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RFID-Systems

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AUTOMATIC IDENTIFICATION MANUFACTURERS -- AIM

AIM (Automatic Identification Manufacturers), the trade association for the Automatic Identification and Data Collection (AIDC) industry, is *the* source for technically accurate, unbiased, commercial-free, and up-to-date information on all AIDC technologies including:

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Biometrics
Machine Vision
Magnetic Stripe
Optical Character Recognition
Optical Cards
Radio Frequency Identification
Radio Frequency Data Communications
Smart Cards
Touch Memory
Voice Recognition

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Our member companies represent a wide array of AIDC technologies either as manufacturers or as providers of equipment, systems, and services. A listing of AIM's worldwide membership is contained in the AIM International Yearbook and Buyers Guide, and on AIM's web site (http://www.aimglobal.org) in a searchable format. Many national affiliates also produce individual membership directories.

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13.56MHz RFID-Systems

1) Introduction

This paper has been written by the members of the AIM 13.56MHz Frequency Forum, a group of international RFID experts. Many of them are involved in standardisation and regulatory activities. It is the goal of this paper to describe the characteristics of 13.56MHzRFID systems and to give a high level summary about its technological capabilities and the regulatory framework.

For that reason it is a general summary and not a list of all existing products. Together with similar papers developed by AIM's Frequency Forums for all other frequencies considered for standardization by SC31/WG4 it will form a summary paper on the different RFID frequencies, their characteristics and their differences.

2) Operating Principle

Today the vast majority of 13.56MHz systems operate "passive", i.e. without the need of an integrated battery. This has positive implications on cost, life-time and the environmental situation. The basic operating principle of passive 13.56 MHz RFID systems is energy and data transmission using inductive coupling. This is exactly the same principle as used in transformers. An antenna of the reader generates a magnetic field, which induces a voltage in the coil of the tag and supplies the tag with energy. Data transmission from the reader to the tag is done by changing one parameter of the transmitting field (amplitude, frequency or phase).

The return transmission of the tag is done by changing the load of the field (amplitude and/or phase). In this context 13.56MHz and <135kHz use the same principle.

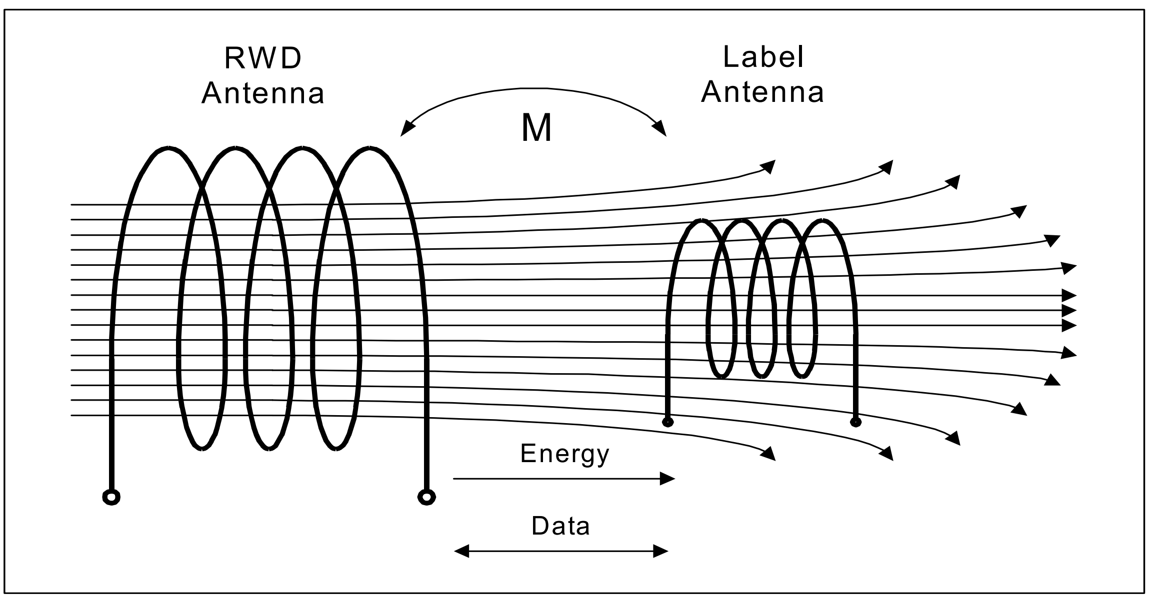


Figure 1 - Basic principle of inductive passive RFID systems

Differing from UHF systems and µW systems, the operating zone of passive (batteryless) inductive RFID systems (13.56MHz and also <135kHz) is in the "near field" of the reader transmission antenna, which results in achievable operating distances of approximately the diameter of the transmission antenna (for single antenna configurations).

For distances longer than this value the field strength decreases with the third exponent of the distance, which means that the required transmission power increases with the sixth exponent of the distance. Limitations are set by regulations.

The diagram below shows (as an example) the value of the normalised field strength in dependency of the distance for a transmitting antenna with a diameter of 0.8m.

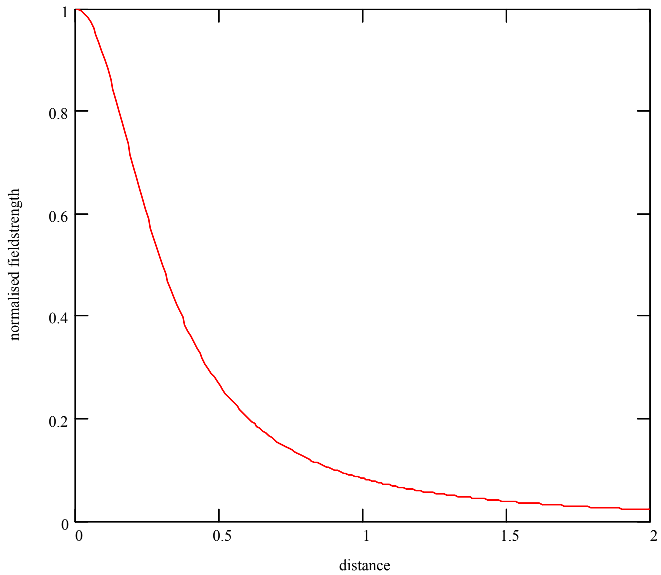


Figure 2 - Typical behaviour of the magnetic field strength versus distance (example)

Differing from UHF- and µW-systems, the RF field at 13.56 MHz is not absorbed by water or human tissue, which allows operation through water or human beings. The influence of water or moisture on the performance is negligible.

Due to shielding or reflection effects RFID systems are sensitive against metal parts in the operating zone. This applies more or less to all RFID systems, although the physical reasons are different.

As the magnetic field has vector characteristics, there exists an influence of tag orientation on performance (distance). The impact of this orientation-sensitiveness can be solved by the usage of more complex transmission antennas (for example by generating rotating fields). Thus it is possible to operate tags in a certain operating zone independently from their orientation.

Due to the fact that inductive RFID systems are operated in the near field (power decreases with 6^{th} order of distance), the disturbing influence of adjacent systems or external noise is much lower compared to UHF and µW systems (power level decreases as the square of the distance).

3) Typical Tags

Today 13.56MHz tags are available in many different shapes and with different functionality. Of course this has been influenced by applications and their requirements. The fact that a few turns (typically <10) of the tag antenna are sufficient to achieve a well-tuned tag is one of the recognized benefits to allow low cost tag production based on different antenna technologies.

Shape

Three main classes for 13.56MHz tags can be found:

- ISO cards: a world-wide application for 13.56MHz (ISO14443, ISO15693)
- Rigid industrial tags for logistical purposes
- Thin and flexible smart label RFID products (also disposable products)

The expectation is that all different types of tags will also be used in future. It is one of the benefits of 13.56MHz that many different shapes and sizes can be realised.

Functionality

- Memory size: typically from 64 bit (simple ID devices) to several Kbytes (used in multi-application smart cards)
- Memory types: factory programmed "read only" (typically ID purposes with small memory size), one time field programmable devices (OTP) and read/write tags (allowing to change data)
- Security: basically all required security levels can be realised (application dependent; today smart card applications (=money transfer) require the highest security levels)
- Multi-tag capability: solved and supported by most of the new products
- Special functions: different features implemented (depending on key applications)

4) Typical Reader/Writer Setup

Without any doubt the tag IC has a big influence on the performance of the final RFID system. However, a professional system integration (including antenna design) is of the same importance to make best use of RFID products. In designing the reader infrastructure special consideration has to be given to regulations (see section 5).

The "heart" of every reader/writer is an RF-module which takes care of the communication between tag and reader/writer. Differences are mainly given by the output power of this RF-module and by the sensitivity and the selectivity of its receiver. Typically two to three types can be found:

- RF module for "proximity" applications (up to approx. 100mm), especially used in handheld devices, printers and terminals. This functionality can also be integrated into one single reader IC, allowing small sized modules and cost reduction.
- RF module for "vicinity" (long range) applications (range limited by technology and regulations; today for leading 13.56MHz technology typically up to 1,5m, if a gate antenna and a credit card sized tag are used). Typically more complex than "proximity" modules, higher power consumption, more sophisticated receiver circuitry.
- sometimes a third class of "medium range" readers can be found (up to approx. 400mm range).

For the user a differentiation in terms of application is more appropriate. Many different reader/writer types can be found depending on the application requirements. There are portable devices (like hand held devices) and stationary devices (like printers, terminals, but also typical configurations with a longer operating distance like gates, tunnel readers and many other arrangements).

Stationary readers are installed along production lines to identify and track items. In some applications shielded or tunnel readers can be used to prevent from external perturbations. New requirements include gate readers as far as Electronic Article Surveillance is concerned for the retail industry and library type applications. As a complement in terms of system offer, label printers are therefore required to allow encoding of a tag inserted in a label at the point of issuance and hand held readers to check and update the tag memory content at any location in stock management applications.

Reader/writers can also allow the use of multiple antennas, eventually multiplexed to significantly enlarge the operating range and the coverage of a volume and or allow to read tags at all orientations.

Typical set-ups of reader/writers possibly include anti-collision protocols to allow multiple readings of tags simultaneously present in the field of the antenna. Performance of such reader/writers depending on site configuration and tag protocol allow the reading of 10 to 30 tags in one second. That corresponds to the successful reading of tagged items on a conveyor running at 3meters par second and spaced 0.10meter one from the other.

Driven by the requirements of smart label markets, many vendors already offer combined barcode- and RFID readers to allow operation of different AIDC front end technologies. For the RFID part, many devices also support more than one product (called multi-protocol reader). Based on tag products that are non-interferent with each other, this is a very important first step towards multi-sourcing of products, but it should not at all question the requirement for international standards to ensure real compatibility.

In this context all activities regarding conformance (driven by SC31/WG3) are a key success factor to achieve this goal.

5) Regulations

Compared to barcode the impact of regulations is much bigger for RFID. There are two areas that have to be considered:

a) Human safety (to protect people)

In the area of human safety compliance to the most important safety standards (world-wide) has been verified by leading manufacturers. This has been done for proximity as well as for vicinity systems operating at 13.56MHz, demonstrating that this frequency can be used without any doubts or reservations and provides a safe means of RFID application. In simple words, it has been shown, that current safety regulations do not reduce system performance as it is defined by today's radiation regulations (see b) and technology capabilities.

There are many standards in place, just to take two very important ones:

+ ANSI C95.1: SAR = 1.6W/kg (averaging 1g mass)

+ ICNIRP: SAR = 2.0W/kg (averaging 10g mass)

Worst case assumption: general public, exposure of head and trunk

SAR = Specific Absorption Rate (= basic restriction, i.e. the physiologically interesting parameter)

b) Radiation (to ensure proper use of the spectrum)

In general RFID technology does not yet face harmonised international regulations (as legislation is still an issue of the different local authorities). However, 13.56MHz is one of the most advanced frequencies in terms of this allocation and harmonisation process, thus offering global use under different environmental (e.g. noise level,..) and regulatory conditions. This is not the case for UHF and µW systems, which suffer from severe performance limitations (range) in Europe and Japan due to radiation limits. In practice such systems cannot be operated under reasonable (= solving requirements of key item management applications) conditions outside US.

This is a short summary of the regulatory situation for radiation limits at 13.56MHz:

<u>Carrier:</u>

+/-7kHz

Europe: 42dBµA/m in 10m

US (FCC): 10 000µV/m in 30m

Japan: 1W reader output power, antenna gain <= -30dBi

<u>Sidebands:</u>

Europe: 9dBµA/m in 10m (carrier +/- 150kHz)

US (FCC): 30µV/m in 30m

Japan: 500µV/m in 3m

Complex figures for the non RFID experts, this means that Japanese regulations are similar to the US ones, and both of them are (at the moment) more stringent than European ones. This allows to reach a higher communication speed (at the same distance) in Europe compared to US and Japan, but it does not prohibit long operating distances at 13.56MHz in US and Japan. In addition it is very likely that FCC regulations will be very similar to European ones within a period of approximately one to two years and that Japan will follow soon.

To summarise, 13.56MHz today offers global use with the prospect of a de facto harmonisation of the regulatory situation within a short time. This is one of the most important enablers for open product platforms as they are required in global applications.

6) Performance

“Performance” is a matter of application requirements. Thus “fit for purpose” is the goal. Whereas functional issues like memory size, security level can be selected according to application requirements, some other key parameters (range, communication reliability and communication speed) are subject to physical laws and therefore show some interdependency. Typically smaller operating distances allow higher operating speed (“proximity” systems operate at approx. 100kBaud and higher), whereas longest operating ranges can only be achieved with slower baud rates (25 to 70kBaud).

This has an impact on system integration and optimisation. However, there is evidence that 13.56MHz RFID systems can reliably achieve operating distances of approx. 1,5 m in “gate” applications or cover a “window” of 1x1m in a tunnel reader and solve the requirements of key item management applications in terms of data size and object movement. This figures are based on a tag of credit card size.

Performance is not only set by the regulations and the data speed, but also dependent on the sensitivity or robustness to noise. Because of the fact that the transponder data signal can be transmitted by a sub-carrier which operates outside the (noisy) ISM band, the system performance can be very stable compared for instance to <135kHz systems. Noise robustness and redundancy can also be enhanced by selective receivers and the fact that both sub-carriers can be processed independently in high performance systems.

This is meant to give an idea on the “performance window” of 13.56MHz RFID systems. Of course, finally “performance” depends on many factors and has to be optimised for any given application.

7) Summary

Internationally recognized as the preferred medium for RFID in contactless cards the 13.56MHz product platform has benefited from adoption by the leading silicon manufacturers in all parts of the world and is utilized in many tag and card forms. A broad base of tag/card manufacturers as well as reader companies and system integrators has been established. Based on this broad vendor platform and with almost 100 million contactless 13.56MHz cards sold so far, we can talk about a mature and industrialized technology.

The growth of the 13.56MHz market has benefited from a more open approach and the robustness of the frequency, anti collision protocols, and the rapid adoption of work in the international standards community.

Further development of 13.56MHz products in recent times including the advances in smart label production have led to increasingly widespread use of this frequency also in item management applications. Now 13.56MHz RFID systems have also demonstrated to be fit for purpose for many item management applications under current world-wide regulations.

In the supply chain community 13.56MHz products share significant portions of the fast expanding needs in the library field, carton marking, advanced shipping label and item level identification where the primary identifier, barcode, suffers from a line of sight problem.

In smart labels the principal vendors have achieved significant breakthroughs in recruiting and training a large number of the worldwide label convertors and this is now impacting the price point as volume grows thus fulfilling the need for a lower priced product without sacrificing competency.

There are many attempted applications but as yet the market would not be sufficiently mature to allow for an unequivocal statement of where 13.56MHz labels could maximize their opportunities but to date success has been achieved in the airline baggage sector, express parcels and high value / big ticket item management.

The vast resources of the principal vendors in all forms and types of 13.56MHz deliverable guarantee a stability of supply and continuing development that should satisfy the most discerning user.

400-1000 MHz UHF RFID-Systems

1) Introduction

This paper has been written by the members of the AIM UHF Frequency Forum, a group of international RFID experts. Many of them are involved in standardisation and regulatory activities. It is the goal of this paper to describe the characteristics of UHF RFID systems and to give a high level summary about its technological capabilities and the regulatory framework.

For that reason it is a general summary and not a list of all existing products. Together with similar papers developed by AIM's Frequency Forums for all other frequencies considered for standardization by SC31/WG4 it will form a summary paper on the different RFID frequencies, their characteristics and their differences.

2) Operating Principle

Radio Frequency Identification systems operating in the UHF frequency range make use of conventional electromagnetic wave propagation to communicate their data and commands, and in the case of battery-less tags also to power the RFID transponders. This is in contrast to low frequency RFID systems, which operate on the induction principle, much like a transformer.

In EM field systems, the interrogator (or reader) transmits an EM wave, which propagates outwards with a spherical wave front. Transponders placed within the field are immersed in this propagating wave and collect some of the energy as it passes. The amount of energy available at any particular point is related to the distance from the transmitter and may be expressed as $1/d^2$ where d is the distance from the transmitter.

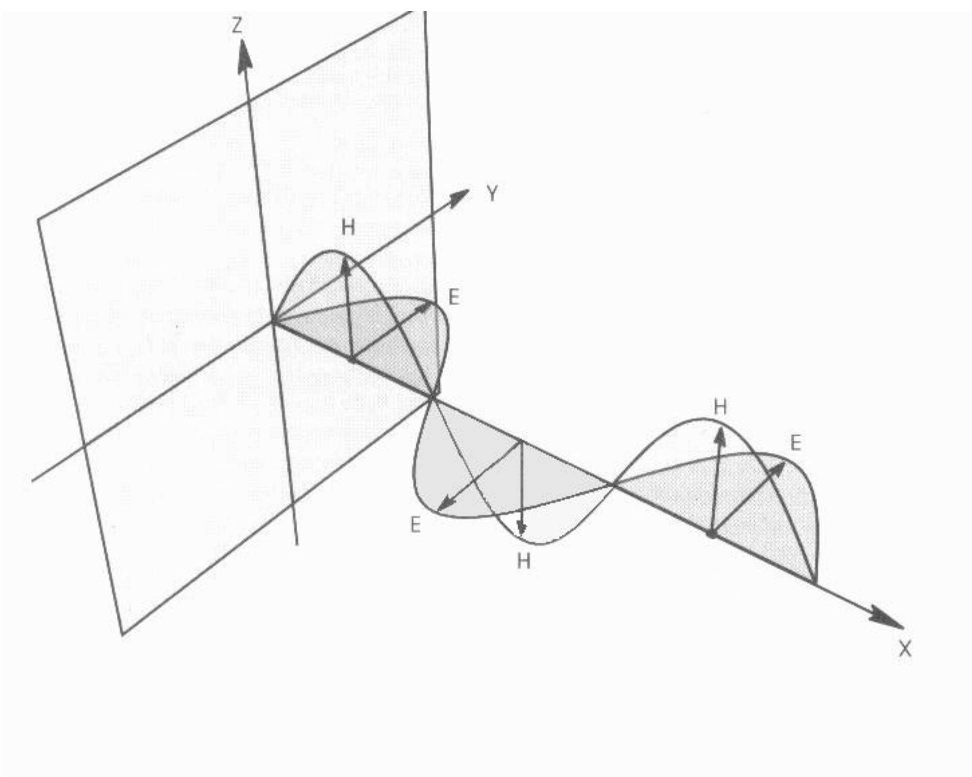


Figure 1 - Electromagnetic wave propagation- The electric "E" component is at right angles to, but in phase with the magnetic (H) component

EM energy propagates through the atmosphere or any other material by exciting electrons, which in turn reradiate energy at the same frequency which then excite nearby electrons which reradiate and so on.

Induction systems rely on the magnetic coupling between the interrogator and transponder and therefore the field strength of the transmitted signal drops at between $1/d^3$ and $1/d^4$ depending on the orientation of the tag to the reader transmitter loop.

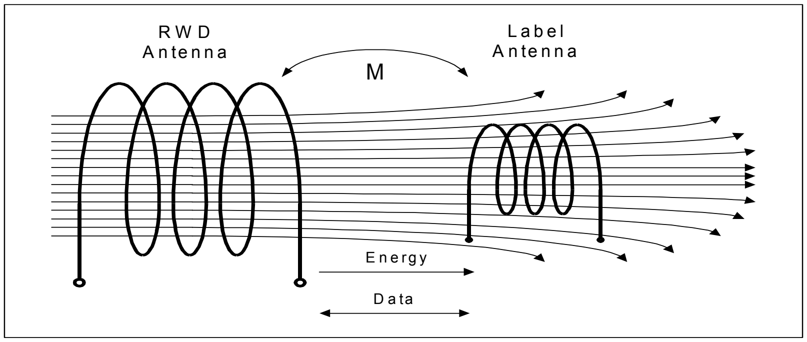


Figure 2 - Basic operating principle, induction technology (drawing by 1356 FF)

Passive tags need energy to power them, this energy is realized from the reader's transmit field.

Power density is not influenced by frequency, however, received power is dependent on antenna size which in turn is dependent on frequency.

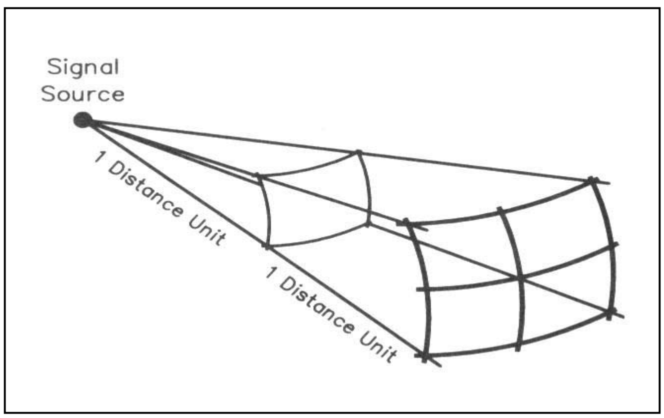


Figure 3 -

The amount of energy collected is a function of the aperture of the receiving antenna, which in simple terms is related to the wavelength of the received signal.

Consider for a moment a simple ½ wave-receiving antenna that is 0,5 meters long at 300MHz and 0,25 meters at 600MHz. The electrically active area around the antenna is roughly an ellipse in shape

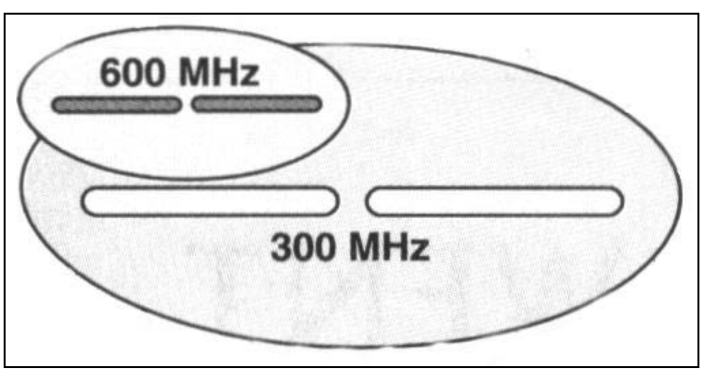


Figure 4 -

The area enclosed by the ellipse at 300 MHz is approximately 4 times the area enclosed at 600MHz. Therefore, at 300 MHz the effective energy collection area is four times that at 600 MHz.

The receiving antenna may be made physically smaller and still have the same aperture, but there are trade-offs to reducing the antenna size, such as reduced bandwidth and critical tuning. In practice, operating range is dependent on the radiated power of the reader, the operating frequency and the size of the tag antenna.

In order for passive RFID technology to be properly exploited, the reader must produce an adequate energy field to power tags at a usable distance. Under current radio regulations, enforced in much of Europe, radiated power is limited to 500mW erp, which translates to a read range of approximately 0.7 meters at 870 MHz. In the USA and Canada and some other countries, license free regulations permit a radiated power of 4-Watts erp which will yield a read range in the order of 2 meters. An RF output of 30-Watts erp under USA site license conditions will yield a read range in the order of 5.5 meters.

3) Typical Tags

4) Typical Reader/Writer Setup

5) Regulations

Until recently, frequencies in the UHF range were scarce almost everywhere except in North America. Australia and South Africa permit RFID and Europe's ERO DSI III working group has recommended the allocation of additional bands for RFID. These recommendations have been based on the USA model of a common shared band with FHSS as the basis for sharing and frequency re-use. The shift to UHF reduces the spectrum requirements as the propagation characteristics at 900MHz increases the ability to re-use frequencies.

a) Human safety (to protect people)

The safe limits of human exposure are a function of conducted power, antenna gain, exposure time and body mass. For most recommendations, the exposure is averaged over a 6-minute period at pulse duration times not exceeding 30µS.

Organization	Power Density W/m²	Averaging time In minutes	Peak Power Energy Density
ICNIRP	10	6	20mJ/m²<<30µs pulse
CENELEC ENV 50166-2	10	6	20mJ/m²<<30µs pulse
NRBP/UK	100	6	10mJ/m²<<30µs pulse

Calculation of protection distance.

Power density is a function of the conducted power into the antenna and the exposure area at a distance from the antenna.

As an example it can be calculated that for a worst case scenario with:

1. A conducted power of 1.25 W,
2. An effective duty cycle of 10%,
3. An antenna gain of 6 dB, and
4. An exposure limits of 10 W/m², or for a radiated power of 6 watts, that the protection distance would be 6.2 cm.

This distance would only be of relevance if a persons head or trunk was 6.2 cm away from the antenna for a continuous 6 minute period, RF interrogations are made during the full 6 minutes and the duty cycle is averaged over 6 minutes. In the event that the exposure time, or the duty cycle is less, the resultant required protection distance would be less.

However, the interrogation rate is dependent of the number of tags in the read area. A person present in this area would absorb RF energy in tissue. This, due to the reader not seeing the tags, will result in a reduced interrogation rate. A lower interrogation rate will reduce the duty cycle with a major reduction in the required protection distance. Conversely, for a higher duty cycle rate, the required protection distance would be increased.

It can therefore be seen that the required protection factor varies with radiated power and the duty cycle, which in turn is a function of the number of tags being interrogated.

b) Radiation (to ensure proper use of the spectrum)

Frequencies presently available or proposed for UHF RFID

Band	Region	Max. Power EIRP
433.05-434.79 MHz	Europe	25mW
865-868 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe
868-870 MHz	Europe	500mW* Still under consideration
870-875.4 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe
902-928Mhz	USA/Canada	50mV/m at 3 meters (Single freq. Systems)
	USA/Canada	4W using spread spectrum
	USA/Canada	30W FCC Part 90, LMS (3W conducted)
918-926MHz	Australia	1W all new equipment designs
915.3-915.6 MHz	South Africa	15W (5 Watt conducted)
915-921 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe

2.4-2.4835 GHz	Europe	25 mW
	Europe	500mW spread spectrum
	USA/Canada	50mV/m at 3 meters (Single freq. Systems)

6) Performance

• Absorption

When electromagnetic energy passes through any substance other than a vacuum, some of the energy is absorbed and is converted to heat. Attenuation of radio signals (by absorption) depends on the characteristics of the material through which the EM wave propagates. Absorption of energy is caused by some of the energy being dissipated in material that poses a resistance to the wave and being converted to heat.

• Reflection, Refraction And Diffraction

UHF EM waves are related to light and behave in a similar manner. They can be reflected off radio conductive reflective surfaces, they can be refracted as they pass across the barrier between dissimilar dielectric media or they can be diffracted around a sharp edge.

Whereas induction systems have a long wavelength relative to objects such as people, pallets, boxes etc, UHF waves have much shorter wavelengths and so are more prone to these phenomena. This phenomenon can be both a benefit and a disadvantage.

For an EM wave to pass through an aperture in a conductive object, its wavelength must be shorter than at least one dimension of the aperture. At 900 MHz the wavelength is 0.3 metres, therefore a 900 MHz system will read through a 1 meter.

• Reflection

EM waves can be reflected off any conductive or partially conductive surface, such as metal, water, concrete etc. Reflection can work for us by causing the waves to be reflected around objects that would normally act as a barrier to radio waves.

Reflection can also cause a problem in that should a direct wave meet at some point with an opposite phase reflected wave, a cancellation or null occurs at that point, resulting in a no-read situation. Should the waves reach the same point in phase, the signal strength is enhanced. The use of multiple antennae, easily configured at 900 MHz wavelengths, can reduce the effects of this problem. It should be noted that nulls are far more prevalent than enhancements

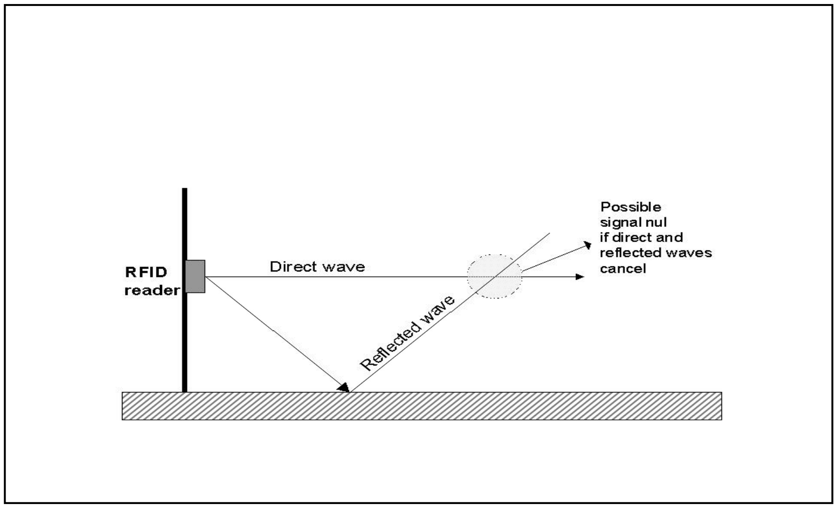


Figure 5 - The effects of multi-path signals

- **Refraction**

Refraction is caused by the change in velocity of an EM wave when it crosses a boundary between one propagating medium and another. If this crossing is at an angle, then one part of the wave front will change speed before the other so changing the direction of the wave.

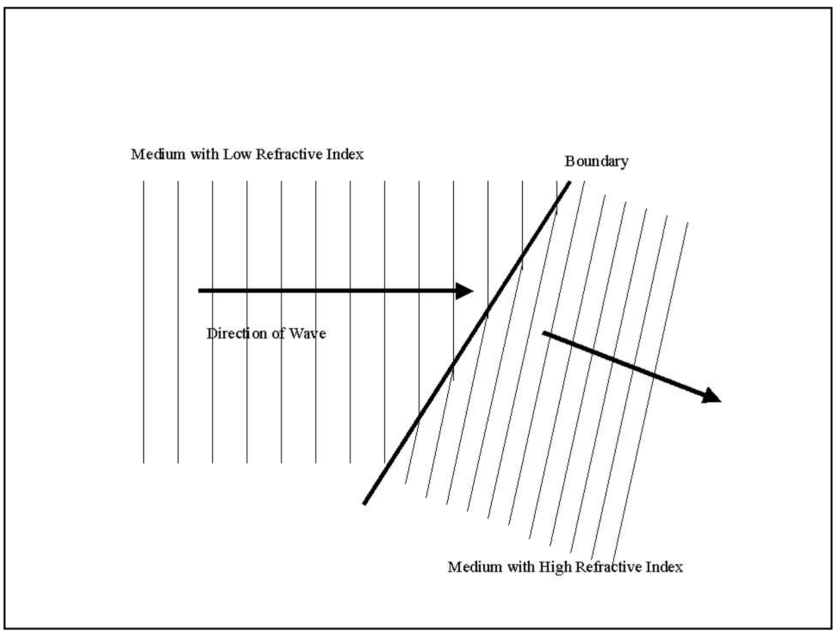


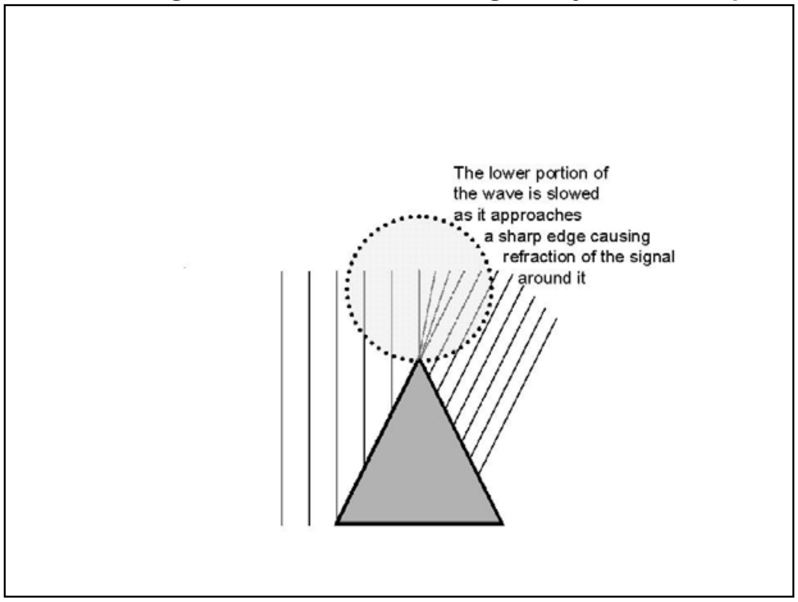
Figure 6 - Example of refracted wave

This may be illustrated by the apparent bending of a stick when partially immersed in a pond. The amount of bending is dependent on the ratio of the refractive indices of the two media. (Refractive index is the velocity of a wave in free space divided by its velocity in the medium).

- **Diffraction**

Diffraction of an EM wave occurs as it passes a sharp corner. The sharp edge (or knife-edge) slows a portion of the wave front thus allowing some of the energy to appear behind an otherwise solid object. At lower frequencies, typically within the medium to short wave frequencies, this effect is virtually non-existent with the angle increasing into the vhf and uhf bands. The higher the frequency, the greater the angle and consequentially the smaller the shadow

Figure 7 - Effect of knife edged object in wave path



- ## Penetration Into Liquids

Radio Waves will penetrate into different liquids depending on the electrical conductivity of the liquid. For example, water has a high electrical conductivity and will therefore tend to reflect and absorb EM energy, whereas oil and petroleum based liquids with low conductivity will allow EM energy to pass with relatively low levels of attenuation.

- ## Read Range

Read range is dependent on the transmitter power output and in the case of passive tags, on the energizing requirements of the tags. The effective read range would also depend on the absorption factor of the type of material to which the tag is affixed.

Tag size plays a major role in determining read range. The smaller the tag, the smaller the energy capture area, therefore the shorter the read range. Proper design of the system and optimization of reader power, antenna positioning and optimum tag placement will help to overcome many of these limitations.

- ## Interference

Electrical noise from motors, florescent lights etc is minimal at UHF frequencies. At the higher UHF frequencies(around 900MHz) there is very little electrical noise.

Of most concern is the effect of other RFID systems, mobile phones, ISM etc. Most of these sources of radio signals are relatively narrow band.

Frequency hopping spread spectrum. (FHSS) is one of the most effective ways to avoid the effects of interference and to avoid causing interference to other users of shared spectrum. This way the transmitted energy is distributed, reducing the potential for interfering with other systems, and because the receiver frequency is continually changing it avoids the effects of other users blocking the reader's receiver.

- **Directional Reading Capability**

The nature of UHF radio allows the use of relatively small directional antennas. This permits the reader beam to be directed towards a particular area and so selectively read a group of tags or discriminate against other tags. This directional capability has an additional benefit, in that it allows the reader to discriminate against potential interference from other readers or transmitter sources.

As much, as 20 to 30dB of discrimination is possible. (100 to 1000 times discrimination). High directivity may permit lower conducted power levels with a resultant reduction of the possibility of causing harmful interference as well as enhanced possibilities for frequency re-use.

- **Tag Orientation**

The orientation of the tag antenna with respect to the reader antenna will impact on the range. Linear polarization is normal with a simple antenna, such as a dipole or yagi. With linear polarization, the tag's antenna must be in the same orientation as the reader antenna to be able to receive maximum energy. It is possible and highly undesirable, for the polarization of reader and tag antennas to occur at right angles, with a resultant signal null occurring. If non-linear polarization of the reader antenna is used then it is not important which way the tag is oriented Circular polarization of the reader antenna, easy achievable at 900 MHz, allows any tag antenna orientation.

- **Benefits Of Longer Read Range**

Tag Talks First:

Works very well with longer read ranges to capture and record fast moving objects such as motor vehicles, cyclists, sporting event competitors, objects moving along conveyor belts, (baggage, parcels etc) There are a number of collision avoidance schemes which enhance the use of Tag Talks First

Reader Talks First:

Useful where there is a large volume of items where collision avoidance is required and unique identification of individual tags is needed. This system is most useful when tags are stationary or very slow moving.

7) Summary

2450 MHz RFID Systems

1) Introduction

This paper has been written by the members of the AIM 2450 MHz Frequency Forum, a group of international RFID experts. Many of them are involved in standardization and regulatory activities. It is the goal of this paper to describe the characteristics of 2450 MHz RFID systems and to give a high level summary about its technological capabilities and the regulatory framework. For that reason this paper is a general summary and not an exhaustive review of all existing products. Together with similar papers developed by AIM's Frequency Forums for all other frequencies considered for standardization by SC31/WG4, a summary paper will be developed on the different RFID frequencies, their characteristics and their differences.

2) Operating Principle

Microwave RFID systems have been in widespread use for over 10 years in transportation applications (rail car tracking, toll collection and vehicular access control).Systems operating in the UHF and microwave regions are divided between “active power” and “passive power” tags. Operational range and functionality can be extended with active power (a battery in the tag), and passive power provides extended life and lower costs. In the past, microwave RFID tags have been relatively complex and expensive because of the challenge of processing microwave signals with CMOS integrated circuits. This barrier to simplification of tag construction has been overcome, and the majority of present microwave RFID systems for article tracking use a single integrated circuit and passive power. This has positive implications on cost, life-time and the environmental situation. The basic operating principle of 2450 MHz RFID systems is energy and data transmission using propagating radio signals (“E” field transmission). This is exactly the same principle as used in long-range radio communication systems. An antenna of the reader generates a propagating radio wave, which is received by the antenna in the tag. A passive power tag converts the signal to DC voltage to supply the tag with energy. Data transmission from the reader to the tag is done by changing one parameter of the transmitting field (amplitude, frequency or phase).

The return transmission from the tag is accomplished by changing the load of the tag's antenna (amplitude and/or phase).In this context, the microwave, 13.56 MHz and <135 kHz systems use the same principle. For microwave RFID systems, this method is called modulated backscatter. Alternatively, a signal of different frequency can be generated, modulated, and transmitted to the reader. These later types of systems are referred to as using “active RF transmitter” tags.

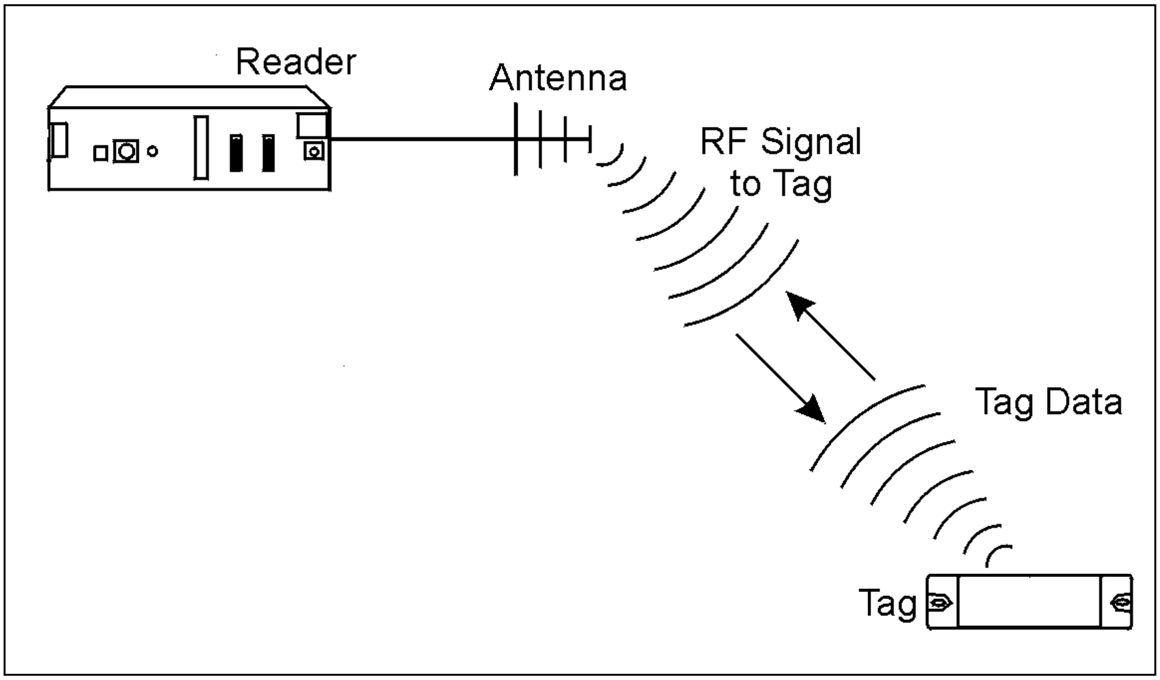


Figure 1 - Basic principle of microwave RFID systems

Differing from inductive RFID systems (13.56 MHz and also <135 kHz), UHF systems and microwave RFID systems operate in the “far field” of the reader transmission antenna. Achievable operating distances 0.5 to 12 meters is possible for passive power tags and beyond 30 meters for active power tags depending on microwave frequency, regional regulations, and antenna details (for single reader antenna configurations). Since the systems operate with the tags in the far field of the reader antennas, the field strength decreases with the first exponent of the distance, which means that the required transmission power increases with the second exponent of the distance. Limitations are set by regulations. As reference value and depending on the chip technology, power consumption and data rate used, a passive 2.45 GHz tag at 4 W erp yield some 0.5-1 meter range and active tags range approx. up to 15-20 meter.

UHF and microwave signals are attenuated and reflected by materials containing water or human tissue, and are reflected by metallic objects. Unlike inductive RFID systems, it is possible to design tags that work flat on metallic objects. Line of sight transmission is not required for operation. UHF and microwave signals easily penetrate wood, paper, cardboard, clothing, paint, dirt, and similar materials. Additionally, because of the short wavelength of the radio signal and reflective properties of metallic objects, reader systems can be designed to have high reliability reading in regions with a high metallic object content. As the propagating field has vector characteristics, there exists an influence of tag orientation on performance (distance). The impact of this orientation-sensitiveness can be solved by the usage of more complex transmission antennas (for example by generating rotating fields). Thus it is possible to operate tags in a certain operating zone independently from their orientation.

UHF and microwave systems are allocated many megahertz of spectrum in several operating bands. This allows higher data rates than the inductive systems and allows many systems to operate independently without interference within a small operating area. The immunity of UHF and microwave RFID systems to noise and interference is well proven by the many years of operation in revenue and tracking applications in the transportation industry.

3) Typical Tags

Today 2450 MHz tags are available in many different shapes and with different functionality, influenced by applications and the applications’ requirements. Unlike inductive RFID tags which require substantial surface area, many turns of wire, or magnetic core material to collect the magnetic field, UHF and microwave tags can be very small requiring length in only one dimension. Thus, in addition to longer range over the inductive systems, the UHF and microwave tags are easier to package and come in a wider variety of configurations. Tag lengths of 2 to 10 cm are typical. The tag's thickness is limited only by the thickness of the chip as the antenna can be fabricated on thin flexible materials. Since tags operating in the E field do not require antennas with extremely low impedances, inexpensive flexible antennas able to withstand considerable bending are achievable.

Shape

Two main classes for 2450 MHz tags can be found:

Rigid industrial tags for logistical purposes

Thin and flexible smart label RFID products (also disposable products)

The expectation is that all different types of tags will also be used in future. It is one of the benefits of 2450 MHz that many different shapes and sizes can be realized. An additional benefit for article tracking and supply chain applications is that UHF and microwave tags are widely used in the transportation function and thus a single reader system can read tags on rail cars, inter-modal containers, trucks, trailers and automobiles as well as parcels, packages, garments, pallets, boxes and the like.

Functionality

The memory size (as with all frequencies) is limited only by economics. A larger die with kilobits of data storage is possible but the chip size (cost) will increase accordingly. Typically memory size ranges from 64 bit (simple ID devices) to several Kbytes (used in data rich logistic applications)

Memory types: factory programmed "read only" (typically ID purposes with small memory size), one time field programmable devices (OTP) and read/write tags (permitting data to be changed)

Security: basically all required security levels can be realized (application dependent; today toll collection applications (=money transfer) require the highest security levels)

Multiple tags can be read within in the same capture zone.

Special functions: different features implemented (depending on key applications)

4) Typical Reader/Writer Setup

Without any doubt the tag IC has a big influence on the performance of the final RFID system. However, a professional system integration (including antenna design) is of the same importance to make best use of RFID products. In designing the reader infrastructure special consideration has to be given to regulations (see 5).

The "heart" of every reader/writer is an RF-module which takes care of the communication between tag and reader/writer. Differences are mainly given by the output power of this RF-module and by the sensitivity of its receiver. Typically two to three types can be found:

RF module for "proximity" applications (up to approx. 100 mm), especially used in printers and terminals. This functionality can also be integrated into one single reader IC, allowing small sized modules and cost reduction.

RF module for "vicinity" (long range) applications (range limited by technology and regulations, today for leading 2450 MHz technology typically more than 1.5 meters). Typically more complex than "proximity" modules, higher power consumption, more sophisticated receiver circuitry. Handheld devices can achieve longer ranges and use these type of modules. Additionally, some applications require ruggedized packaging and added functionality.

For the user a differentiation in terms of application is more appropriate. Many different reader/writer types can be found depending on the application requirements. There are portable devices (like handheld devices) and stationary devices (like printers, terminals), and also configurations like gates, tunnel readers, rail side, road side and many other arrangements that utilize the extended reading range capability of UHF and microwave RFID systems.

Stationary readers are installed along production lines to identify and track items and could be shielded like tunnel readers to prevent from external perturbations. New requirements include gate readers as far as Electronic Article Surveillance is concerned for the retail industry and library type applications. As a complement in terms of system offer, label printers are therefore required to allow encoding of a tag inserted in a label at issuance level and handheld readers to check and update the tag memory content at any location in stock management applications.

Reader/writers can also allow the use of multiple antennas, multiplexed to significantly enlarge the operating range and the coverage of a volume.

Typical set-ups of reader/writers include anti-collision protocols to allow multiple readings of tags simultaneously present in the field of the antenna. Such reader/writers can successfully read 20 to 50 tags in one second, depending on site configuration and tag protocol. UHF and microwave RFID systems are in use in very high-speed applications for trains and vehicles at speeds in excess of 400 kph.

Driven by the requirements of smart label markets, many vendors already offer combined barcode- and RFID readers to allow operation of different AIDC front-end technologies. For the RFID part, many devices also support more than one product (called multi-protocol reader). Based on tag products that are non-interfering with each other, this is a very important first step towards multi-sourcing of products, but it should not at all question the requirement for international standards to ensure real compatibility.

In this context all activities regarding conformance (driven by SC31/WG3) are a key success factor to achieve this goal.

5) Regulations

Compared to barcode the impact of regulations is much greater for RFID. There are two areas that have to be considered:

a) Human safety (to protect people)

In the area of human safety compliance to the most important safety standards (world-wide) has been verified by leading manufacturers. This has been done for UHF and microwave systems as well as proximity and vicinity systems operating at 13.56 MHz. RFID systems of all frequencies can be used without any doubts or reservations and provides a safe means of RFID application. In simple words, it has been demonstrated that current safety regulations do not reduce system performance as defined by today's radiation regulations (see b) and technology capabilities.

There are many standards in place. In the US, the standard ANSI C95.1-1991 was reaffirmed in 1997 and is presently undergoing revision. The latest standard is IEEE Std. C95.1, 1999 Edition that reaffirms and updates the ANSI standard and is summarised here. The standards have many facets, but the basic premise is that no effects occur at a specific absorption rate (SAR) level of 4 W/kg. A safety factor of 10 is provided for 'occupational environments' and 50 for the general public. The SAR is the rate at which energy is absorbed by the human body from electromagnetic waves. The standard covers all frequencies of interest for RFID.

The standards also list the strengths of the fields permitted at the various frequencies, derived from the allowed SAR values. The following table lists the limits for several frequencies of interest (using the occupational limits):

Frequency	Electric Field	Magnetic Field	Power Density
125 kHz	614 V/m	130 A/m	-
13.56 MHz	136 V/m	1.2 A/m	-
915 MHz	-	-	3 mW/cm^2
2450 MHz	-	-	8 mW/cm^2

In EUROPE, the EU Commission has issued on July 12thaCouncil Recommendation for the general public on the limitation on EM Fields and specified basic restrictions and reference levels. Either the reference levels OR the basic restrictions must be met.

The basic restrictions for localised SAR between 100 kHz and 10 GHz is 2 W/kg for 'head and trunk' and 4 Watt/kg for 'limbs'.

Reference Levels

Frequency (f)	**Electric Field (V/m)**	**Magnetic Field (A/m)**
3 – 150 kHz	87	5
0.15 – 1 MHz	87	0.73/f
1 - 10 MHz	$87/f^{1/2}$	0.73/f
10 – 400 MHz	28	0.073
400 – 2000 MHz	$1.375\ f^{1/2}$	$0.0037\ f^{1/2}$
2 – 300 GHz	61	0.16

b) Radiation (to ensure proper use of the spectrum)

In general RFID technology does not yet face harmonised international regulations (as legislation is still an issue of the different local authorities).However, 2450MHz is one of the most advanced frequencies in terms of this allocation and harmonisation process, thus offering global use under different environmental (e.g. noise level) and regulatory conditions. Operation is possible in the UHF and/or microwave regions world-wide. Operation is possible under both unlicensed and licensed conditions. At present, the power allowed in Europe is less than in the United States. There is recent activity in the standards bodies to achieve a level of harmonisation due to the longer range possible with UHF and microwave systems without interfering with other radio services. The wider bandwidths available at UHF and microwave frequencies also permit multiple channels and higher data rates.

This is a short summary of the regulatory situation for radiation limits at 2450 MHz:

United States:

FCC 15.247

Frequency : 902-928 MHz, 2400-2483.5 MHz, 5725-5850 MHz

Transmitter power : 1 W

Antenna gain : 6 dBi

Resulting EIRP maximum : +36 dBm

Communication protocol : spread spectrum, DSSS or FHSS

Licensing : unlicensed

FCC Sub Part M, 90.350-90.357

Frequency : 902-904, 909.75-921.25 MHz

Maximum EIRP : 30 W

Licensing : licensed

Europe:CEPT/ERC Rec. 70-03

Frequency 2400-2483MHz??	Maximum EIRP:	10 mWatt.
	Standard	I-ETS 300 440
Frequency 433.05 – 434.790 MHz, Duty cycle max 10%.		
	Maximum EIRP :	10 mWatt
	Standard	EN 300 220-1
Frequency : 2446-2454 MHz(for Railway applications only)		
	Maximum EIRP:	500 mWatt
	Standard	EN 300 761

Japan:

Standard	RCR STD1	RCR STD29	RCR STD33
License	yes	no	no

Frequency	2427-2471	2427-2471	2471-2497
Transmitter power	300mW 10mW	10mW/MHz	3 to 10 mW/MHz
Antenna gain	20 dBi	20 dBi	2.14 dBi

Japanese values:

ARIB STD-38 (Radio frequency-Exposure Protection ARIB Standard) Ver.1 was established on September 9, 1993 and it was revised for Ver.2 on October 26, 1999. The revised point is for a localised exposure for body. The basic restrictions for localised SAR between 100kHz to 3GHz is 2W/kg for 'general' and 4W/Kg for 'limbs and body surface'. The Electromagnetic field strength standard is not changed.

6) Performance

"Performance" is a matter of application requirements. Thus "fit for purpose" is the goal. Whereas functional issues like memory size, security level can be selected according to application requirements, some other key parameters (range, communication reliability and communication speed) are subject to physical laws and therefore show some interdependency. For active systems data transmission rates are not greatly influenced by operating range for UHF and microwave RFID systems, whereas for passive systems the low chip power consumption dictates lower data rates. Long range systems (greater than 15 meters) are operating at data rates up to 1 Mbit/s. Passive or active UHF and microwave article tagging RFID systems operate typically at data rates of 10 to 50 kbits/s. The symbol rate (the modulation frequencies) are higher since the user data is encoded.

Ranges of 0.5 to 5 meters from a single antenna are typical for passive power UHF and microwave RFID systems. The range of the UHF (915 MHz) systems are generally longer than the microwave systems (2450 MHz) because the wavelength is longer at the lower frequency, antennas collect more energy, and parasitic effects are less.

Compared to the low frequency inductive systems, the UHF and microwave systems can have longer range, higher data rates, smaller antennas, and more flexibility in form factors and antenna designs. On the other hand object penetration and reading range under no line-of-site conditions can be more robust with inductive systems. Date Rates with active UHF and Microwave systems are higher than inductive systems whereas with passive systems the difference might not be significant.

7) Summary

Since today's supply chains are global, it is essential that the devices used to identify and collect transaction data operate on a global scale to facilitate the international flow of goods. The selected Microwave frequency range of 2400 – 2483.5 MHz is the only practical and realistic place in the frequency spectrum where adequate bandwidth is available to accommodate multiple, unlicensed and unsynchronized systems. While UHF frequencies would provide greater range, these frequencies are not available on a world-wide basis.2450 MHz provides RFID solutions at comparable cost and complexity but greater range than inductively coupled counter parts providing ERP regulations are in the 4 Watt range.

Abbreviations:

CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal & Telecommunications Administrations
EIRP	Effective Isotropic Radiated Power
EM	Conference Europeenne des Postes et des Telecommunications
erp	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FHSS	Frequency hopping spread spectrum
HF	High Frequency
ICNIRP	International Commission on Non-Ionizing Radiation Protection
mW	milliWatt
NRPB/UK	National Radiological Protection Board/U.K.
RFID	Radio Frequency Identification
ss	Spread Spectrum
UHF	Ultra High Frequency
VHF	Very High Frequency

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