Radio Frequency Identification (RFID)

Chapter · September 2015

DOI: 10.1002/047134608X.W8155

6 authors, including:

Andrew Shields
Institute of Technology, Tralee

Ultan Mc Carthy
University College Dublin

Daniel Riordan
Institute of Technology, Tralee

Pat Doody
Institute of Technology, Tralee

Radio Frequency Identification (RFID)

Andrew Sheilds, Ultan Mc Carthy, Daniel Riordan, Pat Doody, Joseph Walsh, Ismail Uysal

[1]RFID Lab for applied research,Department of Electrical Engineering, College of Engineering, ENB118, University of South Florida, 4202 E. Flower Ave., Tampa FL 33620, USA

[2]IMaR Technology Gateway(Intelligent Mechatronics and RFID), Institute of Technology, Tralee, Co. Kerry, Ireland

Contents

1. Abstract

Radio Frequency Identification (RFID) technology, as the name suggests is a method of wirelessly transferring data between transceiver and transponder where the transponder (tag) is attached to a variety of objects and used to automatically identify each object acrossa variety of industrial purposes. The fundamentals of RFID technology are based on the princples surrounding electromagnetic energy, originating with Michael Faraday's explanation of light and radio waves dating back to 1846.This technological approach has the ability to identify virtually any object in any location in real time. Tags, may be attached to any item either living or inanimatehave the ability to manipulate propagating radio waves in such a fashion as to enable them to carry data, which may be customised to the item (item level traceability), an approach which is core to the functioning of these systems. This provides us with the core competency of RFID which is its ability to provide uniqueness to each individual item and make it identifiable in real timemaking RFID technology one of the most popular auto ID technologies in use to date.

As a technology it has beensuccessfully used to track, trace, locate and identify many objects and offers a new approach to asset traceability / visibility.RFID has beensuccessfully integratedacross a wide variety of industries including animal identification, pharmaceutical industry, building access control, toll collection, vehicle immobilisation systems, aviation industry, waste management and mining industries(Chao et al., 2007)(Ngai and Riggins, 2008)(Roberts, 2006). Its ability to wirelessly transfer data offers many operational advantages andpresents many advantages over the conventional bar.

In terms of basic functionality an RFID system contains three core components. A transponder (tag) is attached to the asset that is to be tracked and identified, where the selection of each tag being application dependant. Tags are available in a variety of shapes and sizes and possess a variety of functional capabilities. Secondly, transceivers (readers) are also available in a variety of shapes and sizes and levels of mobility and are attached to a PC tofacilitateend user control of the system. Finally attached to both tag and reader are antennas. These actas the primary facilitator of wireless data transfer between tag and reader and as a result come in a variety of shapes and sizes, which are, functional dependent.

2. Technology overview:

A basic RFID system consists of three main components (1) tag, (2) reader and (3) antenna which are collectively responsible for the generation of the radio wave.The tag (transponders)consists of an integrated circuit, an antenna, and may or may not have an on-board power source. They are classified as active (i.e., contain an on-board power source to cater for all electrical power needs); passive (i.e., no internal power source and rely on the interrogation wave from the reader for all power requirements), or semi-passive / semi-active (i.e., contain their own power source, yet rely on the interrogation wave for coupling, while the on-board source is used to power the tag circuitry)(Glover and Himanshu, 2006)(Mc Carthy et al., 2010). The RFID market has gathered tremendous traction in the area of environmental temperature monitoring. Sensor tags are becoming more and more commonplace across many industries and common users of this type of technology include argi-food pharmaceutical and defense supply chains.

The reader (transceiver), may be either stationary or portable andare responsible for transmitting an electromagnetic wave via in built or external antenas which communicates (couples) with the transponders via radio signal propogation using a fitted antenna. The reader is usually connected to a PC or contains an internal PC, in handheld versions, which provides a user interface to the operator(Mc Carthy et al., 2009b). The third and final component is the antenna which emits a radio wave and as they are the primary medium of communication between tag and reader their importance cannot be over emphasised. The communication process between tag and reader is commonly refered to as coupling.

RFID technology may be grouped further into a frequency based caterogisation i.e. Low frequency (LF), High Frequency (HF) and Ultra High frequency (UHF). With each frequency variation come differing operational characteristics thus making the selection of a particular system dictated mainly by the desired end use (application environment) of the system. For many years RFID technology has been fine tuned to the extent that each of the individual frequencies have been tailored to a number of particular commercial applications(Glidden et al., 2004)(Ukkonen et al., 2006). It is important to consider frequency when selecting RFID systems for a particular application as many unsucessful applications are based on incorrect frequency selection leading to an inability to acquire the true benefits of the technology.

3. How RFID works

Irrespective of tag type, classification, antenna configuration, orientation or operating frequency RFID systems require the establishment of a wireless link between tag and reader to successfully communicate (couple) without which the system cannot function.This wireless link is used to carry encoded data signals thereby forming a medium for data transfer across non-physically linked objects. As with all wireless communication systems the power of the signal in relation to the frequency and communication protocol are bound by a global governing authority. This is to ensure system standardisation and interoperabilityas radio waves form the primary method of communication between tag and reader their importance cannot be over emphasised.An important metric in the classification of RFID systems istheir method of coupling. A broad generalisation differentiates RFID systems based on near field or far field communication protocols andbelow is a brief introduction to both principles.

In Low and High frequency systems the antenna are structured in such a way that the propagation component of the propagating wave is small or even non-existent and these systems operate in the near field via a process called load modulation. Near field operation relies on magnetic coupling and is the chosen protocol for LF and HF systems(Ylinen et al., 2009). A current flowing through a coil will lead to the formation of a magnetic field in the immediate surrounds. The magnetic field is high in the immediate environment of the transmitting coil yet decays rapidly (inverse cubed proportion) with distance.

Backscatter coupling occurs in the far field region and the short wavelengths of these frequencies enable the construction of transponder antenna significantly smaller in dimension than lower frequency systems facilitating RFID identification down to item level. In this communication link the field effectively breaks away from the antenna and as a result communication occurs in the far field. In this type of coupling the reactive component is small and the propagationary component dominates. It is achieved by modulating the radar cross section of the tag antenna. This is based on how close the tag is to the reader antenna and on the operating frequency of the RFID system. Current flows on a transceiver antenna resulting in an electromagnetic wave. This propagating wave is picked up by a tag antenna lying within range, inducing a voltage, a portion of which is used to power interal cuirtutry and the remaining portion used to generate the backscatered signal.

4. Commercial applications of RFID technology

There is clear evidence to suggest that the advantages of RFID technology are not limited to any single industry and are in fact transferable across a number of industries in a variety of applications. Initially as the technology was mandated by a number of large companies the advantages were more difficult to quantify as most of these mandated adoptions served a mere “slap and ship” approach towards the technology and the implementers were never afforded the opportunity to leverage the full potential of the technology.However as the technology is advancing in terms of cost reduction, enhanced functionality and more sleak form factors the advantages and benefit of the technology are becoming more achievable.

Over the last number of years RFID technology has provided a number of competitive attributes across a variety of industries such as transportation, retail, library services, waste management, mining industries, construction, aviation, automobile, animal identification, food and health industries(Mc Carthy et al., 2009c).RFID as a data carrying technology has presented many cases of aiding in the development of competitive differentiation and as the technology evolves these differentiation applications are becoming more and more commonplace. Advantages of RFID in the supply chain include a reduction in labor cost and material handling and also offer increased data accuracy, improved information sharing between the relevant bodies, better space utilization during storage, automatic asset management, reduced stock-out in retailers, improved customer service and lower cost of inventory (Tajima, 2007). Given the diversity and ever increasing applications of RFID Technology the table below includes many of the main applications of RFID technology according to industry and application. Table 1 lists a variety of industries benefiting from RFID implementation and included in table 2 are typical business processes benefiting from the technology.

Table 1 Common Industrial applications of RFID Technology

Industry	Source

Food	(Martínez-Sala et al., 2009)(Angeles, 2005)(Wamba et al., 2008)
Pharmaceutical	(White et al., 2008)
Automotive / Aviation / Transport	(Mehrjerdi, 2010)(Lin and Ho, 2009)(Ustundag and Tanyas, 2009)

Table 2 Sources of value adding across industry

Value Adding	Source
Increased Transparency	(Stewart, 1995)(Delen et al., 2007)(Visich et al., 2009)
Inventory management	(Roh et al., 2009)(Mohsen, 2007)(de Kok et al., 2008)(Bottani et al., 2010)
Information sharing	(Sodhi and Son, 2009)(Dias et al., 2009)(Visich et al., 2009)

5. Radio Wave basics

Radio waves are the primary data carrying medium between tag and reader. In context, they form a small portion of a larger more commonly known electromagnetic spectrumand are situated towards the lower end of the frequency range.During coupling RF signals are systematically encoded and modulated with user defined information which is then transmitted wirelessly between tag and reader, thus forming basic functioning of RFID systems(Glover and Himanshu, 2006). Commercial RFID systems may be categorised intogroups; Low Frequency (LF), High frequency (HF), Ultra High Frequency (UHF) and Microwave frequency (MW). Basic radio waves may be expressed as a combination of bothelectrical and magnetic field components thus possess amplitude, wavelength (λ), velocity (v) and frequency (f), in a relationship expressed as:

$$v = \lambda . f$$

Similarly, Electromagnetic energy has been best described as a stream of photons each travelling at the speed of light in a wave like pattern. An electromagnetic wave propagates in a direction that is at right angles to both the electrical and magnetic oscillating field(Winder and Carr, 2002). As previously mentioned the fact that they are situated towards the lower end of the Electromagnetic spectrum means that they posses lower amounts of energy compared to microwave frequency waves, a property that is manipulated by industry to facilitate the adaptation of the technology to each particular application and according to Plank's equation may be expressed as:

$$E = h \cdot f$$

Built on the fact electromagnetic waves may be characterised in terms of frequency, wavelength or energy, Taking c the speed of light (c = 3 x 108), λ= Wavelength and f = frequency, using the previous relationship it is now possible to say (Meyers, 2007):

$$c = \lambda . f \quad , \quad \lambda = \frac{c}{f} \quad \text{or} \quad f = \frac{c}{\lambda}$$

A structured and consistent ability to manipulate the propagationary characteristics of the electromagnetic wave make it possible to establish tag to reader data transfer (coupling).

1. Formation of the electromagnetic wave

An electromagnetic wave may be presented in a variety of manners, including in terms of frequencies, with which come varyingpropagation characteristics, many of which are in use today for a wide range of tasks and applications across industries. These waves may be best described as a combination of both electrical and magnetic energy travelling in unison through space. These electrical and a magnetic components travel orthogonally to one another and to the direction of propagation. It is through manipulation of a variety ofproperties of this electromagnetic wave (amplitude, frequency and phase) that facilitate the transfer of data between transponder and reader antenna. It is firstly important to gain an understanding of the propagation characteristic of radio waves at commercial RFID frequencies to better understand and predict their commercial performance. In its most basic description a current flowing through a coil will result in the formation of a magnetic field in the immediate surrounds. The magnetic field is high in the immediate environment of the transmitting coil yet decays rapidly (inverse cubed proportion) with distance, an area known as the near field. This will then lead to the formation of a surrounding electrical field, which is now known as the far field, which in turn will lead to another magnetic field, continuing this cycle(Finkenzeller, 2003). Both LF and HF systems operate within the near field range and UHF and MW systems operate in the far field seperated by a virtual boundary approximated by

$$r = \lambda/2\pi$$

In practical terms this represents the point where the electrical and magnetic components of the electromagnetic wave separate from the antenna into the surrounding environment forming a propagating electromagnetic wave (Want, 2006b). The field attenuates as a square function of the distance in the far field. The ratio of electrical (E) to magnetic (H) field has the constant value of 120 π or 377 Ω commonly known as its intrinsic impedance. It is possible to conclude that the far field begins where the near field ends. Both near firled and far field communication protocols will be detailed in more detail in a later section.

6. RFID Middleware

For RFID to function there lies a requirment to create cyberphysical linkages which requires all three components (tag, reader and antenna) facilitated using what is termed middleware.The term "middleware" in the context of RFID refers to a software application layer that consists of multiple components which enable communication between RFID interrogators and enterprise software. Middleware serves a number of purposes some of which include configuring and managing RFID hardware, such as interrogators, RFID encoders and motion sensors. It also processes RFID tag data, cleaning out duplicate tag reads and aggregates back-end applicationsdata.

The availability of a middleware layer provides significant RFID benefits, as it facilitates system to interact with heterogeneous RFID device hardware, allowing service developers to focus only on the implementation of specific business applications. The correct management and strategic exploitation of RFID middleware is proving to be a crucial building block in successful RFID deployments in a variety of complex environments (logistics, supply chain management, etc.) which consist of multiple RFID readers, ERP systems, legacy ICT systems, as well as complex business processes. Organizing and integrating the multiple parts of an RFID system are made simpler with a middleware system which boasts elevated adaptability and flexibility. This middleware must take into account the need to arrange and managing various reader units, filtering and distributing RFID information, interpreting low-level information to high level business process which facilitates knowledge management and finally coordinating RFID frameworks with legacy ICT frameworks and applications. (Kefalakis, et al., 2009)

In recent year's middleware has been the common approach for dealing with the increasing complexity of distributed infrastructures such as RFID systems, sensor networks and smart environment (Hadim & Mohamed, 2006). These frameworks are dependent upon a Service-oriented Architecture, where the underlying communication layer is abstracted from the user of the system. They incorporate support for distributed and centralised architectures, security, trust and model-driven development of applications. (Carsten, 2008)

The common middleware approach is to offer a set of abstractions to developers in order to simplify the production cycle of distributed applications. This approach presents some drawbacks however as It usually offers a fixed scheme of abstractions, optimized for tackling the specific problems of an application field or hardware technology. This approach leads to isolated bespoke systems and to pillars of communication protocols that often replicate efforts for solving similar problems, adding unwanted complexity that can easily become unmanageable. Moreover the communication between different middleware solutions (e.g., a sensor network may need to be integrated with a real time positioning system and with RFID tracking) may be hindered by abstractions which are incompatible with a given application. It is the collection of this complexity that renders such systems not fit for purpose.

Standardised systems are available which define a complete stack of protocols for collecting, processing, storing and accessing RFID data or events across organisation boundaries. An example is the EPC infrastructure (GS1, 2014), The true purpose of the EPC infrastructure is sharing information among all the actors of supply chains with the help of RFID which can facilitate an elevated element of transparency and automation.

7. Communication protocols and data signal optimisation

7.1. Near and Far Field communication theory

From an earlier section we can now conclude that the boundary between near and far field is approximated by $r = \lambda/2\pi$, and is representative as the point where the electrical and magnetic components of the electromagnetic wave separate from the antenna into the surrounding environment forming a propagating electromagnetic wave(Want, 2006a). It was also stated that the far field begins where the near field ends which is an important functional attribute of RFID systems and in the context of coupling these two modes are known as reactive coupling and backscatter coupling.The electromagnetic field attenuates as a square function of the distance in the far field where the ratio of electrical (E) to magnetic (H) field components has the constant value of 120 π or 377 Ω commonly known as its intrinsic impedance.

7.2. Near fieldCommunication

According to Ampere's law a current passing through an inductor creates a surrounding magnetic fieldwhich remains within the vicinity of the coil (near field) i.e. is not propogationary (Lehpamer, 2008)(Finkenzeller, 2003)(Paret, 2005). For both LF and HF systems data transfer is limited to the range of themagnetic field region where the dominant magnetic component is responsible for carrying the data between tag and reader. This data transfer is made possible by a process of coding the carrier wave where the most common form of coding being load modulation. For this communication link to occur the field effectively remains in contact with the antenna at all times thus implying near field communication. It suffices to ignore the electrical component (of the electromagnetic wave) and only deal with the magnetic component (Lehpamer, 2008)given the fact that these low frequency systems have wavelengths greater than the distance between reader and tag antenna.

Therefore, in accordance with Ampere's law a current passing through an inductor creates a non-propagating magnetic field with a representativestrength of

$$B = \frac{\mu_0 I N a^2}{2r^3} \quad \text{[Weber/m}^2\text{ or Tesla]}$$

Where:

I = current through the coil, N = number of windings in the coil, a = Radius of coil, μ_0 = permittivity of free space and r = perpendicular distance from antenna to an arbitrary point in space. When r >> a (i.e. increased distance from the source) is the main limiting factor of RFID the magnetic field strength diminishes according to $1/r^3$ relationship. This indicatesthe magnetic field strength is dominantin the immediate environment of the source yet very low in the far fieldregion (thus, limiting the far field functioning potential of these systems) and occurs as follows;

$$I = \frac{V}{Z_L} = \frac{V}{\omega L} \qquad)$$

where L is,

$$L = \mu_0 \pi a N^2$$

Now giving:

$$B = \frac{Va}{2\omega N \pi r^3}$$)

It is now possible to say that B is inversely proportional to N. This is because the current increase proportional to $1/N^2$. It is important to highlight that a desired increase in field strength at a fixed antenna dimension, requires a current increses to the antenna.

The resonant frequency (f_0) of the reader is(Chen and Thomas, 2001),

$$f_0 = \frac{1}{2\pi}\sqrt{LC}$$

Where,

L= Inductance of the antenna (determined by the radius of the coil, number of windings, thickness of the windings and the length of the coil), C= tuning Capacitor, The same applies for the tag's resonant frequency and in this case,

L = inductance (Henry) of antenna coil in and C = Capacitance (Farad).

$$Z(j\omega) = R + j(X_L - X_C)$$

At resonance $X_L = X_C$ implying $Z(j\omega) = R$. When tag and reader 1 are placed in close proximity the reader antenna's time varying magnetic field induces a voltage (emf) in the tag's antenna coil. This voltage causes a flow of current which is equal to the time rate of change of the magnetic flux (ψ) giving.

$$V = -N\frac{d\psi}{dt}$$)

Where,

N= Number of turns in antenna coil

ψ = Magnetic flux through each turn

The negative signal signifies that the induced voltage opposes the change in the magnetic flux produced by the reader. The magnetic flux is representative of the total magnetic field (B) passing though the entire surface of the antenna coildetermined by:

$$\psi = \int B \bullet dS$$

where (S) signifies the surface area of the coil and $(\bullet)$ is the inner product cosine angle between two vectors (B) and (S). This is found through the voltage across the tag antenna, at a resonant frequency given by(Chen and Thomas, 2001):

$$V_{TAG} = 2\pi f N Q B (S \cos\alpha)$$

Where,

f = frequency of the carrier signal, Q = Quality factor of the resonant circuit given as X/R, (reactance / resistance), S = Area of coil m^2.

As highlighted earlier the process of near field couplinghase been described as occurring via a process ofreactive coupling which may be further categorized into sub-groups of Capacitive and Inductive coupling as follows (Finkenzeller, 2003).

Near Field Reactive coupling

Low frequency (≤ 135 KHz) and high frequency (13.56 MHz) RFID use reactive (inductive / capacitive) coupling where the system's dominant magnetic component in this case is responsible for carrying the data in the communication link process. In this link the field effectively remains in contact with the antenna at all times suggesting all communication occurs in the near field. This reactive coupling process may be divided into two main groups.

Capacitive coupling:

This is the transfer of energy from one circuit to another by mutual capacitance existing between two circuits (Finkenzeller, 2003). These types of systems usually operate at ranges of between 0 and 1 cm. These systems offer the possibility of high power transfer and may also facilitate the use of microprocessors. Their antenna may be constructed from materials of considerably higher resistance than is possible with inductively coupled systems. The low range of operation makes them ideal in areas where a high level of access control is required.

Inductive coupling:

Inductive coupling relies on mutual inductance between two circuits. This is most commonly used in LF and HF RFID systems given the fact that these low frequency systems have wavelengths greater than the distance between reader and tag antenna it suffices to ignore the electrical component and only deal with the magnetic component of the electromagnetic wave (Lehpamer, 2008). These systems operate in a similar fashion to transformer coupling by passing information between the reader (primary coil) and the tag antenna (secondary coil) only if the tag will not exceed the boundaries of the near field.

Load modulation

Both Low-frequency and High-frequency systems use load modulation to couple. We can now establish that load modulation is achived through modulating the impedence of the tag in relation to the reader and can be divided as follows.

Load modulation with subcarrier:

Switching a tag's load resistor ON and OFF rapidly will lead to the formation of two spectral lines around the transmission frequency. This creates two backscattered sidebands which contain the tags data information. This technique allows improved reply signalling as the reply information is contained in modulated sidebands symmetrically placed around the readers' carrier frequency.

Sub-harmonic Procedure:

This method makes use of a secondary frequency which is usually half of the reader's transmission frequency. One commonly used frequency is a 128 KHz reader transmission frequency with a response signal being 64 KHz (in LF RFID systems).

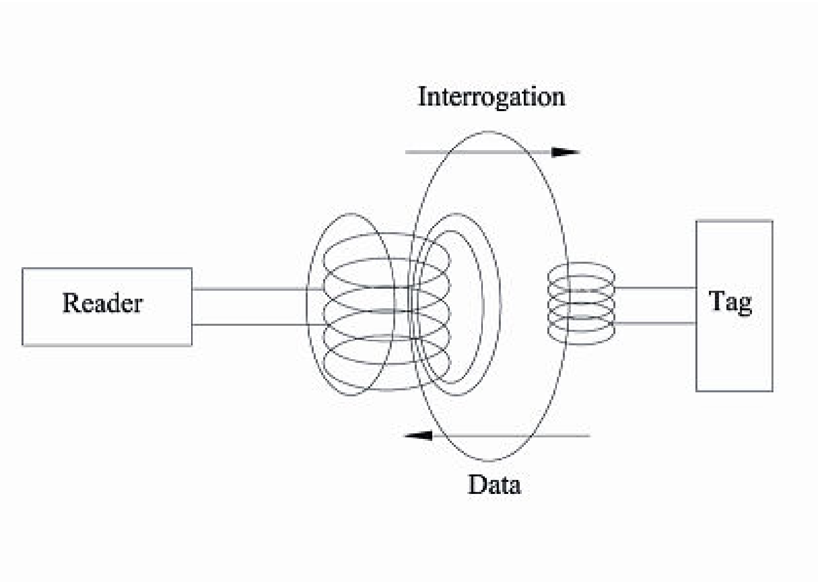

Figure Near Field Coupling

7.3. Far field Communication

RFID systems operating in the far field depend on the bi-directional communication link between tag and reader. During this process the reader propagates an unmodulated (base) signal and before this signal is reflected back to the reader the tag undergoes a process of encoding and modulation representing its own unique identification information(Keskilammi et al., 2003).If the load is varied resulting in a mismatch where a certain level of backscatter occurs (Want, 2006b). On the other hand, if the antenna is matched to the load, no reflection (hence no backscatter) occurs (Curty et al., 2007)(Dobkin, 2008). A sequence of shifting between these two states, the pattern of which is determined by the microchip, forms the ID information unique to each transponder to be sent to the reader for demodulation(Qiasi et al., 2009).

The efficiency of this communication “coupling”is dependent on a number of factors including the transmitters power, reader sensitivity, path loss in both directions, the radar cross section (Schussler et al., 2008). It is also limited by the amount of energy reaching the transponder and also its consumption level of signal from the reader(Fuschini et al., 2008). The amount of energy reflected by an object is dependent on a number of factors including the size of the reflective area, design of its surface and its composition, and the material used. This implies the larger the reflective area of an object the more it reflects - a property known as its radar cross section (Δ RCS) (Mats et al., 2007). The coefficient of reflection (reflection due to mis-match between tag and reader load) can now be calculated.

$$\rho = \frac{Z_c - Z_A}{Z_c + Z_A}$$

Where,

Z_c = load impedance of the chip

When:

$Z_A = R_A + jX_A$ = complex antenna impedance

$Z_C = R_C + jX_C$ = complex chip impedance.

As previously mentioned backscatter is achieved through a change in the impedance of the tag antenna(Sydanheimol et al., 2008). The ratio between these two states $(\Delta\rho)$ differential coefficient of reflectivity may now be calculated:

$$\Delta\rho = \rho_1\left(1-(\rho_1)^2\right)+\rho_2\left(1-(\rho_2)^2\right)$$

Where ρ_1 and ρ_2 represent IC states 1 and 2 respectively. This assumes ideal conditions with no reflection or diffraction of the wave. In the case of an antenna match the RCS is equal to the antenna effective aperture A_e. In the case of a mis match the theoretical RCS is

$$\sigma = \Delta RCS = A_e.G_T.(\Delta\rho)^2 = \frac{\lambda^2.G_T^2(\Delta\rho)^2}{4\pi}\left[M^2\right]$$

Where,

ρ = Differential reflection coefficient of the tag modulator

G = Antenna gain (squared due to the bi-directional flow during backscatter)

As previously mentioned backscatter is a bidirectional flow of information meaning that the returned signal (tag to reader) is also dependent on a number of factors including power (P_{ret}), power density (S_D) and the gain of the reader antenna (G_R). The RCS may then be given as:

$$P_{ret} = \frac{P_R}{4\pi r^2}.G_R.\sigma[W]$$

where P_R is the power transmitted from the reader.

The power density received at the reader:

$$S_{REC} = \frac{P_{ret}}{4\pi r^2} = \frac{P_R.P_G}{(4\pi)^2 r^4}$$

As the reflected signal encounters the same conditions as the transmitted power the amount of modulated power that is scattered from the tag back to the reader during backscatter (backscatter radio link budget) is given as follows:

$$P_{REC} = S_{REC}.A_e = \frac{P_R.P_{G.}\sigma}{(4\pi^2 r^4)}.\frac{\lambda^2 G_R}{4\pi} = \frac{P_R.G_R^2.\lambda^2\sigma}{(4\pi)^3 r^4}$$

The power received by the RFID tag is a core requirement of system functioning. This power may be divided into two parts (1) being the actual portion used by the tag chip and (2) the remaining part which is the reflected portion of the wave. It is the manipulation of their proportion that will be one of the critical factors in determining the coupling range. In a case of ideal tag to reader dipole alignment (G_{Tag} = 2 dBi) it is possible to express the voltage induced at the tag antenna terminals as:

$$V_{Tag} = (\lambda / 4\pi r)\sqrt{P_R.G_R.G_T.R_C}$$

Where,

P_R and G_R is the EIRP of reader and the maximum practical value of R_C is 600 Ω (Lehpamer, 2008). The activation range of the RFID system is reduced due to polarisation losses because reader to tag polarisation / orientation is unknown. It is important to note circular polarised antenna introduce a loss of 3 dB due to their rotational characteristics a property which has proved to be commercially beneficial given the final application environment(Mc Carthy et al., 2009a). The read range may be calculated using the following formula (Lehpamer, 2008):

$$r = \frac{\lambda \cos\theta}{4\pi}\sqrt{\frac{P_R G_R G_T \left(1-(\Delta\rho)^2\right)}{\mathrm{P}_{th}}}$$

For $0 \leq (\Delta\rho)^2 \leq 1$

Where,

G_T = gain of the tag antenna, $P_R G_R$ = EIRP of the reader, λ= Wavelength, P_{TH}= minimum threshold power required to power an RFID tag, θ= angle made by the tag with the reader plane and $(\Delta\rho)^2$= power reflection coefficient. The ratio of reflected power to incident power by the tag. It is important to note that in the case of circular to linear polarization mismatch the read range will be reduced by a factor of $\sqrt{2}$.

Backscatter coupling

Backscatter coupling occurs in the far field region and the short wavelengths of these frequencies enable the construction of transponder antenna significantly smaller in dimension than lower frequency systems facilitating RFID identification down to item level. In this communication link the field effectively breaks away from the antenna and as a result communication occurs in the far field. This method of communication is used for systems operating in the UHF and microwave regions.

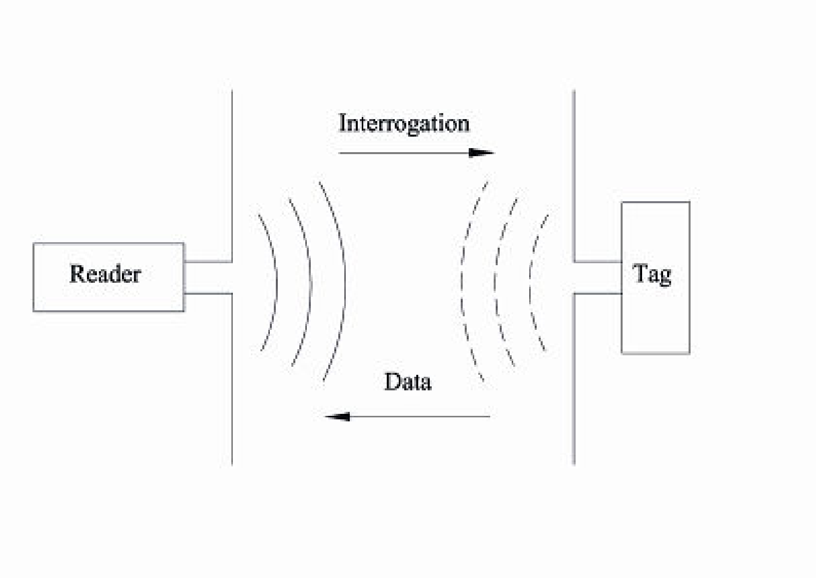

Figure Far Field Coupling

7.4. Signal Coding

Once a wireless radio link has been established between tag and reader the next stage of the coupling process reqires an ability to encode this signal with information- a process commonly referred to as *source encoding*. This source encoded then undergoes a process known as *channel encoding (Finkenzeller, 2003)*. This facilitatesdata to be embedded in the radio waves thus forming the core data carrying functionality of RFID systems. Tags will encode informationwith reference to a particular coding scheme and in synchronisation with a specified data transfer rate. This data will then be transferred to the readerwhich will then decode the incoming data stream (i.e., separating clocks and data). To successfully incorporate a sucessful coding system one must consider a number of factors including (1) *Synchronisation*:relating to timing needs to be incorporated into the code, to facilitate the relevant information may be extracted, for clock synchronization. (2) *Transmission power and bandwidth efficiency:* The transmission power is ideally as low as possible similar to the transmission bandwidth which will also ensure interference if kept to a minimum.(3) *Spectral power density*:The time-domain signal should be suited to the transmission channelto avoid wandering (fluctuation of voltage levels) within the data stream. (4) *Low error rate*:A low error rate is obviously the ideal scenario, yet not possible due to a high noise environment or a corrupt signal arriving. It is then highly desirable for the reader to be able to recover the original message with a low error rate. (5) *Error detection*:This should forman integral part of the encoding/decoding scheme as an error correction facility, should such a situation arise. (6) *Clear signal*:It is vital that each combination of 1 and 0 be transmitted correctly regardless of a variation in the order they appear. A code is said to be clear when the coded signal is correctly received.

Types of channel encoding

Level codes and transition codes form the two main types of RFID system coding(Chen and Thomas, 2001). *Level codes* are representative of a binary bit corresponding to a particular voltage level and secondly whereas*Transition codes* are representative of a binary bit being represented as a change in voltage level. To avoid an exhaustive list there are also a number of different coding types available according to Lehpamer, (2008) which are grouped as follows.

Non return to zero (NRZ)

A logic 1 is coded as one dc level and a logic 0 is another. It requires time co-ordination yet is relatively simple leaving a low error probability. Traditional NRZ coding is undesirable in wireless communication transfer given the fact that the data streams may contain long strings of 1 or 0 and this may cause the receiving system to lose synchronisation with the transmitted clock.(Khan et al., 2008).

Return to zero (RZ)

This line code is characterised by a drop in the signal to 0 between each pulse when the bit is one. This type of signal is self clocking however it occupies double the bandwidth of NRZ coding And due to the fact it is DC component based may experience baseline wandering

Manchester

This coding scheme involves a transition in the middle of each binary bit. Logic 0 is represented as a transition from low to high and logic 1 is represented as a transition from high to low. The codes are self clocking and virtually error free as the noise would have to invert the signal both before and after the transition to cause error(Chen and Thomas, 2001).

FM 0

This is the simplest form of coding applying to EPC global Class 1 Generation 2 protocols which are useful in implementing a global coding scheme according to GS1 standards. It is characterised by a change at the end of each bit period but a bit 0 being represented by a transition in the middle of the bit period. In this coding scheme, the sequence of bits always ends with a dummy data bit 1 at the end of each transmission sequence.

Miller

This process has also commonly been termed delayed modulation.It is represented by a transition for each included bit. A bit 1 is represented as a central bit transition while consecutive 0 is represented as a transition at the bit boundary between them. There is a transition in the middle of a bit period if it is a bit 1; and there is also a transition at the start of the bit period if a 0 bit is followed by another 0 bit. In the case of a sequence of a 0 followed by a 1 or a 1 followed by a 0 no transition occurs at the symbol interval. This particular coding scheme has proven to be efficinet given its ability to occupy half the bandwidth of other coding schemes.However a slight drawback is the fact that it is not dc free.
Often grouped together, however there is one major difference Miller Squared coding states that the transition of an even number of 1 occurring between two 0's is omitted (01110 occupies five cells and has three transitions whereas 011110 also occupies six cells but also has three transitions), resulting in a dc free code.

7.5. Baseband modulation

This process a process that involves the alteration or modification of the carrier wave in accordance with the message signal(Chen and Thomas, 2001)(Curty et al., 2007). The modulation process determines how the communication bits are transferred according to the message to be transferred between tag and reader. There are three main types of digital modulation namely Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), Finkenzeller. (2003) and Frequency Shift Keying (FSK) (Dobkin, 2008). The type of modulation determines the data transfer rate, system power consumption and bandwidth requirements of the RFID system and commonly varies across RFID systems.

Amplitude Shift Keying (ASK)

A number of variations of ASK can be identified including; double sideband-ASK (DSB-ASK), single side band-ASK (SSB-ASK). SSB-ASK is better suited to countries with strict bandwidth restrictions, whereas DSB-ASK is the easiest to produce with OOK (on / off keying) of the carrier signal although this is less efficient in terms of bandwidth usage. Phase reversal-ASK (PR-ASK) as the name suggests changes phase 180^o each time a symbol is sent. This enables an easily detectable clock signal as the amplitude briefly goes to zero when changing symbols. PR-ASK has a C/N and bandwidth requirements that more closely match PSK than DSB-ASK making it more attractive for narrow band and longer read range applications.

Phase Shift Keying (PSK)

Similar to FSK except a singlefrequency is used in this case. A shift in the phase of the backscatter clock by 180^o results in the transmission of 1 or 0. Two common types are a phase change at any 0 or secondly a phase change at any data change 0 to 1 or similarly 1 to 0. PSK provides a good level of noise torerence, also a reasonable simple reader design and also providesa higher data transfer rate than FSK.

Frequency Shift Keying (FSK)

As the name suggests this uses two frequencies for data transfer with the most common being f_c /8 to f_c/10. A binary 0 is an amplitude-modulated clock cycle with a period corresponding to the carrier frequency divided by 8. A 1 is transmitted as an amplitude clock cycle period equal to carrier frequency divided by 10. As a result the amplitude modulation switches between two states $f_c/8$ and $f_c/10$ and the reader counts cycles between the clock edges to decode the data based on this information (Finkenzeller, 2003).

8. Challenges with the Technology

Radio waves range roughly from 3 KHz to 300 GHz within the Electromagnetic spectrum. When a radio wave comes into contact with an object part of or the full wave may penetrate the material and depending on the composition of the material a portion may also be reflected back into the environment. This ratio of penetration to reflectanceis important to the functioning of passive RFID and is also directlydependent on thedielectric properties of the substance to which the tag is atached(NAS, 1994)(Virtanen et al., 2006). There are a number of different ways electromagnetic waves may interact with materials in their immediate surrounds which underpins the need to be familiar with them prior to technology implementation(Wu et al., 2006)(Domdouzis et al., 2007). This, lack of experience and familiarity with the technology is the main cause of unsucessful commercial RFID implementations and for the most part can be easily addressed with a variation of the operating frequency of the system.Twocommon substances which have proven to have a significant effect on RFID systems coupling (especially systems operating at UHF and above)include metal and water(Jones et al., 2005)(Singh et al., 2008). In a commercial setting a propagating electromagnetic wave in the environment will encounter a variety of objectsand surfaces each of which may cause a variety of wave interactions leading to inconsistent coupling and unpredictable systems performance. It has been reported that environmental factors may decrease the reader range of passive RFID systems by at least 50 % (Keskilammi et al., 2003). It is also important to highlight that an object or surface may also affect radio waves differentlyat varying temperatures(NAS, 1994)(Mc Carthy et al., 2009d). It is a well documentedfact that higher frequencies experience greater attenuation levels than lower frequencies(Keskilammi et al., 2003), however this lowering in the frequency will also result in a decrease in the operating range of the system. With this in mind it is important to consider the potential factors having a significant effect on the coupling capabilities of RFID systems some of which have been included below

Internal challenges with RFID technology:

System Frequency:

It is important to note that system frequency has a significant effect on RFIDsystems coupling performance. An increase in frequency bringsa welcome increase in the functional data transfer range (.ie. increase range of the system) of an RFID system yet this is not without its disadvantages. This frequency increase will also bring an unwanted element of un-predictability in relation to radio waves in commercial environments, based on the previously mentioned unpredictability of radio waves in the presence of metals and high moisture environments.

Signal Interference:

This is caused as a result of a number of systems operating in the same environment. The presence of more than one wave in a space may result in interference between individualwaves, which can be constructive (they reinforce one another), or destructive (cancel in whole or in part one another), in either case the net result is unpredictable system performance.

Signal scattering:

When the medium in question contains particles that are small in comparison to the wavelength. This leads to the scattering of waves in many random directions which are a result of the rough surfaces, small objects or irregularities in the transmission medium, again leading to potential coupling losses.

Signal fading:

Generally caused by a variation of signal strength with time(Meyers, 2007). Fade zones tend to be small areas of space within the interrogation zone that result in periodic attenuation of a received signal. The presence of the effects of fading are more prevelant with increase distance from the source antenna. The random occurrence of fading makes it impossible to accurately predict signal strength at a particular point in time thus leading to overall system inconsistencies

Signalrefractive index:

Commonly occurs in the presence of objects such as paper, corrugated paper, non-conductive plastics and textiles(Penttilä et al., 2005). These non-absorbing materials possess low refractive indexes. Radiation incident on such materials experience little or no reflection due to a refractive index mis-match. Radiation absorption is also negligible. Such materials are generally referred to as being RF-Lucent. Contrary to this are RF-Opaque objects such as metals and water where metals will generally reflect all radiation incident upon it and waters will reflect a significant portion of the incident wave and absorb most of the remaining portion. Depending on the item being tagged both RF-Lucent and RF-Opaque significantly affect RFID system performance.

Signal diffraction /refraction:

Radio waves diffraction may be due to materials in the immediate environment (Similar to light waves,)leading to RF shadows in the neighbouring environment. Similarly refraction is a change in the direction and speed of travel of a radio wave when they move from one medium of a certain refractive index to another medium of a different refractive index. The net result of both cases are unpredictable system performance.

Signal reflection:

In an RF environment both water and metal act as excellent reflectors. Glass will also reflect at differing degrees corresponding to the angle of incidence. This reflection of waves may cause an area that is normally RF shadowed to become RF illuminated. These reflections act in a totally unpredictable manner enabling them to cancel the wave from the reader antenna thus leading to inconsistent system performance.

Collectively, the importance of these properties cannot be over emphasised as they are all hugely important in relation to RFID systems as they impact on how the electromagnetic wave (essential for coupling) will interact with a variety of environmental materials. A loss or deterioration in signal strength as a result of any of the above mentioned factors will prevent coupling from occurring and lead to overall system failure.

External challenges with RFID technology:

Unit timing:

A major challenge lies in a readersability to interrogate multiple tags simultaneously, and also individually select them from a number of tagsand can only be achieved via the use of various tag inventory commands(EPCglobal, 2008). A variation in both thefrequency and protocol of the system will result in a variation in the number of tags that can be interrogated where a typical high frequency (HF) system has the ability to handle up to 50 tags per second compared to 200 tags per second using an ultra high frequency(UHF) system. For commercial applications involving a conveyor / automated style production approach the amount of time a tag spends in the operating area T_r (interrogation zone) must, therefore, be carefully considered and be greater than or equal to the time taken for the reader to detect and/or read or write (operating time), to ensure correct system functioning which is represented as follows (Lehpamer, 2008);

$$T_r \geq T_c + T_d \tag{3}$$

where T_c is Reader operating time [seconds] including the time taken for detection and/or read or write each tag and T_d represents the amount of time required for detecting the existence of all tags [seconds]. The reader operation time T_c may further be expressed as:

$$T_c = A_{cn} \times (D_t / D_r) \tag{4}$$

where D_t = Data transfer volume of the tag [bit], D_r = Data transfer rate [bps], T_c = Operation time [seconds], A_{cn} = Average number of tag read operations [count].From this formula it is evident that if the value of the tag data (D_t) increases, the data transfer rate (D_r) decreases, or if A_{cn} increases and operation time needed (T_c) increases.

$$T_r = L / V_{tag} \tag{5}$$

When L = Distance a tag moves in the operating area [m], V_{tag} = Tag movement velocity [m/second].

T_c and T_d are predetermined by the standard design and manufacture of tags, whereas L and V_{tag} are variables. For a given conveyor speed, the value of L must be maintained above a certain value which is a function of the conveyor speed (production speed) and through equating equation 3 and 5 it is now possible to say

$$L / V_{tag} \geq T_c + T_d \text{ and} \tag{6}$$

$$L \geq (T_c + T_d) V_{tag} \tag{7}$$

As $V_{tag} \geq 0$ in all cases.

Operating distance:

Distance between tag and reader antenna affects the power flow per unit area in an inverse square proportion for UHF systems. Hence, for a UHF RFID tag to successfully couple with the reader, the distance, *R*, between the tag and the reader antenna must be limited(Finkenzeller, 2003)(Ayalew et al., 2006)where P_{tag} represents the power required at the tag antenna output, G_{tag} is the tag antenna gain, EIRP is the effective isotropically radiated power (for a general antenna) which is equal to 1.64 times ERP (effective radiated power) if a dipole antenna is considered, and λ is the wavelength of the carrier radio frequency (all in SI system of units).
It is also worth noting that passive RFID systems have a limited operating range (in comparison to active, semi-passive/semi-active systems). As highlighted earlier this is due to the fact that passive transponders do not have their own internal power source and rely on a process of backscatter for coupling. Active RFID tags on the other hand are not limited by backscatter and have read distances significantly greater than passive systems.

Antenna polarisation:

Antenna polarisation is another important factor to consider. There are two types of reader antenna polarisations namely linear and circular. Linearly polarised antennaelaunchuniaxial electromagnetic waves into the surrounds. When both reader and tag antennae are linearly polarised along the same axis they are said to be - matched in terms of polarisation. An angular misalignment between two linearly polarised antennae results in a polarisation mismatch, and in the case of passive RFID systems may have a negative effect on the coupling process - the extent of angular mis-alignmentmay be approximated (Lehpamer, 2008) using the relation:

$$\text{Polarisation mismatch loss [dB]} = 20 \log (\cos \theta). \qquad (2)$$

where θ is the angle of misalignment between reader and tag antennae.

A circularly polarised antenna, on the other hand, launches the interrogation wave in such a way that the polarization of the electric field rotates about the propagation axis one full circle during every electromagnetic period. As a result of the non-static direction of polarization, circularly polarized antennae cause a 3 dB (half) decrease in the power delivered to a stationary tag with a dipole antenna compared to a matching linearly polarized reader antenna for the same reader interface power. The fact that the polarization rotates, however, enables circularly polarised antennae to be less prone to the effects of tag-reader polarisation mismatch (Burger et al., 2007), yet at the cost of coupling range.

9. RFID in business

With expanding global markets and mounting pressures towards globalisation a strong business case can be presented for RFID applications to improve overallbusiness efficiency and profitability (Carthy et al., 2013).RFID is a data carrying technology with the ability to wirelessly transfer actionable data across the organisation supporting business processes proving to be a direct source of competitive advantage delivering cost reduction potential, chain analysis capability and overall chain responsiveness(Wamba et al., 2008)(Bottani et al., 2010)leading to the formation of smart, sustainably and cost competitive global supply chains. RFID technology presents the ability tofacilitate networked global supply chain management systems and global logistics management which present significant industrial game changing potential across many industries. This can be achieved by creating synergies through increased operational transparency, monitoring and report of environmental conditions in real time and making the transitionfrom paper to electronic transactions. RFID adds cyber intelligence in the form of actionable data which can be obtained from operations and used as a blueprint to form the strategy of the organizationIt has been shown that RFID has the ability to generate 30 times more data than conventional methods such as the bar code(Visich et al., 2009) and is an established fact that this information, when used correctly may form the basis of a competitive advantage through more informed decision making(Schuster et al., 2007)(Ferrer et al., 2010)

However, to truly quantify these benefits one must adopt a strategic perspective and view RFID technology as more than just simple hardware (tag and reader) and focus on the virtual capability of the technology. RFID technology has the ability to link the physical (asset) to the virtual (cloud support infrastructure) has been instrumental in increasing transparency and delivering synergies in business processes. These RFID initiated cyberphysical linkages deliver an end-to-end production and supply chain integrity monitoring system that relays a constant flow of real time product-critical information thus providing the basis of responsive management systems and dramatically improve supply chain applications.

This is further complimented by the use of EPC coding and the EPCnetwork platform when implementing RFID technology(Ayalew et al., 2006). This delivers enhanced network control and greatly enhances the performance of the organisation through the adoption of standardised information sharing formats across business boundaries(Guinipero et al., 2008). EPC coding is a common data structuring scheme in operation between an ever increasing number of trading partners which accommodates both existing and new coding schemes in an attempt to unify and standardise global supply chain management and asset tracking(Roussos and Kostakos, 2009).

RFID technology has the ability to add value to the vale chain. With this in mind it is important to point out that JIT and LEAN principles are also closely linked to ERP systems which would indicate that RFID and the EPCnetwork will aid in the implementation of LEAN and JIT(Dias et al., 2009)(Delen et al., 2007)(Chu and Lee, 2006).

10.Barriers to Implementation

One major shortcoming of RFID technology is a clear lack of a business case. It is important to highlight that this is not due to any technological shortcoming, it is merely due to the fact the technology is constantly evolving and its full potential is still being realised.As well as these technological issues to consider there are also cultural issues to be addressed with RFID adoption in an organisation relating to changing processes and cultures within organisations to facilitate the introduction of the technology(Senneset et al., 2007). In terms of helping to secure successful implementation it is important to have a knowledge of the technology and also to maintain a realistic multi-dimensional approach towards the technology as experience has shown not all organisations along the supply chain will gain equally from its incorporation(Mo et al., 2009). It is the opinion of the author that partial implementation of RFID, while being a move towards the right direction is not necessarily the correct move as it may impose unwanted burden on a single organisation and encourage unequally cost burden along the supply chain. This is of huge concern to potential implementers and is a significant barrier to implementation While there are a number of documented barriers to implementation it should however be noted that none of these barriers are insurmountable and time and time again it has been shown that a working knowledge of the technology greatly reduces these barriers..

System Cost

Unit cost of the technology and moreover the tags may also prove prohibitive for many organisations. This is further exhadurated by the fact that transponders are not always returnable and they present a once off cost the the implementer which may prove too expensive over large volumes(Michael and McCathie, 2005). This was also a recurring theme to appear throughout literature as the majority of experts make reference to implementation cost. In extension to this it is challenging to directly assign a cost to RFID and its accompanying software implementation into an organisation. To gain a true reflection on the value of implementation it is important to take a comprehensive look at all aspects of the organisation (marketing, finance and operations) to gauge its added value to each part of the organisation given the ability of the technology to implement collaborative engagement more effectively with external trading partners irrespective of geographical location. Similarly enterprise systems are not cheap. It is also important to gain an insight into the cost of such systems. It is estimated that IT costs make up 46% of all capital investment in the US(Wamba et al., 2008). The cost of or the inability to predict the cost thereof is one of the major barriers to widescale adoption(de Kok et al., 2008), which reverts the reader back to the lack of a business case and lack of empirical evidence.

Return-on-Investment (ROI)

The question of a comprehensive and accurate return on investment (ROI) metric for RFID has yet to be accurately quantified for a particular industry. To comprehensively address the issue of an accurate ROI model one must firstly tailor the model to each particular industry, its supply network, internal profit margins and also level of implementation. This has proven challenging to both academics and industry alike as each individual organizational costing structure can potentially vary significantly based on circumstance even within similar sectors. While it is relatively simple to calculate the cost of implementing RFID systems within an organisation (number of tags and readers etc) its true ROI is a lot more difficult to calculate(Mohsen, 2007). When calculating ROI it is important to note that information may be a burden (storage costs etc) on an organisation or it may prove to be imperative in the development of a sustainable competitive advantage provided it is interpreted and used correctly – which suggests that the culture within the organisation ios also important. It is for this very reason that the cost of implementation is relative to the ability to use this information which suggests that ROI is specific to each organisation from an operational perspective.

Security and Sharing

Within an organisation and across the wider supply chain there must be a willingness to share information. By its very nature RFID and the EPC must be incorporated horizontally across the organisation which will require commitment from all functional groups, with the correct cultural attitude, including finance, HR and manufacturing which can prove a daunting task to many managers(Hansen and Gillert, 2008)(Chu and Lee, 2006). Offset against this is the need to address certain security issues in relation to RFID technology.A hugely important issue in relation to organisational information is the ability to have controlled access. This is vital to organisations as it prevents the leaking of sensitive information and the loss of a source of competitive advantage. This is also another key barrier to implementation relating to RFID adoption(Schuster et al., 2007).

Level of Implementation

With good intentions at time of implementation, the act of mandating the technology may have been intended to increase RFID adoption, when in fact it has been viewed as many as being counterproductive as organisations that adopt the technology under a mandate do not realise true benefits. This is because they usually incur the expense of the technology and did not have the opportunity to do and feasibility tests and were forced to adopt a “slap and ship” approach which attracts a culture of compliance as opposed to exploitation of the technologies benefits(Mohsen, 2007)(Li et al., 2006)(Twist, 2004). This links strongly back to the need to be an early implementer to gain all the spoils of the early adopter as it has been previously reported that the organisations currently adopting the technology are versatile organisations with an innovative culture, which are important characteristics for the development of a competitive advantage(Lin and Ho, 2009)(Hollensen, 2007)

Global Standardisation

RFID technology within the UHF spectrum does not operate on a global standardised frequency. This leads to interoperable issues across the geographical regions yet this is an issue that is currently being under review as it poses difficulties for international organisations wishing to adopt the technology(Wamba et al., 2008). Similarly once the frequency standards have been adhered to there also lies the problem of standardising the data so organisations transporting items across the globe can be assured that their item maintains its uniqueness. Organisations such as GS1 have developed the EPC code structuring for RFID data which has been successful in recommending a coding structure (global language) for RFID tagged items being traded across the globe.

Properties of tagged items

Another drawback associated with the coupling capabilities of UHF RFID relates to the fact that the item being tagged can affect the overall performance of the RFID system (Mc Carthy et al., 2009b).As outliner in an earlier section there are a number of factors that have the potential to effect propagating electromagnetic waves within a particular environment. Overall this can result in an inability for the tags and reader to couple, thus leading to system failure resulting from tag detuning due to materials different from those at design in the immediate environment of the transponder (Sweeney, 2007; Mc Carthy et al., 2009c; Ayalew et al., 2006)

11.Recent Developments of RFID Technology

While there are many obvious advantages of RFID technology in an auto ID application (i.e. the ability to wirelessly obtain identification form an object) there are also numerous value adding developments in terms of the technologicial and environmental applications offering clear field advantages some of which include.

Environmental mapping

RFID tags with embedded temperature and humidity sensors are proving increasingly valuable in supply chain management applications due to its ability to make visible virtually any object, in real time, in terms of identification, temperature and humidity in the supply chain thus benefiting both the manufacturer and the retailer (Zhou, 2009).The market need for this technology is driven by a recent study showing temperature-controlled shipment increase above the specified temperature in 30% of supplier to the distribution centre trips, and 15% of trips from the distribution centre to the store. The opposing incidence of lower-than required temperatures occur in 19% of supplier to distribution centre trips and in 36% of distribution centre to the store trips (Ruiz-Garcia and Lunade, 2010).

RTLS location mapping

Similar to environmental monitoring many RFID tags are now being fitted with internal GPS functionality. This has proven to be advantageous in many supply chain applications where each stakeholder has the ability to view the location of their units in real time using RTLS (Real Time Location Systems). This has been particularly advantageous for distributers and retail managers as they now have the ability to view the asset and prepare for its arrival. This has the ability to bring a local dimension to Global supply chain applications.

Another area of research in RFID technology is with the use of UHF UWB technology. The system comprises tags, sensors and specialised software location platform which functions within a predefined physical boundary "specially networked environment". These systems function by attaching a tag to a person/asset who is identifiable within the "specially networked environment". At regular intervals the tags transmit brief RFID pulses that are received by sensors strategically placed within the environment making it possible to verify the real time location of a particular person/asset within the environment relative to the placement of the antenna sensors. These systems also provide the ability to track the movement history of a particular person/asset based on the frequency of tag transmission and logging capabilities of the system.

12.The future of RFID Technology

When we think of RFID technology it is important to think of wireless data transfer not being limited to tag and reader linear communication. The true value adding of RFID technology is its ability to be linked with the "internet of things" and the data revolution thus enabling an era of BIG DATA management. The networking potential of RFID technology facilitates the development and strategic infrastructure of information highways acrossindustry which help break down information silos and promote synergies. These cloud-based platforms will address conventional dysfunctional and fragmented business processes and supply chains and replace them with a user-orientated information highways.

To achieve this RFID tags and readers will need to be networked (via radio satellite communication) to a cloud based management system and will provide an essential source of real time data gathered at operational level (primary production, secondary processing and distribution) then wirelessly transferred to a cloud based decision supported infrastructure where this data undergoes a mining process. This mining process involves converting this gathered data to a useful source of information forming the basis of effective management decisions"data revolution". The core competency delivered by RFID technology is the ability to establish a fully networked value chain. This will give stakeholders an elevated level of transparency and access to real time actionable data delivering end-to-end production, supply chain integrity monitoring and product verification across supply networks. This level of integrated functionality will lead to a fully flexible more adaptable and responsive supply chain which will have the ability to respond in times of exception and provide advanced knowledge-based solutions towards improving primary production, secondary processing and distribution.

13.Bibliography

ANGELES, R. 2005. Rfid Technologies: Supply-Chain Applications and Implementation Issues. *Information Systems Management,* 22**,** 51 - 65.

AYALEW, G., MC CARTHY, U., MC DONNELL, K., BUTLER, F., MC NULTY, P. B. & WARD, S. M. 2006. Electronic tracking and tracing in food and feed traceability. *Logforum,* 2.

BOTTANI, E., MONTANARI, R. & VOLPI, A. 2010. The impact of RFID and EPC network on the bullwhip effect in the Italian FMCG supply chain. *International Journal of Production Economics,* 124**,** 426-432.

BURGER, E., WOODS, B., HUYSAMEN, J., SUN, R. & REDDY, C. J. 2007. Understanding UHF RFID Systems with the Aid of Computational Electromagnetics. *RF & Microwave Solutions Update*

CARTHY, U. M., UYSAL, I., LANIEL, M., CORKERY, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2013. Sustainable Global Food Supply Networks. *In:* NORTON, T., TIWARI, B. & HOLDEN, N. (eds.) *Sustainable Food Processing.* Wiley-Blackwell.

CHAO, C.-C., YANG, J.-M. & JEN, W.-Y. 2007. Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005. *Technovation,* 27**,** 268-279.

CHEN, S. C. Q. & THOMAS, V. Optimization of inductive RFID technology. Electronics and the Environment, 2001. Proceedings of the 2001 IEEE International Symposium on, 2001. 82-87.

CHU, W. H. J. & LEE, C. C. 2006. Strategic information sharing in a supply chain. *European Journal of Operational Research,* 174**,** 1567-1579.

CURTY, J. P., DECLERCQ, M., DEHOLLAIN, C. & JOEHL, N. 2007. *Design and Optimization of Passive UHF RFID Systems,* New York, Springer Science & Business Media, LCC.

DE KOK, A. G., VAN DONSELAAR, K. H. & VAN WOENSEL, T. 2008. A break-even analysis of RFID technology for inventory sensitive to shrinkage. *International Journal of Production Economics,* 112**,** 521-531.

DELEN, D., HARDGROVE, B. C. & SHARDA, R. 2007. RFID for Better Supply-Chain Management through Enhanced Information Visibility. *Production and Operations Management,* 16**,** 613-624.

DIAS, J. C. Q., CALADO, J. M. F., OSÓRIO, A. L. & MORGADO, L. F. 2009. RFID together with multi-agent systems to control global value chains. *Annual Reviews in Control,* 33**,** 185-195.

DOBKIN, D. M. 2008. *The RF in RFID Passive UHF RFID in Practice,* Oxford, Elsevier Science and Technology.

DOMDOUZIS, K., KUMAR, B. & ANUMBA, C. 2007. Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics,* 21**,** 350-355.

EPCGLOBAL 2008. EPC™ Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz – 960 MHz. 1.2.0 ed.: EPCglobal Inc™.

FERRER, G., DEW, N. & APTE, U. 2010. When is RFID right for your service? *International Journal of Production Economics,* 124**,** 414-425.

FINKENZELLER, K. 2003. *RFID Handbook: Fundamentals and applications in contactless smart cards and identification,* West Sussex, John Wiley & Sons Ltd.

.

FUSCHINI, F., PIERSANTI, C., PAOLAZZI, F. & FALCIASECCA, G. 2008. Analytical Approach to the Backscattering from UHF RFID Transponder. *Antennas and Wireless Propagation Letters, IEEE,* 7**,** 33-35.

GLIDDEN, R., BOCKORICK, C., COOPER, S., DIORIO, C., DRESSLER, D., GUTNIK, V., HAGEN, C., HARA, D., HASS, T., HUMES, T., HYDE, J., OLIVER, R., ONEN, O., PESAVENTO, A., SUNDSTROM, K. & THOMAS, M. 2004. Design of ultra-low-cost UHF RFID tags for supply chain applications. *Communications Magazine, IEEE,* 42**,** 140-151.

GLOVER, B. & HIMANSHU, B. 2006. *RFID Essentials,* Cambridge, UK, O'Reilly Media Inc.

GUINIPERO, L. C., HOOKER, R. E., JOSEPH-MATTHEWS, S., YOON, T. E. & BRUDVIG, S. 2008. A decade of SCM literature: past, present and future implications. *The Journal of Supply Chain Management,* 44**,** 66-86.

HANSEN, W.-R. & GILLERT, F. 2008. *RFID for the Optimization of Business Processes,* Chichester, England, John Wiley & Sons Ltd.

HOLLENSEN, S. 2007. *Global Marketing,* Milan, Italy, Prentice Hall.

JONES, P., CLARKE-HILL, C., COMFORT, D., HILLIER, D. & SHEARS, P. 2005. Radio frequency identification and food retailing in the UK. *British Food Journal,* 107.

KESKILAMMI, M., SYDANHEIMO, L. & KIVIKOSKI, M. 2003. Radio frequency technology for automated manufacturing and logistics control. Part 1: Passive RFID systems and the effects of antenna parameters on operational distance. *International Journal of Advanced Manufacturing Technology,* 21**,** 769-774.

KHAN, M. A., SHARMA, M. & BRAHMANANDHA, P. R. FSM based Manchester encoder for UHF RFID tag emulator. Computing, Communication and Networking, 2008. ICCCn 2008. International Conference on, 2008. 1-6.

LEHPAMER, H. 2008. *RFID Design Principles,* MA 02062, Artech House, Inc. .

LI, S., VISICH, J. K., KHUMAWALA, B. M. & ZHANG, C. 2006. Radio frequency identification technology: applications, technical challenges and strategies. *Sensor Review,* 26.

LIN, C.-Y. & HO, Y.-H. 2009. RFID technology adoption and supply chain performance: an empirical study in China's logistics industry. *Supply Chain Management: An International Journal,* 14**,** 369-378.

MARTÍNEZ-SALA, A. S., EGEA-LÓPEZ, E., GARCÍA-SÁNCHEZ, F. & GARCÍA-HARO, J. 2009. Tracking of Returnable Packaging and Transport Units with active RFID in the grocery supply chain. *Computers in Industry,* 60**,** 161-171.

MATS, L., HAWRYLAK, P. J. & MICKLE, M. H. In-Situ characterization of passive rfid tag performance at absolute minimum power levels. Antennas and Propagation Society International Symposium, 2007 IEEE, 2007. 2741-2744.

MC CARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2009a. The effects of item composition, tag inlay design, reader antenna polarization, power and transponder orientation on the dynamic coupling efficiency of backscatter ultra-high frequency radio frequency identification. *Packaging Technology and Science,* In Press.

MC CARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2009b. The effects of item composition, tag inlay design, reader antenna polarization, power and transponder orientation on the dynamic coupling efficiency of backscatter ultra-high frequency radio frequency identification. *Packaging Technology and Science,* 22**,** 241-248.

MC CARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2009c. Impact of reader antenna polarisation, distance, inlay design, conveyor speed, tag location and orientation on the coupling of UHF RFID as applied to modified atmosphere packaged meat. *Computers and Electronics in Agriculture,* 69**,** 135-141.

MC CARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2009d. Permittivity of Meat Fish and their Components at UHF RFID Frequencies and Industry Relevant Temperatures. *Agricultural Engineering International: the CIGR Ejournal,* XI.

MC CARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2010. The effect of increased interrogation zone, reader antenna polarization and application factors in the performance of UHF RFID tag detection on modified atmosphere packaged meat. *Packaging Technology and Science,* 23**,** 339-350.

MEHRJERDI, Y. Z. 2010. Coupling RFID with supply chain to enhance productivity. *Business Strategy Series,* 11**,** 107-123.

MEYERS, M. 2007. *Mike Meyers' RFID+ Radio Frequency Identification Certification Passport,* New York,, McGraw-Hill.

MICHAEL, K. & MCCATHIE, L. The pros and cons of RFID in supply chain management. International Conference on Mobile Business, 2005. IEEE Computer Society.

MO, J. P. T., GAJZER, S., FANE, M., WIND, G., SNIOCH, T., LARNACH, K., SEITAM, D., SAITO, H., BROWN, S., WILSON, F. & LERIAS, G. 2009. Process integration for paperless delivery using EPC compliance technology. *Journal of Manufacturing Technology,* 20**,** 866-886.

MOHSEN, A. 2007. RFID: an enabler of supply chain operations. *Supply Chain Management: An International Journal,* 12**,** 249-257.

NAS 1994. Microwave Processing of Materials. Washington: The National Academies.

NGAI, E. & RIGGINS, F. 2008. RFID: Technology, applications, and impact on business operations. *International Journal of Production Economics,* 112**,** 507-509.

PARET, D. 2005. *RFID and Contlactless Smart Card Applications,* West Sussex, England, John Wiley & Sons, Ltd.

PENTTILÄ, K., KESKILAMMI, M., SYDÄNHEIMO, L. & KIVIKOSKI, M. 2005. Radio frequency technology for automated manufacturing and logistics control. Part 2: RFID antenna utilisation in industrial applications. *The International Journal of Advanced Manufacturing Technology,* 31**,** 116 - 124.

QIASI, L., LI, G., QING, L., GANG, Z. & JUNYU, W. A low-power dual-clock strategy for digital circuits of EPC Gen2 RFID tag. RFID, 2009 IEEE International Conference on, 2009. 7-14.

ROBERTS, C. M. 2006. Radio frequency identification (RFID). *Computers & Security,* 25**,** 18-26.

ROH, J. J., KUNNATHUR, A. & TARAFDAR, M. 2009. Classification of RFID adoption: An expected benefits approach. *Information & Management,* 46**,** 357-363.

ROUSSOS, G. & KOSTAKOS, V. 2009. Rfid in pervasive computing: State-of-the-art and outlook. *Pervasive and Mobile Computing,* 5**,** 110-131.

RUIZ-GARCIA, L. & LUNADE, L. 2010. Monitoring Cold Chain Logistics by Means of RFID. *In:* TURCU, C. (ed.) *Sustainab Radio Fequency Identiation Soltions.* INTECH.

SCHUSSLER, M., DAMM, C., MAASCH, M. & JAKOBY, R. Performance evaluation of left-handed delay lines for RFID backscatter applications. Microwave Symposium Digest, 2008 IEEE MTT-S International, 2008. 177-180.

SCHUSTER, E. W., ALLEN, S. J. & BROCK, D. L. 2007. *Global RFID The value of the EPCglobal Network for Supply Chain Management,* Berlin, Springer-Verlag.

SENNESET, G., FORAS, E. & FREMME, K. M. 2007. Challenges regarding implementation of electronic chain traceability. *British Food Journal,* 109**,** 805 - 818.

SINGH, S. P., MCCARTNEY, M., SINGH, J. & CLARKE, R. 2008. RFID research and testing for packages of apparel, consumer goods and fresh produce in the retail distribution environment. *Packaging Technology and Science,* 21**,** 91-102.

SODHI, M. S. & SON, B.-G. 2009. Supply-chain partnership performance. *Transportation Research Part E: Logistics and Transportation Review,* 45**,** 937-945.

STEWART, G. 1995. Supply chain performance benchmarking study reveals keys to supply chain excellence. *Logistics Information Management,* 8**,** 38-44.

SYDANHEIMOL, L., NUMMETLA, J., UKKONEN, L., MCVAY, J., HOORFAR, A. & KIVIKOSKIL, M. 2008. Characterization of Passive UHF RFID Tag Performance. *Antennas and Propagation Magazine, IEEE,* 50**,** 207-212.

TAJIMA, M. 2007. Strategic value of RFID in supply chain management. *Journal of Purchasing and Supply Management,* 13**,** 261-273.

TWIST, C. C. 2004. The impact of radio frequency identification on supply chain facilities. *Journal of Facilities Managemant,* 3**,** 226 - 239.

UKKONEN, L., SCHAFFRATH, M., ENGELS, D. W., SYDANHEIMO, L. & KIVIKOSKI, M. 2006. Operability of Folded Microstrip Patch-Type Tag Antenna in the UHF RFID Bands Within 865-928 MHz. *Antennas and Wireless Propagation Letters, IEEE,* 5**,** 414-417.

USTUNDAG, A. & TANYAS, M. 2009. The impacts of Radio Frequency Identification (RFID) technology on supply chain costs. *Transportation Research Part E: Logistics and Transportation Review,* 45**,** 29-38.

VIRTANEN, H., KESHVARI, J. & LAPPALAINEN, R. 2006. Interaction of radio frequency electromagnetic fields and passive metallic implants - A brief review. *Bioelectromagnetics,* 27**,** 431-439.

VISICH, J. K., LI, S., KHUMAWALA, B. M. & REYES, P. M. 2009. Empirical evidence of RFID impacts on supply chain performance. *International Journal of Operations & Production Management,* 29**,** 1290-1315.

WAMBA, S. F., LEFEBVRE, L. A., BENEDAVID, Y. & LEFEBVRE, E. 2008. Exploring the impact of RFID technology and the EPC network on mobile B2B eCommerce: A case study in the retail industry. *International Journal of Production Economics,* 112**,** 614-629.

WANT, R. 2006a. An introduction to RFID technology. *IEEE Pervasive Computing,* 5**,** 25-33.

WANT, R. 2006b. *RFID Explained: A Primer on Radio Frequency Identidication Technologies,* U S A Morgan & Claypool.

WHITE, A., JOHNSON, M. & WILSON, H. 2008. RFID in the supply chain: lessons from European early adopters. *International Journal of Physical Distribution & Logistics Management,* 38**,** 88 - 107.

WINDER, S. & CARR, J. 2002. *Newnes Radio and RF Engineering Pocket Book,* Oxford OX2 8DP, Newnes.

WU, N. C., NYSTROM, M. A., LIN, T. R. & YU, H. C. 2006. Challenges to global RFID adoption. *Technovation,* 26**,** 1317-1323.

YLINEN, J., KOSKELA, M., ISO-ANTTILA, L. & LOULA, P. Near Field Communication Network Services. Digital Society, 2009. ICDS '09. Third International Conference on, 2009. 89-93.

ZHOU, W. 2009. RFID and item-level information visibility. *European Journal of Operational Research,* 198**,** 252-258.

Carsten, R., 2008. EuroTRUSTAmI workshop : European R&D towards trusted Ambient Intelligence. In: R. Carsten, ed. Developing Ambient Intelligence. Paris: Springer Paris, pp. 180-239.

GS1, 2014. EPCglobal | Knowledge Centre | Standards Development | Standards | GS1 - The global language of business. [Online] Available at: http://www.gs1.org/gsmp/kc/epcglobal [Accessed 28 January 2014].

Hadim, S. & Mohamed, N., 2006. Middleware: middleware challenges and approaches for wireless sensor networks. Distributed Systems Online, IEEE, Volume 7, pp. 1-1.

Kefalakis, N., Leontiadis, N., Soldatos, J. & Donsez, D., 2009. Middleware Building Blocks for Architecting RFID Systems. Volume 13, pp. 325-336.