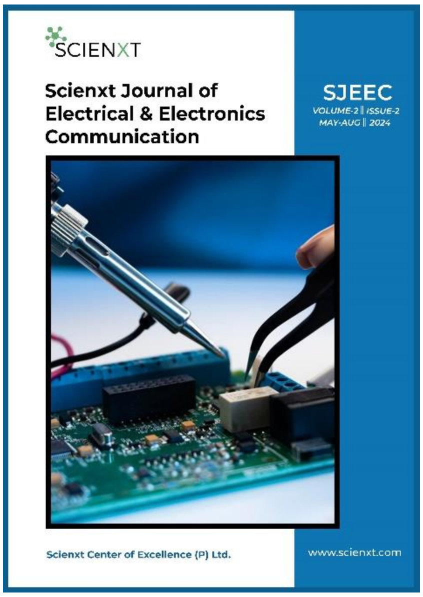

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Chipless rfid sensors: A review of technologies and trends

Viveka Krishna Gond
Student, Department of ECE, Dayanand Sagar Academy of Technology and Management, Bangalore

Dr. Mallikarjun P. Y
Professor & HOD, Department of ECE Dayanand Sagar Academy of Technology and Management, Bangalore-82

**Corresponding Author: Viveka Krishna Gond*
Email: vivekgond783@gmail.com

Abstract:

Radio-frequency identity (RFID) sensors have emerged as a key generation in the Internet of Things (IoT) environment, providing an unbroken interface for records trade between bodily objects and the cloud. These chipless sensors provide key benefits which include printability, passive operation, low energy consumption, and performance in harsh environments. Multibit chipless tags have shown incredible success, sparking interest in extending their sensing capabilities to include physical, chemical, structural, and environmental. This paper provides a comprehensive review of chipless RFID sensor technology, including various construction methods and material requirements for sensing applications It focuses on state-of-the-art sensor classes and their applications, among other things, and temperature and humidity monitoring, proximity hearing, structural health assessment provides an outline of beauty and provides possible solutions to overcome these limitations. In addition, it explores recent advances in integrating RFID sensors with artificial intelligence to improve sensitivity and selection as well as machine learning techniques Combining insights from chip-based and chipless RFID sensor technologies, this paper describes the transition to chipless solutions and provides a road map for future research efforts in this area Chips through interdisciplinary approaches affecting the development of materials science, wireless communications, and data analytics jointly provide

Keywords:

Chipless RFID Ultrahigh-frequency (UHF) RFIDs, Microstrip antenna, ultrawideband (UWB) frequency.

1. Introduction:

The Internet of Things (IoT) has fundamentally altered how we interact with generations by incorporating connectivity into commonplace objects to gather data and automate processes. The Internet of Things (IoT) relies heavily on sensors, which act as the network's eyes and ears. This is the network of related gadgets that can be equipped with sensors, software, and connectivity to be able to collect and share information. The Internet of Things has the potential to completely transform a few industries, but the advent of smart cities is one in which its effect is specifically considerable. [1]

The method known as radio frequency identification makes use of electromagnetic fields to identify and identify tags attached to objects automatically these days, IOT sensors are utilized in sensor networks that require a circuit to be connected to a power source and cannot be used in difficult settings like high temperatures or low pressure. In such circumstances, electrical waste and price increases also the [base paper]. Facts recorded electronically are contained in the tags. RFID no longer has to be in the line of sight for the reader to retrieve data from the tags, in contrast to barcode generation. In recent years chipless RFID has been mainly used in sensor networks for its unique features like low cost and low power usage these will be the major factors that affect the usage of chipless RFID sensors in the current scenario, Active devices use the Battery for the function that makes to change alternative cases either chipless will be beneficial compared to the active IOT sensors.[2][3] the benefits of chip-based sensor systems, such as a long reading range, a straightforward reader design, high accuracy, and memory capacities, chipless sensors provide a straightforward and affordable substitute for chip-based sensors. One benefit of chipless sensors is that they require less power, which can be obtained from external energy sources, or none at all.[2][3][4]

Chipless RFID presents several challenges, including read range, materials, and multi-parameters.[5] These are not the only issues. While utilizing deep learning and machine learning methods to increase the efficiency of the sensors [6][7] This is how the remainder of the article is structured. The scope and methods of this review paper, along with the working concept of RFID sensors, are covered in Section I of the following. A proposed classification scheme for chipless RFID sensors is presented in Section II. Section III presents many uses for RFID sensors, and Section IV discusses the obstacles that still need to be overcome before RFID sensors may be implemented. This section presents potential solutions found in the literature. Recent papers using deep learning (DL) and machine learning (ML) for RFID sensor applications are highlighted in Section V. Section VI concludes by discussing upcoming research trends.

1.1. Scope & methodology:

Nowadays, the current generation devices are becoming smaller and more energy-efficient, which significantly impacts the cost of sensors, particularly in sectors where chipless RFID technology is predominantly utilized. When using

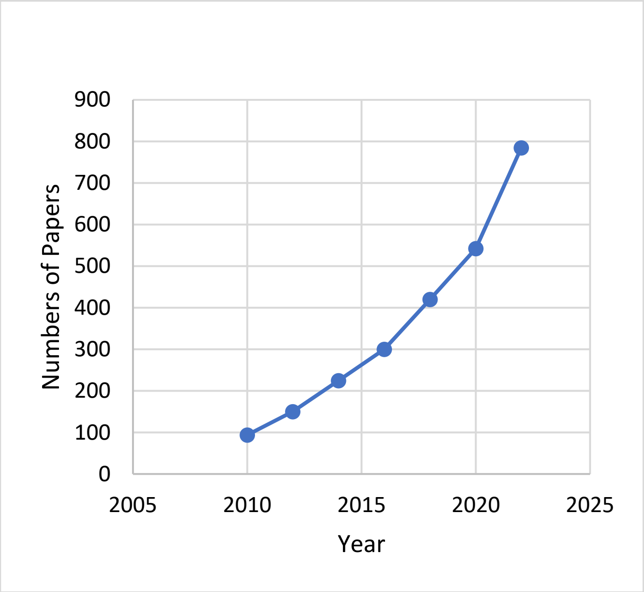

Figure. 1: Distribution of articles on chipless RFID sensors by year, showcasing a steady rise of interest in the technology since 2012

chipless RFID technology, antennas play a crucial role in transmitting information at resonant frequencies. Changes in antenna size directly affect the resonant frequency. This impact extends across sectors such as agriculture, humidity sensing, and gas detection. With the current focus on artificial intelligence, machine learning, and deep learning techniques, there's a growing trend toward integrating these technologies into RFID systems. This integration enhances sensing accuracy and probability. Graph data since 2012 indicates increasing research interest in chipless RFID sensors, which offer versatile and cost-effective solutions for various industries, enhancing efficiency, visibility, and sustainability. The emphasis on chipless RFID sensors by modern researchers suggests their potential to revolutionize future technological landscape

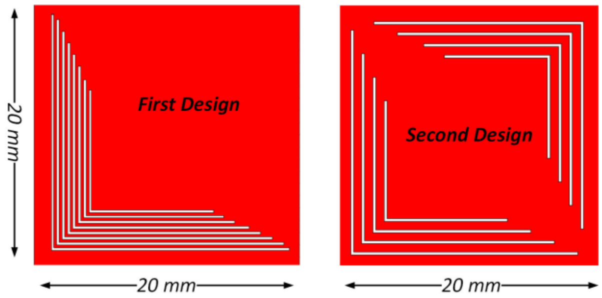

Figure. 2: (a) Designs of L-resonators based backscattering chipless tags

1.2. Operating principle:

The patch antenna-based chipless RFID tag depends on variables like resonant frequency, radar cross-section, phase, and bandwidth. Environmental conditions also have an impact on its performance in hostile locations, thus they are important considerations.[9] The backscattering-based tags only reflect the incoming signal toward the reader; they are antenna-free. It resembles a radar system in that an object is found by receiving a signal that is delivered from the transmit antenna. Fig. 2(a) shows two backscattering 8-bit Chipless RFID tags [10].

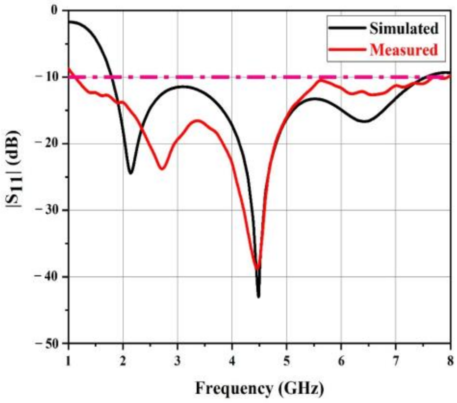

Figure. 3: (a)

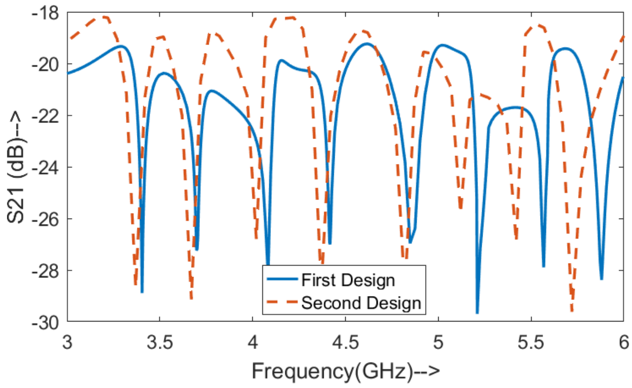

Figure. 3: (b) Measured Response of both the chipless tag designs. [8]

The resonance frequency of the Microstrip patch antenna, which is being investigated by the researchers for integration into the RFID tag sensor needs to be ascertained. This is illustrated below.

$$f_{10} = \frac{c}{2\sqrt{\varepsilon_{ref}}}\frac{1}{L} \qquad \text{-(1)}$$

Let L be the radiating path's length, C be the medium's light speed, and ε_{ref} be the dielectric substrate of the material.[9] In this case, the line extension ΔL is minimal because the substrate height (h) is much less than the radiation patch's dimensions. Equation 1 therefore reduces to.[9]

$$f_{10} = \frac{c}{2L\sqrt{\varepsilon_{ref}}} \qquad \text{-(2)}$$

We may compute the full derivatives in the following way to determine the relationship between the antenna frequency shift δf_{10} and variations in ε_{ref} and L

$$\delta f_{10} = \frac{\partial f_{10}}{\partial \varepsilon_{ref}}\,\delta\varepsilon_{ref} + \frac{\partial f_{10}}{\partial L}\,\delta L \qquad \text{-(3)}$$

Equations 1 and 2 show how changes in the environment affect the dielectric constant. Thus, normalising $\delta f_{10}$with regard to the f_{10}results allows one to calculate the resonant frequency shift brought on by antenna adjustments as follows: [9]

$$\frac{\delta f_{10}}{f_{10}} = -\frac{1}{2}\frac{\delta\varepsilon_{ref}}{\varepsilon_{ref}} - \frac{\delta L}{L} \qquad \text{-(4)}$$

Consequently, it reveals the basic idea and principle behind microstrip antenna sensors. According to the equation, the first term is related to the sensitivity of the sensor to the effective dielectric constant of the antenna, which can be adjusted for biochemical environmental sensing The second step can use the antenna to monitor temperature, pressure and breakdown as it shows how sensitive the resonant frequency of the antenna is to volume changes in the radiation band. The microstrip antenna sensor's resonant frequency is displayed in Figure 3. The antenna performed from 2 to 7 GHz, and it had reflection coefficients of less than 10 dB.

When it comes to temperature sensing, an antenna temperature sensor's effective dielectric constant should show a linear relationship with temperature fluctuationsΔT.

$$\frac{\delta\varepsilon_{ref}}{\varepsilon_{ref}} = \alpha_{\varepsilon}\Delta T \qquad \text{-(5)}$$

Let the temperature coefficient of the dielectric constant be represented by α_ε.Thermally induced length chages and the thermal coefficient of dielectric constant $(TCD)_K$ are expressed as follows:

$$\frac{\delta L}{L} = \alpha_T \varDelta T \qquad -(6)$$

We will offer the normalized equation involving ΔT and strain ε_L over its length for the TM_{01} and TM_{10} modes with a temperature change.

$$\frac{\delta f_{10}}{f_{10}} = -\left(\frac{1}{2}\alpha_\varepsilon + \alpha_T\right)\Delta T = K_T \Delta T. \qquad -(7)$$

While the strain and temperature sensitivities of the antenna resonant frequencies are being examined here, K_T stands for the temperature sensitivity of resonant frequency and strain. Thus far, the resonant frequency of the antenna's strain and temperature sensitivity have been determined separately. The effects of temperature and strain on the resonant frequencies of the antenna are related, though, as is the case with many other strain sensors

$$\Rightarrow \begin{cases} \frac{\delta f_{10}}{f_{10}} = K_T \Delta T - \varepsilon_L \\ \frac{\delta f_{01}}{f_{01}} = K_T \Delta T - \vartheta \varepsilon_L \end{cases}$$

$$\Rightarrow \begin{cases} \varepsilon_L = -\frac{1}{\vartheta - 1}\left(\frac{\delta f_{10}}{f_{10}} - \frac{\delta f_{01}}{f_{01}}\right) \\ \Delta T = -\frac{1}{K_T}\left(\frac{\delta f_{10}}{f_{10}} + \varepsilon_L\right) \end{cases}. \qquad -(8)$$

By utilising the two orthogonal antenna radiation modes, these two impacts can be separated in the event that the antenna sensor undergoes uniaxial strain. Under length direction strain & and a temperature change ΔT, the normalised frequency shifts of the TM_{01} and TM_{10}modes can be stated.

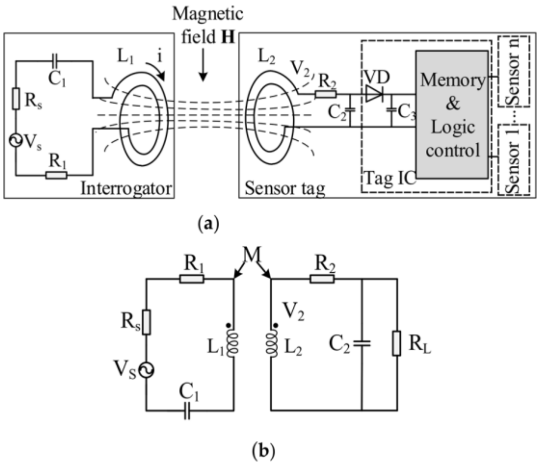

Figure. 4: Structure of (a) HF RFID sensors with inductive coupling and (b) its equivalent circuit [12].

Ultrahigh-frequency (UHF) RFIDs rely on far-field backscattering to function. As such, comparing the power backscattered from the original configuration with the power reflected following an environment change provides insight into the environment change. Given a transmitted power of distance R between the tag and reader, the signal detected by the tag antenna may be calculated using the following equation from [6]:

The power received by the antenna in the UHF RFID will be calculated using.

$$P_{Rx} = \frac{P_{Tx}G_{reader}}{4\pi R^2} * \frac{\lambda^2}{4\pi} G_{Tag}(c)\eta_{pol} \quad -(9)$$

The quality of the material added as a contaminant in the pure substrate is denoted by c in this instance. Received power is denoted byP_{Rx}, and transmitted power via the antenna is denoted byP_{Tx}. $G_{Tag}(c)$ is connected to the antenna's gain. The polarisation mismatch between the tag and reader antennas is represented by η_{pol} . The following formula can be used to express the power that the RFID chip extracts from the tag antenna:

$$P_{r_{chip}} = \left(P_{Tx} * \frac{G_{reader}\,\lambda^2}{(4\pi R)^2}\right) *$$

$$\left(G_{tag}(c)\, \eta_{pol} * \tau(c)\right) \quad -(10)$$

In Eq(10) $\tau(c)$ will measure the impedance mismatch between the RFID chip and tag, also known as the power transmission coefficient. the RFID reader extracts the received signal strength indicator (RSSI) from the backscattered power as follows:

$$P_{RSSI}(c) = \left(\frac{1}{4\pi}\left(\frac{\lambda}{4\pi R}\right)^2 P_{Tx}G_{reader}^2\right) * \quad \left(RCS_{Tag}(c)\eta_{pol}^2\right) \quad -(11)$$

Where RCS_{Tag} can be obtained from following equation.

$$RCS_{Tag}(c) = \frac{\lambda^2}{4\pi} * G_{Tag}^2(c)|\Gamma_m(c)|^2 \qquad \text{-(12)}$$

Γ_m (c) is the reflection coefficient of the tag and is related to the power transmission coefficient in the equation below

$$\Gamma(c) = 1 - |\Gamma_m(c)|^2 \qquad \text{-(13)}$$

L2 and C2 stand for the inductor and capacitor of the tag antenna for receiving, whereas L1 and C1 represent the capacitance and inductor of the resonant transmitter for power transfer. In this case, there is a 0-degree angle between the magnetic induction, B, and the coil's area, SN. Subsequently, the voltage computation will be.

$$f_0 = \frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}} \qquad \text{-(14)}$$

$$\vartheta_2 = -M\frac{di}{dt} \qquad \text{-(15)}$$

M represents the coefficient of mutual induction, and ϑ_2 represents the supply power to the RFID chip and sensor module for data collection and transmission [12]

2. Classification:

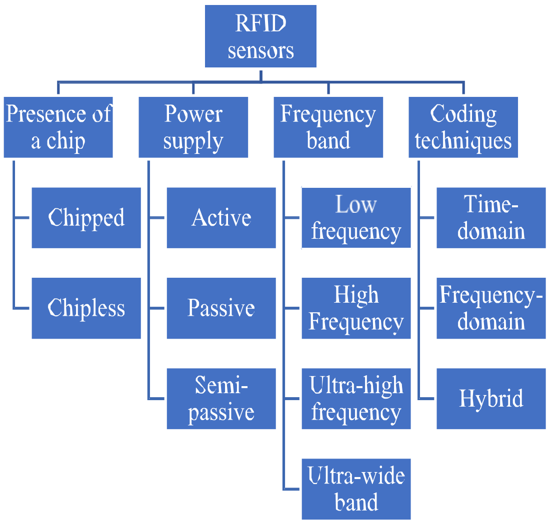

Figure. 5: classification of the RFID

As illustrated in Fig. 5, RFID tags can be categorized in multiple ways according to their operational frequency band, power consumption, coding methods, and reading range. Taking into account in both chipped and chipless RFIDs, the frequency band, low frequency (LF), HF, and UHF have frequently used RFID sensors. RFID tags also operate in the ultrawideband (UWB) frequency range. The data rate and read range between the reader and the tag both increase when switching from LF to UHF, however, the system's performance degrades in the vicinity of metals and liquids. [13]

Chipped RFIDs can also be divided into groups according to how much power they use. To power their integrated circuits and transmit data, active RFID tags are equipped with an internal power source. RFID tags that are passive do not have an internal power source. These tags use the energy gathered from the interrogation signal to power their ICs and provide data to the reader. Lastly, some tags that require a battery are semi-passive. These employ electromagnetic energy from the interrogation zone to transmit data, but they also use batteries for other purposes, such as powering the IC.[13]

On the other hand, depending on the encoding method used, an RFID sensor that is chipless can be divided into three groups: time domain (TD), frequency domain (FD), and hybrid coding. TD-based tags can be further subdivided into TD multiplexing (TDM)-based tags and TD reflectometry (TDR), which includes surface acoustic wave (SAW)-based and transmission line-based tags. TD-based tags encode data in TD. The data in TDR-based surface acoustic wave (SAW) tags is encoded via temporal delays between the reflected pulses, which are produced by an interdigital transducer (IDT) converting electrical signals into surface acoustic waves. Resonators with a surface area of up to 256 bits can produce tags with a lot of data bits. However, compared to other RFID tags, SAW tags are more expensive due to the use of piezoelectric elements. Transmission line-based tags, which are frequently used for structural fracture detection, are the other kind of TDR-based tags. Lastly, ID codes are incorporated into the amplitude-modulated signals that TDM-based tags generate.[16][14][15]

The information in the FD is encoded by the FD-based chipless RFID tags. They include several resonators that, within a specified bandwidth, generate resonances at various frequencies. Retransmission-based tags refer to a class of chipless RFID tags that also have transmit and receive antennas; backscattering or RCS-based tags are FD-based chipless tags that do not have antennas. Regarding FD-based tags, there are two primary obstacles to overcome: the quantity of resonators and the bandwidth needed to encode more data. In recent years, hybrid coding solutions have been proposed to alleviate these restrictions. These encoding techniques code data fragments over several domains, increasing the suggested tag's informational potential. For example, coded information can be realized by utilizing both frequency-amplitude and frequency-phase. [14][16]

In both chipped and chipless RFID systems, antennas are essential components, so selecting the right antenna arrangement is key to ensuring that the RFID tag and reader communicate with each other. To encode data in chipless RFID tags, various structures for resonators and antenna sensors have been proposed in the literature. These include filter-based techniques that employ stepped impedance resonators (SIRs); transmission lines loaded with stubs or resonators, such as spiral and LC resonators; and dipole-inspired resonators, such as split ring resonators (SRRs), C-shaped resonators, slots, L-shaped resonators, ring resonators, and frequency selective surfaces (FSS), electric-inductive-capacitive (ELC) resonators, space-filling curves, substrate integrated waveguide (SIW), first artificial impedance surfaces (AISs). [15][14].

3. Application of chipless RFIDs:

Figure. 6: Different applications of chipless RFID sensor network [8]

3.1. Security:

A chipless radio frequency identification system with a large data capacity that can be used for authentication and security purposes. The near-field coupling between the tag, a series of identical split ring resonators (SRRs) printed on a (usually flexible) dielectric substrate (such as paper, plastic, or liquid crystal polymer), and the reader is what allows the reading to occur. Sequential bit reading is the basis for tag identification (ID), while the presence or absence of SRRs at predetermined (equidistant) places in the chain achieves encoding. Specifically, the tag needs to be moved slightly in a longitudinal direction across the reader, which is a microstrip line that is supplied by a harmonic signal and loaded with an SRR. In this way, the amplitude of the harmonic signal is modulated, and the envelope function which an envelope detector may access contains the (ID) code. Although close proximity to the reader is necessary for tag reading with this method, many applications in the security and authentication space do not have this problem (e.g., secure paper for corporate documents and certificates). As proof-of-concept demonstrations, multiple circular-shaped 40-bit encoders (installed in a commercial microwave substrate) and the matching reader are conceived and built. Included are programming techniques for the tags as well as the first proof-of-concept chipless RFID tag made by inkjet printing on a plastic substrate. [17]

The chipless RFID era offers a promising way to advance security and authentication measures across industries. Leveraging accurate identification codes or patterns embedded within tags, chipless RFID allows anti-counterfeit measures especially in product authentication This time digs software in record authentication, including passports, ID cards, and certificates, and allows binding, provides real-time tracking of treasured assets along with equipment and inventory Access Manage systems benefit from chipless RFID by providing static access mechanisms through RFID-enabled badges or cards. Additionally, chipless RFID helps provide the chain of command security by allowing complete tracking and tracing, thereby reducing the risk of tampering or piracy in areas such as pharmaceuticals, chipless RFID helps authenticate medication receipt, and ensures patient safety as proof of medication authenticity and legality Nonetheless, chipless RFID in many industries and systems It is emerging as a powerful multifunctional technology greater strengthening safety certification process.

3.2. Supply chain:

Development of an environmentally friendly chipless RFID (UCR) tag designed for supply chain management. The purpose of the UCR tag is to provide a unique identifier and monitor temperature. It addresses the limitations of existing chipless RFID tags by generating unique IDs for manufacturing changes and ambient temperature changes. The UCR tag consists of two parts: UCR Part I, which provides a unique ID for concentric ring slot resonators, and UCR Part II, which monitors temperature with a stand-alone circular ring slot resonator The UCR system Security of the supply chain, developed to enhance anti-counterfeiting measures and thermal monitoring of sensitive materials Encryption algorithms are integrated to beautify safety and confidentiality, on the facet of the functionalities of non-replicable bodily entities. The automated monitoring system, referred to as the UCR device, operates efficaciously with capabilities together with batch scanning, non-line-of-sight get right of entry to, and minimum human involvement in the statistics garage. Furthermore, the research examines the resilience and effectiveness of the UCR set of regulations in opposition to capability assaults, emphasizing its capability to mitigate times of false unauthorized proper of entry.[18]

3.3. Health:

Numerous possible uses for RFID sensors are covered in the literature. Of particular note are chipless antenna sensors, which have special qualities that make them ideal for widespread wireless structural health monitoring (SHM). Sensors within SHM have been created to measure strain, track corrosion, and identify cracks [3]. Important areas are emphasised as strain sensors for detecting deformation in infrastructure and fatigue cracks, which account for a large share of structural failures. Furthermore, corrosion damage can have disastrous outcomes even if it is covered up by paint, which emphasizes the significance of early diagnosis [3]. Research has been done to quantify strain and crack, with Wang et al. suggesting RFID tags with chips for crack surveillance [19]. They looked into tag placement techniques and found that while the distance between tags influences mutual coupling, reverse placement minimizes interference in a dual-tag system. Moreover, their research showed that placing fractures in the middle of RFID tags produces the best sensitivity [19]. In their investigation, a single microstrip antenna to sense strain and temperature, and the findings were encouraging [21]. In [20], a new crack sensing system was unveiled. It incorporated a circular microstrip patch antenna as the system's sensing component and four tip-loaded dipole resonators as the ID component. The orientation of the crack was identified using frequency shift, and the depth of the crack was determined using the resonant frequency amplitude. But as [7] notes, there are more uncertainties in the signal's amplitude, which increases the risk of erroneous detection.

3.4. Positioning:

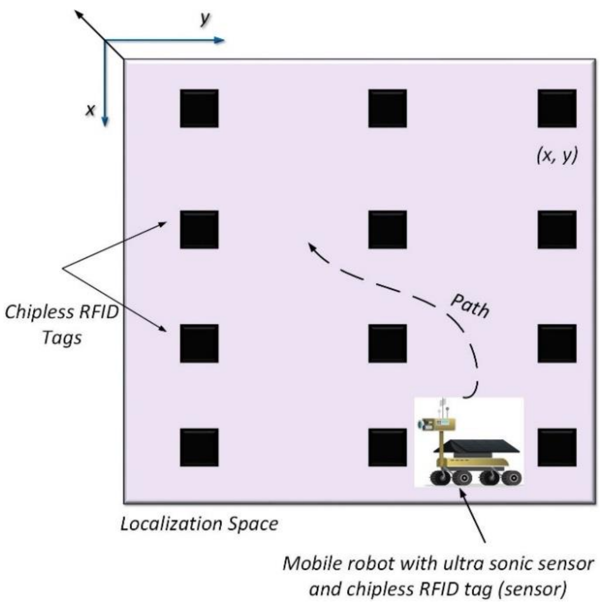

Figure. 7: A general floor-based localization system using chipless RFID tags. [8]

The idea of localization is figuring out where something is in three dimensions. A well-known instance of localization is the use of the Global Positioning System (GPS), which is utilized by millions of individuals globally to determine a place's location and directions. Since GPS signals cannot pass through indoor spaces, RFID has improved on this idea [22]. By using higher frequencies (GHz to THz) to operate, chipless RFID goes one step further and increases the precision of the object's position. The S-parameter results for different distances in the positive and negative directions are documented in the localization experiment [23]. The recorded response from the chipless RFID tag shows variations in both magnitude and frequency. Once more, the majority of current work prefers to use backscattering principles for tags because of their low cost, straightforward design, and ease of fabrication. According to current research, chipless tags are likewise smaller than standard localization methods. [24] Robots for entertainment and services are being used in more practical ways. Localization is a basic problem for mobile robots in the field of robotics [25]. In the field of robotics, recognizing the robot's position in a different environment can be identified as a localization problem. Fig. 7 depicts a general floor-based Chipless RFID localization system that uses several Chipless RFID tags to determine the position and path of the mobility robot. Chipless RFID uses a variety of sensors, including wheel encoders and ultrasonic sensors.

3.5. Gas sensing:

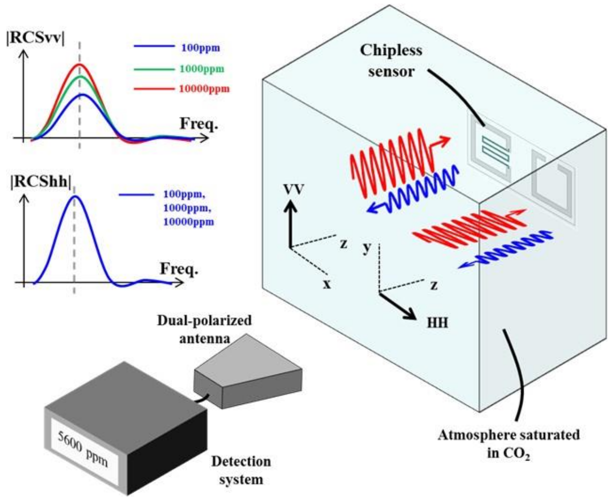

Figure. 8: Principle of wireless detection of gas centration with a chipless sensor [26]

Chipless RFID gas sensors work by changing their electromagnetic characteristics when they come into contact with particular gases. When target gases contact with the detecting material in these sensors, changes occur in conductivity, dielectric properties, or other electromagnetic properties. The chipless RFID gas sensor is questioned by an RF reader or scanner, which sends out electromagnetic waves at specific frequencies. When comparing a chipless sensor to a traditional RFID sensor, the method for extracting the measured parameter and sensor identifier is essentially different. Any transmission technique cannot be used because there is no chip-integrated circuit (IC), unlike in a classical modulation method. The ID and gas concentration extraction for a chipless sensor depends on the frequency-domain or time-domain static backscattered response [3]. In this study, we present a frequency-encoded electromagnetic response sensor. The 2.45 GHz ISM band is the intended operating frequency for the sensor shown in Figures 8. It is predicated on two 90-rotated split ring resonators (SRRs). A variant usage of the squared SRR shape has already been documented in [4]. Compared to a closed loop, this shape enables a factor two miniaturization. Moreover, there is additional flexibility in that the resonant frequency can be adjusted based on the gap length.

Figure 8 shows the diagram of a chipless sensor for wireless gas detection. Chipless sensors are a type of sensor that does not have any integrated circuits, which makes them simpler and cheaper to manufacture than traditional sensors shows that the sensor is made of two antennas: an RCSvv antenna and an RCShh antenna. These antennas are designed to resonate at a specific frequency when they are exposed to gas molecules. When the sensor is exposed to gas, the resonance frequency of the antennas shifts. This frequency shift can be measured and used to determine the type and concentration of gas in the atmosphere. [26][27][28]

3.6. Temp sensing:

Temperature sensing: Dual performance tag having ability of Auto-ID and environment sensing is proposed here and is shown in Figs. 10a and b. The functionality of temperature sensing is added in 30 bits capacity passive tag and enlisted as Tag 3. All the dimensions are same as mentioned in Table. 1 except the innermost slot which is 0.4 mm wide.

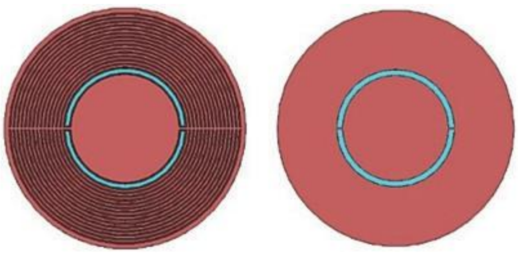

Figure. 9: Temperature sensing 30 bit chipless tag

Table. 1: 30 bit chipless tag dimensions

Parameter	***Distance (mm)***
Patch radius (R_p)	12
Substrate radius (R_s)	12.5
Inner ring radius (R_c)	5.8
Metal ring width	0.2
Slot width	0.2
Split width (S_w)	0.2
$d = R_s – R_p$	0.5

Temperature variations can cause changes in the electrical resistance of polyamide resin, a thermoplastic polymer. The electrical resistance of the polyamide resin changes in tandem with temperature changes. When an RFID reader or scanner reads an RFID tag without a chip, it examines the return signal to look for variations that could indicate changes to the tag's electrical properties, such as the resistance of the polyamide resin. The RFID reader then interprets these measured changes and converts them into temperature data.

This translation manner establishes a courting among located fluctuations in electrical resistance and specific temperature values the usage of a preset calibration curve or algorithm. The received temperature readings are then sent to a monitoring machine or proven for consumer assessment. By including temperature sensing functionality, the chipless RFID tag's makes use of are prolonged beyond simple monitoring and identity to include far flung temperature monitoring of tagged objects. Applications needing correct temperature manipulate or tracking, such cold chain management and environmental tracking in sensitive situations, advantage substantially from this development. [29]

3.7. Other applications:

RFID sensors can monitor the aforementioned factors, which can be utilized to provide early warnings of possible hazards. They are now present in many different Internet of Things sensing applications and will be used in the pharmaceutical, agricultural sensing, Humidity, food quality monitoring biomedical, and door security sensor industries in the future in smart homes, virtual reality, and robotics [2, 3, 6]. Because of its smaller size, flexibility, cheaper cost, and dependability, chipless RFIDs appear to be a feasible alternative to chipped RFIDs based on a review of the literature and comparison of chipped and chipless RFIDs across many applications. Section IV discusses the difficulties of putting these sensors into practice.

4. Challenges faced:

Some of the major challenges that passive chipless RFID sensors face are listed below, along with potential solutions. Since they lack onboard batteries and integrated circuits, some of these challenges such as antenna read range and miniaturization have been extensively studied in the literature, while others like the placement of tag antennas on metal remain to be further explored.

4.1. Read range:

One of the main issues with chipless RFID systems is read range. The read range of an active antenna is greater than one meter, but a passive chipless RFID has a read range of only a few centimetres. Noise and interference from the surrounding environment might cause read range to further deteriorate. Consequently, this technology necessitates efficient ways to increase its reading range. The literature has demonstrated the use of high-gain array antenna configurations to increase the read range of RFID antennas. [30] Other studies in [30], [31], [32], and [33] attempted to increase the read range of chipless RFIDs. While work [67] used a self-interference cancellation (SIC) circuit in the reader antenna, work [30] extended the read range by incorporating a high-gain reflect array antenna as the reader. The transmitter's output signal leaks into the receiver, causing self-interference or self-jamming at the reception. Consequently, this lowers the system's sensitivity and narrows its reading range. When compared to the reader antenna without SIC, this study's antenna reading distance improvement was up to four times greater. ML approaches were applied in [34] to improve the interrogating range of chipless RFID devices.

The maximum read range of a tag, which is interrogated by a reader, can be calculated based on the following equation [35].

$$R_m = min\left(\sqrt[4]{\rho \cdot P_{in} \cdot G_r^2 \cdot G_{tag}^2}\,\frac{\lambda}{4\pi} \times \sqrt{\left(1 - |\Gamma_{tag}|^2 \cdot \rho \cdot\ P_{in} \cdot G_r \cdot G_{tag}\right)}\right) \qquad \text{-(13)}$$

where λ is the wavelength, is the tag's reflection coefficient, G_{tag} is the tag's gain, G_{tag} is the reader antenna's gain, R_m is the RFID system's reading range, and ρ is the polarisation match between the tag and the reader. The regulatory norm limits Pin, the reader's transmitted power, to the order of milliwatts in (13), which poses a significant obstacle to the chipless RFID system's reading range [14]. This equation also suggests that increasing the strength in either the reader or the tag antenna, or increasing the polarisation matching between the reader and the tag antenna, will increase the read range.

4.2. Smart materials:

Smart substances, additionally known as nanostructured practical materials, are excellent options for chipless RFID sensors because of their sensitivity to environmental modifications. Compared to standard RFIDs, they are able to feel a variety of factors, together with gas, temperature, humidity, and pH, greater precisely [36]. These substances include metallic oxides [37], phenanthrene [38], and PVA [39] many more. Since chipless RFIDs don't include a reminiscence module, they are able to handiest be used for real-time tracking and sensing. As a result, they cannot report adjustments in the surroundings. But a few smart materials can also act as a reminiscence device further to being sensing materials. Certain substances have the capacity to check in adjustments within the surrounding environment. For instance, some clever substances' permanent changes in dielectric traits occur when a temperature threshold is finished. They show a steady dielectric property after this point, which means that more temperature fluctuations might not have an impact on them [2]. At eighty ◦C, phenanthrene indicates this type of behaviour [2]. It is a relatively high temperature, although. In [40], there is some other instance. Here, the device undergoes a no reversible exchange because of a pH-based soluble layer, which produces a non-volatile reminiscence impact that records the pH threshold violation.

The fact that using clever substances will increase the fee of the sensor is one of the difficulties. For a value-effective solution, careful choice of clever materials is therefore important.

4.3. Multie parameter sensing:

In order to correctly investigate adjustments in the surroundings, including the ones associated with meals freshness, one-of-a-kind packages require the size of a couple of parameters, which includes temperature, humidity, pH, and fuel [41]. The assignment in more than one parameter sensing comes from the fact that a few clever substances which might be sensitive to temperature also are touchy to humidity [14], and there are different issues with a number of the supposed parameters being particularly coupled to every different. Such as humidity tiers in microclimates can notably have an effect on the pH dimension. Significantly have an effect on the pH size, in order to accomplish the true adjustment inside the preferred parameter, researchers might propose adding a reference tag, assessing the diploma of unwanted parameter in this tag, and deducting its impact from the reaction of the sensing tag. For instance, we are able to decide the effect of humidity on the reaction of the sensing tag via evaluating a pH-sensitive tag with a reference tag (a tag without smart materials) and monitoring how the humidity influences the reference tag. It is able to isolate the impact of humidity and have a clean draw close of the actual pH stage change. The size and cost of the sensors are expanded through this method, although. Substantially affect the pH measurement while it stays a tough task to decouple several indicators, like temperature and humidity, we will gain from rising strategies like employing ML and DL algorithms for higher sensitivity and selectivity. The literature has tested those techniques, mainly with reference to food great monitoring. Nevertheless, chip-primarily based RFIDs have been the focus of the majority of this research. The possibilities for growing the fee of chipless RFID sensors through the software of ML and DL algorithms is enormous.

4.4. Cost challenges:

Significantly affect the pH measurement one of the issues being solved by employing chipless RFIDs is achieving inexpensive tagging and sensing. Further cost reductions are still necessary for these tags [42]. Several strategies were put up to lower the price of chipless tags. Using inks with less electrical conductivity is one method. As stated in [42], a number of surveys revealed that utilizing less expensive, but still sufficient, electrically conductive inks could save printing costs. As an example, compared to tags based on silver and copper, tags based on graphene have demonstrated acceptable performance and can reduce the cost of manufactured RFID sensors [43]. Significantly affect the pH measurement In [44], it was looked into how ink conductivity affected the resonance frequency, bandwidth, and notch depth of a tag. According to this reference study, while the resonance frequency remains nearly constant within the bandwidth, increased ink conductivity results in a drop in bandwidth as well as an increase in signal attenuation and higher quality factor. Significantly affect the pH measurement. Further reduction in the tag price may result from the selection of a suitable manufacturing technology. The advancement of printing technology has already resulted in a decrease in manufacturing costs. Furthermore, certain production processes are more economical than others. For example, screen printing is less expensive than aerosol jet printing in addition to having better reproducibility [42].

5. Usage of machine learning and deep learning:

As there is no handshake mechanism between chipless tags and readers, reading chipless RFID tags involves some inherent unpredictability. Machine learning techniques have been applied to numerous difficult tasks involving pattern identification or prediction [45]. ML was used in RFID sensors to achieve several goals, including reading and interrogation incrementation as suggested in [46], accuracy and sensitivity increase as reported in [7], and categorization [6]. There are fewer published works on chipless RFIDs using ML and DL than on chipped RFIDs. Therefore, we look into the use of ML and DL for both chipped and chipless RFIDs in this part. A supervised support vector machine (SVM) algorithm was used in [45] to increase the accuracy of tag reading for RFID sensor tags without chips. Using a provided dataset, this approach was able to train the reader and identify bit information as "1" or "0." SVM was trained using a dataset consisting of the phase and magnitude information of the backscattered signals at various frequencies. Following training, the RFID reader is capable of choosing by identifying tag ID or sensor data. SVM training was conducted using the experiment's |S21| values, which were measured for 501 points throughout the designated bandwidth of 1–10 GHz.

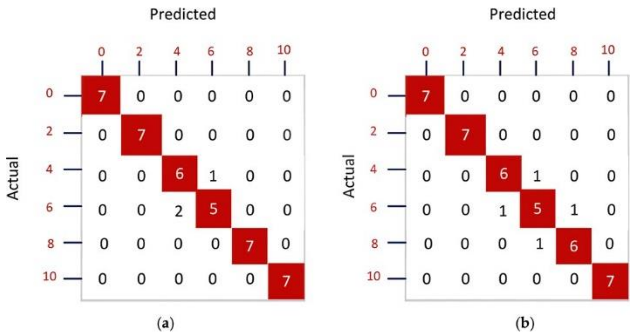

Figure. 10: Confusion matrix of food contamination detection with (a) salt as contaminant and (b) sugar as a contaminant [6]

This experiment was designed to find resonance frequencies at 5.7 and 3.45 GHz. SVM demonstrated better accuracy when compared to the other training methods, which included boosted trees, decision trees, and k-nearest neighbours (kNNs). In [7], a chipless RFID sensor with multiparameter sensing and machine learning support was presented. The purpose of this method was to measure the rate of corrosion and improve the accuracy and sensitivity of the system. An RFID tag without a chip based on FSS was the suggested construction. The backscattered signal underwent feature fusion, feature extraction, and preprocessing calibration. Background measurement and self-interference in the reader antenna were corrected during testing. Subsequently, several characteristics were taken out of the chipless RFID sensor's resonant frequencies in order to detect corrosion. By adding up the features with predetermined weights, several traits were combined. One fused feature that might be utilized to gauge corrosion progress was created by weighted fusion. In this system, simple sum and confidence-weighted averaging (CWA) were used in a feature fusion process. The sum of all feature values for n features from n resonance frequencies is called the simple sum; it is not weighted. The maximum recorded sensitivity for resonance frequency at 5 GHz was found in this article. The reported sensitivity against corrosion thickness and exposure period were 0.81 MHz/µm and 10.6 MHz/month, respectively. Simple addition yielded a sensitivity of 1.34 MHz/µm, or 17.3 MHz/month, at 5 GHz. In addition, the fused feature that combined CWA and simple sum had a smaller average standard deviation when compared to individual resonance frequency features. The average standard deviation of features with individual resonance frequencies is higher than 0.06%, while the value for feature fusion is approximately 0.035%. Indicates that the suggested structure's dependability was raised by the feature fusion technique. The phase and RSSI of the backscattered signal—which is the signal from the RFID tag that was applied to the food sample's surface—have been measured. Additionally, the model was trained using the XGBoost technique in machine learning to produce an accurate food quality evaluation. In the end, our technique achieved a 90% accuracy rate in differentiating between salty and regular spring water. Fig. 16 shows a confusion matrix with the results of identifying salt and sugar as pollutants.

6. Conclusion and future work:

Future chipless passive RFID sensor technology offers an exciting environment full of opportunities for research and development. Several important areas require focused attention and coordinated efforts as scientists and inventors work to realize the full potential of this technology.

First, one of the key goals for the development of chipless RFID sensors is still to get smaller. Researchers can push miniaturization boundaries and create more flexible and compact sensor designs by investigating new materials and improving fabrication procedures. Furthermore, there is a great deal of potential for broadening the deployment of chipless RFID structures across a variety of packages through efforts to embellish their read range by creative antenna arrangements and sign processing techniques. Additionally, the advancement of multiparameter sensing capabilities is a promising area for chipless RFID research. Through the combination of sensors that may discover various environmental traits in chipless RFID systems, researchers can open up new avenues for complete information collection and analysis. This method is mainly applicable to fields that include commercial automation, healthcare, and environmental monitoring, in which comprehensive knowledge is vital for making nicely knowledgeable decisions. For the chipless RFID era to be broadly followed, realistic issues like value-effectiveness and scalability ought to be addressed in concert with generation improvements. Reducing material fees, streamlining production tactics, and optimizing production approaches are all important to bring down the general value of chipless RFID structures. Additionally, the creation of uniform frameworks and protocolize sensor era has superior drastically with the quick development of chipless passive RFID sensors, starting up a wide variety of ability applications in diverse industries. Even with those significant benefits, chipless RFIDs nevertheless face several barriers that require coordinated efforts to overcome. These demanding situations encompass essential elements like downsizing, enhancing the range of antenna examination, improving multiparameter sensing skills, and incorporating more intelligent materials. However, recent advancements have proven encouraging solutions to those tough situations, such as the usage of open-stub resonators and nested slots for miniaturisation and reader antenna arrays and SIC for extra have a look at range.

In addition, price-effectiveness needs to be addressed in order for chipless RFID generation to be widely utilized by agencies. There are numerous methods to reduce the fee of the device, consisting of simplifying resonator systems and employing inks with reduced conductivity. Future instructions for chipless passive RFID sensors display amazing capacity for increase and innovation. Through expanding the variety of applications and projects, chipless RFIDs can spoil thru conventional obstacles and spur innovative trends. For example, using ML algorithms and incorporating chipless RFIDs into smart bandages could rework medical diagnostics, mainly within the location of persistent wound evaluation.

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