Visibility of a Supply Chain with Passive RFID Technology and Product Codes

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Abstract—**The objective of this research work is a passive radio frequency identification (RFID) system for supply chain purposes, based on backscatter and inductive coupling technology. With RFID technology it is possible to reach an identification system that tolerates environmental factors and rough conditions. In this paper a basic principle of a supply chain and passive RFID technology are explained. The choice of used frequency band is discussed briefly. Different types of product codes that enable global identification are discussed and analysed in more details on the basis of the research work and evaluation done in EAN International, UC-Council and Auto-ID Centre. Several properties that affect to functionality of RFID system are discussed and analysed.**

Index Terms—**Product Code, Reading Time, RFID, Supply Chain Management**

I. Introduction

THE demands of identification system of products have increased dramatically in resent years. It is required to be confident, fast and as automated as possible. Also it should not disturb profitable activities of a product line remarkably. Identification systems should be resistant for environmental disturbance, like other radio signals, air humidity, temperature permutations and dirt. Identifying systems that are widely used nowadays, like barcodes and magnetic stripes, tolerate these factors very poorly. With radio frequency identification (RFID) technology it is possible to reach an identification system that tolerates environmental factors and rough conditions. In the second chapter the basic idea of supply chain and its demands are explained in more details.

The basic principle of a passive RFID technology is explained in chapter three. Radio frequency identification is based on data transmission via electromagnetic waves. The actual connection between transmitting and receiving antenna occurs whether in the far field or near field of the electromagnetic field. The frequency used affects dramatically to functionality of RFID system. In chapter four, the choice of used frequency band is discussed and analysed shortly. Tag's policy and memory type and environmental demands and limitations are also factors that affect to the functionality of RFID system. Different tags of several manufacturers are analysed on the basis of these properties in chapter five.

Global and unique identification codes are needed to identify products individually. A product code or a product type code, which is stored in tag's memory, is a reference number to the data stored in external database. The global codes that are presented by Auto ID-Centre and EAN/UCC organization are discussed in more details in chapter six.

Chapter seven summarises the research work presented in this paper and presents shortly the future research work of TUT's RFID research group.

II. Supply Chain Management

To understand demands and challenges of a supply chain it is very important to clarify the steps and phases of it. From manufacturer to user, a supply chain is multiphase organized. Fig.1 illustrates identification steps of a supply chain. Typically a manufacturer identifies products several times during manufacturing procedures, for example during production, packaging and storage. Products may be packaged into bigger units, like cases and pallets, and those may be identified again. Transportation companies identify all the packages or products that they deliver to distributors. Again, distributors identify all the products that they deliver forward. The chain may consist of several transportation and distributor parts, depending on the origin, the transportation methods and the destination of the delivery. At the almost end; stores identify products, that they take into sales. Finally, products are identified when customers buy them. So basically, every intermediate part of a supply chain identifies products or pallets that go throughout them.

Using barcodes is the most popular identification method used nowadays. Reading of codes is done manually and it

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takes an enormous amount of time from workers. It is unreliable and impractical. Barcodes do not offer an opportunity to change information stored in it and a new code must be printed. Reading a barcode may be difficult since it does not tolerate dirt and erosion very well.

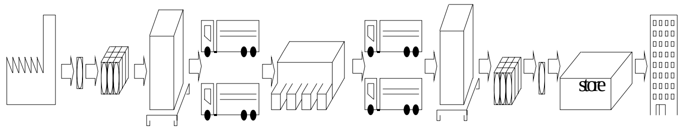

Fig. 1. Identification steps of a supply chain: manufacturer – item – case – pallets – trucks - distributors – trucks – pallets – case – item – store – user.

By using RFID system the identification cycle of products and pallets will be fastened and can be make fully automated. Workers resources can now be focused to the customer services. By automating identification of products it is possible to reach fast and flexible system. Labour costs and warehouse loses are minimised and control of products is visible and can be kept in real-time.

RFID system can also be used to track products at factories, warehouses and stores, to mention just a few. In the future, the database of a global RFID system could be affiliated to global positioning system (GPS), which would allow tracking of products all over the world. [6][7][10]

III. Passive RFID Technology

RFID system consists of three components. RFID transponders i.e. tags are attached to objects that are identified. Readers are either mobile or stationary, depending on the needs and purposes of used application. A host unit controls the whole system. It is typically a terminal to the database used. If an application is large, there might be several PCs as slaves to the host.

RFID technology is based on data transmission via electromagnetic waves. The word passive means that a tag of the system has no internal power supply. The tag takes all the energy it needs from the electromagnetic field that a reader has transmitted and stores it into its capacitors. The maximum reading distance between the reader and the tag is defined carefully. RFID reader covers a certain area, typically a spherical, a hemispherical or cone shaped volume, depending on its antenna structure and properties, transmitted field power and used frequency. Effects of the frequency band used will be discussed later in chapter four.

Typical modulation method that is used in RFID reader is commonly known amplitude or phase shift keying (ASK or PSK). ASK is much more simpler and cheaper to implement and since more used. Coding method is typically transition code, for example Manchester (split phase), Miller (delay modulation) or FM0 (biphasic-space). By using transition-coding method, the collision effects between different tags can be detected. Collisions between different readers and between a tag and two (or more) readers can prevent by using anti-collision algorithms. One simple solution is to divide readers into groups so that the interrogation zones of the readers do not overlap at any time inside the group. Then, by letting every group to use a certain time slot of the time interval and letting every reader inside each group use different frequency channel, are these collision problems solved. The division of time slots and frequency channels must be done in all reader groups. When using RFID system for low security applications, for example an identification of a supply chain, there is no need to use complicated data encrypting methods. Data check method is typically longitudinal redundancy check (LCR) or cyclic redundancy check (CRC). Either of these methods cannot repair bit errors and the data transmission must be repeated.

RFID tag uses load modulation to modulate the backscattering signal. Load modulation is based on a change of the tag's antenna impedance. A function of a tag is not active. The reader goes systematically thru the different branches of the binary tree in small pieces. The tag responds to the reader only if its identification binary code is asked. This minimises the amount of transmitted signals and therefore collision problems between different tags.

Passive RFID technology can be divided into two main functionality groups, inductive coupling and backscatter technologies, which will be discussed in more details in the following. [5]

A. *Inductive Coupling Technology*

Inductive coupling RFID system is based on data transmission via a magnetic part of an electromagnetic field. The basic principle of an inductive coupling RFID system is presented in Fig.2. The tag modulates its antenna impedance by switching the drain-source resistance of its FET (field effect transistor. Electromagnetic fields are connected via large antennas, which are actually coils – that is a consequence of the relatively low frequency band used. The interrogation zone is not very large, typically from few cubic centimetres to couple of hundreds cubic centimetres.

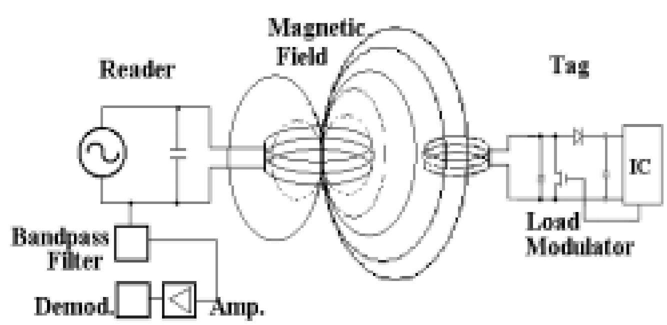

Figure 2 The basic principle of an inductive coupling RFID system

Inductive coupling RFID technology has an important advantage comparing to backscatter technology; the absorption rate to water is non-significant at 13,56 MHz band. This is a consequence of the wave behaviour at that frequency band [12]. Therefore inductive coupling systems are more common than backscatter system. Since the frequency used is low, the data transmission rate is typically quite slow. Following these factors inductive coupling RFID systems can typically be used in short-range identification systems, for example public transport ticketing.

B. Backscatter Technology

Backscatter RFID system is based on data transmission via electromagnetic waves. Transponders reflect the field the reader has send to them. The transponder modulates the data signal by changing its antenna impedance by switching the load resistor R_L on and off. The reader has a directional coupler between the antenna and the radio part of the circuit to separate the transmitted and the weak received signal. The operating frequency of the reader is created by the multiplication of a lower oscillation frequency. Modulation is performed at the lower frequency. The designing rules of microwave implementation must be taken to account very carefully. Therefore designing the radio part of a backscatter RFID reader is more complicated and challenging. The basic principle of backscatter RFID system is presented in Fig.3.

Backscatter technology is forecasted to be the most popular identification technology used in the future. It enables identification from much larger area than other passive identification methods. Typical reading range is couple of meters. This enables versatile usage in industry. There are though several problems left to solve. One of the largest is the absorption of electromagnetic waves to polar and conducting materials. The penetration to nonconductive materials depends on the frequency band used and the nature of the material. By increasing the frequency used is the absorbed power is also increased [11]. Several research groups all over the world are trying to find out methods to solve these problems. [5]

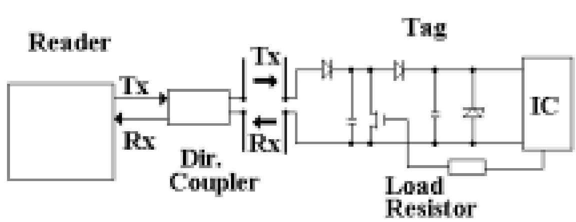

Fig. 3. The basic principle of RFID system based on backscatter technology

IV. The Choice of Used Frequency Band

Frequency spectrum used in RFID technology can be divided into radio and microwave frequencies. The specific 13,56 MHz, 868/915 MHz and 2,45 GHz bands are discussed in the following.

A. 13,56 MHz Band

13,553 – 13,567 MHz band is the typical frequency band used in inductive coupling systems. The ERP (Effective Radiated Power) power regulations done by ETSI and FCC limit the power of the electromagnetic field, and therefore affect to the reading range. When the reading range is wanted to be larger than few centimetres, the regulations will become a big problem. Therefore 13,56 MHz band is typically used only with inductive coupling RFID systems that are based on very close contact between reader and transponder.

B. UHF Band

UHF-band is defined separately to European (865 – 870 MHz) and North American (902 – 928 MHz) bands. These are the typical bands - together with 2,45 GHz band – used in backscatter systems. Since the European ERP regulation for narrowband applications at 868 MHz band is much smaller than at 915 MHz band in North America, it is impossible to design an efficient, a globally accepted and usable identification system for this frequency band. Fortunately the European regulations will likely to be changed more close to North American regulations in the near future.

At 2,45 GHz band EPR regulations are equal in Europe and North America. This is an ideal situation for global business, but since several applications already use this band it is quite occupied. Secondly, at 2,45 GHz band, the electromagnetic field is absorbed to nonconductive substances very easily. The absorption rate is now remarkably higher than at 868/915 MHz band [10].

C. Comparing Frequency Bands

From the properties of typically used RFID frequency bands: 13,56 MHz, 868/915 MHz and 2,45 GHz can be gathered that 868/915 MHz band is the most optimal solution to supply chain purposes, which demands longer reading distances. The conclusion is based on the presumption that European new ERP regulations will be obtained and the fact that identified pallets in supply chain are quite large, typically about one cubic meter. When identification distances can be very short, it is much more recommendable to use lower frequencies and close coupling techniques. The identification procedure is much more certain at 13,56 MHz band than at UHF band on the basis of the knowledge commonly have in the RFID area nowadays. [5]

V. Efficiency of Processing with RFID Tag

Several factors besides the frequency band and coupling technology used affects to the functionality and efficiency of RFID system. Affects of the reading range, speed of reading multiple tags and memory types of tags are discussed in more details in the following.

The reading range can be defined by using commonly known antenna equations. The field density of the transmitted field by the reader, $\overline{s_t}$ and the power received by the tag, P_r

are defined as following [4][5]:

$$\overline{s_t} = \frac{G_t P_t}{4\pi r^2} \quad (1)$$

$$P_r = \overline{s_t}\,\frac{G_r \lambda^2}{4\pi} \quad (2)$$

Where G_t is the gain of the reader's antenna, P_t is the power transmitted by the reader, r is the distance between the reader and the tag, G_r is the gain of the tag's antenna and λ is the wavelength corresponding the frequency used. Equal equations can be defined to the signal reflected from the tag to the reader:

$$\overline{s_{back}} = \frac{P_r}{4\pi r^2} \quad (3)$$

$$P_{back} = \overline{s_{back}}\,\frac{G_t \lambda^2}{4\pi} \quad (4)$$

Where $\overline{s_{back}}$ is the reflected field density at the reader's antenna and P_{back} is the reflected power received by the reader. From equations (1) – (4) can be gathered that the maximum reading range that carry out the data transmission from the reader to the tag and from the tag to the reader is:

$$r = \frac{\lambda}{4\pi}\sqrt[4]{G_r G_t^2 \frac{P_t}{P_{back}}} \quad (5)$$

Where the reflected power P_{back} is now the conditional minimum limit to the successful communication between the reader and the tag. If this power is too low, the reader cannot separate the reflected field from environmental noise and other radio signals. From the equation (5) can be seen that the reading range is proportional to the wavelength. By increasing the frequency (i.e. decreasing the wavelength) the reading range decreases. This is particularly true when operating at far field. At near field the coupling mechanism is different and these equations are not valid anymore [12]. Also from the equation (5) can be seen that when the reading range is wanted to increase by certain multiplication factor, must the transmitted power of the reader multiply by the same multiplication factor rise to a power of four.

The speed of reading multiple tags depends on the frequency band used, since the higher the band is the higher the data transmission rate can be. Typically the reading time can be divided into two sections. Fixed share of the time is constant regardless of the amount of tags in the reading range. Another part of the time is multiplex time duration of a single slot. For example Philips Semiconductor's I-Code time duration of multiple tag reading is 52 ms for fixed share of time and 4,9 ms for a single time slot [2]. Though these time intervals depend on the amount of the data request, in the example above only 8-bit identifier were used. The amount of multiplexed time depends on the number of the tags and the speed of the tags in the reading range at certain time.

Tag's memory is typically divided in to read only and read/write memory. The manufacturer's identification code is stored into tag's read only memory. Read/write memory is reserved for the users' data. Typically the data stored in read/write memory is temporary and includes some information about the product. Since the memory size of the tag affects dramatically to its price, few manufacturers has started to produce read only tags. Also Auto-ID Centre encourages to this solution and has released the EPC code, based on tags that have no read/write memory and all the users' data has stored into external database via Internet. The EPC code is presented in more details in chapter six. [3]

Table I, table II and table III three present sizes of memories, reading ranges and multiple reading speeds of tags of several manufacturers. Table I shows these values at 13,56 MHz band, table II at 915 MHz (using North America ERP regulations) band and table III at 2,45 GHz band. From table I can be seen that multiple reading speeds varies from 30 tags/second to 100 tags/150 ms. The remarkably longer reading distances of Philips Semiconductors' and Mageillan Technologies' tags can probably be explained with antenna design, since by using larger antennas can the reading range be increased. Memory sizes are typically manufacturer dependant, and affect straight to the costs of tags.

TABLE I
AN EXAMPLE OF DIFFERENT RFID TAGS AT 13,56 MHZ BAND
[11][12][13][14]

Manufacturer	Read only memory	Read/write memory	Reading range	Multiple reading speed
Texas Instruments	64 bit	2 kbit	20cm	50 tags/s
Philips Semiconductors	128 bit	384 bit	1,2–1,5m	30 tags/s
Mageillan Technologies	?	-	0,5–1m	100 tags /150ms
SCS Corporation	?	-	30cm	50 tags /450ms

From table II can be seen that multiple reading speeds vary from 50 tags/450ms to 200 tags/second. Reading distance depends on the antenna used, and at these examples it varies form 1,5 m to 5m. Read only memory sizes are typically fewer than 100 bits.

Same factors of 2,45 GHz band tags are presented on table III. Reading ranges are now remarkably shorter than at UHF band, which has also proved in equation (5). Multiple tags reading speed is slower than at UHF band, though the communication speed should increase when the frequency used increases. In this case, since tags of only few manufacturers were researched, the reason of the data transmission speed could be dependant of manufacturing methods and components that were used.

TABLE II
AN EXAMPLE OF DIFFERENT RFID TAGS AT 868/915 MHZ BAND
[11][14][15]

Manufacturer	Read only memory	Read/write memory	Reading range	Multiple reading speed
Texas Instruments	72 bit	24 bit	2,44m	?
Alien Technologies	80 bit	-	5m	200 tags / s
SCS Coeporation	?	-	1,5-2m	50 tags /450ms

TABLE III
AN EXAMPLE OF DIFFERENT RFID TAGS AT 2,45 GHZ BAND
[14][16]

Manufacturer	Read only memory	Read/write memory	Reading range	Multiple reading speed
Sensormatic	?	104 bit	60-80cm	50 tags /s
SCS Corporation	?	-	30–50cm	50 tags /450ms

Choosing a RFID system for an application is always an application specific choice. When planning an identification system that includes several hundreds or perhaps even thousands of identified products, the RFID system must be fast and the speed of reading multiple tags high. When the identified objects are large or packaged into large pallets or cases, the system must have large interrogation zone. When users must write some data into tags' memories during the identification process, the read/write memory should be large enough. These were just few examples, and in practice the designing operation is not so simple. Typically it is a combination and a compromise between different properties of the system.

VI. PRODUCT CODES

For designing a worldwide RFID system it is essential to state global standards for the technology used. The standardization concerns besides the technology a product code or a product type code used. Global barcodes, that are used nowadays for object identification are standardised. These are for example UPC (in North America) and EAN-13 (in Europe). Despite the widespread utilization of these codes they are regional and non-compatible with each other's. Because of these aspects several work groups all around the world are developing new global object identification code, which might arise to new standardised system in future. In the following, the basic structure of most popular barcodes and a new EPC code structure, developed by Auto-ID Centre are reviewed.

Barcodes that are used for product identification are called GTIN family codes. EAN International and Uniform Code Council have globalised the use of these codes by insertion zeros at the front of the code until the 14-numbered code structure is achieved. The basic principle of GTIN structure is presented in Fig.4. [4]

GTIN code

number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
UPC	0	0	1	2	3	4	5	6	7	8	9	10	11	12
EAN-13	0	1	2	3	4	5	6	7	8	9	10	11	12	13
EAN-14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
EAN-8	0	0	0	0	0	0	1	2	3	4	5	6	7	8

Fig. 4. The Basic Principle of the GTIN Code

EAN International and UC-Council has introduced a GTAG code, which includes all the barcodes used in supply chain for certain product. Besides GTIN it may include shipping and transportation codes, like SSCC (Serial Shipment Container Code). The GTAG code may be stored into RFID tag's memory. This follows to a situation, in which the tags must contain a quite large memory. [10]

EPC code is a new code concept presented by Auto-ID Centre. It enables a unique and global identification of products, cases and pallets. EPC is based on the idea to have all information possible in an external database and to store just the identification number into the tag's memory. This principle makes the manufacturing of the tags less expensive since the tags have minimum amount of memory. [1][3][7]

The EPC code may consist different amount of bits, depending on the application. The code is divided into three sections. At the front of code part is a header, which defines the application area of the product. The first part of the product is EPC-manager, which is provided for the manufacturer. The second part of the code object class, which divides the products of a certain manufacturer into different groups. The last group is serial number, which is unique for each product, for example for each soda can. A basic structure of 96-bit type-I EPC code is presented as an example in Fig.4.

96-bit EPC

XX	XXXXXXX	XXXXXX	XXXXXXXXX
Header	EPC-manager	Object Class	Serial number
8-bit	28-bit	24-bit	36-bit

Fig. 5. The Basic Principle of the 96-bit Type-I EPC Code

Auto-ID Centre has also defined a shorter, 64-bit EPC code to get the costs of tag's memories even lower. The lengthiness of the identification code used affects to the price of the tag's memory and though the final price of the tag. Different identification codes are needed to cover the different needs and requirements of different phases of supply chain. As an example 96-bit EPC code enables about 80 $*10^{15}$ unique identification codes and 64-bit EPC code about 2,1 $*10^{12}$ unique identification codes to be at usage at the same time. Both of these figures are more than enough to cover the product space to guarantee unique identification of supply chain [7], [9].

To compare these two identification schemes it is obvious that EPC code is more desirable since it enables a really unique identification for cheap and individual products. The GTIN or GTAG code have though an advantage since it is much more easier to move from the usage of barcodes to the usage of GTIN or GTAG code than to the usage of EPC codes. This is because the basic structure of GTIN and GTAG codes are similar to barcodes.

VII. Conclusions and Discussion

In this paper the basic principles of supply chain management and radio frequency identification technology were presented. Several issues, like frequency band used, identification speed of multiple tags and interrogation zones of readers, that must be considered when developing RFID system were discussed. Backscatter and inductive coupling technologies and frequency bands that are forecasted to be the most used in the future were analysed. Also two different types of identification codes were reviewed on the basis of the commonly available research work and evaluation performed at MIT's Auto-ID Centre and EAN/UCC-organisation.

Possibilities that RFID technology offers for manufacturers and retailers are enormous and amount of applications are limited only by imagination. Therefore it is very important to recognise different realisation opportunities of RFID technology. With RFID technology supply chain applications will be more visibly and though well controlled, adjusted and positioned. Visibility of supply chain allows together with well automated warehousing and manufacturing more cost efficiency and productivity supply chain management.

The research work doing at this area has increased dramatically in few years. Finding solutions for using ultra high frequencies in rough environment, where several field absorbing and reflecting substances and objects can be found, will open a new world for product tracing and identification. On the basis of this research paper and other ongoing research projects of TUT, there will be further field-testing and research concerning several supply chain applications.

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