THESIS SUMMARY

Dielectric Characterization of Biological Tissues for Medical Applications

Author: Alejandro Fornés Leal
Supervisor: Dr. Narcís Cardona and Dr. Concepción García Pardo
Defended on October, 28, 2019

Nowadays, a careful knowledge of the electromagnetic properties of biological tissues is required for developing a great number of applications. The development of wireless medical devices, the design of in-body and on-body antennas, specific absorption rate evaluations, cancer treatment techniques such as hyperthermia and detection techniques like medical imaging are some examples of applications that rely on these data.

Since cancer causes modifications on the biological structure of cells that can lead in turn to changes in the electromagnetic properties of the tissues, it is possible to develop novel detection applications taking advantage of it. One potential target is colorectal cancer (CRC), as suspicious tissues can be accessed quite easily through colonoscopy procedures. This kind of cancer is one of the most spread kinds, being responsible of about 1 out of 10 new cancer cases and deaths. There are several risk factors currently related to the apprising of this cancer, although in essence the higher the age of the population, the higher the incidence of CRC.

Screening programs are key for detecting and diagnosing cancer: if found at early stages, the probability of survival increases greatly, and the cost of the treatment can be reduced as well. One of the major objectives of this thesis is proposing applications for detecting CRC that aid in the colonoscopy procedures by making use of the differences in electromagnetic properties. Aside from enhancement in the diagnosis of CRC, improving the colonoscopy procedure can lead to collateral benefits like a lowering of the burden of anatomical pathology unit.

With the aim at demonstrating the feasibility and the potential future development of these applications, in the framework of this thesis the dielectric properties of healthy, cancerous and pathological human colon tissues were measured and compared in order to find electromagnetic differences. Measurements were carried out by means of an open-ended coaxial system. Its principle of operation has been revisited with the aim at maximizing the accuracy of the method, and the calibration procedure has been optimized serving the same purpose. Two main sources of colon tissue have been analyzed: samples from colonoscopy biopsies and samples from surgery resections. Given the variability that can appear among subjects, the electromagnetic properties of suspicious tissues from a particular patient have to be always compared with those of his healthy ones, not evaluated independently. Significant differencies between the dielectric properties of healthy and malignant tissues were found for both sources, which can be exploited to develop novel CRC diagnostic applications.

The second major objective of this thesis involved the development of a new database of electromagnetic properties of biological tissues obtained at *in vivo* conditions. Nowadays, the available collections are limited either in the number of tissues or the measured frequencies, and hence researchers have to make use of more complete databases but that were performed *ex vivo*. The drawback of using these collections is that results can be compromised by factors such as lack of blood perfusion and tissue dehydration. This new database can facilitate the design of applications that needs of a careful knowledge of these properties.

THESIS SUMMARY

Metallic lens antenna design using the Theory of Characteristic Modes

Author: Daniel Antonio Santillán Haro
Supervisor: Dr. Miguel Ferrando Bataller and Eva Antonino Daviu
Defended on March 3, 2020

In recent years, the worldwide data traffic is increasing significantly. Consequently, the new telecommunications systems seek to increase the data transmission rate with a wide coverage area. To cope with the current demand, the new communications systems move to new frequency bands of the radio spectrum, especially in the range of millimetre waves, because of the greater bandwidth available and less interference, what allows considerable size reduction of the antennas.

In these new systems, satellites that generate multiple beams are used with a frequency and polarization reuse scheme, increasing the capacity and the number of users. Moreover, to facilitate new user demands, the future telecommunications systems require the integration of advanced multimedia services through heterogeneous networks, such as fixed terrestrial and wireless networks.

To cope with these challenges, lens antennas and their variants are promising solutions.

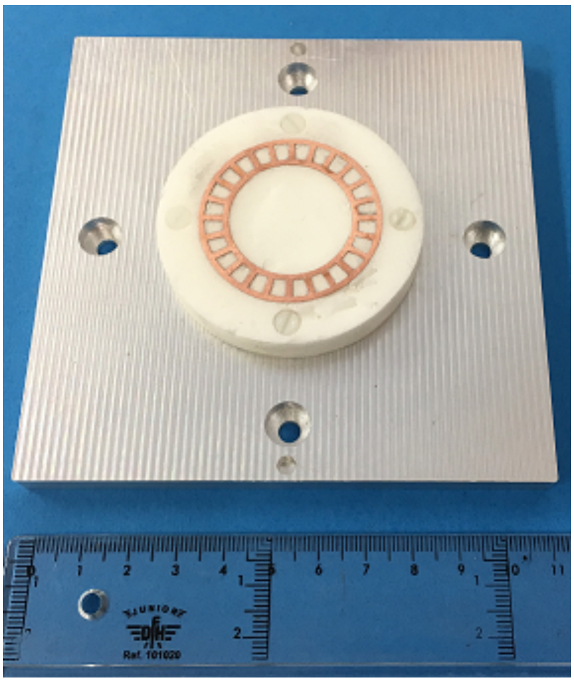
Lenses have interesting properties because they have generally low losses and great directivity, which are the basic requirements that antennas must satisfy for these new communications systems.

The aim of this thesis has been to propose the use of the Theory of Characteristic Modes to facilitate the design, optimization, and analysis of metallic lenses with high gain in a large bandwidth, achieving a compact size for the structure.

The analysis with the Theory of Characteristic Modes has been used as a starting point to evaluate the modal behaviour and provide a physical insight of the radiation characteristics of the metallic structure in a certain frequency range. In this work, a study of the characteristic modes of the main regular geometric objects with symmetry of revolution was carried out to investigate its potential to be employed in the design of the metallic lenses.

Specifically, the modal significance and characteristic angle was investigated, along with the contribution of each mode to the total radiated power when illuminating the conducting body by a plane wave.

Using the information considered by the eigenvalues, the shape and size of the metallic structure was optimized and the optimal feeding was determined, which allowed to excite the desired mode in the structure. Then, an alternative method was proposed to calculate the focal point of the metallic structure.



Furthermore, in this thesis we have studied the most important lens feeders that have been developed in recent years, and two practical feeders with low cross polarization level have been proposed to operate in microwave and millimeter-wave frequencies.

When studying the lenses, we have begun to compare and describe the techniques most used in the design of these structures. Then, the Theory of Characteristic Modes has been applied to the metallic lenses design. First, the modal currents have been analysed in various metallic structures, and then this information has been used to design low profile lenses. The same approach has been then applied to antennas with single-layer structures, which have larger physical dimensions. Subsequently, a two-layer metallic lens has been studied and designed, and various combinations of the metallic structures have been analysed to achieve greater directivity.

In addition, a three-layer metallic lens and a single-layer antenna with double feeder have been designed. Finally, a lens has been proposed for a dual-polarization base station, with the possibility of obtaining up to four orthogonal radiation modes.

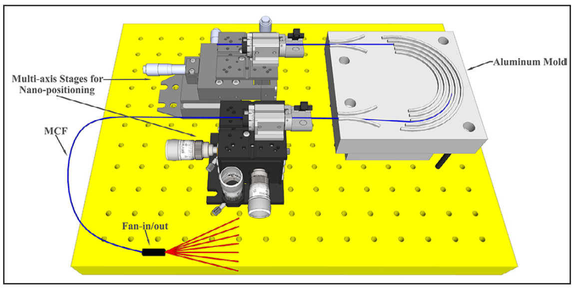
The last chapter of this thesis presents the prototypes and the performance of the following antennas: a single-layer lens formed by a central circular metallic ring surrounded by a set of eight metallic rings, an antenna formed by two metallic rings of different diameter distributed in two layers, a new low-profile metallic lens antenna formed by twelve metallic rings distributed in a single layer and arranged along a ring, and a low-profile lens antenna formed by two metallic rings with strips short-circuiting both rings.

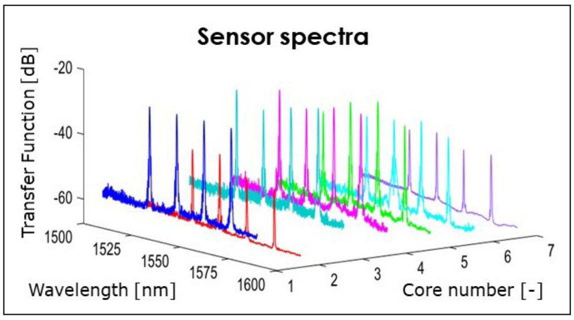
In this part, the main measurements of gain, efficiency and cross polarization have been presented for the aforementioned lenses. The designs have been verified, obtaining good results in a wide bandwidth, thus validating the proposed technique.

Optical Multicore Fiber Shape Sensors. A numerical and experimental performance assessment

Author: Ignazio Floris
Supervisor: Dr. José Miguel Adam and Pedro Antonio Calderón García
Defended on June 25, 2020

Structural Health Monitoring (SHM) is a discipline that quantitatively assesses the integrity and performance of infrastructures, relying on sensors, and support the development of efficient Maintenance and Rehabilitation (M&R) plans. Optical Multicore Fiber (MCF) Shape Sensors offer an innovative alternative to traditional methods and enable the reconstruction of the deformed shape of structures directly and in real-time, with no need of computation models or visual contact and exploiting all the advantages of Optical Fiber Sensors (OFS) technology. Despite the intense research efforts centered on this topic by research groups worldwide, a comprehensive investigation on the parameters that influence the performance of these sensors has not been conducted yet. The first part of the thesis presents a numerical study that examines the effects of strain measurement accuracy and core position errors on the performance of optical multicore fiber shape sensors in sensing three-dimensional curvature, which is at the basis of shape reconstruction. The analysis reproduces the strain measurement process using Monte Carlo Method (MCM) and identifies several parameters which play a key role in the phenomenon, including core spacing (distance between outer cores and sensor axis), number of cores and curvature measured. Finally, a set of predictive models were calibrated, by fitting the results of the simulations, to predict the sensors performance. Afterward, an experimental study is proposed to evaluate the performance of optical multicore fiber in sensing shape, with particular focus on the influence of strain sensors length. Two shape sensors were fabricated, by inscribing long (8.0 mm) and short (1.5 mm) Fiber Bragg Gratings (FBG) into the cores of a multicore seven-core fiber. Thus, the performance of the two sensors was assessed and compared, at all the necessary phases for shape reconstruction: strain sensing, curvature calculation and shape reconstruction. To conclude, an innovative approach, based on the Saint-Venant's Torsion Theory, is presented to determine the twisting of multicore fiber and to compensate the errors due to twisting during shape reconstruction. The efficiency of the theoretical approach was then corroborated performing a series of twisting tests on a shape sensor, fabricated by inscribing FBGs sensors into an optical spun multicore seven-core fiber. The investigation of the mechanical behavior of multicore optical shape sensors has synergically involved diverse disciplines: Solid Mechanics, Photonics, Statistics and Data Analysis. Such multidisciplinary research has arisen from the prolific cooperation between the Institutes of the Institute of Science and Technology of Concrete (ICITECH) and the Institute of Telecommunications and Multimedia Applications (iTEAM) - Photonics Research Labs (PRL) - of Universitat Politècnica de València (UPV), in addition to valuable collaboration with other members of the European ITN-FINESSE project, to which this work belongs. This research work aims to enhance the performance optical multicore fiber shape sensors and support the development of new sensor geometries, with great potential for structural health monitoring applications.





Location and Tracking for UWB In-Body Communications in Medical Applications

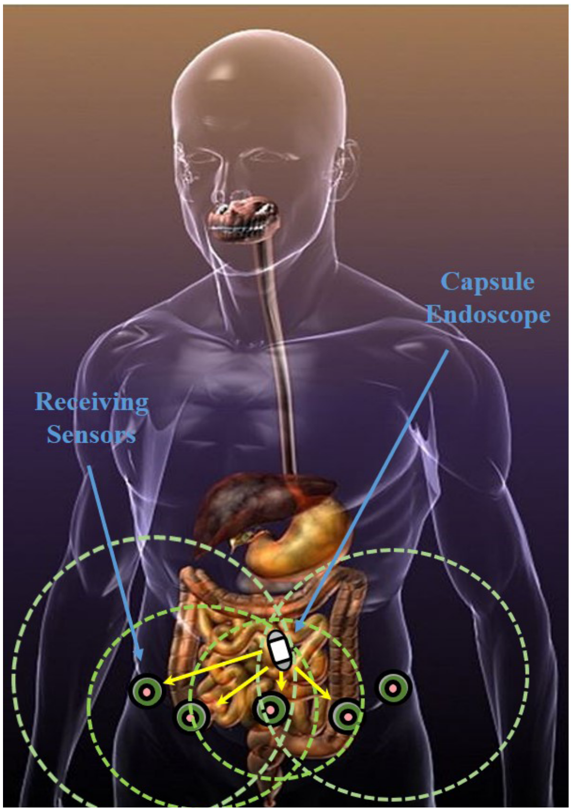
Author: Martina Barbi
Supervisor: Prof. Narcís Cardona Marcet and Dr. C. Garcia Pardo
Defended on November 28, 2019

Wireless Capsule Endoscopy (WCE) is a remarkable and attractive technology adopted in the biomedical sector several years ago. It provides a non-invasive wireless imaging technology for the entire gastrointestinal (GI) tract. WCE allows specialists to recognize and diagnose diseases affecting the whole GI tract. Although physicians can receive clear pictures of abnormalities in the GI tract, they have no information about their exact location. Precise localization of the detected disorders is crucial for the subsequent removal procedure by surgery.

Currently, the frequency band allocated for capsule endoscopy applications is the MICS band (402-405 MHz). This band offers data rate up to 500 kbps, which is insufficient to transmit high quality images. Recently, Ultrawideband (UWB) technology has been attracting attention as potential candidate for next-generation WCE systems. The advantages of UWB include simple transceiver architectures enabling low power consumption, low interference to other systems and wide bandwidth resulting in communications at higher data rate.

In this dissertation, performance of WCE localization techniques based on Radio Frequency (RF) information are investigated through software simulations, experimental laboratory measurements involving homogeneous and heterogeneous phantom models and *in vivo* experiments which constitute the most realistic testing scenario. Ultra-Wideband technology (3.1-10.6 GHz) is considered as communication interface in Wireless Capsule Endoscopy. In such scenario, the wireless transmitter is located in the gastrointestinal track while one or more wireless receivers are located over the surface of the body. Received Signal Strength (RSS)-based approach is mainly explored due to its implementation simplicity and less sensitivity to bandwidth limitations. Impact of the position and the number of selected receivers on the localization accuracy is analyzed. Finally, a graphical user interface (GUI) is developed to

visualize the three-dimensional (3D) localization results obtained through *in vivo* measurements.



THESIS SUMMARY

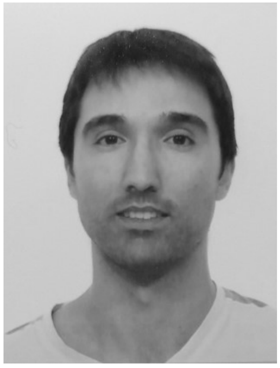
Optimization and improvements in spatial sound reproduction systems through perceptual considerations

Author: Pablo Gutiérrez Parera
Supervisor: Dr. José Javier López Monfort
Defended on April 3rd, 2020

The reproduction of the spatial properties of sound is an increasingly important concern in many emerging immersive applications. Whether it is the reproduction of audiovisual content in home environments or in cinemas, immersive video conferencing systems or virtual or augmented reality systems, spatial sound is crucial for a realistic sense of immersion. Hearing, beyond the physics of sound, is a perceptual phenomenon influenced by cognitive processes. The objective of this thesis is to contribute with new methods and knowledge to the optimization and simplification of spatial sound systems, from a perceptual approach to the hearing experience. This dissertation deals in a first part with some particular aspects related to the binaural spatial reproduction of sound, such as listening with headphones and the customization of the Head-Related Transfer Function (HRTF). A study has been carried out on the influence of headphones on the perception of spatial impression and quality, with particular attention to the effects of equalization and subsequent non-linear distortion. With regard to the individualization of the HRTF a complete implementation of a HRTF measurement system is presented, and a new method for the measurement of HRTF in non-anechoic conditions is introduced. In addition, two different and complementary experiments have been carried out resulting in two tools that can be used in HRTF individualization processes, a parametric model of the HRTF magnitude and an Interaural Time Difference (ITD) scaling adjustment. In a second part concerning loudspeaker reproduction, different techniques such as Wave Field Synthesis (WFS) or amplitude panning have been evaluated. With perceptual experiments it has been studied the capacity of these systems to produce a sensation of distance, and the spatial acuity with which we can perceive the sound sources if they are spectrally split and reproduced in different positions. The contributions of this research are intended to make these technologies more accessible to the general public, given the demand for audiovisual experiences and devices with increasing immersion.

New spatial audio and HRTF measurement facility built at ITEAM

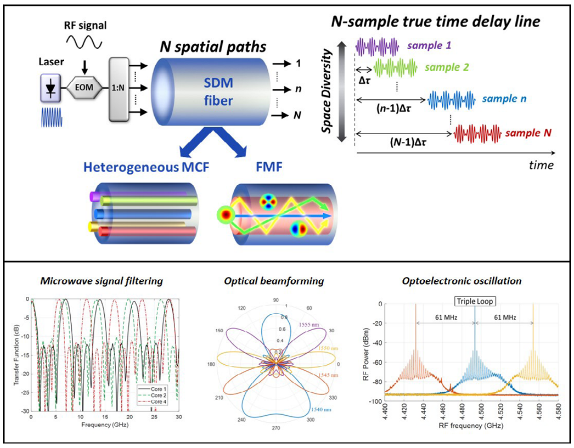
Distributed radiofrequency signal processing based on space-division multiplexing fibers



Author: Sergi García Cortijo
Supervisors: Dr. Ivana Gasulla Mestre and Dr. J. Capmany Francoy
Defended on June 11th 2020

Space-division multiplexing fibers emerged as a promising solution to overcome the imminent capacity crunch of conventional singlemode fiber networks. Despite these fibers were initially conceived as distribution media for long-haul high-capacity digital communications, they can be applied to a wide variety of scenarios including centralized radio access networks for wireless communications, data-center interconnects, Microwave Photonics signal processing and fiber sensing. Particular interest is raised by emerging communications paradigms, such as 5G and The Internet of Things, which require a full integration between the optical fiber network and the wireless segments. Microwave Photonics, discipline that focuses on the generation, processing, control and distribution of radiofrequency signals by photonics means, is called to play a decisive role. One of the major challenges that Microwave Photonics has to overcome to satisfy next-generation communication demands relates to the reduction of size, weight and power consumption while assuring broadband seamless reconfigurability and stability. There is one revolutionary approach that has however been left untapped in finding innovative ways to address that challenge: exploiting space, the last available degree of freedom for optical multiplexing.

In this Thesis, we propose to exploit the inherent parallelism of multicore and few-mode fibers to implement sampled discrete true time delay lines, providing, in a single optical fiber, a compact and efficient approach for both Microwave Photonics signal distribution and processing. For the multicore fiber approach, we study the influence of the refractive index profile of each heterogeneous core on the propagation characteristics as to feature specific group delay and chromatic dispersion values. We designed and fabricated two different heterogeneous trench-assisted 7-core fibers that behave as sampled true time delay lines. While one of them was fabricated by using 7 different preforms to feature a plenary performance, the other one employed a single preform with the aim of minimizing fabrication costs. In the case of few-mode fibers, we propose the implementation of a tunable true time delay line by means of a custom-designed fiber with a set of inscribed long period gratings that act as mode converters to properly tailor the sample group delays. We designed and fabricated a true time delay line on a 4-mode fiber by inscribing 3 long period gratings at specific positions along the fiber link. As a proof-of-concept validation, we experimentally demonstrated different Microwave Photonics signal processing functionalities implemented over both multicore and few-mode fiber approaches. This work opens the way towards the development of distributed signal processing for microwave and millimeter wave signals in a single optical fiber. These true time delay lines can be applied to a wide range of Information and Communication Technology paradigms besides fiber-wireless communications such as broadband satellite communications, distributed sensing, medical imaging, optical coherence tomography and quantum communications.



Wideband Electromagnetic Body Phantoms for the Evaluation of Wireless Communications in the Microwave Spectrum

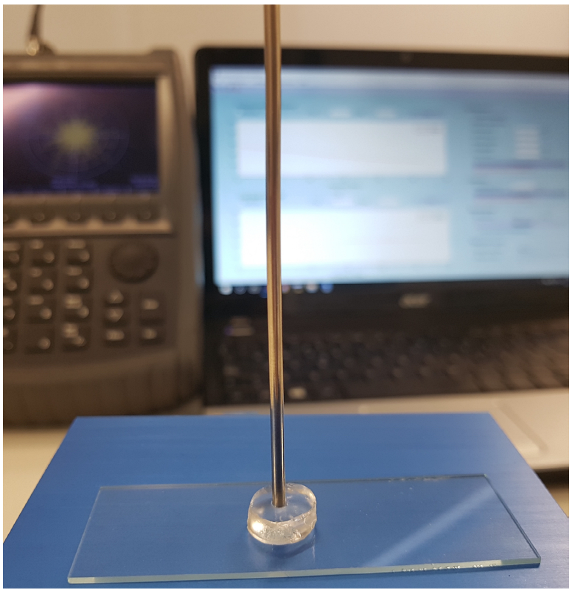
Author: Sergio Castelló Palacios

Supervisor: Dr. Narcís Cardona Marcet and Dr. Concepción García Pardo and Dr. Ana Vallés Lluch

Defended on October 28th, 2019]

The constant evolution of technology and the search for new applications that improve people's lives has led to the arrival of the incorporation of these technologies in the organism. Wireless body area networks (WBANs) are a good example of this, consisting of communications networks located in the body itself, both on the surface and implanted inside it through the use of wireless devices. These networks use the human body as the transmitting medium, so its influence over the propagation has to be assessed. Besides, new generations of mobile communications are moving towards the use of higher frequencies, as the millimetre waves, which are more sensitive to the presence of any object in the environment, including humans. The research and design of antennas and devices that take into account the human body requires testing in the environment where these are supposed to be used. Phantoms become a tool for evaluating the transmission of electromagnetic signals in a body-equivalent medium in order to avoid experimentation on humans or animals. In addition to that, the influence of these electromagnetic waves over the tissues themselves can be studied with regard to the specific absorption rate (SAR).

The objective of this thesis has been to obtain phantoms with the relative permittivity of the tissues from the human body. These were both in liquid and gel form, so that the appropriate medium can be chosen according to the type of experiment. Polymeric materials were used for the gel form, which are capable of providing mechanical consistency and own the possibility of being synthesized with the desired shape, i.e., that of the tissue in question. In the case of liquids, these were confined in containers with the shape of the tissues in order to adapt them to the type of test. For



that purpose, the main 3D printing materials were studied from the point of view of degradation in time with the presence of these liquid mixtures.

It was necessary to analyse the dielectric behaviour of different chemical compounds within the frequency band of interest. The selected bands were the main ones for biomedical use, as well as the new millimetre wave frequencies that will be used in the new 5G generation. Once the ideal compounds were chosen, a great number of tissues from the body were imitated, prioritising those of greatest relevance for the cases of use. Finally, these phantoms were used in different real tests, such as channel characterization or antenna matching, in order to obtain useful information for the design of future wireless communication devices.

In-body to On-body Experimental UWB Channel Characterization for the Human Gastrointestinal Area

Author: Sofia Pérez Simbor
Supervisor: Dr. Concepción García Pardo and Prof. Narcís Cardona
Defended on November, 28th, 2019

The current global population in developed countries is becoming older and facing an increase in diseases mainly caused by age. New medical technologies can help to detect, diagnose, and treat illness, saving money, time, and resources of physicians. Wireless in-body devices opened a new scenario for the next generation of medical devices. Frequencies like the Ultra Wide-band (UWB) frequency band (3.1 - 10.6 GHz) are being considered for the next generation of in-body wireless devices. The small size of the antennas, the low power transmission, and the higher data rate are desirable characteristics for in-body devices. However, the human body is frequency dependent, which means higher losses of the radio frequency (RF) signal from into out-side the body as the frequency increases. To overcome this, the propagation channel has to be understood and known as much possible to process the signal accordingly. This dissertation aims to characterize the (RF) channel for the future of in-body medical devices.

Three different methodologies have been used to characterize the channel: numerical simulations, phantom measurements, and living animal experiments. The phantom measurements were performed in a novel testbed designed for the purpose of in-body measurements at the UWB frequency band. Moreover, multi-layer high accurate phantoms mimicking the gastrointesintal (GI) area were employed. The animal experiments were conducted in living pigs, replicating in the fairest way as possible the phantom measurement campaigns. Lastly, the software simulations were designed to replicate the experimental measurements. An in-depth and detailed analysis of the channel was performed in both, frequency and time domain. Concretely, the performance of the receiving and transmitting antennas, the effect of the fat, the shape of the phantom container, and the multipath components were evaluated. As a result, a novel path loss model was obtained for the low UWB frequency band (3.1 - 5.1 GHz) at GI scenarios. The model was validated using the three methodologies and compared with previous models in literature. In addition, from a practical case point of view, the channel was also evaluated for UWB signals at lower frequencies (60 MHz) for the GI area. Finally, for the next generation of leadless pacemakers the security link between the heart and an external device was also evaluated. The results obtained in this dissertation reaffirm the benefits of using the UWB frequency band for the next generation of wireless in-body medical devices.