OULUN SEUDUN
AMMATTIKORKEAKOULU

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SUITABILITY OF RFID BASED ACCESS CONTROL SYSTEM

IN FACTORY ENVIRONMENT

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Jarkko Eskola
Bachelor's thesis
Spring 2013
Degree Programme in
Information Technology
Oulu University of Applied
Sciences

TIIVISTELMÄ

Oulun seudun ammattikorkeakoulu
Tietotekniikan koulutusohjelma, langattomien laitteiden suuntautumisvaihtoehto

Tekijä: Jarkko Eskola
Opinnäytetyön nimi: Suitability of RFID Based Access Control System in a Factory Environment
Työn ohjaaja: Riitta Rontu
Työn valmistumislukukausi ja -vuosi: Kevät 2013 Sivumäärä: 37 + 7 liitettä

Opinnäytetyössä arvioitiin ja testattiin RFID-tekniikan toimivuutta tehdasympäristössä. Työn toimeksiantaja oli Outokumpu Stainless Oy, joka halusi arvioida Tornion tehdasalueen uuden F3 sulaton RFID-järjestelmän toimivuuden. Päätavoitteena oli tutkia RFID-pohjaisen kulunvalvonta-järjestelmän soveltuvuutta tehdasympäristöön toteuttamalla testimittauksia ja keräämällä luotettavaa mittaustietoa järjestelmän toimivuudesta. Lisätavoitteena oli hyödyntää työkaluja, joita järjestelmän hallinnoijat tulevat käyttämään jatkossa.

Opinnäytetyö sisälsi selvitystyötä RFID-tekniikan perusteista järjestelmän ylläpitäjän kannalta ja käyttöympäristössä suoritettuja mittauksia ja käyttötestejä. Tehdasympäristöön soveltuvuutta arvioitiin tutkimalla järjestelmän komponenttien teknisiä määrittelyjä ja vertaamalla niitä sulatolla järjestelmän asennuspaikoilla tavallisesti vallitseviin olosuhteisiin. Mittaustietoa kerättiin käyttämällä lukijaan sulautettua ohjelmistoa, jossa painotuttiin RSSI-tietojen tallentamiseen jokaiselta lukupaikalta. Lisäksi toimivuutta tarkisteltiin myös lukijan mahdollistamalla antennien ympäristön radiotaajuisen spektrin analyysillä.

Lopputuloksena havaittiin, että kyseisen järjestelmän kokoonpano soveltuu F3 sulaton ympäristöön hyvin ja sen toiminta ei normaaliolosuhteissa häiriinny ulkopuolisten tekijöiden vuoksi. Yllättäen ympäristön suuri metallipintojen määrä vaikutti tehostavan järjestelmän toimintavarmuutta esimerkiksi antennikaapelien suosituspituuksien ylittymisestä huolimatta. Johtopäätöksenä voidaan sanoa, että nykyisiä RFID-laitteita voidaan hyödyntää vaativissakin olosuhteissa, kunhan käytetään tarkoitukseen sopivia lukija-, antenni- ja tagimalleja ja järjestelmä suunnitellaan perusteellisesti.

Asiasanat: RFID, tehdas, kulunvalvonta, ympäristö, RSSI, sulautettu ohjelmisto, tagi

ABSCTRACT
Oulu University of Applied Sciences
Degree Programme in Information Technology, Option of Wireless Devices

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Author: Jarkko Eskola
Title of thesis: Suitability of RFID Based Access Control System in a Factory Environment
Supervisor: Riitta Rontu
Term and year when the thesis was submitted: Spring 2013
Pages: 37 + 7 appendices

In this Bachelor's thesis the functionality of RFID technology was assessed and tested in a factory environment. The subscriber was Outokumpu Stainless Oy, who wanted to evaluate the operability of the RFID system at the new F3 smelt shop in Tornio. The main goal was to study the suitability of RFID based access control system in a factory environment by conducting test measurements and collecting reliable measurement data of the functionality of the system. An additional goal was to utilize tools, which system administrators will be using in the future.

The thesis includes research of the RFID technology from the view of system administrator and measurements and tests carried out in the installation environment. Suitability to factory environments was assessed by studying technical specifications of the system components and comparing them to the normal conditions at the installation locations. Measurement data was gathered by using the embedded software of the reader, with emphasis on the collection of RSSI information at every ready zone. Moreover, functionality was examined by using the radio frequency spectrum analyser of the reader, which presents RF spectrum from all connected and working antennas of the reader.

As result, it was detected that the system is fitting to F3 melt shop environment quite well and the functioning of it is not disturbed by external factors in normal circumstances. The large amount of metallic surfaces seemed to enhance the operation of the system despite restrictions, such as exceeding the recommended length of antenna cabling. In conclusion, it can be argued, that current RFID devices can be utilized in demanding conditions as long as the correct reader, tag and antenna models are being applied and the system is thoroughly designed.

Keywords: RFID, factory, access control, environment, RSSI, embedded software, tag

ACKNOWLEDGEMENTS

First of all I would like to thank my family and friends for supporting me during my studies at Oulu begun in the fall 2009, and particularly during this Bachelor's thesis offering many challenges to encounter.

I would like to thank Outokumpu Stainless Oy, especially my instructor Veli Maijanen and the other members of Network and Telecommunications Services team for giving me the chance to carry out my Bachelor's thesis under their supervision and for the past three summer traineeships they have offered to me. Also I would like to thank my supervisor Riitta Rontu from Oulu University of Applied Sciences for guidance she has offered along the work.

Moreover, I would like to issue my thanks to other co-operation sides that were supporting me during the thesis work by offering information and expertise.

April 2013, Oulu.

Jarkko Eskola

CONTENTS

SYMBOLS AND ABBREVATIONS

EM	Electromagnetic
ETSI	European Telecommunications Standards Institute
FICORA	Finnish Communications Regulatory Authority
HF	High Frequency, RFID technology’s standard frequency of 13.56 MHz
IFF	Identify Friend or Foe
ISM	Industrial, Scientific and Medical
LF	Low Frequency, in RFID 125 – 134 kHz
RST	Reader Startup Tool
RDT	Reader Diagnostic Tool
RTT	Reader Test Tool
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indicator
UHF	Ultra High Frequency, in RFID 860 – 930 MHz and 2.4 GHz

1 INTRODUCTIONS

This thesis studies suitability of RFID (Radio Frequency Identification) technology as a part of access control system in a factory environment. The system is designed to provide security personnel real time information of the number of employees on a designated factory floor. As such, the system is not capable of precisely locating any individual person within given premises.

The subscriber of this bachelor’s thesis is Outokumpu Stainless Oy. Outokumpu Stainless Oy is a part of the company’s Finnish manufacturing site Outokumpu Tornio Works and Outokumpu Group, an international stainless steel company.

During my studies at the Oulu University of Applied Sciences I have worked at Outokumpu Tornio Works as a summer trainee for the past three years and in the year 2011 Outokumpu started a project to double ferrochrome production in Finland. In order to achieve the goal, Outokumpu begun construction of a new melting shop named F3. A part of the F3 project is the implementation of a new access control system based on the use of RFID technology. This provided a fitting subject for my bachelor’s thesis and Outokumpu’s Network and Telecommunication Services team in Tornio was willing to offer me the chance to carry it out under their supervision.

The system’s hardware and installation were provided by external suppliers. Therefore, Outokumpu saw it important to test the system right after the installation was finished in order to guide further development. Especially, since Outokumpu is developing software, which uses the data of the RFID hardware to create a visual access control application.

I took up the challenge to study the installed system in order to figure out its reliability in terms of antenna positioning, hardware testing and overall usability of provided administration software for fault localization. This bachelor’s thesis does not include either profound research of fundamentals of RFID technology or testing of initial configuration of the readers.

2 HISTORY OF RFID

RFID technology originates from the early 20th century, when identification of aircrafts during the Second World War was conducted by using radio broadcast technology combined with the radar technology. Essentially, an aircraft was equipped with a transponder to enable identification, when radar system initialised identification procedure automatically by sending a specific signal to the target. This formed the first IFF (Identification Friend or Foe) system. (1.)

The first patent for RFID technology was granted in the year 1973 for RFID active tag. Later in the same year a RFID key was patented, which is comparable with modern day access control RFID keys. The development of RFID technology hastened in the 1970’s and 1980’s and ever since RFID has become more and more widespread in different fields; industries, logistics and other services. For example, one of the first commercial applications for RFID was automated road toll system in the USA in the mid 80’s. (1.)

Another ground breaking step was the development of passive 125 kHz LF (Low Frequency band) tags used to identify cows during feeding in order to administer medicine correctly. The system is still in use and the LF band was utilized in key chains and key cards as well. However, the LF band was replaced by HF (High Frequency) band of 13.56 MHz, which nowadays is likely to be the most common frequency used in key cards, mass transportation tickets and other smart cards. (1.)

In the early 1990’s a new frequency range to be used in RFID was patented by IBM. The new UHF (Ultra High Frequency) band operates at 860 – 930 MHz and later microwave band 2.45 GHz ISM (Industrial, Scientific and Medical) frequencies offer longer reading distance and faster data transfer speed in comparison to the LF and HF bands. Hence, the UHF bands are being adapted especially to enhance access control and logistic surveillance, for example, military forces and many trade and industry companies take advantage of the modern RFID technology. (1.)

3 RFID SYSTEM ELEMENTS

In short, a RFID system builds around two main hardware components, a reader unit and a transponder, or more commonly known as a tag. Tags are categorized as passive, active or semi-passive transponders, the difference being in the method of powering the tag. Naturally, an important aspect is application software to enable hardware's functioning through embedded and separate operating systems.

3.1 Reader

The most complicated hardware part is the reader for it is the most active element on any RFID system. A reader consists of a controller, antenna and network interface in one casing, although the antenna may be an external component in which case some reader models support multiple antennas connected at the same time. (2.)

Reader controller is in key position when it comes to enabling read or read-write processes to a transponder in antenna's reach and running the needed protocols during those activities. Depending on the application and RFID system the controller is used in, the complexity of it varies considerably. (2.)

The network interface is activated when a reader unit needs to communicate with the central controller of the RFID system to conduct programmed actions after reading tag information. Normally the interface has been established by standard data transfer busses such as RS232, RS422, Ethernet, Wi-Fi, Bluetooth, ZigBee. (2.)

3.2 Antenna basics

An antenna used in RFID is either a coil or a dipole depending on coupling technique. Coil antennas operate at LF band utilizing inductive coupling for means of communication with RFID tags. Dipole antennas are used at HF and UHF bands with radiative systems and short wavelengths. (5, p. 40 – 51.)

RFID antenna does not differ from other antennas on the basic properties. It is a tuned circuit to which power is fed in order to generate radiating EM wave into free space. There are a number of useful parameters and definitions for antennas when looking at RFID technology, for example (6):

- Bandwidth. The band over which the antenna will operate satisfactorily. Normally antennas operate as resonant elements and therefore their performance falls either side of the centre frequency. (6.)

- Feed impedance. The current and voltage will vary along the length of the antenna element. Voltage rises towards the ends and the current falls and is also dependent upon the length of the antenna, etc. As impedance is the ratio of current and voltage, the feed impedance varies. To ensure the maximum power transfer the source and load impedances should match. (6.)

- Voltage Standing Wave Ratio (VSWR). The ratio of maximum and minimum voltage in a standing wave pattern in the transmission line. Indicates impedance mismatch with transmission line and the load. The higher VSWR, the greater mismatch. (7, search word voltage standing wave ratio.)

- Polarization. The property describing the orientation or time varying direction and amplitude of an electromagnetic wave. (7, search word polarization.)

- Gain. The ratios of output current, voltage or power to input current, voltage or power. (7, search word gain.)

- Horizontal and vertical beam widths. The angle between the half-power (3-dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe. (7, search word beam width.)

3.3 Tags and coupling

Essentially, tags are built from two main elements, an antenna and electronic circuitry from which the antenna needs the largest area in comparison. Tags contain a memory chip and may have their own power source to power the tag or to enhance data transmission range. (3.)

Passive tags do not have built-in power supply, but they generate operating voltage by interacting with the reader unit through antennas. There are three distinct ways to do so; capacitive, inductive or propagative coupling. Firstly, capacitive coupling is used with LF bands requiring physical contact between a tag and a reader. Both have contact plates which need to touch in order for the reader to conduct operating voltage through the electrodes into the tag. (4.)

Secondly, inductive coupling operates generally with LF and HF band systems. A tag entering a reader generated electromagnetic (EM) field at close proximity induces voltage in the coil of a tag. There is no need for physical contact and read range of 1 meter can be achieved. (4.)

Lastly the propagative, also known as backscattering coupling, used with UHF bands offers maximum read range of 10 meters. Basically, a reader unit transmits radio frequency signal, which the tag uses to draw energy converting it to voltage to modulate properties of the received RF signal. (4.)

Equipping a tag with own power source and making it an active component considerably increases the reading range from maximum of approximately 10 meters of a passive tag to over a hundred meters. Adding power source to transponders enable more complex sensor network to be established with RFID technology. (3.)

Semi-passive tags use built-in power source only to power internal activities of a transponder, but relies on reader to supply power for transmission of data to reader (3). Therefore, read range is similar in comparison to a passive tag, but information on a semi-passive tag and processing of it can be more complex.

4 RFID BASED ACCESS CONTROL SYSTEM

In this chapter the focus is to describe hardware and administration software of the RFID system and the factory environment at Outokumpu's F3 melt shop where the system will be operating. The hardware involves reader writer units by Sirit Inc., antennas by Aerial Oy, antenna cabling by L-com Inc., transponders by Smartrac N.V. and it is planned to be used with FerroChrome Works' RFID Access Control System software. The system architecture is presented in figure 1.

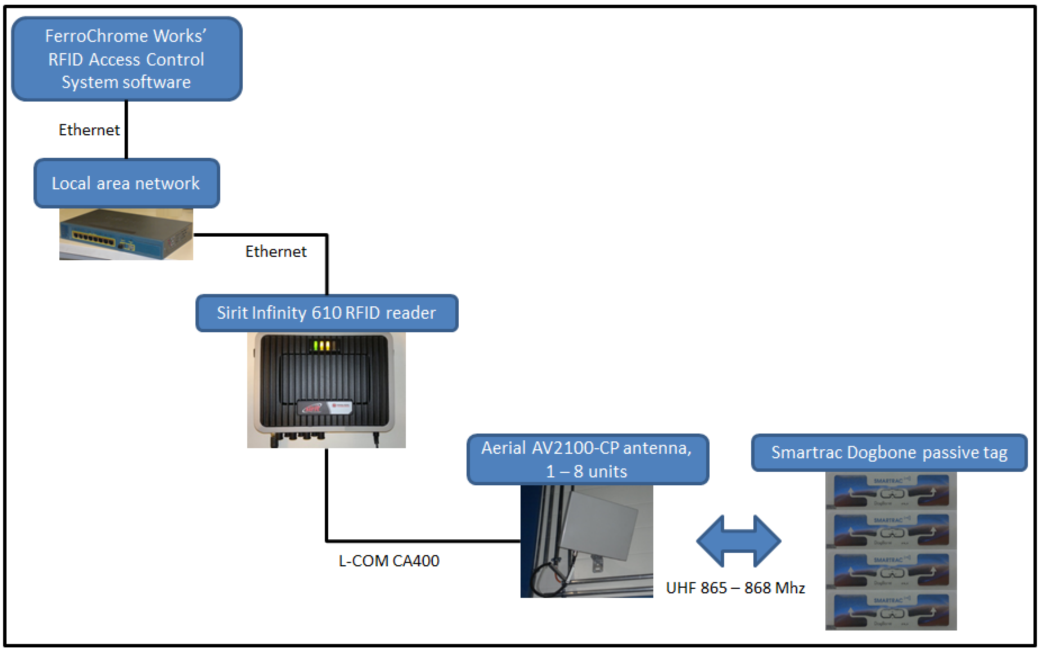

FIGURE 1. Outokumpu F3 melt shop access control system architecture.

4.1 F3 melt shop factory environment

The F3 melt shop officially started production during November 2012 while the installation of RFID hardware was still under way. The environmental conditions of the production area can be described as extreme during melting process, when temperature of the molten ferrochrome (FeCr) metal rises up to 1 700 °C radiating to surrounding area (8). In addition, the electric arc furnace uses approximately 3.125 MWh of electrical energy to melt a ton of FeCr. (9).

Under these conditions the highest safety risks are produced by fire lit from electrical failure or molten steel and life threatening carbon monoxide (CO) levels from factory processes, incidents which none can be completely avoided. Even more, strong electromagnetic fields are being generated at the proximity of furnace transformers during FeCr melting. In order to avoid losses of life, safety measures such as evacuation routes leading to outdoors, efficient ventilation of premises and preventing CO gas escapes by sealing different floors from each other as effectively as possible have been implemented. Additionally, the CO levels are monitored automatically and employees in the premises are equipped with personal CO gas alarms to indicate when the environment is not safe. Finally, during melting operation movement near the production areas is restricted (10.)

The role of the RFID equipment in this environment is to monitor the number of personnel on each of the seven levels of F3 melt shop, from ground level to the rooftop. Therefore, equipment locations are designed in a way that they cover the main passages leading in and out of a floor or the factory premises; staircases, elevators and doorways. Normally these locations are not exposed to extreme temperature or electromagnetic fluctuations to minimize the risk of placing employees in the harm's way, therefore, considering surrounding conditions operation of the RFID hardware should be ensured. (11.)

4.2 Sirit INfinity 610 ETSI reader

Reader hardware

The multi-protocol reader and writer unit INfinity 610 has been fitted to match European regulations by European Telecommunications Standards Institution (ETSI). Manufactured by an American company Sirit Inc., the reader supports mandatory and optional features of standards EPCGlobal Class 1 Generation 2 and ISO18000-6C. In addition, support for ISO18000-6B and Ucode 1.19 with future protocols through firmware updates will be available. (12.) The operational frequency band is set between 865.0 – 868.0 MHz, which is exempt from licensing set by Finnish Communications Regulatory Authority (FICORA) in regulation 15 AD/2012 M (Appendix 1) and is in line with ETSI EN 302 208 standard. More accurate hardware specification is presented on appendix 2.

The reader electronics are protected by aluminium casing to ensure durability on varying conditions (Figure 2). On top of robust casing, the reader units at F3 melt shop are placed inside industrial enclosures for further environmental protection.

FIGURE 2. Front of INfinity 610 ETSI reader unit

On the side panel the reader has eight coaxial interfaces, or RF ports, for externally connected antennas, which can be used either as eight mono-static or four bi-static antennas. Furthermore, the device is equipped with RS-232, USB 2.0 with A and B type sockets, TCP/IP 10/100 Ethernet, 4x Digital I/O interfaces. (Figure 3.) (13, p. 1 – 2.) On the front of the casing there are four LED lights to indicate reader status (Table 1).

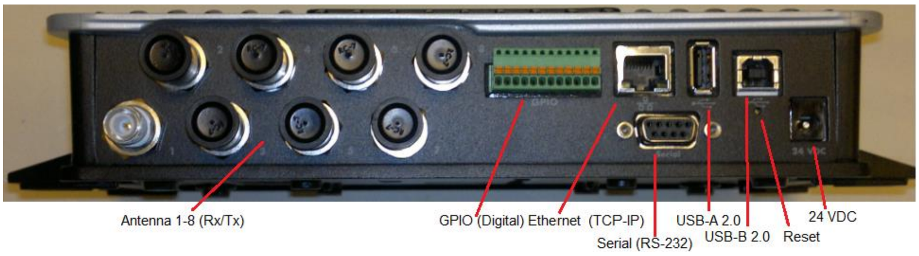

FIGURE 3. Sirit INfinity 610 Inputs, outputs and power interfaces

TABLE 1. INfinity 610 LED indications (13, p. 2)

Number (from left to right in reference to figure 2.)	Indication	Colour/State	Indication
1	Power	Off Amber Amber flashing Green	Power off Boot loader executing Linux initializing Unit operational
2	Activity	Off Green Green flashing Amber	RF off TX active Tag detect Antenna check failed
3	User	Amber	User defined
4	Status	Off Amber Green flash Red	Ok Firmware update GPIO activity Fault

Reader software

INfinity 610 reader is delivered with two software applications for configuration and control purposes. Reader Startup Tool (RST) is an application for Microsoft Windows, with which an administrator can access all reader units on the network for modification of communication, network and operational parameters. In addition, RST includes Reader Test Tool (RTT) and Reader Diagnostic Tool (RDT) for expert level users in system error conditions and management tools for tag and antenna configuration. (13, p. 22 – 40.) The reader units have Linux based embedded Remote Configuration Tool (RCT) offering the same reader management tools as RST, apart from RTT and RDT, over Ethernet connection (13, p. 41 – 68).

4.3 Antennas

Aerial AV2100-CP

The external dipole antennas connected to INfinity 610 ETSI readers are produced by a Finnish company Aerial Oy (Figure 4). The antenna type is AV2100-CP and it meets the in-use test parameters defined in the standard ETS 300 019-1-4 class 4.1 E determined by ETSI. (14.) The standard contains the classifications of environmental test conditions in stationary use at non-weather protected locations. In the scope of this bachelor's thesis the document states the following operational limits:

- temperature -45 °C – 45 °C
- relative humidity 8 % – 100 %
- rate of change of temperature 0.5 °C/min.

Other conditions in the standard documentation were not seen relative to the system environment at this stage. (15.)

FIGURE 4. Aerial AV2100-CP antenna installation at F3 melt shop.

The antenna has the operative frequency band of 850 – 870 MHz with 7.5 dBi gain and impedance of 50 Ω, which is the correct load for the antenna interface of the reader. The beam widths of the antenna are horizontally 90° and vertically 70°, where the output power drops to half of its mid-band level and reading of a transponder is relatively certain. (16.) More specification details are presented on appendix 3. The polarization of the antenna is left handed circular, which offers more constant tag readability regardless of tag orientation in relation to the antenna. (17, p. 82.)

L-com CA-400 antenna cabling

The antenna coax cabling CA-400 used with the system is manufactured by American company L-com Inc. The most important characteristics are impedance of 50 Ω to match the requirement of the reader for RF port load, operating temperature of -40 °C to 80 °C, minimum bend radius of 51 mm and attenuation of 12.8 dB over 100 meters at the frequency of 900 Mhz (18). More technical specification presented on appendix 4 among other details.

4.4 DogBone tag

The DogBone model passive transponders used are self-adhesive labels attached to safety helmets. The dipole antenna is an aluminium foil sealed between surface layers. (Figure 5.) The tags are produced by Smartrac N.V. The labels are compatible with ISO 18000 and EPCGlobal Class 1 Gen2 standards to ensure interoperability with same standard components.

Figure 5. Smartrac DogBone RFID tag

Tag’s operating frequency band is 860 – 960 MHz and operation temperature for electronic parts is between -45 °C and 85 °C. Maximum bending diameter for the inlay is 50 mm with maximum tension of 10 N. Important factor considering usage is shelf life of two years. This is the ensured time of operation from manufacturing date while stored under proper conditions temperature and humidity wise. (19.) More in depth technical specification is presented on appendix 5.

4.5 FerroChrome Works' RFID Access Control System Software

The RFID hardware will be used with customized personnel monitoring application FerroChrome Works' RFID Access Control System. Still at development stage, the .NET Framework based software will present a visual crosscut of the factory divided in eight sections from Ground level to the rooftop (Figure 6). Each person entering the F3 melt shop will be registered to the software by unique RFID tag ID codes through MySQL database updated by Outokumpu.

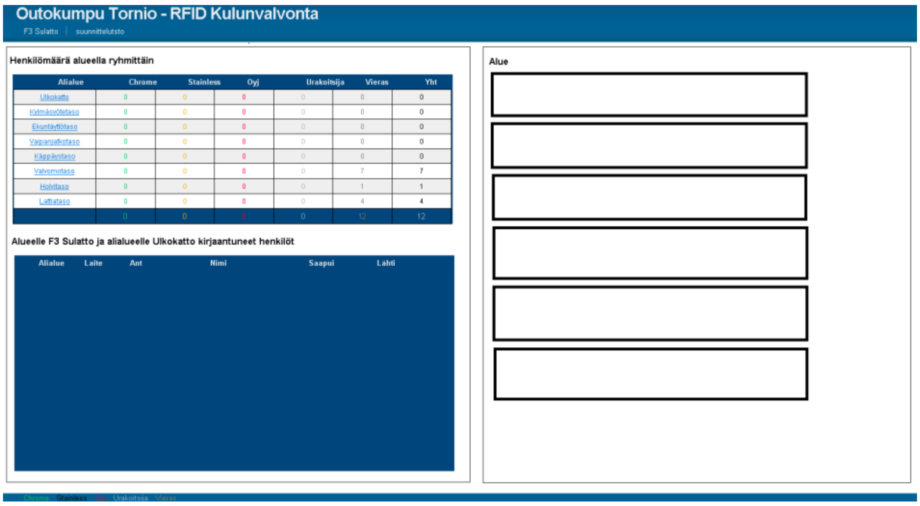

FIGURE 6. FerroChrome Works' RFID Access Control System user interface.

The level specific location of a person will be updated as one enters read range of a RFID reader at different levels. In practice, the antennas are used as checkpoints for updating the locations and number of personnel through the factory premises to the user interface of the system, which is viewed at F3 Control room and at Security building. The accuracy of the location is restricted to a reader antenna receiving the entry on certain level; therefore real time tracking of employees is prohibited. The application is ordered from external software company by Outokumpu who owns the source code. (20.)

5 COMISSIONING OF RFID SYSTEM

5.1 Preliminary assessment of hardware installations

After hardware installations of the RFID system were completed at F3 melt shop, preliminary inspections were conducted to ensure proper placement of 14 reader units and alignments of 37 antennas. By visual valuation the installations were accepted as they were, although it was noted that actual reading tests would be made with system supplier in order to present more accurate results with tag read zones at different antennas.

During inspection the reader units were powered up and connected to the factory area network via Ethernet to assure functioning and enable remote configuration prior to the actual commissioning of the system. Each reader was assigned with a unique IP address for device monitoring purposes, for example, should a reader disconnect from the network, the monitoring system generates an e-mail and an optional SMS message to the administrators (21).

After the inspection, the distances between antennas from their respective readers raised a clear concern, one which was anticipated from the original technical drafting. The antenna cable attenuations in many cases exceeded 3 dB value recommended by the antenna manufacturer. With the used cabling, 3 dB attenuation level would be reached with the length of 23.44 meters, when calculated with equation 1.

$$l = \frac{L_{max}}{A} \qquad \textit{EQUATION 1}$$

Where L_{max} is 3 dB, the maximum loss of the antenna cable and attenuation *A* is 12.8 dB/100 m, retrieved from L-COM CA-400 specification using the value given with 900 MHz frequency. Even though the RFID utilizes lower frequency, the 900 MHz used in the calculations was seen sufficient value in practical terms offering accurate results with a small buffer value in length in actual implementation. (22.)

The attenuation values along the installed cables varied between a minimum of 0.3 dB to maximum of 7.9 dB as shown in appendix 6 provided by system supplier. In short, 47 % of the cables are too long in comparison to the recommended length surpassing the 3 dB attenuation limit. It was expected that the antennas connected to over 23.44 meter cables would have greatly diminished reading ranges. (22.)

5.2 Initial tests on original setup

In preparation of the commissioning period, the RFID readers were modified with short python script provided by system supplier to enable continuous state of active mode, which was originally disabled. Without the script the readers would fall into a standby mode after a short period of time and would not continue read actions automatically when a tag enters the read zone. With the access control application a constant tag reading is essential. Therefore the script was left on running.

Test methods

During the commissioning the RFID hardware was tested in terms of read reliability at the main entrances one antenna at a time by using tag report data gained from the Reader Diagnostic Tool. Another utilized function from the RDT was spectrum analyser, generating a graphical presentation of alternating spectral composition of radio waves in the surrounding environment of the antennas connected to a reader (Figure 7) (13, p. 39).

The figure presents the RF noise levels observed by RFID reader of Preheater charging level at three different antenna locations in dBm at 866.90 MHz. To give perspective to the power levels, conversion of dBm to watts is made with equation 2 (23).

$$P = 10^{\frac{x-30}{10}}$$ *EQUATION 2*

Where the power *P* is in watts and *x* is power ration in dBm. In the figure highest power value is slightly under -83.62 dBm (4.35 pW) and lowest slightly over -156.72 dBm (0.21 aW) originating from the factory environments.

When viewed in real time, the central frequency changes between four different operational frequencies of 865.70, 866.30, 866.90 and 867.50 MHz, which are shown as power peaks in the figure as the reader scans read zones for tags. This is due to the standard's goal to decrease data transmission collisions at high density transponder areas by confining reader signals in specified frequency bands, while signals originating from tags are set around those to avoid reader signals over powering transponder signals (24, p. 4). The gaps between operating signals depict the RF noise level coming through the surrounding environment and on the far right of the diagram a clear peak in RF noise has been generated.

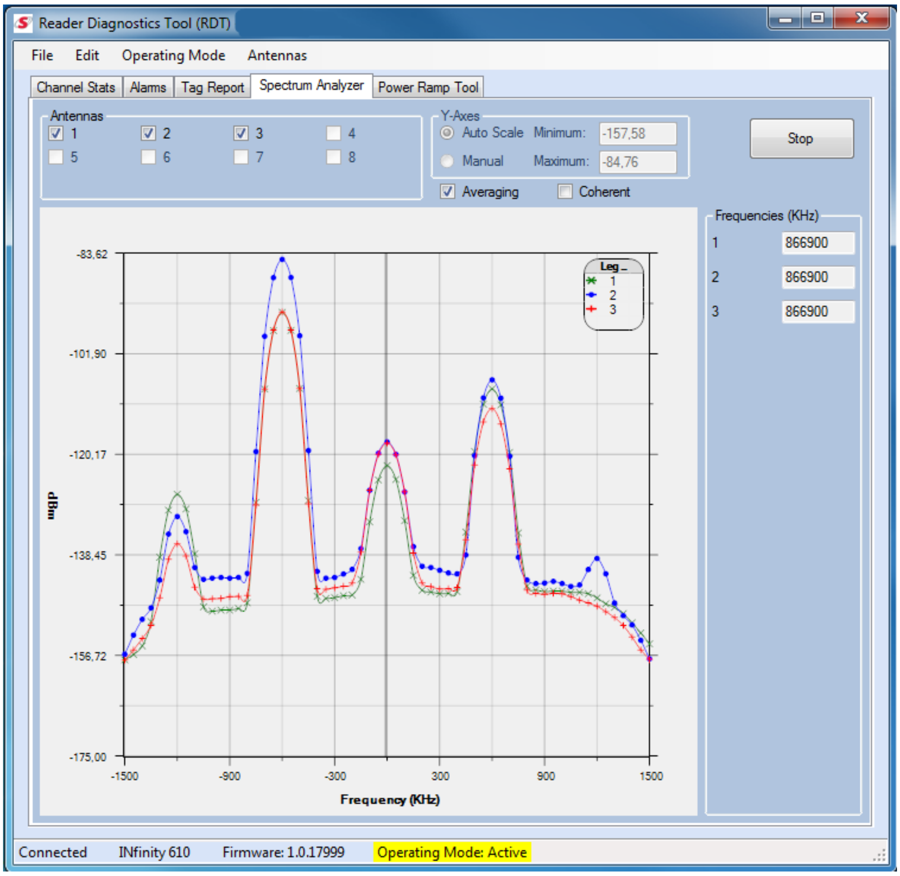

FIGURE 7. RDT Spectrum analyzer with three operational antennas.

The purpose was to take advantage of the tools offered by the reader itself in order to estimate their usefulness in system maintenance. This way the local administrators could use same the methods in future tasks to upkeep and further develop the system with minimal additional equipment. With the gained information a comprehensive view from normal usage of the RFID hardware at doorways with different directions of travel could be established.

The data observed were:

- RSSI (Received Signal Strength Indicator)
- transmit power of the reader; tx power
- timestamp from registration of the tag in the read zone
- identification number of registering antenna
- tag identification code; tag ID

The software uses tag ID to replace more widely used term EPC (Electronic Product Code), which is easily interpreted as TID (Tag Identifier); a fixed serial tag number for each transponder generated by the manufacturer. Tag ID is the code which administrator can modify. View of the data gathered is presented in figure 8.

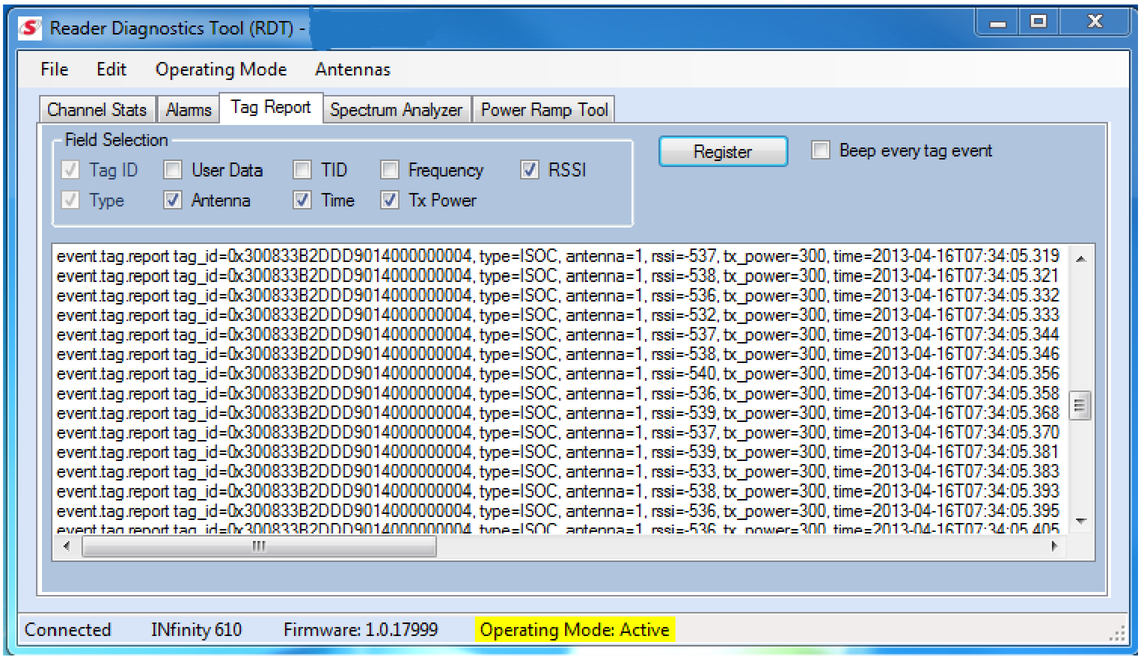

FIGURE 8. Presentation of tag report data log received with RDT software.

In practice the readability tests were carried out by accessing the reader with RDT and starting the tag report registering, while the transmission power was set to the maximum of 31.5 dBm (1.41 W) from the reader. Next a test subject with a DogBone label tag attached inside a safety helmet, on the front section, entered the floor behind closed a door. This test setup revealed if an antenna cable was properly attached to the connector and whether the attenuation was restricting the data transfer between the reader and a tag.

While in the read zone of a well working installation, the tag registration speed was revealed by the report log when within a second the system listed a hundred read events, which is the maximum amount the RDT tag report shows at a time. A property included in the EPCGlobal Class1 Generation 2 standard, which is designed for fast reading of high density of tags passing through the read range of an antenna (24, p. 3).

After a confirmed tag read at a floor entry, the test subject moved in different directions towards and away from the entry point and RDT observer gave him real time instructions when he left the read range of the antenna. This method revealed the coarse perimeters for the read zone at the entrance and from which the zone coverage was evaluated in relation to different direction where a person could head to.

Test results

After a battery of described tests throughout the RFID hardware, the results showed on contrary to expectations that the antenna cables exceeding recommended length did not obstruct tag reading at any antenna location. The reason for this was concluded to be the sum of

- environmental factors
- enhanced read properties of EPC Global Class 1 Generation 2 standard
- and top quality antenna cabling and the installation of it.

Essentially the factory structures are loaded with metal surfaces, which magnify the multipath phenomenon of radio signals and allow the tag to gather energy from multiple signals despite the level of attenuation of the original radio wave (25). With this the read zones are set at acceptable distances from a floor entrance where the installation consists one antenna intended to cover one doorway.

At this point the RSSI magnitude was roughly measured to set between -400 and -800 units at which tag readings were registered. RSSI (Received Signal Strength Indicator) in this case represents the power level a tag uses to send signal back to the reader. In open space, RSSI correlates with distance; the farther a tag is from an antenna, more negative value is shown, since the tag needs to use more energy to be able to send data to the receiving antenna (26). RSSI levels at measure points with weaker antenna coverage areas at the same range as given entrance point were not seen important for closer analysing.

The spectrum analyser diagnostics were run at every reader before registration tests to ensure antenna connections and to gain knowledge of RF noise levels at entrances. While the noise levels influencing at different antenna locations were constantly alternating, nearly all of them were found to operate properly in relation to planned read zones when initiating tag registration.

Only exception was found with clear indication of a malfunctioning antenna line. It was located at the F3 control room reader, when the corresponding power curve number 6 on the graph did not fluctuate in the same manner as did the other five on the diagram in live situation (Figure 9). In addition the curve shows sudden slopes on power level either sides of the 866.90 MHz frequency nearing the other operational frequencies. Tag registration failure proved the antenna line error.

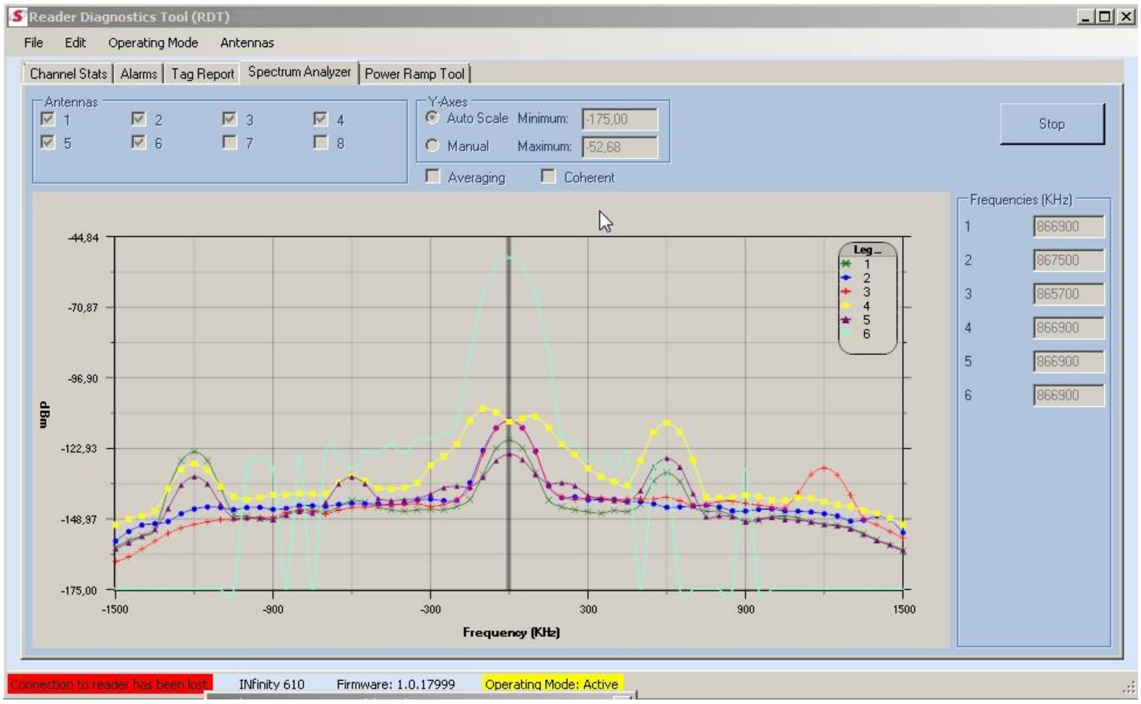

FIGURE 9. Spectrum analyzer indicates malfunction at antenna 6 (turquoise curve).

Exceptions to system coverage are found at top two floors, Cold Charging Level and Preheater Charging Level, where designated antennas covering the freight elevator passage are not installed in lack of proper mounting place. The shortages have been tried to correct with positioning and aligning the nearby personnel doorway antenna with little success. The problem occurs due to lack of read range, since the distance from the antenna to the passageway of the freight elevator increases in many cases over 5 meters.

Furthermore, the surroundings do not have walls or other surfaces as close as in more confined installations to redirect radio waves by multipath properties. Therefore, the tag either cannot gather enough energy from the radio signal to enable data transfer back to the antenna, or the data transfer is successful but the signal of the tag is much weaker in comparison to the one reader sends and may not travel the distance to the antenna.

Similar situation was found at Furnace Roof Level where an antenna registering personnel in a workshop premises is situated, but passage through adjacent door at the staircase into the furnace premises is not covered. The door was added after plans for RFID antenna positioning were made and was left without one. This could have led to a situation that an employee would not be registered by the RFID system at all. Therefore, the passage in question was listed for changes at later time.

In the end, the tests displayed encouraging results on terms of flexibility of the selected RFID hardware in factory environment, especially with read reliability despite the antenna cable lengths.

5.3 Hardware readjustments

Firstly the inoperative antenna line at the F3 control room was inspected and it turned out that the connector installation had most likely short circuited the line. The reasoning for this is that the reader had identified the existence of the line by automatically checking open antenna ports on start-up and spectrum analyser drew the stationary curve on the graph. These would fail with a malfunctioning antenna port.

Moreover, by changing the connector to the antenna end of the cable the malfunction was solved, proven by successful tag registration data and normalization of the RF noise behaviour on spectrum analysis in live situation. As the figure 10 shows in comparison to figure 9, the sudden drops in power levels of the turquoise curve have ceased and it has risen to meet the levels of other antenna lines.

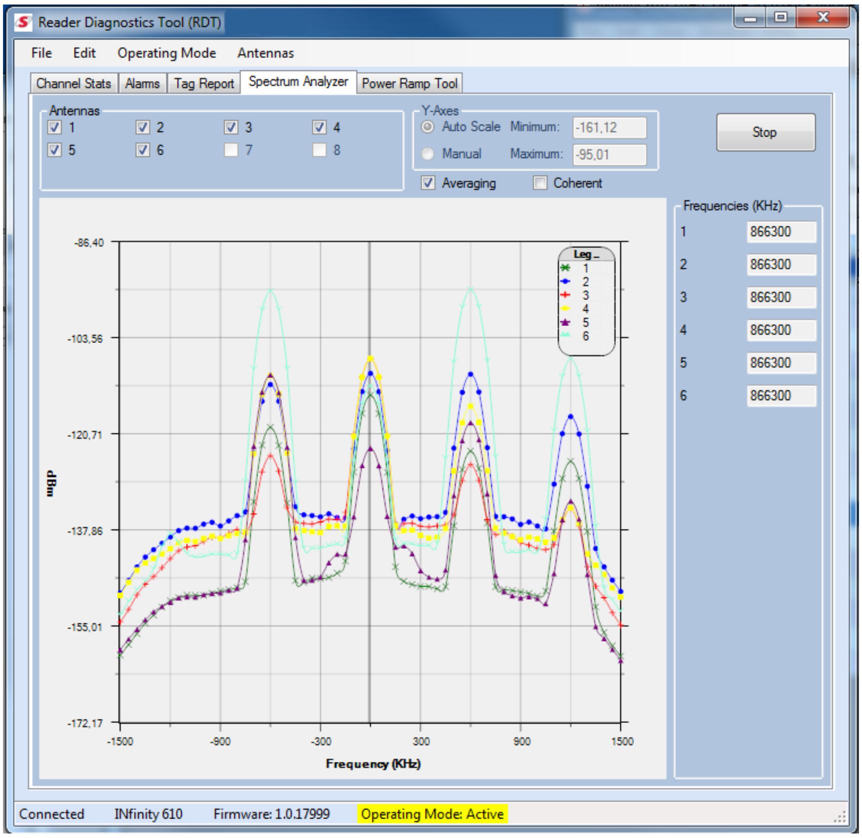

FIGURE 10. Presentation of repaired antenna line 6 (turquoise curve).

Secondly, with conducted tests the following readjustments were made in order to better the operational level of the RFID hardware by relocating some of the antennas where the original setup was found to be slightly off. Changes presented on table 2.

TABLE 2. Repositioning of the antennas.

Sirit host-name	**Factory level of the antenna**	**Antenna location**	**Procedure**
6th floor Sirit 2	Cold charging level	Next to conveyer.	Relocate 2 meters up.
5th floor Sirit 1	Preheater charg-ing level	At the personnel door of freight elevator.	Relocate 2 meters up.
3th floor Sirit 1	Electrode slip-ping level	Opposite to freight ele-vator.	Attachment to pas-sage way above
Level 18.00 Sirit 1	Furnace roof level	Opposite to freight ele-vator.	Align downwards to the door.
Control-room21	Furnace roof level	Inside workshop prem-ises, next to an en-trance to staircase.	Aligned towards stair-case to cover adja-cent door.

The option to reduce conducted antenna power from the reader was not utilized at this point. The reasoning being that the read zones received by the full 31.5 dBm transmission power were not large enough to affect other systems within levels and whilst exceeding the entrance point areas, read zones were not found to overlap between two levels during testing. The heights between levels alone range from 3.2 meters to 12.2 meters and with differing amount of solid materials; pipes, cablings, concrete, etc. conducting readings through floor or ceiling with maximum transmission power is practically impossible.

At Ground level some overlapping was recorded between antennas located inside the building and antennas outside when doors were open. Even so, the transmission powers were not altered to ensure that a person is registered by the system when working between boarders of two or more antennas. As a conclusion, the difference of registering the person inside or outside the factory should be made by the FerroChrome Works' RFID Access Control System software and not with RFID hardware.

6 RSSI MEASUREMENTS WITH RDT

The RSSI data gathered with RDT software was estimated to be the best information considering reliability without additional equipment in use. Particularly with the situation where passing tags have usually narrow entry point to a wide read zone and the antennas are aligned to cast the main radiation lobe towards the entrance. Therefore, recording comprehensive sampling of RSSI values at different distances from every antenna, by either closing in the entrance or passing by an antenna, was conducted in order to determine operational level of the RFID hardware for future reference.

The measurement points were selected in consideration of the location, which lead to variation of distances between 0.2 and 6.0 meters. With these ranges, environmental changes and greatly differing cable lengths, the results can rarely be compared to each other, but they can be used as a guide line to define changes in system operation at a single antenna location. The data was gathered with RDT tag report log by initiating registration when test subject facing the antenna entered the measured distance with label tag attached on the helmet. Once a hundred samples were logged the registration was ended and data saved for further processing. Exception to sample size is the Rooftop antenna with only 25 samples at each distance due to environmental restrictions. From the samples an average value was calculated to represent the RSSI level in each location. The full table of results is presented in appendix 7.

The test setting for the RSSI mapping used offers an easy way for the administrators to repeat the test and get useful values to reference with statics presented in this thesis.

7 SUMMARY

The purpose of the bachelor's thesis was to study the suitability of RFID technology as part of access control system in a factory environment. It included assessment of reliability of the hardware in terms of environmental durability and functioning in the designated read zones, including on site testing in order to gain dependable measurement information of the operational system.

Using RFID in a floor based personnel identification application, being developed by Outokumpu, in a factory has not been done before. This offered me truly first-hand experience considering implementation of such system. Especially, when taking into consideration how little RFID technology is still being utilized throughout Finland at different venues of industry.

The primary concern for the failure of the system was the antenna positioning at nearly all locations. Firstly the antenna cable lengths exceeded the recommendation of the reader manufacturer and secondly the read zones were in many cases over two meters away. With both of these factors summed it was suspected that tag reading would fail completely at most of the entrances covered by the system. Environmental concerns after research and evaluation of the hardware surroundings were seen to fit the different specifications introduced in this thesis in normal operational conditions on the different levels of the F3 smelt shop.

After comprehensive testing of the entrance points at the factory it was surprisingly concluded that tag read registrations were successful at nearly every location and exceptions were restricted only to unsuccessful installation of cable connector or minor antenna misalignments. Genuinely harmfully overlapping read zones from different antennas were not found either. The situation was unheard of even to the hardware supplier and the reason for the success was seen to be the high amount of reflecting surfaces in the antenna surroundings, high quality cabling and seemingly well produced reader model enabling bending of recommended operational limits. One could argue that this was a fine show of what proper hardware can offer to a complex system.

As what comes to measurements, the embedded reader software proves to be a versatile tool to gather statistics from the system. The spectrum analyser was utilized to determine antenna activity and gave clear indications if there were malfunctions. Moreover, the tag report log was well utilized in the collection of the RSSI measurements to establish a reference table of operational system. Which could be used in future shortcomings considering tag reading at a singular antenna.

What little criticism can be found would be associated with the quite complex installation of a single working reader unit at factory environment, which by itself is quite a demanding area. In this case all readers were situated in industrial enclosures; usually two reader to a certain level. This led to a situation where antenna had to be located quite far from the reader itself and with the long distances the amount of work put to complete an installation is very high. That being said, with some experience of implementing new technology in an industrial environment, the work does come with the territory and by all means, with RFID hardware there was not much new to it.

All in all, it is clear that little by little RFID technology will be implemented in various ways to industrial settings and not in all cases only with the somewhat traditional logistics and warehouse applications alone. The technology itself does not limit future development, when correct models of reader, antennas and tags are utilized in a given application. The subject of this thesis is a good indication of it and what a successful commissioning needs, as always with new technology, is careful planning, good co-operation partners and a little bit of luck.

On a personal level the thesis offered me valuable insight to the workings of RFID technology, which in my view promises opportunities considering employment in the future. My studies at Oulu University of Applied Sciences had prepared me well for the undertaking of the thesis by giving me an engineer type mind-set as a problem solver. Moreover, the wide range of courses along the studies truly presented many useful skills to get the job done.

Even so, there is still room for personal development. Especially strengthening research methods and recognizing the right contacts for information. Both which in my opinion are matters of experience, and most likely are to be improved as the time goes by and more situations to put them to the test arise.

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APPENDICES

Appendix 1 FICORA 15AD/ 2012 M

Appendix 2 Reader specifications

Appendix 3 Antenna specifications

Appendix 4 Antenna cable specifications

Appendix 5 Tag specifications

Appendix 6 Antenna cable attenuations

Appendix 7 F3 RFID antenna specific RSSI measurements

ETÄTUNNISTUSLAITTEET (RFID)

865,000 – 865,600 MHz	Efektiivinen säteilyteho ≤ 100 mW ERP. Kanavaväli 200 kHz.[21]
865,600 – 867,600 MHz	Efektiivinen säteilyteho ≤ 2 W ERP. Kanavaväli 200 kHz.[21]
867,600 – 868,000 MHz	Efektiivinen säteilyteho ≤ 500 mW ERP. Kanavaväli 200 kHz.[21]
865,000 – 868,000 MHz	Lukijalaitteen taajuuskaistat: 865,600 - 865,800 MHz 866,200 - 866,400 MHz 866,800 - 867,000 MHz 867,400 - 867,600 MHz Lukijalaitteen efektiivinen säteilyteho ≤ 2 W ERP.
2446,0 – 2454,0 MHz	Efektiivinen säteilyteho ≤ 500 mW EIRP. Efektiivinen säteilyteho ≤ 4 W EIRP ainoastaan sisätiloissa ja toimintasuhde oltava ≤ 15 %.[22]

21 Liikennöintiprotokolla ja kanavointi perustuvat standardiin EN 302 208-2 V1.1.1.

22 Toimintasuhde on oltava ≤ 15 % millä tahansa 200 ms jaksolla (eli 30 ms päällä, 170 ms pois päältä)

INfinity 610 ETSI

High-Performance, Multi-Protocol Reader

sirit vision beyond sight™

Operating Characteristics	
Management Features:	Rich array of diagnostic and statistical reporting tools, user-configurable alarms, and a host of management features based on industry standard protocols. Allows seamless integration into existing IT infrastructures.
Regional Compatibility:	Regions compatible with ETSI regulations.
Air Interface:	High performance radio and modem subsystems employing sophisticated DSP technology and advanced singulation algorithms that optimize read rates in a wide range of end-user applications.
Adaptive Noise Features:	Intelligent algorithms within the INfinity 610 automatically enable the modem to adapt to the instantaneous noise and interference level, thus optimizing air interface performance and robustness for a wide range of deployment scenarios.
Upgradeability:	Upgradeable firmware permits forward compatibility for future protocols.

Specifications	
Frequency:	UHF 865 to 868 MHz
Supported Transponders:	Full support of mandatory and optional features of EPCGlobal Class 1 Generation 2 and ISO18000-6C, including optional user memory and NXP EAS custom commands and Alien's BlockReadLock command. Also supports ISO 18000-6B, and Ucode 1.19 with future protocols supported through firmware updates.
Operating Modes:	Single Interrogator Multiple Interrogator Dense Interrogator
Communications:	10/100 Ethernet Port USB1.1 Type B port Serial Port EIA/TIA-232-F 115 kBaud with hardware handshaking (RTS/CTS), DCE Logical interfaces for Sirit's CLI (providing compatibility with IN510 installations) and EPCGlobal's LLRP v1.0.1
GPIO:	Digital Input/Output Port 4 – optically coupled inputs, 25V max. Controllable input reference 4 – open-collector outputs, 3-40V, 100mA max, 1W max
RF Power:	+31.5 dBm, conducted
Input Power:	24VDC. 10W idle, 18W typical (20W maximum) at 30dBm.
Antenna Connection:	RP-TNC connectors. (reverse polarity)
LED Indicators:	Power, Activity, Environment/User, Status
Upgradeable Firmware:	Yes
Operating Temperature:	-20°C to 55°C (-7°F to 131°F)
Relative Humidity:	5 to 95%, non-condensing
Dimensions (LxWxD):	9.72 x 7.25 x 2.2 in (246.7 x 184.15 x 55.6 mm)
Weight:	4.5 lbs (2.1 kgs)
Regulatory:	Compliant to RoHS, ETSI EN 301 489, ETSI EN 302 208 and IEC 60950
Case Material:	Aluminum

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E-mail: sales@sirit.com

www.sirit.com

About Sirit Inc.

Sirit Inc. is a leading provider of Radio Frequency Identification (RFID) reader technology to OEMs and solution providers worldwide. Harnessing the power of Sirit's enabling-RFID technology, customers are able to more rapidly bring high quality RFID solutions to the market with reduced initial engineering costs. Sirit's products are built on years of RF domain expertise addressing multiple frequencies (LF/HF/UHF), multiple protocols and are compliant with global standards. Sirit's broad portfolio of products and capabilities are easily customized to address new and traditional RFID market applications including Supply Chain & Logistics, Cashless Payment, Access Control, Automatic Vehicle Identification, Inventory Control & Management, Asset Tracking and Product Authentication. For more information, visit www.sirit.com.

The "RFID by Sirit" symbol signifies that Sirit Inc.'s high quality RFID reader technology resides within this product.

DS-0042

AV21-SERIES

Type	AV2100-SP	AV2100-CP	AV2100-DP
Frequency	850...870 MHz	850...870 MHz	850...870 MHz
Bandwidth	20 MHz	20 MHz	20 MHz
Impedance	50 & DC grounded	50 & DC grounded	50 & DC grounded
VSWR	2,0 max.	2,0 max.	2,0 max.
Polarisation	Linear	Left hand Circular	Dual linear
Isolation	-	-	25 dB min.
Gain	7,5 dBi	7,5 dBi	7,5 dBi
Horisontal 3 dB beamwidth	90°	90°	90°
Vertical 3 dB beamwidth	70°	70°	70°
Electrical downtilt	None	None	None
Front to back ratio	20 dB	20 dB	20 dB
Max. Continuous power	0,25 kW	0,25 kW	0,25 kW
RF-connector	N female	N female	2 x N female
Operational windspeed	40 m/s (default)	40 m/s (default)	40 m/s (default)
Survival windspeed	55 m/s (default)	55 m/s (default)	55 m/s (default)
Wind area	0,07 m²	0,07 m²	0,07 m²
Dimensions (H x W x D)	228 x 305 x42 mm	228 x 305 x42 mm	228 x 305 x42 mm
Weight	0,5 kg	0,5 kg	0,5 kg
Mounting diameter	4xM6 threads symmetrically on a 80x190 mm rectangle behind the antenna.	4xM6 threads symmetrically on a 80x190 mm rectangle behind the antenna.	4xM6 threads symmetrically on a 80x190 mm rectangle behind the antenna.
Materials	Aluminium Glassfiber radome Glass reinforced PE	Aluminium Glassfiber radome Glass reinforced PE	Aluminium Glassfiber radome Glass reinforced PE
Options	-	-	-

Aerial Oy

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Finland

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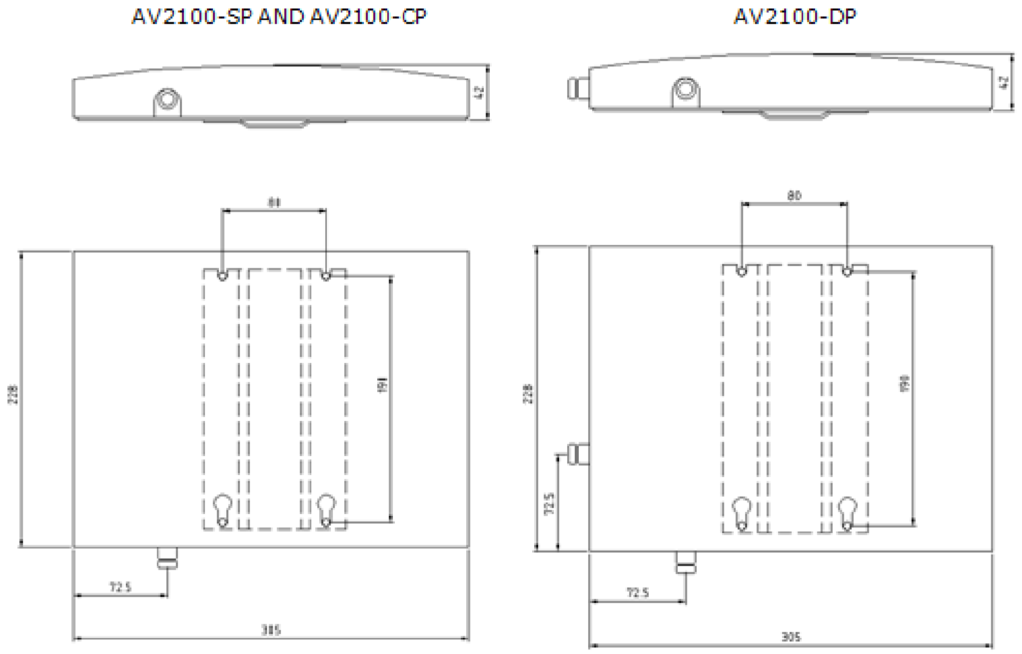
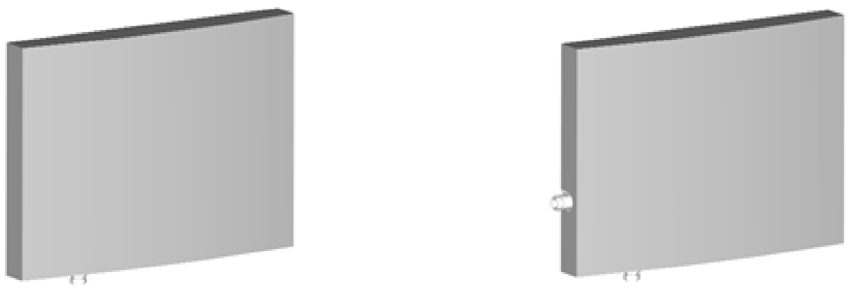
Fax +358 9 2910 210

http://www.aerial.fi
aerial@aerial.fi

SPECIAL : AV21-SERIES





The AV21-series offer an affordable selection of three antennas all with same external dimensions and mounting method. The AV2100-SP and AV2100-CP are equipped with single and AV2100-DP with two N-female panel connectors.

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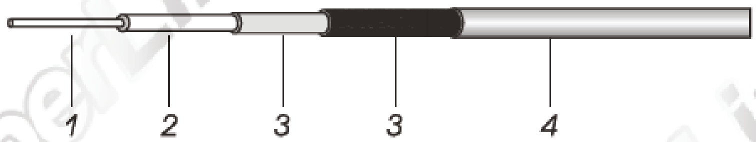
HyperLink Technologies — An L-com Company

Innovative Solutions For Wireless Communications

CA-400

Low Loss Cable



Construction Specification

	Material	Diameter (mm / in)
1. Inner Conductor	Copper/Aluminum	2.74 / 0.108
2. Dielectric	Physical Foam Polyethylene	7.24 / 0.285
3. Outer Conductor	Bonded Aluminum Foil + Tinned Copper Braid	8.13 / 0.320
4. Jacket	Black Polyethylene	10.29 / 0.405

Electrical Characteristics

Capacitance (pF/m)	77.1
Impedance (ohm)	50
Velocity (%)	85
Inner Conductor DC Resistance(Ω/km)	2.92
Outer Conductor DC Resistance(Ω/km)	5.41
Shielding Effectiveness (dB)	>90
Cutoff Frequency	16.2
Peak Power	16KW

Mechanical and Environmental Characteristics

Min. Bend Radius (mm / in)	51 / 2.0
Operating Temp. (°C)	-40 to +80
Tensile Strength (kg / lb)	72.6 / 160
Cable Weight (kg/m-lb/ft)	0.099kg/m – 0.068lb/ft
RoHS Compliant	Yes

Attenuation and Avg. Power (20°C)

Frequency (MHz)	Attenuation dB (100m / 100ft)	Avg. Power (KW)
30	2.2 /0.7	3.30
50	2.9/0.9	2.60
150	5.0 /1.5	1.50
220	6.10/1.86	1.20
450	8.9 /2.7	0.83
900	12.8 /3.9	0.58
1500	16.8/5.13	0.44
1800	18.6/5.67	0.40
2000	19.6/6.0	0.37
2500	22.2 /6.8	0.33
5800	35.5 / 10.8	0.21

HyperLink Technologies — An L-com Company

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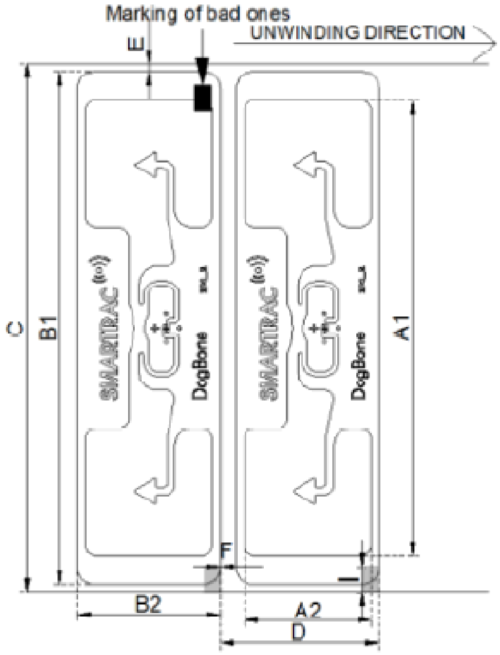
SMARTRAC

Product Specification

DogBone Wet Inlay
EPC Class 1 Gen 2, ISO 18 000-6C
Impinj Monza 4D
Sales code 3001874

Mechanical dimensions

A1 x A2	Antenna size	85,9 x 24 mm	± 0,5 mm	3,382 x 0,945 in
B1 x B2	Die-cut size	97 x 27 mm	± 0,2 mm	3,819 x 1,063 in
C	Web width	100 mm	± 0,5 mm	3,937 in
D	Pitch, length per piece MD	30 mm	± 1,5 mm	1,181 in
E	Die-cut to web edge	1,5 mm	± 1,5 mm	0,059 in
F	Die-cut to register mark	0 mm	± 1,0 mm	0,000 in
I	Minimum size of register mark (width x length)	5 x 3 mm		0,197 x 0,118 in



Electrical characteristics

Integrated Circuit (IC)	Impinj Monza 4D
Air interface protocol	EPC Class 1 Gen 2, ISO 18 000-6C
Operation frequency	860 - 960 MHz
Memory	128 bit EPC plus 32 bit

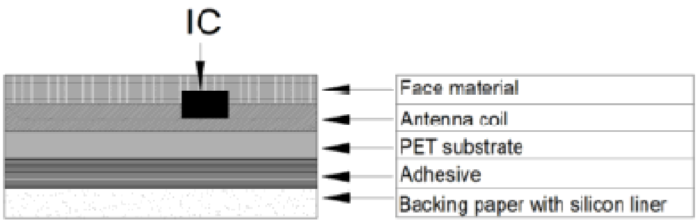
General characteristics of transponder

Operating temperature (electronics parts)	-40 °C / +85 °C	-40 °F / 185 °F
ESD voltage immunity	± 2 kV peak HBM	
Shelf life: From the date of manufacture 2 years in	+20 °C, 50 % RH	68 °F, 50 % RH
Bending diameter (D)	> 50 mm, tension less than 10 N	

Delivery form

Transponder format	Die-cut	
Transponder face material	Clear PET 12	
Transponder antenna material	Aluminum	
Transponder adhesive	RA-2	
- labelling temperature	min. +5 °C	min. +41 °F
- usage temperature	-40°C - 150 °C	-40°F - 302 °F
- peel	min. 8 N / 25 mm (FTM 2)	
Final inspection	100 %, known faulty ones marked	
Minimum delivery yield	97 %	
Reel label	Reel number, Material number, Material description, Yield, qty of functional inlays, qty of non-functional inlays, date, time	

Structure



Delivery details

Appearance	Single row reel form
Reel core	Card board core, inner diameter 76 mm (3 in)
Winding of the reel	Face out
Reel size	5000 pcs/reel Diameter: <205 mm
Package size	5000 pcs/box Deliveries only in full packages.

Disclaimer:
SMARTRAC reserves the right to change its products and services at any time without notice. Our recommendations are based on our best knowledge and experience. As the products are used outside our control we cannot take responsibility for any damage that may be caused when using the product. Use extra care in handling the product.

This technical specification replaces all earlier ones.

Version	4
Update date	8 August 2012
Author	SMARTRAC / k731743
Approved	SMARTRAC / 08.08.2012 k036052

CABLE IDENTIFIER	LENGT, (m)	Loss (dB)
22-53X-10-W01	9	1,2
22-53X-10-W02	4	0,5
22-53X-10-W03	6	0,8
22-53X-10-W04	31	4
22-53X-11-W01	42	5,4
22-53X-11-W02	4	0,5
22-53X-11-W03	32	4,1
22-53X-11-W04	18	2,3
22-53X-12-W01	23	2,9
22-53X-12-W02	36	4,6
22-53X-13-W01	22	2,8
22-53X-13-W02	12	1,5
22-53X-14-W01	23	2,9
22-53X-14-W02	37	4,7
22-53X-14-W03	62	7,9
22-53X-14-W04	23	2,9
22-53X-14-W05	15	1,9
22-53X-14-W06	25	3,2
22-53X-15-W01	15	1,9
22-53X-15-W02	11	1,4
22-53X-16-W01	26	3,3
22-53X-16-W02	11	1,4
22-53X-17-W01	33	4,2
22-53X-17-W02	32	4,1
22-53X-17-W03	41	5,2
22-53X-18-W01	17	2,2
22-53X-18-W02	2	0,3
22-53X-19-W01	34	4,4
22-53X-19-W02	45	5,8
22-53X-20-W01	7	0,9
22-53X-20-W02	18	2,3
22-53X-21-W01	25	3,2
22-53X-21-W02	7	0,9
22-53X-21-W03	25	3,2
22-53X-22-W01	42	5,4
22-53X-22-W02	27	3,5
22-53X-23-W01	52	6,7

Calculated with equation
$L = l * A$,
where A is 12.8 dB/100 m
by technical specialist Pentti Lajunen, Visi Oy.

Average RSSI values calculated from 100 samples. Except Outroof Sirit from 25 samples.					
SIRIT HOSTNAME	**CABLE LENGTH**	**ANT ID**	**RSSI 1 / DISTANCE**	**RSSI 2 / DISTANCE**	**RSSI 3 / DISTANCE**
Outroof Sirit	N/A	22-53X-23-RF01	-561,5 / 1 m	663,2 / 2,5m	
6th floor Sirit 1	42 m	22-53X-22-RF01	-546,2 / 2m		
	27 m	22-53X-22-RF02	-592,1 / 0,2m	-602,6 / 2m	
6th floor Sirit 2	25 m	22-53X-21-RF01	-607,3 / 1m	-577,0 / 3m	
	7 m	22-53X-21-RF02	-592,0 / 0,2m	-562,7 / 3m	-680,8 / 6m
	25 m	22-53X-21-RF03	-607,0 / 0,2m	-612,8 / 3m	-685,3 / 6m
5th floor Sirit 1	34 m	22-53X-19-RF01	-562,4 / 1m		
	45 m	22-53X-19-RF02	-673,2 / 2m		
5th floor Sirit 2	7 m	22-53X-20-RF01	-537,7 / 0,5m		
	18 m	22-53X-20-RF02	-612,0 / 0,2m	-530,3 / 1,5m	
4th floor Sirit 1	33 m	22-53X-17-RF01	-519,4 / 0,5m	-603,6 / 3m	-692,1 / 6m
	32 m	22-53X-17-RF02	-610,1 / 0,5m	-593,4 / 2,5m	-647,0 / 5m
	41 m	22-53X-17-RF03	-576,4 / 0,2m	-565,4 / 2m	
4th floor Sirit 2	7 m	22-53X-18-RF01	-503,8 / 0,2m	-581,9 / 3m	-676,6 / 6m
	2 m	22-53X-18-RF02	-512,3 / 0,5m		
3th floor Sirit 1	26 m	22-53X-16-RF01	-572,4 / 3m	-676,4 / 5m	
	11 m	22-53X-16-RF02	-564,0 / 0,2m	-466,5 / 2m	
3th floor Sirit 2	15 m	22-53X-15-RF01	-492,6 / 1m		
	11 m	22-53X-15-RF02	-443,7 / 1,5m	-587,6 / 3,5m	
Controlroom21	23 m	22-53X-14-RF01	-501,4 / 0,5m	-679,1 / 2m	
	37 m	22-53X-14-RF02	-495,2 / 0,5m	-686,4 / 2,5m	

	62 m	22-53X-14-RF03	-601,5 / 1m		
	23 m	22-53X-14-RF04	-430,1 / 1m		
	15 m	22-53X-14-RF05	-482,0 / 0,5m		
	25 m	22-53X-14-RF06	-587,0 / 0,2m	-558,6 / 2,5m	
Level 18.00 Sirit1	22 m	22-53X-13-RF01	-687,9 / 0,2m	-601,4 / 2,5m	-651,7 / 5m
	12 m	22-53X-13-RF02	-508,9 / 0,2m	-516,6 / 2m	
Level 18.00 Sirit2	23 m	22-53X-12-RF01	-585,9 / 0,2m	-599,9 / 3m	
	36 m	22-53X-12-RF02	-611,2 / 0,2m	-632,3 / 2m	
Level 6.00 Sirit1	6 m	22-53X-11-RF01	-554,3 / 0,2m	-669,2 / 3m	-701,7 / 6m
	4 m	22-53X-11-RF02	-561,1 / 3m	-620,9 / 6m	
	32 m	22-53X-11-RF03	-453,2 / 0,2m	-618,9 / 3m	-699,9 / 6m
	18 m	22-53X-11-RF04	-486,9 / 0,2m	-625,1 / 2,5m	
Level 6.00 Sirit2	9 m	22-53X-10-RF01	-477,1 / 0,2m	-613,8 / 3m	-692,3 / 6m
	4 m	22-53X-10-RF02	-561,4 / 3.5m	-552,5 / 4m	
	6 m	22-53X-10-RF03	-570,1 / 0,2m	-539,2 / 2.5m	-643,0 / 5m
	31 m	22-53X-10-RF04	-525,1 / 0,2m	-623,7 / 3m	-666,6 / 6m