Near Field Communication

Master's Thesis in Electrical Engineering

by
Bekir Bilginer
Paul-Luis Ljunggren

Supervisors: Masar Sadik and Johan Nilsson
Examiner: Tomas Jansson

Department of Measurement Technology and Industrial Electrical Engineering
Lund University, Sweden

Sony Ericsson Mobile Communications AB
Lund, Sweden

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LUNDS UNIVERSITET
Lunds Tekniska Högskola

Sony Ericsson

Abstract

Near Field Communication (NFC) is a form of wireless communication technology enabling data transfer by putting two devices close to each other. The main idea behind NFC is to integrate wireless payment and tag reading in mobile phones along with peer-to-peer communication. An example of the benefit with NFC peer-to-peer communication is that it gives the possibility to quickly set up a Bluetooth or a WLAN connection with a simple swipe. Wireless payment is made possible through the so called card emulation mode and will be used all over the world in a near future. This enables NFC devices to be used not only with the upcoming wireless payment terminals but also to replace contactless plastic cards used in the already established RFID infrastructure. The main purpose of this master's thesis is to assemble an RF measurement system for NFC. The report covers the basics of NFC together with the involved standards and presents test results from different NFC enabled devices.

Acknowledgments

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List of Abbreviations

AIT Austrian Institute of Technology

ATR_REQ Attribute Request

ATR_RES Attribute Response

ASK Amplitude Shift Keying

CMR Common Mode Rejection

CRC Cyclic Redundancy Check

dBm Logarithmic measure of power, related to 1 mW HF-power

DUT Device Under Test

ECMA European Computer Manufacturers Association

EMVCo Europay, MasterCard and Visa Corporation

FSK Frequency Shift Keying

IEC International Electrotechnical Commission

ISO International Organization for Standardization

LSB Least significant bit

MSB Most significant bit

NFCIP Near Field Communication Interface and Protocol

NRZ Non-Return-to-Zero Encoding

NXP Next eXPerience Semiconductors

PCB Printed Circuit Board

PCD Proximity Close-coupling Device

PICC Proximity Integrated Circuit Card

PSK Phase Shift Keying

RF Radio Frequency

RFID Radio Frequency Identification

R&S Rohde & Schwarz

SENS_REQ Sense Request

SENS_RES Sense Response

Nomenclature

Initiator: An initiator is the term used in the ISO standards to describe a close coupling device that takes initiative to start any close coupling communication initiation sequence.

Poller: The name for initiator in the NFC Forum.

Reader: A reader is an active device that powers up and initiates contact with a passive close coupling device. A reader can be seen as a subgroup of an initiator.

Target: This is the term used in the ISO standards to indicate the responding device of any close coupling communication initiation sequence. The reader and transponder are the main components of every RFID system.

Listener: The name for target in the NFC Forum.

Tag: A tag is a passive close coupling device without any specified physical layout. A tag can be seen as a subgroup of a target.

Card: A card is a passive close coupling device with ID-1 format, i.e. typical credit card size. A card can be seen as a subgroup of a target.

Contents

Chapter 1

Introduction

1.1 Background

Near Field Communication, NFC, is an upcoming technology based on RFID. NFC is expected to be heavily deployed within the next two years and trials are currently ongoing all over the world. Examples of applications are public transport payment, credit cards, electronic tickets and configuration of other wireless technologies. The development of NFC is currently driven by the NFC Forum which is an organization of 150 companies working together to promote and develop NFC.

1.2 Thesis Objectives

- Gain overall knowledge of NFC technology
- Survey different NFC component vendors and define pros and cons.
- Investigate competitors' NFC solutions.
- Define constrains and opportunities when designing for NFC.
- Define and build a mock-up for NFC.
- Assemble a measurement system for NFC and define test cases, limits, calibration, etc.

1.3 Structure

The thesis starts by describing the RFID basics since NFC technology is based on RFID. This is followed by chapters describing the physical principles and an introduction to NFC. It proceeds by describing the communication technology with the RF and digital interface and modulation. The main standards are then explained with focus on the ISO/ECMA standard. By then, the reader will have been introduced to all the theoretical background of the technology, the following two chapters describe the complete measurement setup and measurement procedures. This is then followed by a chapter containing the test results from all the DUTs used. The thesis is summed up with a discussion of the findings, a conclusion of the work and suggestions for future proceedings.

Chapter 2

RFID Basics

2.1 Historical Overview

RFID has its origin in military identification systems and was implemented already during World War II in order to identify planes, a system known as Identification, Friend or Foe (IFF). The RFID technology was further developed to enable systems to be used for low cost commercial applications. The first developments were of electronic surveillance tags. They contained two states, on and off, and if the state had not been switched off when the tag passed the readers the alarm would go off. The first tags to exist were passive but with time, active tags were also introduced. RFID is today a widespread technology used in infrastructures all over the world.

2.2 Components of an RFID System

An RFID system consists of two components. The transponder, or tag, which is located on the object to be identified, and the reader, which may be either a read or read/write device, see Figure 2.2.1. A reader typically contains an RF module (transmitter and receiver), a control unit and a coupling element to the tag. The tag, which represents the data-carrying device of an RFID system, usually consists of a coupling element and an electronic microchip. RFID typically operates at 13.56 MHz.

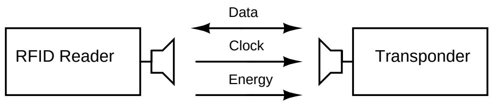

Figure 2.2.1: The main components of every RFID system.

2.3 Passive and Active Communication

In active communication mode, devices have their own power supplies and can generate their own RF signal on which data is carried. Most RFID tags are passive, which means that they have no power supply of their own. Instead, they are powered by the field generated by the reader. Passive tags can therefore be much smaller and cheaper than active tags, although the reading range is more limited. Semi-passive/active tags have a battery dedicated exclusively to power the electronics on the chip.

2.4 Coupling Techniques

The way in which the RFID tag and reader communicate is known as the coupling mechanism and is categorized into three areas:

2.4.1 Backscatter Coupling

Backscatter coupling operates outside the near field region, and the radio signal propagates away from the reader. When the signal reaches the tag, this interacts with the ingoing signal and some energy is reflected back towards the reader. The properties of the tag affect the way in which the signal is reflected back. Cross sectional area, antenna properties etc, are factors that all have an effect on how the tag reflects the incoming signal. The reflected signal properties can be changed by adding or subtracting a load resistor across the antenna. In order to allow transmission and reception of a signal at the same time, a directional coupler is often used to allow the received signal to be separated from the transmitted.

2.4.2 Capacitive Coupling

Capacitive coupling uses capacitive effects to provide the coupling between the tag and the reader. It operates best when items like smart cards are inserted into a reader, meaning the card is in very close proximity to the reader. The AC signal generated by the reader is picked up and rectified within the tag and used to power the devices within the tag. Like with backscatter coupling, the data is sent to the reader by modulating the load.

2.4.3 Inductive Coupling

In terms of operation, inductive coupling is the transfer of energy from one circuit to another through the mutual inductance between the two circuits. When the tag is placed close enough to the reader, the field from the reader coil will couple to the tag coil. A voltage will be induced in the tag that will be rectified and used to power the tag circuitry. To modulate data from the tag to the reader, the tag circuitry changes the load on its coil and this can be detected by the reader as a result of the mutual coupling.

RFID inductive coupling is a near field effect, so the distance between the coils must be less than $\frac{\lambda}{2\pi}$ for the tag to operate.

Here, it should be stated that no electromagnetic field is present in the near field region of a reader. The field generated by the reader is purely magnetic until the transition to the far field. Throughout the report, the term RF field is used even though it actually is a magnetic field.

The range of the RFID system is broadly categorized into three areas:

- Close coupling - within 1 cm
- Remote coupling - between 1 cm and 1 m
- Long range coupling - more than 1 m

Of these types of RFID coupling, inductive and capacitive types are normally used for close and remote range links and RFID backscatter coupling for long range links. The type of used coupling affects not only the range of the RFID system, but also operating frequency and other elements of the RFID hardware.

Chapter 3

Physical Principles

The majority of RFID systems operate according to the principle of inductive coupling. Therefore, understanding of the procedures of power and data transfer requires an understanding of the physical principles of magnetism. This chapter therefore contains a short study of the theory of magnetic fields from an RFID point of view.

3.1 Magnetic Field

3.1.1 Magnetic Field Strength, H

Moving electric charges, i.e. flow of current, generate a magnetic field. The magnitude of the magnetic field is described by the magnetic field strength H. In the general form we can say that: 'the contour integral of magnetic field strength along a closed curve is equal to the sum of the current strengths of the currents within it' as seen in equation 3.1.1. [8]

$$\sum I = \oint \overrightarrow{H} \cdot \overrightarrow{ds} \tag{3.1.1}$$

Two examples of how the magnetic flux behaves when a current passes a conductor can be seen in Figure 3.1.1.

In a straight conductor the field strength H along a circular flux line at a distance r is constant. The field strength H can be expressed as:

$$H = \frac{1}{2\pi r} \tag{3.1.2}$$

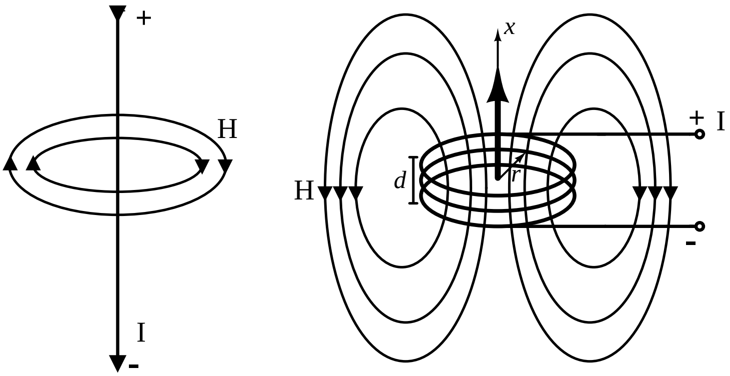

Figure 3.1.1: Lines of magnetic flux around a conductor and a cylindrical coil.

Conductor loops are used as magnetic antennas to generate the magnetic alternating field in the devices of inductively coupled RFID systems.

The magnetic field strength H decreases as the measuring point is moved away from the centre of the coil axis (x axis in Figure 3.1.1). The field strength is reduced by 60 dB per decade in the near field of the coil. The path of field strength along the x axis of a coil can be calculated by using Equation 3.1.3.

$$H = \frac{I \cdot N \cdot r^2}{2\sqrt{(r^2 + x^2)^3}} \tag{3.1.3}$$

Here, N is the number of windings, r is the circle radius and x is the distance from the centre of the coil in the x direction. This equation is only valid when $d \ll r$ and $x < \lambda/2\pi$. The transition into the electromagnetic far field occurs when x exceeds $\lambda/2\pi$.

At the centre of the antenna, $x = 0$, Equation 3.1.3 can be simplified to:

$$H = \frac{I \cdot N}{2r} \tag{3.1.4}$$

3.1.2 Magnetic Flux and Magnetic Flux Density

The magnetic flux is a measure of the amount of magnetic field passing through a given surface and is expressed as ϕ_m.

Magnetic flux density is the amount of magnetic flux per unit area of a section, perpendicular to the direction of flux. The mathematical representation of magnetic flux density can be seen in Equation 3.1.5.

$$B = \frac{\phi_m}{A} \tag{3.1.5}$$

Here, B is magnetic flux density in teslas (T), ϕ_m is magnetic flux in webers (Wb) and A is area in square meters (m^2).

The relationship between flux density B and field strength H is expressed in Equation 3.1.6:

$$B = \mu_0 \cdot \mu_r \cdot H = \mu \cdot H \tag{3.1.6}$$

Here, μ_0 is the magnetic field constant ($\mu_0 = 4\pi \cdot 10^{-7} \frac{H}{m}$), which describes the permeability of a vacuum. The variable μ_r is called relative permeability and indicates how much greater than or less than μ_0 the permeability of a material is.

3.1.3 Inductance, L

When a current flows in a conductor of any shape, a magnetic field is generated around it. The magnetic field will be stronger if the conductor is in the form of a coil. A coil consists of N loops of the same area A, through which the same current I flows. The loops each contribute an equal amount of flux. The total flux Ψ can be expressed as:

$$\Psi = \sum_N \phi_N = N \cdot \phi = N \cdot \mu \cdot H \cdot A \tag{3.1.7}$$

The relationship between the magnetic flux and the current is called inductance and is denoted by L:

$$L = \frac{\Psi}{I} = \frac{N \cdot \phi}{I} = \frac{N \cdot \mu \cdot H \cdot A}{I} \tag{3.1.8}$$

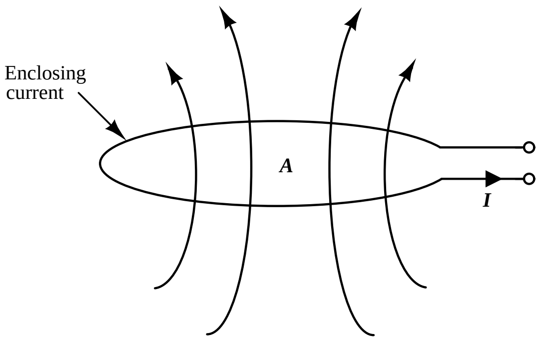

Figure 3.1.2: Definition of inductance L.

The inductance of a conductor loop is dependent on the geometry of the layout and the permeability of the medium that the flux flows through.

3.1.4 Mutual Inductance, M

Mutual inductance describes the coupling of two circuits with a magnetic field and always exists between two electric circuits. Its unit and dimension are the same as for inductance. Mutual inductance is the physical principle which RFID systems are based upon.

If a second conductor loop with an area A_2 is located in the vicinity of the first conductor loop with area A_1, through which a current is flowing, then this will lead to a portion of the total magnetic flux flowing through A_1 to also flow through A_2. The two conductor loops, hereby referred to as coils, are then connected by this flux. The magnitude of the coupling flux Ψ_{21} depends on the position in relation to each other, the magnetic properties of the medium and the dimensions of the coils. The ratio of the partial flux Ψ_{21} enclosed by the second coil, to the current I_1 in the first coil is equal to the mutual inductance M_{21} of the second coil in relation to the first coil, as seen in Equation 3.1.9.

$$M_{21} = \frac{\Psi_{21}(I_1)}{I_1} = \oint_{A_2} \frac{B_2(I_1)}{I_1} \cdot dA_2 \tag{3.1.9}$$

For the mutual inductance M_{12}, the coupling flux Ψ_{12} in the first coil is determined by the current I_2 flowing through the second coil.

The relationship between the mutual inductances is as follows:

$$M = M_{12} = M_{21} \tag{3.1.10}$$

If the magnetic field is homogeneous, the mutual inductance M_{12} between two coils can be calculated using Equation 3.1.9. The resulting equation is as follows:

$$M_{12} = \frac{B_2(I_1) \cdot N_2 \cdot A_2}{I_1} = \frac{\mu_0 \cdot H(I_1) \cdot N_2 . A_2}{I_1} \tag{3.1.11}$$

By replacing $H(I_1)$ with the expression in equation 3.1.3, and substituting A_2 with $r_2^2\pi$, Equation 3.1.12 is obtained.

$$M_{12} = \frac{\mu_0 \cdot N_1 \cdot r_1^2 \cdot N_2 \cdot r_2^2 \cdot \pi}{2\sqrt{(r_1^2 + x^2)^3}} \tag{3.1.12}$$

This equation is only valid when the x axes of the two coils lie on the same plane and $A_2 \leq A_1$.

3.1.5 Coupling Coefficient

The coupling coefficient is a convenient way to specify the degree of electrical coupling that exists between two circuits. The coupling coefficient k is expressed as

$$k = \frac{M}{\sqrt{L_1 \cdot L_2}} \tag{3.1.13}$$

where $0 \leq k \leq 1$. A k value close to 0 equals high decoupling due to e.g. distance while a k value close to 1 equals high coupling. If $k = 1$ then both coils are subject to the same magnetic flux.

3.1.6 Faraday's Law

A change to the magnetic flux generates an electric field strength E_i and this is described by Faraday's law. The effect of this electric field depends on the material of its surroundings. Faraday's law in its general form is written as:

$$u_i = \oint E_i \cdot ds = -\frac{d\Psi(t)}{dt} \tag{3.1.14}$$

For a coil with N windings, Equation 3.1.14 can be expressed as:

$$u_i = N \cdot \frac{d\Psi}{dt} \tag{3.1.15}$$

A time variant current $i_1(t)$ in the first coil generates a time variant magnetic flux $\frac{d\phi(i_1)}{dt}$ which leads to a voltage being induced in both coils. We can differentiate between two cases, self-inductance and mutual inductance. For self-inductance, the flux change generated by the current change induces a voltage in the same conductor circuit. For mutual inductance, the flux change generated by the current change induces a voltage in the adjacent conductor circuit. Figure 3.1.3 shows the equivalent circuit diagram for coupled coils. In an RFID system, L_1 would be the transmitter antenna of the reader and L_2 the target antenna.

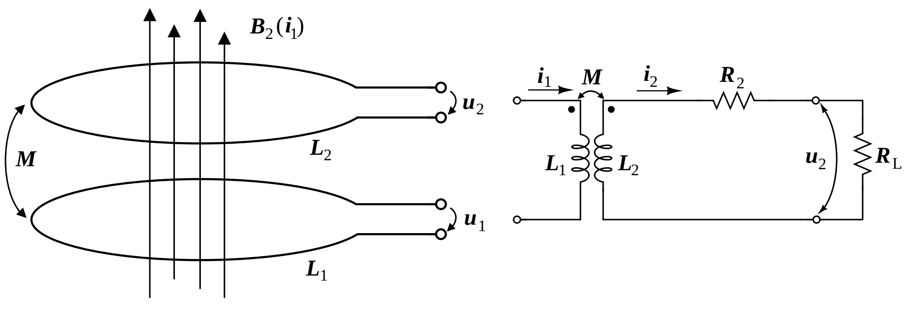

Figure 3.1.3: Left, magnetically coupled coils; right, equivalent circuit diagram for magnetically coupled coils.

The current consumption of the chip is symbolized by the load resistor R_L. A time varying flux in the first coil L_1 induces a voltage u_{2i} in the second coil L_2 due to mutual inductance M. A voltage drop across the coil resistance R_2 is created due to the flow of current, meaning that the voltage u_2 can be measured across R_L. An additional magnetic flux opposing the magnetic flux $\Psi_1(i_1)$ is generated due to the current flowing through L_2. This is summed up in Equation 3.1.16.

$$u_2 = +\frac{d\Psi_2}{dt} = M\frac{di_1}{dt} - L_2\frac{di_2}{dt} - i_2R_2 \tag{3.1.16}$$

Since i_1 and i_2 usually are sinusoidal alternating currents, Equation 3.1.16 can be written in the complex notation:

$$u_2 = j\omega M \cdot i_1 - j\omega L_2 \cdot i_2 - i_2R_2 \tag{3.1.17}$$

If i_2 is replaced by $\frac{u_2}{R_L}$ in equation 3.1.17, then the equation for u_2 can be solved as seen in Equation 3.1.18.

$$u_2 = \frac{j\omega M \cdot i_1}{1 + \frac{j\omega L_2 + R_2}{R_L}} \left\{ \frac{R_L \to \infty : u_2 = j\omega M \cdot i_1}{R_L \to 0 : u_2 \to 0} \right. \tag{3.1.18}$$

The current flowing through L_2 will vary when varying R_L. Since the magnetic flux generated at L_2 will counteract the flux from the reader, there will be a change at the reader field. This change can then be detected at the reader side and if the rate of which the load resistor switches on and off is controlled by data, the same pattern will be detected at the reader. Load modulation and its uses will be explained further in 5.3.1.

Chapter 4

NFC - Near Field Communication

NFC technology development was initiated by Sony and Philips. It consists of an interface and protocol developed on top of RFID which makes the NFC device part of this standard and compatible with already existing RFID technology.

The key feature that differentiates NFC from RFID is the possibility of bidirectional transfer of information which allows bidirectional communication between NFC devices. To connect two devices together, one simply brings them very close together or makes them touch physically. The NFC protocol then automatically configures them for communication in a peer-to-peer network.

In passive communication mode, only one device generates an RF field, the other device uses load modulation to transfer the data. This is an ideal scenario for mobile phones as it would allow them to interact with other devices such as laptops while keeping battery consumption low.

4.1 NFC Applications

NFC has several areas of use. The main idea is to replace people's wallets with digital payments through the mobile phone. Mobile phones and SIM cards that can store and run various software applications make a powerful platform to be utilized together with NFC. The three maybe most promising areas are public transport payment, credit card replacement and advertising. Further possibilities are identity cards, electronic keys, configuration and setting up other communication protocols such as Bluetooth and WLAN.

The magnetic strip and chip cards used today have limited lifetime and are vulnerable to demagnetizing and breakage. These can be replaced by the card emulation mode of NFC and in that way the number of cards used in the everyday life will also be reduced.

Advertising in the form of smart posters is also an interesting feature. For these services, the phone acts as an NFC reader, and collects information from the tags through load modulation. The tag can contain all the information needed, or the tag can give a URI combined with a phone command so that the user is redirected to a phone number or a website to complete the service.

4.2 NFC Chip Suppliers

The largest supplier of NFC chips today is NXP Semiconductors, who supplies several handset manufacturers such as Nokia and Samsung with chips. Current NFC solutions are all standalone chips but future chips will incorporate other wireless technologies such as Bluetooth or WLAN. Other chip manufacturers include Inside Contactless, ST Microelectronics, Texas Instruments, Broadcom, Polaric, etc.

Chapter 5

RF and Digital Interface

5.1 RF Signal Interface

5.1.1 RF Specifications

- The carrier frequency f_c shall be 13.56 MHz ± 7 kHz.
- A reader shall generate an RF field of at least $H_{min} = 1.5\ A/m$ within its defined operating volume.
- A reader shall not generate an RF field higher than $H_{max} = 7.5\ A/m$ at any point.
- If an external RF field with a field strength value equal to or greater than $H_{threshold} = 0.1875\ A/m$ is detected, the internal RF field must be switched off.

5.1.2 Bit Duration

The bit duration, b_D, in NFC is dependent on the communication mode and the data rate chosen by the initiator which initializes the communication. The bit duration can be calculated by the following equation:

$$b_D = \frac{128}{D \cdot f_c}\, s \tag{5.1.1}$$

where f_c is the carrier frequency and the value of the divisor D depends on the bit rate and is given by table 5.1.

Communication Mode	kbps	D
active or passive	106	1
active or passive	212	2
active or passive	424	4

Table 5.1: Definition of divisor D, the initial bit rate is determined by the initiator.

5.1.3 Active Communication Mode

In active communication mode, the specification shall always be the same for both initiator to target and target to initiator communication. At the lowest data transfer speed supported by NFC, the initial bit rate shall be 106 kbps ($f_c/128$). For this bit rate, the initiator shall use 100% ASK modulation of the RF operating field to generate pulses as shown in Figure 5.1.1.

The envelope of the field shall decrease monotonically to less than 5 % of its initial value $H_{INITIAL}$, and remain less than 5 % for a duration of more than $t2$, see Table 5.2.

Overshoots shall remain within 90 % and 110 % of $H_{INITIAL}$. The Target shall detect the "End of Pulse" after the field exceeds 5 % of $H_{INITIAL}$ and before it exceeds 60 % of $H_{INITIAL}$ as defined by $t4$ in table 5.2. This definition applies to all modulation envelope timings.

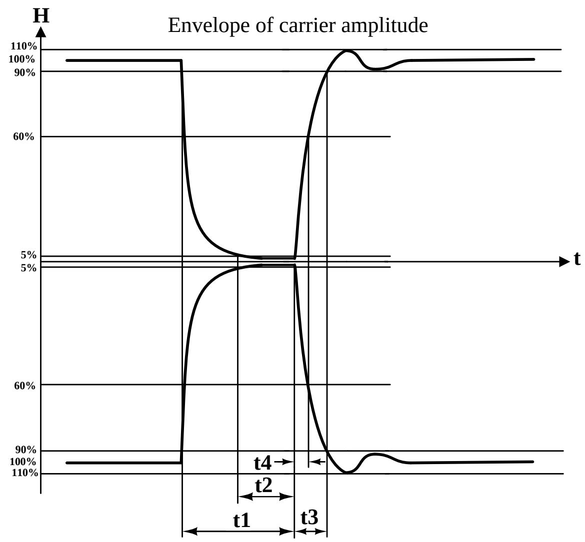

Figure 5.1.1: Pulse shape of 100% ASK modulation.

Pulses length (Condition)	$t1(\mu s)$	$t2(\mu s)$		$t3(\mu s)$	$t4(\mu s)$
		$(t1 \leq 2.5)$	$(t1 \geq 2.5)$		
Maximum	3.0	$t1$		1.5	0.4
Minimum	2.0	0.7	0.5	0.0	0.0

Table 5.2: Definition of time intervals in Figure 5.1.1

The byte encoding shall be LSB first for the bit rate 106 kbps. When transferring data, the following coding is used to represent bits:

- Start of communication: at the beginning of the bit duration a “Pulse” shall occur.
- ONE: after a time of half the bit duration a “Pulse” shall occur.
- ZERO: For the full bit duration, no modulation shall occur with the following two exceptions:
  - If there are two or more contiguous ZEROs, from the second ZERO on a “Pulse” shall occur at the beginning of the bit duration.
  - If the first bit after a “start of communication” is ZERO, a “Pulse” shall occur at the beginning of the bit duration.
- End of Communication: ZERO followed by one bit duration without modulation.
- No information: shall be coded with at least two full bit durations without modulation.

This method is referred to as Modified Miller coding.

When communication at a higher bit rate is selected by the initiator, another scheme is used. The bit rates for the transmission during initialization shall be 212 kbps ($f_c/64$) or 424 kbps ($f_c/32$), respectively.

The modulation scheme used is still ASK, but with a modulation index of 8 % to 30 % of the operating field, referred to as 10 % ASK. The modulation waveform shall comply with Figure 5.1.2. The rising and falling edges of the modulation shall be monotonic. The modulation for the transmission during initialization and single device detection shall be the same. The peak and the minimum signal amplitude are defined by a and b.

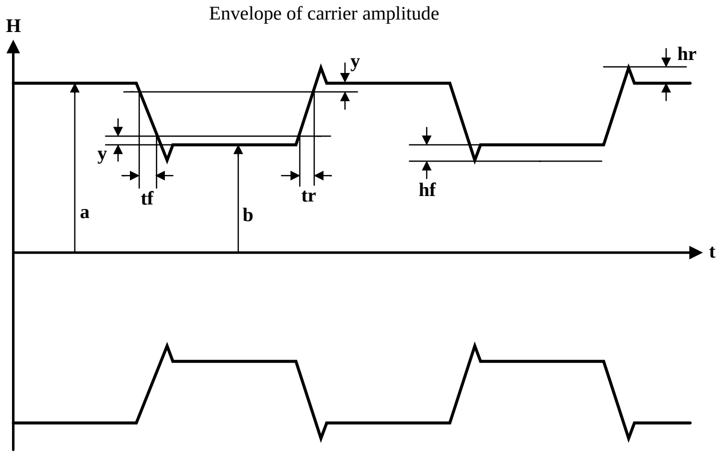

Figure 5.1.2: Waveform of 10% ASK modulation.

	212 kbps	**424 kbps**
t_f	$2.0\mu s\ max$	$1.0\mu s\ max$
t_r	$2.0\mu s\ max$	$1.0\mu s\ max$
y	$0.1(a-b)$	$0.1(a-b)$
h_f, h_r	$0.1(a-b)max$	$0.1(a-b)max$

Table 5.3: Definition of time intervals in Figure 5.1.2

The byte encoding shall be MSB first and the bit representation shall be Manchester coding with obverse amplitude as shown in Figure 5.1.3. Reverse polarity in the amplitude of the Manchester symbols is permitted. The target shall respond with the same load modulating scheme, but the bit duration of the Manchester coding must be changed so that it matches the b_D related to the actual bit rate. The byte encoding shall be MSB in this direction too.

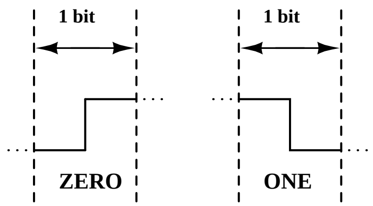

Figure 5.1.3: Manchester bit encoding with obverse amplitude.

5.1.4 Passive Communication Mode

In passive communication mode, the specifications differ slightly for initiator to target and target to initiator communication.

Initiator to Target The modulation, byte encoding, bit representation and coding for the different bitrates from the initiator to the target shall be the same as in active communication mode with the corresponding bit rates.

Target to Initiator The target shall respond via load modulation generating a subcarrier with frequency $f_s = f_c/16$. The load modulation amplitude has to exceed a minimum value relative to the strength of the present magnetic field. Bit representation shall be performed by Manchester coding with obverse amplitude. Bytes shall be encoded with LSB first for the bit rate 106 kbps and MSB first for the higher bitrates.

5.2 Digital Signal Interface

5.2.1 Sequences

An incoming or outgoing signal is called a sequence. A receiving device needs information on when to begin and stop demodulation and how to recognize a sequence. Therefore, a sequence always starts and ends with a specific bit pattern.

The start and end patterns help the receiving device to synchronize with the sender and to identify a valid sequence, and therefore, allow to extract information included in the sequence. The information transported in a sequence is a collection of bits included in a frame.

5.2.2 Frames

Data transmitted between initiator and target is grouped in frames. The format of the frame differs between initialization and data transfer in passive communication mode.

Two types of data frames are used for passive communication at 106 kbps. During initialization, short frames are used. A short frame consists of 7 bits of data together with a start and stop bit. See Figure 5.2.1.

	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	
Start	Command							End

Figure 5.2.1: Short frame.

For data exchange at 106 kbps, standard frames are used and the structure is shown in Figure 5.2.2.

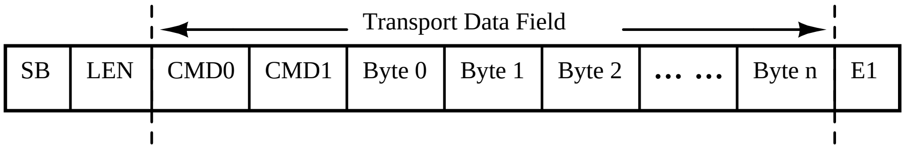

Figure 5.2.2: Frame format for 106 kbps.

The start byte SB shall be set to 0xF0. The length byte LEN shall be set to the length of the Transport Data field plus 1. The value of LEN shall be in the range of 3 to 255. CMD0 and CMD1 are command bytes. E1 is the CRC for the Frame format of 106 kbps. The LSB of each byte shall be transmitted first. Each byte shall be followed by an odd parity bit.

For data frames used in passive communication mode at 212 and 424 kbps, the frame structure shown in Figure 5.2.3 is used.

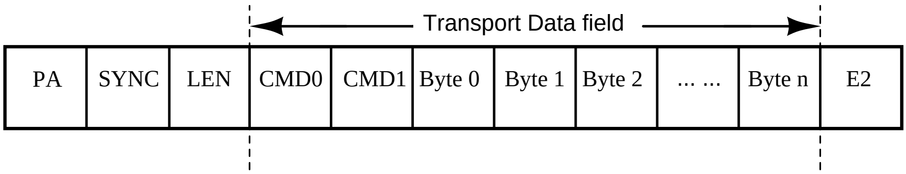

Figure 5.2.3: Frame format for 212 and 424 kbps.

The communication starts with the preamble sequence (PA) of minimum 48 bits with all logical "ZERO" encoded. The synchronization SYNC contains two bytes and shall be set to 0xB2 and 0x4D. The LEN byte shall be set to the length of the Transport Data field plus 1. The value of LEN shall be in the range of 3 to 255. E2 is the CRC for the Frame format of 212 and 424 kbps.

In active communication, the frame format for initialization does not differ from the frame format for data exchange. Communication at 106 kbps is done with the frame format shown in Figure 5.2.2 and communication at the higher bit rates is done with the frame format shown in Figure 5.2.3.

5.3 Modulation

5.3.1 Load Modulation

Using the principle of load modulation, data from a passive target can be transmitted back to the reader. If a target with a resonance frequency equal to the transmission frequency of the reader is placed within the magnetic alternating field of the reader's antenna, the target will be powered by the magnetic field. When a load resistor is switched on and off at the target, the voltage changes at the reader's antenna due to the impedance change in the target resulting in amplitude modulation at the reader's antenna. This is true when the target is located within the near field of the reader's antenna. The transition to the far field occurs at 0.16 λ. If the data on a chip controls the timing with which the load resistor is switching, then this data can be sent from the target to the reader.

5.3.2 Modulation with Subcarrier

Due to the weak coupling factor between the reader's and the target's antenna, the target's response is approximately 80 dB lower than the voltage generated by the reader. The detection of such a signal requires complicated receiving circuitry. Instead of using direct load modulation as explained in 5.3.1, the target uses a subcarrier frequency f_s to modulate data.

When an additional load resistor in the target is switched on and off at a high frequency f_s, two modulation sidebands are created at a distance of $\pm f_s$ from the carrier frequency of the reader f_c, see Figure 5.3.1.

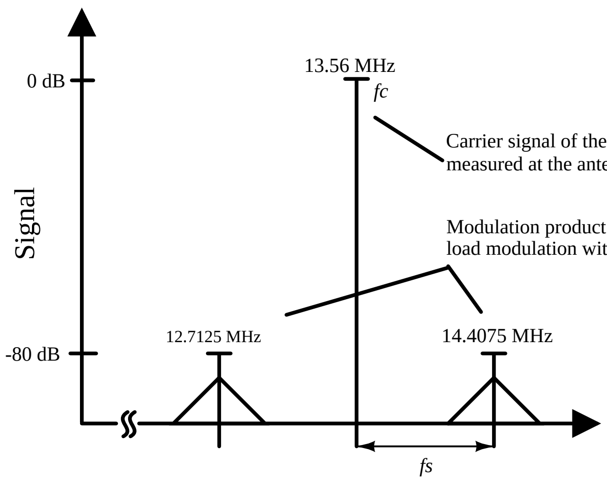

Figure 5.3.1: Modulation products using load modulation with a subcarrier.

To separate the sidebands from the significantly stronger carrier signal, band-pass filtering is used. The filtered subcarrier signal is then amplified at the reader, making it easy to demodulate.

The procedure for subcarrier load modulation is as follows:

- The target generates the subcarrier frequency $f_s = f_c/16 = 847.5$ kHz for the bit rate 106 kbps.
- Data is coded using Manchester coding.
- The Manchester coded data is then modulated at the subcarrier frequency.
- Finally, the subcarrier load modulation is completed.

Two sidebands have now been generated due to the subcarrier load modulation. The upper sideband is located at 14.0475 MHz and the lower one at 12.7125 MHz.

In Figure 5.3.2 the approach of load modulation with a subcarrier is illustrated.

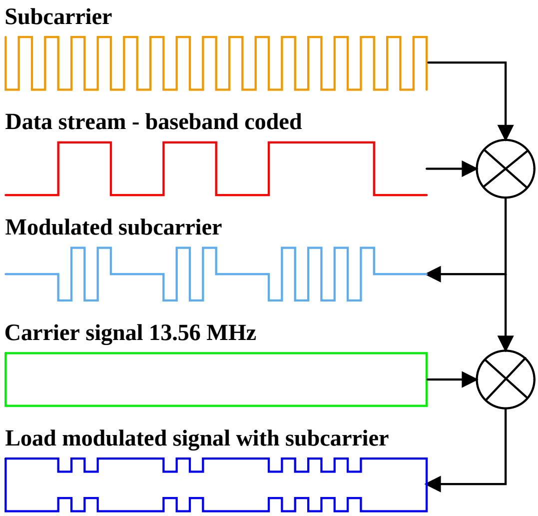

Figure 5.3.2: Step-by-step generation of a load modulated signal with a subcarrier.

5.3.3 Digital modulation methods

In NFC, data transfer is made possible through ASK, PSK or FSK modulation of the subcarrier in time with the data flow.

ASK Amplitude-shift keying is a type of digital modulation that shows digital data in the form of variation in the amplitude of a carrier wave. For binary levels, a 1 is represented by the standard carrier wave and a 0 is represented by a carrier wave with zero amplitude. This type of ASK is called 100 % ASK or on-off keying and is the most basic type of ASK. The percentage defines how much the amplitude is reduced so e.g. 30 % ASK would mean that a logical 0 reduces the amplitude level to 70 % compared to the amplitude level of a logical 1.

PSK Phase-shift keying is another type of digital modulation. It shows digital data in the form of variation of the phase of a carrier wave. For binary phase-shift keying, BPSK, the shift is 180 degrees and for quadrature phase-shift keying, QPSK, the phase shift is 90 degrees. Using QPSK over BPSK enables either higher data rates or lower bandwidth requirements depending on the need.

FSK FSK shows digital data in the form of variation of the frequency of a carrier wave. For binary frequency-shift keying, BFSK, a logical 0 is represented by one frequency and a logical 1 is represented by a different frequency.

Chapter 6

Standardization

NFC is already on its way to becoming a part of everyday life and in order to achieve successful consumer adoption of this technology, involved companies need to work together closely and applications need to be interoperable.

NFC is described in the two standards Near Field Communication Interface and Protocol 1 (NFCIP-1, ECMA-340/ISO 18092) and 2 (NFCIP-2, ECMA-352/ISO 21481). NFC is built upon the RFID standard ISO 14443 and became specified in ISO 18092 in 2003 and in ECMA-340 later on. Test specifications for the RF interface are found in ECMA-356/ISO 22536 and protocol tests are specified in ECMA-362/ISO 23917.

NFC incorporates proximity cards of both type A and type B together with Felica and can therefore show basic interoperability and communicate with already existing reader infrastructure. NFCIP-2 which is defined in ISO/IEC 21481 and ECMA-352 is a gateway between the existing interface standards.

In 2004, the NFC Forum was formed with its main objectives to promote the use of NFC technology in consumer devices and services, provide an extensive framework for interoperable applications by developing standards based specifications, and ensure that products and devices claiming to be NFC compliant conform to the forum specifications. The NFC forum is a non-profit association with the aim to evaluate the technology and ensure interoperability. Thus, they have developed standards based on ISO, ECMA and EMVCo.

6.1 ISO/IEC and ECMA

The ISO/IEC and ECMA NFC standards are the main focus of this thesis. The reason for this is that the NFC Forum RF specifications have not yet been finalized. The ISO/EIC and ECMA standards for NFC are basically identical and will hereby only be referred to as ECMA.

6.1.1 ECMA-340, NFC - Interface and Protocol

This standard defines the communication modes for Near Field Communication Interface and Protocol (NFCIP-1). It defines both the active and the passive communication modes of NFC in order to realize a communication network using NFC devices. The standard specifies RF field, RF signal interface, general protocol flow, initialization, transport protocol and includes CRC calculation methods in its appendix.

The testing specifications for ECMA-340 are ECMA-356, RF Interface Test Methods, and ECMA-362, Protocol Test Methods. The ISO variant of this standard is ISO 18092.

6.1.2 ECMA-356, RF Interface Test Methods

This test standard specifies a test setup used for NFC devices and compliance tests for the RF interface. The ISO variant of this standard is ISO 22536. The test setup used during the thesis is assembled according to this standard.

Test Setup

The test setup consists of a calibration coil, a test assembly and two reference devices. The test assembly itself consists of two sense coils connected to a compensation board and a field generating antenna as illustrated in Figure 6.1.1.

Figure 6.1.1: Test assembly.

Calibration Coil The ECMA-356 standard describes the layout of a calibration coil that permits the measurement of magnetic field strengths in the frequency range of 13.56 MHz. This way, the field strengths and initiator signals are measured and validated before they are applied to the DUT. The calibration coil can also be used to measure ASK modulation levels in the reader signal. During the field strength measurement, particular care should be taken to ensure that the calibration coil is only subjected to high-ohmic loads by the connected measuring device, as every current flow in the calibration coil can falsify the measurement result.

A high impedance oscilloscope probe (e.g. >1 MΩ, <14 pF) shall be used to measure the open circuit voltage in the coil. The open circuit calibration factor for this coil is 0.32 V_{RMS} per A/m. This is equivalent to 900 mV_{pp} per A/m.

Field Generating Antenna A precise and reproducible measurement of the load modulation signal at the antenna of a reader is very difficult due to the weak signal. The standard therefore defines a compensation board, which can be used to compensate the reader's own strong signal. The measuring arrangement for this consists of a field generating antenna and two parallel sense coils. The field generating antenna shall be tuned to 50 Ω by the matching circuit located on the antenna PCB, using suitable measurement equipment such as an impedance analyzer or a measurement bridge.

Sense Coils The two sense coils are located on the front and back of the field generating antenna, each at the same distance from it. They are connected in phase opposition to one another so that the voltages induced in the coils cancel each other out, see Figure 6.1.2. In the unloaded state, the output voltage of this circuit arrangement therefore tends towards zero. A low residual voltage, which is always present between the two sense coils as a result of tolerance-related asymmetries can be compensated by the potentiometer on the compensation board.

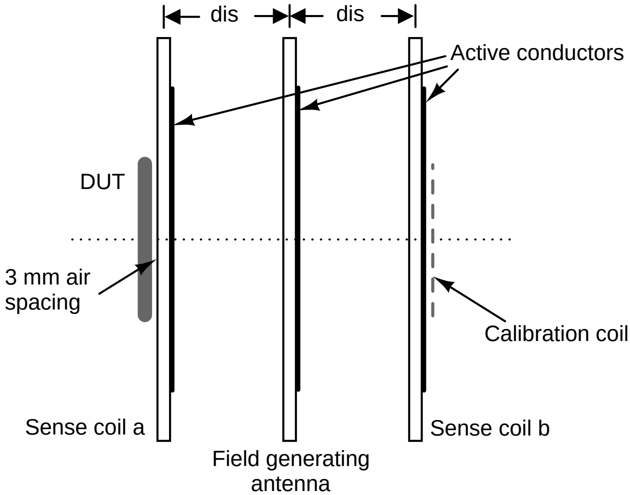

Figure 6.1.2: Test assembly.

Reference Devices Reference devices are needed to be able to verify that an initiator generates a field between H_{min} and H_{max} when a loaded target is within the operating volume. The initiator shall be capable of supplying a target with sufficient energy in the whole operating volume defined for the initiator. These devices are also used to verify that an initiator does not generate a field stronger than H_{max}. Both devices use the same antenna coil and can be seen in Figure 6.1.3.

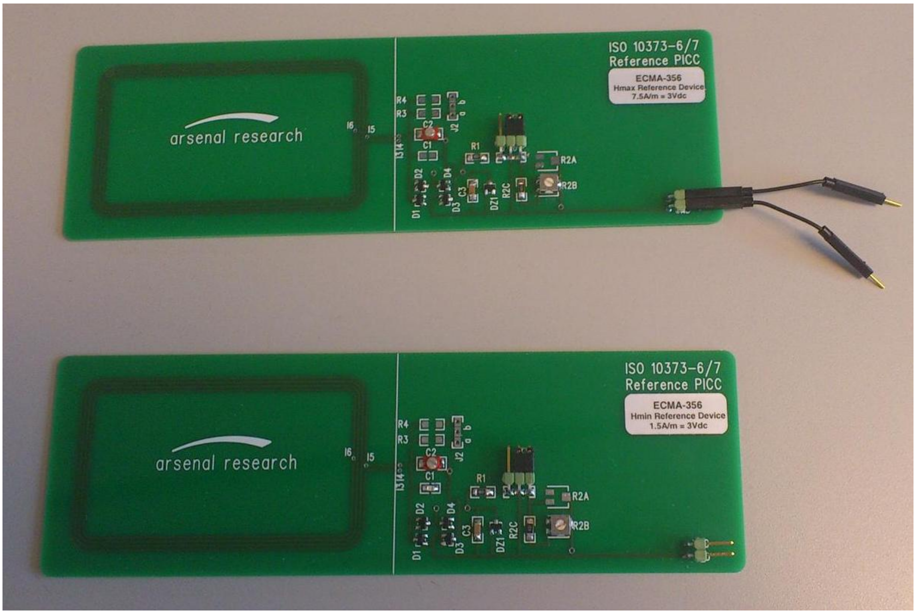

Figure 6.1.3: Reference devices for measuring H_{min} and H_{max}.

RF Interface - Target Tests

This section describes the tests performed on a DUT in target mode.

Target RF Level Detection The purpose of this test is to verify that a device detects an outer RF field stronger or equal to $H_{threshold}$ and does not activate its own RF field as long as this field exceeds $H_{threshold}$. The test assembly described in 6.1.2 is used. To determine the generated field strength, the calibration coil is connected to an oscilloscope. The signal levels generating the corresponding RF fields between 0 and H_{max} are measured without a DUT.

The DUT is set to initiator mode while the signal generator is set to generate an unmodulated signal at the carrier frequency 13.56 MHz. The signal should be increased from $H = 0$ to $H = H_{max}$, where H_{max} is the maximum field verified with the calibration coil, without the target. An oscilloscope is used to measure at which values the DUT switches off its RF field. If the DUT switches off its RF field for values equal to or above $H_{threshold} = 0.1875\ A/m$ and switches on its RF field for values below $H_{threshold}$ the test passes.

Target Passive Communication Mode The purpose of this test is to determine the amplitude of the sidebands of the load modulated signal from the passive target. This test shall be done for field strength values between H_{min} and H_{max}. The amplitude shall be at least:

$$A_{min} = \frac{30}{H^{1.2}}\, mV_p \tag{6.1.1}$$

This means that for a field strength of 1.5 A/m (H_{min}), the minimum amplitude is

$$\frac{30}{1.5^{1.2}} \approx 18.44\, mV_p$$

and for a field strength of 7.5 A/m (H_{max}), the minimum amplitude A_{min} is

$$\frac{30}{7.5^{1.2}} \approx 2.67\, mV_p$$

This test shall be performed for the three specified bit rates, 106 kbps, 212 kbps and 424 kbps. Since different bit coding schemes are used for 212 kbps and 424 kbps compared to 106 kbps, the test methods are slightly different.

In the 106 kbps case, a SENS_REQ command shall be sent to the DUT to obtain a SENS_RES. The amplitude of the upper sideband at $f_c + f_s$ and the lower sideband $f_c - f_s$, the applied fields and modulations shall be measured in this test. Exactly two subcarrier cycles of the sampled modulation waveform shall be Fourier transformed. If the amplitude of the sidebands is above A_{min} the test passes.

For 212 kbps and 424 kbps a polling request is sent to the DUT to obtain a polling response. If the amplitude of the sidebands is above A_{min} the test passes. This test shall be repeated with different field strengths values.

Target Active Communication Mode The purpose of this test is to verify that the generated RF field and modulation of active targets fulfill the specifications when the field strength is varied between H_{min} and H_{max} for the three specified bit rates, 106 kbps, 212 kbps and 424 kbps.

The modulation levels and pulse shapes generated by the DUT shall be verified. If the modulation index of the targets RF field, the timing of the RF field generation and the command sequence at all data rates are according to specification, the test passes.

The modulation index is defined as $\frac{(a–b)}{(a+b)}$ where a and b are the peak and the minimum signal amplitude respectively with the value of the index expressed as a percentage.

RF Interface - Initiator Tests

This section describes the tests performed on a DUT in initiator mode.

Initiator Field Strength The purpose of this test is to verify that an initiator generates a field between H_{min} and H_{max} in the entire operating volume in active and passive communication mode. The test is carried out with the reference devices described in 6.1.2.

For the testing of H_{max}, the reference device is tuned to 19 MHz. The voltage measured with a high impedance voltage meter should be 3V DC for a field equal to H_{max}. The reference device is placed within the operating volume of the initiator and the test passes if the voltage across the resistor R_2 on the reference device does not exceed 3V DC at any position or angle with respect to the DUT.

For the testing of H_{min}, the reference device is tuned to 13.56 MHz. The voltage measured across R_2 with a high impedance voltage meter should be 3V DC for a field equal to H_{min}. The reference device is placed within the operating volume of the initiator. The test passes if the voltage across R_2 exceeds 3V DC within the defined operating volume.

The calibration of the reference devices is described in 8.1.4.

Initiator Modulation Index and Waveform The purpose of this test is to investigate the initiator signal to assure that modulation index, overshoots, rise and fall times are according to specification within the defined operating volume in active and passive communication mode.

The calibration coil is positioned within the operating volume of the initiator. The characteristics of the modulated signal are investigated using an oscilloscope connected to the calibration coil. The procedures for measuring the rise and fall times, overshoots and modulation index for the bit rates 106, 212 and 424 kbps are described in 8.1.5.

6.2 NFC Forum

The NFC Forum is a group of members who develop NFC specifications, ensures interoperability among devices and services, promotes the use of NFC technology and educates the market about it as well. It was formed in 2004 and has over 150 different members ranging from manufacturers, application developers, financial services institutions and more. The NFC Forum aids all interested parties in creating new consumer-driven products and applications through the provided frameworks in the specifications.

The main goals of the NFC Forum are to:

- Develop standards-based NFC specifications that define architecture and interoperability parameters for NFC devices and protocols.
- Encourage the development of products using NFC Forum specifications.
- Work to ensure that products claiming NFC capabilities comply with NFC Forum specifications.
- Educate consumers and enterprises globally about NFC.

As of December 2010, the NFC Forum has developed and adopted a total of 15 specifications. In this report, three specifications will be described. The first is the NFC RF Analog Technical Specification followed by NFC RF Analog Test Specification and finally the NFC Digital Protocol Technical Specifications.

6.2.1 NFC RF Analog Technical Specification Draft 0.34

This document covers the analog interface of an NFC Forum Device. The device shall support Peer Mode Initiator, Peer Mode Target, Reader/Writer Mode and Card Emulation Mode for the three technologies NFC-A, NFC-B and NFC-F for the bit rates 106 kbps, 212 kbps and 424 kbps. The purpose of the specification is to characterize and specify power, transmission, and receiver requirements as well as time, frequency and modulation characteristics for an NFC Forum Device without specifying a design of the antenna.

In short, the document provides a specification that can be used as the basis for testing and approvals. The NFC RF Analog Technical Specification is currently in a draft version and is slated for a September 2011 release.

NFC Technologies The different NFC technologies defined in the Analog Technical Specification use the same frequency but use different modulation schemes, bit level coding and frame formats. The protocols and commands may also differ. Table 6.1 illustrates the characteristics.

Technology	Direction	Modulation scheme	Bit coding
NFC-A	Initiator-Target	100 % ASK	Modified Miller
	Target-Initiator	On-Off Keying	Manchester
NFC-B	Initiator-Target	10 % ASK	NRZ-L
	Target-Initiator	BPSK	NRZ-L
NFC-F	Both	10 % ASK	Manchester

Table 6.1: Comparison of NFC technologies.

NFC Forum – Reference Devices

In order to perform all the various tests stated in the Analog Test Specifications, a number of different devices called NFC Forum – Reference Polling Devices and NFC Forum – Reference Listening Devices are needed. Signal generators and power amplifiers are needed to allow the NFC Forum – Reference Polling Devices to send commands while the response from an NFC Forum - Reference Listening Device can be observed through e.g. a connected oscilloscope.

An NFC Forum – Reference Polling Device is used when a Listening Device is to be tested and an NFC Forum – Reference Listening Device is used when a Polling Device is to be tested.

NFC Forum – Reference Polling Devices The NFC Forum – Reference Polling Devices allow commands to be transferred to a Listening Device. There are three different kinds of polling devices, each with its own antenna coil design, based on different standards. Poller-0 is based on the standard EMVCo PCD whereas Poller-3 and Poller-6 are based on compensated versions of the ISO standardized PICC antenna coil design. The NFC Forum – Reference Polling Devices can be seen in Figures 6.2.1-6.2.3.

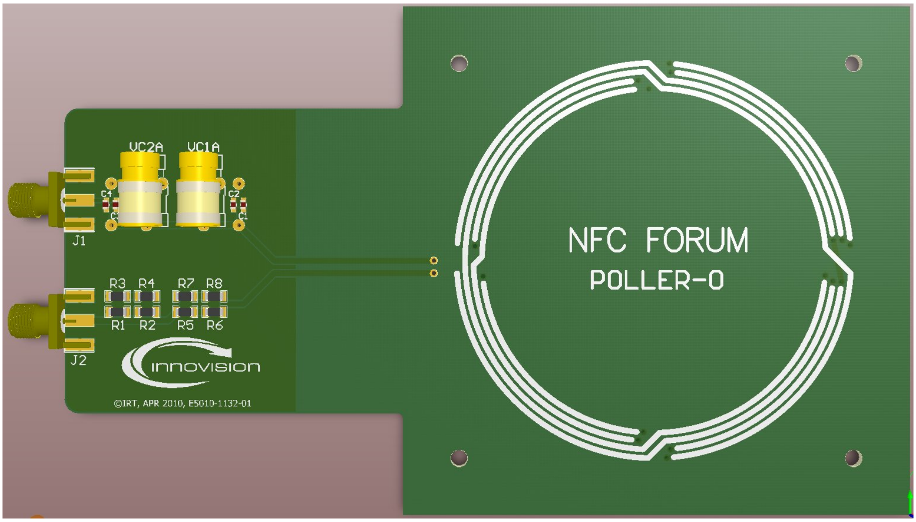

Figure 6.2.1: NFC Forum Reference Poller-0.

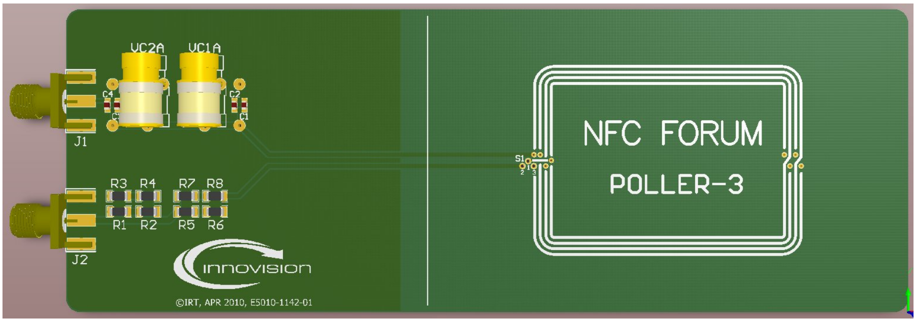

Figure 6.2.2: NFC Forum Reference Poller-3.

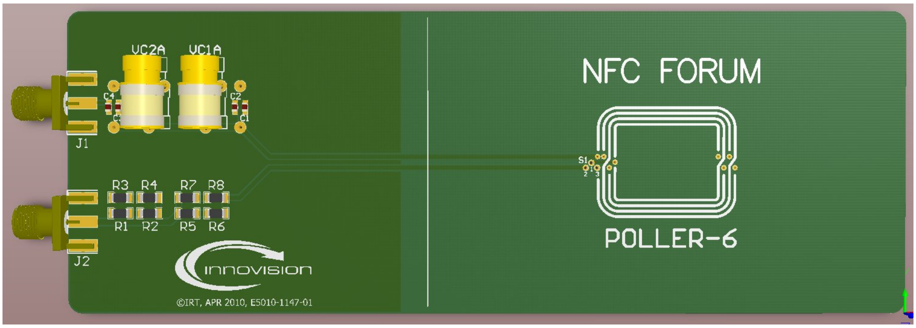

Figure 6.2.3: NFC Forum Reference Poller-6.

NFC Forum – Reference Listening Devices The NFC Forum - Reference Listening Devices allow the signals obtained by a Polling Device to be analyzed. Like the NFC Forum – Reference Polling Devices, the NFC Forum – Reference Listening Devices each have their own antenna coil design. Listener-1, Listener-3 and Listener-6 are based on the outside envelope measurements of the ISO referenced PICC-1, PICC-3 and PICC-6 antenna designations, respectively. The NFC Forum – Reference Listening Devices come equipped with an integrated sense coil. They can send back information through load modulation and be configured with a number of fixed resistive loads. The NFC Forum – Reference Listening Devices can be seen in Figures 6.2.4-6.2.6.

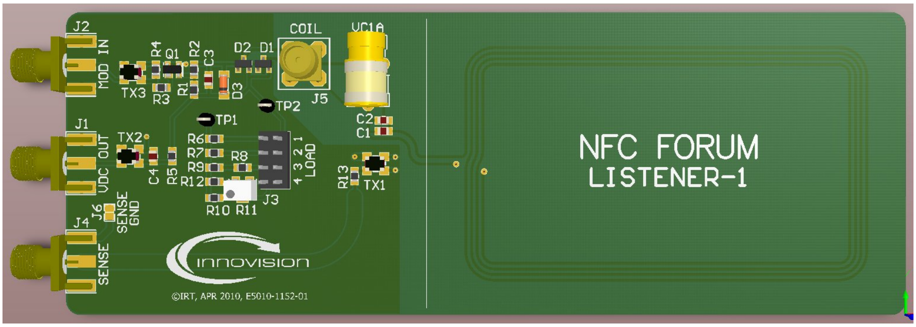

Figure 6.2.4: NFC Forum Reference Listener-1.

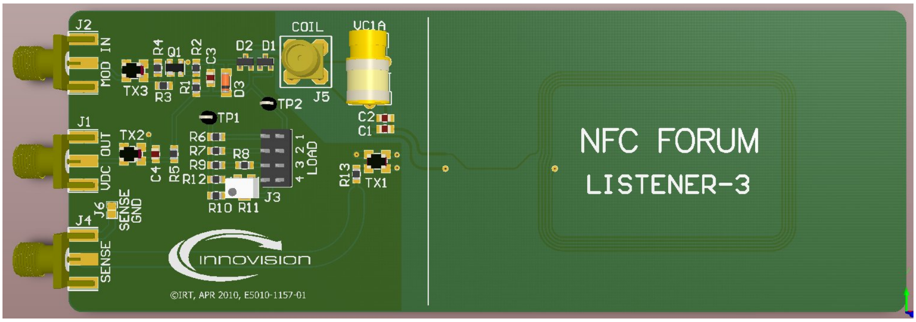

Figure 6.2.5: NFC Forum Reference Listener-3.

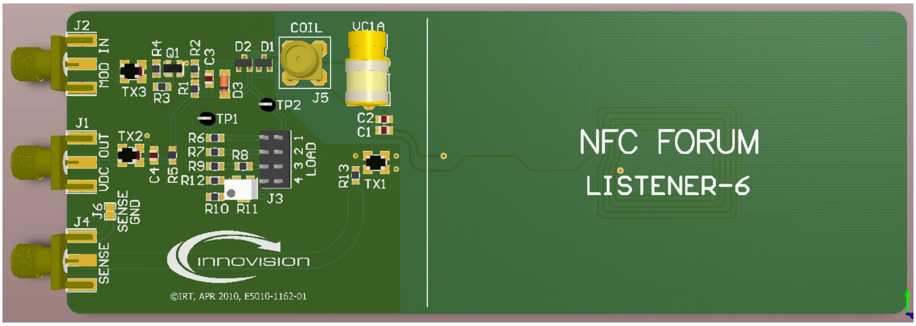

Figure 6.2.6: NFC Forum Reference Listener-6.

Test Descriptions

Each test that has to pass in order to comply with the NFC RF Analog Technical Specification is described with a small introduction, purpose, context and requirements. It is important to note that this document does not contain the actual test instructions but rather general requirements of the tests. The first tests describe requirements for the unmodulated signals. The following tests explain the signal interface requirements between a Reference Polling Device and a Listening Device and a Reference Listening Device and a Polling Device, respectively.

Appendices

The first appendix provides all the specific numerical values for operating volume, RF power and signal interface. It also provides setup values and nominal settings as well as calibration procedures for the NFC Forum Reference Devices.

The second appendix provides all the design information for the NFC Forum Reference Devices including circuit diagrams, PCB layouts and mechanical dimensions.

6.2.2 NFC RF Analog Test Specification Draft 0.16

This document explains in detail the test cases for the NFC RF Analog Technical Specification. Its purpose is to provide detailed instructions on how each test from the Analog Specification should be executed. It is important to note that this specification is under construction and a few chapters are either very short or completely blank. It is currently scheduled for a February 2012 release.

Positioning Conventions and Requirements

The specification elaborates on environment requirements, naming conventions, operating volume and test position definitions. There is, as of this report, no exact definition for how many test positions must be passed for a DUT to pass completely. It is still under discussion by the members of the NFC Forum and so far there are only suggestions that are still being evaluated. In Figure 6.2.7, the operating volume with the defined test points, in blue, is shown.

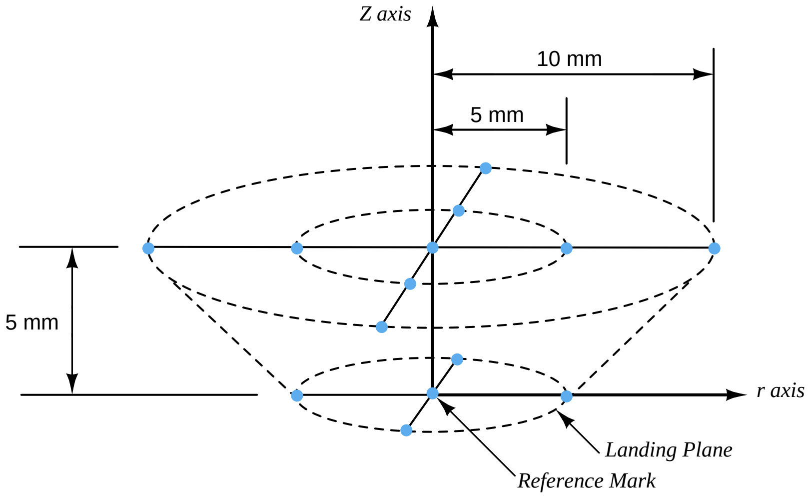

Figure 6.2.7: Operating volume.

Test Bench

The test bench needed for the measurements consists of the NFC Reference Devices and external measurement equipment. The role, requirements and configuration together with uncertainty ranges of each part of the test bench are explained. The complete test bench setup is shown in Figure 6.2.8.

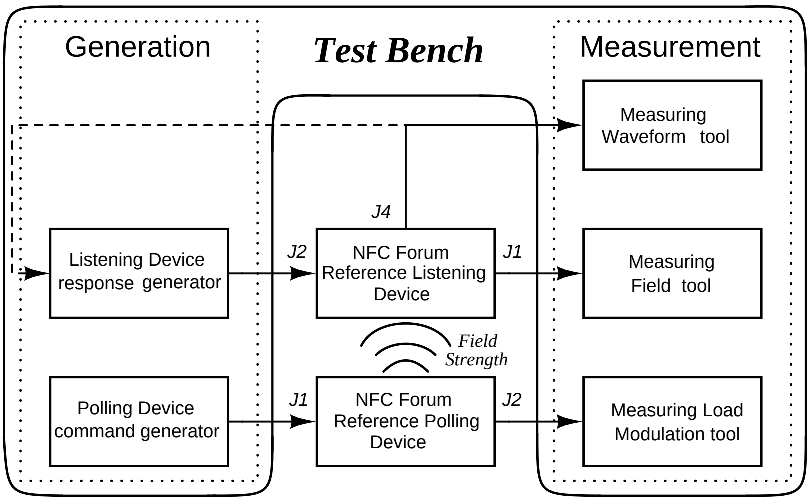

Figure 6.2.8: NFC Forum Test Bench.

Calibration requirements for the test bench and result evaluation are currently missing from the specification.

Test Case Structure

Each test contains the following information:

Section	Explanation
TC Id	Name of test case.
RQ reference	General Requirement reference in RF Analog Specification.
Section reference	Specific section reference in RF Analog Specification.
Test Purpose	Description of test case.
Comments	If necessary, specific information on test case.
Conditions	All reference antennas to be used, setup values and test positions.
Test Configuration Functions	Specific test bench configurations used to achieve tests case.
Acceptance criteria	Describes the acceptance criteria.
Step	Detailed test case procedures.

Table 6.2: Structure of a test case.

Appendices

Annex A contains all the specific numerical values for operating volume, RF power and signal interface and is taken from the RF Analog Spec.

Annex B contains the acceptance conditions for the used measurement tool. These conditions are not completely decided and are still under discussion by the NFC Forum.

Annex C to E are under construction.

6.2.3 NFC Digital Protocol Technical Specification 1.0

The scope of this document covers the digital interface and the half-duplex transmission protocol of the NFC Forum Device in its four roles (Peer Initiator, Peer Target, Reader/Writer, and Card Emulator). The following properties and requirements for NFC-A, NFC-B and NFC-F are explained:

- Sequence format
- Bit level coding
- Frame format

- Data and payload format
- Command sets
- Frame delay and guard times

Active Communication mode is not described in the current version of this document.

6.3 EMVCo

EMVCo is a corporation owned by VISA, American Express, MasterCard and JCB and was formed in February 1999. EMVCo is responsible for several things such as managing, maintaining and enhancing the EMV Integrated Circuit Card Specifications for Payment Systems and also ensuring interoperability and acceptance of payment system integrated circuit cards across the world. The EMVCo standards are therefore the ones to follow when an NFC Device with Card Emulation mode is to be designed and tested. The main focus is laying down the frameworks for wireless payments and making sure they are secure.

EMVCo has several specifications but only one is targeted for contactless payments. The report will therefore only cover that specification.

EMV Contactless The EMV Contactless specification contains itself a few specifications. The report will once again not use all of them since some of the specifications are targeted for payment terminals. The relevant documents are EMV Contactless Communication Protocol Specification v2.0.1 and Level 1 Test Equipment Specifications. The latter contains PICC Manual, PCD Manual, CMR Manual and Gerber Files with the necessary design material for assembling the required EMV Reference Equipment. Note that to get a hold of the equipment specification, an EMVCo subscription of at least Subscriber level is required.

6.3.1 EMV Contactless Communication Protocol v2.0.1

This document describes basic theory, reference equipment, operating volume definition, PCD/PICC requirements and sequences. The specification is mostly based on the ISO RFID standards 14443-1,-2,-3 and 4.

EMV Contactless Level 1 Test Equipment The test equipment consists of three parts:

- EMV - TEST PCD
- EMV - TEST PICC
- EMV - TEST CMR

Just like the ECMA Test Assembly, the EMV – TEST PCD is fed from a signal generator and then used for testing DUTs in target mode. [1]

The EMV – Test PICC is used for testing signals sent out by DUTs in initiator mode and can also send back information through load modulation. The responses from a DUT can then be analyzed through the EMV – TEST CMR.

Additional information regarding the reference equipment can be found in EMV Contactless Specifications for Payment Systems – Level 1 – Test Equipment Specifications – PCD, PICC and CMR manual, respectively.

RF Power, Signal Interface, Sequences and Frames The rest of the document covers the technical descriptions, requirements and test procedures for each case. It follows the same pattern as the ECMA and NFC Forum documents by providing PCD/PICC requirements, how coding should be done, how frames and commands should look like, etc.

Since Card Emulation mode is not supported in Android 2.3 Gingerbread these tests aren't possible to make on handsets with Android until the software support is implemented.

Appendices Annex A contains specific and nominal values for the different parameters throughout the document.

Annex B and C contains measurement and position conventions as well as specifications for how the contactless symbol at a point of sale should look like.

Annex D contains a flowchart describing how a DUT in initiator mode distinguishes between any detectable disturbance and real transmission errors in the response from the DUT in target mode.

[1]

The document actually uses the word PICC for a DUT in target mode and PCD for a DUT in initiator mode but it was decided to use DUT to be more consistent in the report.

Chapter 7

Measurement Setup

The main objective of the thesis was to assemble a measurement system for testing of NFC-enabled devices. In the beginning of the thesis, two different suppliers were considered for the test assembly. The first option was Micropross, a French world-leading provider of smartcard testing tools. The other one was AIT, an Austrian application-oriented R&D company. Due to time constraints, delivery time was a very important factor and since AIT had a shorter delivery time on the test assembly than Micropross and cost half as much, it was decided that the assembly should be ordered from AIT. AIT only delivered a test assembly with no software or hardware and thus additional hardware was required to perform the measurements. Rohde & Schwarz equipment was chosen for the AIT test assembly. A complete test solution from Micropross was acquired a few weeks before the end of the thesis and we were therefore also able to perform measurements with this system.

This chapter describes the instruments and tools that are used to perform the necessary tests.

7.1 Rohde & Schwarz / AIT

The R&S/AIT measurement setup can be seen in Figure 7.1.1. It consists of a signal generator, a test assembly, an oscilloscope, a spectrum analyzer and an amplifier.

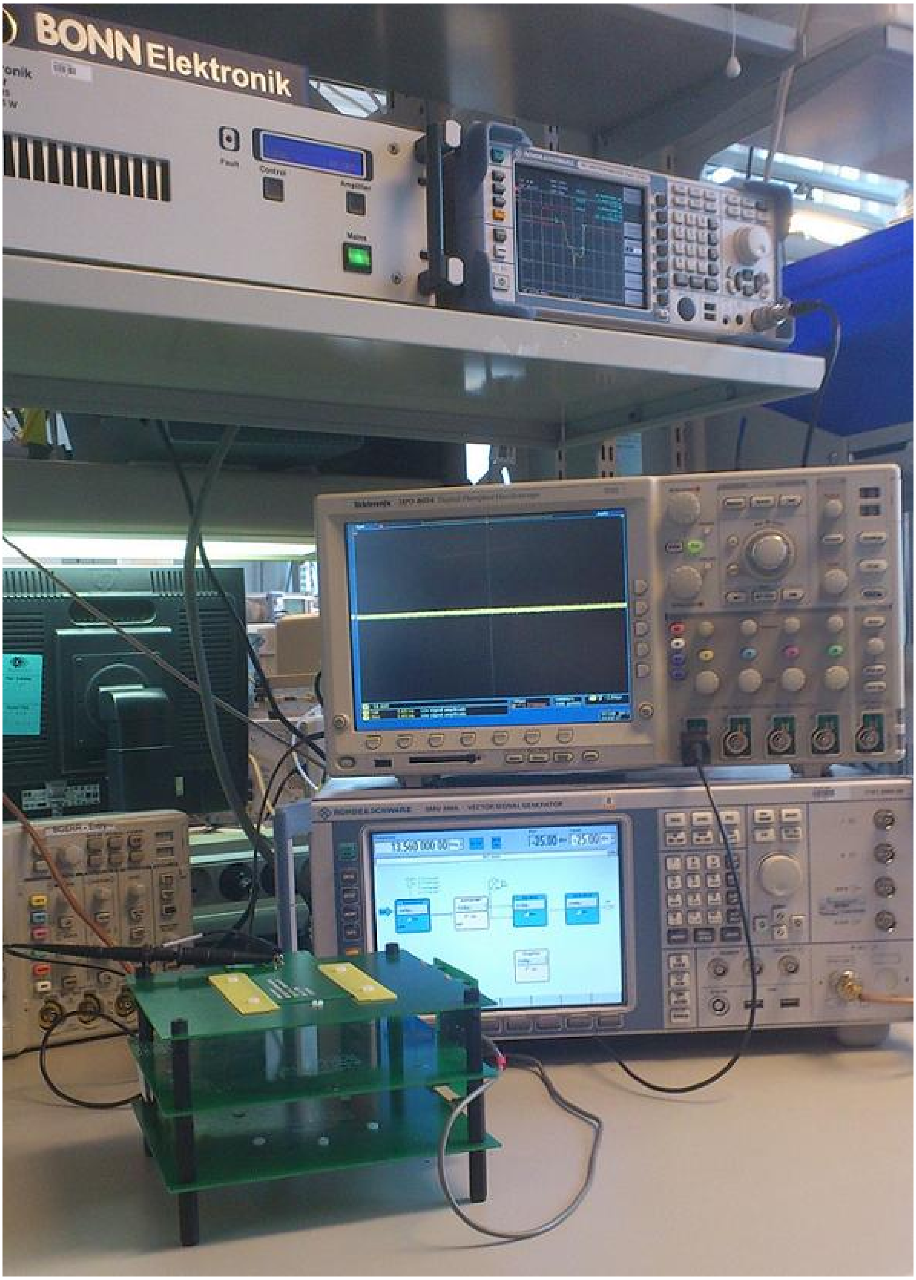

Figure 7.1.1: Test setup R&S / AIT.

7.1.1 Signal Generator

To drive the field generating antenna in the test assembly described in 6.1.2 a signal generator was used. The signal generator was a Rohde & Schwartz SMU 200A with an added software option called K6. This option was needed for communication between the SMU 200A and the R&S K6 Pulse Sequencer software described in 7.1.6.

7.1.2 Test Assembly

The assembly was delivered with a 50 Ω SMB connector mounted on the PCB with the field generating antenna. Since this type of connector was not used at Sony Ericsson and no adapters were acquirable within a reasonable time, the SMB connector was replaced with an SMA connector. The test assembly was built according to the ECMA-356 standard as explained in 6.1.2.

7.1.3 RF Amplifier

While making the initial tests we realized that the 20 dBm output power delivered by the SMU 200A to the field generating antenna was not enough to generate the necessary field strength. The maximum generated field strength was approximately 1 A/m with no amplifier. This was far from the maximum necessary value of 7.5 A/m. After thorough research it was decided that a 25 W amplifier would be sufficient for use in this setup. The amplifier BSA 0125-25 from BONN Elektronik was chosen due to short delivery time. While waiting for the amplifier to arrive, another amplifier was borrowed from Perlos AB. The output power of this amplifier was only 3 W but that was enough to perform some of the measurements.

7.1.4 Spectrum Analyzer

The spectrum analyzer was used for studying the rise and fall times using zero span. Although this may seem a bit unorthodox, the oscilloscope provided by Sony Ericsson during the thesis was not suitable for measuring the timings. The spectrum analyzer gave us better precision since it allowed us to place markers at the desired amplitude levels on the rising and falling edges of the pulse.

7.1.5 Digital Oscilloscope

The oscilloscope was used to check the sent commands sequences and do all the required measurements. The oscilloscope used was a Tektronix DPO 4054.

7.1.6 Software

The computer software used was R&S K6 Pulse Sequencer. The reason for using this software was that it allowed complex pulses and pulse patterns to be generated and sent to the SMU 200A through any VISA interface. The software also supported custom plug-ins for additional test cases.

7.2 Micropross

The Micropross measurement setup can be seen in Figure 7.2.1. It consists of a signal generator, a test assembly, an oscilloscope and an amplifier.

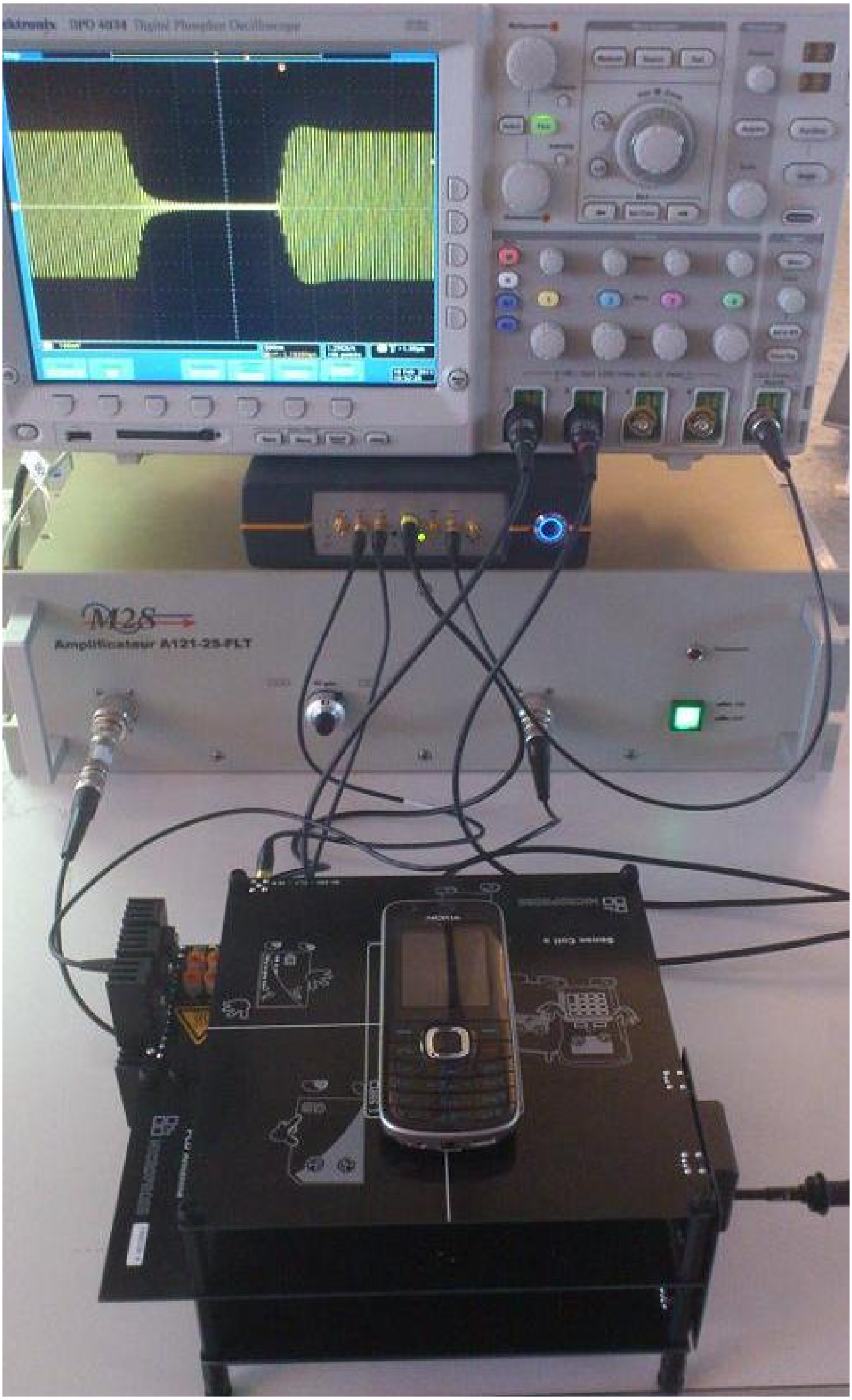

Figure 7.2.1: Test setup Micropross.

7.2.1 Signal Generator

The Micropross solution uses a proprietary signal generator called TCL2. It does not have a display and is completely controlled by the MP Manager software described in 7.2.5.

7.2.2 Test Assembly

The test assembly is mainly built according to ECMA-356 and has a few additions:

- Integrated calibration coil beneath the lower sense coil on the test assembly.
- A 3,5 mm TRS connector on the field generating antenna PCD. This connector allows the TCL2 to make the choice between the two antenna matchings used for the lower and higher data rates, respectively.
- A connector on the upper sense coil allowing the signal from the DUT to be sent back to the TCL2.

7.2.3 RF Amplifier

The amplifier is an M2S A121-25-FLT and has a variable RF gain adjustment on the front panel. This is needed since the output power cannot be adjusted manually from the TCL2.

7.2.4 Digital Oscilloscope

The oscilloscope is a Tektronix DPO 4034 and is one of the few oscilloscope models that are compatible with the Micropross solution today. The oscilloscope is completely controlled by the MP Manager software for the target tests while some manual configurations have to be done for the initiator tests.

7.2.5 Software

The computer software used is called MP Manager. MP Manager is used to control the TCL2 and is a fully integrated development environment. The program can be used to:

- Edit and run script files along with complete test suites.
- Spy on the communication between the reader and a target and then visualize the log events.
- Execute electrical tests functions for calibration purposes.
- Plot graphs that represent how a particular test passes or fails when parameters like frequency or voltage are varied while the test is executed repeatedly.

The software requires a license together with a USB key to be run. If the software is to be run on another computer, the license must first be removed and then entered on the new computer along with the USB key. Micropross has however confirmed that it will shift this license model to a floating license.

Chapter 8

Measurement Procedure

8.1 Rohde & Schwarz / AIT

Calibration and Configuration Since all the tests where the DUT is in target mode are supposed to be done with linear increasing field strength of up to 7.5 A/m, the required power levels must be noted beforehand. The process of measuring the field strength up to H_{max} should be done through the calibration coil with no DUT on the test assembly.

Before any measurements are made, the test assembly has to be calibrated. The first part of the calibration is to make sure that the impedance matching circuit on the field generating antenna PCD is adapted to the SMU 200A output impedance of 50 Ω.

The command sequences used are sent to the DUT with the K6 Pulse Sequencer Software. To start with, the NFC project is loaded through the file menu. The project contains all necessary plug-ins and sequences to perform the RF Interface tests. The command to be sent is selected in the sequence library and built into a waveform. When the waveform is created the final settings such as frequency and output power for the SMU 200A are set on the transfer tab.

Note that care should be taken to make sure that the defined output power from the software does not exceed the maximum input power of the amplifier used!

Triggering the oscilloscope can be quite tricky but since the pulse lengths for the different bit rates are known it makes the procedure easier. Pulse triggering is selected with the corresponding pulse width for the different bit rates. The appropriate threshold level is adjusted depending on the chosen polarity.

Reader Field Strength The field strength emitted from the test assembly is determined by a high-impedance voltage measurement using the oscilloscope connected to the calibration coil of the test assembly. The field strength is then calculated from the measured voltage at the calibration coil, where every 0.32 V_{RMS} of measured voltage corresponds to a field strength of 1 A/m as shown in equation 8.1.1.

$$Fieldstrength_{PCD} = \frac{V_{CalibrationCoil}}{0.32\,V}\,A/m \tag{8.1.1}$$

8.1.1 Target RF Level Detection

The purpose of this test is to verify that the DUT detects an external RF field with a field strength in the range of $H_{Threshold}$ up to H_{max} as described in 6.1.2.

The DUT is placed concentric with the sense coil and put into initiator mode.

- Signal Generator

The SMU 200A is set to generate an unmodulated RF-field at 13.56 MHz. The field strength is then increased linearly from 0 up to H_{max} and the output power level where the phone switches off its RF field is noted. This value is then used to measure the corresponding field strength with the calibration coil.

- Oscilloscope

When a DUT set to initiator mode is placed on the test assembly, the voltage induced in the closest sense coil will be altered due to the RF field generated by the DUT. The signal at the output of the compensation board will therefore be out of balance and not be attenuated by the two counter phased sense coils. This makes it easy to detect whether the DUT has its RF field switched on or off.

8.1.2 Target Passive Communication Mode

The purpose of these tests is to determine the amplitude of the target's load modulation signal while varying the field strength in the range of H_{min} and H_{max} as described in 6.1.2. The DUT is placed on the test assembly, concentric with the sense coil.

- K6 Pulse Sequencer

A SENS_REQ command sequence is sent to the DUT for the bit rate 106 kbit/s to obtain a SENS_RES. For the higher bit rates a Polling Request command sequence is sent to the DUT to obtain a Polling Response.

- Signal Generator

The output power is varied between H_{min} and H_{max}.

- Oscilloscope

The oscilloscope is set to pulse trigging with a pulse width greater than 2 microseconds for the lower bit rate. The pulse width is reduced when the bit rate is increased. Exactly two subcarrier cycles of the sampled modulation waveform is Fourier transformed. The sidebands are located at $f_c \pm f_s$, 12.7125 and 14.4075 MHz respectively for 106 kbps.

8.1.3 Target Active Communication Mode

The purpose of this test is to determine the modulation index and the timing of the target's RF field while varying the field strength in the range of H_{min} and H_{max} as defined in 6.1.2. The DUT is placed on the test assembly, concentric with the sense coil.

- K6 Pulse Sequencer

An ATR_REQ command sequence is sent to the DUT for all bitrates to obtain an ATR_RES.

- Signal Generator

The output power is varied between H_{min} and H_{max}.

- Oscilloscope

The oscilloscope is used to read the timing of the RF field generation and measure the different amplitudes of the modulated signal in order to determine the modulation index. The oscilloscope can also be used to determine that an ATR_RES is acquired.

8.1.4 Initiator Field Strength

This test measures the field strength produced by an initiator in its operating volume as described in 6.1.2. The reference devices defined in 6.1.2 are used to determine two things. First of all, that a DUT is able to supply a field strength of at least H_{min} to power the target placed anywhere within the defined operating volume and secondly, that it does not generate a field higher than the value H_{max}. Once the reference devices have been calibrated, the test assembly must not transmit any RF-field. The generated RF-field could otherwise disturb the H_{min} and H_{max} measurements.

- Signal Generator

When calibrating the reference devices for H_{min} and H_{max}, the SMU 200A is set to produce 1.5 A/m and 7.5 A/m respectively when measuring with the calibration coil.

- Tuning of resonance frequency

The jumper J1 is set to position "a" on the reference device. The calibration coil is driven directly from the SMU 200A set at the required frequency, 13.56 MHz for H_{min} or 19.0 MHz for H_{max}. The calibration coil and the reference device are located as close as possible with the axes of the two coils being congruent. The reference device's capacitor C2 is adjusted to the maximum DC voltage at R1 measured with a high-impedance voltmeter.

- Adjustment of R2

The jumper J1 is set to position "b" on the reference device. The test assembly is calibrated to produce the required magnetic field strength (H_{min} or H_{max}) at 13.56 MHz on the calibration coil with the reference device in the DUT position. R2 is now adjusted to obtain 3V DC across it measured with a high impedance voltmeter. The operating field condition is verified by monitoring the voltage on the calibration coil.

- Oscilloscope

The oscilloscope is used to measure the voltage across R2 while the reference device is positioned within the defined operating volume of the DUT. For H_{min}, the voltage shall exceed 3V DC and for H_{max} the voltage shall be below 3V DC.

8.1.5 Initiator Modulation Index and Waveform

This test is used to determine the modulation index of the initiator field as well as the rise and fall times and the overshoot values as described in 6.1.2 within the defined operating volume. The test is performed by placing the calibration coil within the operating volume of the initiator.

- Oscilloscope

The oscilloscope is used to measure the overshoots of the modulated signal and to determine the modulation index using the method described in 6.1.2.

- Spectrum Analyzer

The rise and fall times are determined using the spectrum analyzer with a zero span configuration. The markers D1, M1 and D2 are placed to determine the time parameters as described below:

MKR: Marker: Marker Delta
Position the D1 marker to $H_{initial}$ (100 % amplitude value).

MKR: Marker 1
Position the M1 at 90 % amplitude of the falling edge. This gives a D1 value of 0.91 dB.

MKR: Marker 2: Marker Delta
Position the D2 marker at 5 % amplitude of the rising edge. This gives a D2 value of -25.11 dB.

The parameter t1 can now be acquired by simply checking the time value for D2. The measurements of parameters t2, t3 and t4 are carried out in the same way.

For parameter t2, set M1 at 5 % amplitude of the falling edge to get a D1 value of 26.02 dB. Marker D2 should now have a value of 0 dB. Parameter t2 can now be read as the time value of D2.

For parameter t3, set M1 at 90 % amplitude of the rising edge to get a D1 value of 0.91 dB. Marker D2 should now have a value of -25.11 dB. Parameter t3 can now be read as the time value of D2.

For parameter t4, set M1 at 60 % amplitude of the rising edge to get a D1 value of 4.43 dB. Marker D2 should now have a value of -21.59 dB. Parameter t4 can now be read as the time value of D2.

8.2 Micropross

The calibration and measurement procedures for the Micropross setup are well documented and this report will therefore only have a guideline on which manuals to follow for the different procedures.

- **Universal Test Bench 2010 - User Manual - Rev E**

  This document describes all the connections in the setup, the calibration of the test assembly and a description of all the separate parts used with the test assembly.

- **MP Manager - User Manual for Contactless - RevC**
  This document describes all the features of MP Manager and how to use them.

- **User Manual Test suite - ISO 22536 - RF - Rev B**
  This document gives a brief overview on how to use MP Manager for the ISO 22536 test cases.

MP Manager provides clear instructions, often with pictures, when a test is executed.

Chapter 9

Test Results

All tests are performed according to the procedures specified in the ISO/ECMA NFC standards.

In Figure 6.2.7, Chapter 6, the operating volume with the defined test positions by the NFC-Forum were shown. In the ISO/ECMA standards, no such test positions are defined. In our case, we positioned the calibration coil at 0 and 10 mm distance from the DUT. The calibration coil was moved around at these fixed distances until the maximum voltage was obtained. Note that the distance 10 mm is not defined in any standard and is merely used for comparison.

9.1 Rohde & Schwarz / AIT

This measurement setup is not able to perform any tests in target active communication mode. These tests are therefore not performed.

9.1.1 DUT A

Target RF Level Detection

The DUT has its RF field on and polls continuously as long as no external field is present and switches off as soon as a field is detected. This makes it easy to find the threshold value of the DUT, see Figure 9.1.1. The DUT detects the external RF field from the test assembly at an output power of -57.2 dBm from the signal generator. The voltage measured at the calibration coil is 22.6 mV_{RMS} which corresponds to a field strength value of 0.0706 A/m. The DUT passes the test with a good margin since the threshold value for RF level detection is 0.1875 A/m.

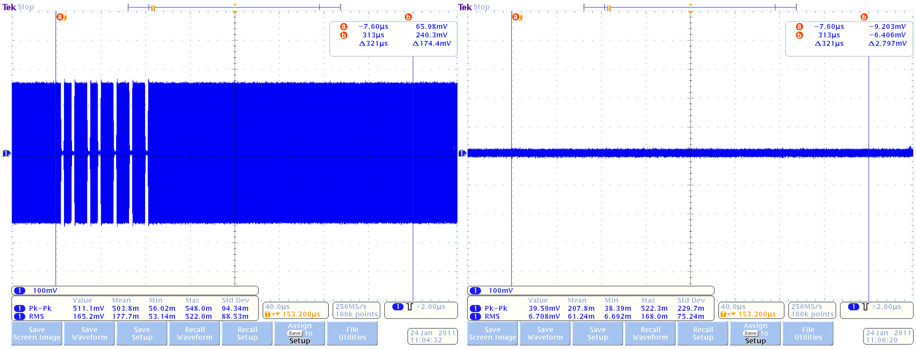

Figure 9.1.1: To the left the RF field is turned on, to the right the RF field is turned off since an external RF field is detected.

Target Passive Communication Mode

The DUT does not support passive communication mode at higher bit rates and the tests have therefore been omitted.

For the bit rate 106 kbps, a SENS_REQ command is sent from the signal generator to obtain a SENS_RES from the DUT. In Figure 9.1.2, we see the SENS_REQ sent from the signal generator and the load modulated SENS_RES from the DUT.

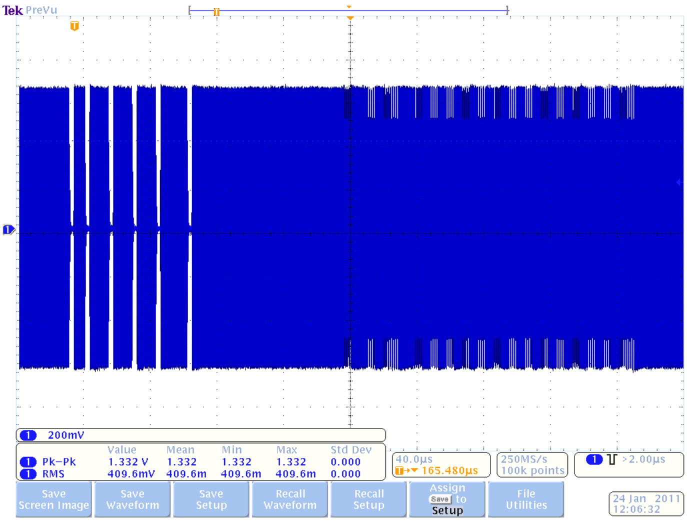

Figure 9.1.2: A SENS_REQ command is seen to the left and a SENS_RES command to the right.

The amplitudes of the sidebands are measured as described in 6.1.2. The load modulation amplitude shall be at least $A_{min}= 30/H^{1.2}$ mV$_p$. The frequency responses for H_{min} and H_{max} are seen in Figures 9.1.3 and 9.1.4.

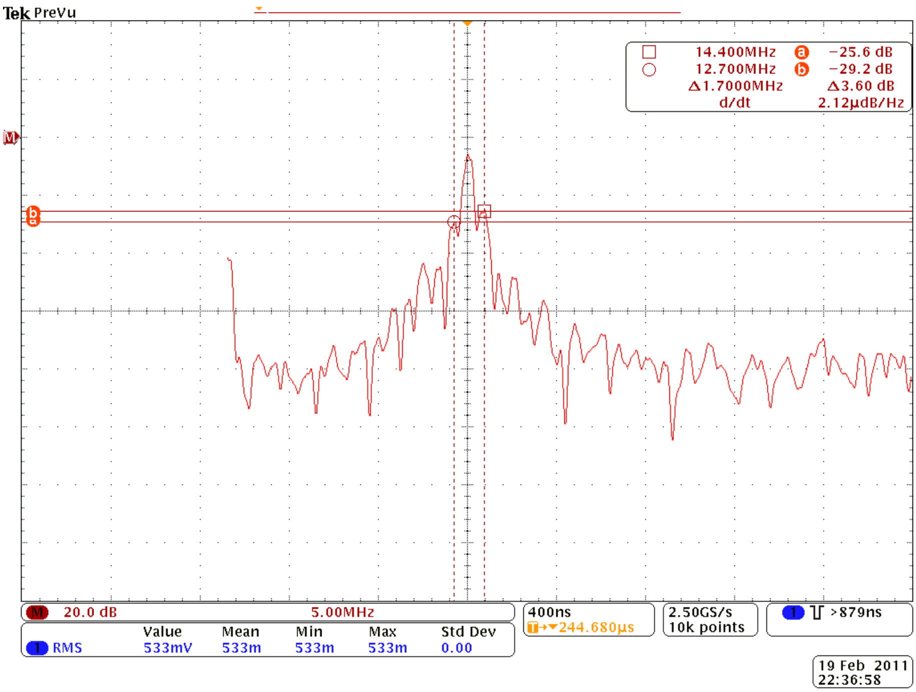

Figure 9.1.3: The frequency response at H_{max} with cursors set to the peak amplitude of the sidebands.

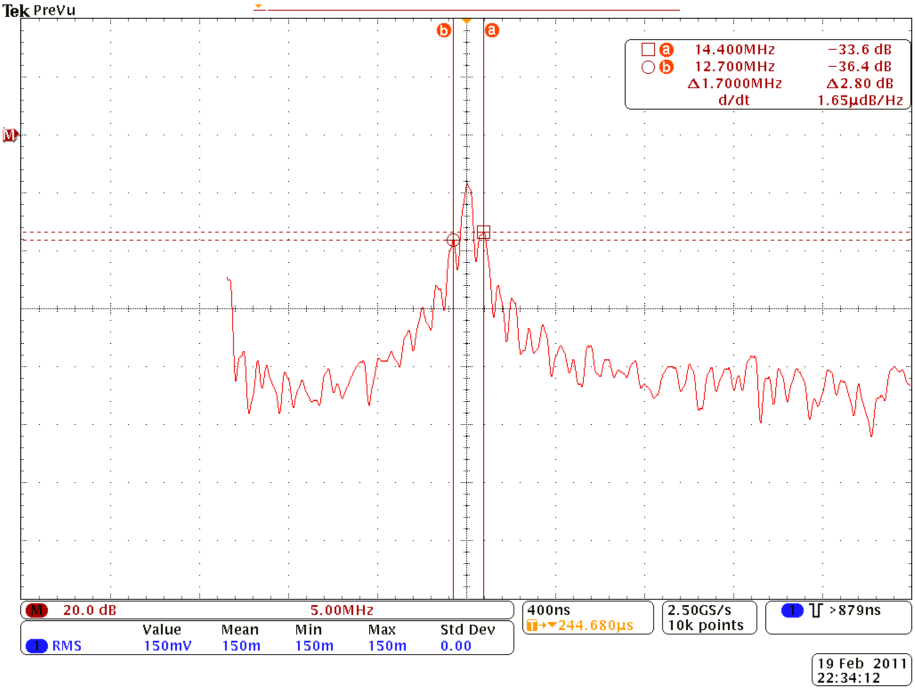

Figure 9.1.4: The frequency response at H_{min} with cursors set to the peak amplitude of the sidebands.

The measured amplitude levels for the sidebands are converted from dBV to the corresponding voltage values in mV_p. The results can be seen in Table 9.1.

H	**Sideband**	**Requirement, mVp**	**Measured values, mVp**
H_{min}	Lower	18.44	21.41
	Upper	18.44	29.55
H_{max}	Lower	2.67	49.03
	Upper	2.67	79.22

Table 9.1: Minimum requirements on sidebands and measured amplitude levels.

The DUT fulfills the requirements for the minimum amplitude values for the sidebands at H_{min}. The test passes.

Initiator Field Strength

Parameter	Distance, mm	Voltage, V
H_{min}	0	1.41
	10	0.71
H_{max}	Any	0.31

Table 9.2: Field strength values for DUT A.

The test fails due to H_{min} not reaching 3 V at any position.

Initiator Modulation Index and Waveform

For 212 kbps, the DUT does not provide a stable enough signal to trigger on. Since no proper triggering can be done, the tests for this bit rate have been omitted. The DUT does not support communication at 424 kbps.

For 106 kbps, the rise and fall times are determined by placing markers D1, M1 and D2 as described in 8.1.5. The envelope of the carrier amplitude and the definition of the time intervals are described in 5.1.3. The timing results are illustrated in Figures 9.1.5-9.1.8.

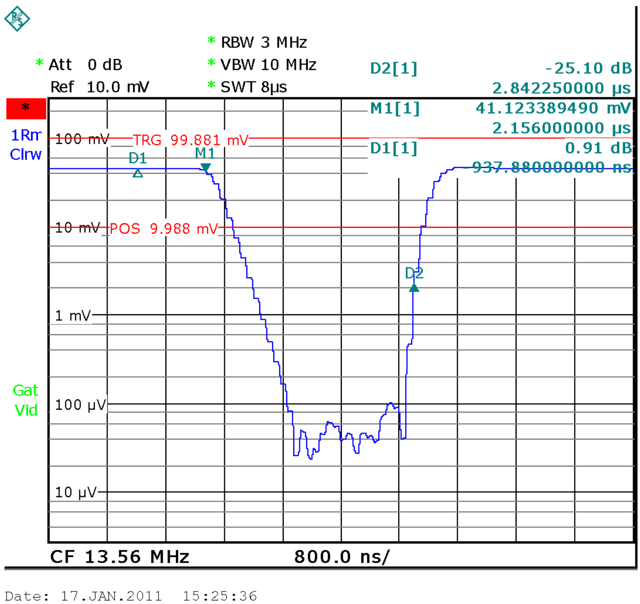

Figure 9.1.5: Parameter t1 is acquired by reading the time value for D2.

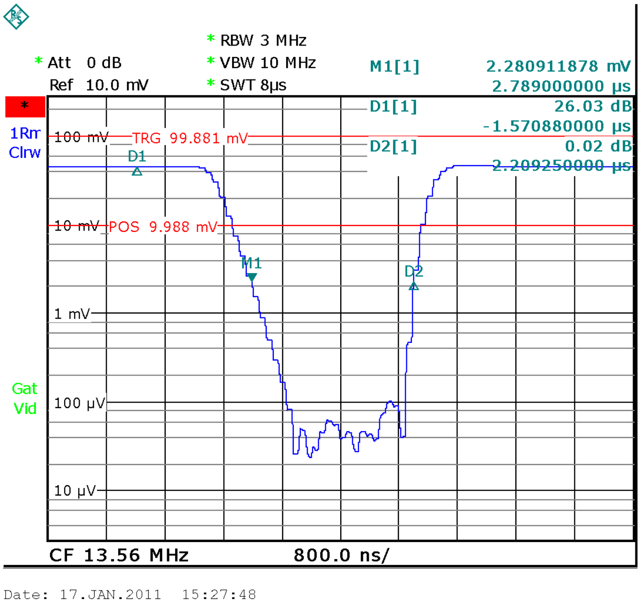

Figure 9.1.6: Parameter t2 is acquired by reading the time value for D2.

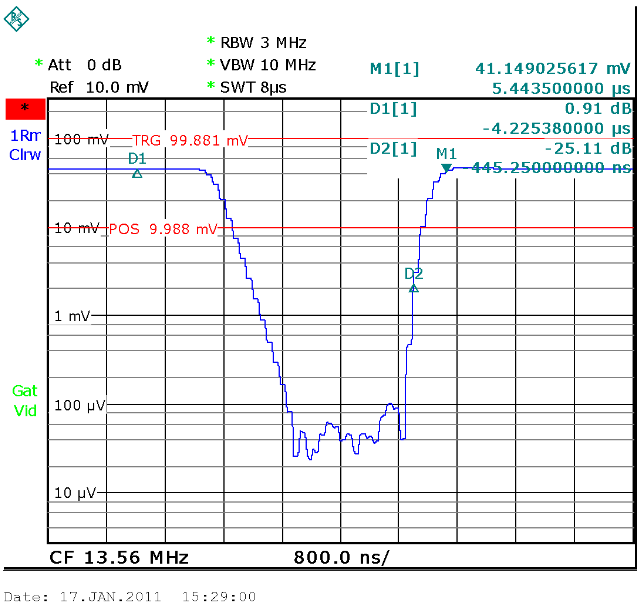

Figure 9.1.7: Parameter t3 is acquired by reading the time value for D2.

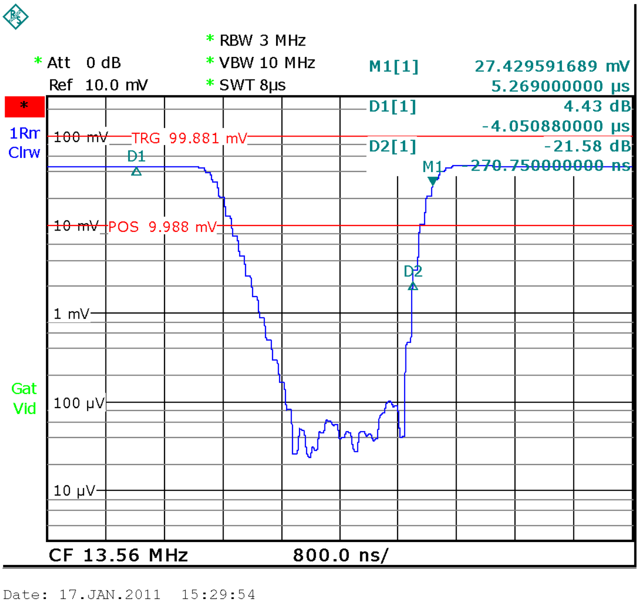

Figure 9.1.8: Parameter t4 is acquired by reading the time value for D2.

The results are summarized in table 9.3

Time parameter	t1	t2	t3	t4
Time	2.84 μs	2.21 μs	445 ns	270 ns

Table 9.3: Parameter values for DUT A.

As mentioned in 5.1.3, the overshoots shall remain within 90% and 110% of $H_{INITIAL}$. The overshoots reach $\frac{648\,mV}{620\,mV} \approx 104,3\%$, see Figure 9.1.9.

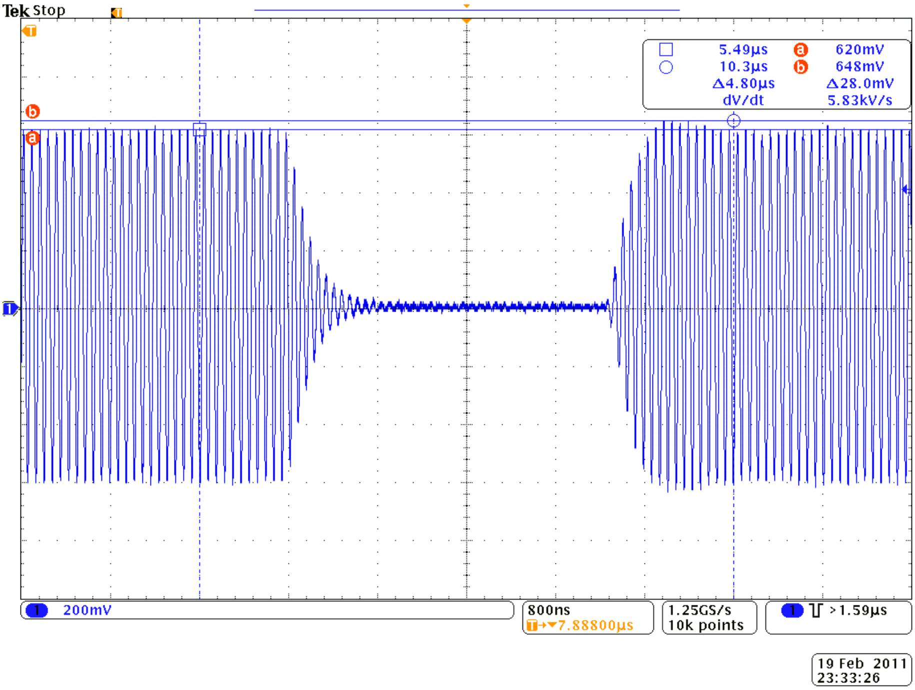

Figure 9.1.9: Pulse shape with cursors set to determine the positive overshoots.

The modulation index is calculated as $\frac{(a–b)}{(a+b)}$ where a and b are the peak and the minimum signal amplitude respectively with the value of the index expressed as a percentage. In this case, the modulation index is $\frac{(872-16)\,mV}{(872+16)\,mV} \approx 96,4\%$, see Figure 9.1.10.

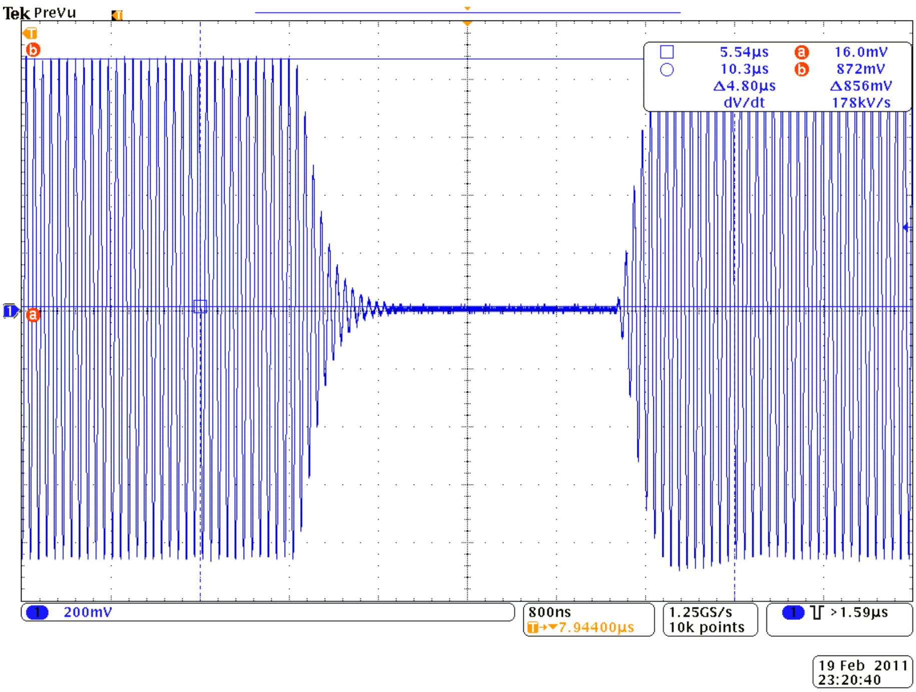

Figure 9.1.10: Pulse shape with cursors set to determine the modulation index.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	Result
Target RF level detection	PASS
Target passive communication mode	PASS
Initiator field strength	FAIL
Initiator modulation index and waveform	PASS

Table 9.4: Summary of test results for DUT A.

9.1.2 DUT B

Target RF Level Detection

The DUT detects the external RF field from the test assembly at an output power of -45.4 dBm from the signal generator. The voltage measured at the calibration coil is 76 mV_{RMS} which corresponds to a field strength value of 0.2375 A/m. The DUT fails on this test since the threshold value for RF level detection is 0.1875 A/m.

Target Passive Communication Mode

The DUT is currently running Android 2.3 Gingerbread, which does not support card emulation mode.

Initiator Field Strength

Parameter	Distance, mm	Voltage, V
H_{min}	0	4.26
	10	2.76
H_{max}	Any	1.28

Table 9.5: Field strength values for DUT B.

The test passes.

Initiator Modulation Index and Waveform

The timing results are illustrated in Figures 9.1.11-9.1.14.

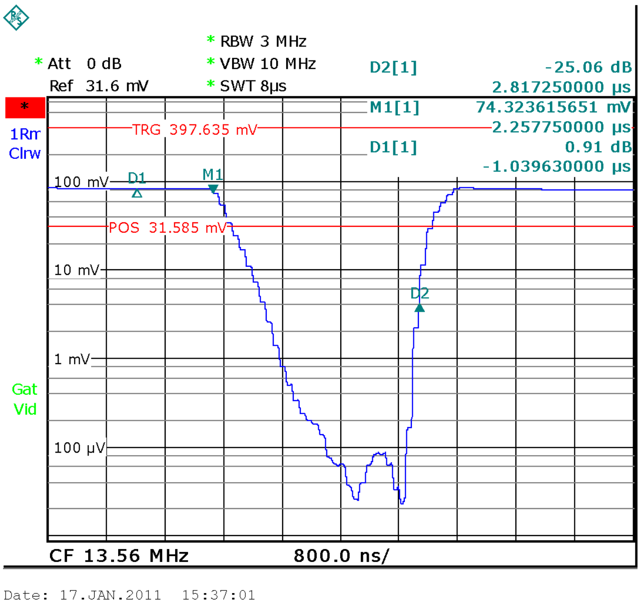

Figure 9.1.11: Parameter t1 is acquired by reading the time value for D2.

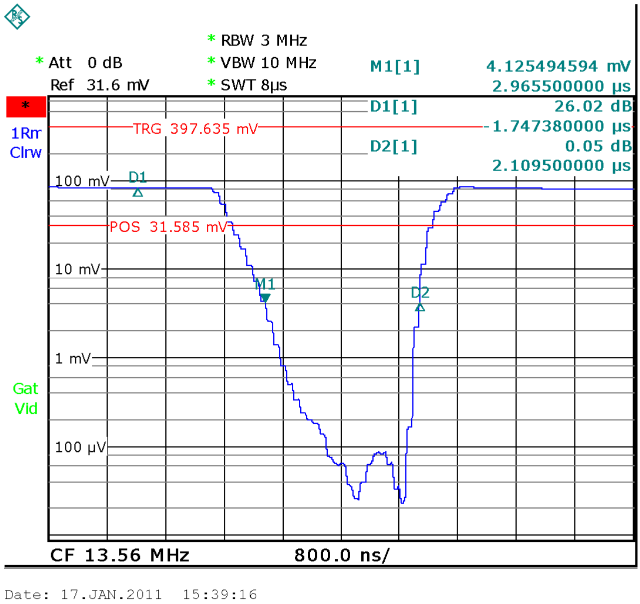

Figure 9.1.12: Parameter t2 is acquired by reading the time value for D2.

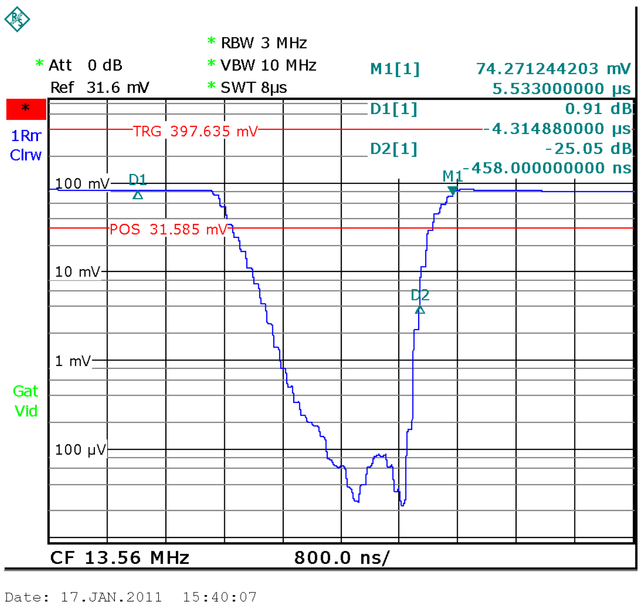

Figure 9.1.13: Parameter t3 is acquired by reading the time value for D2.

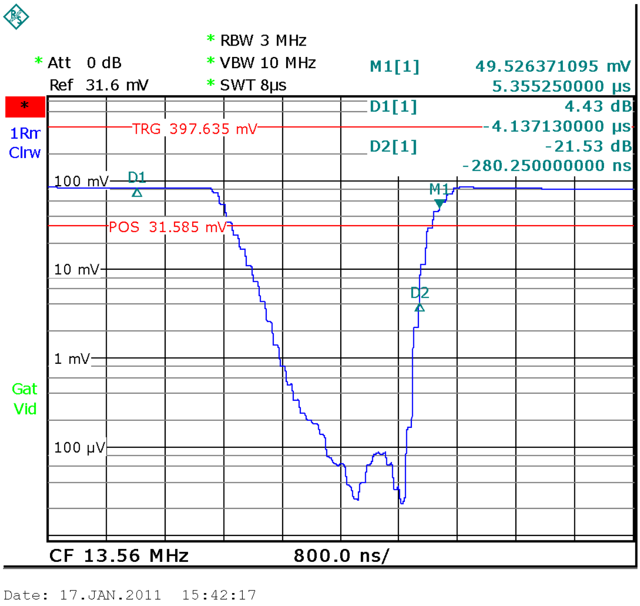

Figure 9.1.14: Parameter t4 is acquired by reading the time value for D2.

The results are summarized in table 9.6.

Time parameter	t1	t2	t3	t4
Time	2.82 μs	2.11 μs	458 ns	280 ns

Table 9.6: Parameter values for DUT B.

The overshoots reach 104.1 %.

The modulation index is 98.2 %.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	**Result**
Target RF level detection	FAIL
Target passive communication mode	N/A
Initiator field strength	PASS
Initiator modulation index and waveform	PASS

Table 9.7: Summary of test results for DUT B.

9.1.3 DUT C

Target RF Level Detection

The voltage measured at the calibration coil is 230 mV$_{RMS}$ which corresponds to a field strength value of 0.719 A/m. The DUT fails on this test since the threshold value for RF level detection is 0.1875 A/m.

Target Passive Communication Mode

The DUT is currently running Android 2.3 Gingerbread, which does not support card emulation mode.

Initiator Field Strength

Parameter	Distance, mm	Voltage, V
H_{min}	0	2.45
	10	1.06
H_{max}	Any	0.56

Table 9.8: Field strength values for DUT C.

The test fails due to H_{min} not reaching 3 V at any position.

Initiator Modulation Index and Waveform

Due to poor matching, triggering on the higher bit rates is not possible and the tests for these bit rates have been omitted.

For 106 kbps, the timing results are illustrated in Figures 9.1.15-9.1.18.

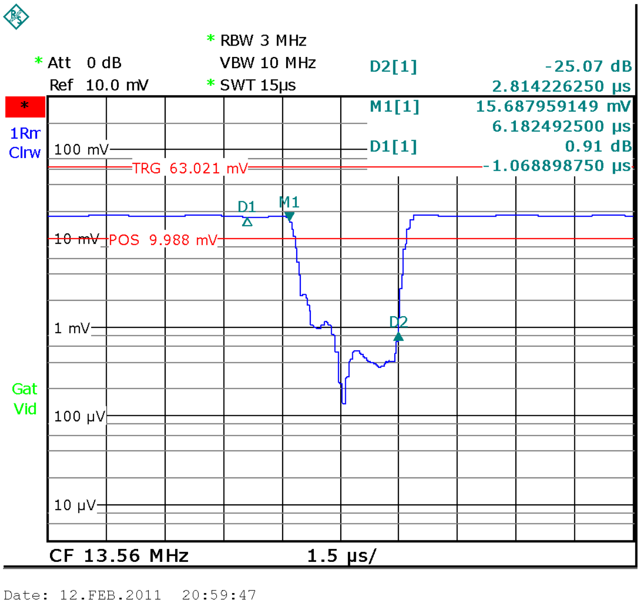

Figure 9.1.15: Parameter t1 is acquired by reading the time value for D2.

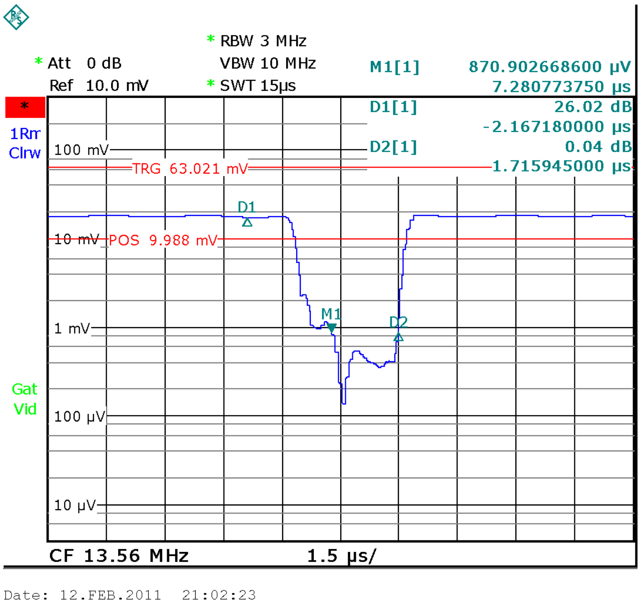

Figure 9.1.16: Parameter t2 is acquired by reading the time value for D2.

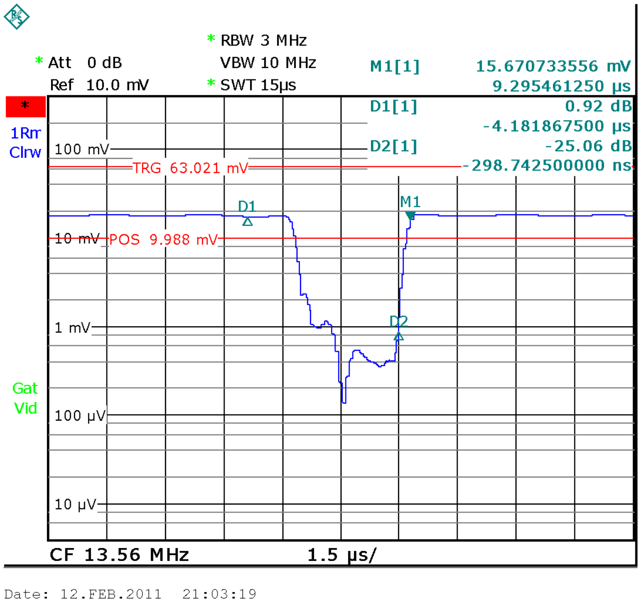

Figure 9.1.17: Parameter t3 is acquired by reading the time value for D2.

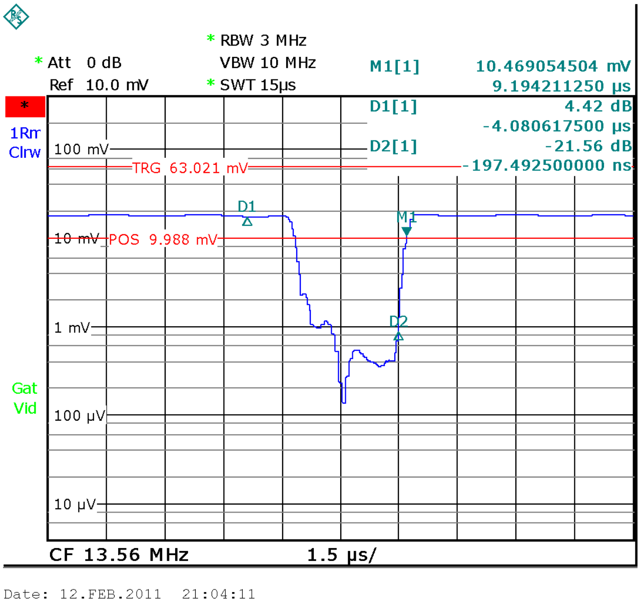

Figure 9.1.18: Parameter t4 is acquired by reading the time value for D2.

The timing results are summarized in table 9.9.

Time parameter	t1	t2	t3	t4
Time	2.81 μs	1.72 μs	299 ns	197 ns

Table 9.9: Parameter values for DUT C.

The overshoots reach 106.32 %.

The modulation index is 97.24 %.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	**Result**
Target RF level detection	FAIL
Target passive communication mode	N/A
Initiator field strength	FAIL
Initiator modulation index and waveform	PASS

Table 9.10: Summary of test results for DUT C.

9.2 Micropross

9.2.1 DUT A

Target RF Level Detection

The DUT turns off its RF field when the external RF field has a field strength value of 0.0653 A/m. The test passes.

Target Passive Communication Mode

The DUT does not support passive communication mode at higher bit rates and the tests have therefore been omitted.

For 106 kbps, the DUT passes at 1.5 A/m. When the test was performed with higher field strength values, no answer was received from the DUT. This was very odd since the DUT passed the test with the R&S / AIT setup for field strength values up to 7.5 A/m. After some troubleshooting, we noticed that the pause timing on the R&S signal generator was 2500 ns compared to 2100 ns on the signal generator from Micropross. We decided to use Shmoo to study the behaviour of the DUT when the field strength was increased. A script containing a SENS_REQ was loaded and sent with increasing pause timing at different field strengths. The pause timing was varied between 0 and 3000 ns with a step size of 50 ns and the field strength was varied between 0 and 7.5 A/m with a step size of 5 %. As seen in Figure 9.2.1, the required pause timing, x-axis, increases with increased field strength, y-axis.

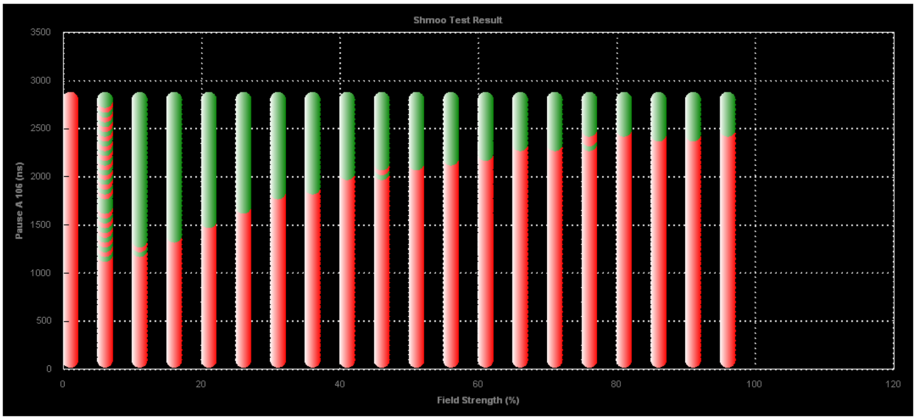

Figure 9.2.1: Shmoo data for DUT A.

Initiator Field Strength

Parameter	Distance, mm	Voltage, V
H_{min}	0	1.44
	10	0.72
H_{max}	Any	0.35

Table 9.11: Field strength values for DUT A.

The test fails due to H_{min} not reaching 3 V at any position.

Initiator Modulation Index and Waveform

For 212 kbps, the DUT does not provide a stable enough signal to trigger on. Since no proper triggering can be done, the tests for this bit rate have been omitted. The DUT does not support communication at 424 kbps.

For 106 kbps, the results are seen in Table 9.12 and 9.13.

Time parameter	t1	t2	t3	t4
Time, ns	2847.2	2088.8	304	185.6

Table 9.12: Parameter values for DUT A.

Overshoots	107.48 %
Modulation index	96.26 %

Table 9.13: Parameter values for DUT A.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	Result
Target RF level detection	PASS
Target passive communication mode	FAIL
Initiator field strength	FAIL
Initiator modulation index and waveform	PASS

Table 9.14: Summary of test results for DUT A.

9.2.2 DUT B

Target RF Level Detection

The DUT turns off its RF field when the external RF field has a field strength value of 0.2272 A/m. The test fails.

Target Passive Communication Mode

The DUT is currently running Android 2.3 Gingerbread, which does not support card emulation mode.

Initiator Field Strength

Parameter	Distance, mm	Voltage, V
H_{min}	0	4.17
	10	3.1
H_{max}	Any	1.36

Table 9.15: Field strength values for DUT B.

The test passes.

Initiator Modulation Index and Waveform

For 106 kbps, the results are seen in Table 9.16 and 9.17.

Time parameter	t1	t2	t3	t4
Time, ns	2782.4	2244	386	266.4

Table 9.16: Parameter values for DUT B.

Overshoots	104.35 %
Modulation index	97.73 %

Table 9.17: Parameter values for DUT B.

The modulation index, timings and overshoots are within the defined limits. The test passes.

For 212 kbps, the results are seen in Table 9.18.

Parameter	t_f	t_r	h_f	h_r	m
Value	279.2 ns	624.8 ns	0.001 V	0.003 V	19.4 %

Table 9.18: Parameter values for DUT B.

The modulation index, timings and overshoots are within the defined limits. The test passes.

For 424 kbps, the results are seen in Table 9.19.

Parameter	t_f	t_r	h_f	h_r	m
Value	242 ns	159.2 ns	0 V	0.001 V	17.9 %

Table 9.19: Parameter values for DUT B.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	**Result**
Target RF level detection	FAIL
Target passive communication mode	N/A
Initiator field strength	PASS
Initiator modulation index and waveform	PASS

Table 9.20: Summary of test results for DUT B.

9.2.3 DUT C

Target RF Level Detection

The DUT turns off its RF field when the external RF field has a field strength value of 0.6987 A/m. The test fails.

Target Passive Communication Mode

The DUT is currently running Android 2.3 Gingerbread, which does not support card emulation mode.

Initiator Field Strength

Parameter	**Distance, mm**	**Voltage, V**
H_{min}	0	2.4
	10	1.2
H_{max}	Any	0.52

Table 9.21: Field strength values for DUT C.

The test fails due to H_{min} not reaching 3 V at any position.

Initiator Modulation Index and Waveform

Due to poor matching, triggering on the higher bit rates is not possible and the tests for these bit rates have been omitted.

For 106 kbps, the results are seen in Table 9.22 and 9.23.

Time parameter	t1	t2	t3	t4
Time	2830 ns	1836 ns	350 ns	141 ns

Table 9.22: Parameter values for DUT C.

Overshoots	106.02 %
Modulation index	97.68 %

Table 9.23: Parameter values for DUT C.

The modulation index, timings and overshoots are within the defined limits. The test passes.

Summary

Test	**Result**
Target RF level detection	FAIL
Target passive communication mode	N/A
Initiator field strength	FAIL
Initiator modulation index and waveform	PASS

Table 9.24: Summary of test results for DUT C.

Chapter 10

Summary and Conclusions

NFC has a broad range of uses. Public transport payment, credit card functionality and setting up other types of wireless connections are only a few examples of the possibilities. Since NFC technology is mainly intended for use in mobile phones, all the features that NFC brings become available in your pocket.

The main objective for this thesis was to assemble an NFC measurement system for use at Sony Ericsson Mobile Communications. This was not as easy as initially foreseen. We had no previous experience with NFC technology and when there were questions, the available help was limited due to the lack of experience in the area at the company. Also, the initial order of the test setup had to be done very early due to long delivery times and the general time constraints of the thesis.

The ISO/ECMA standards for NFC are not very clear when the test cases, calibration and requirements are explained. ECMA-340 and ECMA-356 have not been updated since 2004 but the NFC Forum is fortunately working on rewriting and improving the RF specifications. In these new specifications, the test assembly used in ECMA-356 is replaced with Reference Devices and EMVCo testing capabilities are added together with RFID Type B. The RF specifications are not yet finalized and have been delayed several times. The latest update provided is that the Analog Specification will be ready by September 2011 and the Analog Test Specification by February 2012.

The solution from Micropross is very promising although some improvements have to be made for it to be a completely viable solution. There are a few limitations in the software, e.g. changing pause timing and the way the software operates with the oscilloscope. These issues have been reported directly to Micropross.

As shown in Chapter 9, our own measurement setup provides virtually the same results as the solution from Micropross. The neglectable differences are most likely due to measurement uncertainties.

A disadvantage with the setup is that it is not as automated as the solution from Micropross. Another disadvantage is that it does not support testing in active communication mode. This was, however, not an issue during the thesis since there were no available handsets that supported active communication mode.

10.1 Future work

Micropross currently offers an automated reference PICC and a robotic arm which considerably facilitates testing of the operating volume. These items should be considered to complement the existing measurement setup to make testing even more automated.

Rohde & Schwarz is currently working on a brand new NFC solution based on NFC Forum specifications. Communication with R&S needs to be maintained to follow the development as they stand at Sony Ericsson's disposal for any possible feature requests.

Once Google has released an Android version that supports card emulation mode, the testing on DUT B and C should be continued to verify the performance in target mode with the NXP PN544 and PN65 chips.

Appendix A

Micropross Test Reports

A.1 DUT A

TEST SUITE REPORT

Device Name	***TCL2***
Device Serial Number	*MP3.11.05.01*
Testing Date	*12-02-2011 17:47*
Report Date	*12-02-2011 17:59*
Description	
Operator	*Bekir*
Manufacturer	*DUT A*
Reference	
Reference DUT (Device Under Test)	

1. RESULT TABLE

1.1. Test Suite Name : ISO 22536 RF NFC Device

	Test Type	Test Name	Log Status
1	\18092_NFC IP1 (normative tests)\8. Functional test Target	TC 8.1 Target RF level detection	**PASSED**
2	\18092_NFC IP1 (normative tests)\8. Functional test Target\TC 8.2 Target passive communication mode	TC 8.2 106kbps (NFC-A)	**FAILED**
3	\18092_NFC IP1 (normative tests)\8. Functional test Target\TC 8.2 Target passive communication mode	TC 8.2 212kbps (NFC-F 212)	**FAILED**
4	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmax	**PASSED**
5	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmin	**FAILED**
6	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)	Calibration coil	**PASSED**
7	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and	Calibration coil	**FAILED**

	waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)		

2. DETAIL REPORT

2.1. Test Suite Name : ISO 22536 RF NFC Device

1. Test Name : TC 8.1 Target RF level detection

Test Type : 18092_NFC IP1 (normative tests)\8. Functional test Target

Test Result : PASSED

Test Log :
HThreshold = 0,0653 A/m

<--- TC 8.1 Target RF level detection Succeeded

2. Test Name : TC 8.2 106kbps (NFC-A)

Test Type : 18092_NFC IP1 (normative tests)\8. Functional test Target\TC 8.2 Target passive communication mode

Test Result : FAILED

Test Log :

Set Field to 1,486 A/m
Test REQA - ATQA expected
<--- ATQA: 0002
CSV Creation : C:\Documents and Settings\23058147\Desktop\ISO 22536 NFC Device RF - EXEC - Version 1.1.3\ISO 22536 RF NFC Device\Tmp\T001_F001_F002_F003_12022011_174724\fourier_points_1,5A-m [0].csv
Uabs : 30,044 mVp
Labs : 20,914 mVp
Vlma : 18,656 mVp
<--- OK

Set Field to 1,452 A/m
Test REQA - ATQA expected
<--- ATQA: 0002
CSV Creation : C:\Documents and Settings\23058147\Desktop\ISO 22536 NFC Device RF - EXEC - Version 1.1.3\ISO 22536 RF NFC Device\Tmp\T001_F001_F002_F003_12022011_174724\fourier_points_1,5A-m [1].csv
Uabs : 29,598 mVp
Labs : 21,128 mVp
Vlma : 19,18 mVp
<--- OK

Set Field to 1,453 A/m
Test REQA - ATQA expected
<--- ATQA: 0002

CSV Creation : C:\Documents and Settings\23058147\Desktop\ISO 22536 NFC Device RF - EXEC - Version 1.1.3\ISO 22536 RF NFC Device\Tmp\T001_F001_F002_F003_12022011_174724\fourier_points_1,5A-m [2].csv
Uabs : 31,574 mVp
Labs : 19,409 mVp
Vlma : 19,159 mVp
<--- OK

Set Field to 4,494 A/m
Test REQA - ATQA expected
ERR: No Response

Set Field to 4,542 A/m
Test REQA - ATQA expected
ERR: No Response

Set Field to 4,551 A/m
Test REQA - ATQA expected
ERR: No Response

Set Field to 7,494 A/m
Test REQA - ATQA expected
ERR: No Response

Set Field to 7,544 A/m
Test REQA - ATQA expected
ERR: No Response

Set Field to 7,552 A/m
Test REQA - ATQA expected
ERR: No Response

ERR: TC 8.2 106kbps (NFC-A) Failed

3. Test Name : TC 8.2 212kbps (NFC-F 212)

Test Type : 18092_NFC IP1 (normative tests)\8. Functional test Target\TC 8.2 Target passive communication mode

Test Result : FAILED

Test Log :

Set Field to 1,489 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 1,5 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 1,5 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 4,493 A/m

Test Polling request - Polling response expected
ERR: No Response

Set Field to 4,549 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 4,549 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 7,501 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 7,544 A/m
Test Polling request - Polling response expected
ERR: No Response

Set Field to 7,548 A/m
Test Polling request - Polling response expected
ERR: No Response

ERR: TC 8.2 212kbps (NFC-F) Failed

4. **Test Name : Procedure for Hmax**
   Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

   Test Result : PASSED
   Test Log :
   Results : The maximum vale measured is 0.35 V.

   <--- TC 9.1 Initiator field strength in active and passive communication (Hmax) Succeeded

5. **Test Name : Procedure for Hmin**
   Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

   Test Result : FAILED
   Test Log :
   Results : The highest value is 1.44 V and is measured at 0 mm.

   ERR: TC 9.1 Initiator field strength in active and passive communication (Hmin) Failed

6. **Test Name : Calibration coil**
   Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)

   Test Result : PASSED
   Test Log :

Measures :
t1 Measured : 2847,2 ns
<--- OK
t2 Measured : 2088,8 ns
<--- OK
t3 Measured : 304 ns
<--- OK
t4 Measured : 185,6 ns
<--- OK
overshoot Measured : 107,48 %
<--- OK
m Measured : 96,26 %
<--- OK

<--- TC 9.2 Initiator 106kbps (NFC-A) Succeeded

7. **Test Name : Calibration coil**

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)

Test Result : FAILED

Test Log :
Measures :
tf Measured : 740 ns
<--- OK
m Measured : 0.22 %
ERR: m not between 8 % and 30 % : NOK
tr Measured : 5729,6 ns
ERR: tr not between 0 ns and 2000.0 ns NOK
hf Measured : 0,234 V
ERR: hf not between 0 V and 0.0002 V NOK
hr Measured : 0,018 V
ERR: hr not between 0 V and 0.0002 V NOK
m Measured : 0.3 %
ERR: m not between 8 % and 30 % : NOK

ERR: TC 9.2 Initiator 212kbps (NFC-F 212) Failed

3. SUMMARY REPORT

3.1. Test Suite Name : ISO 22536 RF NFC Device

Log Status	Number	%
Passed	3	42,86 %
Failed	4	57,14 %
Not Applicable	0	0,00 %
Inconclusive	0	0,00 %

Error	0	0,00 %
TOTAL	7	100 %

Ooo End of Report ooO

A.2 DUT B

TEST SUITE REPORT

Device Name	***TCL2***
Device Serial Number	*MP3.11.05.01*
Testing Date	*12-02-2011 18:03*
Report Date	*12-02-2011 18:16*
Description	
Operator	*Bekir*
Manufacturer	*DUT B*
Reference	
Reference DUT (Device Under Test)	

1. RESULT TABLE

1.1. Test Suite Name : ISO 22536 RF NFC Device

	Test Type	Test Name	Log Status
1	\18092_NFC IP1 (normative tests)\8. Functional test Target	TC 8.1 Target RF level detection	**FAILED**
2	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmax	**PASSED**
3	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmin	**PASSED**
4	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)	Calibration coil	**PASSED**
5	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)	Calibration coil	**PASSED**
6	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and	Calibration coil	**PASSED**

	waveform in active and passive communication\TC 9.2 424kbps (NFC-F 424)		

2. DETAIL REPORT

2.1. Test Suite Name : ISO 22536 RF NFC Device

1. Test Name : TC 8.1 Target RF level detection

Test Type : 18092_NFC IP1 (normative tests)\8. Functional test Target

Test Result : FAILED

Test Log :
HThreshold = 0,2272 A/m

ERR: TC 8.1 Target RF level detection Failed

2. Test Name : Procedure for Hmax

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

Test Result : PASSED

Test Log :
Results : The maximum value measured is 1.36 V.

<--- TC 9.1 Initiator field strength in active and passive communication (Hmax) Succeeded

3. Test Name : Procedure for Hmin

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

Test Result : PASSED

Test Log :
Results : The maximum measured value is 4.17 V at 0 mm and 3.1 V at 10 mm.

<--- TC 9.1 Initiator field strength in active and passive communication (Hmin) Succeeded

4. Test Name : Calibration coil

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)

Test Result : PASSED

Test Log :
Measures :
t1 Measured : 2782,4 ns

<--- OK
t2 Measured : 2244 ns
<--- OK
t3 Measured : 386 ns
<--- OK
t4 Measured : 266,4 ns
<--- OK
overshoot Measured : 104,35 %
<--- OK
m Measured : 97,73 %
<--- OK

<--- TC 9.2 Initiator 106kbps (NFC-A) Succeeded

5. **Test Name : Calibration coil**

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)

Test Result : PASSED

Test Log :
Measures :
tf Measured : 279,2 ns
<--- OK
m Measured : 19.15 %
<--- OK
tr Measured : 624,8 ns
<--- OK
hf Measured : 0,001 V
<--- OK
hr Measured : 0,003 V
<--- OK
m Measured : 19.67 %
<--- OK

<--- TC 9.2 Initiator 212kbps (NFC-F 212) Succeeded

6. **Test Name : Calibration coil**

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 424kbps (NFC-F 424)

Test Result : PASSED

Test Log :
Measures :
tf Measured : 242 ns
<--- OK
m Measured : 17,97 %
<--- OK
tr Measured : 159,2 ns
<--- OK
hf Measured : 0 V
<--- OK

hr Measured : 0,01 V
<--- OK
m Measured : 17,89 %
<--- OK

<--- TC 9.2 Initiator 424kbps (NFC-F 424) Succeeded

3. SUMMARY REPORT

3.1. Test Suite Name : ISO 22536 RF NFC Device

Log Status	**Number**	**%**
Passed	5	83,33 %
Failed	1	16,67 %
Not Applicable	0	0,00 %
Inconclusive	0	0,00 %
Error	0	0,00 %
TOTAL	6	100 %

Ooo End of Report ooO

A.3 DUT C

Sony Ericsson

TEST SUITE REPORT

Device Name	***TCL2***
Device Serial Number	*MP3.11.05.01*
Testing Date	*19-02-2011 16:39*
Report Date	*19-02-2011 16:47*
Description	
Operator	*Bekir*
Manufacturer	*DUT C*
Reference	
Reference DUT (Device Under Test)	

1. RESULT TABLE

1.1. Test Suite Name : ISO 22536 RF NFC Device

	Test Type	Test Name	Log Status
1	\18092_NFC IP1 (normative tests)\8. Functional test Target	TC 8.1 Target RF level detection	**FAILED**
2	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmax	**PASSED**
3	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication	Procedure for Hmin	**FAILED**
4	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)	Calibration coil	**PASSED**
5	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)	Calibration coil	**FAILED**
6	\18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and	Calibration coil	**FAILED**

	waveform in active and passive communication\TC 9.2 424kbps (NFC-F 424)		

2. DETAIL REPORT

2.1. Test Suite Name : ISO 22536 RF NFC Device

1. Test Name : TC 8.1 Target RF level detection

Test Type : 18092_NFC IP1 (normative tests)\8. Functional test Target

Test Result : FAILED

Test Log :
HThreshold = 0,6987 A/m

ERR: TC 8.1 Target RF level detection Failed

2. Test Name : Procedure for Hmax

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

Test Result : PASSED

Test Log :
Results : The maximum measured value is 0.52 V.

<--- TC 9.1 Initiator field strength in active and passive communication (Hmax) Succeeded

3. Test Name : Procedure for Hmin

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.1 Initiator Field strength in active and passive communication

Test Result : FAILED

Test Log :
Results : The maximum measured value is 2.4 V at 0 mm and 1.2 V at 10 mm.

ERR: TC 9.1 Initiator field strength in active and passive communication (Hmin) Failed

4. Test Name : Calibration coil

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 106kbps (NFC-A)

Test Result : PASSED

Test Log :
Measures :
t1 Measured : 2830 ns
<--- OK

Sony Ericsson

t2 Measured : 1836 ns
<--- OK
t3 Measured : 350 ns
<--- OK
t4 Measured : 141 ns
<--- OK
overshoot Measured : 106.02 %
<--- OK
m Measured : 97,68 %
<--- OK

<--- TC 9.2 Initiator 106kbps (NFC-A) Succeeded

5. Test Name : Calibration coil

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 212kbps (NFC-F 212)

Test Result : FAILED

Test Log :
Measures :
tf Measured : 5476,8 ns
ERR: tf not between 0 ns and 2000.0 ns NOK
m Measured : 2.78 %
ERR: m not between 8 % and 30 % : NOK
tr Measured : -4390,4 ns
ERR: tr not between 0 ns and 2000.0 ns NOK
hf Measured : 0,056 V
ERR: hf not between 0 V and 0.0004 V NOK
hr Measured : 0,01 V
ERR: hr not between 0 V and 0.0004 V NOK
m Measured : 3.15 %
ERR: m not between 8 % and 30 % : NOK

ERR: TC 9.2 Initiator 212kbps (NFC-F 212) Failed

6. Test Name : Calibration coil

Test Type : 18092_NFC IP1 (normative tests)\9. Functional test Initiator\TC 9.2 Initiator modulation index and waveform in active and passive communication\TC 9.2 424kbps (NFC-F 424)

Test Result : FAILED

Test Log :
Measures :
tf Measured : 5476,8 ns
ERR: tf not between 0 ns and 1000.0 ns NOK
m Measured : 2.78 %
ERR: m not between 8 % and 30 % : NOK
tr Measured : -4390,4 ns
ERR: tr not between 0 ns and 1000.0 ns NOK
hf Measured : 0,056 V
ERR: hf not between 0 V and 0.0004 V NOK
hr Measured : 0,01 V

ERR: hr not between 0 V and 0.0004 V NOK
m Measured : 3.15 %
ERR: m not between 8 % and 30 % : NOK

ERR: TC 9.2 Initiator 424kbps (NFC-F 424) Failed

3. SUMMARY REPORT

3.1. Test Suite Name : ISO 22536 RF NFC Device

Log Status	Number	%
Passed	2	33,33 %
Failed	4	66,67 %
Not Applicable	0	0,00 %
Inconclusive	0	0,00 %
Error	0	0,00 %
TOTAL	6	100 %

Ooo End of Report ooO

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