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RFId technologies for the hospital. How to choose the right one and plan the right solution?

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1. Introduction

RFId is an acronym for Radio Frequency Identification. Many different technologies are gathered under this abbreviation, each optimized for some particular tasks. Factories can take advantage of RFId for managing and optimizing their supply-chains, inspecting the content of a pack without actually opening it. Stores use RFId as a substitute to barcode labels because it works even without any lines of sight. Many offices and car parks use some RFId based solutions to allow the access for authorized people only. Recently, RFId technology has been used to implement fast and secure payment services, using disposable wristbands that stop functioning once removed from the wrist and cannot be put back together.

Besides military systems, the first spread use of RFId technology dates back to the late 1960s, when the first Electronic Article Surveillance (EAS) systems were implemented against shopliftings. They were based on simple transponders transmitting a single bit just to signal their presence.

We must wait for the 1990s to see some modern RFId equipments, thanks to the great miniaturization of the electronics and to the resulting reduced power requirements.

Nowadays, also the healthcare world is rapidly approaching to RFId, both for increasing the automation level and for reducing the overall clinical risk for patients. Following, a few examples.

Passive RFId tags are used on surgical tools to read the composition of a sterile surgical kit prior to start the operation.

RFId wristbands can be worn by patients for reducing identification errors and for tracking their therapies or treatments. If the wristbands are equipped with active RFId tags, the patient position inside the hospital can also be easily monitored and tracked: this is particularly useful to caregivers for managing children or patients with reduced cognitive functions.

Blood transfusion errors can be heavily reduced by using RFId in the blood supply chain: patients and bags of blood can be tagged to make sure every patient receives the right blood product.

Similarly, the pharmaceutical supply chain could take advantage of RFID technology both for replacing barcodes and for implementing single-dose delivery automated systems.

2. RFID technology

An RFID system is typically composed by at least two components: tag and reader. In the simplest functioning mode, when the reader “wakes up” the tag (forward link), this responds by transmitting its own unique ID code (reverse link). If the tag is passive, i.e. is not provided with a battery power, the reader itself must energize the tag. The communication between the reader and the tag can hence be only initiated by the reader.

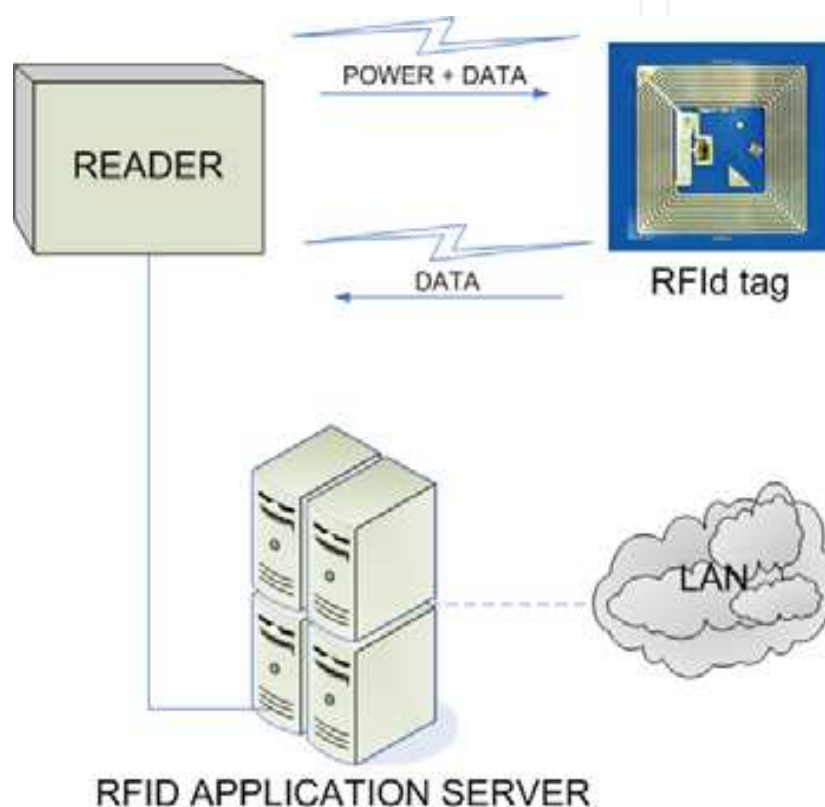


Fig. 1. A simple RFID system

A simple reader can be made by the following parts:

- *rx/tx antenna*
- *modulator*, used to query or to transfer data to the tag
- *demodulator*, to decode the received data
- *control unit*, a microcontroller used to manage the link with the tag and to transfer the read data to some external devices like a PC
- *power adaptor or battery*

The tag, or transponder, incorporates at least the following four components:

- *antenna*, used both to receive the power by the reader (if the tag is not provided with a battery) and to exchange data with the reader

- *microchip*, that is used to manage the data link implementing the desired protocol, frequency and modulation.
- *memory* (sometimes internal to the microchip)
- *package*, that keeps together and protects all the components; this part can be very variant depending on the intended use of the tag (labels, wristbands, glass cylinders, etc.)

The tag types are usually classified basing upon their powering modes: passive, semi-passive and active tags.

2.1 Passive tags

Passive tags are fed directly by the reader. This can be achieved by using an inductive coupling (LF or HF) or even a backscatter coupling (UHF).

In the first case, both the reader and the tag are provided with coil antennas. The inductive coupling between the two antennas, assimilable to the primary and the secondary coils in an electric transformer, transfers energy to the tag for the operation of the microchip. This can happen if the two devices are close enough: the tag must be within 0.16λ meters from the reader's antenna in order to be in the near field region. Typical frequencies used are 13.56 MHz and 135KHz, hence the wavelengths are much greater than the distance between the reader's coil antenna and the tag (22.109 m for 13.56 MHz; 2220.7 m for 135 KHz systems). Therefore the electro-magnetic field may be treated as a simple magnetic alternating field.

An alternate voltage is generated by induction in the tag's coil antenna leadings, and is then rectified by means of a simple diode and used to power up to the microchip. The antenna coil inductance is used, together with a capacitor connected in parallel, to obtain an LC parallel resonant circuit. The resonant frequency is chosen same as the reader's transmission frequency.

The reverse link communication is obtained modulating the voltage of the tag's antenna by switching on and off a load resistance with a very high frequency f_s (*load modulation*). These controlled variations create two spectral lines at a distance of $\pm f_s$ around the transmission frequency of the reader and are reflected as an amplitude modulation of the *subcarrier* f_s to the "primary coil" on the reader. This method can be used to send back data from the transponder to the reader. [www.rfid-handbook.com]

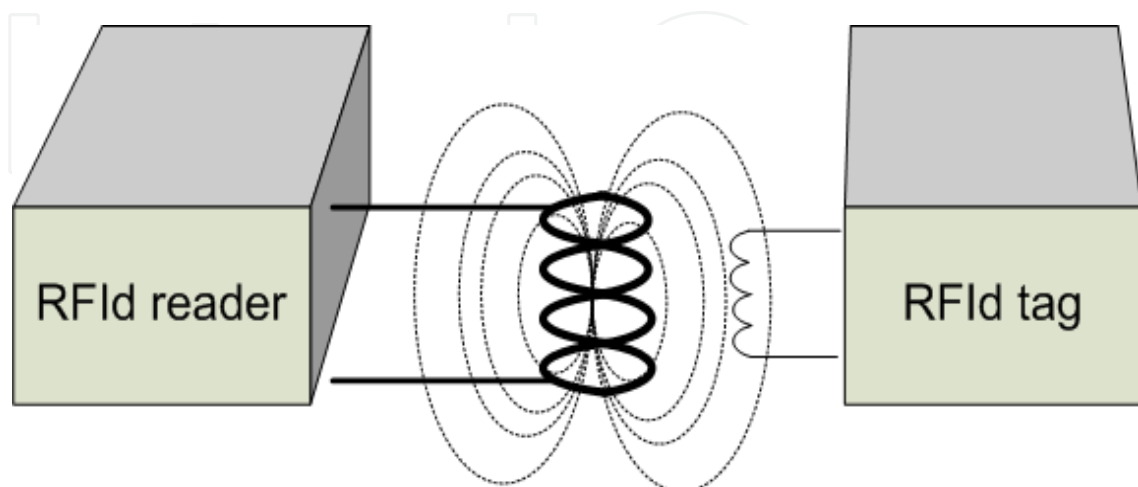


Fig. 2. Inductive coupling (LF and HF)

UHF passive RFID systems use dipole antennas both on the tag and on the reader. The typical work frequencies are 868MHz (EU), 915MHz (US) and above (microwave). Since the higher is the frequency the smaller is the wavelength, these system make it simple to design smaller antennas. These are called long-range systems since the distance between the reader and the tag can be greater than 1m. The tag is fed by the reader using electromagnetic coupling.

A backscattering phenomenon is used to allow the tag to perform the reverse link. Here is how it works: a fraction of the power that comes from the reader is reflected by the transponder dipole antenna back to the reader depending on the tag's antenna reflection *cross-section*. This characteristic parameter can be altered by switching on and off a load resistor connected in parallel to the transponder antenna. You can take advantage of this phenomenon to transmit data from the tag to the reader by modulating the power fraction reflected back.

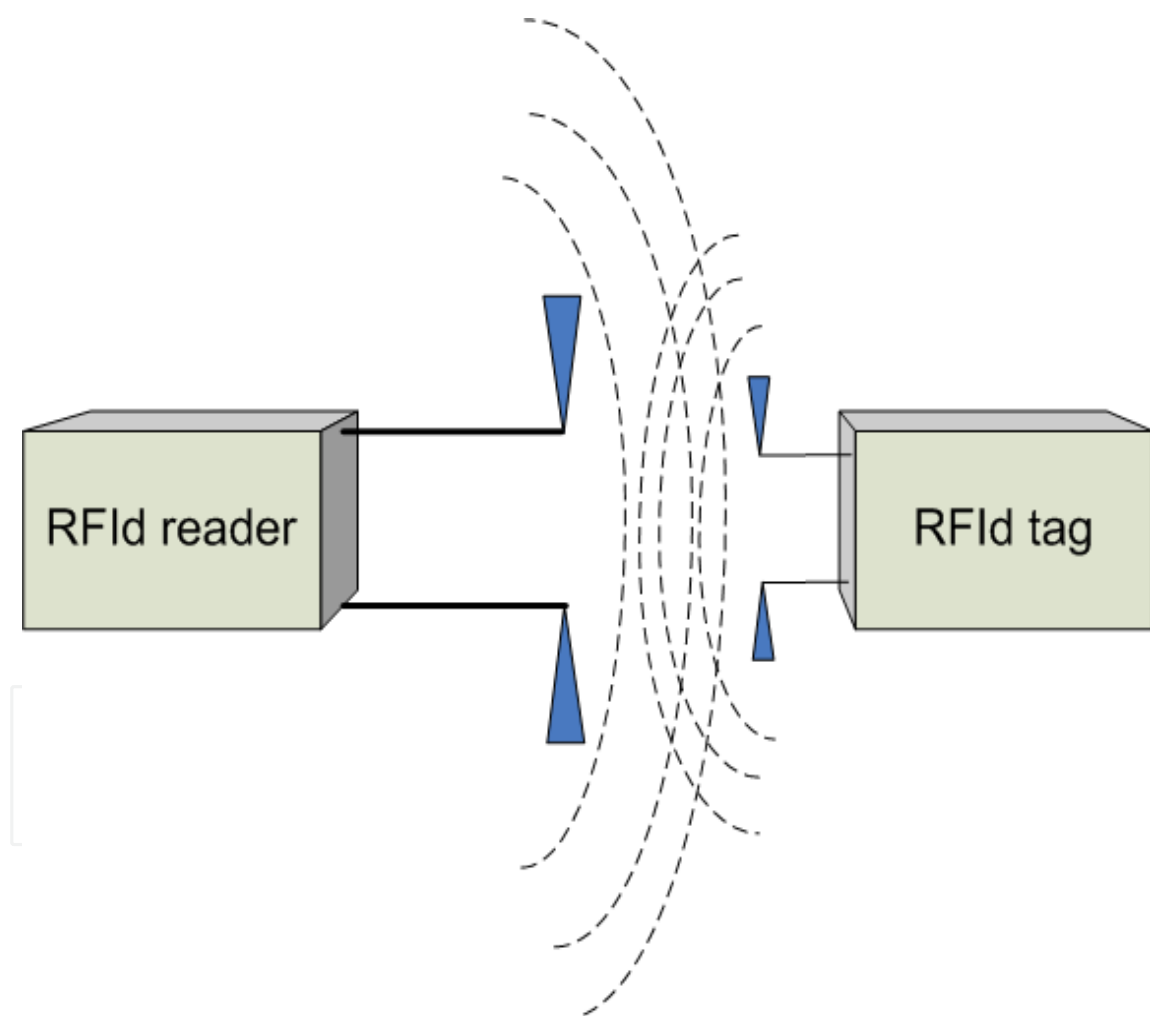


Fig. 3. Backscattering coupling (UHF)

2.2 Semi-passive tags

These tags are in all similar to passive ones, but are provided with an onboard battery used for feeding some sensors (accelerometers, temperature sensors, pressure sensors, etc.). Anyway, the battery is not used to feed the tag microchip or antenna; this means that these transponders cannot start a communication autonomously. The reliability is of course affected by the presence of the battery itself.

2.3 Active tags

An RFID tag is called “active” when it is equipped with a battery, to be used to feed the tag's microchip and antenna and also as a source of power for onboard sensors. These tags are proper transceivers, therefore they are able to start a transmission even if not queried by any readers.

Some typical work frequencies are 433MHz, 868MHz, 915MHz, 2.45GHz and 5.8GHz. The higher bandwidth gives you the chance to implement a real complete communication system.

The maximum communication distance can reach tens or even hundreds of meters, according to the work frequency used and to the output power (according to national regulations).

Active RFID technology gives you the opportunity to implement a real tracking system, provided that the tag's spatial position can be calculated using some RTLS (Real Time Location System) algorithm or some other source of spatial information.

The main drawbacks are the transponder end user price, tens of times higher if compared to passive tags, the increased size and weight, and the necessity for maintenance.

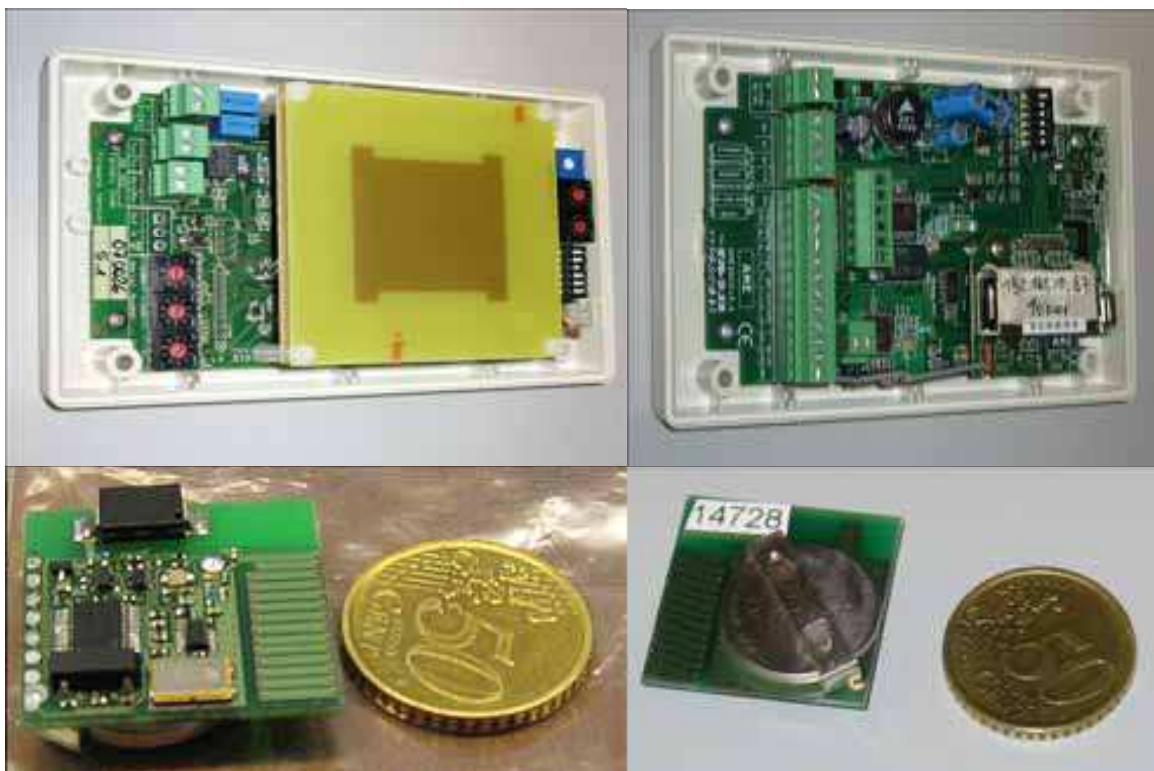


Fig. 4. Active RFID system (courtesy of AME, www.ameol.it)

2.4 UWB (Ultra Wide Band)

UWB (Ultra Wide Band) is a technique that makes use of a broad frequency range (3,1 GHz - 10,6 GHz). This is often obtained by using radiofrequency impulses with a very low time duration, few tens of picoseconds, that translates in a very wide spectrum. Also, since the time-pulse is so short, the UWB is slightly sensible to interferences caused by wave reflections. The energy needed to generate such narrow time-pulses is very low: this is a great plus of this technology because it can at once save the tag's battery life and generate few electromagnetic interferences.

All this makes UWB very good for use in "noisy" environments like factories or hospitals. This technology has been widely used in military field, in the last 20 years for telecommunications and geolocalization. After 2004 US government has allowed the use of UWB for civil scopes.

UWB can show its potential in healthcare applications, because of the following issues:

- the short duration of time pulses reduces the possible interferences due to reflected signals, since such a short signal is correctly received and processed before any mirrored out-of-phase signals can be;
- tag battery life is preserved since tag's total power consumption (Tx+Rx) is reduced down to 1 mW;
- reduced or no interferences at all with other narrow band communications in the same range (3,1 GHz - 10,6 GHz);
- if combined to recent powerful Real Time Location System algorithms (RTLS), UWB allows for very good performances in locating assets, patients or personnel, in terms of precision and accuracy;
- high data rates
- high insensitivity to obstacles, fluids and metals if compared to other narrow band active RFID systems
- simplified tag circuitry, compared to narrow band RFIDs: pure digital signals can be generated and transmitted by UWB transponders without having any DAC/ADC onboard or any analog modulators/demodulators.

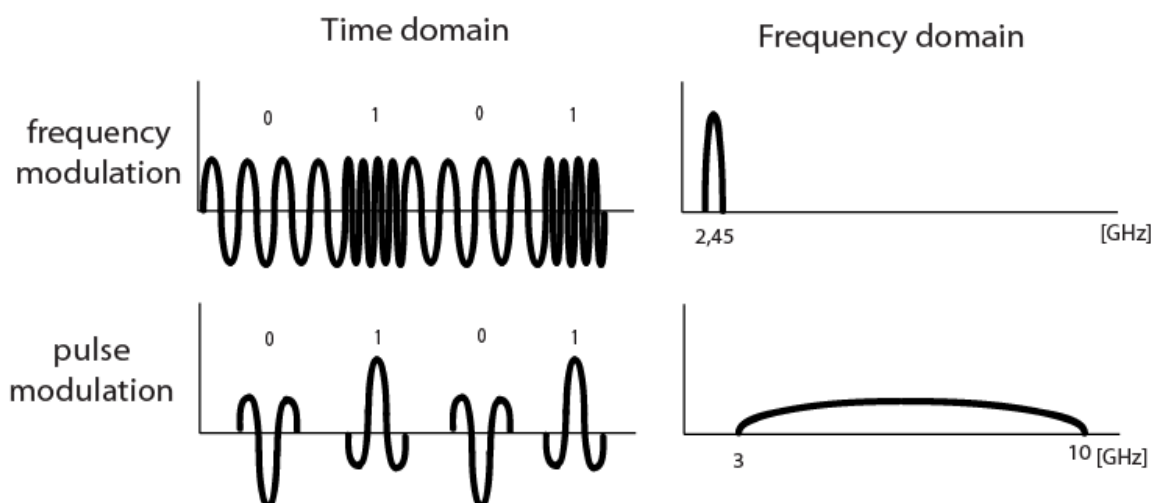


Fig. 5. Narrowband vs UWB functioning principles

3. Applications of RFId in healthcare

This paragraph summarizes some applications of RFId to healthcare. The listed experiences are an abstract of the investigation performed by the author together with Dr. Roberto Bonaiuti, former member of his research team.

3.1 Drugs management

RFId technologies, alone or combined with others like barcodes, are used for the automation of the drugs management process. Many steps can be managed: drugs production and packaging inside the factories, deliveries to the hospital pharmacy, automation of the pharmacy storage and retrieval, patient's bedside therapy preparation and tracking.

The Ospedale "G.B.Morgagni-L.Pierantoni" di Forlì is an Italian public owned hospital (Azienda Unità Sanitaria Locale di Forlì, Servizio Sanitario Regionale Emilia-Romagna) counting about 550 beds. It has been equipped with a Pillpick system by Swisslog (www.swisslog.com).

The solution consists of an automated management of the pharmacy, combined with an interface to the prescription software (CPOE - Computerized physician order entry) and to the Hospital Information System and an unit dose process in the wards. The drugs are placed in holders tagged with RFId and managed using an automated robot. The data recorded in the tag are about operator, drug type and posology, drug's expiring date and more. These data are read by nurses at the bedside using handheld passive RFId readers; then this data are coupled with patient's ID using barcode wristbands. (Bianchi, 2008)

3.2 Tracking of biopsic specimens

The Mayo Clinic (www.mayoclinic.com Rochester, MN, USA) uses passive RFId tags to track biological gastrointestinal tissue specimens, from their collection in one building to the pathology laboratory in another.

The system has been developed by 3M (http://solutions.3m.com/en_US/). It uses ISO 18000-3 compliant passive RFId tags operating at 13,56MHz attached to the sample holders. Each tag's unique ID is linked to patient's data from the EPR in the HIS central database. These data also include the sample coded description coming from a surgical database. (Bacheldor, 2007 a)

3.3 Tracking of blood bags for transfusion

Blood bags for transfusion are an important field of application for RFId in healthcare. In fact blood, plasma and blood products are stored at low temperatures for cryopreservation. This causes ice on the bag's surface. Therefore optical based identification technologies like barcodes are useless for this scope.

The hospital of Saarbrücken (Germany) uses RFId to track blood bags, record transfusions and perform a matching of patients and blood bags. Patients are provided with a passive RFId wristband. Blood bags are tagged with self-adhesive passive RFId labels operating at 13,56MHz. The labels are equipped with a 2KB memory to store an unique ID and some informations about the blood composition.

Both these tags are read using an handheld PDA equipped with a passive RFId reader. The data matching is then verified by a central software. Hence, the operator is able to verify the

correct coupling between patient and blood bag, thus reducing significantly the occurrence of errors. (Wessel, 2006)

3.4 Asset tracking

The Harmon Medical Center (Las Vegas, NV, USA) uses an asset localization solution developed by Exavera Technologies (www.exavera.com).

The system makes use of active RFID tags and readers operating at 915MHz frequency. A custom software lets you locate the assets using a cartographical map.

Every room is equipped with active readers that locate the assets and send their ID to the central software via LAN. These data are then linked to the information coming from the clinical engineering department like datasheets and maintenance operations performed. (Bacheldor, 2007 b)

The Spartanburg Regional Medical Center (Spartanburg, SC, USA) uses an 802.11g solution to locate more than 550 intravenous infusion pumps.

The system is developed by McKesson (www.mckesson.com) using hardware and RTLS (Real Time Location System) by Ekahau (www.ekahau.com). The whole hospital is covered using more than 300 Wi-Fi access points. The active tags “beep” once in an hour to communicate their unique ID. Each time a tag detects a change of position, thanks to movement sensors mounted onboard, it communicates its ID waiting just six seconds. This behaviour lets the batteries go on for even two years.

A web based software shows the pump positions over a plan of the hospital. The system is as well capable of sending alarms in case some pumps enter particular areas.

(Bacheldor, 2007 c)

The Washington Hospital Center (District of Columbia, USA) uses an UWB RFID system from Parco (www.parcomergedmedia.com) to track and localize medical devices, mainly devices used to move patients like litters, wheelchairs, wheel beds and portable radiographs. The UWB transponders are shaped in cubes 2.5cm wide screwed or glued to the device to be tracked. Tags can be located by readers within a 180m radius with a pretty good accuracy of less than half meter. The tag's battery can last 4 years with a pulse frequency of 1 Hz. Every transponder is provided with a 32 bytes of data memory and is capable of transmitting its ID number together with some more info about battery life and manumissions.

A GIS software is included to show the position of every tag on a map of the hospital.

(Bacheldor, 2007 d)

4. RFID and electromagnetic interferences (EMI): case study

Radio Frequency Identification (RFID) technology is quickly entering hospitals, as shown in the above chapter 3, often close to the patient himself.

Some of the outlined tasks can be done having recourse to simple passive RFID tags: mother-baby matching with wristbands to avoid mix-ups; patient-drug tracking using RFID tagged packaging; blood bags tracking; sterile surgical tools tracking, etc.

On the other hand, active RFID systems allow some tasks not achievable with passive ones or using older technologies like barcodes, video-cameras or else. Some studies show that the

active technology is particularly suitable for tasks such as the location of patients or assets (Iadanza, 2008; Fry, 2005; Davis, 2004; Wicks, 2006, Sangwan, 2005)

RFId use in healthcare is also receiving much attention to assess the implications in terms of patient safety. (Ashar, 2007; Van der Togt, 2008)

The possible EMI on medical equipment is a concern, primarily when the life of the patient is related to the medical device correct function. Some recent studies showed contrasting results, pointing out the need for further investigations to be done case by case (Van der Togt, 2008; Christe, 2008). The focus of this paragraph is examining the EMI between an active RFId system and the critical care equipment in a children's ICU.

As mentioned above, an active RFId system consists of three main devices: illuminator, receiver and tag. The system is then connected to a data network and is managed by a master software. The tag is battery-powered and is normally in stand-by mode; when entering an illuminator field cone, it wakes up and it starts to transmit its ID code together with the illuminator's ID code to a receiver. The various systems on the market use many different transmitting frequencies and modes of operation, also depending on the different national regulations.

The electrical medical equipment must comply to UL/EN/IEC 60601 standard plus some national deviations. In particular the collateral standard TE 60601-1-2 applies to electromagnetic compatibility of medical electrical equipment and medical electrical systems. Nevertheless many medical devices, still widely used in hospitals, only meet older versions of the standard that required lower immunity test levels over the frequency range 26 MHz to 1 GHz.

Here is why it is important to test the RFId system for possible EMIs on the hospital medical electrical equipment.

The tested RFId hardware is an active dual frequency system, LNX®, by Advanced Microwave Engineering S.r.l. (www.ameol.it, Florence, Italy). The LNX system includes three devices: the illuminator, the tag and the reader. (Iadanza, 2008)

The major EMI source in the system is the illuminator. The system is tested for its possible use in a children's hospital intensive care department.

In this application the footprint of its antenna is designed to cover a single ICU room. It consists of a 2.45 MHz PLL oscillator cascaded with a OOK modulator and a medium power MMIC amplifier. The radiation pattern of the antenna has 120 degrees -8 dB angular aperture. Circular polarization is employed because the orientation of the tag, that uses a linear polarized antenna, is unpredictable in many applications. The signal transmitted by the illuminator provides a programmable ID code and few more setting commands that are used for programming the operation mode of the tag entering its field pattern. The RF output power of the illuminator can be set from 0 dBm to 20 dBm (Biffi Gentili, 2008). For each test, the maximum power of 20dBm has been used.

The RFId tag is a battery-powered dual frequency device that can be activated and programmed by the illuminator. It comes with a 4 Kbytes memory board and it is in a low power consumption stand-by mode until it is activated. Then it transmits its own ID code and the illuminator code to a receiver unit, using a 433 MHz centred band and a maximum output power of 0 dBm.

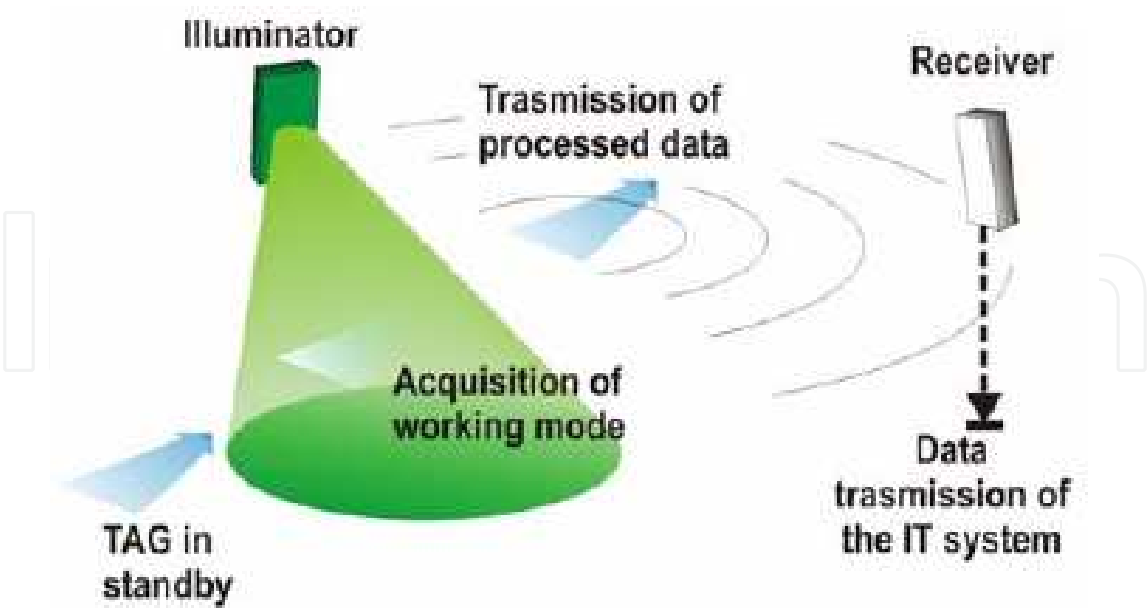


Fig. 6. LNX System working scheme

The tested critical care devices are a typical equipment for a children’s resuscitation. An ICU room, away from the patients area, was set up with a moveable RFid illuminator and some active RFid tags.

The medical equipment was operated by healthcare personnel, trained to manage it in everyday use. Table 1 shows a list of the 16 devices, tested in two different times.

DEVICE	N. OF DEVICES
<i>Ventilator</i>	4
<i>Syringe pump</i>	4
<i>Volumetric Infusion pump</i>	3
<i>Defibrillator / Monitor</i>	3
<i>Multi-parametric monitor</i>	2

Table 1. Tested critical care equipment

EMC assessment on all the medical equipment has been performed starting from their documentation. For each medical device it has been developed a particular checklists containing the tests to perform.

Only the two ventilators were compliant to the latest IEC 60601-1-2:2003 standard, that specifies a general immunity test level to radiated RF noise of 10 V/m. The remaining 14 devices, according to their manuals, were compliant to previous versions of the same standard, that required a level of immunity of just 3 V/m.

All the tests were performed switching on a single appliance at a time in a fully operating critical care room without any patients.

The test method was based on the American National Standards Institute recommendation ANSI C63.18 to assess the electromagnetic immunity of the medical devices by the RFId illuminator and an active tag (IEEE; 1997). The standard has been integrated with checklists, as stated above, designed for each medical device after the analysis of its operational and maintenance documentation.

Each electrical medical device was first checked using its own internal test procedure and by healthcare staff. If necessary the devices were connected to the provided simulators.

Then the illuminator was turned on. The distance between the illuminator and the device was reduced, according to ANSI C63.18 standard, in three following steps from 2m to 0,6m to 0.01m (indicating illuminator on top of the device, below the minimal distance for the RF immunity tests imposed by IEC 60601-1-2). For each step the device was turned off and then on, the device internal test procedures were performed and the performances were evaluated by the healthcare personnel.

Each test was repeated having a battery powered transmitting tag attached to the device body. At the minimal distance, the illuminator was moved in three different positions on the axes x (frontal), y (lateral) and z (above the device).

No malfunctions spotted on the ventilators in Paw, flow, respiratory frequency or other parameters for any of the tested modes:

1. IPPV (Intermittent Positive Pressure Ventilation);
2. SIMV (Synchronized Intermittent Mandatory Ventilation);
3. MMV (Mandatory Minute Volume Ventilation);
4. CPAP (Continuous Positive Airway Pressure);
5. ASB (Assisted Spontaneous Breathing);
6. BIPAP (Biphasic Positive Airway Pressure);
7. APRV (Airway Pressure Release Ventilation);
8. PPS (Proportional Pressure Support).

No malfunctions in the alarms, tested simulating alert situations, neither for the older devices of the set, that conformed just to the first version of the IEC 60601-1-2.

None of the tested pumps, set to give 5 mL/h, revealed malfunctions during the tests. Alarms correct functioning was assessed by simulating an occlusion, then waiting for the alarm beeps and for the error message, both disappeared as soon as the shrinkage was eliminated.

No anomaly as well for the defibrillators. Tests were performed using device's 'User Test' mode with no actual defibrillator shots. Also the ECG trace, obtained by connecting the electrodes to a test subject, showed no errors: the ECG curve has not revealed distortions and heart rate remained constant. The 'signal absence alarm' functioning was verified, after removing an electrode. The alarm stopped as soon as the electrode was repositioned.

Also the Siemens multi-parametric monitors, tested detecting the ECG and the pulse oximetry signal, worked properly during all the performed tests.

Eventually, our study found no evidence that the use of an active low power microwave RFId system does affect the performances of the neighboring medical devices.

The set of devices tested does certainly not cover the broad spectrum of the devices on the market. Nevertheless it is heterogeneous, composed by critical devices and containing many outdated models.

Therefore it is feasible enough to extend these results to a generic hospital ward equipment.

5. A multi-layer method to design a technical RFId solution for in-patients tracking

In this paragraph we will discuss a design method to correctly identify the technical solution that best responds to aims and imposed constraints. (Iadanza 2008)

The method consists in four consecutive steps. The first thing to do is to focus all the project aims. This step has to be performed together with the client, that in this case is the top management of the hospital. The higher is the position, on the hospital organization chart, of your interlocutor, the best are the chances to spot the final wishes of the client.

The second step is addressed to the translation of the upper level aims in functional requirements that the final system must satisfy. Also in this phase it is important to maintain a close connection to the people that will actually take advantage of the system, like head of department, caregivers or technical personnel.

Afterwards, the functional requirements must be transformed in technical constraints; this step can be completely managed by the designer himself.

Eventually, many technical solutions are compared in order to assess which one best fits the upper levels constraints.

Therefore, as in a four layer planning architecture, the top layer (layer I: “project aims”) must be satisfied as much as possible be the lower layer (“functional requirement” - layer II). Similarly, the “technical constraints” layer III is created to satisfy as much as possible its upper level (layer II). Using this operating mode, the technical solution comes out very coherently to the main project aims.

LAYER	DESCRIPTION
LAYER I	PROJECT AIMS
LAYER II	FUNCTIONAL REQUIREMENTS
LAYER III	TECHNICAL CONSTRAINTS
LAYER IV	TECHNICAL SOLUTION

Table 2. The four layers in the proposed multilayer design method

5.1 Layer I: Project aims

Project aims can be divided in three main categories: functionality, economical efficiency, compliance to standards and laws.

- *Functional* aims: the system must have both a good spatial and time resolution. It must be thought to be used by medical and paramedical staff. It must ease the duty of staff when they want to inform patient relatives about the progress of cares to their kinsman (especially in wards like Emergency Department). It must be provided with alarm procedures for danger situations in which the in-patient, possibly confused, could be. It must be open to an interface towards Hospital information System (HIS).
- *Economical* aims: the system must provide a total cost reduction for patients logistics management. It must lower costs due to clinical errors by reducing error probability.

- *Safety and laws*: the system does not have to be an obstacle to clinical practice and must guarantee a good cohabitation with EMI sensitive devices.

5.2 Layer II: Functional requirements

According to Layer I aims, 28 different requirements were spotted. Some of these are shown here:

- real-time tracking
- indoor and outdoor tracking capability
- coverage range
- system-to-HIS integration
- alarms
- procedure to associate tag and patient
- design and ergonomics of tag support
- tag support resistance, cost efficiency and duration
- interaction with Medical Devices
- patient privacy

5.3 Layer III: Technical constraints

Technical specifications come directly from the upper layer II functional requirements and are the base to assess the technological solution. Many specifications categories are provided to cover the whole range of constraints just showed:

- Technology
 - i. Active RFId
 - ii. Functional range illuminator-tag > 10m
 - iii. Functional range tag-reader > 20 m;
 - iv. Each illuminator must define an area of interest
 - v. Site survey and plan of fixed devices location
 - vi. RFId provided with a robust anti-collision algorithm
 - vii. Not disposable reprogrammable tags
 - viii. 32 Kbit or more on the tag
 - ix. Frequency range: 433 MHz – 2,45 GHz, in compliance with Italian laws
 - x. Tag battery duration > 2 years
- Interface
 - i. Reader must become a node of the HIS (Hospital Information System) via LAN or wireless-LAN
 - ii. Custom software to process tag information and show it on the hospital floor plan;
 - iii. Critical areas recognition and link to some alarm system
- Standard and laws
 - i. Privacy protection
 - ii. accordance of the RFID system with electro-magnetic compatibility and safety guidelines

- Economics
 - i. Reusable tag (re-programming tag separable from the support);
- Device package
 - i. Both indoor and outdoor use
 - ii. Easily wearable tag (custom solutions also for children and injured people)
 - iii. Use of an armlet as support for the tag (not for use in Neonatal Intensive Care Units)
 - iv. Total weight 'support + tag' < 35 g
 - v. Cut-to-remove armlet
 - vi. Possibility to separate the tag from the support for sterilization purposes

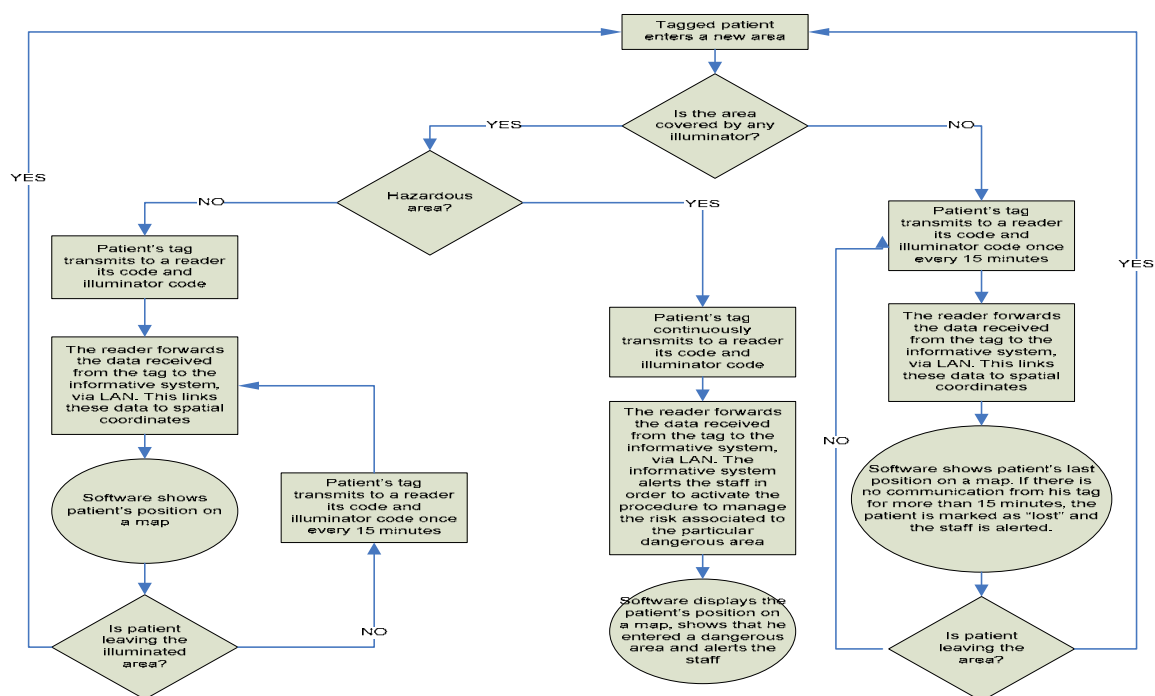


Fig. 7. Patient Tracking Process flow chart

5.4 Layer IV: Technical solution and system configuration

The technical solution that best fits all the above constraints is the same as described in the above section 4 and, therefore, is not described once more in this paragraph.

For patient tracking scope it comes useful a particular operational mode provided by the system: the “beeper fast” operating mode. It allows you to implement a system not just based on a “gate” working model but on an “area recognition” model. In beeper fast mode the tag, once activated, transmits the same signal (tag factory code and illuminator area code) at programmable intervals of time until it enters a different illuminator’s antenna lobe. This functioning mode is useful to extend tag’s battery life: when the tag enters a closed area (e.g. a room) it could be programmed to transmit once every 15 minutes or more to save energy, whereas the owner patient can’t be but inside the room. Out of the room the tag will be enlightened by a different illuminator: this will cause an immediate new transmission.

6. Case study: RFID for children and newborns in intensive care

This paragraph shows how to apply the above multilayer design method (see par. 5) in designing a system to identify and know the actual position of patients in a children's Intensive Care Unit (ICU).

As a first step you must spot the system purposes. In this case the main objective is to provide the ICU with a system to lower down the clinical risks related to misidentification of patients or unintentional rooms swaps.

Still, this does not exhaust the correct definition of all the project scopes. In the first layer, "project aims", you must also take into account many aspects that are linked to functional aims as well as to financial aspects and to quality and standards. The whole system must be designed following standards and laws about privacy and data protection in healthcare.

Also, the technical solutions may be very different according to the patients type, age and cognitive conditions and according to the hospital building types and shapes. A hospital with separate pavilions requires solutions that may be very different from multilevel monoblock buildings. Similarly, in designing a tracking solution for non cooperative patients, you will face requirements very different from surgical patients or newborns.

Furthermore, if delicate healthcare tasks are involved in the process that the system is called to manage, like drugs administrations and Electronic Medical Record (EMR) updates, it will have to deal with many other requirements such as the drugs inventory system, the identification of caregivers, the interface with the Hospital Information System (HIS). (Iadanza 2008)

Children in a resuscitation ward have, in most cases, no cognitive abilities and a wide range of variability in age, weight and dimensions (from newborns to overweight children). This makes it hard their identification by healthcare personnel. They could have no alive parents at all; newborns are often similar one to another; senseless patients simply cannot tell you their name, etc.

The diagnostic and therapeutic process for these children involves frequent movements to other hospital departments for diagnostic tests, surgeries or ward transfers. This raises the risk of rooms misplacement when they come back to the ICU.

The described active RFID solution is intended to identify ward rooms, cradles/beds and patients with unique ID numbers. It also lets the caregivers trace the patients movements on a wide screen, giving warnings and alerts to the nurses in case of dangerous situations.

The proposed system addresses all the constraints induced by the particular environment. Critical care children are of course stationary in their bed, but they can often be moved in a new bed for many reasons (cleaning up, going out, coming from thermal cradle, etc.). They are sometimes not well recognizable one from another, therefore if we use some RFID identifying tags we must lower down as much as possible the need for tags removing and replacement.

Wristbands are not a suitable solution, since these patients can be very weak, small and delicate, hence we must be aware of it in designing the tag case.

The system is composed of five different hardware devices and a tracking software, purposely designed and realized in collaboration with Advanced Microwave Engineering (AME, www.ameol.it). (Biffi Gentili, 2008)

6.1 Reader

This is the only standard device. It is an AME LX 2002 433 MHz receiver provided with an omnidirectional monopole antenna. The signal received from the CRADLE_TAG (see below) is forwarded to the central software system, once added the internal date and time of the receiver, using an Ethernet or IEEE 802.11g wireless interface. (Biffi Gentili, 2008)

6.2 Illuminator

It provides a programmable ID code that can be used to spot the spatial position, once linked to a cartographic map. It is able as well of programming the operation mode of the CRADLE_TAG entering in its field pattern. The illuminator is a custom device obtained modifying a commercial unit AME LX2101 (Biffi Gentili, 2008), changing the antenna and modifying the firmware. It consists of a 2.45 MHz PLL oscillator cascaded with an OOK modulator and a medium power MMIC amplifier. It is attached to the ceiling inside the area you want to outline (room, corridor, nurse space, exits etc.) and it is used to create a confined area underneath itself, in which a tag, provided with a 2.45 GHz receiving section, can receive the Illuminator's ID and some more information that you can set via software.

To narrow the area covered by the Illuminator, obtaining a good separation between two adjoining rooms, we introduced an uniform linear array of eight planar patch antennas. The radiation pattern of this antenna has about 30 degrees -8 dB angular aperture. Circular polarization is employed because the orientation of the CRADLE_TAG, that uses a linear polarized antenna, could vary depending on how it is fixed to the bed.

Placing two Illuminators on a line we obtain a well defined "dark zone" where there is no signal: we could use this zone to discriminate two different areas in an open-plan ICU environment or, simply, two adjoining rooms.

6.3 CRADLE_TAG

This device is used as a bridge between the BABY_TAG and the environment since the system is thought to let the children be moved in a new bed or cradle whenever it is needed. It must be fixed on the bed/cradle side. It gives a link between the BABY_TAG and the system (Readers and Illuminators). The unit is battery powered to be easily mounted on hospital beds or cradles in accordance to safety and convenience of movements. Indeed, this unit is used also when the bed or the cradle are moved elsewhere in the hospital, to follow and track its way.

It is made of four sections:

- a 433 MHz receiver to get Baby-ID from the BABY_TAG;
- a 2.45 GHz receiver to get the Illuminator ID
- a 433 MHz transmitter to send to the Reader unit a string containing Baby-ID, Illuminator-ID and Cradle-ID;
- a passive RFid reader capable of reading passive RFid tags compatible to ISO15693 standard using a frequency range of $13.56 \text{ MHz} \pm 7\text{KHz}$.

6.4 BABY_TAG

Small, active (battery powered) patient tag fixed underneath the child foot. It can transmit a Patient-ID code to the CRADLE_TAG using a 433 MHz centred band. The device has on board, in addition to a microcontroller, a 3V CR2032 battery, an external 433 MHz

transmitting loop antenna and a miniaturized 2.45 GHz receiving antenna. The receiving section is used to program the unit using an Activator (see below) during the admission of the patient to the ICU. The BABY_TAG could also incorporate a passive RFId tag with the same Patient-ID. This lets the caregivers accurately identify the patient when administering drugs or treatments, even in wards not covered by the active infrastructure.

6.5 ACTIVATOR

It consists of a standard portable Illuminator (see above). The only differences are the antenna (a small single patch model) and the ID number: every activator ID starts with '99'. This device is used to initialize the BABY_TAG once fixed to the patient. It also lets the tracking software to link the Patient-ID to the actual patient identity and EPR.

6.6 SYSTEM MANAGEMENT SOFTWARE

A custom software has been developed to implement every step of the identification and tracking process, from the admission of the baby to the ICU, to his discharge from hospital. The software gets UDP packets coming from the Reader unit via Ethernet or wireless LAN and monitors the ward searching for anomalies like room swaps, empty cradles or beds, empty rooms, etc. It is provided with a graphical interface showing the ward map and can log every warning or alarm coming from possible danger situations (see fig. 5). The software is supplied with a "track mode" that is able to find and follow a single patient moving from his room to a surgical block or a diagnostics department covered by the active RFId infrastructure.

7. Conclusion

This chapter showed that there is a broad field of healthcare applications in which RFId technology can seriously improve efficiency, speed, accuracy, safety, risk management.

In planning an RFId solution it is vital to contemplate an accurate design phase, in order to establish the final characteristics of the system working together with the actual final users.

The adoption of an off-the-shelf solution is not a good idea for healthcare systems, since you must cut out the best system and choose the right technology after assessing all the particular requirements and constraints for the specific environment you are working with.

There is a need for rigorous evaluations of safety related issues, like electromagnetic compatibility and privacy, much more central in healthcare than elsewhere. In fact medical electrical equipment is involved as well as patient's personal data.

Bioengineers must be the chief architects of these systems; they must coordinate the team of experts that should include clinicians, electromagnetism experts, IT solution providers, hospital designers.

This is a relatively new field of bioengineering, hence bioengineers should be encouraged – also during their course of studies – in acquiring all the necessary competences to be leading actors in designing RFId systems for healthcare.

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The field of biomedical engineering has expanded markedly in the past ten years. This growth is supported by advances in biological science, which have created new opportunities for development of tools for diagnosis and therapy for human disease. The discipline focuses both on development of new biomaterials, analytical methodologies and on the application of concepts drawn from engineering, computing, mathematics, chemical and physical sciences to advance biomedical knowledge while improving the effectiveness and delivery of clinical medicine. Biomedical engineering now encompasses a range of fields of specialization including bioinstrumentation, bioimaging, biomechanics, biomaterials, and biomolecular engineering. Biomedical engineering covers recent advances in the growing field of biomedical technology, instrumentation, and administration. Contributions focus on theoretical and practical problems associated with the development of medical technology; the introduction of new engineering methods into public health; hospitals and patient care; the improvement of diagnosis and therapy; and biomedical information storage and retrieval. The book is directed at engineering students in their final year of undergraduate studies or in their graduate studies. Most undergraduate students majoring in biomedical engineering are faced with a decision, early in their program of study, regarding the field in which they would like to specialize. Each chosen specialty has a specific set of course requirements and is supplemented by wise selection of elective and supporting coursework. Also, many young students of biomedical engineering use independent research projects as a source of inspiration and preparation but have difficulty identifying research areas that are right for them. Therefore, a second goal of this book is to link knowledge of basic science and engineering to fields of specialization and current research. The editor would like to thank the authors, who have committed so much effort to the publication of this work.

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