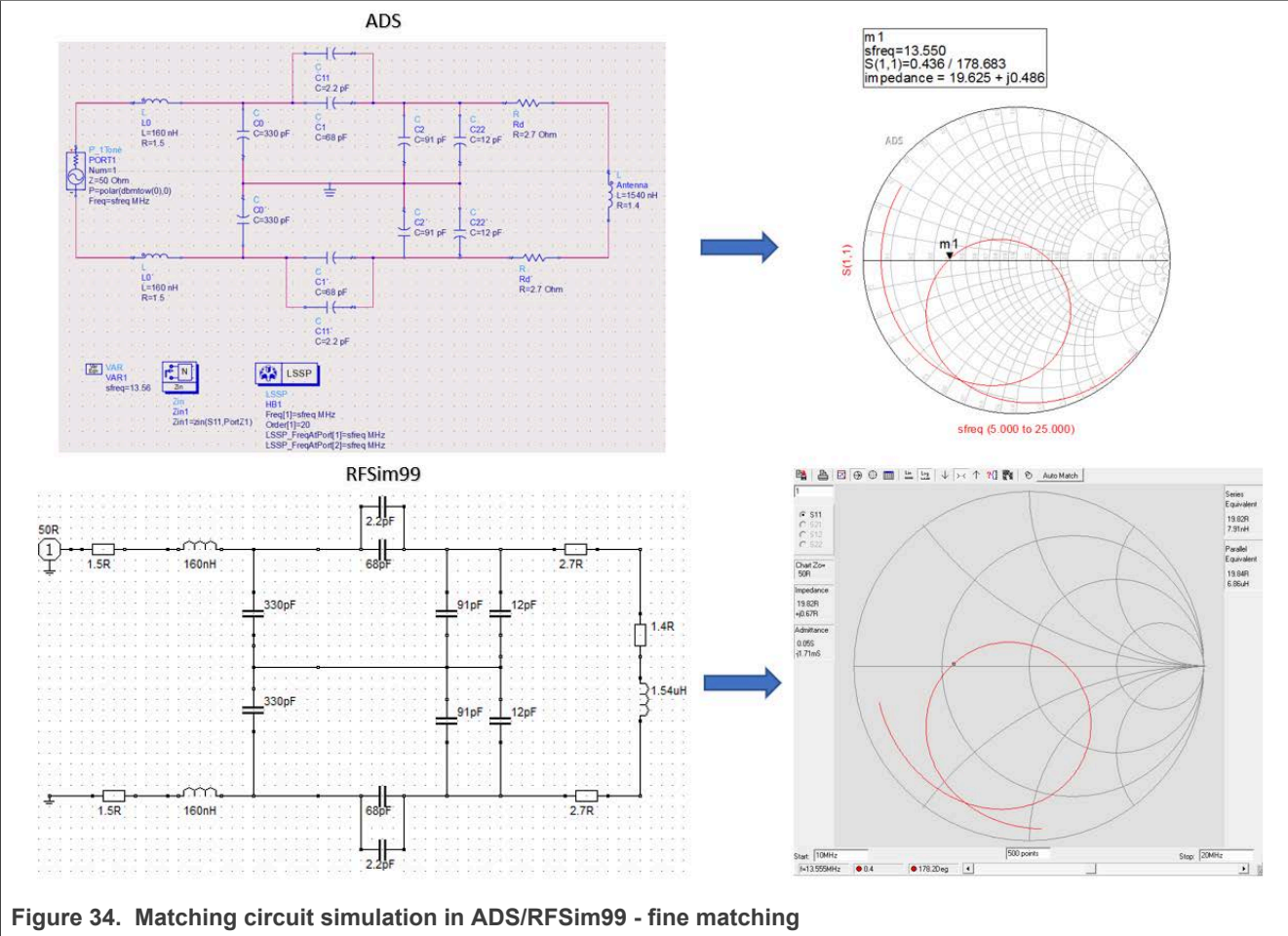


Figure 34 shows the antenna matching after the fine-tuning. The C1 and C2 have been adapted to achieve the 20 Ω target.



Both tools show more or less the same results. The advantage of the ADS tool is that it can be used also for advanced transient signal analysis.

6 Rx path tuning (R_{rx} and C_{rx} definition)

6.1 Receiver block functionality

The RX block includes an automated gain control (AGC). The AGC regulates the voltage at RX pins to reach the optimum receiver input voltage. To optimize the receiver input voltage, the AGC can use a voltage divider to attenuate the RX signal coming from the antenna. The series resistance is external to the device. The shunt resistance is in the RX block, switchable within a certain range.

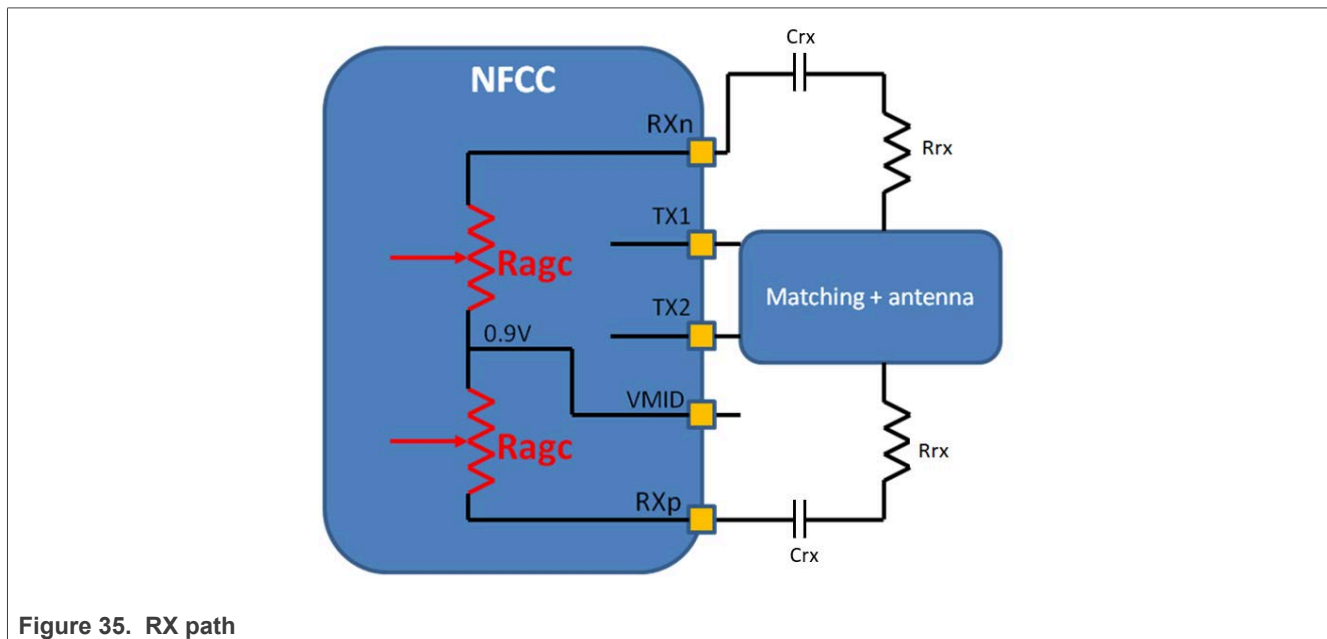


Figure 35. RX path

The serial value resistor R_{rx} is in the range of 1 k Ω to 10 k Ω . The value of 2.2 k Ω is a good starting value.

The C_{rx} capacitors provide an AC coupling of the RX signal. A value of 1 nF can generally be used.

Once the R_{rx} resistors are assembled. The continuous RF Field can be turned on and the peak (Max) voltage between RX and GND can be measured as shown in [Figure 36](#). As an alternative, the AGC value can be measured directly using the PN7160 device as described below.

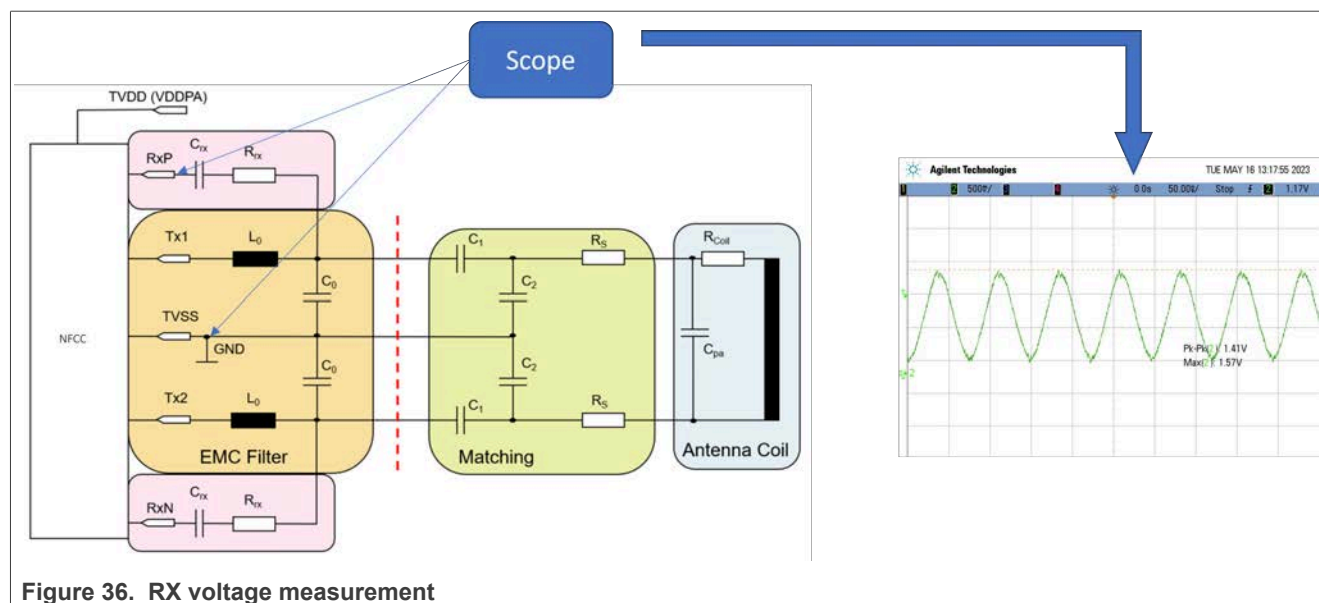


Figure 36. RX voltage measurement

The V_{rx} voltage should be approx. $1.6 V_p (\pm 0.15V)$

- High R_{rx} -> Lower V_{rx} voltage
- Low R_{rx} -> Higher V_{rx} voltage

The information about AGC value can also be measured by PN7160 using the NCI command **2F 3D 04 02 C8 60 03**.

For example, the NFC Factory Test application (*NfcFactoryTestApp.c*) can be extended as shown below:

```
static void AGC (int handle)
{
    char get[] = {0x2F, 0x3D, 0x04, 0x02, 0xC8, 0x60, 0x03};
    char Answer[255];

    printf("Get AGC value (enter 'ff' during tag ID selection step to leave):\n");

    while (1)
    {
        printf("\n");

        tml_transceive(handle, get, sizeof(get), Answer, sizeof(Answer));

        if ((Answer[0] != 0x4F) || (Answer[1] != 0x3D) || (Answer[3] != 0x00)) {
            printf("Error, cannot get parameter value\n");
        }
        else {
            printf("\n");
            printf("Measured AGC Value (LSB)= %.2Xh", Answer[4]);
            printf("\n");
            printf("Measured AGC Value (MSB)= %.2Xh", Answer[5]);
            printf("\n");
        }
    }
}
```

The following two lines have been added to the "do-while loop" at the end of *NfcFactoryTestApp.c* code.

```
printf("\13. Get AGC value\n");
```

```
case 13: AGC(nHandle); break;
```

```
-----
NFC Factory Test Application
-----
PN7160 NFC controller detected
Select the test to run:
    1. Continuous RF ON mode
    2. Functional mode
    3. PRBS mode
    4. Standby mode
    5. Dump RF settings
    6. Set RF setting
    7. Get NCI parameter value
    8. Set NCI parameter value
    9. Get proprietary parameter value
   10. Set proprietary parameter value
   11. Get current value
   12. DPC Check
   13. Get AGC value Check
enter 0 to leave the application
Your choice: 13
Get AGC value (enter 'ff' during tag ID selection step to leave):

Measured AGC Value (LSB)= F6h
Measured AGC Value (MSB)= 02h

Measured AGC Value (LSB)= EEh
Measured AGC Value (MSB)= 02h

Measured AGC Value (LSB)= EFh
Measured AGC Value (MSB)= 02h

Measured AGC Value (LSB)= F1h
Measured AGC Value (MSB)= 02h
```

Figure 37. AGC value obtained by the NFC Factory Test Application

The extended NFC Factory Test Application for Linux can be found [here](#).

The recommended AGC value is $500_{10} < \text{AGC} < 800_{10}$. For the example showed in [Figure 37](#), the value is approx. $0x02F6 = 758_{10}$.

- AGC Minimum → 0x0000
- AGC Maximum → 0x03FF

6.2 RX connection

For small antennas, connect the RX Path directly to the antenna as, due to the low antenna coupling, the signal amplitude at the EMC filter is likely to be smaller than 1 V.

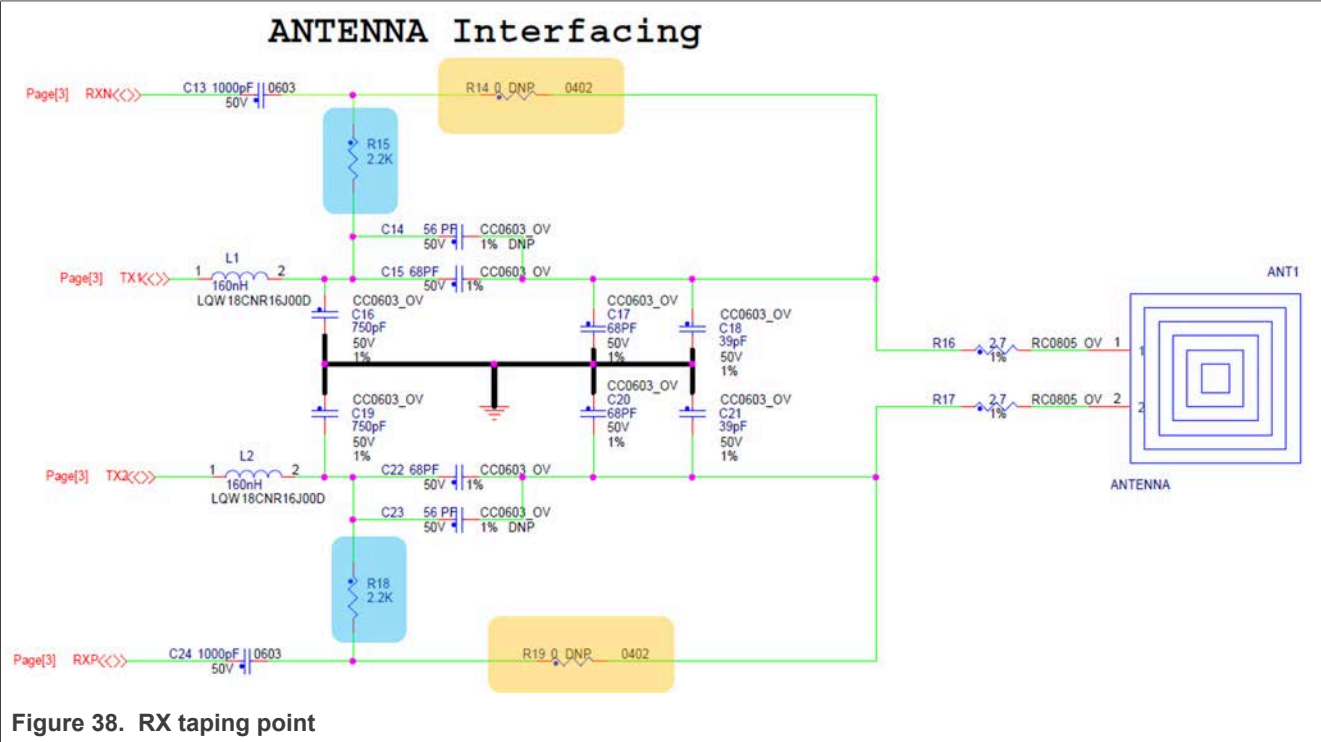


Figure 38. RX tapping point

- If the antenna size is $> 800 \text{ mm}^2$
- Use R15 and R18, and do not populate R14 and R19
- If the antenna size is $< 800 \text{ mm}^2$
- Use R14 and R19, and do not populate R15 and R18

Table 7. RX connection pros and cons

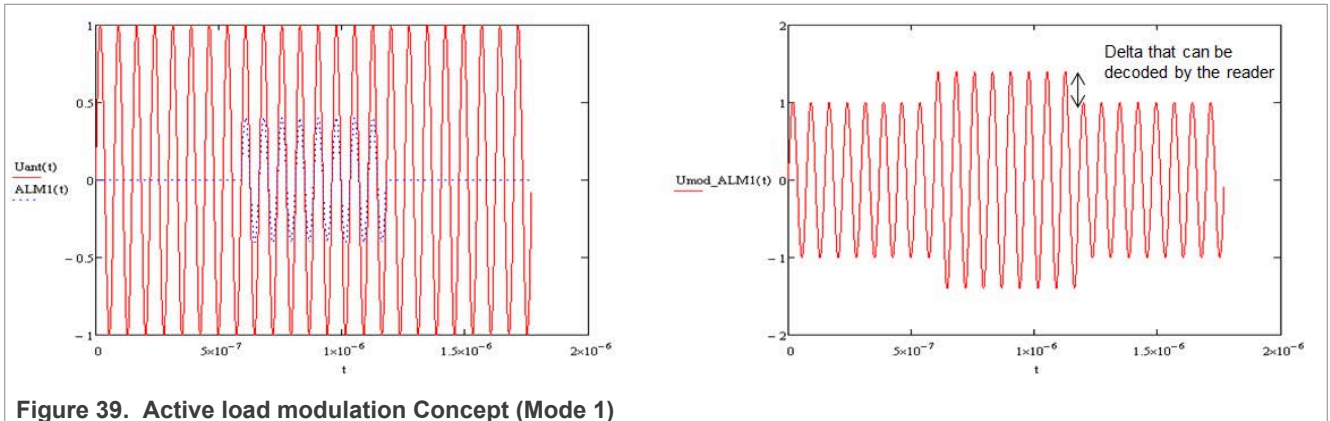
	Pros	cons
RX connected to EMC filter	- RX path connection does not decrease the Q factor - Recommended connection for large antenna	Amplitude signal might not be enough to guarantee good performances, especially with small antenna and ALM
RX connected to Antenna	Maximize the signal captured by the RX path=> useful for clock recovery accuracy for ALM	The RX resistor value impacts the Q factor

NXP recommends to use antenna RX tap point for small antennas (typically smaller than 800 mm^2) and EMC filter tap point connection for large antennas (typically larger than 800 mm^2).

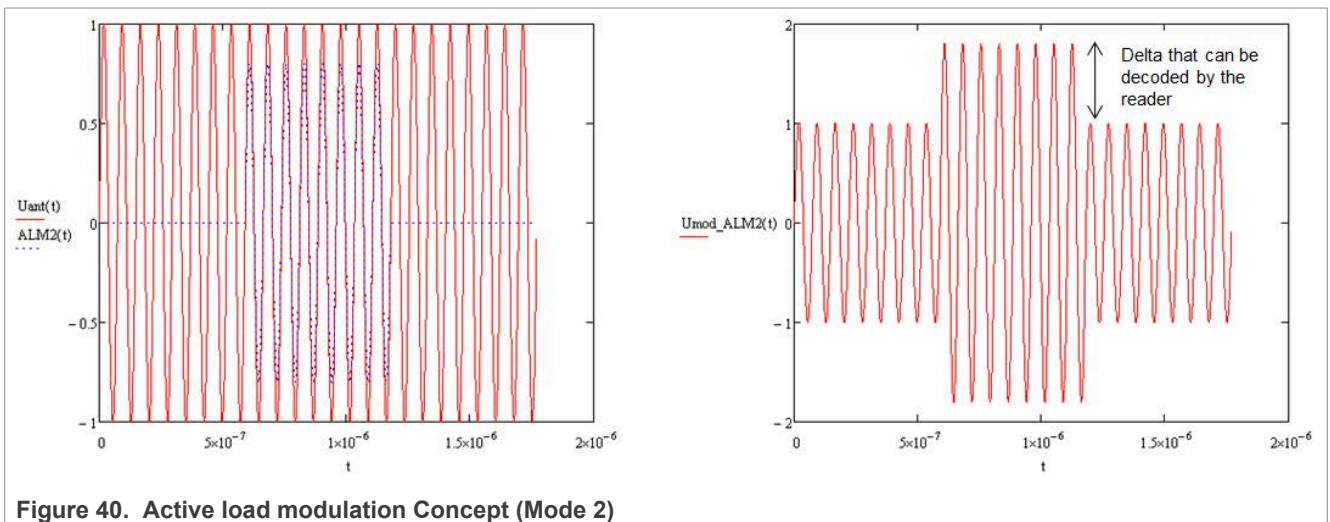
7 Antenna design/tuning for all NFC modes (RM and CM)

PN7160 was designed for the Active load modulation (ALM) concept. ALM provides high performances and significant margins to NFC standard criteria. It also allows the use of smaller antenna.

In CARD mode, PN7160 provides three modes to generate the load modulation Amplitude (LMA): mode 1 (SINGLE), mode 2 (DUAL), and mode 3 (DUAL+BPSK). The three modes are programmable ([7]) using CLIF_TX_CONTROL_REG.



On the left graph, the red curve shows the 13.56 MHz voltage at the NFC device antenna that is induced by the reader field. The blue curve shows the modulation pattern. This modulation pattern is generated by actively driving 13.56 MHz with TX1 or TX2 while the other TX pin (TX2 or TX1) is kept silent. On the right, we can see the modulated reader field.



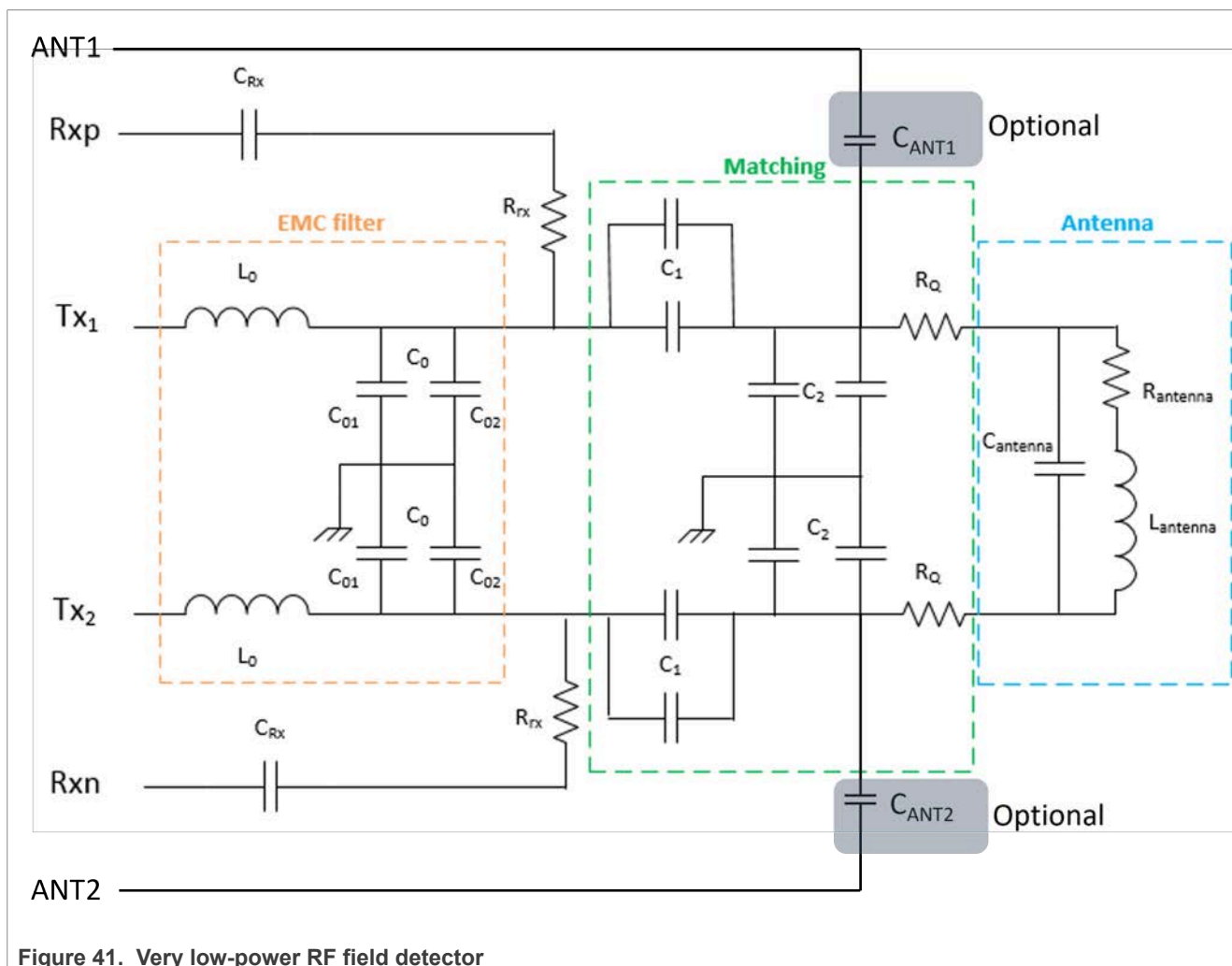
In this mode, the modulation pattern is generated by actively driving 13.56 MHz with TX1 and TX2. The modulation depth observed is twice the modulation depth of mode 1.

The antenna design to support all NFC modes is as described in [Section 4](#).

With Active load modulation, the matching is the same between Card mode and Reader mode.

7.1 Default configuration for reader and card mode

The [Figure 41](#) shows the RF path configuration for both NFC modes (RM and CM) of the PN7160. The matching circuit is the same for Reader Mode and Card Mode.



Optionally, the ANT1 and ANT2 pins of the PN7160 can be connected with the help of C_{ANT} capacitors.

ANT1 and ANT2 pins work as very low-power RF field detector. The NFC controller can detect the presence of an external magnetic field and notify the host system about its presence, when the NFCC is in Power Off mode.

If an RF field is present, the voltage (2.7 V) can be measured on the $V_{DD(HF)}$ pin (monitor rectifier output voltage). **12 pF** is a good starting value for C_{ANT} .

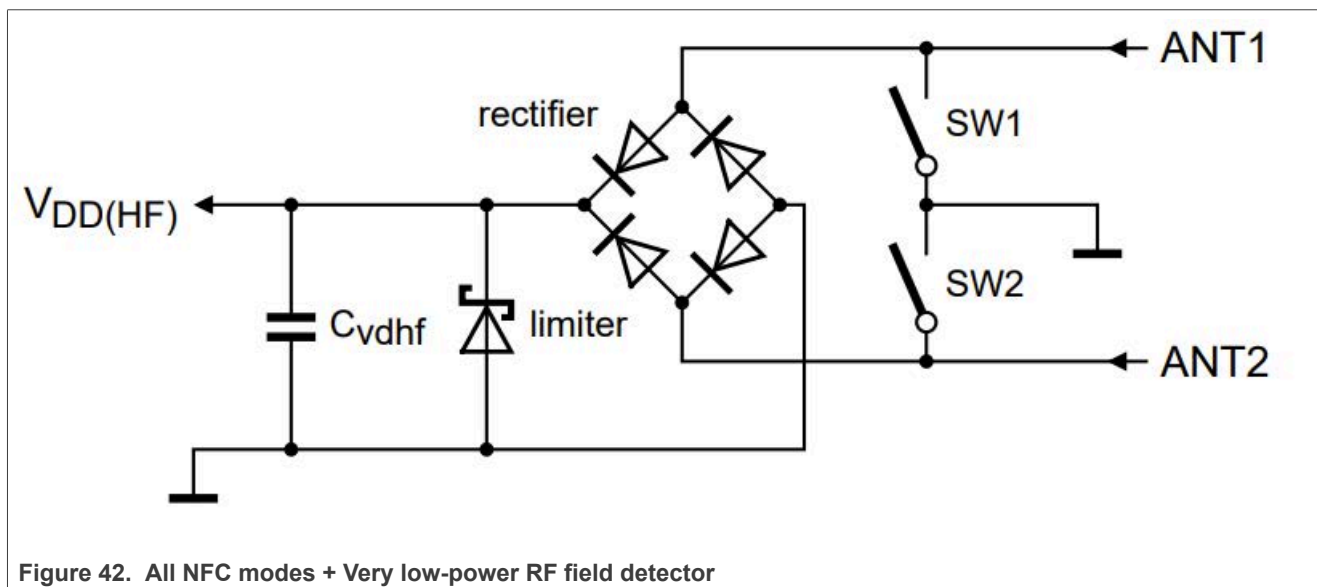


Figure 42. All NFC modes + Very low-power RF field detector

Figure 43 shows the output voltage on the $V_{DD(HF)}$ pin when the PN7160 is in Power Off mode and the external magnetic field has been detected.

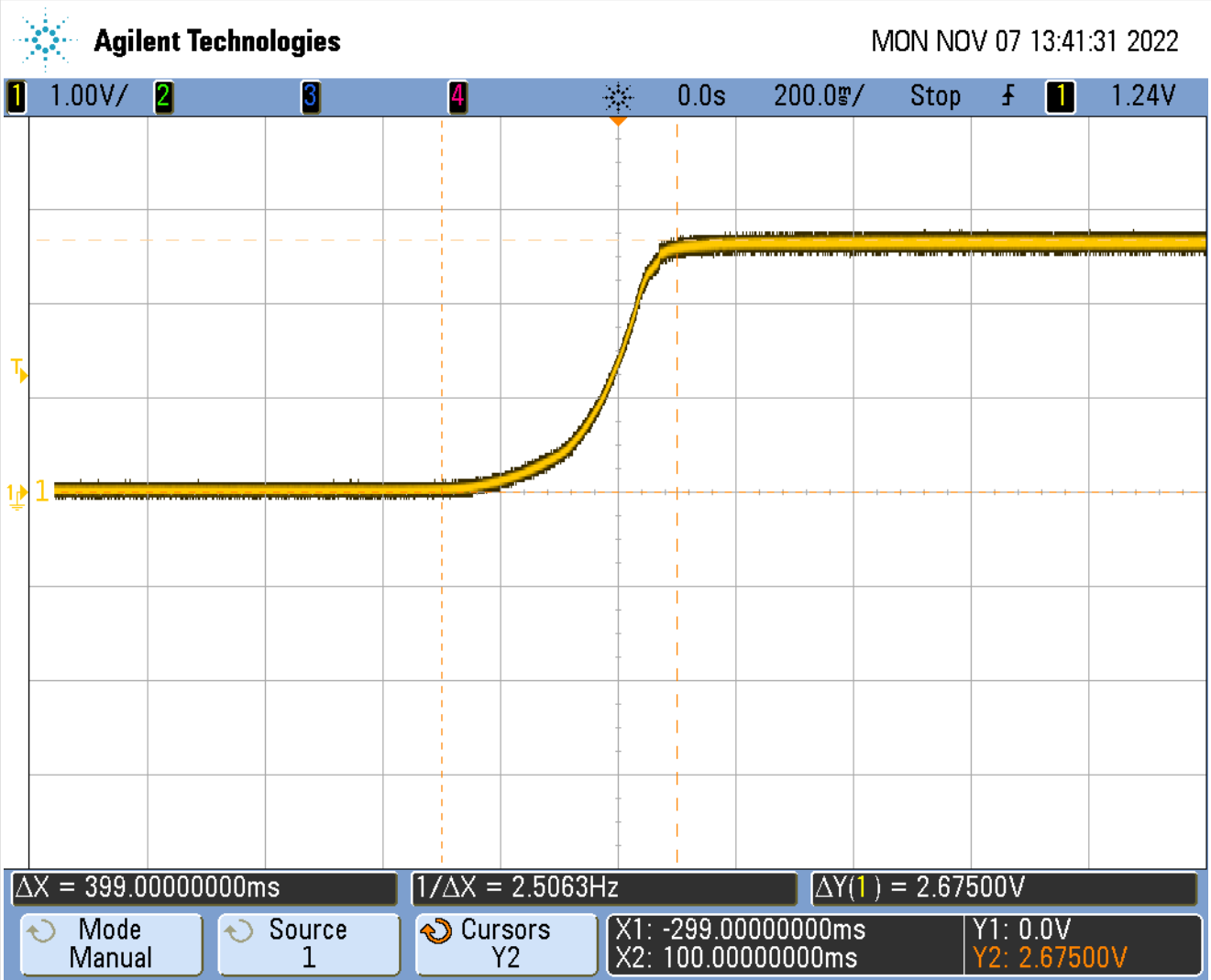


Figure 43. $V_{DD(HF)}$ when the NFCC is in Power Off mode + an external magnetic field

If you choose to use the Very low-power RF field detector feature, the reading range can be reduced due to the additional antenna loading.

8 Dynamic load modulation Amplitude (DLMA)

The NFCC supports the dynamic LMA control (DLMA) feature for Card mode. DLMA is used to adapt the load modulation amplitude to the received field strength.

With DLMA, the device can generate an optimized signal in Card mode, and achieve better interoperability with readers and larger communication distances.

The NFCC in Card mode receives the RF signal from the reader on its RX path. On the RX path, the internal AGC and ADC each generate a code based on the RF signal strength received.

The two codes can be mapped as a function of the reader field strength. The sensitivity of the RX path that is the antenna performance and overall RX path losses must be considered.

From the mapping, a lookup table can be built to adjust the LMA according to the AGC values where:

- For large field strength, small LMA gain can be used.
- For small field strength, larger LMA gain can be applied.

For more details, refer to the dedicated application note [\[8\]](#).

For most of the standard applications, the DLMA can be disabled and one of the Card Emulation modes can be used. For more details, refer to the section *Card emulation does not work at close range* in [\[11\]](#).

9 Dynamic Power Control (DPC)

In reader mode, the NFCC can adapt the current injected into the antenna according to the antenna detuning. This feature called Dynamic Power Control (DPC) monitors the current generated on the TX drivers and if antenna detuning, it limits this current (preventing it from clamping) by adjusting the TX signal amplitude.

Thanks to DPC, the NFC antenna can be matched (**symmetrical tuning**) in order to always deliver the maximum power, with no risk of having the TX current going beyond its specification.

Without DPC enabled, the matching must target **higher impedance** or **asymmetrical tuning** in order to have guard bands against high antenna detuning.

For more details, refer to the dedicated application note [\[1\]](#).

10 Performance verification and fine-tuning

10.1 Field strength measurement

When PN7160 is configured in reader mode, a Reference PICC placed at a short distance of the PN7160 antenna is used to measure the strength of the emitted RF field. The reference PICC is calibrated on the relevant test bench: its output voltage corresponds to a well-defined field strength. The output voltage of the Reference PICC can be measured either with an oscilloscope, or with a voltmeter (PN7160 configured to emit a continuous RF field).

Based on the targeted standard compliance, different PICCs are used. For example, the Reference PICC to be used to check compliance with the *ISO/IEC14443 standard* [\[4\]](#) is described in the *ISO/IEC10373-6 standard* [\[3\]](#).

The specification of the field strength in the *ISO/IEC14443* standard requires:

- No operating volume
- A minimum field strength of 1.5 A/m
- A range of 1.5 A/m to 7.5 A/m

This requirement is met at a short distance (<2 cm).

The *NFC Forum standard* [\[5\]](#) defines three Reference PICC or reference listeners. The required operating volume is smaller than EMVCo: the distance is up to 0.5 cm. This specification can be met more easily with all three Reference PICC.

10.2 Carrier envelop shape verification

The following pulse shape checks are a quick way for investigating the shaping of the generated RF field when the PN7160 is configured in reader mode.

The Reference PICC of the relevant standard has to be used for checking compliance of the waveform timings instead of the simple probe loop that is described below.

This measurement is also an indirect verification of the Q-factor provided that it has a direct influence on the edges of the modulation shape.

An oscilloscope with a bandwidth of at least 50 MHz has to be used to carry out the shaping measurements ([Figure 44](#)).

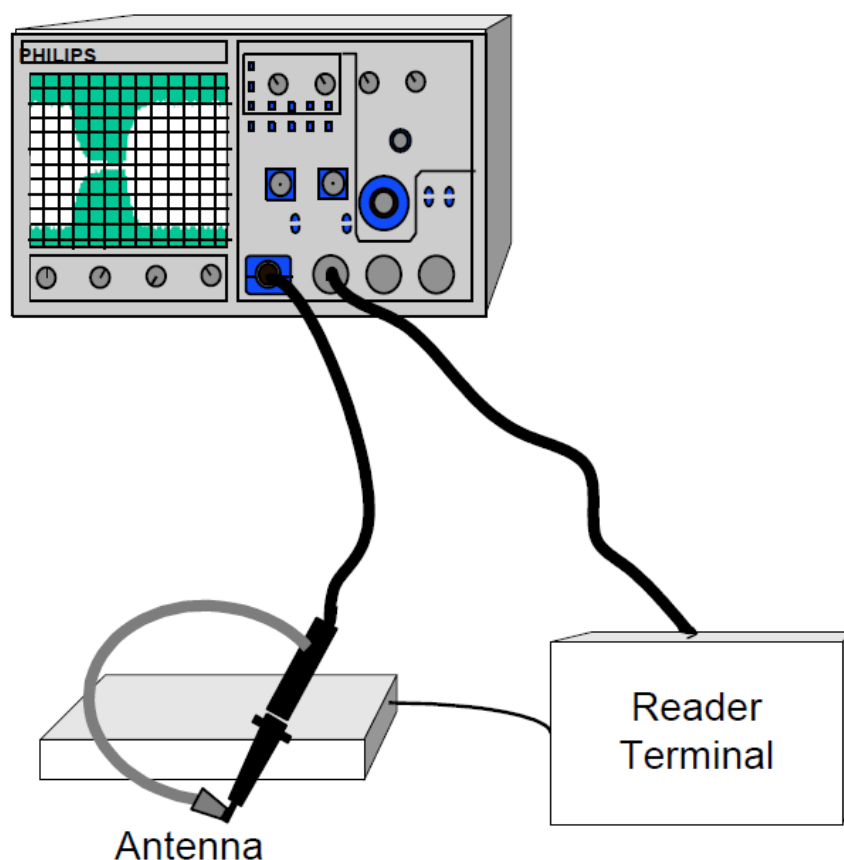


Figure 44. Setup to check the Q-factor

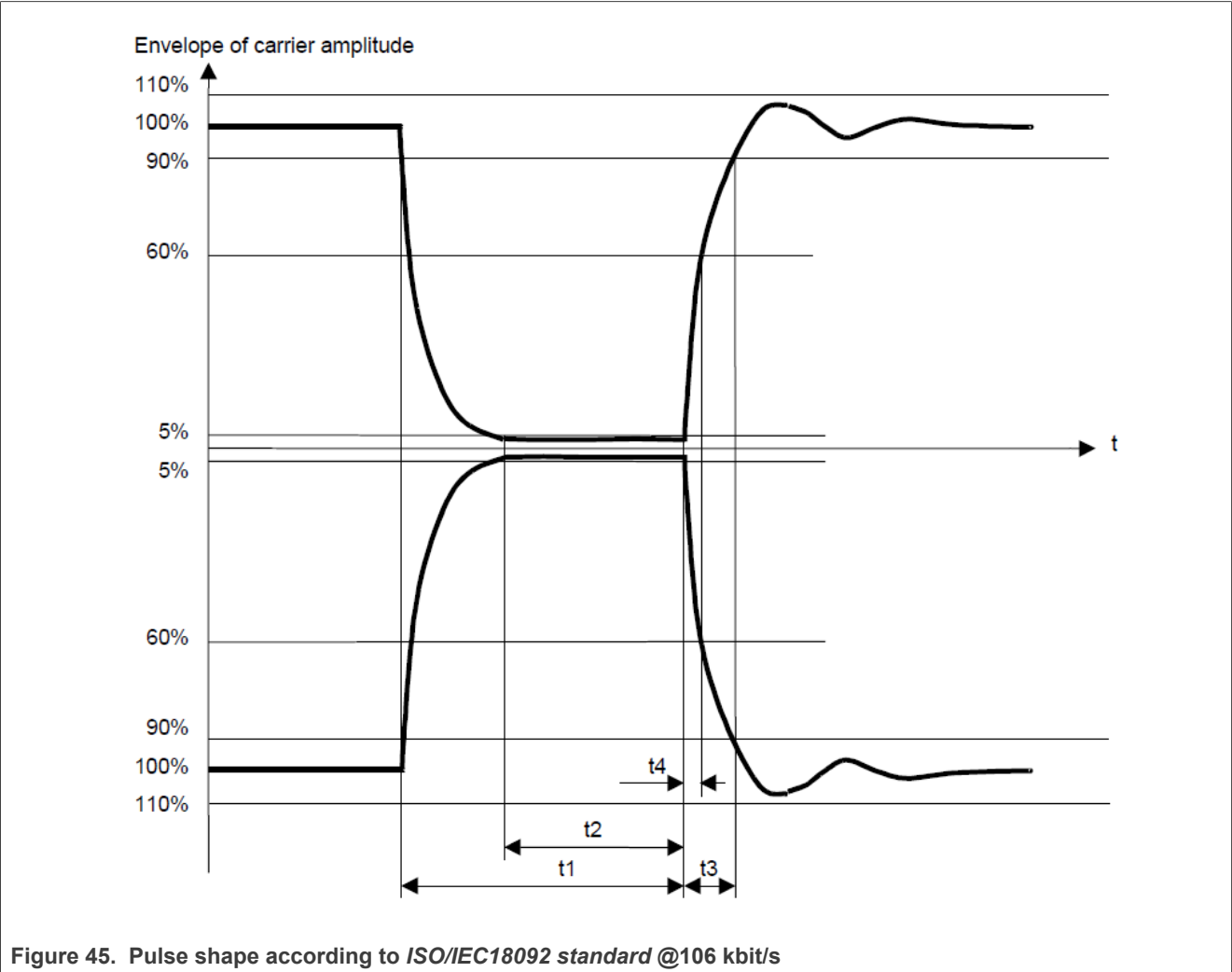
CH1: Use a loop with the ground line shortcut at the probe to enable inductive signal coupling. Hold the probe loop closely above the antenna. When the shaping compliance to a given standard is verified, the corresponding reference PICC must be connected to CH1.

CH2: Used as trigger if possible

The absolute measured voltage in CH1 depends on the coupling (= distance) between the probe loop and the reader antenna. The influence of the coupling on the shape can be neglected. The complete antenna tuning and Q checking should be done without any card (or metal environment) at proximity of the PN7160 antenna.

10.2.1 Pulse shape according to the ISO/IEC 18092 standard

It is recommended to check the pulse shape according to the values given in [Figure 45](#) and [Figure 46](#).



The time t1-t2 describes the time span, in which the signal falls from 90 % down below 5 % of the signal amplitude. As the pulse length of the PN7160 is accurate enough, only the time t2 has to be checked: the signal has to remain below 5 % for the time t2.

The most critical time concerning rising carrier envelope is t4. It must be checked that the carrier envelope at the end of the pause reaches 60 % of the continuous wave amplitude within 0.4 μ s.

Table 8. Pulse shape definitions according to ISO/IEC18092 standard @106 kbit/s

Pulse length (Condition)	t1 [μ s]	t2 [μ s]		t3 [μ s]	t4 [μ s]
		(t1 \leq 2.5)	(t1 > 2.5)		
Maximum	3.0	t1		1.5	0.4
Minimum	2.0	0.7	0.5	0.0	0.0

Note: The standard can evolve so the value mentioned in [Table 8](#) are only shown for reference. The final value must be retrieved from the latest official publication of the corresponding standard.

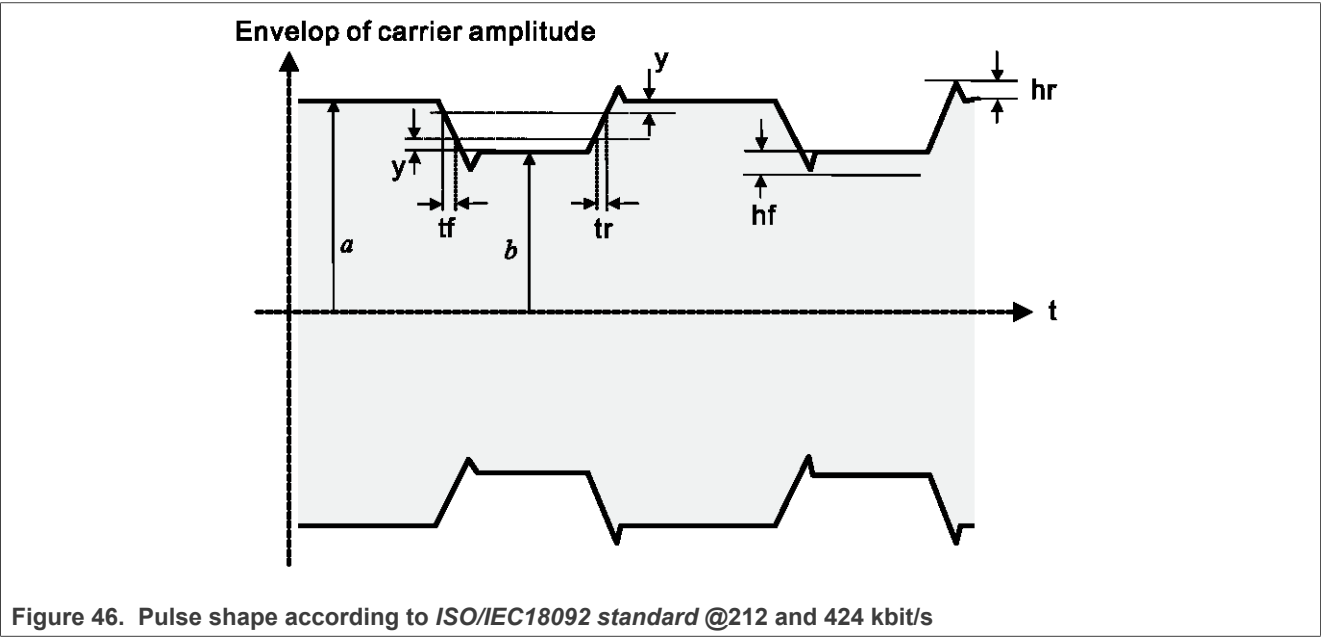


Table 9. Pulse shape definitions according to ISO/IEC18092 standard @212 and 424 kbit/s

	212 kbit/s	424 kbit/s
tf	2.0 μ s max	1.0 μ s max
tr	2.0 μ s max	1.0 μ s max
y	0.1 (a-b)	0.1 (a-b)
hf, hr	0.1 (a-b) max	0.1 (a-b) max

Note: The standard can evolve so the value mentioned in [Table 9](#) are only shown for reference. The final value must be retrieved from the latest official publication of the corresponding standard.

10.2.2 Pulse shape according to the ISO/IEC14443 standard

The shaping measurement can be done in a similar way for *ISO/IEC14443 standard* (see [4]). The relevant Reference PICC has to be used.

The *ISO/IEC14443 standard* type B modulation index has also to be measured: it should be in the range from 8 % up to 14 %. It is the main parameter to verify for *ISO/IEC14443 standard* type B compliance.

Modulation index calculation is depicted in the next figure.

It must be noted that the PN7160 integrates an automatic adjustment of the modulation index to keep it constant whatever the antenna environment.

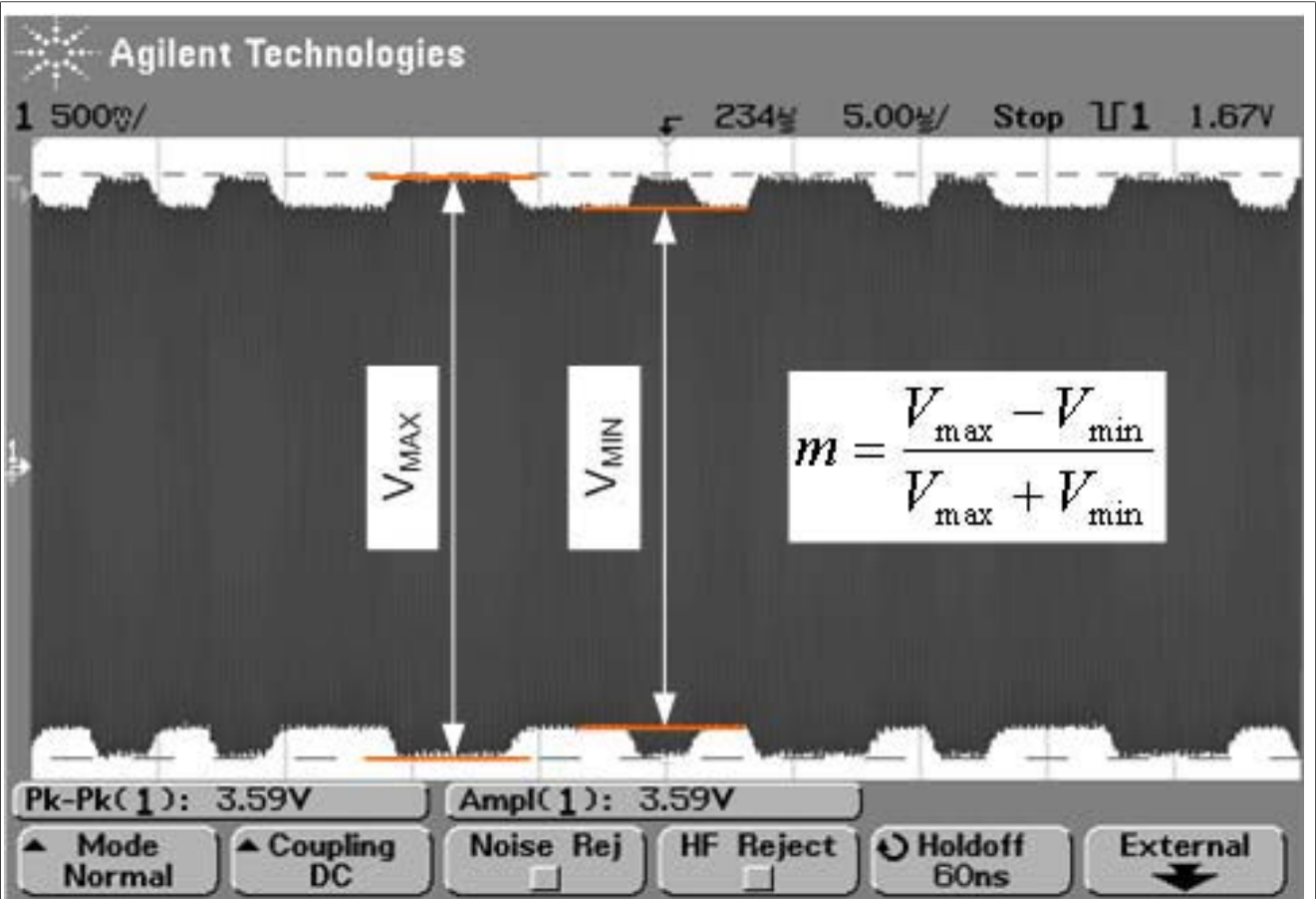


Figure 47. Modulation Index (m) calculation in Reader/Writer mode

10.3 Load modulation amplitude measurement

When configured in card mode, the PN7160 can transmit data to the external reader/writer (or NFC passive initiator) by modulating the amplitude of the external RF field. [Figure 48](#) shows an example.

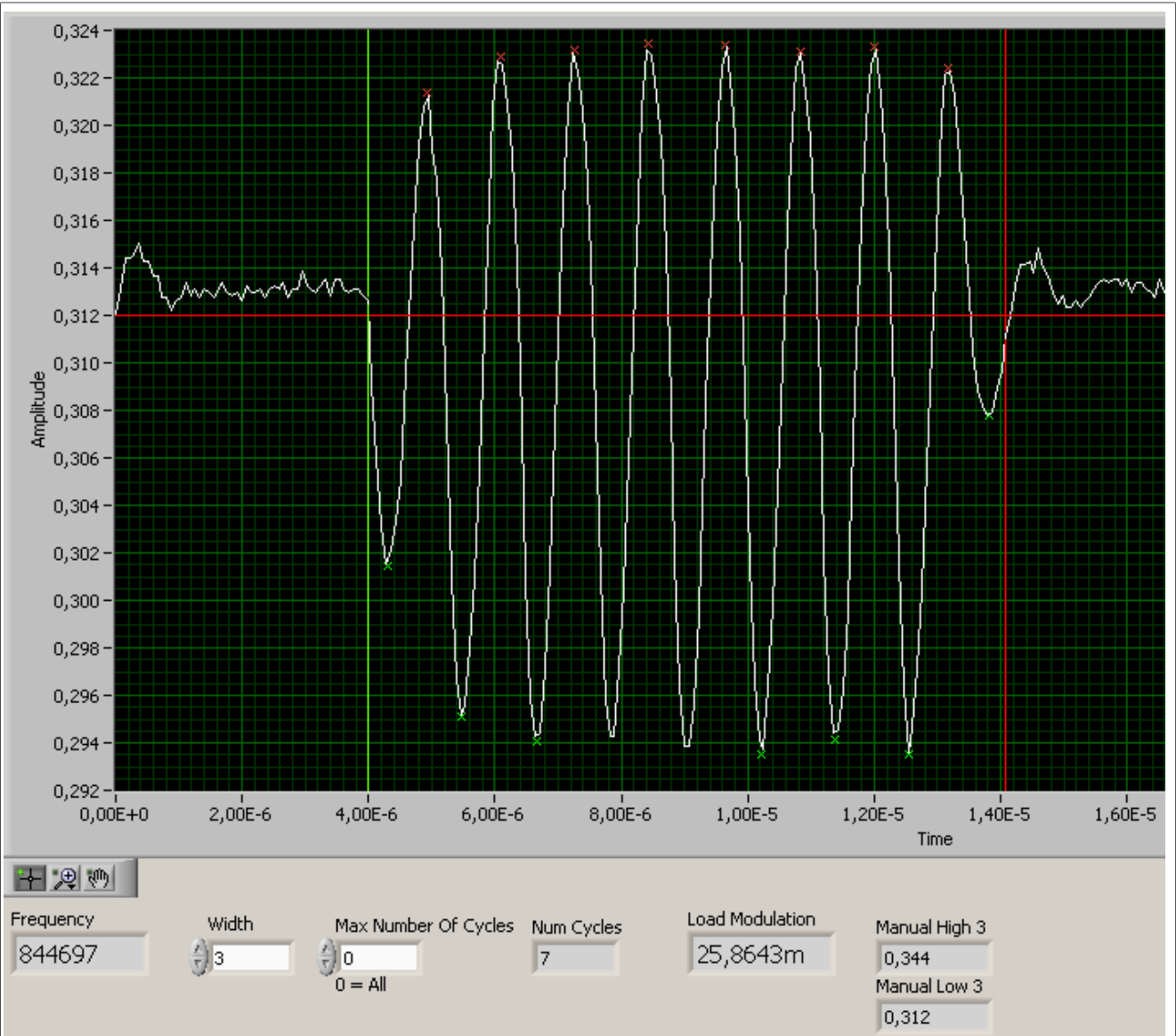


Figure 48. Card Emulation: EMVCo test bench measurement

The different standards define the amplitude of the load modulation in card mode. It varies with the field strength of the reader/writer or the distance from its antenna.

The load modulation amplitude or sideband level amplitude has to be measured by using a specific test bench which is different for each standard (ISO, EMVCo, NFC Forum).

10.4 Fine-tuning through registers

In addition to the matching/tuning methodology, the RF performance can be fine-tuned with registers accessible from the PN7160 host interface.

Refer to the *PN7160 user manual* ([6]) and the *PN7160 RF settings guide* ([7]) for the register descriptions, and their use to optimize the performance in card and reader modes.

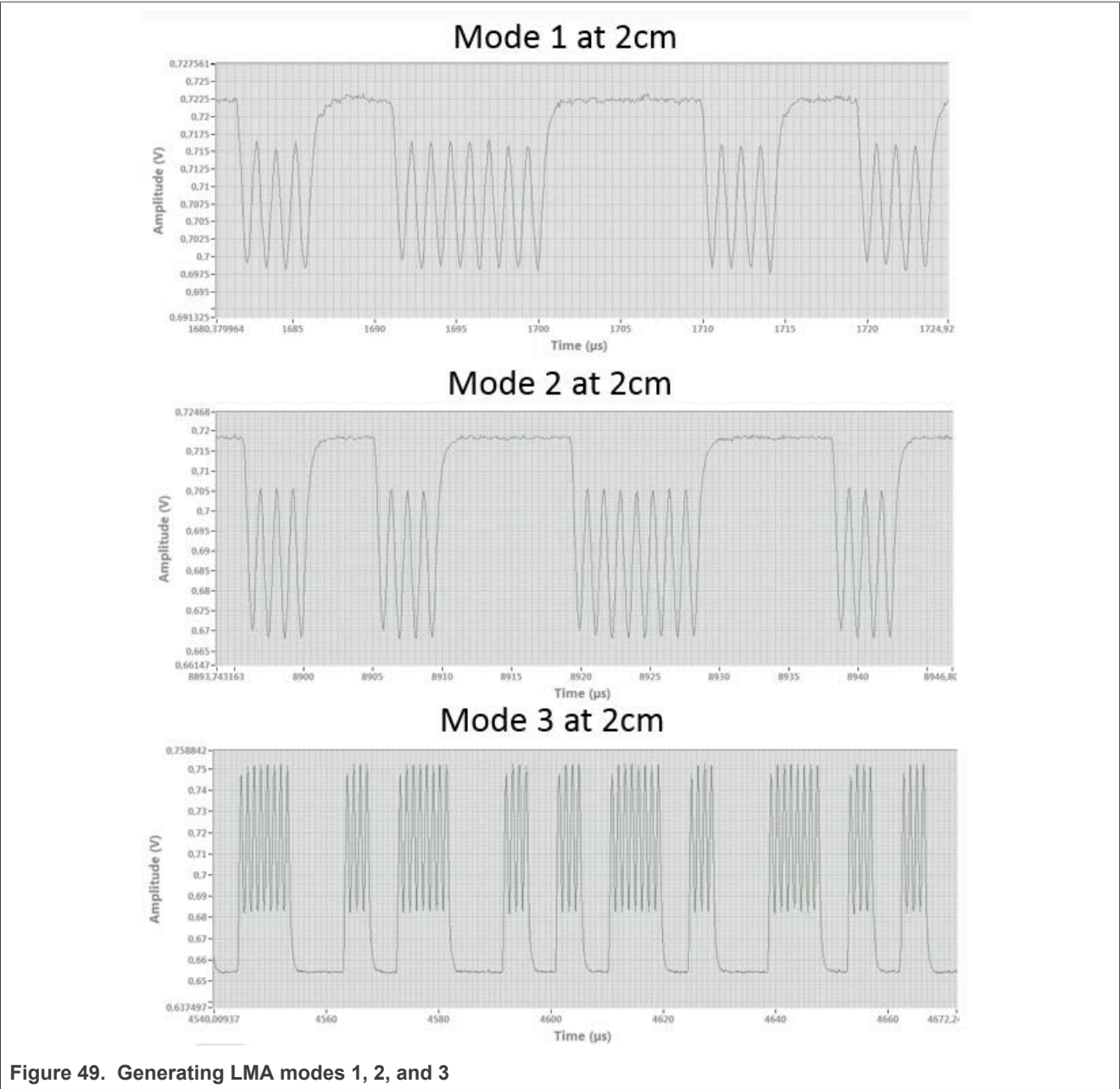
10.4.1 Card mode

First, the load modulation mode (Card mode) is selected with the register `CLIF_TX_CONTROL_REG` (transition `RF_CLIF_CFG_TARGET`).

[Table 10](#) shows the register values.

Table 10. Load modulation generation modes register values

Mode	Register value
Mode 1	0x28
Mode 2	0x08
Mode 3	0x48



Two registers can be used to fine-tune the load modulation amplitude: `CLOCK_CONFIG_DLL_ALM` and `CLIF_ANA_TX_AMPLITUDE_REG`. Use the `CLOCK_CONFIG_DLL_ALM` register first to adjust the phase offset between the received signal and the transmitted signal (by 45° steps).

Based on this offset, the signal emitted is in phase with the emitted field from the reader. Therefore, the signal impact on the amplitude of the reader field is different, and can drastically impact the corresponding load modulation.

[2:0] bits define for the phase-offset correspondence:

0x00 0x00 => 0° phase offset.

0x2D 0x00 => 45° phase offset

0x5A 0x00 => 90° phase offset

0x87 0x00 => 135° phase offset

0XB4 0x00 => 180° phase offset

0XE1 0x00 => 225° phase offset

0x0E 0x01 => 270° phase offset

0x3B 0x01 => 315° phase offset

Practical consideration:

To adjust the clock phase, place the setup on the EMVCo test bench at 2 cm distance, and check the load modulation test. Visualize the signal captured by the EMVCo test bench, and adjust the register value for optimal LMA.

[Figure 50](#) shows the signals captured on an EMVCo test bench for a setup placed at 2 cm distance.

- The top picture shows the resulted load modulation signal for a setup with a well-adjusted clock.
- The bottom picture shows the resulted load modulation of the same setup but with a clock phase not adjusted.

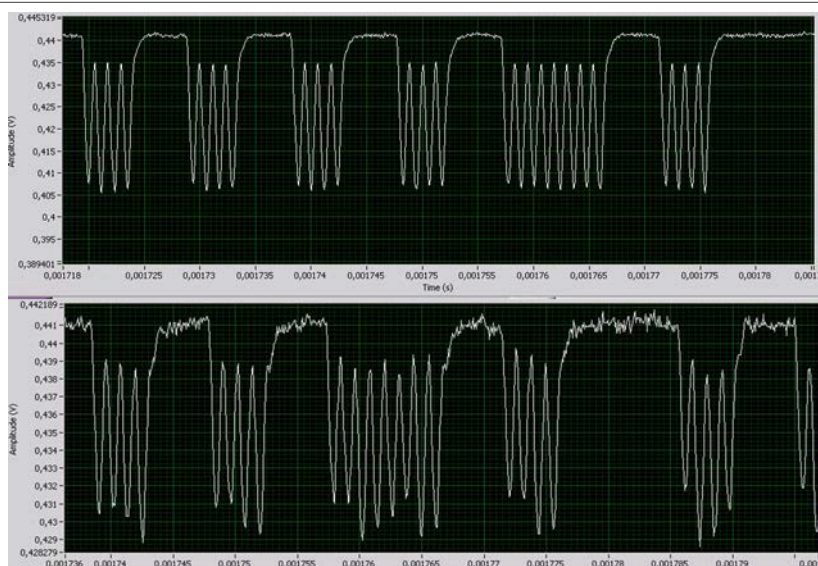


Figure 50. ALM – Phase offset adjustment

Next, use the `CLIF_ANA_TX_AMPLITUDE_REG` register to adjust the N-MOS transistor conductance value that is applied during the modulated and nonmodulated phases. The load modulation shape requires some adjustment to comply with the targeted standards.

For ALM, two parameters are used for the transmission in card mode:

- `TX_GSN_CW_CM` parameter defines the impedance of the N-MOS transistor applied during the continuous wave period in card mode.
- `TX_GSN_MOD_CM` parameter defines the impedance of the N-MOS transistor applied during the modulation period in card mode.

Also, the load modulation amplitude can be adjusted by choosing the amplitude of the output signal generated at PN7160 TX pin. Mainly, the amplitude range is from 0 V to TVDD. A TVDD drop can be applied to reduce the amplitude, using the `TX_CW_AMPLITUDE_ALM_CM` bits of the `CLIF_ANA_TX_AMPLITUDE_REG` register. The available drops are:

- Maximum amplitude – typically 150 mV
- Maximum amplitude – typically 250 mV
- Maximum amplitude – typically 500 mV
- Maximum amplitude – typically 1000 mV

10.4.2 Reader mode

For reader mode, some registers can be used to optimize the communication distances with tags (ex: MIFARE Ultralight, MIFARE DESFire, topaz...).

The first check to be done is to compare the communication distance and the power distance for reference cards. The power distance corresponds to the maximum distance at which the tag starts to wake up, but fails to exchange the data properly. The communication distance corresponds to the maximum distance at which the tag exchanges the data correctly with the reader. When the setup is correctly programmed, both distances are nearly equal (only a couple of mm differences).

The method to evaluate the POWER distance and READING distance is usually the following:

0. Set the chip in normal polling mode (not Low-Power detector polling)

1. Put a scope probe loop #1 on top of the antenna (on a corner of the antenna in order not to disturb the field too much). You can make 2 loops with the GND wire to capture more field power.

2. Set the trigger for Probe #1 (typically trigger on a low pulse detection min=450 ns / max=6 µs for type A request)

3. Put a 2nd probe loop on a type A card and check the max distance (using plastic spacers) at which the card is powered but where the device does not necessarily see the card.

1st Probe to trigger the scope



2nd Probe to spy the card response

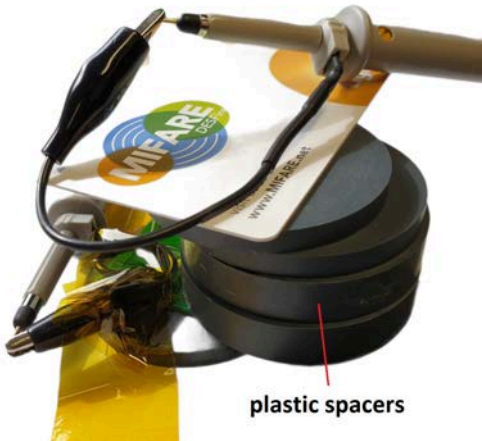


Figure 51. Reader Mode: POWER distance and READING distance check

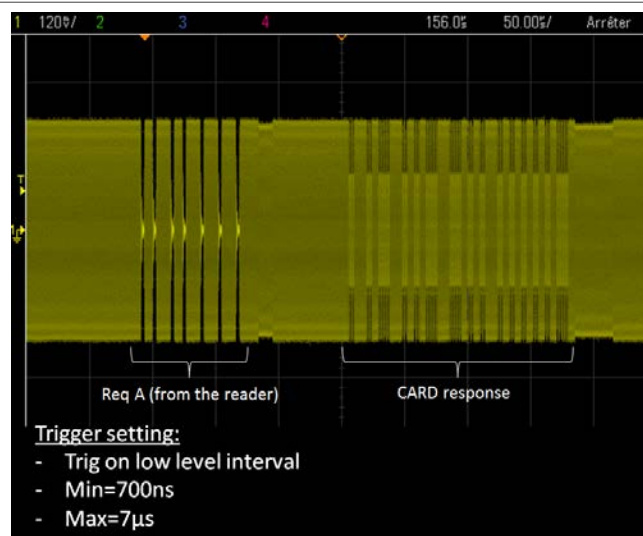


Figure 52. Type A card response captured with the oscilloscope

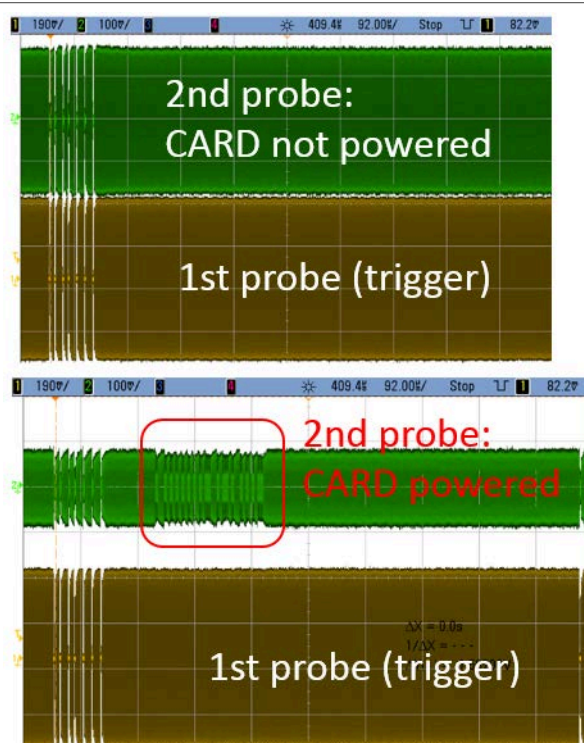


Figure 53. Oscilloscope capture with the 2 probes

When the difference between POWER distance and READING distance is too high (5 mm or more), it means that the RX path can be optimized thanks to the following register:

CLIF_ANA_RX_REG: to set the AGC gain

CLIF_SIGPRO_RM_CONFIG1_REG: to set the level detection threshold (MIN LEVEL)

10.5 Functional performances

10.5.1 Basics

The performance verification of the setup using PN7160 can be finalized by some functional checks to evaluate the user experience.

Reader mode:

For instance, the communication distance in reader mode with some cards can be verified:

- MIFARE Ultralight
- MIFARE DESFire
- Topaz 512
- FeliCa card
- ISO/IEC14443-B card
- Phone in P2P mode

Card mode:

The communication distance in card mode with some readers can be verified:

- Pegoda
- Omnikey 5321
- Vivopay 5000
- ACR122
- ...

In case unsatisfying results are met during the performance verification step, the tuning/matching circuit must be adjusted (fine-tuned) to improve.

10.5.2 Performance of a PN7160 demo board 50 mm x 30 mm antenna

Figure 54 shows the results obtained on the demo board PN7160 at 3.3 V TVDD, using a 50 mm x 30 mm antenna on metal plate + ferrite. The matching impedance is 15 Ω.

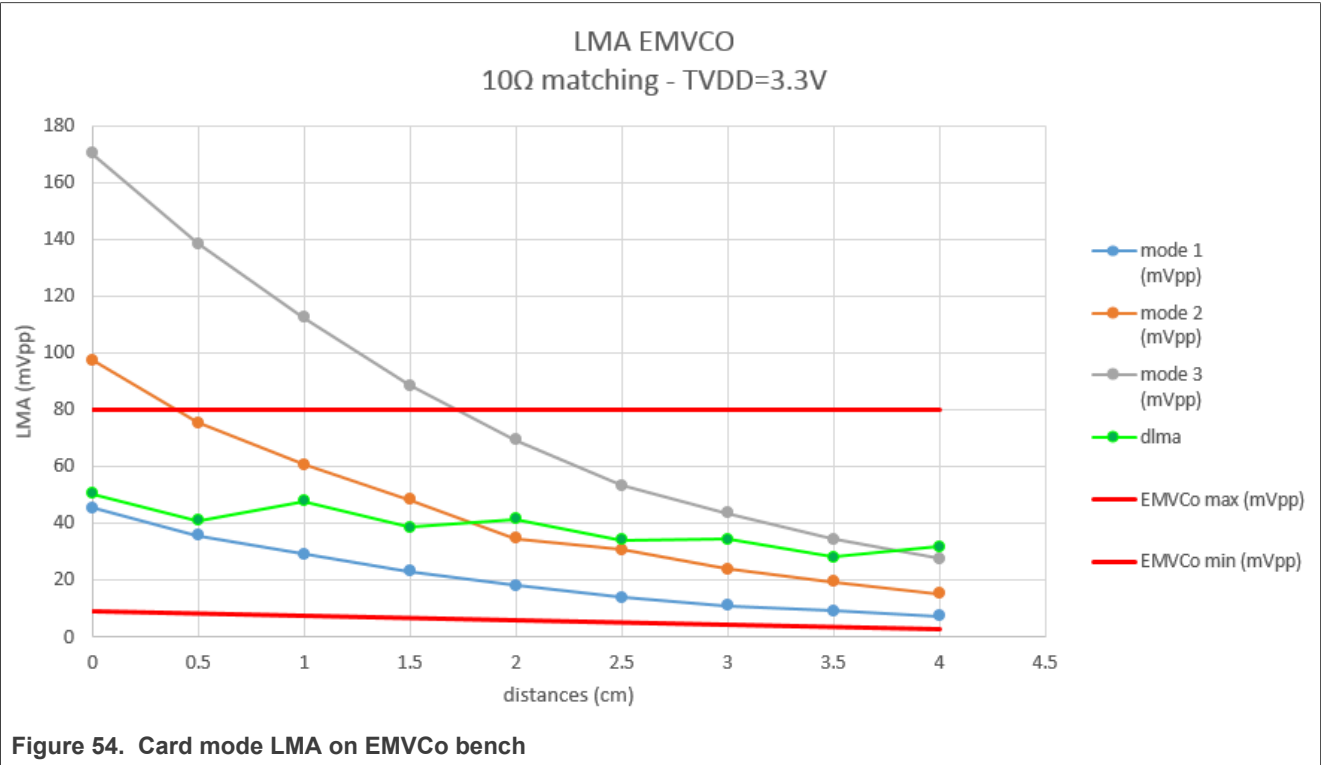
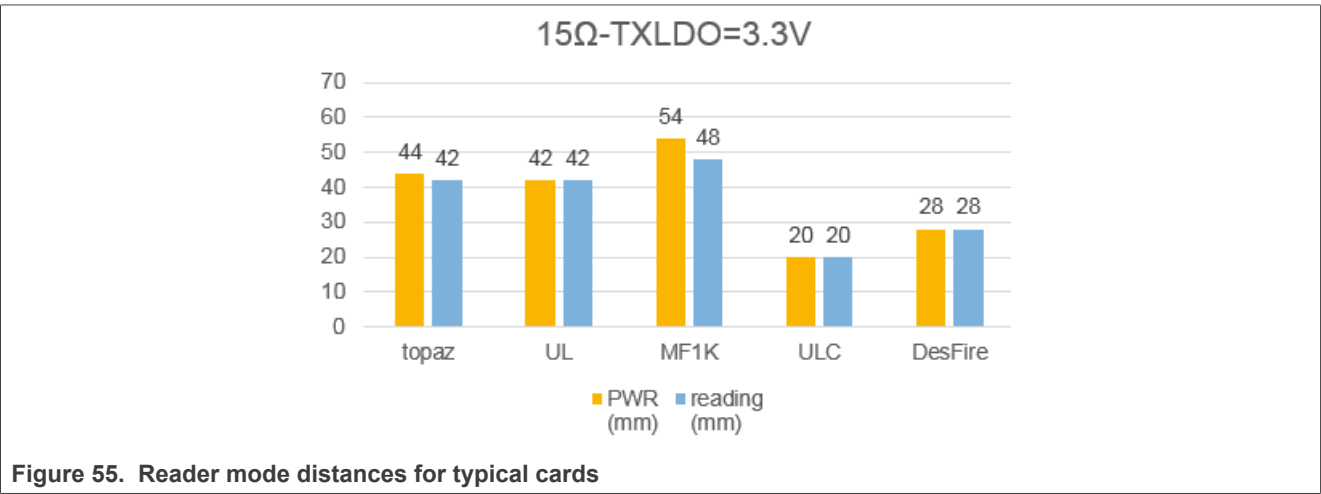


Figure 54 shows that without DLMA (green curve), mode 2 and mode 3 cannot be used at 0 cm. The LMA for both modes is 80 mVpp over EMVCo specification. DLMA green curve provides the optimized LMA for all distances: under the maximum limit at short distances, and the highest LMA values at long distances.

Figure 55 shows the POWER versus READING distances obtained with the setup described above for different Type A cards.



11 Abbreviations

Table 11. Abbreviations

Abbreviation	Meaning
A/m	Ampere per meter (magnetic field strength measurement unit)
AGC	Automated gain control
AN	Application note
CH1 / CH2	Channel 1 / Channel 2
EMC	Electromagnetic compatibility
Hmin / Hmax	Minimal and maximum magnetic field strength
H-field	Magnetic field
IC	Integrated circuit
ISO/IEC	International Standard Organization / International Electrotechnical Community
mA	milli Ampere
MHz	Megahertz
NFC	Near Field Communication
NFCC	NFC controller (that is, PN7160)
PCB	Printed-circuit board
PCD	Proximity coupling device (contactless reader)
PICC	Proximity-integrated circuit card (contactless card)
Q / Q-factor	Quality factor
RF	Radio frequency
TBD	To be defined
V	Voltage
Vpp	Peak-to-peak voltage

12 References

- [1] [AN13224](#) - PN7160 Dynamic power control guide
- [2] [NFC Antenna Design Hub](#) - Available via [nxp.com](#)
- [3] ISO/IEC10373-6 standard – Identification cards – Test methods – Part 6: Proximity cards – 2001 release
- [4] ISO/IEC14443 standard – Identification cards - Contactless integrated circuit(s) cards – Proximity cards – 2001 release
- [5] NFC Forum – NFC Analog Specification
- [6] UM11495 - PN7160 User manual, available on [PN7160 product page](#) (sign in is required)
- [7] [AN13218](#) - PN7160 RF settings guide
- [8] [AN13223](#) - PN7160 Dynamic load modulation amplitude guide
- [9] Path Wave Advanced Design System (ADS)
- [10] RFSim99
- [11] [AN13892](#) - PN7160 frequently asked questions

13 Note about the source code in the document

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14 Revision history

Table 12. Revision history

Document ID	Release date	Description
AN13219 v.1.5	27 February 2024	<ul style="list-style-type: none">• Section 6.1 "Receiver block functionality":<ul style="list-style-type: none">– Added RX voltage measurement.– Added AGC value measurement.• Section 12 "References": added AN13892.• Section 13 "Note about the source code in the document": added.
AN13219 v.1.4	9 November 2022	<ul style="list-style-type: none">• Section 4.1.3.2 "Asymmetrical versus symmetrical tuning": updated.• Section 10.4.1 "Card mode": updated.• Section 4.1.3.1 "Default configuration for reader mode (RM)": updated the content about RF field detector.
AN13219 v.1.3	27 April 2022	<ul style="list-style-type: none">• Editorial changes
AN13219 v.1.2	13 September 2021	<ul style="list-style-type: none">• Security status changed to "Company public". No change in the content.
AN13219 v.1.1	20 August 2021	<ul style="list-style-type: none">• Security status changed to "Company restricted".
AN13219 v.1.0	12 April 2021	<ul style="list-style-type: none">• Initial version

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