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Simultaneous Wireless Power and Data Transfer in Different Applications

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Abstract. In Modern Era, the demand for wireless technology has surged exponentially, promising enhanced living comfort and safety. Simultaneous Wireless Power and Data Transfer (SWPDT) has emerged as a critical area of study, finding applications in electric vehicles, underwater autonomous vehicles, and biomedical implants. This technology facilitates real-time monitoring while supplying power, eliminating the need for bulky cables and conventional power sources. Hence this paper addresses the state-of-art of SWPDT in different applications This comprehensive review covers various SWPDT implementation methods for applications like electric vehicles, biomedical implants, and autonomous underwater vehicles. Different techniques for implementation of SWPDT using inductive links and its design recommendations.

1 Introduction

In recent years the need for wireless technology has taken an exponential rise as it enhances the living comfort of human as well as guarantees riskless life. It prevents the need of bulky and messy cables, batteries which consumes much space on board that are poorer to handle in many applications from Electric vehicles [1] to home appliances. Simultaneous Wireless power and data transfer (SWIPDT) has become a major field of study in implementation of wireless technology in many applications like on-road electric vehicles, autonomous underwater vehicles for deep surveillance in water, bio-medical implants inside a human body. SWIPDT helps to monitor the status of model while supplying power to it. Previously renewable power sources like solar energy for Ev's [3], thermal energy for autonomous underwater vehicles [4] and bio-medical implants has been used in various applications to powerup the devices and which omit the use of cables in these applications but the availability of these sources is depended on the certain conditions and surrounding

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environment which emphasis the scientist to switch from renewable source to Electromagnetic and acoustic charging

It is a technology that enables the transfer of electrical power from a power source to an electronic device without the need for physical connectors or cables. This innovative approach relies on electromagnetic fields to transmit energy between a charging pad or station and a compatible device. The process involves two main components: a transmitter coil in the charging pad and a receiver coil integrated into the device to be charged. When the device is placed on the charging pad, the alternating current in the transmitter coil generates an electromagnetic field, inducing a current in the receiver coil of the device [5]. This induced current is then converted back into electrical power, charging the device's battery. Wireless charging offers the convenience of eliminating the need for traditional wired connections, providing a seamless and efficient way to power up various devices, such as smartphones, smartwatches, and even electric vehicles. While the technology has become increasingly popular, ongoing advancements continue to enhance its efficiency, compatibility, and integration into a variety of electronic devices.

Yet, data transfer between primary and secondary side is essential for tracking system behaviour. As a result, in wireless charging domain sharing of the information is frequently required for various purposes such as data collection and transmission to base station for underwater auv surveillance, monitoring the activities of muscles in the application of bio-medical implants, status of the battery, load detection, emergency message in case of electric vehicle. If the system is charged wirelessly, then the data transmission must also be conducted in a similar way, to ensure that information exchange does not make the charging process intricate [5]. Numerous non-contact data transfer techniques like: Bluetooth [6], WiFi , Zigbee [7] or 802.1 which occur in 2.4 GHz band, and relatively high data transmission rate can be achieved by utilizing these techniques but they do possess some major drawbacks like these high frequency data transfer techniques cannot be use for underwater application due to increase in eddy currents in sea water, obstruction from other devices, improper connection or antenna breakdown which prevents the system from functioning properly. In the case of Bluetooth, attackers employ various methods such as Blue-snarfing [10] to compromise devices. These vulnerabilities can have implications for both the charging infrastructure and the system themselves. The accurate pairing process between devices is also identified as a potential point of cyberattack. For 802.11 (Wi-Fi), techniques like Packet Sniffers can be exploited by attackers to gain unauthorized access and intercept data circulating through the network. Threats include Eavesdropping, data manipulation, or injection are related to ZigBee. Notably, these attacks can be executed using low-cost devices that are easily accessible to potential attackers. The overall implication is that these cybersecurity issues pose a risk to the confidentiality and integrity of data within the charging infrastructure, potentially compromising the security of the vehicles and the personal information of their drivers. Apart from these technologies acoustic power and data transfer is also taken into consideration to implement SWPDT where the power and data signals are transmitted in the form of ultra-sonic waves. Since ultrasonic wavelengths are smaller than electromagnetic wave-lengths they can be helpful for incorporating SWPDT for deep biomedical implants and for underwater environment. It considered to be one of the safest approaches for wireless energy transfer when compared to others in addition to this it possesses high penetration depth in the frequency range of 10MHz. Communication through wireless coils can also be considered to implement SWPDT system where the power and data signals are transfer through inductive coils where the electro-magnetic signals are used for data and power transfer through wireless channel [11]. Thus, this paper provides a thorough review of different techniques uses to implement simultaneous wireless power and data transfer has been performed for applications such as electric vehicles, bio-medical implants and underwater autonomous vehicles. In section-2 a brief overview of different methods uses to implement wireless power transfer is studied while in section-3 a survey on previous research made on SWPDT for EV's, AUV's and bio-medical implants is present. In section-4 various techniques use to implement SWPDT using inductive links is discussed and the recommendation to implement the same in different applications.

2 Wireless Power Transfer

Wireless Power Transfer (WPT) stands as a transformative technology that has been a part of our technological landscape for decades, weaving its way through applications such as telemetry, satellite communications, and radio frequency identification (RFID) tags. While historically associated with the transfer of low amounts of power, measured in microwatts to milliwatts, for data transfer purposes, recent industrial developments have shifted the focus toward higher-power applications spanning from a few watts to several kilowatts, covering moderate distances. It is a technology which deals with transmission of electrical energy without any physical link. It can be broadly classified into two i.e., Acoustic power transfer and Electromagnetic field power transfer. In the late 19th and early 20th centuries, the visionary inventor Nikola Tesla conceptualized the revolutionary idea of wireless power transmission through the utilization of electromagnetic fields. Tesla's groundbreaking experiments with resonant inductive coupling laid the groundwork for future endeavors in wireless power transfer (WPT). The mid-20th century saw significant strides in resonant inductive coupling, a technology Tesla had experimented with, leading to the emergence of inductive charging systems. The commercialization of this technology became evident in everyday applications, notably with electric toothbrushes, marking a crucial development in the late 20th century. In the year 2010 the establishment Qi standard results in the foundation of a standard framework for wireless charging technology for various consumer products such as mobile phones, electric toothbrush [12]. Simultaneously, the exploration of acoustic fields for wireless power transfer has a more recent history. In Prior studies the acoustics waves are usually used to transmit the data signals especially for the application of underwater sonar communication but it wasn't untill early 2000's the field of acoustic energy has expanded its application in the field of wireless power transmission. It turns out to be a major technology in efficient and safe power transfer in the challenging conditions such as deep-sea exploration for and interior monitoring of the human body.

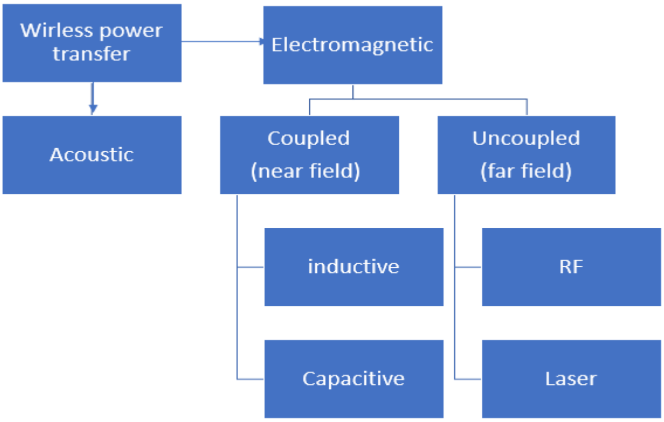

Fig 1. Wireless Power Transfer

As depicted in figure-1 WPT can be broadly classified into two i.e., Acoustic power transfer and Electromagnetic field power transfer. Electromagnetic field power transfer is sub-divided into coupled and uncoupled techniques. Coupled techniques, such as magnetic inductive coupling, depend on the close alignment and proximity of coils in the transmitter and receiver for efficient power transmission while resonant inductive coupling tackles this drawback by using resonant circuits to improve overall efficiency. It works on the principle of Faraday's law of Electro-magnetism and ampere's law. Earlier it finds the applications in the low power applications such as mobile phones, electric tooth-brush but the advancement of these technology has paved the way to introduce its applications in high power system such as electric vehicles where the distance between both coils measure to around mm to cm. For short distance applications capacitive coupling power transfer is the most preferred one where the energy is transferred wirelessly by the means of electric field. Operating frequencies varies from kHz to MHz as these technologies are considered to be working in the near field region [57]. Uncoupled techniques such as radio frequency and laser power transmission eliminate the need of direct coupling between the receiver and transmitter of the system. These technologies are use when the distance between the transmitter and receiver is in the range of m to Km and uses high operating frequencies which comes under far-field region. It usually finds its application in space where the power is transmitted with the clear line of sight and using high frequency energy waves which can be harmful for the living creature. Hence far-field power transmission is mostly avoided in the applications such as electric vehicles, bio-medical implants, underwater AUV

Acoustic power transfer utilizes the sound energy to transmit the signals to its targeted system during this process the required electrical energy is converted into the sound waves by the means of a transducer such as piezoelectric device at the transmitting end then the converted sound energy travels through wireless medium such as water, air or biological tissues and the receiver extract the required electrical energy from these sound signals using a suitable transducer. This technology has created a great positive impact in transmission of energy in a wireless manner especially in the harsh conditions such as deep-sea exploration where traditional electromagnetic waves attenuate due to increase in the eddy currents of the sea water.

Table 1. Characteristic of Wireless Power Transfer.

WPT Technology	Power transfer Capacity	Range	Frequency	Biological impact
Inductive	Watt to Mega Watt	mm	kHz to MHz	Minor
Capacitive	Watt to Kilo Watt	mm/cm	kHz to MHz	Minor
Laser	Watt/Kilo Watt	m/km	>THz	Significant
Radio frequency	Milli Watt/Kilo Watt	m/km	MHz to GHz	Significant
Acoustic	Milli Watt/Kilo Watt	m/cm	kHz to MHz	Significant

Table 1 represents a comparative overview of various Wireless Power Transfer (WPT) technologies, highlighting their key characteristics in terms of power transfer range, frequency range, efficiency, and potential biological impact. In this comparison, each WPT technology is assessed based on its power transfer capabilities, transmission distances, operating frequencies, efficiency levels, and potential impact on biological systems.

3 Simultaneous Wireless Power and Data Transfer (SWPDT)

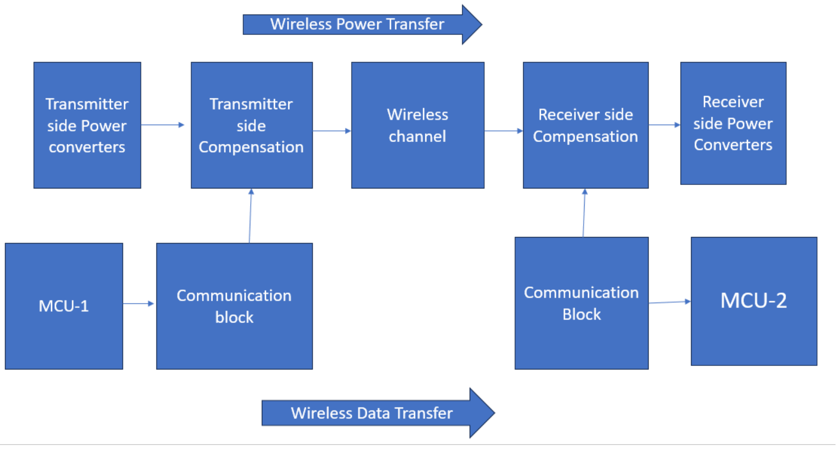

Fig 2. Block diagram for Simultaneous Wireless Power and data Transfer System

Figure 2 represents the overview of SWPDT system the upper part represents the blocks of wireless power transfer system while the lower part of the block diagram depicts the wireless data transfer where MCU stands for microcontroller unit. In recent years WPT technology has found widespread application in diverse fields, including electric vehicles, mobile phones, wireless sensors, medical equipment, and robotics [13][14][15][16]. The seamless integration of WPT has not only revolutionized the way we power our devices but has also emphasise the need to monitor the system in a continuous and proper manner to ensure an efficient and safe power transfer in its applications.

In practical applications of WPT, the need for simultaneous wireless power and data transfer (SWPDT) has emerged as a critical requirement. SWPDT plays a pivotal role in facilitating the bidirectional communication between the transmitter and receiver sides. This bidirectional data transmission is essential for implementing crucial functionalities such as feedback control of power flow, real-time state monitoring of the system, and the detection of load and foreign objects, in some applications such as bio-medical implants it can be used to monitor the critical condition of the patient body and take appropriate steps without the need of frequent surgeries. These reasons emphasis the need for SWPDT solutions which can results in a significant advancement in the field of wireless technology. Hence in the next section a brief survey of recent research on state-of-art of implementation of simultaneous wireless power and data transfer system (SWPDT) for different applications has been covered where practical applications such as electric vehicles, biomedical implants and underwater autonomous vehicles are considered.

4 SWPDT for Electric Vehicles

Simultaneous Wireless Power and Data Transfer (SWPDT) is an innovative approach aims to advance the way we charge EVs by combining wireless power transfer with real-time data communication. The integration of these two functionalities can overcome several challenges associated with traditional charging methods. SWPDT eliminates the need for physical and bulky cables which can be a reason for the frequent shocks to the users while handling it, hence providing a more organized and clutter-free charging experience. The WPT technology offers flexibility in terms of alignment, making the charging process more user-friendly. While the simultaneous data transfer enables continuous monitoring of an EV's performance through data exchange, facilitating real-time monitoring and predictive maintenance. These advancement of the technology plays a major role in the transitions of automated vehicles to the autonomous vehicles, where SWPDT can play a vital role in autonomous navigation to charging stations and seamless communication for updates and maintenance. Additionally, SWPDT opens the door to integration with smart grids, enabling optimized charging schedules and improved energy management. In conclusion, SWPDT in the application of EV technology represents a pivotal advancement, promising efficiency, convenience, and the seamless integration of power and data functionalities.

In [28] the author has analysed the SWPDT system in electric vehicles using near field resonant inductive method where the high-power signal at low frequency is super-imposed with low power data signal at high frequency. Here the author uses power line communication (PLC) method to implement transmission of wireless data with WPT. The objective is to facilitate accurate PLC signal transmission and reception through a WPT coils system. The schematic aims to prevent the PLC signal from passing through the converters. The power source is assumed to originate from the mains, featuring a superimposed PLC signal at the outlet. The WPT system serves a dual purpose: transmitting power to the load and enabling communication to the PLC Device. To separate the high-power signal at low frequency from, low-power PLC signal, a low-pass filter and a high-pass filter are employed, respectively. The power signal undergoes transformation to DC and is subsequently converted into a high-power sinusoid at the resonance frequency (f_o) of the WPT system. This transformation is achieved using a DC-to-radio frequency amplifier. The output of the RF amplifier is filtered through a band-pass filter centered at f_o to eliminate out-of-band noise generated by the amplifier.

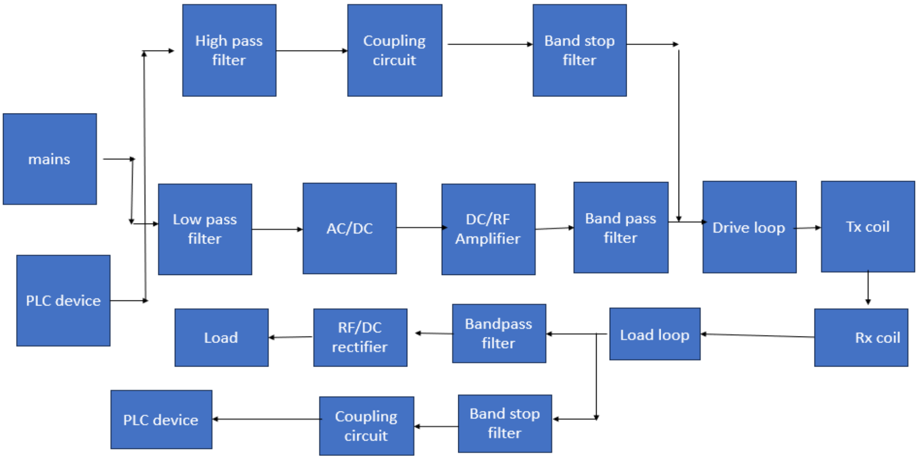

Fig 3. Block diagram of Simultaneous Wireless Power Transfer with PLC

Simultaneously, the PLC signal is coupled at the exit stage of the amplifier. To prevent the propagation of the high-power signal generated by the DC/RF amplifier through the PLC signal path, a band-stop filter with a narrow stop-band centered at f_o is employed. Consequently, the voltage source (V_{source}) at the input of the drive loop in Fig. 3 is represented by the sum of the high-power radio-frequency signal centered on f_o and the low-power PLC signal. The signal progresses to the load loop through the WPT resonators in alignment with the system's frequency response. At

the load loop's output, a band-pass filter centered at f_o isolates the power signal, directing it to an RF/DC rectifier that furnishes power to the DC load. Simultaneously, a band-stop filter centered at fo eliminates the power signal, allowing the extraction of the PLC signal. This PLC signal is then coupled to a PLC device.

The PLC device linked to the load loop can transmit data, propagating similarly from the RX coil to the TX coil as a low-power broadband signal. Notably, frequencies around f_o should be masked in the PLC protocols at the physical layer. This can be easily implemented in Home Plug AV devices utilizing the OFDM protocol. The band stop filters in these devices automatically mask frequencies with low signal-to-noise ratios, including those around f_o. In conclusion, it's significant to note that WPT systems are usually designed with two resonance frequencies, and one of the peaks is unused for power transfer. Consequently, the frequencies around this unused peak will be used for PLC communication [39]. The theoretical channel capacity of PLC can be calculated using Shannon-Hartley's law (1)

$$C = \int_0^B log_2(\frac{S(f)}{N(f)})df \qquad (1)$$

To overcome the drawback of low bit rate and channel interference the author [40] implemented SWPDT for electric vehicles using a plug-and-play toroidal-core inductor for injecting and extracting the data carrier. This design choice has significant implications as it decouples the communication hardware from the power hardware. The independence between these two components streamlines both the design and operation of the communication system, enhancing overall flexibility. The data transmitter employs a Class-E amplifier to achieve differential quadrature phase shift keying (DQPSK) modulation. To ensure simultaneous power and data transfer the author approaches to the frequency division multiplexing technique. In this approach, the author considers two data carriers of 5 and 6.25 MHz operate in parallel. This implementation realizes bidirectional full-duplex communication, allowing for simultaneous transmission and reception of data. FDM is known for its efficiency in optimizing bandwidth usage, making it suitable for enabling parallel communication channels. The proposed method was experimentally verified and a 3.3KW power and a full duplex communication with 64kbps is achieved at the load.

In [31] the author implemented a SWPDT system which establish a bidirectional V_2G and G_2V power transfer and data transfer for electric vehicles without the need of extra coils, introduce hamming codes and fuzzy logic control to improve robustness of communication system and compensate the problems caused by power change, misalignment of the coils and change in the distance between the transmitter and receiver. The SWPDT here is based on the principal of resonance. Two LC tanks are used on both the sides which are responsible for transmitting power, data and status. Two phase shift pulse width modulators (PSPWM) are used to create binary phase shift keying (BPSK) realising two QAM signal required for data transmission. When micro-controller at primary side MCU_{p1} receives G_2V command the PSPWM is used to change the voltage of primary side capacitor (v_{cp}) which will affect the secondary side capacitor voltage(v_{cs}). When v_{cp} drops to 33% it will modulate as digit '0'. MCU_{s2} uses v_{cs} and the period (T) of sync-VC_s to make decision. When v_{cs} is in between threshold S_{peak} and threshold S_{valley} it is recognised as $v_{cs\ modulation}$ (T_0) if v_{cs} exceeds the mentioned limits then it is treated as $v_{cs\ peak}$ (T1) where

$$ThresholdS_{peak} = \sqrt{{v_{cs\,peak}}^2} \qquad (2)$$

$$Threshold\ S_{valley} = \sqrt{{v_{cs\,modulation}}^2} \qquad (3)$$

T0 and T1 can be treated as digit ‘0’ and ‘1’ respectively. Hence the data transmission rate D_{TSR} can be defined as:

$$D_{TSR} = \frac{ND_{sd}}{ND_{pt}} \% \qquad (4)$$

ND_{Pt} is the number of data bytes transmitted at the primary side, and ND_{Sd} is the number of data bytes successfully decoded at the secondary side.

$$bup = 2T \qquad (5)$$

$$BR = \frac{2}{bup} \qquad (6)$$

Where T denotes the period. Based on the nominal operational frequency of 83KHz, the nominal bit rate will be 41.5kbps [30].

In [32] the author implemented SWPDT system through same inductive link using frequency division multiplexing the WPT system operating frequency is selected to be 22.4kHz while the data carrier frequency is selected as 1.6MHz. The proposed communication cell and power cell with primary and secondary side is magnetically coupled by the means of ferrite core inductors and SP compensation topology is use to implement the resonance condition between the primary and secondary side. The results obtained while implementing the above proposed the method are 500W of power and 20kbs of data at the receiver side of the circuit. This method is suitable for high power WPT operating with low frequency system like Electric vehicle.

In [41] the author proposed the SWPDT system-based on hybrid methodology where data is transfer through capacitance way while the power is transfer through inductive coupling since the data is transferred via parasitic capacitance the need for additional coil is omitted which reduces the size of coupling structure. During the analysis of the system, it is observed that the entire transfer delay from input data to output data is around 5us which is very low when compared to traditional communication protocols like Zigbee, Bluetooth and RF communication. The implementation of the proposed method has resulted in the successful construction of a 40 W prototype, showcasing its practical viability. Notably, the achieved data transfer speed stands at an impressive 230 kbps, affirming the efficacy of the communication technology. Through rigorous experimentation, it has been demonstrated that the data transfer channel has minimal impact on power transfer. This finding underscores the robustness and independence of the communication and power transfer processes within the system.

Table 2. Recent research on SWPDT for Electric vehicles

Reference	Year	Methodology for SWPDT	Output power	Data rate
[41]	2018	Hybrid	40W	240kbps
[42]	2023	Inductive	1KW	1Mbps
[43]	2021	Inductive	150W	166.7Mbps
[44]	2020	Inductive	300W	500Kbps
[45]	2022	Inductive	100W	1Mbps
[46]	2023	Inductive	1.1KW	1Mbps

Table 2 present the recent research on implementation of SWPDT for electric vehicles application. The table provides an idea of different methodologies use for implementation of SWPDT for electric vehicles with their respective output power and data transfer rate. Inductive methodology is commonly used in recent years as per the above data. The inductive method is commonly favoured for the implementation of simultaneous wireless power and data transfer (SWPDT) in electric vehicles (EVs) due to several advantageous features specific to inductive coupling as it offers relatively high efficiency in power transfer, ensuring that a significant portion of the transmitted power reaches the intended receiver. Inductive systems are effective over short distances, making them well-suited for applications like EV charging where close proximity is often maintained. The magnetic fields generated in inductive systems are generally confined to the vicinity of the coils, reducing potential health and safety concerns for users and bystanders. For the safety purpose standardized regulations are laid by organizations such as SAE and IEC such as minimal operating frequency of the system (i.e. 85-90KHz) different power charging levels to ensure the integration of inductive charging in Ev with full safety for the users. Hence these factors boost the adoption of inductive method as the means to integrate wireless charging system in electric vehicles.

4.1 SWPDT for Bio-Medical Implant

The integration of simultaneous data and power transmission is paramount in the realm of biomedical implants such as pacemaker, neurostimulators and various medical devices which are implanted for various purposes inside the human body. Traditionally these devices consists of leads and charged by the means of primary batteries which are inserted through human muscles to power and monitor the device but careless and improper handling of these implanted devices can release the battery chemical inside the human body which can be a serious issue and results in degradation of the users health and sometimes can also led to death, while the batteries used in the traditional implants are the non-rechargeable which can last up to 5-7 years and displacement of them can be possible only by means of surgeries which are must costlier. Hence the integration of simultaneous power and data transfer paved a way to build a leadless and battery less or rechargeable implants which not only ensures the comfort also reduces the high expense of the users due to frequent surgeries. It is essential to acknowledge that near-field magnetic techniques represent just one facet of the diverse methods available for power and information transmission in implantable biomedical applications. Beyond far-field electromagnetic (EM) technologies, alternative approaches include ultrasonic and optical methods, capacitive coupling, intra-body communication (IBC), among others. Each of these methods, however, presents its own set of limitations [11].

In [12] the author proposed a SWPDT system for Cochlear or retinal implants where PWM-ASK technique is used to deliver the power through PWM signals while data transfer can be done through ASK modulation technique. This model is based in single link single carrier methodology in which single channel is used to implement SWPDT hence minimizing extra channel thereby reducing the complexity and full power consumption by the system. The system employs Class-E amplifiers with specific circuit components and modulation techniques like PWM-ASK to efficiently transmit power and data to biomedical implants. The choice of components and modulation techniques is carefully made to optimize power consumption and address challenges associated with continuous sequences of zero data bits. The receiver side incorporates a power-efficient detector for demodulation, and the selection of codes plays a significant role in the overall performance of the system.

In [13] author proposed a multi-carrier-based model for SWPDT using offset quadrature pulse shift keying technique (OQPSK). The frequency of data carrier is set to 13.56MHz and 1MHz for power transfer, to tackle the misalignment of the coil coplanar square coils The system is designed for 900mV load requirement. The system consists of 6 coils in which 1-2 coil is for power transfer, 3-4 is for downlink data path and 5-6 coil serves as uplink data path. The experimental analysis results with the efficiency of 61% for 0.37 coupling coefficient and the data transfer rate is found to be 4.16Mbs while reducing the bit error rate to less than 2x10^{-6}.

In [21] the author introduces an innovative approach to power a battery-free electrical implant using ultrasound. Unlike commonly employed RF and inductive methods, the use of ultrasonic power transmission addresses issues related to electromagnetic coupling and provides flexibility in selecting data frequencies without being constrained by national regulations. The proof-of-concept for the data and power link relies on the utilization of piezoelectric crystals. Experimental measurements conducted in degassed water indicate the viability of the ultrasonic link, achieving efficiencies ranging from 21% to 35% at distances spanning 5 mm to 105 mm. The communication link was established using a ceramic PZT (lead zirconate titanate) ultrasound transmitter and receiver, both resonating at a frequency of 840 kHz. The diameters of the transducers were 30 mm and 25 mm, respectively. The receiver material possessed a slightly higher piezoelectric charge coefficient than the transmitter material, making it more suitable for receiving purposes. For controlled movement, a stepper motor was employed to adjust the transmitter in increments of 0.1 mm. The received power was quantified using an oscilloscope with a 50 Ω input. To ensure compatibility, the transducer impedances were aligned with 50 Ω and 0^{o}, matching the characteristic impedance of the signal wires, oscilloscope inputs, and power amplifier output. Prior to reaching the PZT transmitter, the 840 kHz sine signal underwent amplification and was measured using a serial power meter positioned between the amplifier and the impedance matching setup.

In [23] the author proposed a prototype of the implant which has dimensions of 4 mm by 7.8 mm and incorporates a piezoelectric receiver, an integrated circuit (IC) developed using a 65 nm CMOS process, and an off-chip antenna. The IC is designed to sustain a maximum DC load of 100 W when exposed to an acoustic intensity that is 5% of the FDA diagnostic limit. To establish a hybrid bi-directional data link, the proposed system combines an ultrasonic downlink and an RF uplink. The falling edge of the ultrasound input serves as downlink data. For uplink data transmission, the implant emits an ultra-wideband (UWB) pulse sequence.

In [35] the author proposes the Resonant Capacitive-Coupling (RCC) method, for wirelessly powering deep implants. This method utilizes the same plates for both power transfer and uplink data transmission. The RCC model is further improved by introducing the concept of Intermediate Plate Capacitance (RCCI). This addition is designed to enhance the Power Transfer Efficiency (PTE) of the system. These investigations are carried out in human-tissue-mimicking liquid at a controlled pressure level and in pork tissue, providing insights into the system's behavior in realistic scenarios. The paper explores the uplink data transfer aspect by employing Amplitude Shift Keying (ASK) modulation technique at a rate of 50 kb/s. This investigation is conducted for the traditional Capacitive-Coupling (CC), Resonant Capacitive-Coupling (RCC), and RCC with Intermediate Plate Capacitance (RCCI) systems conducted for the traditional Capacitive-Coupling (CC), Resonant Capacitive-Coupling (RCC), and RCC with Intermediate Plate Capacitance (RCCI) systems Table 3 displays the recent methodologies use for implementation of SWPDT system in bio-medical implants application. Though acoustic power and data transfer is proposed for deep biomedical implants but still less research has been done on this technology in the field of bio medical implants when compared to inductive method. Lack of standardized protocols and more implementation cost can be the reason behind slow development of simultaneous acoustic power and data transfer in bio medical implants. While Capacitive Power and Data Transfer (CPDT) faces several challenges that may contribute to its lesser popularity compared to inductive power transfer in biomedical implants. Factors such as it typically has a shorter operating range compared to inductive coupling. Inductive coupling has seen significant development and optimization in terms of power efficiency over the years, making it a more established and reliable choice.

Table 3. Recent research on SWPDT for Bio-medical Implants

Reference	Year	Methodology use for SWPDT	Output power	Data rate
[47]	2021	Acoustic	Not specified	20Kbps
[48]	2022	Capacitive	52% (PTE)	6.5Mbps
[49]	2010	Inductive	61%(PTE)	4.16Mbps
[50]	2022	Inductive	92.42mW	564.68Kbps
[51]	2007	Inductive	58mW	2.08Mbps
[52]	2022	Inductive	69.13mW	564Kbps

Inductive coupling may have more mature solutions for ensuring secure data transmission. Inductive power transfer has been more widely adopted in various industries, including biomedical applications. Standardization of protocols and compatibility with existing systems play a crucial role in technology adoption, and inductive systems may have a head start in this aspect. Developing and implementing CPDT systems can involve significant costs. Inductive coupling technologies may have more established and cost-effective solutions due to years of development and refinement.

4.2 SWPDT for Autonomous Underwater Vehicles

With the growing interest of underwater exploration, it is important to supply a stable and efficient power transfer for massive subsea vehicles such as autonomous underwater vehicle (AUV’s) and remote operated vehicles. Generally, power transfer to these vehicles is provided through means of connectors but frequent use of cables during charging can led to generation of sparks which results in decrease the efficiency of system. Meanwhile the data collected during the surveillance must be transfer to the base station in a secure and efficient way. For air medium there are some wireless data transfer technologies such as Bluetooth, Wi-Fi, Zigbee and radio frequency communication [33]. But these technologies cannot be applied to sea region due to increase in eddy currents in saline water.

Hence alternate techniques such as acoustic communication, optical communication and magneto-inductive communication comes into play in these scenarios. While acoustic communication has been employed for data extraction, it faces challenges such as low transmission rates and limited bandwidth. This method is susceptible to environmental factors like water quality, temperature, pressure, and undersea noise. In contrast, undersea optical communication has been suggested as a viable solution for marine environments. Its compact receiver and transmitter components offer advantages such as low cost, low power consumption, wide bandwidth, high speed, and simplicity in design. However, environmental interference poses significant restrictions on undersea optical communication technology. Undersea magnetic communication utilizes electromagnetic fields as its transmission mode. This communication method typically comprises a transmitter and a receiver, enabling magnetic induction communication with other wireless sensing nodes employing magnetic induction. The variable conditions of the transmission medium in the undersea environment have minimal impact on magnetic induction communication. This results in a stable channel state, mitigating the effects of path loss and reducing network delay. Furthermore, undersea magnetic communication enhances the reliability of information transmission. The next section in this paper consists of previous research made on analysis and implementation of SWPDT for underwater environment.

In [33] the author proposed the SWPDT system for marine application using time sharing multiplexing theory where power is sent in first half switching cycle while data is sent in second half switching cycle of the system. The signal is modulated using frequency shift keying technique with two frequency carriers. As a result, same channel can be used for simultaneous transfer of power and data. The serial-serial inductive topology is selected in this paper with capacitor compensation network. On the primary side, the initial DC voltage undergoes inversion into high-frequency AC voltage through a full-bridge circuit. Meanwhile, on the secondary side, the resonant voltage undergoes filtration using a full-bridge diode circuit. The control transistor Q1, responsible for power transfer, is injected into the midline of the full-bridge circuit, allowing adjustment of the power transfer period. The primary side's transmitter unit is for data transfer comprises an FSK modulation module, a power amplifier, and a data transfer switch. On the secondary side, the receiver unit for data transfer includes a bandpass filter, power amplifier, and FSK demodulation module. The transistor Q2 governs data transfer control, and both transistor Q1 and transistor Q2 are complementarily toggled between on and off states. The FSK modulation method, is employed to generate the data carrier. In FSK, two carrier signals generate modulated waveforms, each represented by distinct frequencies. These frequencies are termed "mark frequency" and "space-frequency," where the mark frequency signifies logic 1 and the space-frequency represents logic 0. The sole distinction between the two carrier signals lies in the higher frequency of one compared to the other. The signal carrier frequency is set to >90MHz while ‘0’ is modulated to high frequency of 10MHz while ‘1’ is modulated to low frequency of 2MHz. The bandwidth is calculated as 804000Hz using:

$$W = |f_2 - f_1| + 2f_s \tag{7}$$

The power transfer efficiency of 60% at distance of 10cm during experimental verification and calculated maximum signal transmission rate is $80.57*10^5$ bps

In [53] this investigation, a unified system was proposed to achieve both wireless power supply and data communication through a single hardware setup. The author conducted a foundational study by designing a system for power and data transfer, followed by a comprehensive evaluation of its performance through experimental tests. Initially, the author designed two helical coils with a resonance frequency of approximately 100 kHz and assessed their transmission characteristics. Subsequently, the author demonstrated wireless data communication modulated by Orthogonal Frequency Division Multiplexing (OFDM) using the same hardware. The study further explored the relationship between Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER) in the context of wireless data communication. Key findings from the experiments revealed that wireless power transfer could be achieved with an efficiency of 81% in saltwater, with similar efficiency observed in both air and freshwater environments. Additionally, the results indicated the feasibility of achieving high-quality data communication with a low BER of 0.1% within a proximity of 30 mm, all utilizing the same hardware.

Table 4 displays the recent research on SWPDT for autonomous underwater vehicle application where inductive methodology can be seen very frequently when compared to acoustic, optical and capacitive method. Since magnetic communication experience no delay, no doppler effect and no multi-path during the data transfer which can be helpful to provide a robust data transfer for underwater application but this case is exactly opposite in acoustic and optical communication which may be the reason for more research for SWPDT for underwater using inductive links. Capacitive coupling has a relatively short-range compared to other methods, and this limitation can be more pronounced in saltwater due to its conductivity. The electrical conductivity of water can lead to signal attenuation, impacting the efficiency and range of capacitive power and data transfer. Changes in water conditions, such as salinity and temperature, can affect the performance of capacitive coupling, requiring careful consideration in real-world applications. Achieving high energy transfer efficiency over longer distances can be challenging with capacitive coupling, especially in underwater environments

Table 4. Recent research on SWPDT for Autonomous underwater Vehicles

Reference	Year	Methodology use for SWPDT	Output power	Data rate
[54]	2022	Inductive	200W	30kbps
[55]	2023	Inductive	936W	Not specified
[56]	2023	Inductive	518W	700kbps
[57]	2023	Inductive	884W	1Mbps
[58]	2021	Capacitive	1KW	Not specified

4.3 Different Techniques for implementation swpdt using inductive links

From Table 2,3,4 it has been observed that most of the recent works has adopted inductive method for implementation of simultaneous wireless power and data transfer for Electric vehicle, bio-medical implants and underwater vehicles applications. The reason behind this can be the efficiency as since the adoption of wireless charging in the practical world inductive or resonant power transmission comes to be at top in terms of efficiency in range of 90-95% while the capacitive and acoustic are still low in terms of their system efficiency and power transfer capability while the standard framework and regulations laid by the organizations such as SAE, ICE ensures the safety of the user as these types of standards usually not available in case of other two techniques. Since inductive power transfer uses magnetic field for power transmission which are unharmful to living beings in certain range while acoustic power transfer uses the high sound energy for the means of power transmission and it has a negative impact on the living creature especially on the birds which can be the reason of their extinction while the capacitive uses the electric field which may be fatal in severe weather conditions like snowfall or rain. Inductive techniques can also be used to generate a bi-directional communication system with simultaneous power transfer for various application in an efficient and cost-effective manner since the expansion of the market manufacturers in the field of inductive technology paved a way to manufacture the products in a bulk volume and less cost while the acoustic and capacitive market are still in its infant age.

The integration of data and power transmission using inductive techniques in a system offers a versatile landscape with multiple implementation approaches. The SWPDT system can be defined in terms of the number of signals and transmission channels utilized, the method of signal combination, the type of communication established, the modulation schemes applied to the transmitted data and the compensation techniques use to enhance the system performance.

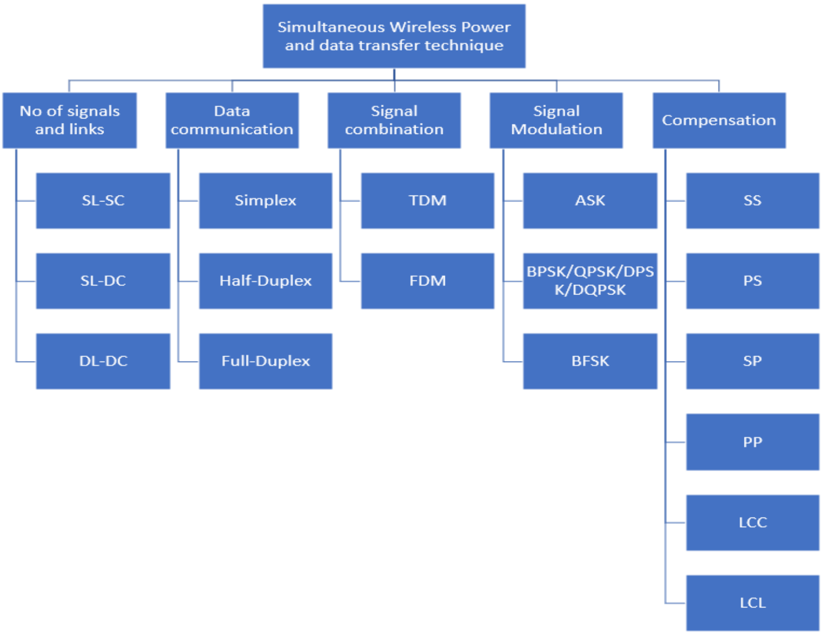

Fig 4. Various Design approach for Implementation of SWPDT using inductive links

The design of SWPDT can be done using different criteria. In this section all the different criteria's, their advantages, disadvantages as well as their compatibility according to the application for which it is selected is mentioned

In Wireless Power Transfer (WPT) systems, the concept of a wireless link is established through a paired set of coupled coils. The number of links and signal carriers plays a crucial role in defining the system architecture. Basically, there are 3 types of approach that can be adopt to create a wireless link in SWPDT. Firstly, it can be done using single link single carrier (SL-SC) technique where the power and data are considered to be superimposed and transmitted through a single channel. Alternatively, when the both are treated as separately can also be transferred through separate channels which can be termed as double link double carrier technique (DL-DC). Lastly, it can also be transmitted using single channel while considering the power and data separately (SL-DC).

Depending upon the direction of data transfer in SWPDT system data transfer type can be classified as Simplex (Uni-directional) , Half-duplex (Two-way data transfer with each at one time), Full-duplex (Simultaneous two way data transfer).

For simultaneous transfer of two signals through same circuit different which is mostly seen in case of SL-DC multiplexing techniques can be adopted such as: Frequency Division Multiplexing (FDM) which involves the simultaneous transmission of two or more signals by utilizing different frequencies within the available bandwidth. By assigning different frequency bands for each signal, multiple data streams can be transmitted simultaneously without interference. Time Division Multiplexing (TDM) on the other hand, relies on the use of different time slots where the two signals are assigned with different timeslots which allows them to realize simultaneous operations.

The information of the system can be encode using various modulation techniques such as amplitude shift keying (ASK) where the data is encoded by varying amplitude of the message signal, frequency shift keying (FSK) frequency of message signal is change accordingly. Binary Phase shift keying (BPSK) conveys the message by modulating phase of the data signal while the differential phase shift keying (DPSK) modulates the phase of the signals in the successive order which overcome the problem related to phase fluctuation while Quadrature phase shift keying (QPSK) enables the transmission of two bits per symbol by modulating phase of the signal with four different phase shifts.

Table 5. Summary of Different Techniques Use in Recent research for SWPDT using Inductive links

Reference	No of links and signal	Data communication types	Modulation	Compensation	Multiplexing	Power frequency	Data frequency
[25]	SL-SC	Simplex	FSK	S-S		85KHz	5KHz 10KHz
[26]	SL-DC	Half duplex	OOK	S-P	FDM	22.4KHz	1.67MHz
[27]	DL-DC	Simplex	ASK	LCC-S		200 kHz	6 MHz
[28]	SL-SC	Not specified	ASK	S-S		85KHz	1MHz
[29]	SL-SC	Half duplex	FSK	S-S		85kHz 83kHz	85kHz 83 kHz
[30]	SL-DC	Full duplex	ASK	LCC-S	FDM	50KHz	2MHz
[31]	SL-DC	Full duplex	ASK	LCC-CLC	FDM	85 kHz	2MHz 1.2 MHz
[32]	SL-DC	Simplex		S-P		22.4KHz	1.6MHz
[33]	SL-DC	Not specified	FSK	S-S	TDM	200KHz	2MHz 10MHz
[34]	DL-DC	Simplex	ASK	LCC-S		200KHz	6MHz
[35]	SL-DC	Not specified	ASK	S-P			Not specified
[36]	SL-DC	Full duplex	OQPSK	S-P		1MHz	13.56MHz
[37]	SL-DC	Half duplex	OOK	LCC	FDM	85KHz	1MHz
[38]	SL-DC	Half duplex	ASK FSK	SS		28KHz	756KHz

In the model of simultaneous wireless power and data transfer (SWPDT), the selection of compensation techniques plays a pivotal role in establishing a reliable and efficient channel for the transmission of the signals, particularly in scenarios where misalignments are experienced such as in case of AUV due to ocean currents. Various compensation strategies, including series-series, series-parallel, parallel-series, parallel-parallel, LCL, and LCC configurations, present distinct advantages and considerations for enhancing bandwidth for data transfer and to overcome the negative effects on power transfer capability of the system due to misalignments Misalignment considerations are paramount in these compensation techniques. The goal is to ensure robust power and data transfer even in scenarios where coils may not align perfectly. The incorporation of resonant elements in LCL and LCC configurations not only enhances bandwidth but also contributes to improved communication efficiency. Existing SWPDT system can be implemented in terms of no. of signals and links by following configurations i.e., Single Link Single Carrier (SL-SC), Double link Double carrier (DL-DC), Single Link Double Carrier (SL-DC), Double Link Single Carrier (DL-SC). DL-SC arrangement is impractical and costly. This can be the reason this configuration is not applied in many SWPDT system.

SL-SC configuration: In this type of configuration power and data is transferred through same channel. To do that power signal is usually use as carrier while data signal amplitude or frequency is modulate depending upon the application. This configuration is seen in [25] [28] [29]. Implementation of Power line Communication with wireless power transfer system is a common example of this configuration. Though this configuration looks simply but it has various disadvantages such as the power signal needs to be altered in order to transmit data from transmitter to receiver section. This alteration can be done by changing the amplitude or frequency of carrier signal which already transmitted in the circuit. Assume if the following modification is done with ASK then the power signal has to increase and decrease its intensity according to the data transfer if the data that to be transfer consists of more no. of ‘0’ then the power signal has to be in decrease form for a long time resulting in charging delay.

The charging time and data rate relation involves the number of "1" bits (md), the number of "0" bits (nd), and the time of bit transmission (τd). Data communication occurs in specific slots during charging, requiring a preamble to signal the start of communication and an ending sequence to indicate the conclusion. The preamble and ending sequence consist of "1" and "0" bits, denoted as np and ne, respectively. The charging time in an SL-SC system is as follows:

$$\boldsymbol{CT_{SLSC} = CT_{WPT} + M(n_p\tau_p + n_e\tau_e) + n_d\tau_d} \qquad (8)$$

DL-DC configuration: This configuration supports two or more than two frequencies for power transmission wirelessly and data is transmitted through two or more channels. DL-DC configuration is costly since to implement this in SWPDT system an extra pair of inductor coils with their control circuits must be added to transmit the signal which led to large size system. Power and data propagate through different channel hence there will be no chance of any delay in charging time as seen in SL-SC. In [27] [34] this configuration has been using to propose SWPDT system. Usually in this configuration the data signal has higher frequency when compared to power frequency and the data is sent with low amplitude. The disadvantage associate with this configuration is addition of extra coils to make separate channel for both quantities which results in cross talk between the coils, increase in cost of the system, as the size of data coils are compact when compared to power coils the smaller the coil area greater the misalignment.

SL-DC configuration: This configuration is the combination of previous configuration where data and power both the carriers are transmitted through a single channel. Generally, two or more frequencies are used for power and data transfer, amplitude of the data signal must be low in comparison to power signal. In this configuration, two coils or transformers are usually linked in the primary and secondary power circuit, which will embed and extract the corresponding data signal from the communication processors. [25] [26] [28] [29] [30] [31] [32] [33] [35] [36] [37] [38] this configuration is used to proposed SWPDT system. Although it is the most flexible configuration but still it has some drawbacks like since both the signals are transmitted through same channel hence there may be chances of interference between them which rises the need for suitable filters to avoid unnecessary interference of signals.

As mentioned earlier there are 3 types of data communication namely Simplex, half-duplex, full-duplex. The drawback associate with simplex communication is there is no sort of acknowledgement from the receiver on the receiving the transmitted data. Therefore, the transmitting circuit never has the knowledge about whether the data is received to correct destination or not. The implementation of simplex communication can be seen in [25] [27] [32] [34]. Whereas the half-duplex communication refers to transfer of data in both direction but not in simultaneous manner the draw back associate with this type of communication is Since the communication channel alternates between transmission and reception, there is an inherent delay in switching between these two modes. This can contribute to increased latency, which may be a critical factor in applications that require real-time communication. Half-duplex systems may not efficiently utilize available bandwidth because the channel is not able to transmit data in both the directions.

This can result in periods of inactivity during which the channel is not effectively utilized. In scenarios where multiple devices are attempting simultaneous power and data transfer in a shared wireless medium, there is a risk of data collision. This can lead to inefficiencies and data errors in the communication system. Achieving simultaneous wireless power and data transfer in a half-duplex system requires the implementation of complex protocols for synchronization purpose. Ensuring that power and data transfer do not interfere with each other requires careful coordination. This method was proposed in [26] [29] [38] [37]. Full-duplex communication mode can be seen in [30] [31] [36] it is the most robust type of data communication which provide exchange of the information in both the direction in simultaneous manner.

Full-duplex communication offers several advantages over half-duplex communication, where data can only be transmitted or received at any given time. The simultaneous transmission and reception of data enable a more efficient use of available bandwidth, resulting in increased data transfer rates. Devices can respond to incoming data while still transmitting, leading to quicker exchanges of information and better responsiveness in real-time applications. It simplifies protocol design, as there is no need for complex mechanisms to manage the switching between transmission and reception modes. This simplicity can lead to more straightforward implementations and reduced chances of errors.

When two signals move through same channel as seen in single link single carrier implementation of SWPDT system both the signals need to be multiplexed with proper technique so that the interference between them is reduced. The FDM technique can be applied to the system where both the frequency must have distant frequency and both of them must be far away from each other to avoid interference [26] [30] [31] [37]. The TDM technique is propose in [33] the implementation of this technique is done using a control switch which concurrently switches the communication direction in alternating transmission way i.e. from primary to secondary and secondary to primary.

In TDM the message signal is split in several parts and send in different time slot. Examining the operating principles, it can be deduced that the Time Division Multiplexing (TDM) technique is well-suited for situations with severely restricted bandwidth for data transmission. This is because TDM facilitates the transmission of data through the same channel at distinct time intervals. On the other hand, in scenarios where bandwidth is not a limiting factor but the transmission time is critical, the most effective solution is the use of Frequency Division Multiplexing (FDM), enabling two-way transmission within the same time slot. This strategy is optimal when the priority is to maximize data transfer efficiency within specific time constraints.

An additional critical aspect of SWPDT system is the modulation strategy employed in data transfer. Basically, the information transmitted in communication systems consists of digital signals. To enable the smooth transmission of the data these digital signals must undergo conversion into analog signals. Depending upon the design and approach several modulation techniques are utilize such as amplitude shift keying [27] [30] [31] [34] [35] [38], frequency shift keying [25] [29] [33] [38], on-off shift keying [26] [37], offset quadrature phase shift keying (OQPSK) [36], phase shift keying, binary phase shift keying, differential quadrature phase shift keying are the modulations techniques which are mostly observed in recent research of SWPDT system for modulation of the data signals.

In the process of selecting the most suitable modulation technique for the given circuit characteristics, various factors must be considered. Amplitude Shift Keying (ASK) modulation is the least complex modulation strategy, however more susceptible to coupling sensitivity. This results in disturbances in ASK strategy which occurred due to misalignment between the coils, ultimately decreasing the efficiency of communication system.

Phase Shift Keying (PSK) modulation overcome the issues related with ASK modulation. PSK modulation shows strong anti-interference capabilities, lowers the impact of misalignment between coils and minimizing co-channel interference. The synchronization demands in PSK modulation may result in the need for longer preamble sequences, making it more suitable for longer messages where synchronization can be effectively maintained. Therefore, the choice between ASK and PSK modulation depends on the specific requirements and characteristics of the communication system, considering factors such as sensitivity to coupling, interference resistance, and the complexity of the modulation/demodulation circuits. In real-world charging scenarios, achieving precise alignment between both coils poses a challenge. Therefore, a critical factor in selecting a compensation system which can handle the misalignment between the coils. Although the impact of misalignments on power transfer has been extensively researched but still, it is important to note that misalignment will directly influences the bandwidth of the data system.

As discussed in [58] vertical misalignment has a more significant effect on the channel capacity when compared to horizontal misalignment. However, the change in bandwidth is not solely determined by the misalignment; it is also influenced by the compensation system in use. The study concludes that a Parallel-Parallel (PP) compensation system provides the highest communication capacity for misalignments along both the horizontal and vertical axes, while Series-Parallel (SP) compensation offers the lowest channel capacity. Importantly, the data rate is intricately connected to bandwidth by the Nyquist theorem.

The compensation system plays a significant role in the accurate demodulation of data in the presence of misalignment. The reflected impedance from secondary to the primary side of the system is influenced by both the mutual inductance and the topology of the compensation system used. Variations in the impedance will alter the amplitude and phase of the primary current, thus affecting the induced voltage on the secondary side.

4.4 Design Recommendations for SWPDT Using Inductive Links

Table 6. Summary for the Design Recommendation for SWPDT

Parameters	Recommendation
Power frequency	For electric vehicles SAE recommended frequency in range of 79 to 90KHz can used.
	For autonomous underwater vehicles power frequency must be below the range of MHz frequency in order to reduce the effects due to eddy currents generated by salt water
	For bio-medical implants frequency which has low SAR must be preferred FCC recommended range must also be taken into consideration
Data Signal	It is recommended to maintain a considerable difference in frequency between data signals and power signals in order to minimize interference and ensure efficient communication.
Multiplexing technique	TDM is a suitable when the data bandwidth is relatively small since it enables the transmission of data over the same channel by allocating different time intervals to each data stream.
	FDM ensures efficient use of time with bi-directional communication by allocating distinct frequency bands to each signal within the same time slot.
Modulation Technique	ASK modulation which is simple, sensitive to coupling and prone to misalignment issues between coils, hindering communication.
	Phase Shift Keying (PSK) modulation offers a solution to the interference challenges associated with ASK.
No. of signals and links	SL-SC, modulation techniques ensure the minimum interference of the data signals with power signals by superimposing data and power signal and transmitting it through a single channel.
	SL-DC, weakens the co-interference of data and power signal of the system by allocating higher order frequency for the data signal when compared to power signal.
	DL-DC, on the other hand utilizes separate frequencies as well as separate channel for the transmission of two signals simultaneously but precision in coil placement is crucial to enhance the system efficiency. Usage of multiple data coils can help to reduce interference of the signals.

5 Conclusion

SWPDT is necessary in the applications to monitor the system. Hence this review provides a brief overview of the wireless power transfer followed by its classification. The study highlights the need for SWPDT in electric vehicles, autonomous underwater vehicles and biomedical implants. Recent methods adopted in implementation of SWPDT studied briefly. At last, the reason for increase in demand for SWPDT using inductive links is studied followed by various techniques use to implement it in the system with the design recommendations.

References

1. Machura P, Li Q. A critical review on wireless charging for electric vehicles. Renewable and Sustainable Energy Reviews. 2019 Apr 1; 104:209-34.

2. Y. Chao, "Autonomous underwater vehicles and sensors powered by ocean thermal energy," OCEANS 2016 - Shanghai, Shanghai, China, 2016, pp. 1-4, doi: 10.1109/OCEANSAP.2016.7485367.
3. S. Soni and S. Gupta, "WPT Techniques based Power Transmission: A State-of-Art Review," 2022 13th International Conference on Computing Communication and Networking Technologies (ICCCNT), Kharagpur, India, 2022, pp. 1-6, doi: 10.1109/ICCCNT54827.2022.9984606.
4. Sherali Zeadally, Farhan Siddiqui, and Zubair Baig. 25 years of bluetooth technology. Future Internet, 11(9), 9 2019.
5. I. Casaucao, A. Triviño and Z. Lin, "Simultaneous Wireless Power and Data Transfer for Electric Vehicle Charging: A Review," in IEEE Transactions on Transportation Electrification, doi: 10.1109/TTE.2023.3309505.
6. Sherali Zeadally, Farhan Siddiqui, and Zubair Baig. 25 years of bluetooth technology. Future Internet, 11(9), 9 2019.
7. Pedram Radmand, Marc Domingo, Jaipal Singh, Joan Arnedo, Alex Talevski, Stig Petersen, and Simon Carlsen. ZigBee/ZigBee PRO security assessment based on compromised cryptographic keys. In Proceedings - International Conference on P2P, Parallel, Grid, Cloud and Internet Computing, 3PGCIC 2010, 2010.
8. Angela M. Lonzetta, Peter Cope, Joseph Campbell, Bassam J. Mohd, and Thaier Hayajneh. Security vulnerabilities in bluetooth technology as used in IoT, 2018
9. Pushpa R. Suri and Sona Rani. Bluetooth security - Need to increase the efficiency in pairing. In Conference Proceedings - IEEE South-Eastcon, 2008.
10. Ratika Bali. Bluejacking Technology: Overview, Key Challenges and Initial Research. International Journal of Engineering Trends and Technology, 4(7), 2013.
11. H. Zheng, Z. Wang, Y. Li and P. Deng, "Data transmission through energy coil of wireless power transfer system," 2017 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), Chongqing, China, 2017, pp. 1-4,
12. Ogbodo Emmanuel Utochukwu, Ifeyinwa Faith Ogbodo, Onyenanu Chukwunonso Nnanyelum, & Nwanonobi Benjamin Chibuzo. (2023). “Electromagnetic Induction Technique of Wireless Power Transfer for Universal Wireless Charging Device”. International Journal of Recent Research in Electrical and Electronics Engineering (IJRREEE), 10(3), 10–21.
13. Alicia Trivino, Jos ˜ e M. Gonz ´ alez-Gonz ´ alez, and Jos ´ e A. Aguado. ´ Wireless Power Transfer Technologies Applied to Electric Vehicles: A Review. Energies, 14(6), 2021.
14. Jongeun Byun, Won-Jin Son, Jae Han Lee, Sangjoon Ann, and Byoung Kuk Lee. Current sensorless ZPA frequency tracking control of IPT system with LCCL-S topology. In 2019 10th International Conference on Power Electronics and ECCE Asia (ICPE 2019 - ECCE Asia), pages 1–6, 2019.
15. Riccardo Ruffo, Vincenzo Cirimele, Michela Diana, Mojtaba Khalilian, Alessandro La Ganga, and Paolo Guglielmi. Sensorless control of the charging process of a dynamic inductive power transfer system with an interleaved nine-phase boost converter. IEEE Transactions on Industrial Electronics, 65(10):7630–7639, 2018.
16. Paul-Antoine Gori, Daniel Sadarnac, Antoine Caillierez, and Serge Loudot. Sensorless inductive power transfer system for electric vehicles: Strategy and control for automatic dynamic operation. In 2017 19th European Conference on Power Electronics and Applications (EPE’17 ECCE Europe), pages P.1–P.10, 2017.
17. Y. Zhao, Y. Du, Z. Wang, J. Wang and Y. Geng, "Design of Ultrasonic Transducer Structure for Underwater Wireless Power Transfer System," 2021 IEEE Wireless Power Transfer Conference (WPTC), San Diego, CA, USA, 2021, pp. 1-4,

18. Chen Anlan, Shao Xuming, Quan Xiangjun, "Hardware Design of Micro PV - Battery System for Underwater Wireless Power Supply", *2023 IEEE 6th International Electrical and Energy Conference (CIEEC)*, pp.3928-3932, 2023.
19. Anwar Khan, Muhammad Imran, Abdullah Alharbi, Ehab Mahmoud Mohamed, Mostafa M. Fouda, "Energy Harvesting in Underwater Acoustic Wireless Sensor Networks: Design, Taxonomy, Applications, Challenges and Future Directions", *IEEE Access*, vol.10, pp.134606-134622, 2022.
20. Q. Wang, W. Che, M. Mongiardo and G. Monti, "Wireless Power Transfer System With High Misalignment Tolerance for Bio-Medical Implants," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 67, no. 12, pp. 3023-3027, Dec. 2020, doi: 10.1109/TCSII.2020.2985056.
21. G. Sun, B. Muneer, Y. Li and Q. Zhu, "Ultracompact implantable design with integrated wireless power transfer and RF transmission capabilities", *IEEE Trans. Biomed. Circuits Syst.*, vol. 12, no. 2, pp. 281-291, Apr. 2018.
22. S. Gabriel, R. W. Lau and C. Gabriel, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues", *Phys. Med. Biol.*, vol. 41, no. 11, pp. 2271, 1996.
23. G. Monti, P. Arcuti and L. Tarricone, "Resonant inductive link for remote powering of pacemakers", *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 11, pp. 3814-3822, Nov. 2015.
24. P. B. Bobba, M. H. Anwar, S. P. Yadav and D. S. Rao, "Effect of Coil Geometry and Dimensions on the Performance of Wireless Power Transfer in AUV Application," 2023 IEEE 3rd International Conference on Sustainable Energy and Future Electric Transportation (SEFET), Bhubaneswar, India, 2023, pp. 1-7,
25. Xin Liu, Xijun Yang, DIanguang Ma, Nan Jin, Xiaoyang Lai, and Houjun Tang. A Novel Simultaneous Wireless Information and Power Transfer System. In 2019 IEEE Wireless Power Transfer Conference, WPTC 2019, 2019.
26. iande Wu, Chongwen Zhao, Zhengyu Lin, Jin Du, Yihua Hu, and Xiangning He. Wireless Power and Data Transfer via a Common Inductive Link Using Frequency Division Multiplexing. IEEE Transactions on Industrial Electronics, 62(12), 2015.
27. Yanling Li, Xiaofei Li, and Xin Dai. A Simultaneous Wireless Power and Data Transmission Method for Multi-Output WPT Systems: Analysis, Design, and Experimental Verification. IEEE Access, 8, 2020.
28. Varun, Alapati & Nadella, Indusaiteja & Bobba, Phaneendra & Upadhayay, Madhur. (2019). Development of wireless charging system along with power line communication used in Electric Vehicles. 10.1051/e3sconf/20198700001.
29. Jie Wu, Chongyan Zhao, Nan Jin, Shuaibiao He, and Dianguang Ma. Bidirectional information transmission in SWIPT system with single controlled chopper receiver. Electronics (Switzerland), 8(9), 2019
30. Tao Zhang, Deqi Zhang, and Wenbin Huang. Research on Inductively Coupled Full Duplex Communication Method with Power Transmission. In International Conference on Sensing, Measurement and Data Analytics in the Era of Artificial Intelligence, ICSMD 2020 - Proceedings, 2020.
31. Yongzhi Jing, Wei Feng, Ke Qiao, Liangtao Yang, Sen Wang, and Linhai Lu. Simultaneous wireless power and data transfer system with full-duplex mode based on lcc/clc resonant network. IEEE Transactions on Power Electronics, 38(4):5549–5560, 2023.
32. Wireless Power and Data Transfer via a Common Inductive Link Using Frequency Division Multiplexing Jiande Wu, Member, IEEE, Chongwen Zhao, Student Member, IEEE, Zhengyu Lin, Senior Member, IEEE, Jin Du, Student Member, IEEE, Yihua Hu, Member, IEEE, and Xiangning He, Fellow, IEEE

33. Yang, Lei & Huang, Jingjing & Feng, Baoxiang & Zhang, Feng & Zhang, Yuanqi & Li, Xaojie & Jian, Jiale & Wang, Zhe & Tong, Xiangqian. (2022). Undersea Wireless Power and Data Transfer System With Shared Channel Powered by Marine Renewable Energy System. IEEE Journal on Emerging and Selected Topics in Circuits and Systems. PP. 1-1. 10.1109/JETCAS.2022.3140954.
34. A. I. Al-Kalbani, M. R. Yuce and J. -M. Redoute, "Design Methodology for Maximum Power Transmission, Optimal BER-SNR and Data Rate in Biomedical Implants," in IEEE Communications Letters, vol. 17, no. 10, pp. 1897-1900, October 2013, doi: 10.1109/LCOMM.2013.13.131505.
35. G. Simard, M. Sawan and D. Massicotte, "High-Speed OQPSK and Efficient Power Transfer Through Inductive Link for Biomedical Implants," in IEEE Transactions on Biomedical Circuits and Systems, vol. 4, no. 3, pp. 192-200, June 2010, doi: 10.1109/TBCAS.2009.2039212.
36. Guo Wei, Jing Feng, Jing Yang Zhang, Chao Wang, Chunbo Zhu, and Sergei Yurievich Ostanin. An Efficient Power and Data Synchronous Transfer Method for WPT System Using Double-D Coupling Coil. IEEE Transactions on Industrial Electronics, 2020.
37. Yusheng Sun, Li Yuegong, Jie Wu, Pengfei Gao, Nan Jin, Kai Feng, and Hengyi Zhang. Bidirectional simultaneous wireless information and power transfer via sharing inductive link and single switch in the secondary side. IEEE Access, 8, 2020
38. S. Barmada, M. Raugi and M. Tucci, "Power line communication integrated in a Wireless Power Transfer system: A feasibility study," *18th IEEE International Symposium on Power Line Communications and Its Applications*, Glasgow, UK, 2014, pp. 116-120, doi: 10.1109/ISPLC.2014.6812357.
39. Z. Qian, R. Yan, J. Wu and X. He, "Full-Duplex High-Speed Simultaneous Communication Technology for Wireless EV Charging," in IEEE Transactions on Power Electronics, vol. 34, no. 10, pp. 9369-9373, Oct. 2019, doi: 10.1109/TPEL.2019.2909303.
40. X. Li, C. Tang, X. Dai, P. Deng and Y. Su, "An Inductive and Capacitive Combined Parallel Transmission of Power and Data for Wireless Power Transfer Systems," in IEEE Transactions on Power Electronics, vol. 33, no. 6, pp. 4980-4991, June 2018, doi: 10.1109/TPEL.2017.2725990
41. C. Da, L. Wang, F. Li, R. Zhang, Y. Zhang and C. Tao, "Analysis of Simultaneous Wireless Power and High-Speed Data Transfer System Based on ASK Modulation," 2023 IEEE Wireless Power Technology Conference and Expo (WPTCE), San Diego, CA, USA, 2023, pp. 1-5, doi: 10.1109/WPTCE56855.2023.10215788.
42. G. Wei, J. Feng, J. Zhang, C. Wang, C. Zhu and S. Yurievich Ostanin, "An Efficient Power and Data Synchronous Transfer Method for Wireless Power Transfer System Using Double-D Coupling Coil," in IEEE Transactions on Industrial Electronics, vol. 68, no. 11, pp. 10643-10653, Nov. 2021, doi: 10.1109/TIE.2020.3038081.
43. Y. Yao, H. Cheng, Y. Wang, J. Mai, K. Lu and D. Xu, "An FDM-Based Simultaneous Wireless Power and Data Transfer System Functioning With High-Rate Full-Duplex Communication," in IEEE Transactions on Industrial Informatics, vol. 16, no. 10, pp. 6370-6381, Oct. 2020, doi: 10.1109/TII.2020.2967023.
44. M. Zeng, Y. Wang, Z. Lang, T. Li, J. Mai and D. Xu, "A Simultaneous Wireless Power Transfer and Data Transfer System With High Misalignment Tolerance," 2022 IEEE Industrial Electronics and Applications Conference (IEACon), Kuala Lumpur, Malaysia, 2022, pp. 25-30, doi: 10.1109/IEACon55029.2022.9951780.
45. Y. Fan, Y. Sun, P. Deng, H. Hu, C. Jiang and Y. Feng, "A Simultaneous Wireless Power and High-Rate Data Transfer System Based on Transient Responses Regulation," in IEEE Transactions on Power Electronics, vol. 38, no. 8, pp. 9362-9366, Aug. 2023, doi: 10.1109/TPEL.2023.3278749.

46. S. Ozeri and O. Amrani, "Backward Data Transfer From Deeply Implanted Device Employing Ultrasonic Load Amplitude-Phase Shift Keying," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 69, no. 1, pp. 199-207, Jan. 2022, doi: 10.1109/TUFFC.2021.3118722.
47. A. N. M. Shahriyar Hossain, P. Mohseni and H. M. Lavasani, "A Resonant Capacitive Wireless Power and Data Transfer Link with 52% PTE and 6.5 Mbps Data Rate for Biomedical Implants," 2022 IEEE Biomedical Circuits and Systems Conference (BioCAS), Taipei, Taiwan, 2022, pp. 292-296, doi: 10.1109/BioCAS54905.2022.9948595.
48. G. Simard, M. Sawan and D. Massicotte, "High-Speed OQPSK and Efficient Power Transfer Through Inductive Link for Biomedical Implants," in IEEE Transactions on Biomedical Circuits and Systems, vol. 4, no. 3, pp. 192-200, June 2010, doi: 10.1109/TBCAS.2009.2039212.
49. X. Ma and S. Mai, "Narrowband FSK Transceiver Circuit for Wireless Power and Data Transmission in Biomedical Implants," 2022 IEEE International Symposium on Circuits and Systems (ISCAS), Austin, TX, USA, 2022, pp. 152-155, doi: 10.1109/ISCAS48785.2022.9937407.
50. L. H. Jung, P. Byrnes-Preston, R. Hessler, T. Lehmann, G. J. Suaning and N. H. Lovell, "A Dual Band Wireless Power and FSK Data Telemetry for Biomedical Implants," 2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Lyon, France, 2007, pp. 6596-6599, doi: 10.1109/IEMBS.2007.4353871.
51. A. Liu, Q. Wang, W. Qi and S. Mai, "A Dual Resonant Frequencies Tuning Circuit Based on FSK Modulation for Wireless Power and Data Transmission in Medical Implants," 2022 IEEE Biomedical Circuits and Systems Conference (BioCAS), Taipei, Taiwan, 2022, pp. 515-518, doi: 10.1109/BioCAS54905.2022.9948697.
52. M. Ogihara, T. Ebihara, K. Mizutani and N. Wakatsuki, "Wireless power and data transfer system for station-based autonomous underwater vehicles," OCEANS 2015 - MTS/IEEE Washington, Washington, DC, USA, 2015, pp. 1-5, doi: 10.23919/OCEANS.2015.7404400.
53. Y. Zeng, C. Lu, R. Liu, X. He, C. Rong and M. Liu, "Wireless Power and Data Transfer System Using Multidirectional Magnetic Coupler for Swarm AUVs," in IEEE Transactions on Power Electronics, vol. 38, no. 2, pp. 1440-1444, Feb. 2023, doi: 10.1109/TPEL.2022.3214318.
54. C. Cai, J. Li, S. Wu, Z. Qin, W. Chai and S. Yang, "A Bipolar and Unipolar Magnetic Channel Multiplexed WPT System With Simultaneous Full-Duplex Communication for Autonomous Underwater Vehicles," in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 15086-15090, Dec. 2023,
55. Y. Wang, T. Li, M. Zeng, J. Mai, P. Gu and D. Xu, "An Underwater Simultaneous Wireless Power and Data Transfer System for AUV With High-Rate Full-Duplex Communication," in IEEE Transactions on Power Electronics, vol. 38, no. 1, pp. 619-633, Jan. 2023, doi: 10.1109/TPEL.2022.3203038.
56. C. Da, L. Wang, F. Li, C. Tao and Y. Zhang, "Analysis of Undersea Simultaneous Wireless Power and 1 Mb/s Data Rate Transfer System Based on DDQ Coil," in IEEE Transactions on Power Electronics, vol. 38, no. 10, pp. 11814-11825, Oct. 2023, doi: 10.1109/TPEL.2023.3290162.
57. Detka, Kalina, and Krzysztof Górecki. 2022. "Wireless Power Transfer—A Review" *Energies* 15, no. 19: 7236. https://doi.org/10.3390/en15197236
58. Alicia Trivino-Cabrera, Zhengyu Lin, and Jos ˜ e A. Aguado. Impact of ´ coil misalignment in data transmission over the inductive link of an EV wireless charger. Energies, 11(3), 2018.