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RFID Applications for Sanitary Environments

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1. Introduction

Healthcare represents one of the most significant sectors where the diffusion of RFID technology is growing day by day. Many different applications have already been studied and developed, with both active and passive devices working at all the available operative frequencies.

Sanitary environments are nowadays extremely complex structures employing several thousands of people with very strict safety requirements: in emergency situations for example 5 minutes can make the difference for a patient between survive and die. RFID is especially indicated to be employed in these scenarios for two main reasons: first of all because it's a particularly reliable technology, with good performances, few errors and fast interaction, and secondly because, due to the presence of many different technological systems, ad-hoc solutions can be designed on the specific requirements of the application to be realized.

At present the most common RFID applications in healthcare can be divided into two main categories: the items tracking and the tracking and identification of people, patients and sanitary operators. The items tracking is performed in order to avoid the loss of expensive devices and to reduce wasting of time during assistance operations: systems studied and realized for this purpose cover all the range of RFID systems and provide different services according to their different performances. Passive systems are mainly thought for the tracking of large amounts of items, providing identification also to low value items, and are mainly based on gate structures. Active systems are designed for the tracking of big and expensive items and use long range antennas located at specific key points.

RFID systems for the identification of people probably represent the most interesting sector, due to the variety of different applications that can be studied and realized. The most common systems foresee the use of RFID for the tracking of sanitary operators or patients during their assistance operations: these solutions are very similar to the one described for the tracking of items and are already working in many structures around the world. Along with this many other applications have been implemented, including systems operating the unambiguous matching between the patient and his treatments (for example the medicine or the blood sack) or between the mother and the child in the paediatrics departments: these applications mainly foresee the use of passive technology, due to the lower costs, and ad-hoc items like electronic bracelets have already been realized and can be commonly found off the shelf. Finally the availability of a memory on the transponders fostered to the use of RFID technology also as a mean to promptly store and retrieve patient related information: for example electronic case history or electronic medical prescription applications have been studied and developed.

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The chapter is divided into five sections: in the first section we will describe the main characteristics of sanitary environments, focusing on scenarios where the use of RFID technology is mainly required.
In the second part we will describe some standard applications for the "items tracking" scenario. The applications described will include systems covering all the operative range, including both passive and active devices.
The third part will be focused on the applications for the people. All the scenarios described before will be analysed and different systems and solutions will be described.
In the fourth section we will discuss potential problems deriving from the introduction of a radio technology in an environment with sharp safety requirements, focusing on the possible interferences with other devices and on the law recommendations.
Finally, in the conclusions we will analyse the possible future applications and the potential improvements deriving from the refinement of the technology.
In Table 1 is shown a summary of RFID technology and its possible applications in healthcare scenarios (Supply Insight, 2006).

	APPLICATIONS	HEALTHCARE
Low Frequency (125-148kHz)	Mainly passive systems, Animal tracking, Access control	Applications with organic materials, Tracking of cadavers, Implantable Under-The-Skin tags
High Frequency (13.56MHz)	Mainly passive systems, Smart cards, Payment system, Tracking, Access Control	Access Control, Tracking of assets and patients, Smart Cabinets, Electronic Case Histories
Ultra High Frequency (300-1000MHz)	Passive and Active systems, Items and people tracking, Integration with sensors	Tracking applications, Monitoring of patients, Localization, Sensors systems
Microwave (2.4-5.8GHz)	Mainly active systems, applications also based on Wi-Fi, ZigBee, Localization and Tracking on large environments	Long Range Localization, Integration with Sensor Networks
Ultra Wide Band (3-10GHz)	New Technology, Emerging Tracking Applications	Pilot applications for the items and patient tracking

Table 1. RFID frequency bands and their applications

2. Sanitary environments and RFID

When we speak about sanitary environments we cover a wide range of different structures, with specific features deriving from their different functions and kinds of patients treated. Along with hospitals and Emergency Rooms under the term "Sanitary environments" have also to be included retirement houses, pharmacies and every other kind of structure where the patients assistance and care is the main goal.

All these kinds of structures present specific requirements and limitations according to the operations performed. While hospitals have many difficulties in the management of items and people, Emergency Rooms have to perform fast and safe assistance operations, retirement houses have to ensure the safety and the health of elderly people and pharmacies have to guarantee the proper medicine.

All these operations can be performed more efficiently introducing RFID systems, which can speed up all the operations enhancing the quality of the assistance operations. Moreover, RFID can improve the management of items reducing the losses and optimizing the operating expenses.

Currently killer RFID applications in the healthcare domain are (Datamonitor, 2004):

- Medication Administration: the right association between patient and medication achieved with RFID tags can reduce errors and speed up all the assistance operations;
- Medication authentication and restocking: medications have to be stocked and their expiration dates and quantities kept under control;
- Hospital equipment tracking: RFID can improve the management of inventories, keep trace of lent and lost items and ensure proper medical instruments handling, for example in operating rooms;
- Medical supplies tracking: medical supplies like surgical parts or pacemakers need not only to be tracked but also to be monitored. This means that RFID can become also a sensing structure, controlling parameters like temperature, localization or expiration date;
- Asset and substance tracking: sensible substances, like medical supplies, have not only to be tracked but in many cases also preserved in ideal humidity and temperature conditions, and RFID can become also a sensing platform;
- Medical waste tracking: medical waste is not the same business as common rubbish. RFID is used to ensure its correct storage and disposing;
- Patient tracking: RFID tags and wristbands are used not only for the tracking of patients inside the sanitary structures but also as devices to store vital information such as allergies, blood type or medications to be undertaken;
- Blood banking: one of the first applicative fields of RFID in healthcare has been the correct association between blood type and patient, in order to avoid errors and to optimize the managing of blood reserves;
- Lab and pathology sample tracking: next to blood, also other organic materials like serum or tissue can be tracked, performing also in this case monitoring operations
- Self-medication for seniors: RFID can improve the life conditions of elderly people helping them in common operations like medicine administration or first aid callings.

All these applications can be roughly divided in two main groups according to the nature of what has to be identified: in fact on one side we can find the tracking of items, from blood sacks, drugs, assets or medical waste while on the other side we find all the applications dealing with patients, from the simple tracking to most complex systems involving electronic medical prescription, electronic case history or applications focusing on t patient safety.

In any case, every time that a technological system has to be introduced in public environments many limitations appear, mainly due to electromagnetic compatibility requirements and space constrains. This fact is even more critical in sanitary environments for the following factors:

- The obvious limitations in electromagnetic emissions are even more severe due to the presence of children, elderly and infirm people;
- The presence of other electronic devices requires ad-hoc studies to verify the compatibility of the new systems with the existing technological infrastructure. This problem also involves wearable and inner devices from which in many cases the life of patients is directly dependant;
- Space constrains are even more strict and new devices introduced must be the less cumbersome possible avoiding to get in the way of stretchers or other sanitary equipments moved along corridors and rooms.

3. The tracking applications

3.1 Applications based on passive technology

While the common passive RFID systems work at Low (125-135kHz) or High (13.56MHz) Frequencies some examples of applications can be found also in the UHF (Ultra High Frequency – 860-930MHz) band and even in Ultra Wide Band systems.

Before moving to the description of the applications some consideration on the devices have to be made (Finkenzeller, 2003). First of all, the identification devices in passive tracking systems are obviously the common smart labels: passive systems present lower performances than active ones, but their cost is notably lower. This means that they are suitable for applications where huge quantities of items have to be identified. In this sense, the simpler is the transponder, the lower is its price. Anyway, some ad-hoc devices have been studied, mainly to be directly embedded at the moment of the fabrication in the item to be identified. The second consideration refers to the reading device. In most cases two different categories of devices can be employed: handheld devices or fixed structures. While handheld devices provide a short read range and require the operator to manually detect the transponder before reading it, with fixed structures transponders are automatically located and the information is read without the direct intervention of an operator. Finally, while handheld devices present quite the same shape even at different operative frequencies, fixed structures can vary a lot according to their operative frequency. In particular, Low Frequency and High Frequency gates are big devices whose positioning can be very difficult while at higher frequencies the different physical protocol forces to use smaller antennas with a lower impact on the surrounding environment.

Starting from the lower RFID band, 125kHz passive transponders have been used in applications where the item to be identified is made of organic materials. In fact this kind of materials present a high percentage of water, which is a partial insulator. In particular, pure water is an insulator, but the presence of other materials turns natural water into a partial conductor. Attenuation depends in inverse proportion from the frequency of the electromagnetic wave and transmissions in presence of water is possible only at low frequencies: for example all under-the-skin RFID tags work at Low Frequencies, from 125kHz to 135kHz.

While implantable tags present many legal limitations due to privacy violation risks and to possible health hazards deriving from electromagnetic emissions, thus limiting their use for patient identification purposes, some applications have been developed with low frequency used to track organic materials like human organs or body parts.

An interesting example comes from the United States, where The University of California's Anatomical Services Department uses this technology to track human cadavers (O'Connor

(a), 2009): an ISO 11784 or 11785 RFID transponder storing an alphanumeric identification code is sutured to every body and then read with handheld devices. When a specific part is removed form the body, for example a section or an organ, an additional transponder is issued, and then sutured to the body part or, when not possible, attached to the box where it is stored. With an ad-hoc software is then possible to create an electronic inventory with the real-time association of all the body parts with the original cadaver, with a substantial reduction in the operating times. A last consideration has to be made on what happens at the end of the usefulness of the specimen: due to the very low costs of the transponders it's more convenient to leave the tags on the cadavers when they are cremated than recollect them.

Moving to the High Frequency band many examples can be found of systems operating at 13.56MHz: this is in fact the most common operative frequency for passive systems, and many devices can be found on the market, with prices pretty low and a good level of reliability. Due to its vast diffusion several solutions have been studied, mainly for what concerns the readers:

- from the common handheld readers ad-hoc solutions for hospitals have been studied, with mobile computing platforms designed to be employed by doctors or sanitary operators, embedding HF readers;
- from fixed readers many different solutions have been studied, including smart cabinets and ad-hoc analysis devices, and new technical solutions have been tested to improve the performances for what concerns the accuracy of the readings and to reduce the environmental impact of bigger devices.

Examples of High Frequency applications can be found worldwide. Many hospitals use this technology to manage the storing of materials and assets in order to reduce the losses and the number of unused items. Transponders can be affixed on the items to be identified using adhesives, tie-wraps or mechanical hardware. They can be incorporated directly into the equipments and they can be designed to be used in presence of metallic materials. Once positioned, their identification number is stored inside an informative system. Then through ad-hoc devices like gate antennas, smart cabinets or simply handheld readers, every time that the item is moved through a structure, its new location is recorded and updated inside the database, speeding up the retrieval of a specific item and reducing the expenses for the materials. Obviously, next to the simple tracking many other operations can be performed, getting advantage of the memorization capabilities of the transponders.

An interesting system, covering different technical solution, has been set up at the Memorial Hospital, Chattanooga, Tennessee, where passive HF RFID is used to track high value items (Swedberg (a), 2009). In this structure every new item received is tagged, and the identification number is read with a desktop reader and then stored into a database with many other related information, like product type or expiration date in case of perishable materials. All these materials are then stored inside cabinets equipped with one RFID reader per shelf which, periodically, perform a reading of all the items stored in the cabinet. When an item is removed the reader notifies the missing item to a management system. Then, if the removed item is brought for example in an operating room the employees use a handheld reader to read the transponder and notify to the system the new location of the item. If an item remains in the "missing" state for a predetermined span of time an alert is generated, pointing out the lost item.

With a similar structure the University of Michigan Health System manages the storage of all the organic tissues (Swedberg (b), 2009). Each tissue is tagged with a Texas Instrument



Fig. 1. ad-hoc RFID devices (Smart cabinet and computing platform)

ISO 15693 tag, attached to the bottom of the box or to the plastic bag containing the tissue, then all the items are constantly checked by the readers embedded in the cabinets in which they are located. The cabinets are also equipped with a Low Frequency (125kHz) reader used to control the opening by the operators. The choice of a different operative frequency is mainly justified by the necessity to avoid interferences between the two systems.

The two systems described before foresee the use of short range readers: this means that both in the case of the handheld reader and in the case of the smart cabinet the identification of an item takes place only when it is positioned in a specific place (the cabinet) or when the operator brings the mobile reader close to the transponder. To perform effective tracking operations the localization and the identification of an item should be automatically made, and the only way to perform such an operation is to build a fixed wireless infrastructure covering all the environment where the items should be tracked or to provide all the doors between two adjacent rooms with gate structures identifying all the items crossing them. The short ranges achievable with passive HF systems don't allow the creation of a wireless infrastructure. Moreover, also the creation of efficient gate is extremely difficult: in fact common commercial HF gates provide reading ranges up to 1.60m which is evidently a range too short to cover common hospital doors which are usually up to 2m wide.

An alternative gate structure has nevertheless been realized providing a 2m reading range and, most important, reading transponders in all the orientation (Benelli et al., 2009). In fact it can be easy to enlarge the reading range of a system when transponders are put in the best coupling direction, but an efficient reading in all the orientation is very difficult to be achieved. The structure is made of 4 partially overlapped antennas and it uses, to widen the reading range, the mutual coupling phenomenon between all the antennas. Anyway, due to its dimensions, its introduction in crowded environments like hospitals can be quite difficult

and new solutions are being studied in order to reduce the dimensions keeping the same performance levels.
The HF band is the most common for passive systems, but some examples of applications can be also found at higher frequencies: in particular some systems operating in the UHF have been implemented, and applications working with the new Ultra Wide Band technology are also emerging.
For what concerns the UHF, smart cabinets similar to the ones described before have been realized, working with the same protocol: both items and operators are provided with a transponder, which is used to manage the supplies and to control the identity of the operators accessing to them. This ensures a cost effective optimization of the storages and provides higher efficiency for what concerns the times of assistance.
UHF technology is used also for the tracking operations and while by one side it has the big advantage of the small dimensions of the antennas, on the other side it presents some problems of electromagnetic compatibility. First of all at this band the interference created by the presence of different materials makes more difficult the reading of the tags and their positioning on different items. Moreover specific studies indicate that problems of interference with other biomedical devices may occur, making the introduction of such a kind of system in sanitary environments quite complex, requiring specific studies customized on the features of each environment.
Finally few words have to be spent on the Ultra Wide Band systems: passive tags have been developed to track the location of blood specimens in medical laboratories, with transmission frequencies of 5.8GHz and 6.7GHz (Swedberg (c), 2009). Next to good localization performances these devices present extremely low dimensions (around 2mm), making them suitable for a large range of other applications.



Fig. 2. UWB tags next to a tube for blood samples

3.2 Applications based on active technology

As in the case of passive RFID, active systems present many different operative frequencies, with different features and subsequent different possible applications. While the lower frequency bands (LF and HF) are used only by passive systems active healthcare applications operate at 433MHz, in the UHF band and up to 2.45 and 2.48GHz. Moreover

we can list as active RFID also systems realized with technologies like ZigBee or Wi-Fi performing however automatic identification.
Active technology is obviously more expensive than passive, and it's then more suitable for the tracking of high value items, whose amount is not too high. On the other side while costs are higher performances are significantly better, with reading ranges up to hundreds of meters and dimensions of the readers extremely reduced: the positioning of the devices doesn't require then specific interventions.
Active asset tracking systems exist at all the frequencies: active tags are located on valuable items and their position is constantly monitored with an adequate number of antennas covering all the surface of the structure. While most of this kind of systems is not of particular interest, due to its standard functioning, some words have to be spent of 2.45GHz Wi-Fi systems: the biggest advantage in using this technology derives from the fact that the readers can be the common Wi-Fi access points used for the wireless infrastructures that in many structures are already existing. Even if sometimes the number of access point to perform the localization of an item with a good approximation has to be increased (this kind of systems is able to localize an item with a precision around 4-5 meters), the chance to use an existing system can notably reduce the final realization expense.
Together with the tracking systems many other solutions, performing more complex operations, have been studied, in some cases also in combination with other technologies like Infrared (IR) or sensors.
Starting from the lower frequency (433MHz) an interesting example on how a common tracking system can be turned in something more useful comes from the El Paso County's 911, Texas, where 433MHz active tags are used with temperature-tracking sensors to control the temperature of the equipment rooms and the offices. In particular, a tag with a built-in sensor is positioned in all the most important rooms, while two readers are located on the two sides of the building, thus covering all the structure (the devices used provide a maximum 50m reading range depending on the type of antenna). Tags transmit the temperature associated with their ID number every minute to the readers, which turn them into an informative system analyzing the eventual overtaking of the thresholds. This kind of devices can be found also with other sensors: in particular the same producer also sells tags equipped with humidity sensors.
UHF is probably the most common solution for active RFID: many kinds of different applications can be found, even though some limitations in its use have already been underlined in the previous section. Sensor equipped tags have been studied to track and monitor blood sacks (Fraunhofer Institute for Integrated Circuits, Germany) (Wessel, 2009), joining this function with the right association between patient and blood, to track the temperatures of refrigerator and freezers (Wake Forest University Baptist Medical Center, USA) (Swedberg (d), 2009), joining it with tracking of assets. To improve the efficiency of the tracking systems RFID has also been integrated with the infrared technology: combining the two localization techniques the performances increase in a considerable way reducing the risk of errors.
At higher frequencies RFID tends to merge with other technologies: in particular 2.45GHz systems are, as described above, basically Wi-Fi systems, while 2.48GHz systems operate with the ISO 802.15.4 ZigBee protocol. Applications using Wi-Fi RFID for the tracking of assets are emerging day-by-day all around the world, with more complex systems adding sensing capabilities, due mainly to the presence of many companies offering efficient solutions for what concerns both the hardware and the software applications.



Fig. 3. Wi-Fi RFID reader and tag

ZigBee RFID systems are less common, but the features of the ZigBee protocol allow solutions not possible with the other technologies. First of all ZigBee allows mesh networking: ever node of the network (in this case every RFID tag) can receive and forward the data sent by other nodes. This means that the number of gateways (the RFID readers) can be significantly reduced, with a reduction of the total cost of the system (even though ZigBee nodes have higher costs than other active tags). Another important feature of ZigBee derives from the fact that this technology has been developed mainly for Wireless Sensor Networks. As a result, the introduction of additional sensors on the nodes is very simple and new functionalities can be easily added. Two examples of ZigBee systems can be found in the USA where the Advocate Good Samaritan Hospital, Downers Grove Illinois uses this technology to track surgical trays (Bachelor (a), 2009) and the Jackson Memorial Hospital, Miami, Florida uses it for the tracking of medical equipment (Bachelor (b), 2009). In the first case ad-hoc transponders have been designed able to withstand steam autoclave cycles and liquid sterilization methods: this means that, once localized, the trays can be sterilized without removing the tags and then being transferred to the surgical room. In the second case temperature sensors are also associated with some tags, monitoring not only the items position but also the environmental conditions of the rooms in which they are kept.

4. Patient centred applications

4.1 Applications based on passive technology

While the standard technical features of passive RFID don't change moving to applications focusing on the safety of patients, some new interesting devices have to be introduced before describing some applicative solutions. Some words have already been spent in describing the under-the-skin implantable tags: currently the use of this kind of devices is strongly discouraged mainly due to privacy concerns and electromagnetic compatibility hazards. Applications have been studied at prototypical level and functioning systems don't seem to exist in any area of the world. Moreover the number of producers of this kind of devices is extremely limited (only one company is offering such a commercial solution) and some local authorities around the world are presenting drafts of a law totally banning their use.



Fig. 4. Implantable Under-The-Skin RFID tag

Another interesting device especially realized for patient applications and with a vast diffusion is the RFID wristband: this is simply a plastic bracelet with an embedded passive tag (typically of small dimensions) to be read with a handheld reader. Several producers sell these devices and many applications have already been developed worldwide.

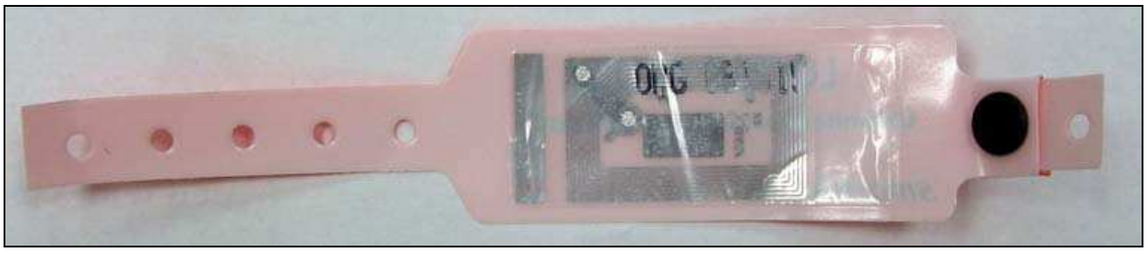


Fig. 5. Passive RFID wristband

While LF RFID is used mainly for access control, several interesting applications have been studied with HF and UHF technologies, with complex systems operating to improve the safety and the life conditions of patients, with a specific attention to patients affected by chronic diseases like for example Alzheimer disease.

Before moving to higher frequencies only an application using Low Frequency has to be cited, mainly for it peculiar use. Cambridge Temperature Concepts, a UK company, has realized a system using passive 125kHz transponders to help women to predict their ovulation cycles (O'Connor (b), 2009). The RFID transponder is used in combination with a basal temperature sensor: due to the fact that the body temperature of a woman increases of one-half to one degree Fahrenheit during the ovulation, this change can be used to predict the fertility periods. The module integrating the sensor and the tag is attached to the skin of the woman under the armpit through an adhesive module. Then through a handheld reader the temperature information is downloaded periodically and analyzed with an ad-hoc software predicting exactly the fertility periods.



Fig. 6. Tag and Reader of the ovulation prediction system

High Frequency wristbands are used in many applications. The Children Hospital "Vittore Buzzi" in Milano, Italy uses this technology to ensure the right association between mothers, newborn children and their case histories. Both mother and child are provided with a wristband and every time that mother and child meet their identity is checked comparing the identification codes of the tags. The same happens every time that a medicine is administered to the child. Similar applications are also used to ensure the right association between patients and blood sacks and between patient and medication.

The presence of a memory on transponders has also encouraged their use as electronic case histories or electronic prescriptions. Common passive transponders provide up to 4kBytes of memory: this space can be used to store vital information on the patient in order to avoid possible errors during the assistance operations. Through an ad-hoc codification of the information a big amount of data can be stored on a single transponder: presence of allergies and vaccines, blood types or personal data can be stored inside a smart card or a wristband and then retrieved and decoded with a handheld device like a PDA or an ad-hoc laptop like the ones already mentioned in section 3.1. Finally, an interesting application operating at 13.56MHz has to be described before moving to higher frequencies: RFID has been used by the New York Public Schools District 75 in Queens, USA, to help non verbal children to communicate through an ad-hoc reading device incorporating 5 readers put side by side (Swedberg (e), 2009). The child is then provided with a big quantity of ISO15693 smart cards with images corresponding to words printed on the front: when the child wants to "speak" he simply places the cards on the antennas and the required word is read by the device.

Finally, some applications operating in the UHF band also exist: in particular an interesting system has been set up in Shady Palms, Florida, USA. It's basically an assisted-living facility where some patients suffering from dementia are housed: in order to avoid their attempts to leave the structure a tracking system has been realized. While initial studies focused on the introduction of 125kHz transponders inside the soles of the shoes to be read with antennas buried underground, the final solution foresees the use of waterproof UHF EPC Gen2 tags sewn into the clothing. Readers have been mounted near the entrances and the exits of the structure and every time that a monitored patient crosses one of these doors an e-mail containing an alert is sent to an appropriate staff member.

4.2 Applications based on active technology

As in the case of items, active systems mainly operate at higher frequencies. Applications operating in the UHF band are very common while applications compliant with Wi-Fi technology perform the tracking of patients exactly in the same way as they track items. Anyway, an interesting application operates at the two unregulated frequencies of 262kHz and 318MHz (Bachelor (c), 2009. Swedberg (f), 2009): in this system, installed in two different structures in the USA, RFID bracelets are used to monitor the position of children, and to detect whether a tag is tampered of a child is taken away from the structure. The two frequencies are used to communicate with interrogators, located in doorways (262kHz) and with readers, deployed in hallways and other locations (318MHz). The receivers are mainly used to check the right functioning of the tags, while the interrogators generate an alarm every time that a tag comes close to a doorway.

Moving to higher frequencies some applications exist operating at the new ISO 18000-7 433MHz frequency, in combination with IR (Infrared): six hospitals in Alaska, Washington and Oregon (USA) are using this technology to track patient location and treatments, while the University of Miami-Jackson Health System Center for Patient Safety is studying a system to check the washing of hands by their operators. In the first application RFID badges are issued to the emergency patients to track their position throughout the facility (Swedberg (g), 2009). The combination of RFID and Infrared provides a long read range (RFID) and the location precision (IR). Every tag transmits a signal every 3 seconds but, if its position remains unchanged for a long time, it switches to dormant mode conserving the battery power. With a precise tracking of patient the assistance operations can be optimized, with a significant reduction of the times and with an increase in the quality of service. The second application is a little bit complex, with a checking software developed to control the performing of the hand washing (Swedberg (h), 2009): every staff member in the structure is provided with a hybrid RFID-IR tag. When the operator presses the hand-sanitizing dispenser containing soap a sensor embedded in the dispenser reads the tag number through IR signal. Then, through the RFID tag the badge number is transmitted to a reader linked to a PC, confirming the washing of the hands. The system measures the time elapsed from the moment of the washing: a reader positioned above a patient bed captures then the ID of the tag and if too much time has passed or if the washing has not been performed an alarm is generated.

As already underlined many patient tracking applications exist in the UHF band: in this kind of systems readers are usually located in strategic positions in the rooms of the structure, allowing a quite accurate localization of the patients (usually with a precision of 1-5m). These data are used by the operators of the structure to optimize the assistance operations but can also be shown, in the case of Emergency Rooms, to relatives in the waiting room through monitors following all the movements throughout the structure. An interesting application enhancing the services provided is the system developed at the Tan Tock Seng Hospital in Singapore (Friedlos, 2009), where RFID is not used only for the tracking of patients but also to monitor their health conditions. In particular, ad-hoc studied transponders operating at 868.4MHz can constantly read the body temperature of the patients, also monitoring their vital signs.

The last application described is the system Developed by the University of South Florida to diagnose early dementia through Ultra Wide Band RFID (O'Connor (c), 2009): analyzing the

movement patterns of patients it is possible to find clues indicating early stages of dementia. The tags used in this system emit radio pulses over multiple bands (from 6GHz to 8GHz) simultaneously. These signals can be transmitted for a much shorter duration of time, improving the reading rate and the final accuracy of the survey.



Fig. 7. RFID tag integrating a temperature sensor



Fig. 8. Active wristbands

5. Laws and regulations

RFID technologies must be compliant with European legislation, which is actually divided in two different levels:

- CEPT recommendations (the European regional organization dealing with postal and telecommunications issues);
- Directives of the European Commission, whose decisions are binding on E.U. member countries and their failure is subject to economic sanctions and legal procedures.

Each user has to verify that products are compliant with the laws. At low frequencies the density of the induced current in tissues must be monitored, while at high frequencies we have to refer to the specific absorption rate (Specific Absorption Rate - SAR), defined as the power density absorbed by human body per mass unit. These quantities depend on the intensity of electromagnetic field emitted from the device and on its position compared to the human body. There are different thresholds for general population and for hospital staff exposed to continuous emission of electromagnetic field.

Usually the compliance of RFID systems is certified following the EN50357-2001 standard procedures. This standard provides three distinct stages:

- Direct measures: they provide the measure of the amplitudes of the electromagnetic field near to the under-test device, without the presence of human bodies, at a distance indicated by the standard for different configurations. Only if averaged values on the volume occupied by the human body are needed, the standard indicates the geometry and position of measuring grids, that usually refer to the human head and torso.
- Measurements of compliance with the Basic Restrictions: it's required to take into account the spatial variation of the electromagnetic field and whether the exposure occurs in the near or far field zone. The electromagnetic field produced by the device can be measured on a grid or with electromagnetic simulation softwares. The induced density current (low frequency) or SAR (high frequency) must be evaluated and compared with the Basic Restrinctions.
- Numerical dosimetry: it's made on models of the human body. These models are obtained from three-dimensional images from Nuclear Magnetic Resonance or from pictures of human dissections. Then the incident electromagnetic field can be obtained as above, while the interaction with the model of the human body is finally calculated using the appropriate electromagnetic simulators. The parameters confronted with the Basic restrictions are still the induced current density (low frequency), and the SAR (for devices operating at high frequency).

For frequencies up to 13.56 MHz, the coupling between the reader and the tag is an inductive coupling, and is said the system works in near field conditions.

The frequency or the band (as in the case of the UHF), the transmission power and the maximum time for communication between tags and readers are the regulated parameters; in particular in this case the transmission power is represented by the maximum field strength (H-Field), which is expressed in dBμA/m (In the Fig. 9 we can see an example of the following ISM frequencies: 6.78MHz and 13.56MHz).

The recommendation CEPT ERC/REC 70-03 Annex 9 establishes the technical requirements and regulations for the use of harmonized of Short Range Devices (SRD) among the countries belonging to the CEPT.

For HF RFID CEPT ERC/REC 70-03 a.9 establishes:

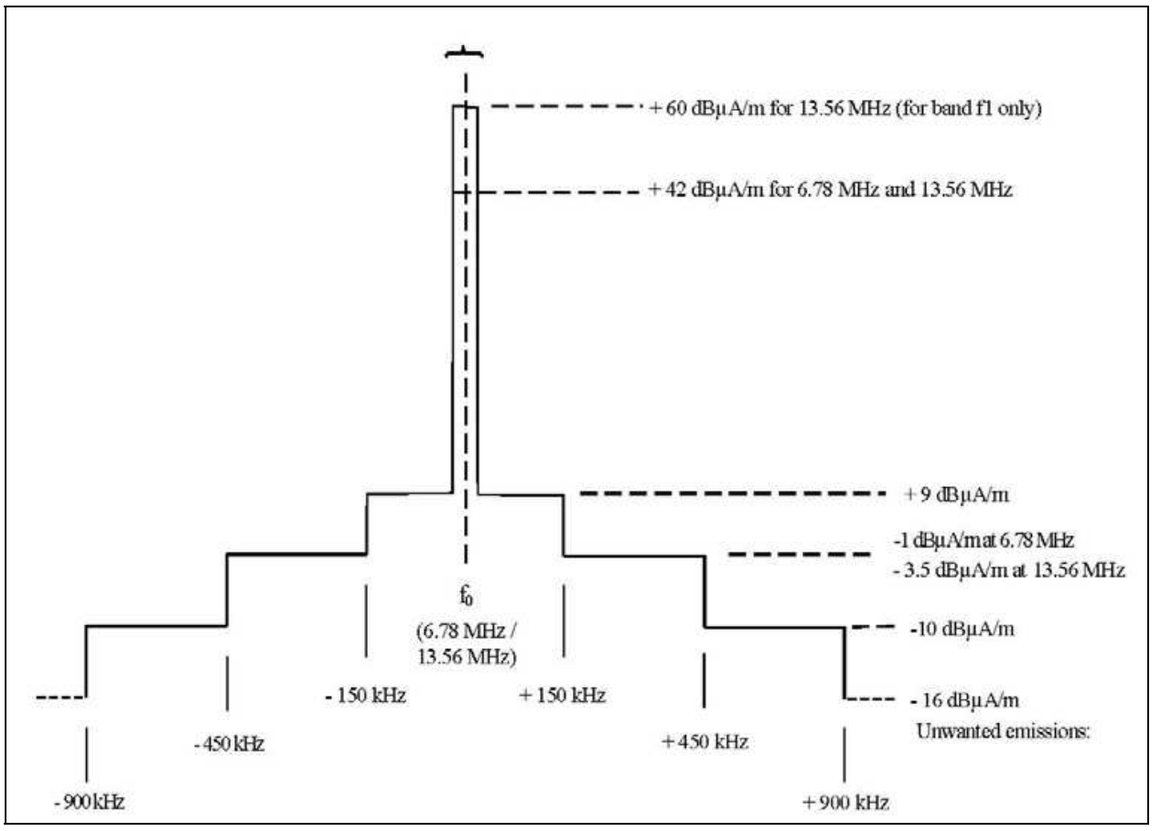


Fig. 9. ISM frequencies for 6.78MHz and 13.56MHz

- Frequency: 13.553-13.567MHz for RFID and EAS (Electronic Article Surveillanc only;
- Intensity of magnetic field: 60dBµA/m at 10m;
- Duty cycle: No Restriction;
- Channel spacing: No spacing.

RFID technology in the Healthcare is understudied yet, but in the June 2008 an issue of the Journal of the American Medical Association (JAMA), (Van Der Togt et al., 2008) reported results from a nonclinical study, completed in the Netherlands in May of 2006, demonstrating that active and passive radio frequency identification (RFID) systems can be manipulated to produce electromagnetic interference (EMI) with medical devices commonly used in hospital critical care units (e.g., infusion pumps, external pacemakers, defibrillators, monitors). The study was a non-clinical study, in fact no patients were involved, and the manner in which the tests were performed was not analogous to the way RFID systems are conventionally used in a modern hospital. Without a patient being connected, EMI by 2 RFID systems (active 125 kHz and passive 868 MHz) was assessed under controlled conditions during May 2006, in the proximity of 41 medical devices (in 17 categories, 22 different manufacturers) at the Academic Medical Centre, University of Amsterdam, Amsterdam, The Netherlands. In 123 EMI tests (3 per medical device), RFID induced 34 EMI incidents: 22 were classified as hazardous, 2 as significant, and 10 as light. The passive 868-MHz RFID signal induced a higher number of incidents (26 incidents in 41 EMI tests; 63%)

compared with the active 125-kHz RFID signal (8 incidents in 41 EMI tests; 20%); difference 44% (95% confidence interval, 27%-53%; P < .001). The passive 868-MHz RFID signal induced EMI in 26 medical devices, including 8 that were also affected by the active 125-kHz RFID signal (26 in 41 devices; 63%). The median distance between the RFID reader and the medical device in all EMI incidents was 30 cm (range, 0.1-600 cm). In a controlled nonclinical setting, RFID induced potentially hazardous incidents in medical devices.

Another study, in contrasts with the University of Amsterdam study, instead showed that UHF systems created no EMI when used with antenna positions and power settings that would be seen in a typical hospital setting. Implementation of RFID in the critical care environment should require on-site EMI tests and updates of international standards.

A key factor contributing to a wireless medical device's safety is the limited amount of RF spectrum available and potential competition among wireless technologies for the same spectrum. This is managed in different ways for different RF wireless communication technologies that may be available for use in healthcare communication and health informatics exchange.

6. Conclusion

The worldwide diffusion of RFID technology in the healthcare scenario is evidently an unstoppable process: new applications are emerging day-by-day, and new technical solutions provide the means to realize systems performing operations once unthinkable.

Among the technologies whose diffusion in the next years will probably modify many of the actual habits of common people one of the most important is without doubt Near Field Communication (Benelli et al. (b), 2009). NFC is a new short range communication system based on RFID technology. NFC systems can work like traditional RFID systems, where a master device reads some information from a slave device, but they can also set up a two-way communication between two items. In particular, NFC devices can be integrated on mobile phones, widely enhancing the intercommunication capabilities of the users. NFC phones integrate the functionalities of RFID tags and readers: this means that a phone can act as a smart card, with information stored inside its internal memory card and readable with an external reader even if the telephone is turned off. But this also means that a telephone can read the data stored in a common smart card, acting then as an handheld reader.

Evidently many of the applications described before could be transferred on such a device, turning it alternatively into an electronic case history or into personal assistant for doctors, able to read and write smart cards.

This and many other technologies will probably change in a considerable way all the technological infrastructure in sanitary environments, but estimations are very difficult to be made, because the evolution rate of technologies is so fast that probably tomorrow some new devices will appear, whose existence was just a dream only the day before.

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Sustainable Radio Frequency Identification Solutions

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Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

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