Literature Review

Near Field Communication Wireless Power Transfer with Energy Harvesting Capability

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Abstract: Wireless Power Transfer (WPT) is an emerging technology that enables the transfer of electrical energy from a power source to a device without the use of wires or connectors. WPT is currently being developed for a wide range of applications, including electric vehicles, wireless charging of mobile devices, and implantable medical devices. However, the technology also faces several challenges, including low power transfer efficiency, limited range, and electromagnetic interference. NFC (Near Field Communication) technology was first introduced in 2002 as an extension of RFID technology, enabling simple contactless data transfer between 2 devices. NFC can be used for WPT on low power applications, as the amount of power that can be transferred is low. Energy harvesting refers to the process of capturing and storing small amounts of energy from the environment or from a system and converting it into usable electrical power. This technique can be used to power low-power devices, sensors, and other electronics that require small amounts of energy. The review covers an overview of the WPT technology, particularly focusing on the one based on inductive coupling and the main challenges that must be resolved in order to unblock the commercialization of the full potential of this technology. Then the review shows how NFC can be used for WPT and the pros/cons of this technology compared to other near and far fields WPT. Finally, an overview of the state of art of the energy harvesting technology and how it can be used for building battery less sensors systems. Some examples of already existing applications will be showed too.

Keywords: Battery less systems; Energy Harvesting; Energy Transfer; Inductive WPT, IoT; Near Fields Communication; NFC; WPT; Wireless Power Transfer.

1. Introduction

Wireless power transfer (WPT) was originally proposed by Nikola Tesla and the end of 19th century [1]. Tesla did study how to transfer power on near fields using inductive coupling and in the far fields using radio waves. The earliest forms of wireless power technology were developed in the 1800s, thanks to the invention of the transformer, which involved inductive power transfer between wire coils placed near one another. Resonant inductive wireless energy transfer was employed successfully in the 1960s for implantable medical devices, such as artificial hearts and pacemakers [2]. Between 1970 and 1990, as microwave technology progressed, various research initiatives were launched to explore wireless charging options also for electric vehicles [3]. In recent times, there has been a surge in the commercialization of RFID technology at the 920-MHz band. This trend has been further amplified by the increasing prevalence of mobile rechargeable batteries, which has created a greater demand for wireless charging solutions in various applications.

In the past, neither inductive coupling nor magnetically coupled wireless power transfer technologies garnered much attention as a groundbreaking innovation. Inductive-coupling WPT had limited range between the transmitter and receiver, while magnetically coupled WPT had low efficiency between them. However, the introduction of resonance-coupling WPT by the MIT group overcame these limitations and allowed for efficient wireless charging and battery-free electric devices. This breakthrough technology paved the way for the widespread recognition of WPT as a viable solution for these applications [4].

Wireless networks of the future will rely heavily on the Internet of Things (IoT) and massive machine-type communications, enabling an increasingly intelligent world with ambient-assisted living, smart control systems, and real-time data monitoring. To achieve this vision, trillions of low-power wireless sensors, actuators, and small computing devices must be pervasively connected to form cost-effective and self-sustainable wireless sensor networks (WSNs). Near field inductive coupling WPT are expected to be commercialized very soon. Far-field WPT via radio waves is expected to be commercialized following the commercialization of inductive-coupling WPT [5].

Beam focusing and Energy Harvesting are the most interesting features that make this technology attracting.

Near field communication (NFC) was standardized in 2004, which revolutionized the consumer electronics market and enabled various applications such as electronic transactions, mobile payments, and data transfer, among others, at the beginning of the 21st century. The technology has been used a lot for exchanging data in the near fields, and it is now raising a lot of interest because it can be used for WPT too. Various wireless charging solutions have been suggested, but compared to them, combining NFC and wireless charging in the same implementation can result in more cost-effective and compact charging interfaces for portable devices, a wider charger infrastructure in the future with reduced costs, and the potential to integrate NFC-based services into charging applications.

Currently, WPT and energy harvesting are not feasible for far-field applications due to low efficiency between the transmitter and receiver. Although wide beams WPT has the potential to increase the distance, the technology is not yet mature.

Energy harvesting in near field communication (NFC) technology has become an area of increasing interest in recent years. NFC energy harvesting typically relies on magnetic induction or capacitive coupling, where energy is harvested from the near field of an NFC reader or another NFC-enabled device. The harvested energy can then be used to power low-power electronic devices, such as sensors or RFID tags. NFC energy harvesting has the advantage of being able to operate at very low power levels and can potentially provide an infinite source of power to electronic devices near an NFC-enabled device. However, the amount of energy that can be harvested is limited by the strength of the magnetic or electric field generated by the NFC device, which decreases rapidly with distance.

In this literature review I first show an overview of WPT using inductive coupling, focusing on the distance within where the power can be transferred with best efficiency and performance. Then I will look at how NFC can be used for WPT and how to integrate Energy harvesting for creating a battery less sensors system. I will talk about the pros and cons comparing NFC WPT to other WPT solutions. The comparison includes the advantages/disadvantages of near fields WPT applications with the far field ones, discussing the potential applications that could be unblocked when some WPT challenges will be solved. Finally, some examples of applications where NFC WPT and Energy harvesting is already used for creating battery less sensors systems.

2. Wireless Power Transfer

Wireless power transfer (WPT) is a method of transmitting electrical power from a power source to an electrical load without the need for physical connections such as wires. There are several different types of WPT technologies, each with their own unique characteristics and advantages [6]:

- Inductive coupling: This is the most used form of WPT, which uses electromagnetic fields to transfer energy between two coils. The primary coil is connected to the power source, and the secondary coil is connected to the load. The energy is transferred when the two coils are placed near each other.

- Resonant coupling: This method uses resonant circuits to enhance the energy transfer between the two coils. The system is designed to match the resonant frequency of the two coils, resulting in a higher efficiency of energy transfer.

- Radio frequency (RF) coupling: This method uses high-frequency electromagnetic waves to transfer energy from the power source to the load. The energy is received by a rectifying circuit that converts the RF signal into DC power.

- Magnetic resonance coupling: This technology is based on the principle of magnetic resonance, where energy is transferred between two objects that have the same natural frequency. The power source generates a magnetic field that is then picked up by a resonant receiver, which converts the energy into electrical power.

- Laser power transfer: This technology uses laser beams to transfer energy from a power source to a receiver. The power is transmitted through the air, and the receiver converts the laser energy into electrical power.

2.1 WPT classifications

WPT can be classified in several ways, depending on the perspective and criteria used. Following the three common classifications [6]:

- Distance over which power is transmitted:

    - Near-field WPT: This category includes technologies that transfer power over a short distance, typically less than a wavelength of the electromagnetic wave used. Near-field WPT technologies include inductive coupling, capacitive coupling, and magnetic resonant coupling.

    - Far-field WPT: This category includes technologies that transfer power over a long distance, typically greater than a wavelength of the electromagnetic wave used. Far-field WPT technologies include radio frequency (RF) coupling, microwave beamforming, and laser power transfer.

- Frequency range of the electromagnetic wave used for power transmission:

    - Low-frequency WPT: This category includes technologies that use frequencies below 100 kHz, such as inductive coupling and capacitive coupling.

  - High-frequency WPT: This category includes technologies that use frequencies above 100 kHz, such as magnetic resonant coupling, RF coupling, and microwave beamforming.

- The power level of the application (from milliwatts to megawatts):

  - Low-power WPT: This category includes applications that require power levels below 1 W, such as wireless charging of mobile devices and wearables.

  - Medium-power WPT: This category includes applications that require power levels between 1 W and 1 kW, such as wireless charging of electric vehicles and drones.

  - High-power WPT: This category includes applications that require power levels above 1 kW, such as wireless power transmission for industrial and grid-scale applications.

2.2 Inductive WPT

Inductive WPT (IWPT) systems have been a popular choice for modern short-range wireless power transfer applications since the 1990s.

IWPT is a type of near-field WPT technology that uses magnetic induction to transfer power between two coils. This technology is based on the principle of electromagnetic induction, which states that a changing magnetic field can induce an electromotive force (EMF) in a nearby conductor. In inductive WPT the transmitter coil is energized by an alternating current (AC) source, which generates a magnetic field that induces a voltage in the receiver coil. This voltage is then rectified and used to power the load. Inductive WPT is commonly used for low-power applications, such as charging mobile devices and wearable technology. It has a short-range transmission distance of up to a few centimeters, making it suitable for applications where the transmitter and receiver coils can be in proximity. One of the main advantages of inductive WPT is its efficiency, which can be as high as 90% for well-designed systems. However, the efficiency can be affected by the distance between the coils, the orientation and the alignment of the coils [6].

The reasons for using the near-field magnetic coupling and resonance techniques together are for compensating the leakage inductance.

For efficient wireless power transfer, it was demonstrated that using magnetic resonance between a pair of magnetically coupled coil resonators allow to achieve optimal energy transfer [7].

2.3 Fundamental Power Transfer Concepts – Maximum Power Transfer and Maximum energy efficiency

2.3.1 Maximum Power Transfer

The maximum power transfer principle is a fundamental concept in electrical engineering that relates to the transfer of power from a source to a load. The principle states that the maximum amount of power is transferred from a source to a load when the impedance of the load matches the impedance of the source. In other words, the maximum power is transferred from the source to the load when the impedance of the load is equal to the impedance of the source. If the impedance of the load is lower than the impedance of the source, then some of the power is reflected to the source, resulting in a lower amount of power being transferred to the load. If the impedance of the load is higher than the impedance of the source, more power is dissipated in the source and therefore less power is transferred to the load.

The maximum power transfer principle is important in many practical applications, such as audio systems, power amplifiers, and power supplies. It is used to design circuits that can transfer maximum power from the source to the load, which results in efficient and optimal operation of the circuit [8].

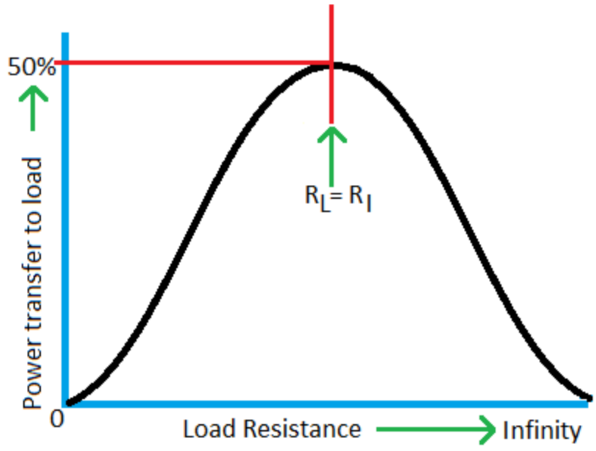

Figure 1 - Power dissipated in a load, versus load resistance

2.3.2 Maximum Energy Efficiency

The maximum energy efficiency principle is a concept that relates to the efficient use of energy in a system. The principle states that the maximum energy efficiency is achieved when the power output of a system is matched to the power demand of the load.

A system operates at maximum energy efficiency when the power output of a system is equal to the power demand of the load. If the power output of the system is lower than the power demand of the load, then the system doesn’t work at max energy efficiency simply because it could operate with higher power. Instead, if the power output of the system is higher than the power demand of the load, then the excess energy is wasted, and the system is not operating at maximum energy efficiency.

The maximum energy efficiency principle is used in several applications, such as electric motors, HVAC systems, power plants and renewable energy systems [8]..

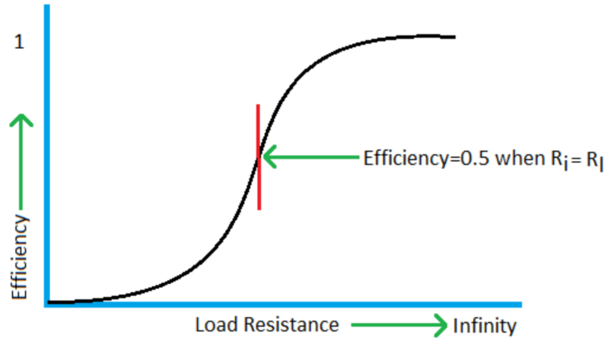

Figure 2 - Power transfer efficiency vs Load resistance

3 Near field communication magnetism – NFC and RFID

NFC (Near Field Communication) and RFID (Radio Frequency Identification) are both wireless communication technologies that are used for identification and data transfer. While they share some similarities, there are several key differences between the two technologies.

The main difference between NFC and RFID is the range of communication. NFC is designed for short-range communication, typically between two devices that are held in proximity (less than 10 cm). This short-range communication is achieved through inductive coupling between the devices. In contrast, RFID can operate over much longer distances, typically several meters, and can be used for tracking and identification of objects over a wide area.

Another difference is their data transfer rates. NFC typically has a much slower data transfer rate than RFID, with a maximum data transfer rate of around 424 kbps. RFID, on the other hand, can achieve much higher data transfer rates, up to several megabits per second.

NFC and RFID also differ in their power requirements. NFC devices typically do not require an external power source, as they can be powered through the electromagnetic field generated by another NFC device. In contrast, RFID devices typically require an external power source, such as a battery, to power the communication between the RFID reader and the RFID tag.

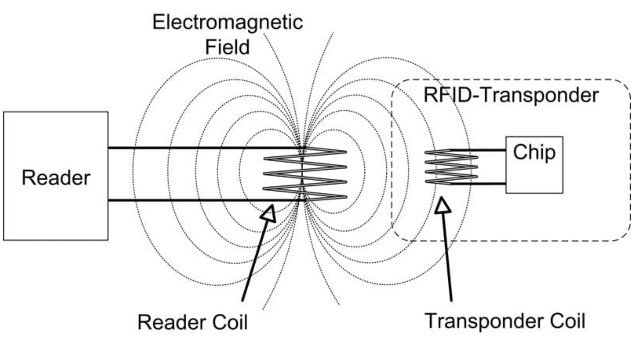

Figure 3 - Data transfer between Reader and Tag

3.1 NFC basic concepts

NFC was first introduced in 2002 by Sony and Philips, as an extension of RFID technology [9]. The initial purpose of NFC was to enable simple and secure contactless transactions, such as mobile payments, by allowing two devices to communicate with each other when held in proximity (typically within 10 cm). Since its introduction, NFC has continued to evolve, with improvements in speed, security, and functionality. Today, NFC is widely used in a variety of applications, such as mobile payments, contactless ticketing, data transfer, and access control. One of the key drivers behind the growth of NFC technology has been the widespread adoption of smartphones, which are now equipped with NFC chips that allow users to make mobile payments, share files, and connect to other NFC-enabled devices [9].

An NFC system is composed by:

- NFC Reader/Writer: This is the device that reads and writes data to the NFC tag. It can be a smartphone, tablet, or other device that is equipped with an NFC chip.

- Antenna: The NFC reader/writer contains an antenna that is used to generate an electromagnetic field that powers the NFC tag and enables communication between the two devices.

- NFC Tag: This is the device that stores data and communicates with the NFC reader/writer. It can be a small sticker or embedded chip that is placed on or embedded in an object.

- Memory: The NFC tag contains a small amount of memory that can store data such as a website URL, contact information, or other types of data.

- Modulation Circuit: The NFC tag contains a modulation circuit that is used to encode and decode data between the tag and the reader/writer.

- Power Management Circuit: The NFC tag contains a power management circuit that regulates the amount of power received from the reader/writer to ensure proper operation of the tag.

NFC works with the principle of inductive coupling between the transmitter and the receiver.

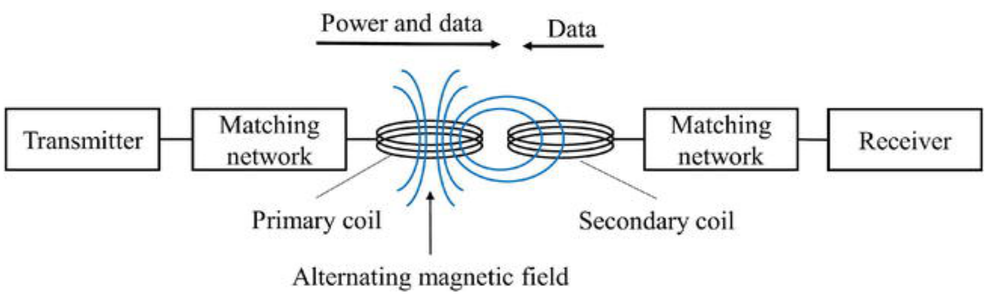

Figure 4 - Inductive coupling between transmitter and receiver coils

3.2 WPT for NFC

WPT can be used with NFC, this is known as Wireless Charging using NFC. NFC-based wireless charging allows for the transfer of power between two NFC-enabled devices without the need for wires or cables. The charging process begins when the two devices are brought close together, typically within a few centimeters.

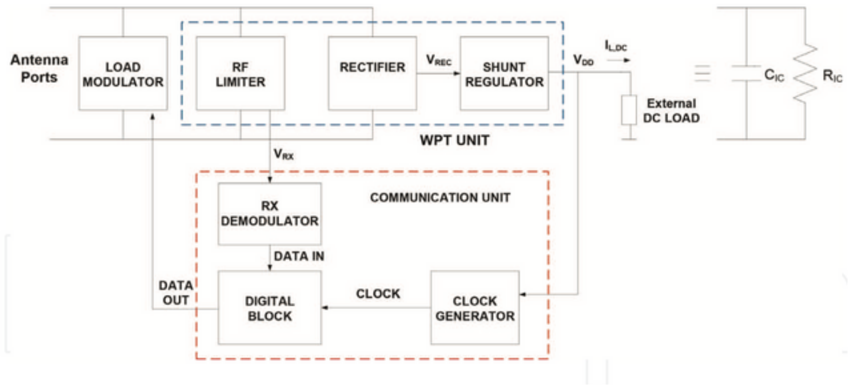

Figure 5 - NFC IC block diagram

The NFC antenna in the receiving device picks up the wireless signal from the transmitter device and converts it into electrical energy to charge the battery.

One of the benefits of NFC-based wireless charging is that it provides a secure and convenient way to charge devices. Since the devices need to be brought close together, it reduces the risk of unauthorized access or interference.

However, NFC-based wireless charging is not as efficient as other wireless charging methods, such as Qi wireless charging. This is because the transfer of power is limited by the short range of the NFC antenna and the low power output of NFC technology. As a result, it may take longer to charge a device using NFC-based wireless charging than other methods.

Figure 6 shows the power class difference between Qi and NFC.

	Power Class	Value	Unit
Power Transfer	Class 0	250	mW
	Class 1	500	mW
	Class 2	750	mW
	Class 3	1000	mW

	Power Class	Value	Unit
Power Transfer	BPP	5000	mW
	EPP	15000	mW

Figure 6 - NFC Wireless Charging power class vs Qi power class

In Figure 7 instead there is a comparison between RFID technologies. As the power class, read range and sizes are different, the products targeted by these technologies are not the same.

Feature	Chipless RFID	NFC	UHF RFID	BLE
Communication method	Backscattering far field	Backscattering near field	Backscattering far field	Transceiver far field
Read range	Typically, <50 cm for frequency-coded 2–3 m for time-coded UWB	1–2 cm for proximity cards with energy harvesting, 0.5 m for vicinity cards	Up to 15 m with inlay tags with −22 dBm read IC sensitivity Up to 3 m UHF sensors (with −9 dBm read IC sensitivity) Up to 30 m BAP	About 10 m
Energy source	Passive	Passive or semi-passive	Passive or semi-passive	Active
Tag price	Moderate	Low	Low	High
Reader cost	High, no commercial	Low, smartphone	High 1–2 k$	Low, smartphone
Standard	No	Yes	Yes	Yes
Universal frequency regulation	No, often used UWB	Yes, ISM	No, by regions	Yes, ISM
Tag size	Large	Medium	Medium	Small
Memory capacity	<40 bits	<64 kbits	96bits EPC, typically 512 bits for users (<64kbytes)	Several Kbytes depending on the microcontroller
ID rewritable	No	Yes	Yes	Yes
Setup time	—	Less than 0.1 s	Less than 0.1 s	Approx. 6 s
Energy harvesting	No	Approx. 10 mW	Few μW	No
Tag substrate	Low-loss microwave substrates	Low cost or FR4	Low cost or FR4	FR4
Tag flexibility	Depends on the substrate	Depends on the substrate	Depends on the substrate	No
Tag robustness	High	Low (inlays)	Low (inlays)	Moderate

Figure 7 - Comparison of RFID technologies [10]

3.3 Power Transfer Efficiency

The power transfer efficiency between loop antennas for NFC (Near Field Communication) depends on several factors, including the distance between the antennas, the size and geometry of the antennas, and the frequency and power level of the NFC signal.

The power transfer efficiency for NFC is relatively low compared to other wireless power transfer technologies such as magnetic induction or magnetic resonance. This is because NFC operates at a frequency of 13.56 MHz, which is in the high-frequency range, and the energy transfer is limited to a very short range of a few centimeters [10]. Moreover, the magnetic field strength decreases rapidly with distance, and the energy absorbed by the receiving antenna decreases accordingly.

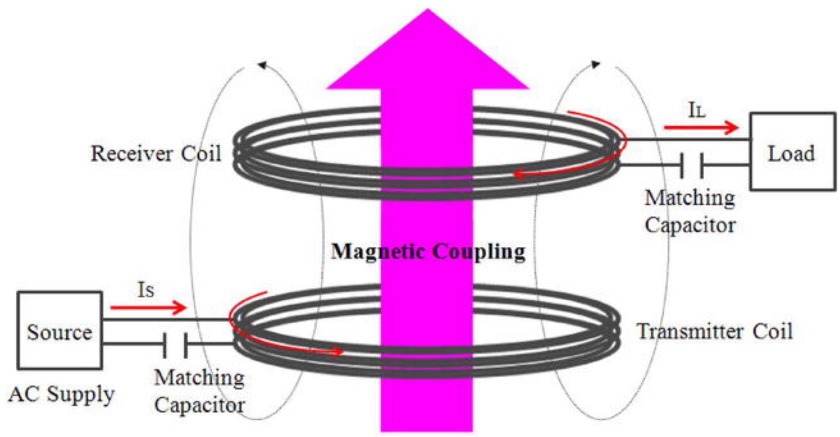

Figure 8 - Mutual magnetic coupled coils for wireless power transfer systems [11]

The schematic diagram in Figure 8 depicts two coil antennas that are mutually magnetically coupled and are part of a WPT system.

The power transfer efficiency between loop antennas for NFC is highest when the antennas are closely matched in terms of size and shape, and when they are placed near each other. The efficiency can be improved also by optimizing the design of the antennas, such as by increasing the number of turns in the loop or using a higher quality conductor.

The power transfer efficiency decreases rapidly as the distance between the antennas increases, due to the rapid decay of the electromagnetic field over distance. The frequency of operation also affects the power transfer efficiency. NFC operates at a frequency of 13.56 MHz, which is in the range of the electromagnetic spectrum used for wireless power transfer using inductive coupling. However, the efficiency of the power transfer decreases as the frequency increases, due to the increased losses in the antennas and the surrounding medium.

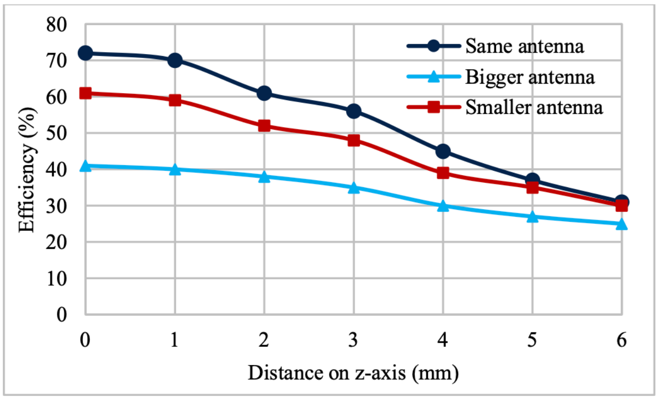

Figure 9 - Impact of the antennas size on efficiency

One of the challenges in NFC (Near Field Communication) technology is the generation of eddy currents in conductive materials that can interfere with the NFC signal. Eddy currents are circulating currents that are induced in a conductive material when it is placed in a changing magnetic field. These currents can cause heating, power losses, and electromagnetic interference (EMI) that can degrade the performance of the NFC system

[9]. Ferrite materials are often used in NFC applications to mitigate the effects of eddy currents. Ferrites are ceramic materials that have a high magnetic permeability and a low electrical conductivity. When a ferrite material is placed near a conductive surface, it can act as a magnetic shield that diverts the magnetic field away from the surface, reducing the induction of eddy currents [11].

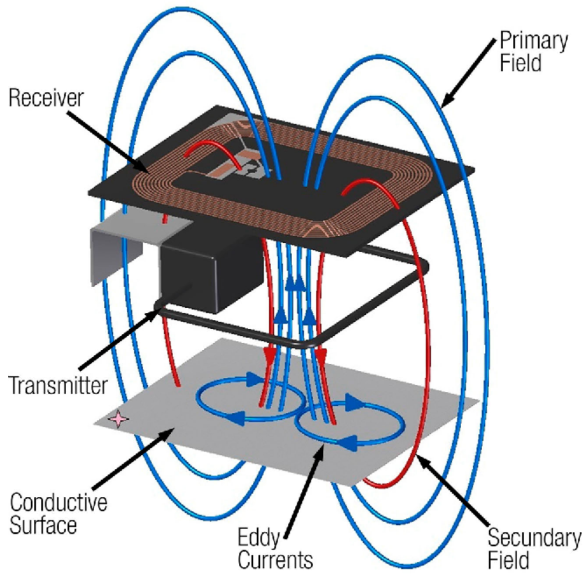

Figure 10 - Diagram of the stray effects caused by placing a conductive surface close to the NFC communication area without shielding

In NFC applications, ferrite materials can be used as a layer in antennas, as a core in inductors, or as a shield around the NFC device to reduce EMI. By using ferrite materials in the design of NFC devices, the performance of the system can be improved, and the effects of eddy currents can be minimized [12].

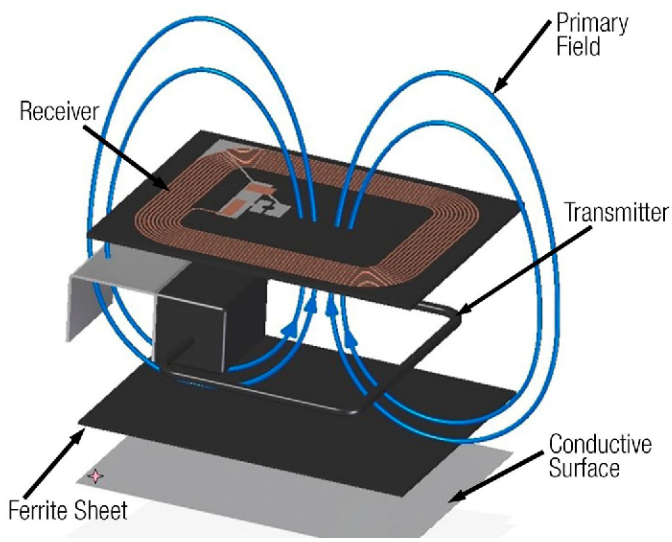

Figure 11 - Diagram of magnetic field produced when a conductive surface is close to the NFC communication area with shielding.

4 Energy Harvesting

The process of obtaining and accumulating small quantities of energy from the environment or a system and converting it into electrical power that can be used is known as energy harvesting. This approach is utilized in a variety of applications to supply low-power devices, sensors, and other electronics with the necessary small amounts of energy.

There are various sources of energy that can be harvested, including [13]:

- Solar energy: Photovoltaic cells can convert sunlight into electrical energy, which can be used to power small devices.

- Thermal energy: Heat can be converted into electrical energy using thermoelectric generators, which use a temperature gradient to generate a voltage.

- Vibration energy: Mechanical vibrations can be converted into electrical energy using piezoelectric materials, which generate a voltage in response to mechanical stress.

- Radio frequency (RF) energy: RF signals from Wi-Fi routers, cell phone towers, and other sources can be converted into electrical energy using RF harvesters.

Energy harvesting can find application in various fields, including wireless sensors, wearable devices, and remote monitoring systems. It can also be beneficial for powering low-power electronic devices in remote or off-grid locations where conventional power sources are impractical or unavailable. The technology continues to evolve, and energy harvesting devices are increasingly efficient and cost-effective, making them accessible for a broad range of applications.

Table 1 - Energy sources with their characteristics and applications [13]

Energy Source	Types	Characteristics	Amount	Applications
Solar [3]–[7]	Solar/light	Uncontrollable, partially predictable	100 mW/cm^2	Outdoor, wireless sensors, cellular base stations
Illumination [9], [10]	Solar/light	Partially controllable, predictable	10 μW/cm^2 ~ 100 μW/cm^2	Indoor, wireless sensors
Thermal [6], [7], [11]	Thermoelectric	Uncontrollable, unpredictable	10 μW/cm^2 ~ 1 mW/cm^2	Human body, wearable, consumer devices
Wind [15], [16]	Motion/vibration	Uncontrollable, unpredictable	100 mW at wind speeds 2 m/s ~ 9 m/s	Outdoor, wireless sensors, cellular base stations
Car engine [2], [14], [17]	Motion/vibration	Controllable, predictable	30 mW	Vehicle, wireless sensors
Blood vessel [2], [14], [17]	Motion/vibration	Controllable, predictable	1 μW	Human body, wearable devices
Knee bending [2], [14], [17]	Motion/vibration	Controllable, predictable	7 W	Portable, wearable devices
EM induction [20]	Electromagnetic radiation	Controllable, predictable	high efficiency $\geq$ 80 %	Portable devices (distance: < 1 m)
Ambient RF [20]	Electromagnetic radiation	Uncontrollable, unpredictable	0.2 nW/cm^2 ~ 1 μW/cm^2	Wireless sensors, RFID (distance: ~ 10 m)
Dedicated RF [28]	Electromagnetic radiation	Partially controllable, partially predictable	5 μW at transmit power 4 W, distance 15 m	Wireless sensors, portable devices, power stations (distance: <~ km)

4.1 Energy harvesting in IoT

Energy harvesting is a promising technology for powering IoT (Internet of Things) devices, as it allows them to operate without the need for batteries or other traditional power sources. This is particularly useful for IoT devices that are deployed in remote or hard-to-reach locations, where replacing batteries can be difficult and costly.

One of the challenges of energy harvesting in IoT is the limited amount of power that can be generated from these sources. IoT devices typically require only small amounts of power to operate, but energy harvesting devices may not be able to generate enough power to sustain the device's operation continuously. Therefore, energy management techniques, such as power optimization, duty cycling, and energy storage, must be used to ensure that the device's power requirements are met.

Energy harvesting has great potential for powering IoT devices, and it is expected to become increasingly popular as the technology continues to improve and become more efficient.

4.2 Energy harvesting with NFC

Energy harvesting can also be used in conjunction with NFC technology to power small devices or sensors that do not require a continuous power supply. NFC technology uses inductive coupling between two antennas to transfer data and power wirelessly over a short distance. The energy transfer in NFC can be used to power low-power sensors or devices that require only small amounts of power.

Energy harvesting in NFC can be achieved by adding an energy harvesting circuit to the NFC tag. This circuit can use various energy harvesting techniques, such as solar, thermal, or vibration harvesting, to convert ambient energy into usable electrical power. The harvested energy can be stored in a small battery or capacitor, which can be used to power the NFC tag or other low-power devices.

One of the advantages of energy harvesting in NFC is that it allows for passive operation of the NFC tag, which means that the tag can be powered without the need for an external power source or battery. This makes it ideal for applications such as wireless sensors or RFID tags that need to operate for extended periods without maintenance or replacement of batteries.

- Advances in these systems

5 Existing NFC WPT Applications with Energy harvesting

6. Conclusions

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