AN11535

Measurement and tuning of a NFC and Reader IC antenna with a MiniVNA

Rev. 1.1 — 3 November 2014
291911

Application note
COMPANY PUBLIC

Document information

Info	Content
Keywords	Antenna tuning, Measurement, PN512, CLRC663, NFC and Reader IC, MiniVNA
Abstract	This application note gives a guideline how to measure and tune/match a NFC and Reader IC antenna with the MiniVNA network analyzer tool. The MiniVNA allows a cost efficient antenna design.

Revision history

Rev	Date	Description
1.1.	20141103	Corrections after MiniVNA user interface update
1.0	20140403	First official release

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1. Introduction

1.1 Scope

The document will introduce the MiniVNA Pro instrument for measuring HF loop antenna parameters and antenna matching for NXP RFID transceiver.

Compared to classical Vector Network Analyzer this instrument is cheap and portable.

It can be used by technical person in a real application environment and the instrument had capability to deliver result good enough for the purpose.

NXP reference boards are tuned for optimal performance in air or with metal surfaces at distance bigger than 2 – 3 cm (distance is depending on antenna dimension).

In this Application Note will be explained how to read and interpret result from Smith Chart , how to use Mini VNA instrument for basic antenna parameter and Return Loss measurement, fundamental rules for antenna tuning adjustment are provided.

A setup where a metal surface is quite close to the antenna is evaluated, inputs for antenna retuning are given and S11 Return Loss parameter measured.

As example Blueboard PNEV512B is chosen.

1.2 What you need

Below the list of equipment which is needed:

- MiniVNA Pro Network Analyzer
- Calibration Kit
- USB Cable
- Windows FTDI USB driver (www.nxp.com/redirect/ftdichip.com/Drivers/VCP)
- Software Application
- PC/ Laptop with administration rights

The Calibration KIT can be a self-made one (Fig 6). The SW application can be downloaded via this link: www.nxp.com/redirect/miniradiosolutions.com/minivnapro.

2. Network Analyzer

2.1 Network Analyzer – General

A **network analyzer** is an instrument that measures the network parameters of electrical networks. Network analyzers are often used to characterize two port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports.

Network analyzers are used mostly at high frequencies. Operating frequencies can range from 5 Hz to 1.1 THz. Special types of network analyzers can also cover lower frequency ranges down to 1 Hz. These network analyzers can be used for example for the stability analysis of open loops or for the measurement of audio and ultrasonic components.

The two main types of network analyzers are

- **scalar network analyzer** (SNA) — measures amplitude properties only
- **vector network analyzer** (VNA) — measures both amplitude and phase properties

The basic architecture of a network analyzer involves a signal generator, a test set, one or more receivers and display. In some setups, these units are distinct instruments. Most VNAs have two test ports, permitting measurement of four S-parameters (S11, S12, S21, and S22) but instruments with more than two ports are available commercially.

Typical applications are S parameters, Amplifier Gain Compression, conversion Gain/Loss, material measurement, signal integrity.

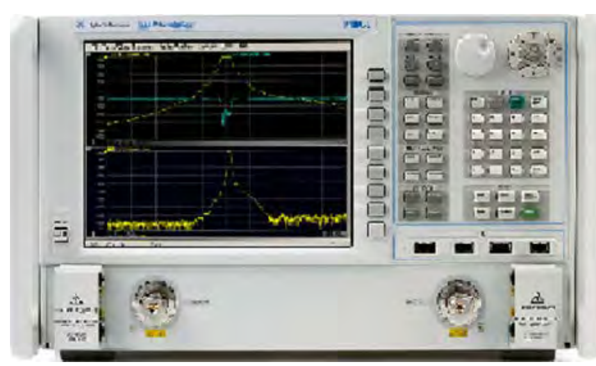


Fig 1. Agilent PNA-L Network Analyzer

This kind of Network Analyzer is offering the following features:

- 300 kHz to 20 GHz Frequency range
- 2- or 4-ports with single built-in sources
- 133 dB system dynamic range, 32,001 points, 200 channels, 15 MHz IF bandwidth
- High output power (+13 dBm)
- Low noise floor of -120 dBm (10 Hz IF bandwidth)

A Network Analyzer as the Agilent PNA-L Microwave Network Analyzer with a price of ~ 100kUSD is a big investment.

2.2 Mini VNA

The miniVNA PRO, by mRS: Miniradiosolution (see http://www.nxp.com/redirect/miniradiosolutions.com), is a small Vector Network Analyzer supporting features to measure RFID reader antennas and RF circuits for everybody who has not the budget for an expensive Network Analyzer. The miniVNA is low budget solution with the advantage that it can be used as a mobile device as well. The cost of this tool is around 600USD.

Fig 2. MiniVNA PRO PC Based Network Analyzer

Features supported by this device:

- Frequency Range from 100 kHz to 200 MHz
- Range of Z: from 1 to 1000 Ohm
- Extended Dynamic Range: up to 90 dB in Transmission & 50 dB Reflection
- Two ports VNA with S11 and S21; displayed and save results
- I/Q DDS Generator 2 channels AD9958 by Analog Devices
- Two separate buffered RF output I/Q for SDR experiment and IMD test with independent 0 - 55 dB attenuator; Phase adjustment resolution of 1 degree. Output power of 0 dBm
- Built in Bluetooth Class 1 with external antenna on PCB for remote measurements up to 100mt
- Internal Battery Li-ion with 1000 mA/h (4 hours full- scan operation)
- Built-in battery charger (up to 400 mA)
- Low power consumption, 220 mA @ 3.6 V (analyzer mode using USB port)
- Power save mode
- Accessory port for future optional interfaces and frequency extenders
- Calibration using open-short-load for accurate results
- Management by the VNA/J: User friendly FREE software interface for PC -Windows XP- Vista-Win7 / Linux and Mac (JAVA – JRE6 based) by DL2SBA, see http://www.nxp.com/redirect/dl2sba.com/index.php

- Measurements of motional crystal parameters, cable length, & moreExport data in several formats – JPEG, EXCEL, ZPLOT, S2P, PDF

2.2.1 Mini VNA Driver test and calibration for S11 measurement

As a first step a Mini VNA driver test and calibration must be done.

1. Select the menu ANALYZER->SETUP
2. Choose right driver and COM port
3. Press the buttons Test (1) & Update (2), if an error occurs, press the red button on the mini VNA and try again or select a different port.

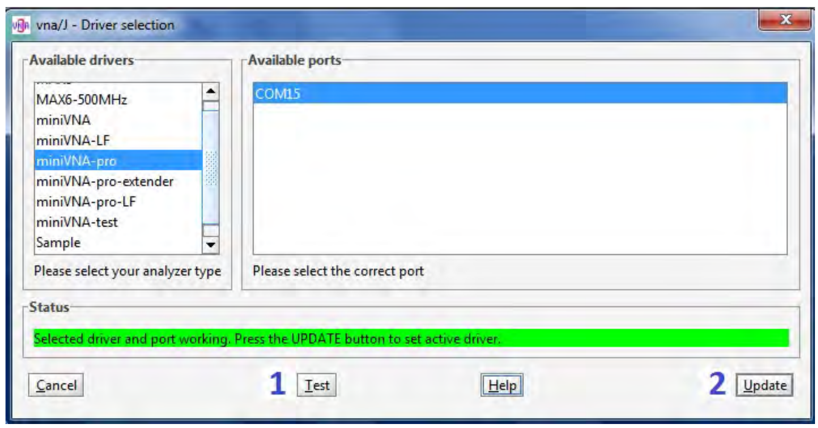


Fig 3. Driver selection and test

4. Select as Mode in the right bottom corner of the window "REFLEXION"
5. Select the menu CALIBRATION->CREATE

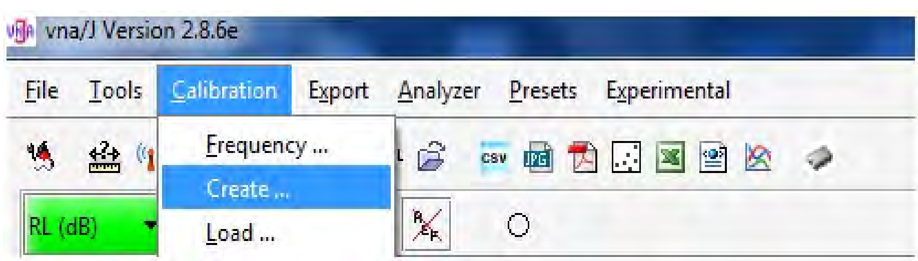


Fig 4. Create a Calibration

6. Calibration in a sequential order (calibration kits connected to the Mini VNA, make sure not to mix the DUT/DET connections of the MiniVNA, the calibration probe and all measurements require the connection to the DUT marked input). As calibration frequency range, a range from e.g. 100 Hz to 25 MHz is sufficient.
   a. OPEN
   b. SHORT

c. LOAD

d. Press “save” calibration & press the “update” button (closes the window)

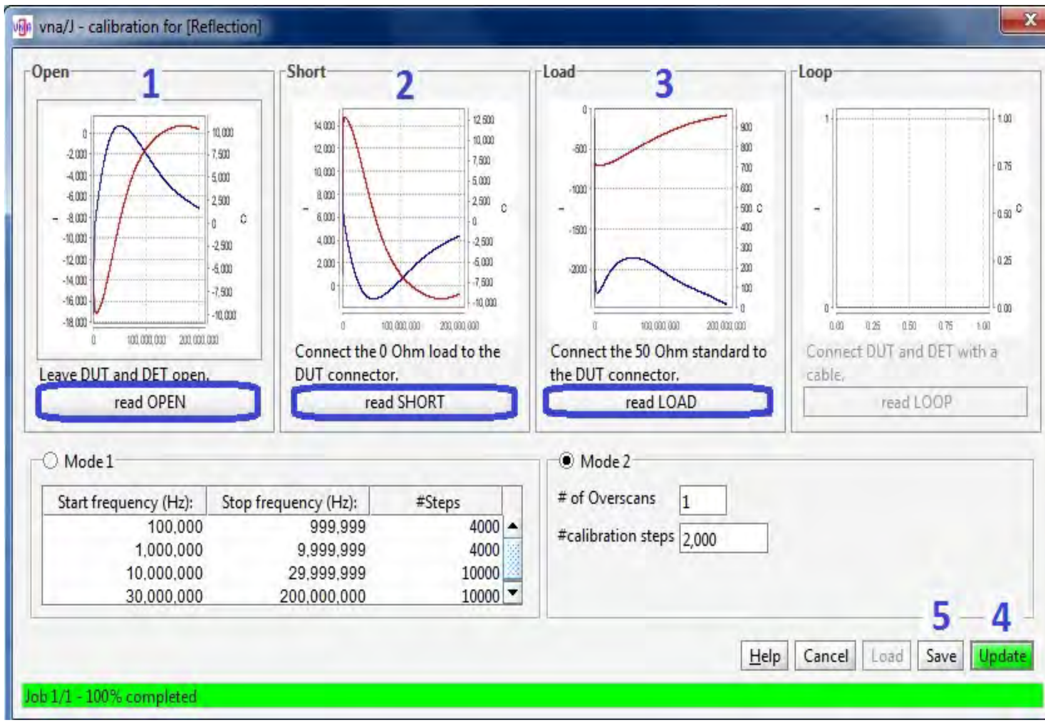
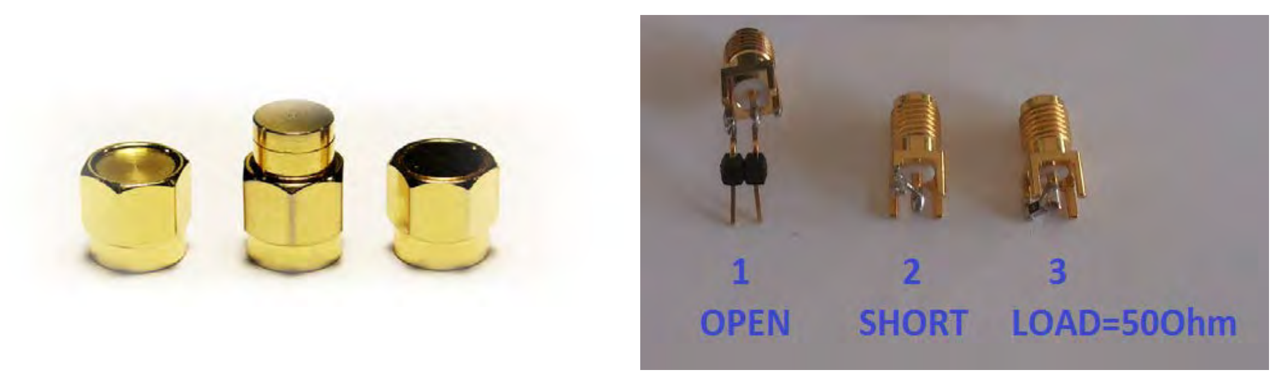


Fig 5. Calibration Window

For the calibration you can use a professional calibration kit or a handmade. Click here to order an SMA kit:
http://www.nxp.com/redirect/wimo.com/instrumentation_e.html#21010sma



a. Professional

b. handmade

Fig 6. Calibration kit

Important Note: any additional cable and wires from the calibration port to the measurement points on the PCB board should be ideally as short as possible (max. 20mm). This does not mean that the cable from the MiniVNA to the calibration port needs to have a length of 20mm. The influence of a cable between MiniVNA DUT input and calibration port is eliminated by the calibration.

3. Smith Chart

3.1 Smith Chart – General

The Smith chart is a graphical aid or nomogram designed for electrical and electronics engineers specializing in radio frequency (RF) engineering to assist in solving problems with transmission lines and matching circuits.

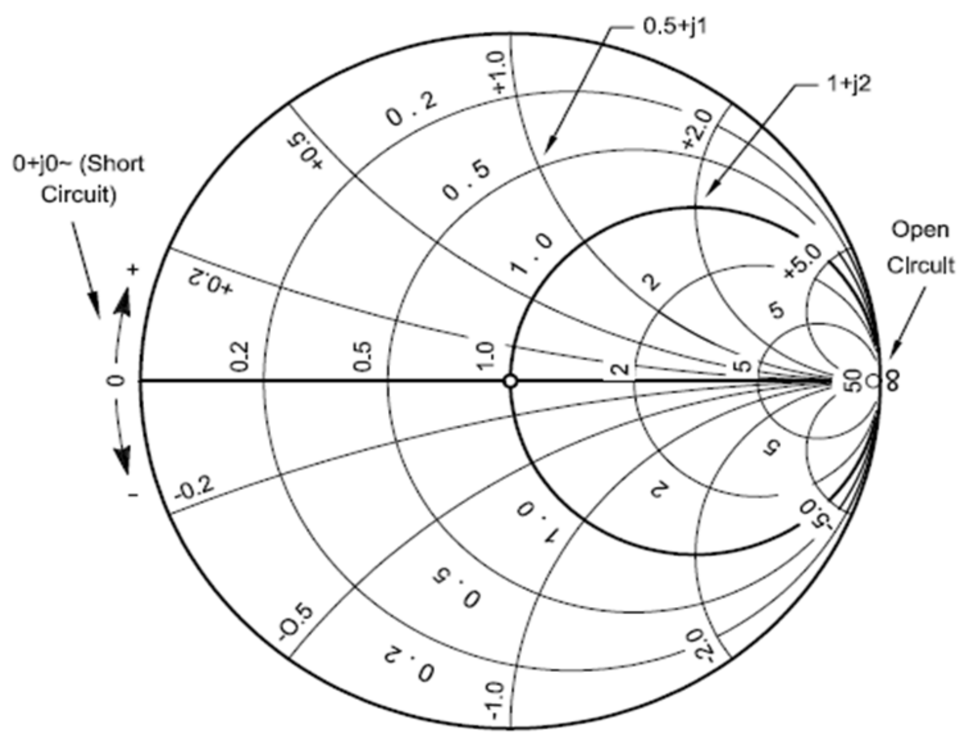


Fig 7. Smith Chart normalized to 50 Ohm

The Smith chart is plotted on the complex reflection coefficient plane in two dimensions and is scaled in normalized impedance. These are often known as the Z, Y and YZ Smith charts respectively. Normalized scaling allows the Smith chart to be used for problems involving any characteristic or system impedance which is represented by the center point of the chart. The most commonly used normalization impedance is 50 ohms.

Z_L will be the load impedance. The reflection coefficient is completely determined by the impedance Z_L and the 'reference impedance' Z_0.

Z0 can be viewed as the impedance of the transmitter, or what is trying to deliver power to the antenna. Hence, the Smith Chart is a graphical method of displaying the impedance of an antenna, which can be a single point or a range of points to display the impedance as a function of frequency.

The circles in the Smith Chart shown in Fig 7 are representing the constant real part of the impedance, the other lines the constant imaginary part.

The complex reflection coefficient Γ for an impedance ZL attached to a transmission line with characteristic impedance Z_0 is given by:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1)$$

For our measurement Z_0 = 50 Ohm (Smith chart normalized to 50 Ohm in the graph).

The complex reflection coefficient must have a magnitude between 0 and 1.

The center of the Smith Chart is the point where the reflection coefficient is zero - this is the point where no power is reflected by the load impedance.

3.2 Smith Chart S11 Parameter

In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient, sometimes written as gamma: Γ or return loss. If S11 = 0dB, then all the power is reflected from antenna and nothing is radiated. If S11 = -10 dB, this implies that if 3 dB of power is delivered to the antenna, -7dB is the reflected power.

Formula for S11 (Return Loss)

$$RL(dB) = -20\log|\Gamma| \quad (2)$$

Example1: RL = -3 dB it means that 50% of power is transmitted and 50% reflected

Example2: RL = -10 dB it means that 90% of power is transmitted and 10% reflected

For our target of Z(matching) = 50 Ohm consider to have $|RL| > 10dB$

Table 1. Return loss conversion table

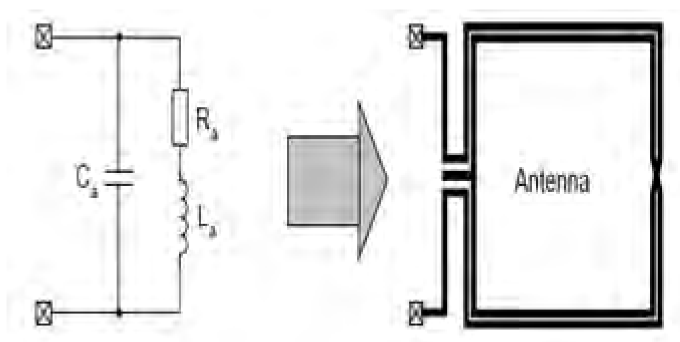
Return Loss [dB]	VSWR	Reflection Coefficient, G	Mismatch Loss [dB]	Reflection Power [%]	Through Power [%]	Return Loss [dB]	VSWR	Reflection Coefficient, G	Mismatch Loss [dB]	Reflection Power [%]	Through Power [%]
1	17,39	0,891	6,868	79,43	20,57	21	1,20	0,089	0,035	0,79	99,21
2	8,72	0,794	4,329	63,10	36,90	22	1,17	0,079	0,027	0,63	99,37
3	5,85	0,708	3,021	50,12	49,88	23	1,15	0,071	0,022	0,50	99,50
4	4,42	0,631	2,205	39,81	60,19	24	1,13	0,063	0,017	0,40	99,60
5	3,57	0,562	1,651	31,62	68,38	25	1,12	0,056	0,014	0,32	99,68
6	3,01	0,501	1,256	25,12	74,88	26	1,11	0,050	0,011	0,25	99,75
7	2,61	0,447	0,967	19,95	80,05	27	1,09	0,045	0,009	0,20	99,80
8	2,32	0,398	0,749	15,85	84,15	28	1,08	0,040	0,007	0,16	99,84
9	2,10	0,355	0,584	12,59	87,41	29	1,07	0,035	0,005	0,13	99,87
10	1,92	0,316	0,458	10,00	90,00	30	1,07	0,032	0,004	0,10	99,90
11	1,78	0,282	0,359	7,94	92,06	31	1,06	0,028	0,003	0,08	99,92
12	1,67	0,251	0,283	6,31	93,69	32	1,05	0,025	0,003	0,06	99,94
13	1,58	0,224	0,223	5,01	94,99	33	1,05	0,022	0,002	0,05	99,95
14	1,50	0,200	0,176	3,98	96,02	34	1,04	0,020	0,002	0,04	99,96
15	1,43	0,178	0,140	3,16	96,84	35	1,04	0,018	0,001	0,03	99,97
16	1,38	0,158	0,110	2,51	97,49	36	1,03	0,016	0,001	0,03	99,97

Return Loss [dB]	VSWR	Reflection Coefficient, G	Mismatch Loss [dB]	Reflection Power [%]	Through Power [%]	Return Loss [dB]	VSWR	Reflection Coefficient, G	Mismatch Loss [dB]	Reflection Power [%]	Through Power [%]
17	1,33	0,141	0,088	2,00	98,00	37	1,03	0,014	0,001	0,02	99,98
18	1,29	0,126	0,069	1,58	98,42	38	1,03	0,013	0,001	0,02	99,98
19	1,25	0,112	0,055	1,26	98,74	39	1,02	0,011	0,001	0,01	99,99
20	1,22	0,100	0,044	1,00	99,00	40	1,02	0,010	0,000	0,01	99,99

4. HF Antenna Basics

4.1 HF RFID Loop Antenna

4.1.1 Measurement and calculation of equivalent parameters



(1) R_a, L_a, C_a and Q damping calculation

Fig 8. Antenna equivalent circuit

It is recommended to measure the inductance as well as the series resistance value at 1MHz.

The self-resonance frequency (f_{res}) and the parallel resistance can be obtained at the resonant point of the system where the imaginary part is zero.

The antenna capacitance C_a can be calculated with:

$$C_a = \frac{1}{(2 \cdot \pi \cdot f_{res})^2 L_a} \quad (3)$$

4.2 Antenna Q Factor

The quality factor of the antenna is calculated with:

$$Q_a = \frac{\omega \cdot L_a}{R_a} \quad (4)$$

Target value for Q is 30 (±10%), if higher an external damping resistor R_Q has to be inserted on each antenna side to reduce the Q-factor to the target value.

$$R_Q = 0{,}5 \cdot \left(\frac{\omega \cdot L_a}{30} - R_a \right) \quad (5)$$

4.3 NXP Recommended Matching Network: Directly matched antenna

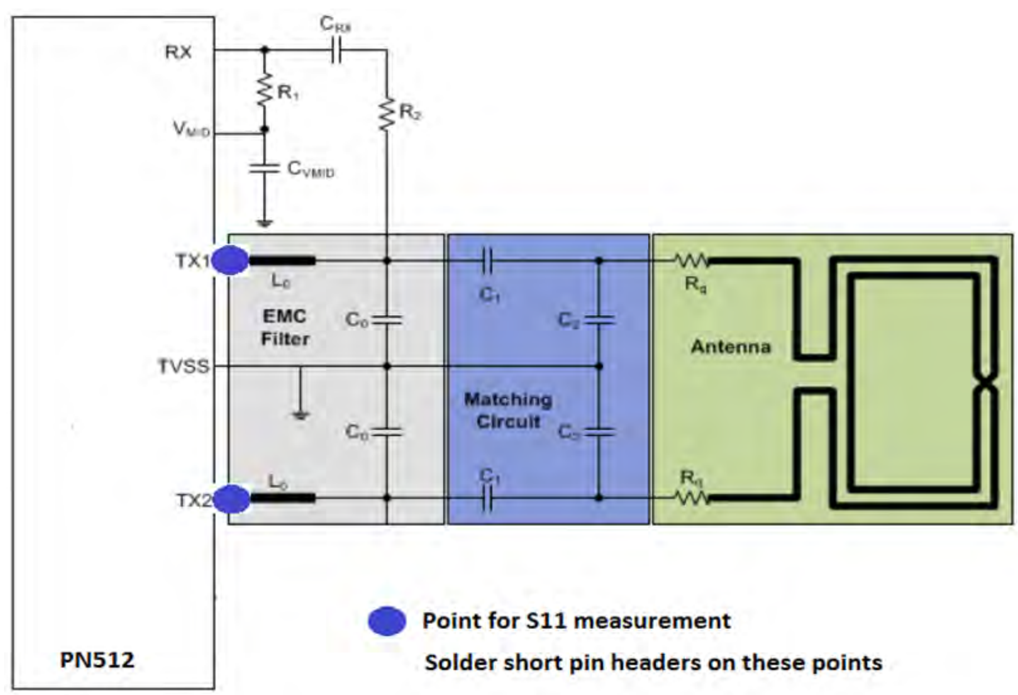


Fig 9. Antenna tuning schematic

The main blocks of the schematic above are:

- EMC filter (L_0, C_0)
- Matching circuit (C_1,C_2)
- R_Q (Q damping factor resistor)
- Antenna (can be represented with the equivalent circuit)

More detailed information about antenna matching can be found in the NXP Antenna Design Guide.

4.4 PNEV512B Antenna measurement example

This chapter will show how to measure the electrical parameters of an antenna with the MiniVNA. As example the antenna of the PNEV512B will be used.

Fig 10. PNEV512B Antenna PCB

Before starting you have to remove all matching components (capacitors and resistors) or use an unpopulated antenna and follow these steps:

1. Connect MiniVNA with SMA adaptor and the antenna (short pin header)
2. Set at the MiniVNA a frequency span 1 – 5 MHz
3. Measure $L_a(X_S)$ and R_a (R_S) at 1 MHz

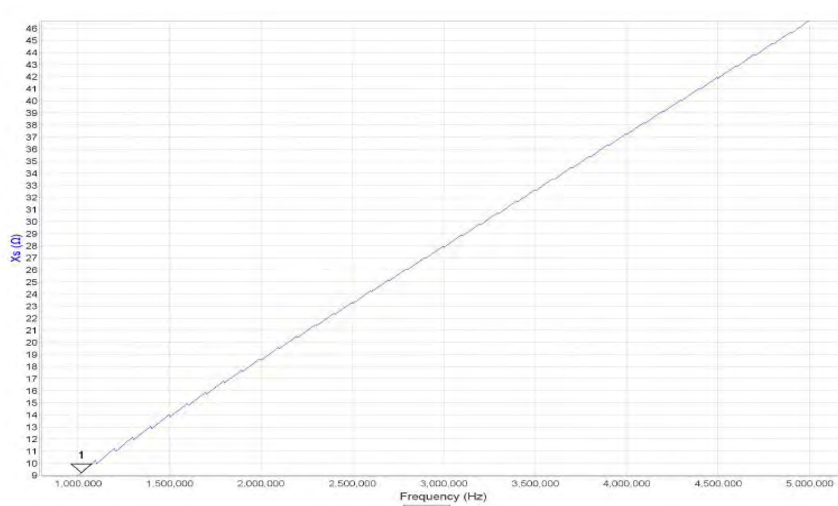


Fig 11. X_S measured @ MiniVNA

Table 2. R_S, X_S - measured antenna values

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	1.017.316	-0,12	159,14	0,00	0,00	46,63	9,2	0,4	9,2

4. Out of this measurement we get for R_a = 0,4 Ohm and X_S = 9,2 Ohm.
5. The antenna inductance L_a and the Q damping factor resistor R_Q can be calculated (4) & (5): $X_S = \omega L$ → L_a (1MHz) = 1,46µH and R_Q = 1,9 Ohm (2,2 Ohm value selected)

6. Calculation of the antenna capacitance C_a. To get this parameter the self-resonance frequency of the antenna must be measured.
    a. Set at the MiniVNA a frequency span 1 – 100 MHz
    b. The point where the imaginary part X_S is going from an inductive value to capacitive value (negative) is the self-resonance frequency SRF.
    c. The measured SRF = 70,75 MHz
    d. The capacitance C_a of the equivalent circuit can now be calculated (3) → C_a = 3,46pF

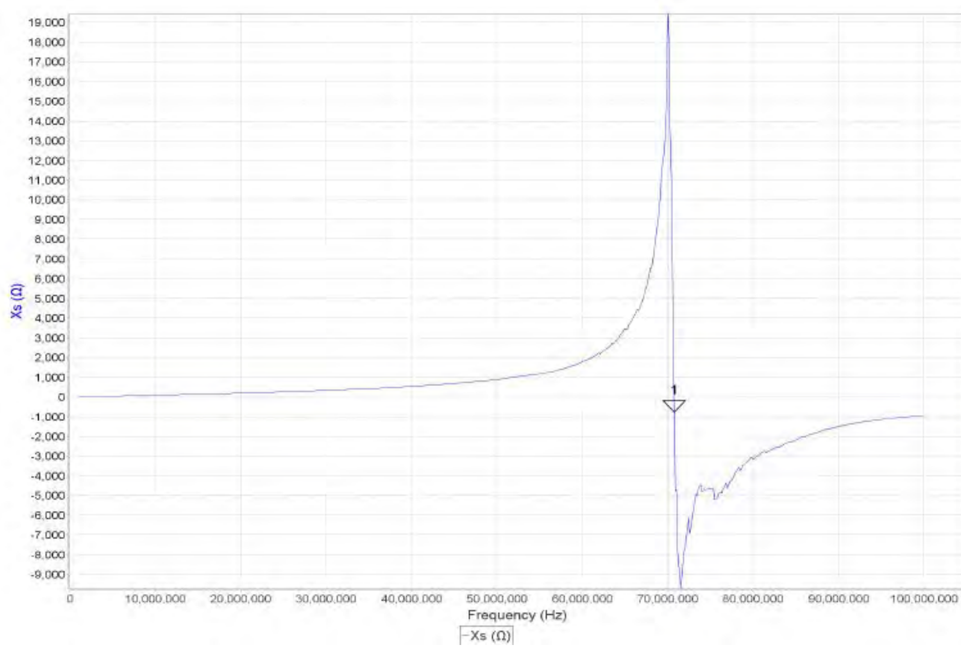


Fig 12. X_S measured with MiniVNA – marker @ SRF

Table 3. R_S, X_S - measured antenna values

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	70.749.442	-0,04	-0,01	0,00	0,00	83,13	24143,7	24131,1	-780,9

5. Matching Example – based on the PNEV512B

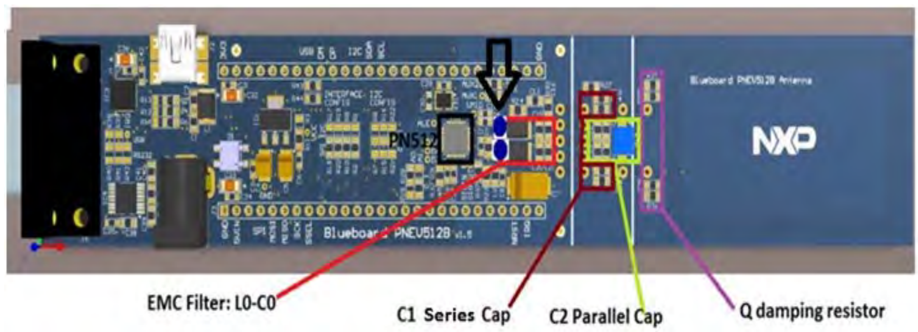


Fig 13. PNEV512B

The measurement points are marked in the Fig 13 with two blue dots. These both points are between TX1 & TX2 of the PN512 and the L_0 inductors of the EMC filter.

The PNEV512B is tuned for a Z target, matching to 50 Ohm (40 – 60 Ohm as optimal range):

- L_0 = 470 nH
- C_0 = 100pF + 56pF
- C_1 = 33 pF
- C_2 = 100 pF + 47 pF
- R_Q = 2.2 Ohm

5.1 Setup PNEV512B measurement – antenna in air

Fig 14. MiniVNA connected to PNEV512B and PC via USB

As a first step connect the MiniVNA to the PNEV512B at the measurement points shown in Fig 13.

As a next step you measure the antenna return loss with the MiniVNA.

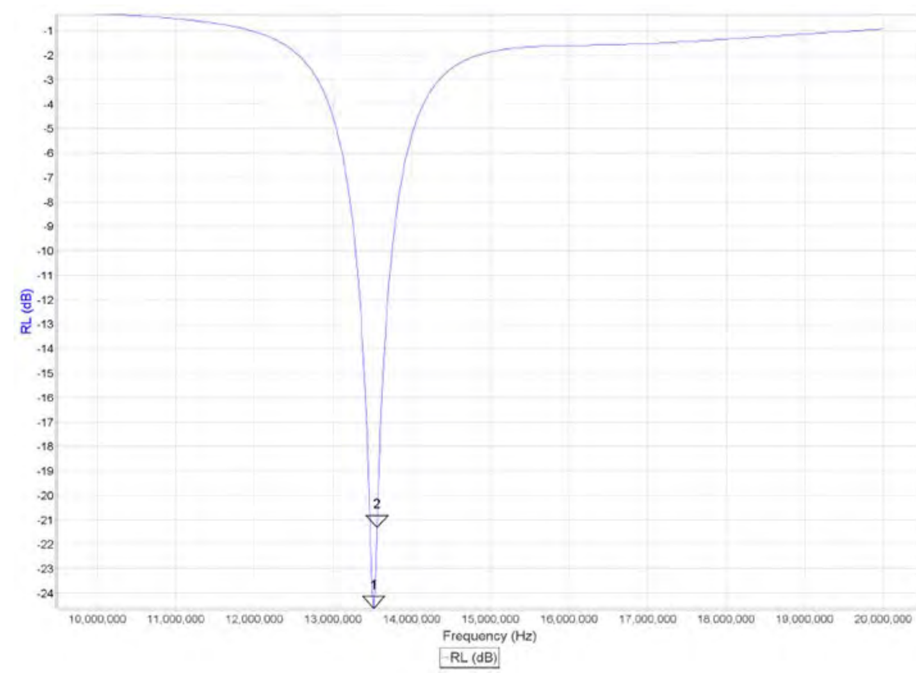


Fig 15. Antenna return loss without detuning (Z = 50 Ohm @ 13.56 MHz)

Table 4. Return loss and Z values (antenna correctly tuned)

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	13.517.150	-24,62	84,78	0,00	0,00	1,12	50,5	50,2	5,9
2	13.560.438	-21,30	34,19	0,00	0,00	1,19	57,6	57,4	5,6
1 – 2	43.288	3,32	50,60	0,00	0,00	---	7,1	7,2	0,3

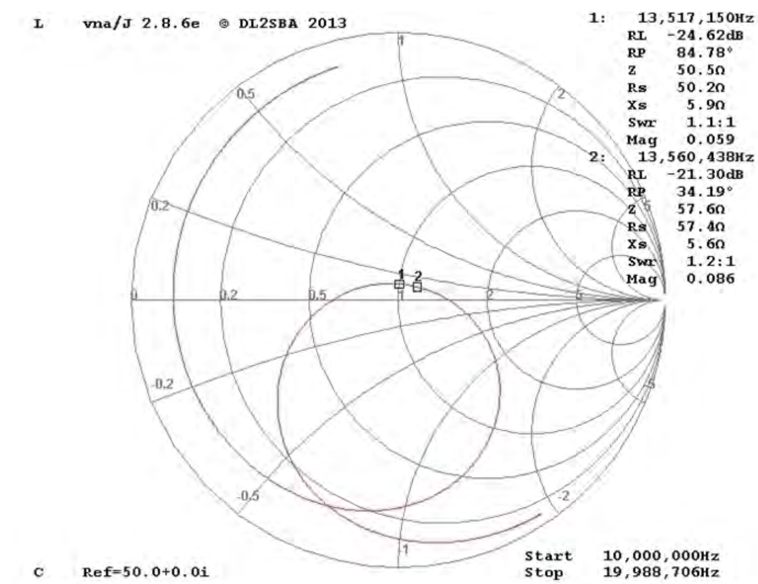


Fig 16. Smith Chart antenna matching without detuning

5.2 Recommended tuning for PN512 transceiver

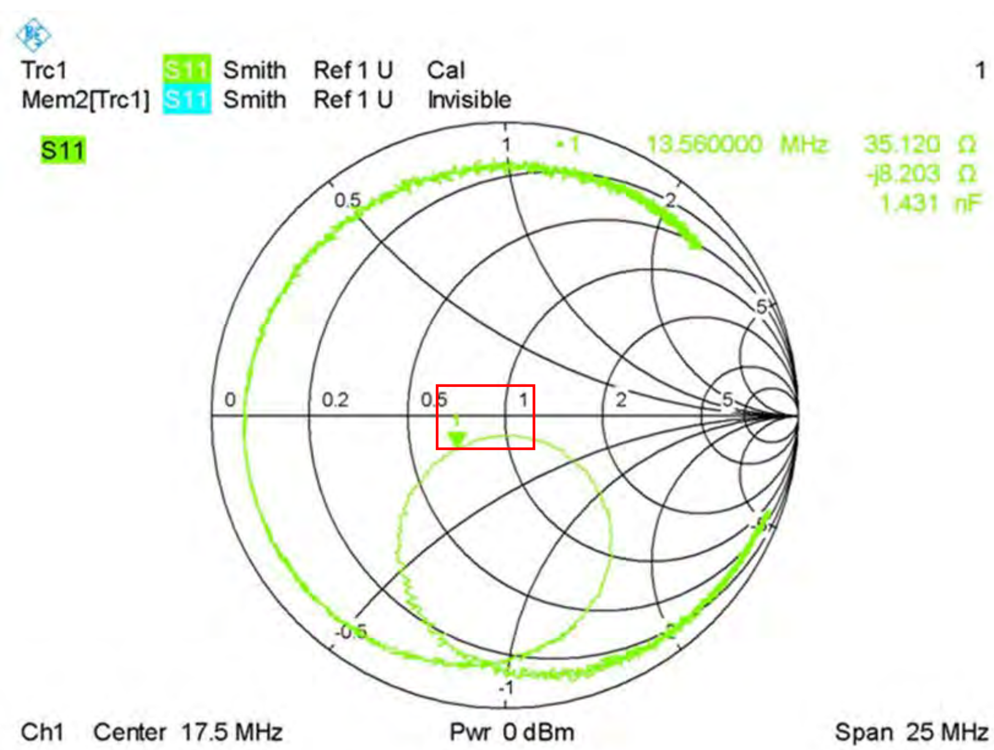


Fig 17. Smith Chart – recommended antenna matching

The area in the red rectangle (Fig 17) shows the recommended impedance range.

It is across the real axis (the impedance is real) and the best Z value is around 40 Ohm. Do not go below 35 Ohm in order to avoid device current limitation (IDD(TVDD)) as specified in the transceiver datasheet.
If performance is not a problem also higher Z tuning can be considered.

Important note:

a) NFC Forum compliant transceiver like PN512 device operates in card and reader mode and a tradeoff for the optimal Z matching must be evaluated.

b) In order to be compliant to NFC standard specification the orientation (angle) of the Z circle is important (see Fig 17)

6. Antenna Detuning

This chapter will explain how the Smith chart of a detuned antenna looks like and which steps must be done to tune such an antenna.

6.1 Detuned antenna setup

To achieve a detuned antenna setup, a metal surface is placed close to the antenna of the PNEV512B (see Fig 18).

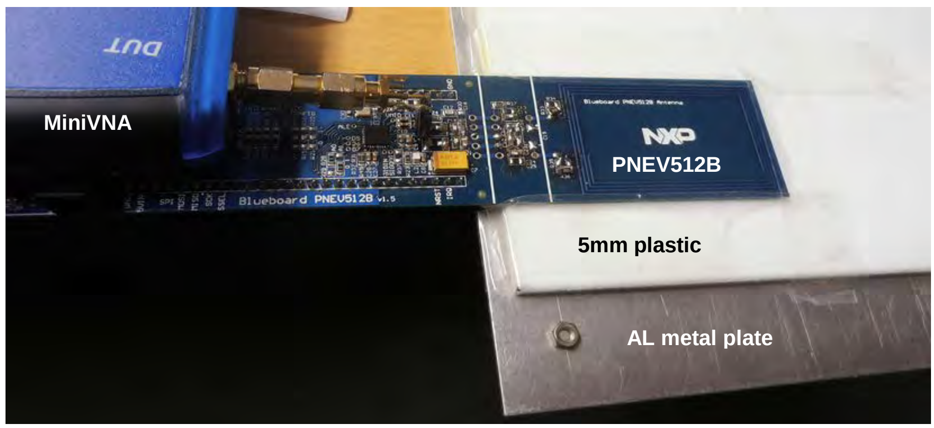


Fig 18. Setup with a metal surface close to the antenna

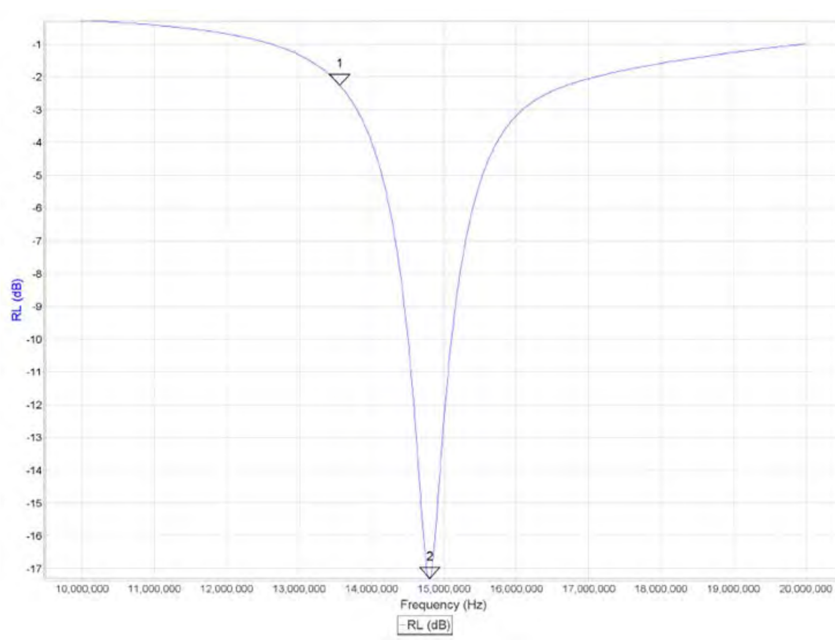


Fig 19. Antenna return loss – detuning effect

Table 5. Return loss and Z values (antenna detuned)

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	13.560.438	-2,26	-123,83	0,00	0,00	7,74	22,7	7,7	-21,4
2	14.804.968	-17,30	53,61	0,00	0,00	1,32	58,7	57,3	12,8
1 – 2	1.244.530	15,04	186,44	0,00	0,00	---	36,00	49,6	34,2

The measurement of the detuned antenna shows, that the minimum return loss RL shifted up to 14.8 MHz. These results indicate that the antenna has less inductance (eddy current on the metal plate); the antenna matching can be compensated by increasing the values of C_1 and C_2.

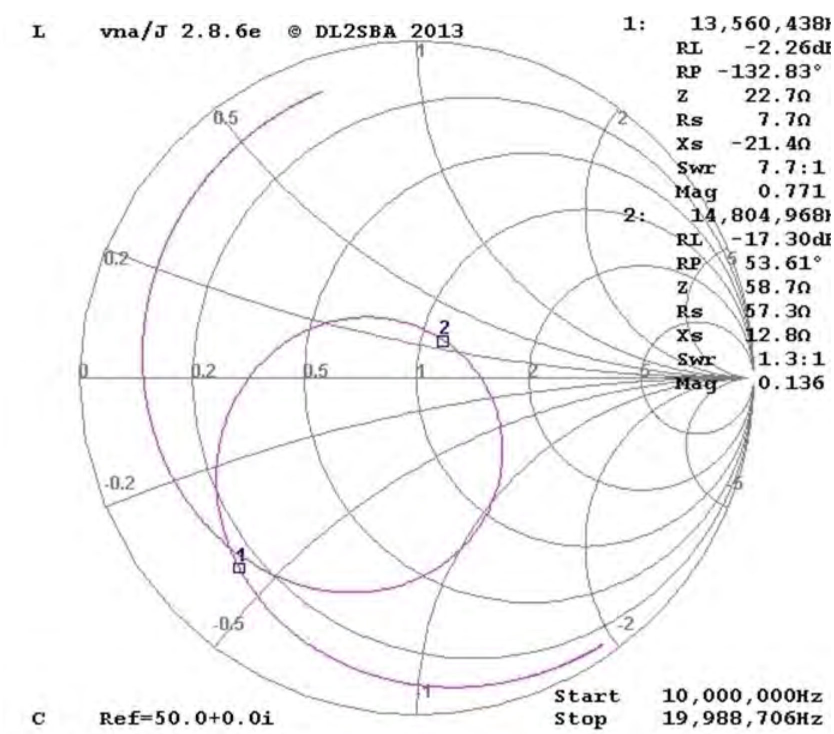


Fig 20. Smith Chart – detuning effect

The Smith Chart shows, that the antenna is not correctly matched. At 13.56 MHz the antenna has an impedance $Z = 7{,}7 - j21$ (marker 1).

6.2 Tuning adjustment steps and measurement

Based on the setup and measurement results from section 6.1, this chapter will explain which changes must be done to get a well-tuned antenna setup.

Some general considerations:

1. Increasing capacitor C_1 (series) – will make the Z circle bigger and will shift down the resonance frequency
2. Increasing capacitor C_2 (parallel) – will reduce the resonance frequency and will make the Z circle smaller.

6.2.1 Tuning of the detuned PNEV512B

The same setup with the metal plate (Fig 18) will be used and the following steps must be done to adjust the matching of the detuned antenna.

Step 1:

- Increase the overall value of C_2 to adjust a lower resonance frequency
- Change C_2 from (100 + 47)pF to (100 + 68)pF

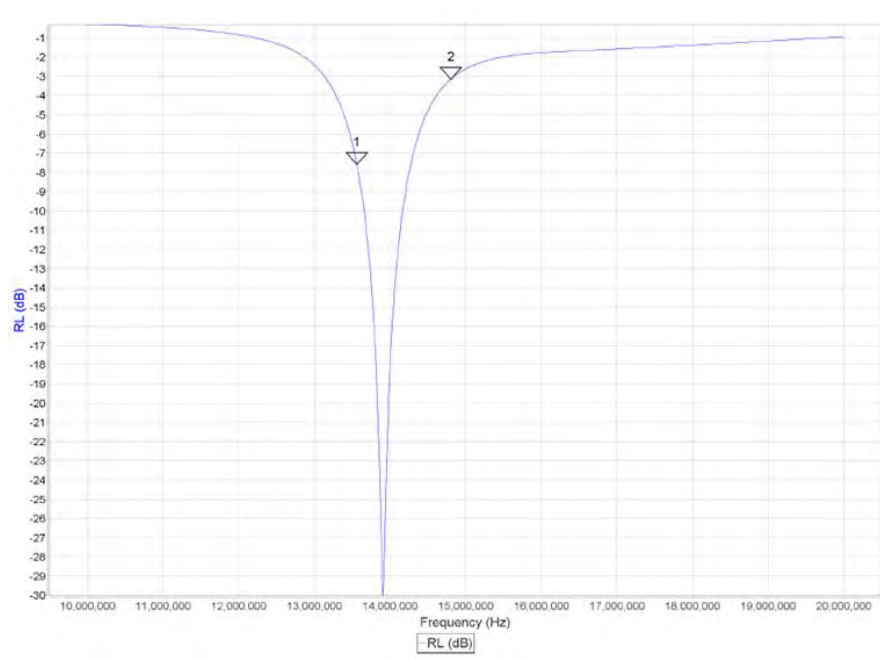


Fig 21. Antenna Return Loss - after first adjustment (Step 1)

Table 6. Return loss and Z values - after first adjustment (Step 1)

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	13.560.438	-7,58	-153,98	0,00	0,00	2,44	23,4	21,4	-9,5
2	14.804.968	-3,15	-85,80	0,00	0,00	5,58	53,6	18,6	-50,2
1 – 2	1.244.530	4,43	68,18	0,00	0,00	---	30,1	2,8	40,7

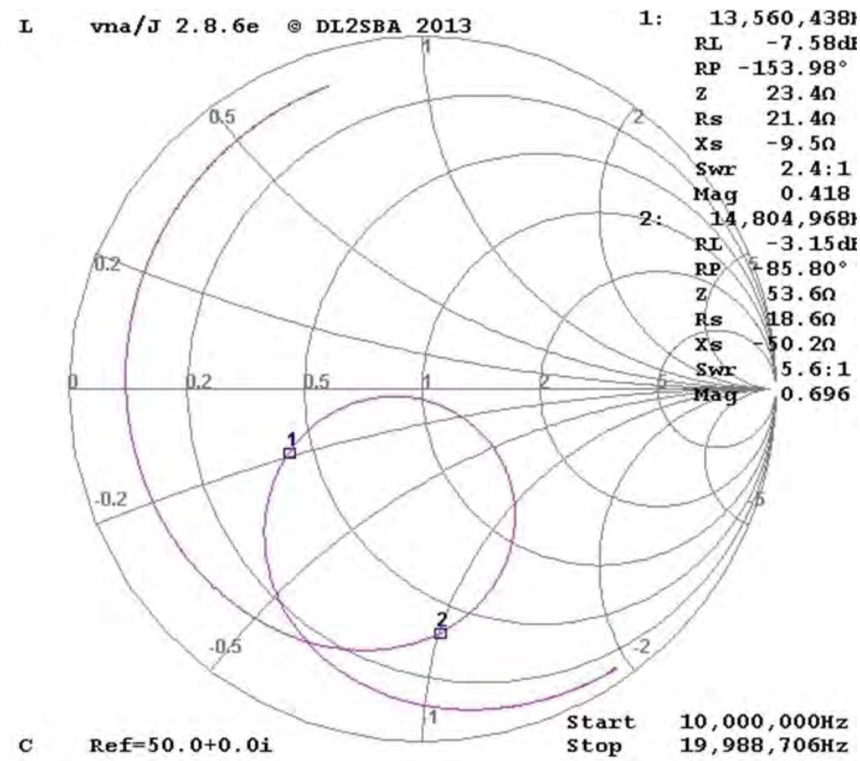


Fig 22. Smith Chart – after first adjustment (Step 1)

The Smith Chart shows, that the increased C_2 made some changes, at 13,56 MHz the antenna has now an impedance $Z = 21{,}1 - j9{,}5$ (marker 1).

The effect of increasing of C_2 was mainly a shrinking of the Z Smith Chart circle and decreasing of the resonance frequency.

Step 2:

- Increase the overall value of C_1 to adjust Z circle radius (the capacitor increase will increase the radius; the capacitor decrease will decrease the radius) and fine tune the resonance frequency.
- Change C_1 from 33 pF to (33 + 6,8)pF

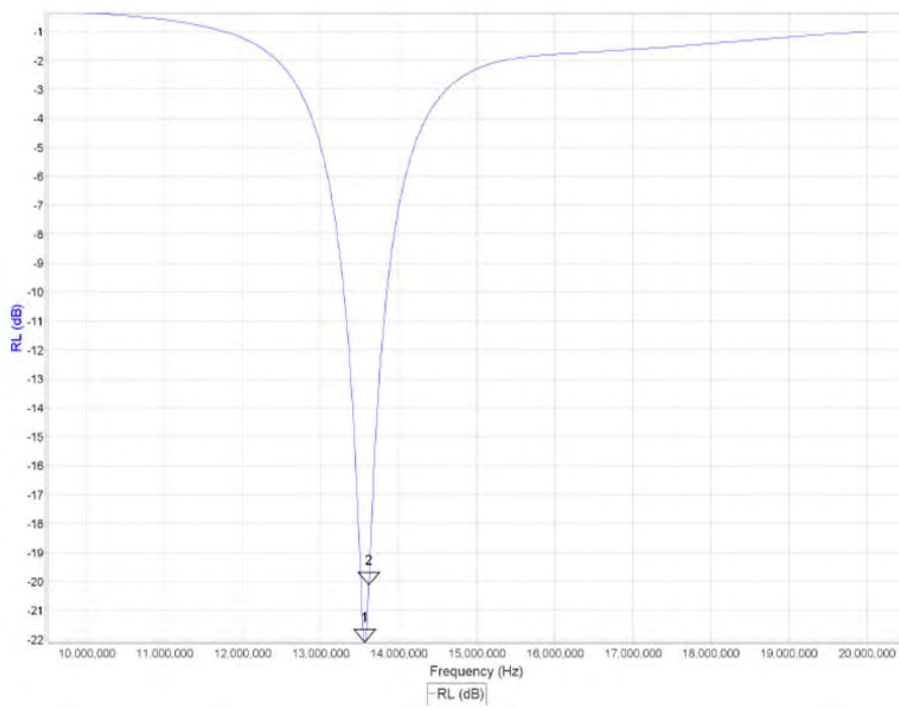


Fig 23. Antenna Return Loss - after second adjustment (Step 2)

Table 7. Return loss and Z values - after second adjustment (Step 2)

Marker	Frequency [Hz]	RL [dB]	RP [°]	TL [dB]	TP [°]	SWR	|Z|	R_S	X_S
1	13.560.438	-22,10	86,97	0,00	0,00	1,17	50,4	49,8	7,9
2	13.614.548	-20,11	41,77	0,00	0,00	1,22	57,9	57,4	7,6
1 – 2	54.110	1,98	45,20	0,00	0,00	---	7,5	7,6	0,2

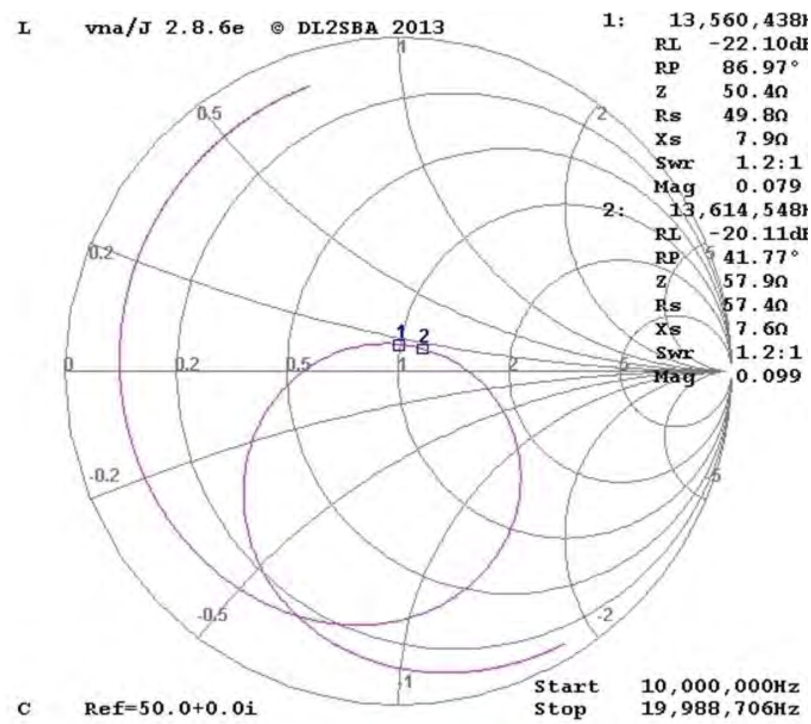


Fig 24. Smith Chart – after second adjustment (Step 2)

The Smith Chart shows, that the increased C_1 made some changes, at 13.56 MHz the antenna has now an impedance $Z = 49{,}8 - j7{,}9$ (marker 1).

The effect of increasing of C_1 was mainly an enlargement of the Z Smith Chart circle and decreasing of the resonance frequency.

Now the antenna is well tuned →

Result: Antenna correctly matched to 50 Ohm @ 13.56 MHz (see section 4.4)

7. Reference documents

7.1 Datasheets

NXP provides the following datasheets:

- PN512; PN512 Full NFC Forum compliant solution;
  http://www.nxp.com/documents/data_sheet/PN512.pdf
- CLRC663; CLRC663 High performance NFC reader solution;
  http://www.nxp.com/documents/data_sheet/CLRC663.pdf

7.2 Application notes

NXP provides the following application notes:

- AN11308; Quick Start Up Guide PNEV512B;
  http://www.nxp.com/documents/application_note/AN11308.pdf
- AN11019; CLRC663, MFRC630, MFRC631, SLRC610 Antenna Design Guide;
  http://www.nxp.com/documents/application_note/AN11019.pdf
- AN1445; Antenna design guide for MFRC52x, PN51x, PN53x
  http://www.nxp.com/documents/application_note/AN1445_An1444.zip

7.3 General purpose simulation tool RFSIM99

In order to get familiarity with antenna tuning effects with matching network variation, NXP recommends this freeware RF simulation tool.

http://www.nxp.com/redirect/electroschematics.com/wp-content/uploads/2008/12/rf-sim-99.zip

It can be downloaded and installed on any Windows PC's and it is straightforward. Some RFSIM99 examples are provided during NXP Mass Market and Identification trainings as supplement software resource to improve customers' RFID antenna design knowhow.

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Date of release: 3 November 2014
291911

Document identifier: AN11535