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Introduction: Toward Biomedical Applications

1.1 Biomedical Devices for Healthcare

The advancement in healthcare and health monitoring technologies has closely paralleled the overarching trajectory of human civilization. In ancient China, for example, practitioners of traditional medicine utilized methodologies such as observation, auditory examination, inquiry, and pulse diagnosis—referred to as "*Wang, Wen, Wen, Qie*"—to determine an individual's health status. These practices, marking the earliest recorded instances of health monitoring, underscored the importance of examining physical manifestations, listening to patients' reported symptoms, inquiring about their medical history, and palpating their pulse in the diagnosis and treatment of various health conditions. Though these methods hinged on subjective assessments, they established an understanding of the crucial linkage between external physical signs and internal health conditions.

With the advent of revolutionary technological and medical breakthroughs, we have embarked on a remarkable journey toward a more precise, quantitative characterization of human health and disease states. This entails harnessing an extensive array of physical, electrical, and chemical indicators in a quest for precise and quantitative comprehension [1] (Figure 1.1). This transition, marking the dawn of modern, data-driven medicine, spurred the development of advanced biomedical devices [2]. These devices integrate sophisticated sensing technologies, data analysis algorithms, and wireless communication capabilities, paving the way for precise and continuous health monitoring [3].

Physical indicators tied to human health include metrics such as heart rate and pulse, which can be gauged through the detection of bodily mechanical movements. Electrical indicators involve signals generated by potential differences within the human body, such as electrocardiograms (ECGs), electroencephalograms (EEGs), and electromyograms (EMGs). These electrical signals reflect the electrical activity of the heart, brain, and muscles, respectively, offering valuable insights into the functionality of these vital organs and our overall physiological state.

Chemical indicators, including metrics such as blood oxygen saturation and glucose levels, provide crucial insights into metabolic activities and bodily functions. These parameters are measured using specialized sensors and analytical techniques, facilitating the early detection and proactive management of a myriad of health conditions, ranging from respiratory disorders and cardiovascular diseases to diabetes.

Antennas and Wireless Power Transfer Methods for Biomedical Applications, First Edition.
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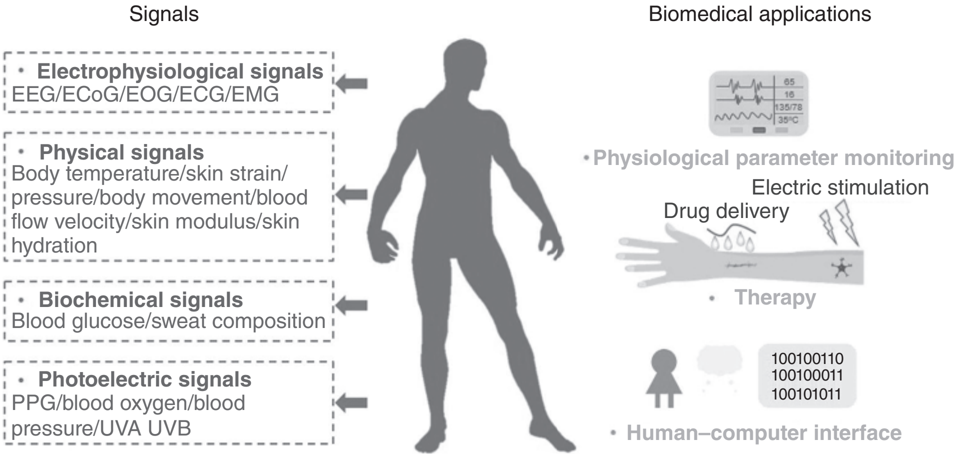

Figure 1.1 Physical, electrical, and chemical indicators for a human body. Source: Chen et al. [1]/Springer Nature/CC BY 4.0.

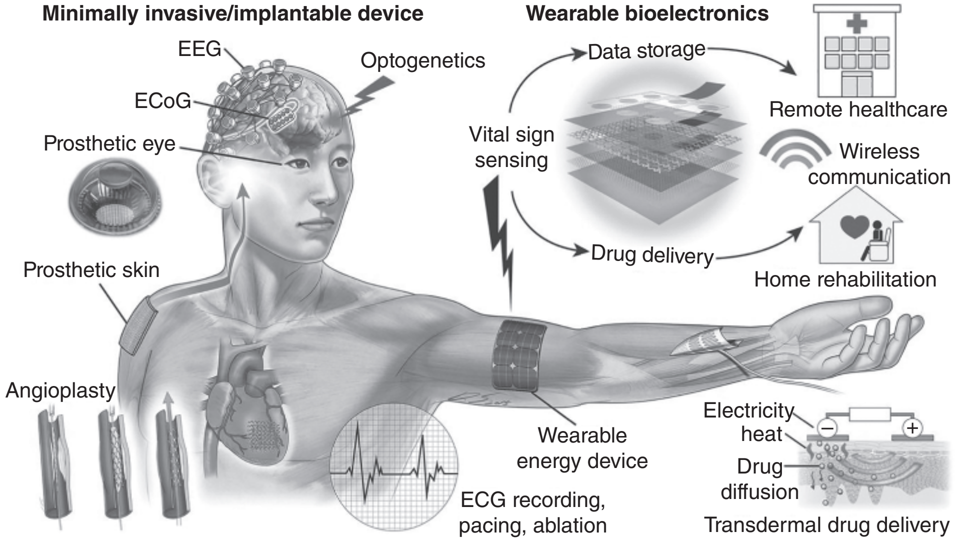

Figure 1.2 Biomedical sensors for health monitoring. Source: Choi et al. [3]/John Wiley & Sons.

The advent of biomedical devices has revolutionized healthcare by integrating these physical, electrical, and chemical indicators into comprehensive health-monitoring systems, as shown in Figure 1.2. Designed to measure, record, and analyze vital signs, these devices equip healthcare professionals with the data necessary to make informed decisions regarding patient diagnosis, treatment, and care. As technology continues to advance, biomedical devices are becoming increasingly miniaturized, accurate, and interconnected. This evolution not only enables individuals to actively monitor their health, but it also fosters the rise of personalized healthcare models, reshaping the healthcare landscape as we know it.

Over the years, the evolution of biomedical devices for healthcare has been marked by substantial advancements, primarily driven by the growing demand for accurate and tailored health-monitoring solutions. Initially, the focus of biomedical devices centered on recording basic vital signs, such as heart rate and blood pressure, using analog tools. However, the emergence of digital technology and the drive toward miniaturization have led to the transformation of these devices into intricate systems capable of monitoring a broad spectrum of physiological parameters [4].

The integration of sensor technologies [4], signal processing algorithms [5], and wireless communication capabilities [6] has spearheaded the development of wearable devices [7], remote health-monitoring systems [8], and implantable medical devices [9]. Wearable devices, such as fitness trackers and smartwatches, have gained significant popularity due to their ability to provide real-time monitoring of vital signs, physical activity, and sleep patterns. These tools empower individuals to keep track of their health and make informed lifestyle decisions.

Remote monitoring systems have brought about a revolution in healthcare, enabling medical professionals to remotely monitor patients' health status and intervene as necessary. These systems typically utilize wearable sensors, home-monitoring devices, and mobile applications, facilitating patients to transmit their health data to healthcare providers for analysis and timely intervention. This approach is especially beneficial for individuals with chronic conditions, the elderly, and those residing in remote locations, as it minimizes the need for frequent hospital visits, thereby enhancing overall healthcare accessibility and outcomes.

Implantable medical devices have also played a pivotal role in the advancement of healthcare. These devices are surgically placed inside a human body to monitor and manage specific medical conditions. Examples of such devices include pacemakers for regulating cardiac rhythm disorders, neurostimulators for controlling chronic pain or movement disorders, and implantable glucose monitors for diabetes management. These devices often incorporate wireless communication capabilities to facilitate data transfer and remote monitoring, enabling healthcare professionals to closely track patients' conditions and adjust treatment protocols accordingly.

The relentless advancements in technology, including miniaturization, improved power efficiency, and enhanced connectivity, have significantly broadened the capabilities of biomedical devices. Further, the integration of artificial intelligence and machine learning algorithms enhances the diagnostic and monitoring abilities of these devices, enabling early detection of irregularities, personalized treatment recommendations, and improved patient outcomes.

In the following sections, we will provide examples of some of the current state-of-the-art wearable and implantable medical devices. These devices showcase the advancements in technology and their potential to revolutionize healthcare.

1.1.1 Wearable Devices

As illustrated in Figure 1.3, wearable devices embody a multitude of forms, merging sophisticated sensing technologies with accessible and user-centric designs [10]. These devices offer an array of capabilities, granting individuals the opportunity to track their health

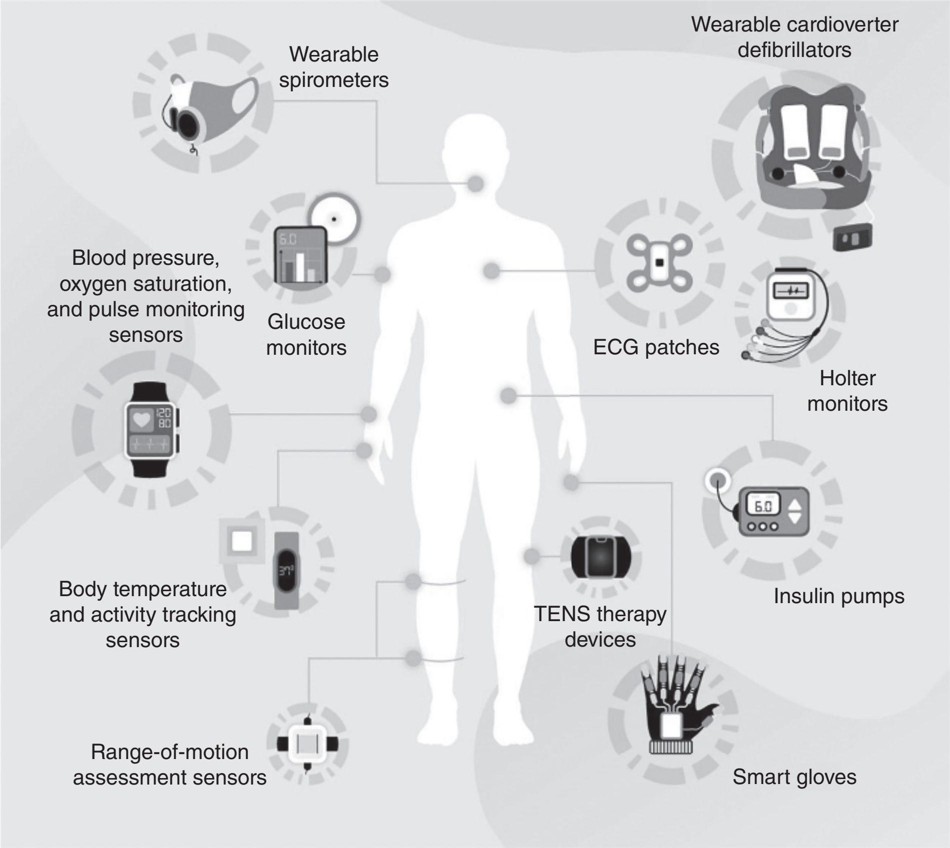

Figure 1.3 Wearable medical devices used in patient care. Source: Ref. [10].

indicators in real-time. Here, we delve into a variety of wearable devices, elucidating their distinct functionalities and application methods.

Wearable spirometers integrated with masks: Specifically designed for individuals managing respiratory conditions such as asthma or chronic obstructive pulmonary disease (COPD), these devices make measuring lung function parameters, including forced vital capacity (FVC) and forced expiratory volume in one second (FEV1), conveniently accessible [11]. The ability to track respiratory health, observe changes in lung function, and adjust medication or treatment plans accordingly equips users with a proactive approach to their health. Additionally, wireless communication technology facilitates data transmission to healthcare providers for remote monitoring and analysis, enabling prompt intervention and personalized care.

Wearable watches and wristbands with integrated blood pressure, oxygen saturation, and pulse monitoring sensors: These devices offer consistent monitoring of vital signs, including blood pressure, oxygen saturation levels, and pulse rate. Throughout the day, users can easily track these parameters, fostering early detection of any potential irregularities. This vital information is particularly useful for individuals managing hypertension, cardiovascular diseases, or respiratory conditions. Furthermore, wireless connectivity supports seamless transmission of vital sign data to healthcare professionals for remote monitoring, providing real-time feedback and proactive condition management [12].

Body temperature and activity tracking sensors**:** Devices equipped with temperature sensors and accelerometers empower users to monitor body temperature variations and track their physical activity levels [13]. These devices find versatile applications, including fitness tracking, sleep monitoring, and remote patient monitoring. With wireless connectivity, data is seamlessly transmitted to healthcare providers, allowing for remote assessments and personalized care recommendations based on collected data.

Upper arm wearable continuous glucose monitors **(*CGMs*):** For individuals managing diabetes, CGMs are invaluable. These devices consistently monitor glucose levels in interstitial fluid, reducing the need for routine finger pricks [14]. Real-time tracking of glucose levels equips users with better glycemic control and informed decision-making regarding insulin administration, dietary choices, and physical activity. The wireless connectivity of CGMs enables data transmission to smartphones or dedicated receivers, supporting remote monitoring by healthcare providers and timely adjustments to diabetes management plans.

Thigh and calf wearable devices for range of motion assessment**:** In rehabilitation settings, these devices are useful for assessing joint mobility and tracking range of motion [15]. They typically incorporate sensors to capture muscle activity signals and motion data, evaluating progress for patients with musculoskeletal conditions or those recovering from joint surgeries. These devices' wireless communication capabilities allow collected data to be transmitted to healthcare professionals for remote assessments and guidance, thereby enabling personalized rehabilitation plans and timely adjustments.

Wearable transcutaneous electrical nerve stimulation **(*TENS*)** ***therapy devices*****:** These devices offer non-invasive pain relief by administering electrical stimulation to specific body areas. Frequently utilized for managing chronic pain conditions such as back pain or arthritis, users can adjust the intensity and frequency of the electrical stimulation to their needs. With the integration of wireless communication technology, TENS devices can be remotely controlled and monitored, enhancing pain management convenience and effectiveness [16].

Insulin pumps**:** These wearable devices provide individuals with type 1 diabetes or insulin-dependent type 2 diabetes with a consistent, precise insulin delivery method throughout the day [17]. Typically worn on the body, these pumps offer continuous insulin infusion, eliminating the need for multiple daily injections. Their wireless connectivity supports remote monitoring of insulin delivery, facilitating personalized insulin dose adjustments, and easing diabetes management.

Smart gloves [18]**:** Particularly beneficial for rehabilitation purposes, these gloves assist individuals with hand injuries or neurological conditions affecting hand movements. Incorporating sensors that capture hand movements, smart gloves offer real-time feedback and guidance during rehabilitation exercises. The wireless connectivity enables remote monitoring by healthcare professionals and supports personalized rehabilitation plans and progress tracking.

Holter monitors and ECG patches**:** These wearable devices provide long-term ECG monitoring. While Holter monitors [19] are typically portable devices, ECG patches

[20] are adhesive patches that adhere directly to the skin. Both continuously record the heart's electrical activity over an extended period, facilitating the detection and analysis of abnormal cardiac rhythms or arrhythmias. Their wireless connectivity allows for remote monitoring and immediate intervention in case of critical events.

Wearable cardioverter defibrillators **(*WCDs*)** [21]**:** These external devices continuously monitor the heart's electrical activity, prepared to deliver a shock to restore normal heart rhythm in the event of a life-threatening arrhythmia. WCDs are prescribed for individuals at high risk of sudden cardiac arrest, providing temporary protection until definitive treatment can be administered. The wireless connectivity enables remote monitoring by healthcare professionals, ensuring prompt detection of arrhythmias and appropriate intervention.

These wearable devices underscore the transformation of healthcare through technology, empowering individuals to monitor their health metrics, manage chronic diseases, and facilitate remote healthcare collaborations. The incorporation of wireless communication technology enables seamless data transmission, remote observation, and personalized healthcare provision. As the wearable devices field continues to progress, we can look forward to more sophisticated advancements in miniaturization, precision, and connectivity, heralding a new era of personalized and preventive healthcare.

1.1.2 Implantable Devices

As depicted in Figure 1.4, implantable devices are meticulously engineered for surgical implantation within the body, providing enduring therapeutic advantages and substantially enhancing the quality of life for patients. In this segment, we delve into a variety

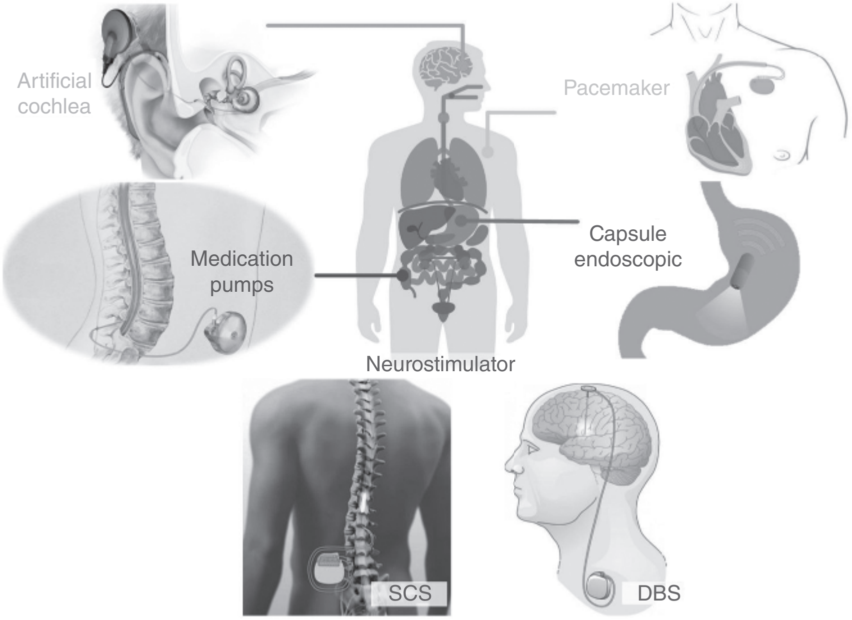

Figure 1.4 Implantable medical devices used in patient care. Source: Mayo Clinic.

of implantable devices, including pacemakers, artificial cochlea, medication pumps, capsule endoscopic systems, and neurostimulators, such as Deep Brain Stimulation (DBS) and Spinal Cord Stimulation (SCS).

Pacemakers: Utilized to manage abnormal heart rhythms or combat bradycardia (a slow heart rate), pacemakers are implantable devices comprising a compact electronic unit and one or more leads that dispatch electrical impulses to the heart muscle, aiding in maintaining a regular heartbeat [22]. They incessantly monitor the heart's electrical activity and deliver stimulation as needed. Tailored to individual requirements, pacemakers can be programmed and adjusted remotely due to advancements in wireless communication technology, thus permitting healthcare providers to ensure optimal device performance.

Artificial Cochlea: More commonly known as cochlear implants [23], these devices are designed to restore auditory sensation in individuals experiencing severe to profound sensorineural hearing loss. The system includes an external speech processor and an internal electrode array that is surgically positioned inside the cochlea. The speech processor captures auditory inputs and converts them into electrical signals. These signals bypass damaged or dysfunctional hair cells in the ear, stimulating the auditory nerve directly, thereby facilitating the perception of sound. Each cochlear implant system is highly personalized, with programming fine-tuned to align with the specific auditory requirements of the individual. Cochlear implants utilize wireless energy and data transmission, enabling efficient communication between the external speech processor and the internal electrode array. The processed audio signals, including speech and environmental sounds, are wirelessly transmitted from the speech processor to the internal electrode array. This electrode array then translates the received signals into electrical impulses, which are delivered to different sections of the auditory nerve, thus simulating the sensation of sound.

Medication Pumps: Also referred to as drug infusion systems, these implantable devices offer controlled and continuous delivery of medication directly into specific body regions or systems [24]. Often used to manage chronic pain, spasticity, or conditions necessitating long-term medication administration, these programmable pumps allow healthcare providers to adjust the dosage and delivery rate based on patient needs. The implantation site varies according to the target area of the medication. Wireless communication technologies enable remote dosage monitoring and adjustment.

Capsule Endoscopic Systems: As a minimally invasive diagnostic tool, capsule endoscopy employs a wirelessly enabled, ingestible capsule embedded with a camera to visualize the interior of the gastrointestinal tract [25]. Upon ingestion, the capsule journeys naturally through the digestive system, capturing images and subsequently transmitting them wirelessly to an external receiver worn by the patient. Given the need for real-time and high-definition image transmission from within the body to the receiver, capsule endoscopic systems pose rigorous demands on wireless communication bandwidth and power consumption. The transmission speed must be sufficiently high to relay quality images without substantial delay or data loss. Additionally, considering that the capsule's voyage through the entire gastrointestinal tract can span several hours, power efficiency becomes critical to ensure the capsule's operation duration and consistent image transmission throughout the procedure. Capsule endoscopic systems provide a non-invasive, patient-centered alternative for diagnosing various gastrointestinal conditions such as Crohn's disease, ulcers, and tumors, particularly in hard-to-reach areas such as the small intestine, traditionally challenging to access with standard endoscopic techniques. By eliminating the necessity for invasive procedures or sedation, capsule endoscopy reduces patient discomfort and minimizes potential complication risks. The wireless communication functionality within these systems facilitates seamless data transmission from inside the body, equipping healthcare professionals with in-depth, accurate visual data necessary for diagnosis and treatment planning.

Neurostimulators**:** These implantable devices, designed to deliver electrical impulses to particular nerves or brain regions, are employed in the treatment of diverse neurological conditions. Techniques such as DBS [26] can alleviate symptoms associated with movement disorders such as Parkinson's disease or essential tremor. In contrast, SCS [27] is used to manage chronic pain conditions by sending electrical stimulation to the spinal cord. Neurostimulators are highly customizable, offering programmable parameters to meet individual patient needs. Alongside their therapeutic functionality, neurostimulators have evolved to incorporate sophisticated features for monitoring and data transmission. For instance, certain closed-loop neurostimulators [28–30] come with physiological sensing capabilities, including the ability to record EEG signals, making them indispensable tools for both scientific research and clinical applications in the realm of brain–computer interfaces. Consequently, these systems have necessitated the transmission of substantial amounts of physiological data from within the body to an external receiver, similar to the demands of capsule endoscopy systems.

Each of these implantable devices brings distinct advantages to the field of healthcare, representing the continuous advancements in medical technology that provide targeted treatment options, enhanced patient outcomes, and improved quality of life. With the integration of wireless communication technologies, these devices offer expanded functionality and improved usability, enabling remote monitoring, customized adjustments, and personalized care. As the research and development of implantable devices progresses, we anticipate further innovations and enhancements in their capabilities, opening up new possibilities for advanced patient care.

1.2 Wireless Date Telemetry and Powering for Biomedical Devices

In the section above, we delved into the world of wearable and implantable medical devices. Observing from a functional standpoint, we found that wireless communication is integral to these devices, facilitating not only the transmission of data but also enabling the adjustment of device parameters, remote monitoring of device status, and tracking of human physiological indicators. In addition, considering the devices' long-term power needs, wireless powering technologies have emerged as a significant focus in their system integration. However, as these devices continue to decrease in size, both wireless communication and power transfer are met with considerable challenges.

1.2.1 Wireless Data Telemetry for Biomedical Devices

Wireless data telemetry is fundamental in the creation of wireless communication systems for biomedical applications [31]. A wide array of wireless communication techniques have

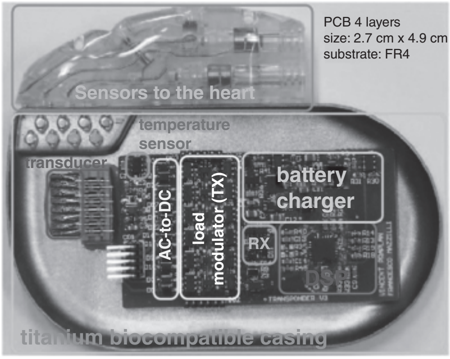

Figure 1.5 Ultrasonic LSK (load shift keying) modulator for uplink communication in deep implanted medical devices. Source: Mazzilli et al. [32]/from IEEE.

been utilized in these systems, encompassing sound (ultrasound), light (near-infrared), electric fields (near-field capacitive coupling), magnetic fields (near-field inductive coupling), and radio frequency (RF) waves (far-field electromagnetic wave radiation). Each carrier waveform presents distinct advantages and is applied according to specific scenarios, mainly determined by the physical attributes of the carrier.

Ultrasound acts as a conduit for the transmission of mechanical vibrational energy, facilitating the conveyance of both power and information. By employing piezoelectric transducers, energy from ultrasound can be harvested, sparking extensive exploration on its use in wireless power transmission and communication for implantable devices. Notably, in 2014, Mazzilli et al. [32] achieved simultaneous wireless power transmission and uplink wireless communication on a Kinetra neurostimulator manufactured by Medtronic, as shown in Figure 1.5. Implantable wireless communication using ultrasound is especially beneficial for low data transmission rates and deep implantation scenarios. However, attaining high data transmission rates and reliable wireless connections over long distances often proves challenging.

Implantable near-infrared wireless communication technology leverages light waves as carrier waves. Thanks to the broad-spectrum properties of light waves, they hold potential for high data transmission rates in implantable wireless communication [33]. Moreover, as light waves can be physically isolated from low-frequency electromagnetic waves, mitigating mutual interference, wireless data transmission, and power transmission can be independently managed in implantable devices using this technology. Recent advances in near-infrared wireless communication technology for biomedical applications demonstrate the potential for ultra-low power consumption and high-speed transdermal wireless communication, as depicted in Figure 1.6. Yet, the transition of implantable near-infrared wireless communication technology toward clinical applications and widespread adoption depends on the resolution of issues related to short transmission distances and system reliability.

Near-field coupled implantable wireless communication primarily employs near-field magnetic coupled links (inductive links) and capacitive coupled links (capacitive links) for transdermal data transmission, as illustrated in Figure 1.7. Characterized as a short-range

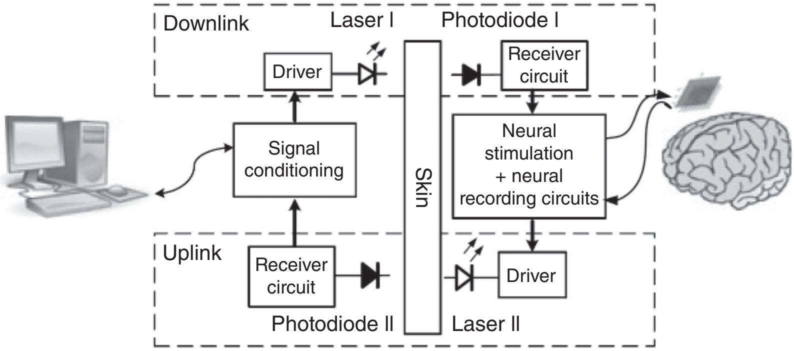

Figure 1.6 Block diagram of bidirectional optical transcutaneous link for brain–computer interface. Source: Liu et al. [33]/John Wiley & Sons.

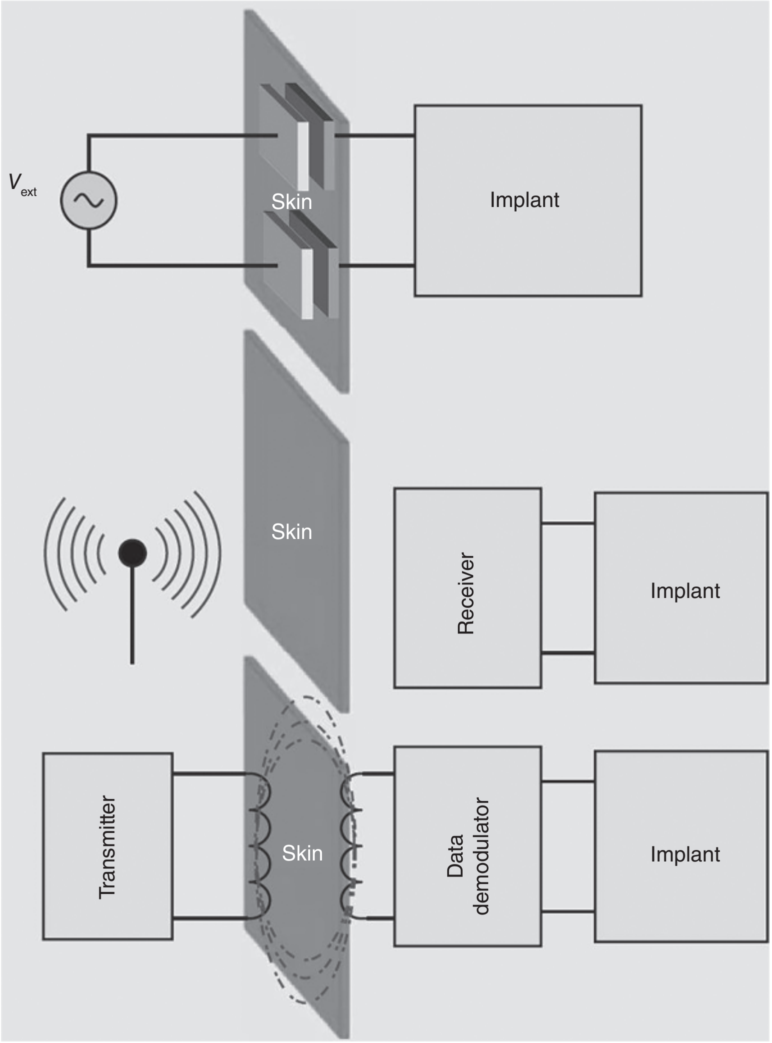

Figure 1.7 Electromagnetic data link: near-field capacitive links, far-field RF links, and near-field inductive links. Source: Bihr et al. [34]/IEEE.

wireless communication, its communication distance is termed as the “touch range” by researchers [35]. Owing to its limited communication distance, it is less suited for scenarios demanding long-distance wireless connections.

Magnetic coupled links, which are conventional implantable wireless communication links, are widely adopted for parameter modifications in various devices such as cardiac pacemakers, neurostimulators, and cochlear implants. These links are often employed for implantable wireless charging, allowing for energy-bearing communication, which makes them a popular choice for most implanted medical devices [36]. The key drawbacks of magnetically coupled links lie in the bandwidth constraints dictated by the low-frequency carrier, which hampers the enhancement of communication speed, and the limited reliable communication range stemming from the nature of magnetic coupling.

Capacitive-coupled links have only recently piqued scholars’ interest, with no reported clinical applications to date. In capacitive-coupled links, the electric field between the internal and external electrodes is leveraged for wireless transmission of power and data [37]. Their transmission characteristics are dictated by the impedance features of the electrodes and human tissue [38]. Given that the RF electric field is well confined between the internal and external electrodes—unlike in traditional magnetic coupled links where the electromagnetic flux is dispersed around the implanted coil—capacitive coupled links experience less energy loss. However, the configuration of the internal and external electrodes has a substantial impact on system reliability, posing challenges for the clinical application of capacitive coupling transcutaneous wireless communication technology. As wearable flexible electronic technology advances, the application of this communication technology may progressively come into play.

RF communication technology surpasses distance limitations, facilitating meter-level range wireless communication. The majority of external devices employ RF communication for wireless connections, allowing implantable medical devices and wearable devices equipped with RF communication technology to establish direct connections with other external devices. Hence, in the near term, RF communication technology emerges as the go-to wireless communication solution for implantable medical devices and wearable devices. However, due to interactions with the human body, the application of RF communication technology in biomedicine necessitates particular attention to the key technical area: implantable and wearable antenna technology.

Among the discussed wireless communication methods, RF and near-field coupling (capacitive and inductive) are most frequently employed in biomedical applications. However, antenna design for these communication forms presents several challenges. Miniaturization stands as a primary challenge considering the limited space within implantable devices. Also, due to factors such as tissue absorption, antenna efficiency often proves low. Optimizing the antenna design requires addressing issues such as broadband impedance matching around and post-implantation, polarization matching with external communication devices, and impedance matching with the human body. Integration with RF modules and hardware systems, as well as the choice of antenna type (single-ended or differential), are crucial. Flexibility in design and the use of biocompatible materials for wearable device integration also warrant consideration.

1.2.2 Wireless Power Transmission for Biomedical Devices

Wireless power transmission for biomedical applications aims to address the power supply issue in implantable devices. Traditional implantable medical devices often rely on batteries for power, but the need for frequent battery replacement due to device functionality and limited lifespan can be inconvenient and time-consuming. Therefore, wireless power transmission technology has been introduced to provide continuous power supply to implantable devices.

One prevalent method for wireless power transmission in biomedical devices is inductive coupling [36]. This involves power transfer between two coils, specifically the transmitter coil and the receiver coil. The transmitter coil, typically located outside the body, generates an oscillating magnetic field, which induces a voltage in the receiver coil implanted within the body. This induced voltage is subsequently rectified and used to power the implanted device. Resonant coupling provides an alternative mechanism for wireless power transmission [39]. This method exploits the resonance phenomenon between the transmitter and receiver coils to achieve efficient power transfer. By synchronizing the frequencies of the transmitter and receiver coils, energy transfer can be markedly boosted. This technique enhances power transmission efficiency and bolsters the overall performance of the implanted devices (Figure 1.8).

Nonetheless, several challenges are associated with wireless power transmission for biomedical devices. A significant issue is the limited power transmission distance. As the gap between the transmitter and receiver coils widens, power transfer efficiency drops. Hence, optimizing the design and positioning of the coils is paramount to maximize power transmission efficiency and ensure reliable operation of the implanted devices.

Additionally, factors such as tissue properties and electromagnetic interference can affect the efficiency of wireless power transmission. Human body tissues present varying degrees of conductivity and dielectric properties, which can lead to energy losses and diminish power transmission efficiency. Counteracting these losses and minimizing the effect of electromagnetic interference are crucial design considerations in wireless power transmission systems for biomedical devices.

Moreover, the biocompatibility of materials used in the wireless power transmission system is vital to guarantee the safety and functionality of the implanted devices. The materials

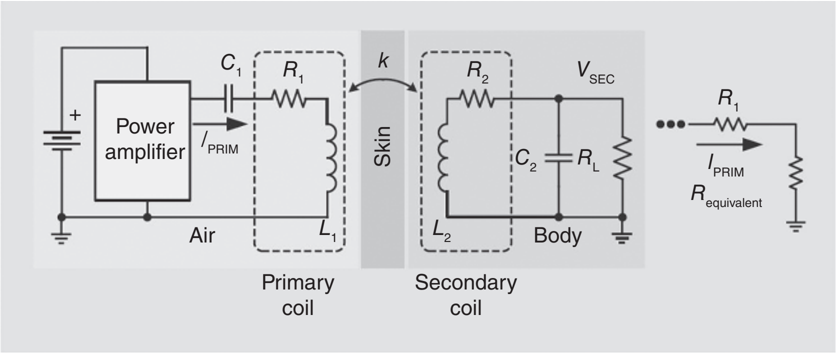

Figure 1.8 Resonant inductive link for implants. Source: Xu et al. [39]/IEEE.

should be biocompatible, nontoxic, and stable within the body to avert any adverse reactions or long-term complications.

Wireless power transmission presents a promising solution for powering biomedical devices. It affords the advantages of extended operation, convenience, and minimized risks tied to invasive surgeries. Overcoming the hurdles of limited power transmission distance, tissue effects, and material biocompatibility is crucial for the successful application of wireless power transmission in biomedical devices. Continued research and advancements in this field are expected to further augment the efficiency and dependability of wireless power transmission systems for biomedical applications.

1.3 Overview of Book

As previously highlighted, biomedical devices have significantly revolutionized our health-monitoring capabilities, disease diagnostic methodologies, and treatment options. In these advancements, wireless technology has played an indispensable role. This book's objective is to offer a comprehensive overview of the application of wireless technology solutions in biomedical devices, laying emphasis on the research contributions of our team in this domain, especially in the areas of antenna design and wireless charging. The book unfolds across the following chapters:

Chapter 2 introduces the design and development of compact, wideband, and multi-frequency band-compatible implantable antennas. It sheds light on the challenges and breakthroughs in antenna design for biomedical applications, tackling topics such as miniaturization, impedance matching, and bandwidth optimization.

Chapter 3 presents designs and techniques for achieving desirable polarization in implantable antennas. It emphasizes the crucial role of polarization matching in ensuring reliable wireless communication in biomedical devices. The chapter discusses various polarization design strategies and their respective influences on system performance.

In Chapter 4, differential-fed implantable antennas are explored. The chapter discusses the benefits and challenges tied to differential-fed antennas and their application in biomedical devices. It encompasses the design principles, impedance matching techniques, and performance evaluation of differential-fed antennas.

Chapter 5 presents wearable antennas designed to facilitate communication between on-body and off-body devices. It explores the design considerations, challenges, and advancements in wearable antenna technologies.

Chapter 6 examines the utilization of capacitive human body communication (HBC) for wireless data transmission. It delves into the principles, modeling techniques, and challenges associated with HBC, covering topics such as channel modeling, modulation strategies, and signal processing techniques for capacitive HBC systems.

Chapter 7 immerses into near-field wireless power transfer techniques for biomedical applications. It discusses the principles, design considerations, and performance evaluation of near-field power transfer systems. The chapter also scrutinizes the challenges associated with power transmission efficiency, coil design, and positioning for reliable and safe wireless charging of implantable devices.

In Chapter 8, the focus is on far-field wireless power transmission for biomedical applications. It explores the principles, system design, and challenges tied to long-distance power transmission, covering topics such as energy-focusing techniques, power optimization, and safety considerations for far-field wireless charging systems.

Chapter 9 illustrates a system design example concentrating on peripheral nerve implants and neurostimulators. It offers a detailed analysis of the design considerations and integration challenges in such systems. The chapter also includes practical examples and case studies to demonstrate the application of wireless technology in peripheral nerve implants and neurostimulators.

Each chapter in the book is fortified with research findings, case studies, and practical insights, providing a thorough understanding of the advancements, challenges, and practical applications of wireless technology in biomedical devices. The book aims to serve as a valuable compendium for researchers, engineers, and healthcare professionals involved in biomedical technology and wireless communication.

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