Review on UHF RFID Tag Antenna

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ABSTRACT

This paper presents a comprehensive review of ultra-high frequency (UHF) radio frequency identification (RFID) tag antennas. Due to multiple benefits, RFID technology has supplanted conventional methods of identification like barcodes, magnetic stripe cards, and smart cards. The size of the antenna plays a crucial role in determining the overall dimensions of the RFID tag, making antennas typically low profile and compact. It is acknowledged as an innovative approach for tracking because of its affordable price, passive wireless power transfer capabilities, versatility, and non-line-of-sight communication. UHF RFID tag antennas find widespread use in various applications such as supply chain management, asset tracking, and vehicle identification. The UHF antennas are favoured because they enable simultaneous detection of more tags, provide greater read ranges and faster reading rates, and necessitate fewer antennas than low frequency and high frequency antennas. Establishing the application requirements, choosing the ideal antenna design and substrate material, developing, and optimizing the antenna, manufacturing the antenna, and connecting the antenna to the RFID tag are all essential processes in implementing an UHF RFID tag antenna. This paper will cover the overview UHF RFID tag antenna, few applications, and its limitations.

Keywords: RFID, UHF, Tag antenna

1 Introduction

In the 1990s, as semiconductor technology advanced, Radio Frequency Identification (RFID) gained popularity 1. It is a commonly used and quickly developing technology that uses radio waves to recognise and track different things. It has become an integral part of various industries such as retail, logistics, healthcare, and manufacturing due to its ability to provide real-time information about the location and status of objects. This method identifies tagged things passively by using electromagnetic fields or radio waves. A radio receiver and a transmitter (connected to an antenna) are coupled to form a radio transponder, which makes up an RFID tag2. RFID tags may be split into passive tags and active tags, which are the two main classifications. In order to communicate data to an RFID reader, active tags contain an internal power source, such as a battery. Without an internal power source, passive RFID tags are dependent on the electromagnetic energy radiated out by the RFID reader to operate and transmit data3. Based on the frequency at which they are intended to operate, RFID tags are divided into several categories. Four primary frequency ranges are namely: low frequency (LF) 125–134 KHz, the high frequency (HF) 13.56 MHz, the ultra-high frequency (UHF) 840–960 MHz, and microwave 2.45 and 5.8 GHz 4. The RFID interrogator and the RFID tag are the two parts of an RFID system. The RFID reader sends out radio waves and then captures the signals that are reflected back from the RFID tag, which is either attached to or implanted within the object or person that is being monitored. The tag contains a microchip and an antenna, and it responds to the reader's signal by sending back its unique identifier. The unique identifier can be used to track the object or person5. For example, a company that produces electronic devices may use RFID tags to track the components and products throughout the supply chain. The tags can be attached to the

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components as they move through the production process, and to the finished products as they are shipped to warehouses, distribution centers, and retail stores.

2 UHF RFID Tag Antenna

In the modern marketplace, UHF band RFID tags are most necessary. Compared to LF and HF tags, UHF tags are smaller and have less multipath interference. They have a lower transmitting power but offer a higher read range. Backscatter modulation is a technique commonly employed in UHF RFID tags. In this method, the reader antenna acts as an interrogator, sending an electromagnetic wave to the tag. The UHF tag functions as a transducer, which converts the electrical signal received from the incoming interrogator5. According to the needs of each individual application, the UHF RFID tag antenna may be created in a range of forms and sizes using conductive materials, such as copper or aluminium. There are various forms of UHF RFID tag antennas available, catering to different applications and requirements such as patch, loop, and dipole. The UHF RFID tag's performance is significantly influenced by the size and design of its antenna. The read range and sensitivity of an antenna often increase with size. There is a trade-off between size and performance, yet larger antennas can also be more expensive and inconvenient. Antennas for UHF RFID tags may be made to work in a range of conditions, including on-metal, off-metal, and high-temperature environments6.

3 Types of UHF RFID Tag Antenna

1) Dipole Antennas: This popular design of UHF RFID tag antenna is frequently used for all-purposes. It is made up of two metal rods that may be bent in different directions and are spaced apart by a short gap. Dipole antennas are simple to manufacture, inexpensive, and provide good performance.

2) Loop Antennas: These antennas, which are composed of a single wire loop, are frequently employed in situations where a compact form factor is necessary, such as asset tracking. Loop antennas are easy to manufacture and have a low profile, but they provide shorter read ranges than dipole antennas.

3) Patch Antennas: These antennas are typically employed in situations where a low-profile, high-gain antenna is required, such as in inventory management. They are constructed from a flat piece of metal. Patch antennas are simple to manufacture and provide good performance, but they are more expensive than dipole or loop antennas.

4) Spiral Antenna: A spiral antenna consists of a spiral-shaped wire or metal trace that is used to generate a magnetic field. This type of antenna is often used for larger tags that require a longer read range. Spiral antennas are more complex to manufacture than dipole or loop antennas, but they provide longer read ranges.

5) Planar Inverted-F Antenna (PIFA): A PIFA antenna is similar to a patch antenna but has a protruding element that extends above the surface of the tag. Mobile gadgets like smartphones and tablets frequently use it. PIFA antennas are more complex to manufacture than dipole or loop antennas, but they provide good performance and have a low profile.

4 Applications

UHF RFID tag antennas are utilized in a variety of applications where quick and accurate item identification and tracking are necessary. UHF RFID tag antennas are frequently used for the following purposes.

4.1 Healthcare

Researchers' interest in creating tiny antennas for use in medical applications has increased in recent years.

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Developed a small antenna for an RFID tag made of metamaterials that may operate near human flesh. In order to maximize comfort when they are deposited on human tissue, RFID devices must be made smaller and more efficient, which has been highlighted by the increased demand for them in the health sector. These devices are typically composed of two main components: an antenna and a chip. Since the typical size of an RFID chip is only a few millimeters, the size of the antenna has a significant impact on the system's overall performance7. The suggested tag produced good results when used close to human tissues, which absorb and reflect electromagnetic signals. The proposed tag antenna offers improved gain and good matching properties when mounted on a human arm phantom. This resulted in a normal radiation pattern and a significant reduction in tag size. The use of L-matching method in designing RFID tag antennas can enhance the working frequency range and improve the antenna's overall effectiveness. Future research will focus on developing an optimal tag layout, which incorporates sensing capabilities for medical applications. Researchers will also look at the possibilities of substituting substrate and conductor materials with better ones that are compatible with human skin14. The use of UHF RFID technology has led to the development of a high-performance, flexible tag antenna that is particularly suitable for blood bag traceability applications. This unique antenna has a smaller size and is designed to enable strong conjugate impedance matching with the IC chip when blood is present, through the use of nested slots and inductive and capacitive components in its construction. The proposed UHF RFID tag antenna was developed using a rapid and cost-effective prototyping method that utilized a low-profile, flexible Kapton polyimide substrate with adhesive properties. This makes it easy to shape and attach to blood bags. This flexible tag antenna could potentially improve patient safety and the dependability of healthcare infrastructures when used in new blood bag traceability systems that employ UHF RFID technology15.

4.2 Vehicle Tolling and Vehicular Applications

For Automatic Vehicle Identification (AVI) applications, installing an RFID tag on a vehicle's window glass has proven difficult for RFID users and service providers since, occasionally, the tag cannot be read properly because some customers do not follow installation instructions. This issue arises because the distances between the windshield's various locations and the car's hood, roof, and A-pillars vary, and these metallic surfaces immediately interact with the tag antenna's radiation resistance and thus alter its performance. The read range of the tag is significantly impacted in certain places on the windscreen while it is greatly improved in others. The Higgs 3 chip is used in the current work to create an RFID tag for automobile window glass. It was found that its read range is greater at every point of the windscreen than that offered by the widely used commercial RFID tag SMARTRAC DogBone with Monza 4 chip. It was also performed a study of the numerous positions of the windscreen in order to discover the best and worst areas to install the tag9.

4.3 Supply Chain Management

RFID is an inexpensive, low-power, non-contact automated identification method. Due to its outstanding capability, SCM has a wide range of possible applications that are expanding globally. Each individual item and carton are properly counted, corrected, and traced via RFID throughout the supply chain. This process starts in the factory where products are source-tagged, proceeds through the distribution center where orders are processed, and culminates with orders being sent to stores. A piece of equipment is numbered using RFID each time it enters or exits a process stage, and any faults are discovered and corrected. RFID technology is an effective tool for managing supply chains since it facilitates digitization and sparks a lot of research interest for a variety of tasks, such as warehousing, packaging, processing, and distribution along value chains10. RFID tags are capable of generating data from suppliers throughout the production process

to sales, thereby increasing efficiency and effectiveness across the entire business. Additionally, the use of RFID technology improves the process of distributing goods11.To initiate the identification procedure, RFID tags are attached to all relevant materials and items. The next step is scanning the tag, which can be done at conveyor belt's terminus. The tag then transmits data to a database, which is typically located in the cloud. After that, the item is delivered to the distribution facility where it is further sorted and dispatched to stores. At every level of the distribution process, readers make it simple to trace the movement and location of the goods. This enables the distribution center to effectively sort and manage the merchandise, ensuring that it reaches the correct destination. The readers are able to identify the movement and location of the items with ease, providing valuable data that can be used to optimize the distribution process12.

4.4 Retail Industry

RFID technology is used in retail to attach RFID tags to merchandise. These tags broadcast signals that are picked up by RFID readers and analyzed by special software. This makes it possible to produce real-time data for transactions, inventory levels, stock tracking, or specific client purchase order histories. RFID technology simplifies the often chaotic and time-consuming retail input procedures that are typically done manually. One of the most desired applications for RFID in retail is item tracking. Item tracking is an important operation of RFID in retail. It entails applying RFID tags to specific items in order to follow their travels from producer to retail shelf across the supply chain. This enables retailers to keep track of inventory levels, monitor stock movements, and reduce out-of-stock situations. RFID can also help retailers to streamline their supply chain processes and reduce labour costs by automating tasks such as inventory management and product tracking. Additionally, RFID can help retailers to improve their customer service by providing real-time information about product availability and location. RFID may be utilised in the retail industry to track items that are often moved and misplaced and to prevent theft. Retailers may follow their merchandise using RFID tags from the storehouse's shelves to the sales floor. The UHF RFID passive tag's architecture, which consists of a single RFID transmitter inductively coupled to a double-circle UHF antenna, is a practical solution that fits the requirements of the harsh cleansing environment. An electrically isolating substance that is immune to leaks and able to bear mechanical, thermal, and chemical stressors houses the RFID tag transponder. It has two electrolytic connections to the inductively linked circle's outstations. By inductively connecting the UHF antenna and transceiver with an extra circle, it is possible to run the tag at minimal power while also shortening the label and improving coupling. Proper equipment and manufacturing processes are employed to produce the UHF antenna, which involves stretching a multifilament pristine sword line on a cloth support to ensure the tag's rigidity and inflexibility. The washable and flexible UHF RFID passive tag was tested for its suitability by conducting bending and washing tests13.

4.5 Access Control

Access control may be provided through RFID technology in a variety of locations, including workplaces, buildings, and gated communities. Access to particular regions or buildings is granted or denied using passive tags or transponders. In order to determine access, the system reads passive tags or transponders using RFID scanners and compares them to an access control list. The RFID reader detects the Passive tag or transponder as the person approaches the entrance point, checks the stored data against a database of approved people, and opens the entry point for authorized people. Unauthorized visitors are sent away16. Bakht proposed a novel form of location security management and RFID-based access control system. The system creates a complex network of internal security management gaps by utilizing a limited number of active and passive RFID devices, as well as several subsystems including regional positioning, regulation of

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non-barrier access and monitoring management. To precisely locate the workers, an enhanced RF packet loss rate localization technique is proposed. The system is capable of providing personnel identification, fixed positions, and tracking records, among other functionalities. It is also stable, has minimal failure rates, and promptly responds to alerts17.

4.6 Meat Freshness Monitoring

It is essential to assess the quality of packaged foods in real time, especially meat items. Distributors can increase productivity by changing the packaging or preservation methods, such as freezing, based on the condition of the items before packing. They will do this by displaying the product's expiration date on an RFID tag. The components of this system include an RFID tag, an RFID reader, a server, temperature, humidity, gas, and an RFID sensor. Water, protein, lipids, and carbohydrates make up meat, which is gradually broken down into volatile gases by the action of the enzymes. A PC analyzes the information from the RFID reader to determine the freshness and expiry date after the gas sensor studies the gas given out by the meat. The signal from the MCU, which receives the signal from the MCU, then transmits it to the RFID reader. Additionally, the server records this operation. The server examines the data on ammonia and presents the findings to the client immediately. Through the integration of RFID technology with gas sensors, temperature and humidity sensors, and other relevant sensors, a correlation was established between the freshness of meat and the gases released from the meat's flesh18.

5 Advantages

Ultra-High Frequency (UHF) RFID tag antennas offer several advantages that make them an ideal solution for many applications in industries such as manufacturing, logistics, and retail. The following list includes some of the advantages:

- UHF RFID tag antennas provide a longer read range than other types of antennas, such as High Frequency (HF) or Low Frequency (LF) antennas. The read range of UHF RFID tag antennas can reach up to 10 meters or more, depending on the specific design and environment. This allows for faster and more efficient asset tracking and inventory management, especially in large warehouses, distribution centers, and retail stores.

- UHF RFID tag antennas have a higher data transfer rate than other types of antennas. UHF RFID tags can transfer data at a rate of up to 1 Mbps, which is much faster than HF or LF RFID tags. This high data transfer rate enables real-time tracking and monitoring of assets, as well as faster processing of inventory data.

- UHF RFID tag antennas can read multiple tags simultaneously, which is a major advantage in applications where multiple items need to be tracked at the same time. With the ability to read and process multiple tags within a few seconds, UHF RFID tag antennas are ideal for use in high-volume manufacturing, supply chain, and logistics operations.

- UHF RFID tag antennas are small in size and can be integrated into a wide range of devices and products. This makes it possible to embed UHF RFID tags into items such as clothes, shoes, and even small electronic devices. As a result, UHF RFID tag antennas are widely used in the retail industry for item-level tracking and inventory management.

- UHF RFID tag antennas are cost-effective and provide a high return on investment (ROI). Due to their long read range and multi-tag reading capabilities, UHF RFID systems require fewer antennas and readers compared to other RFID systems. This reduces the overall cost of deploying and maintaining an

RFID system and allows for a faster ROI.

6 Challenges

When opposed to commercial alternatives, the introduction of RFID technology has created various hurdles in the sensor data transfer protocol, dependability, and environmental compatibility19. The following list includes some of the major technological difficulties:

1) Interoperability: With RFID systems, inter-tag communication is neither practical nor simple to use, unlike with WSN. In order to extend communication or tracking capacities across a large region, it is important to ensure interoperability between tags.

2) Accuracy or reliability of measurement: The functioning principle of the RFID sensor is based on the interaction of electromagnetic waves, making it sensitive to the effects of the surrounding metal environment such as reflection, refraction, and dispersion of radio waves, as well as the object being tested. Therefore, it is important to calibrate an RFID sensor to attain the required level of measurement accuracy20.

3) Information Security or Privacy: Security concerns surrounding RFID identification tags can have significant impacts on individuals and businesses alike. These tags are not entirely secure, leaving them vulnerable to eavesdropping, denial-of-service attacks, traffic analysis, and other malicious activities. Furthermore, readers lacking access restrictions can scan multiple codes without authorization, potentially breaching privacy. Predictable tag perceptions may also lead to attacks on traffic analysis systems, putting user privacy at risk. To ensure the reliability and usefulness of RFID systems, there is a growing effort to design and implement cost-effective security and privacy measures. While several lightweight protocols have been developed, they come with significant costs, offer minimal protection, and do not fully address security concerns. However, through excellent research, it is possible to create extremely lightweight secure communication techniques for reasonably priced RFID systems.

4) Interference Issues: It is widely believed that UHF RFID technology will revolutionize supply chain management, and major corporations like Tesco and Wal-Mart are pushing for its adoption in the 860-960 MHz band. However, the deployment of UHF RFID technology in supply chains will require close collaboration between dozens or even hundreds of readers, which could result in significant disruption problems. Tag interference happens when a reader activates many tags at once, leading each signal to bounce back to the reader. This results in the scattering of waves and makes it difficult for readers to distinguish between specific IDs and markings. Anti-collision techniques like Aloha and binary trees are crucial in addressing these interference issues.

5) Collision Problems: Tags and readers may malfunction due to electromagnetic interference, resulting in inaccurate data and poor decision-making. Transmission problems might result from collisions when many tags and readers use the same radio frequency channel. To address this problem, a collision avoidance protocol is necessary, such as a database tree protocol, binary tree protocol, or split system protocol. However, the efficiency of these protocols is typically below 50%, which limits their commercial viability. As a result, there is a need for improved protocols that can facilitate the implementation of large-scale RFID systems with higher efficiency and accuracy.

7 Conclusion

The paper provided an outline of UHF RFID tag antenna, it's applications and limitations. By utilizing RFID technology, businesses and organizations can enhance their precision, reliability, and security. RFID

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technology was introduced and detailed in the first section of this essay. UHF RFID tags are used in a range of sectors, such as supply chain management, production, medical field, livestock management, automatic toll collection, library administration, and many more. The article discusses the usage of UHF RFID tags as a technique to provide novel functions and realistic techniques for an expanse of applications.

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