

CHAPTER

5

IMPLANTABLE MEDICAL DEVICES IN BIOTELEMETRY APPLICATIONS

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5.1 INTRODUCTION

The implantable medical devices (IMD) are medical implants that use wireless technology to communicate with external devices. IMD has grown in popularity because of their ability to detect and treat medical conditions in real-time using biotelemetric data from many ranges of patients. Implantable antennas are essential to the advancements of healthcare, significantly aiding in the precision of diagnostic accuracy, therapeutic interventions, and medical research. The antennas may contribute to reducing the risk of specific disease-related complications, potentially preventing the progression of chronic conditions.

Electrically compact implantable antennas emit radiation within high-loss environments like human body tissues, presenting unique design challenges. Studies have demonstrated that antennas achieve optimal performance in open space, but implantation in the human body can lead to reduced performance in areas such as gain, frequency detuning, radiation patterns, and radiation efficiency. Consequently, the primary design challenges for effective implantable antennas include minimizing return loss, broadening bandwidth, maintaining a compact structure, ensuring patient well-being, and attaining adequate radiation efficiency.

Advancement of 5th generation (5G) technology necessitates the development of specialized antennas and frequency selective surfaces (FSS). An FSS consists of a periodic arrangement that controls the propagation or attenuation of electromagnetic (EM) waves, depending on the configuration of its geometrical elements, such as patches and slots (Mohamed Nafis et al., 2022). Recent progress in antenna technology and wireless communication networks has significantly impacted biomedical applications. Implantable antennas are crucial in enhancing the quality of healthcare by improving diagnostic accuracy, treatment efficacy, and advancing medical research (Yusri et al., 2022). To ensure optimal performance, wearable antennas must adhere to specific requirements, including flexibility, durability, compactness, a low profile, lightweight construction, comfort, and the ability to adapt to the human body (Biragathis Babu et al., 2024).

A pacemaker is a miniature; battery-operated IMD utilized to monitor and modulate the cardiac rhythm in individuals with bradycardia or arrhythmia. Market Research Future predicts that the global market for pacemakers will reach USD6.6 billion in 2030. The growth is primarily attributed to the rising prevalence of cardiovascular disorders and the demographic of the aging population.

A standard conventional pacemaker (CP) consists of three primary components: a pulse generator, two leads, and electrodes, all constructed from biocompatible materials. A CP is implanted beneath the skin of the chest, with leads inserted into veins that connect to the heart. The pulse generator produces the electrical impulses necessary to stimulate the heart muscle, while the leads transmit these impulses to the cardiac tissues. For example, if the heart rate is slower than normal, an electrical signal travels via the lead to the electrode, stimulating the heart to accelerate the rhythm and restoring a normal rhythm. While a CP can regulate the heart rate, several issues persist, the most significant being the risk of infection from the implantation, which can be life-threatening. Recent research indicates that one out of every fourteen patients undergoing CP implantation experiences an infection, and among those affected, one in five cases results in death. Additionally, the implantation of leads can cause central vein obstruction, pneumothorax, and tricuspid valve failure. To address these issues, St. Jude

Medical and Medtronic introduced leadless pacemakers, or leadless cardiac pacemakers (LCP). They developed LCP systems such as the Nanostim LCP and Micra transcatheter pacing systems (TPS) to mitigate the complications associated with CP.

Leadless cardiac pacemakers (LCP) are capsule-like devices comprising several components, as depicted in Figure 5.1. Unlike CP, LCP integrate the pulse generator and electrode into a single unit, thereby eliminating the need for leads. The LCP is directly implanted into the right ventricle of the heart and has a smaller size compared to CP. Additionally, the implantation procedure for LCP is less invasive, as it does not require a chest incision, thus avoiding the formation of scars or bumps under the skin. Despite these benefits, LCPs have limitations, including concerns regarding battery longevity, efficacy, and wireless telemetry.

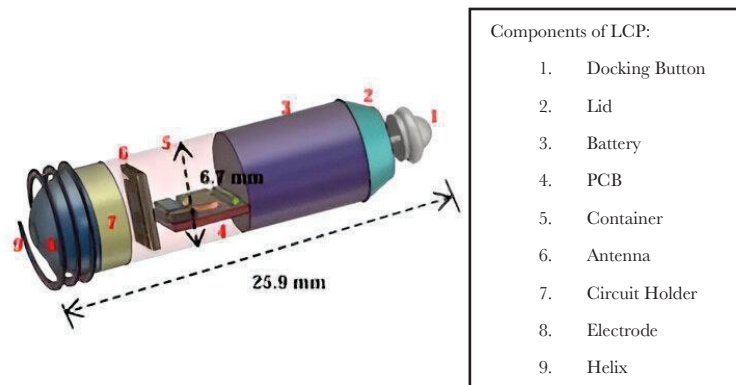


Figure 5.1 Schematic diagram of the LCP and its components
(Source: Paramasivam et al., 2023)

One critical aspect of active IMDs is biotelemetry, facilitating communication between IMD antennas and external patient monitoring devices to monitor patients' heart rates. Developing antennas for LCP systems requires careful consideration of several factors. One key factor is the space available inside IMD devices for accommodating the antenna. Ultra-small IMDs like Nanostim LCP and Micra TPS have limited space, which poses challenges for antenna integration.