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On the Seamless Integration and Co-Existence of Chipless RFID in Broad IoT Framework

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ABSTRACT RFID has permeated in wide-ranging applications that may eventually fall under the broad IoT umbrella. However, the adaption of RFID for commercial purposes of IoT-centric applications still faces numerous technical challenges due to its high cost. The Chipless RFID can become a boon considering its significantly reduced cost and tag complexity in this context. In this article, therefore, different aspects of the chipless RFID are discussed and analyzed, and a potential road map is explored for the effective seamless integration of chipless RFID in the amalgamated IoT. At first, a brief theoretical preliminary about the Chipless RFID is presented, and it is succeeded by the application's specific roles of this emerging RFID in the wide variety of domains. Subsequently, the analysis of various physical parameters shows that chipless RFID technology can greatly broaden IoT's horizon. It essentially shows that it has the potential to bring a paradigm shift in the way RFID can coexist with IoT. Finally, a section which briefs about the future directions is also included to throw some light on Chipless RFID's direct fitment in the IoT.

INDEX TERMS Chipless RFID, frequency domain, IoT, localization.

I. INTRODUCTION

Internet of things (IoT) is a group of competent and intelligent devices around us that are context-aware and connected according to the system requirement. These devices include wearable devices, metering devices, and environmental sensors [1]. IoT devices produce, receive, and deliver data through wired or wireless communication while using the internet. It helps in collecting and analyzing data from devices and objects with efficiency and ensures data safety and security. The word ''Internet of things'' (IoT) was introduced by Kevin Aston while he was working on Auto-ID MIT, the concept of linking supply chain P&F RFID [2] information to the internet.

IoT is the third significant invention in information and communication technology (ICT) after computers and internet technology. The number of devices connected to the IoT reaches 100 billion in 2020 [3] and can cover around 85% of the market. It enhances the quality of life and enables new businesses and markets. It can help in the health sector, business class, consumers, and society as a whole for employment creation. For instance, in the health sector, a heart monitor in ICU can collect and transfer the patients' data to the concerned doctors without any manual intervention, which can save patients' lives with minimal human involvement. It aims to make devices smart as they can process information, self-configuration, and make independent decisions as per the condition.

In addition to that, RFID Technology was the primary step in the process of finding IoT from 2000. IoT can connect to different physical objects with RFID's help, optimize operations, share data, and promote faster decision-making [4]. The RFID system allows secure communication between the devices to transfer certain types of information with other objects. Essentially, the connectivity of various RFID readers, their identification, and tags localization in the system can be facilitated by IoT [5]. Cost reduction, miniaturization of the devices, power-efficient electronic devices, positioning ability, remote monitoring, and tracking are the different advantages of RFID technology [6]. In combination, the RFID and IoT can play a significant role in managing emergency situations like fire and other natural disasters while enhancing

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the safety mechanism for both human and capital resources. Over a period of time, the worth of the RFID market is increasing; As in 2016, the market value of the technology was worth USD 16.95 Billion whereas, according to a report provided by Grand View Research, Inc., [7] it is expected to reach USD 40.5 billion by 2025 along with the expansion of 14.7% at a CAGR.

The RFID concept was introduced during the 2nd world war to track aircraft where reflected electromagnetic waves were used to identify objects. H. Stockman was the first scientist who proposed RFID in his paper "Communication using Reflected Power" [8], which proposed a wireless solution utilizing reflected power. RFID technology has the edge over barcode technology, such as long-range reading, non-line-of-sight (NLOS) reading, and automated identification. In the beginning, the use of RFID was in applications like warehouse management, road toll system, item tracking, animal tracking, E-passport, fare collection system, and pallet identification with progress in technology. For instance, Fig. 1 explains the process of IoT-based warehouse management. RFID directly collects the data from incoming and dispatched inventory and saves it to the IoT cloud. It also helps in the in-house warehouse management using IoT cloud, where users can raise a query and request the solution. The metro smart card and fare collection cards also use RFID technology with an operating frequency of 13.56 MHz. This system's detection range lies within 5 cm to 30 cm. Whereas the far-field RFID tags (used in pallet identification) have a reading range of nearly between 1 m to 10 m, and operating frequency comes in Ultra High frequency (UHF) band [9]. Apparently, RFID's reading range depends on the RFID system's structure, working, and device power.

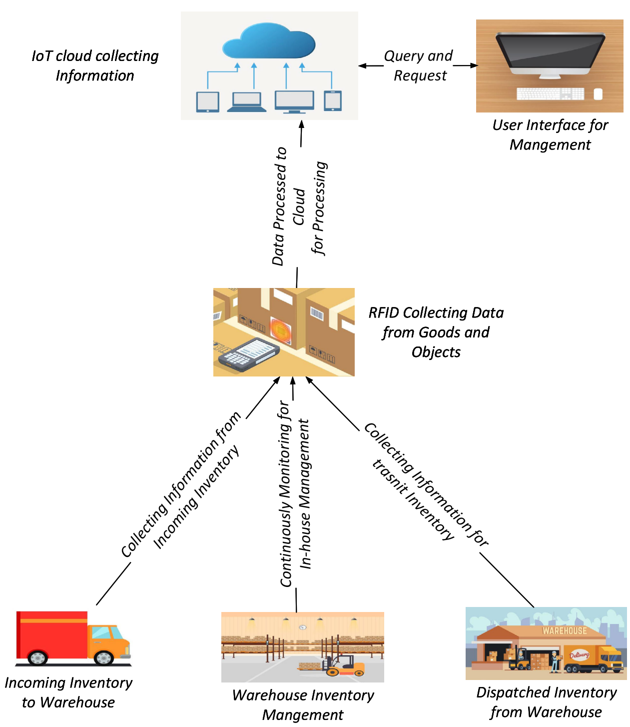

FIGURE 1. IoT-based warehouse management system using RFID.

The main challenge with RFID is to get more bits encoded in limited areas of the tag. The conventional chip-based tags are constrained by bulky nature, robustness, reliability, read range, power consumption, and cost due to an integrated circuit (IC) board. A chip-based tag's cost is independent of its IC design and depends on the required entire wafer's silicon area. The cost of IC fabrication plants is in billions of US dollars [10], which should be included in the chip's overall cost. The management cost of chip-based design increases as the development and implementation of more minor size chips are promoted.

Furthermore, Narrowband RFIDs encounter issues like small coverage areas, insufficient ranging resolution, and interference. Ironically, with the ongoing research of more than 50 years, RFID technology is still far behind from its full potential, and till now, only a few industries are able to use it. With better efficiency, RFID can successfully replace the barcodes and printed labels from the markets. However, the only restriction is the cost associated with it. The other critical drawback of RFID is that it is non-rewritable with limited data capacity.

These constraints can be eliminated by employing the chipless RFID tag without the use of traditional ASIC chips. Chipless RFID tags work on the transmission line's electromagnetic properties for data encoding. In the chipless tags, the electromagnetic properties can be utilized to eliminate memory chips' which are being used for storing the required information [11]. These tags, therefore, have the potential to simplify the system cost along with the complexity. A fully printable chipless RFID is easy to fabricate at a low cost. In the real world scenario, where the tag price is the priority, chipless technology will be used as the best option. Unlike the other technologies, chipless will provide a more prolonged tracking and monitoring of the asset life cycle. The Chipless RFID Market was valued at USD 0.89 billion in 2020 and is expected to reach USD 3.94 billion by 2026 and work at a CAGR of 28% over the forecast period 2021-2026. More than 60% of the market share of chipless RFID technology is equipped with Chipless RFID tags. [12]

Despite multiple benefits of chipless RFID over traditional RFID and other technologies, the literature lacks to show the proper adaption of the chipless technology in the IoT era. This paper focuses on developing and realizing chipless tags for IoT and other applications and filling the gap between chipless RFID and IoT. It has been motivated by the fact that chipless tags realization is more straightforward than a traditional chip-based RFID tag. The different aspects of chipless RFID tags like reading range, received signal strength, reliability and sensitivity, operational mode, and many more have been discussed and analyzed in the paper. This paper will be the first step in making the bridge between chipless technology and IoT, considering all aspects. The paper is divided as follows: Section II and III discuss RFID and chipless RFID systems and their background. Subsequently, the following two sections analyze chipless RFID concerning IoT and related applications. Finally, future directions of chipless RFID and conclusion conclude the article.

II. RFID AND CHIPLESS RFID SYSTEM

In an RFID system, there are three major components: A reader or interrogator, a tag or transponder, and middleware software. The primary communication happens between the RFID reader and the RFID tag, and the middleware or application software is used to process the information from the tag and take action accordingly. It maintains the interface to encode and decode the information from the reader into the personal system.

A. RFID TAG

The tag is the primary element of the RFID system, and system cost depends on the tag's prices, leading to significant research for the RFID tag in the contemporary world. Generally, RFID tags have antennas that communicate to the reader and a circuit board that contains the information. Every RFID tag has a unique identity for identification.

The RFID tags with an IC chip are a well-established and broadly used technology. Due to IC and the established connection between the antenna and IC, the chip-based tag faces the issue of reliability. The chipless RFID can be an excellent alternative to eliminating these issues and enhancing the RFID system's performance. The reflected signal from the chipless tag changes according to the tag's electromagnetic properties in the chipless RFID system.

In chipless RFID, the tag should act as a scatterer, and encoder [13]. The incident field should be scattered as high as possible, and as an encoder, the tag should encode data as much as possible. The challenge in designing a chipless tag for the researchers is to encode the data without a chip, making the task difficult.

A general chipless RFID system has been shown in Fig. 2, where a chipless RFID reader uses the 'frequency sweeping' technique to extract the tag's information. It calculates the received signal's gain corresponding to the bandwidth's interrogation signal and sends it to the control section. Depending on the tag's validity, the chipless RFID system performs the necessary action, and the reader gets ready for the next frequency sweep.

There are three phases of designing a chipless RFID tag, i.e., theoretical analysis, implementation, and development, as depicted in Fig. 3. Ease of understanding, size, cost of the tag, flexibility, orientation, and polarization dependency are a part of the theoretical phase, whereas the Implementation phase emphasizes the selection of material, designing tools, and fabrication process. The last stage, the development stage, includes parametric analysis, fabrication, and real-world testing in different environmental conditions. Detailed background research and classification of chipless RFID have been provided in Section III.

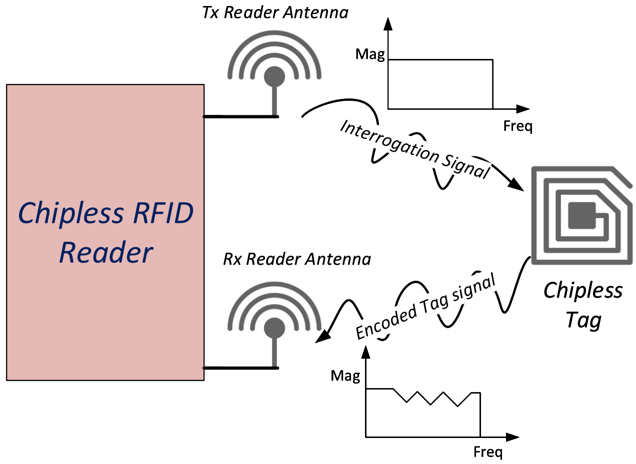

FIGURE 2. Reading mechanism of chipless RFID system.

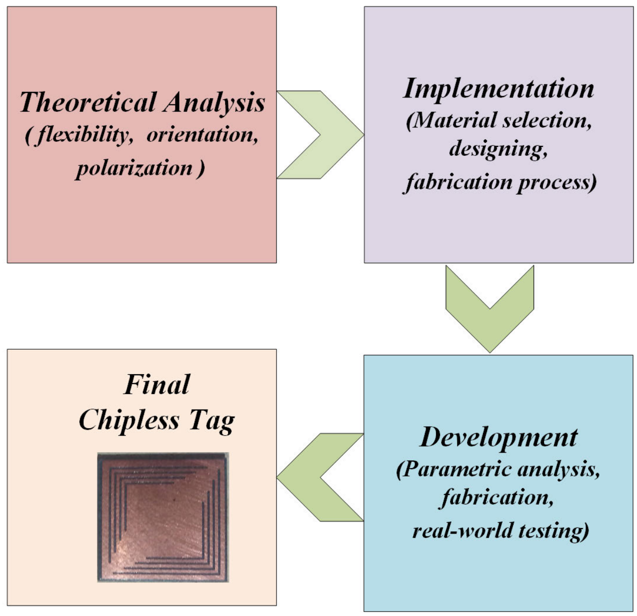

FIGURE 3. Designing process of a chipless RFID tag.

B. RFID READER

RFID reader acts as a transmitter and receiver in the RFID system. It activates the tag and captures the tag's signal, and sends it to the system to process the received signal. The reader can only read and analyze the tag's data within the reader's interrogation zone. The RFID system acts as a master-slave architecture, where the reader can be represented as a master because it controls the signal, and the tag acts as a slave because it responds to the reader's signal. Reader antennas are responsible for the decoding range of the RFID system. The reader is usually constant and connected to the host computer or processing unit.

There are mainly two blocks of the RFID reader; one is a control block, and the other one is an interface block [14], as mentioned in Fig 4. The interface block includes a transmitter, and a receiver, which helps in communication

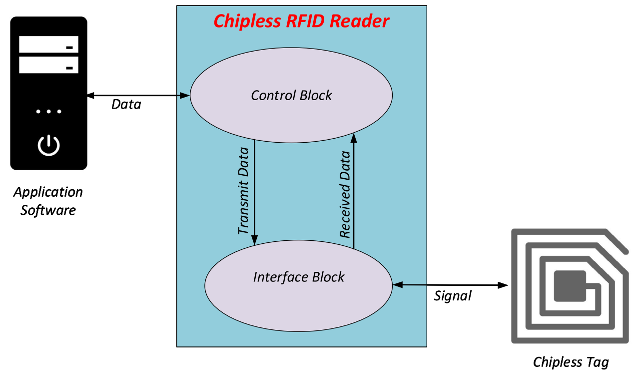

FIGURE 4. Block diagram of RFID reader.

with the tag, and the control block communicates with the system for processing the information. The control block follows a specific protocol and security algorithms, as discussed in [15], to communicate with the system and the tag. The reader needs to implement polarization agility for efficient processing to detect the tag regardless of its orientation. The flow of reading in power saving chipless RFID reader [16] has been explained in Fig. 5.

There are very few reports to address the chipless RFID reader system. In these reports, the Chipless RFID readers have worked with the frequency range of 2-2.5GHz [17] and 5-10.7GHz [18], [19], utilizing frequency domain analysis to capture the tag's information. A complicated and expensive design of the transmitter and receiver structure was used in these readers. The other examples of existing readers [20], [21] use ASK and BPSK to decode the tag's data. These readers use a handshaking algorithm to communicate with the tag, and hence the tag needs to be present in the reader's interrogating range for the whole reading transaction period. Low-cost readers are required to implement the chipless RFID system on a global scale.

III. CHIPLESS RFID BACKGROUND

The first report of chipless RFID tags utilized surface acoustic wave (SAW) substrate for reflecting pulses at specific times [22]. SAW substrate's major limitation is the ohmic loss associated with it, responsible for the RFID system's poor sensitivity to low power signals. In the domain of chipless tags, there have been reports of successive improvements in the design techniques [23]–[26]. Based on developments of chipless RFIDs, it can be divided into two major categories [27], one is time-domain reflectometry (TDR) based, and the other one is frequency-domain reflectometry (FDR) based tag design.

In the TDR-based design, also called Impedance Modulation (IM) based design, the incident wave is reflected at time intervals with discontinuities along with the interrogation signal's path. These reflections are being employed in the chipless RFID design by controlling the impedances causing these reflections and tuning the circuit accordingly. The same has been presented in [28] to place the discontinuities at

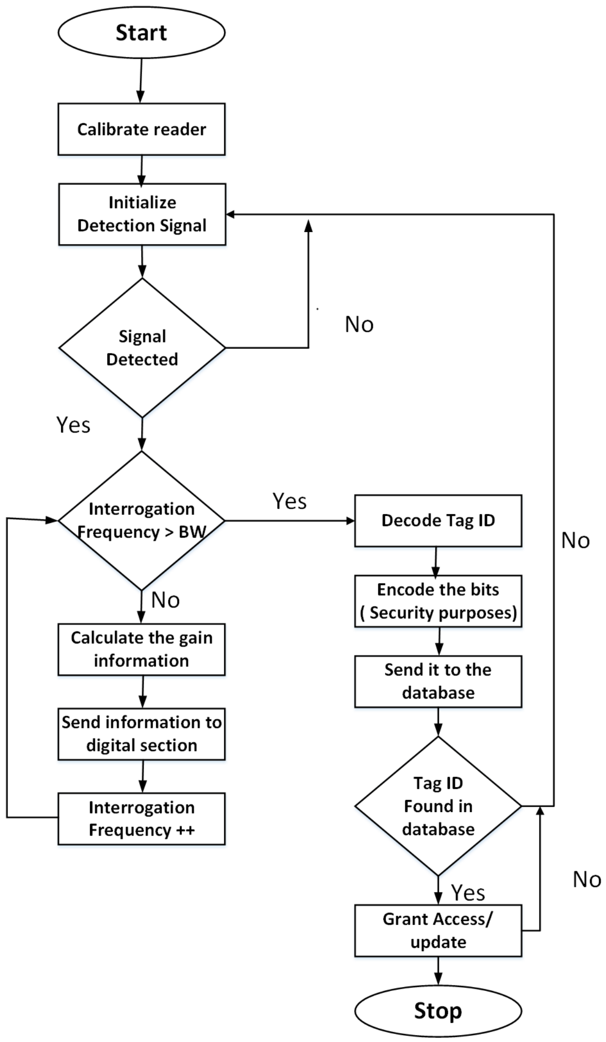

FIGURE 5. Reading process of a power saving chipless RFID reader.

equal distances to represent '1's and '0's. An improvement in this technique has already been proposed to incorporate discontinuities on the substrate after a certain length [29]. This technique improves the RFID system's sensitivity to some extent but faces issues related to ringing reflections that carry no additional information. In addition to that, the signal gets attenuated after each discontinuity [30]. Another method that uses the time-domain reading process, as shown in Fig.6, is placing the capacitances at different distances to obtain a reflecting signal that resembles PPM (pulse position modulation) [31]. The measured time response of the chipless tag for different bit configurations is given in Fig.6 (b), (c), and (d). The measured response shows the noise in the signal after the bit response that affects the reading of the chipless RFID. A delay is introduced after each measurement cycle to avoid the jitter, which affects the chipless RFID reading time. The major disadvantage of the TDR-based design with ringing reflections is the size of the tag and causing the losses as mentioned above. The length of the transmission line used in TDR is very long, which creates losses in transmission.

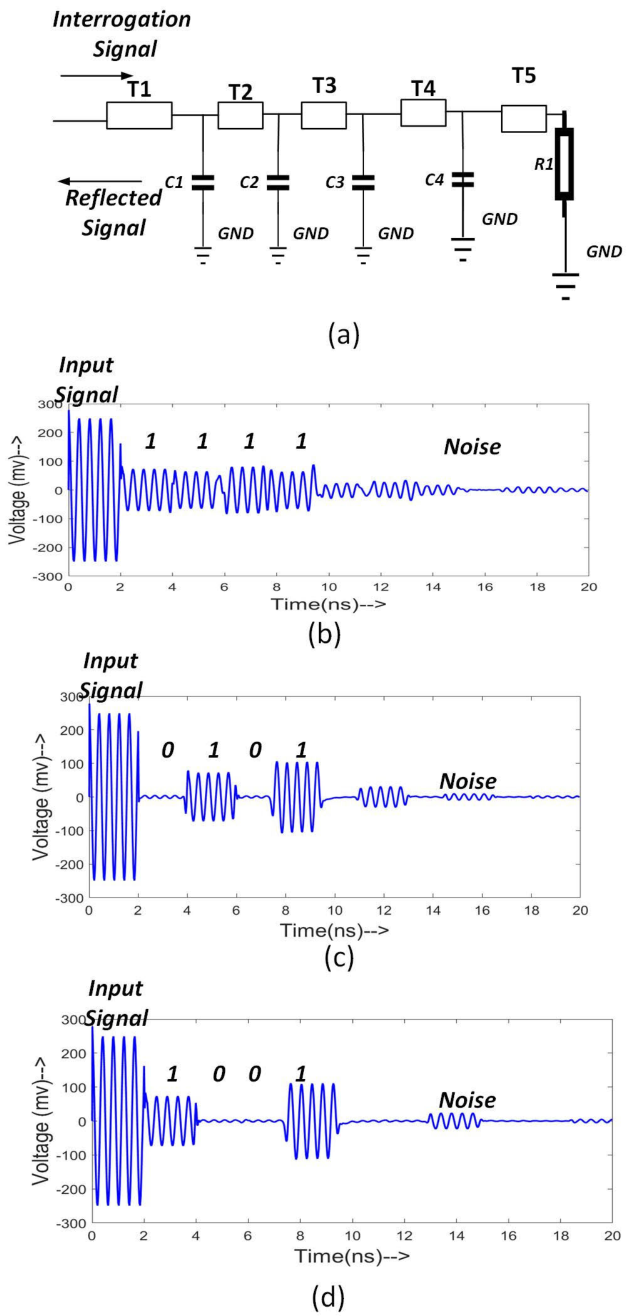

FIGURE 6. (a) Schematic of 4-bit chipless RFID tag, time response of bit code (b) '1111' (c) '0101' (d) '1001'.

On the other side, in the FDR-based or spectral signature-based chipless tag design, resonators are used to scatter the interrogation signal. Based on the scattered signal's spectral response, the reader finds the tag's ID. In these designs, the frequency band is being divided correspondingly from the bit associated with the tag. Each resonator is associated with one or more bit as per the design. Dipole based 11-bit tag [32], and Quarter-wavelength slot-based resonator [33] with 24-bit capacity uses the FDR concept for encoding the information. The resonant frequencies of the tag can be tuned using the slot's length of the resonator. Another essential factor highlighted in the above-quoted papers were the resonator's damping factor, which can be controlled through the resonator's width. The issue with FDR-based design is the existence of coupling among the resonators. The quality factor decreases as the coupling between resonators increase. To improve the quality factor, the gap between the resonators should be increasing. However, due to this inefficiency, the size of the tag also increases. The hybrid technique [34] encodes two independent parameters, i.e., phase deviation and frequency position, enhancing the coding capacity.

Based on the RFID system's spectral signature, Chipless tags can be further classified into two major parts: retransmission-based tag [35] and backscattering tag [36].

A. RETRANSMISSION BASED CHIPLESS TAG

In retransmission-based chipless RFID tags, data encoding occurs in the spectral signatures that arise due to multiple resonating structures. The retransmission tag utilizes the cross-polarized antennas to receive the reader's interrogation signal and further transmits the encoded data. These antennas improve the tag's reading range, but in return for increased size, weight, and cost [17].

A significantly enhanced chipless RFID tags' design is based on multiple LC resonators [37]. These tags utilize frequency domain data for analysis purposes and provide an alternate, more straightforward design approach. However, a fundamental limitation of this technique is lower resolution in the identification of the received signal. Perhaps, the tag sizes can be larger due to the use of lumped components. The use of multiple quarter wavelength slots resonator highlights the concerns of using the natural resonance in the design [38], and it still suffers from a lower resolution. Other designs using the same approach include a set of cascaded resonators that achieve resonance at defined frequencies [39].

The group delay-based RFID tags [40], [41] require a large area for more bits, which essentially entails increased tag size [42]. Another limitation of this technique is the relatively poor detection ability. L-resonators type retransmission-based chipless [43] RFID tag employs a microstrip transmission line that uses the spectral signature for encoding as explained in Fig. 7, which comprises a general reading process of retransmission based tags. The tags exhibit a large difference of more than 15dB in the S_{21} magnitude between the absence and presence of the bits and allow for easy encoding and detection of the data. Another example of retransmission chipless RFID tag is based on multiple open-loop resonators [44] with UWB circular antenna, as given in Fig. 8. The essential characteristic of the open-loop resonator-based tag is its ability to provide reconfigurability.

B. BACKSCATTERING BASED CHIPLESS TAG

The backscattering tag scatters the modulated interrogation signal in the direction of the reader. Their working principle

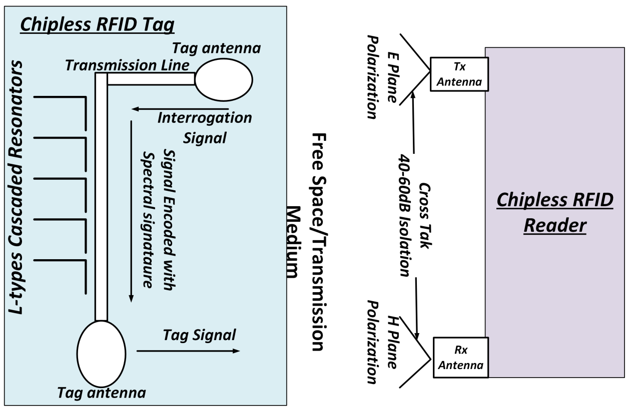

FIGURE 7. **Reading process of retransmission based chipless RFID tag design.**

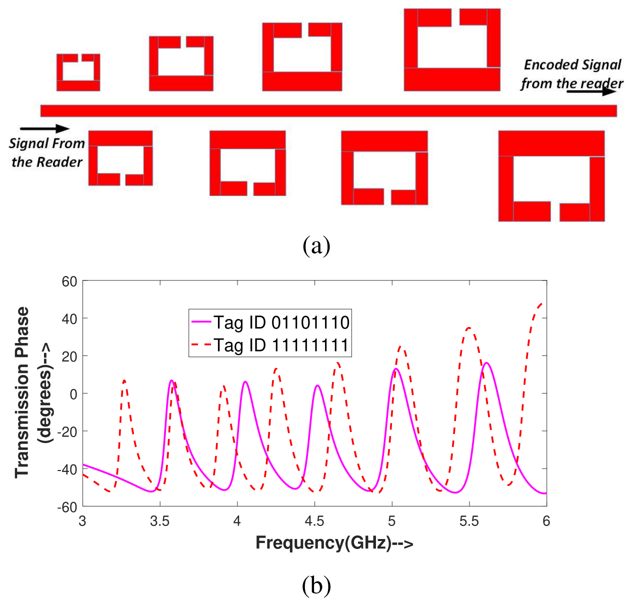

FIGURE 8. **(a) Cascaded 8-bit Open loop resonator chipless RFID tag for the tag ID '11111111' (b) Measured transmission phase (degree) response of the chipless tag for the ID of '11111111', and '01101110'.**

is similar to the retransmission type tags, albeit with a reduced size, due to the absence of antennas, and therefore finds significance in tracking and identification in the IoT ecosystem [45]. Backscattering-based chipless tag resonator occupies a bandwidth of 100-200 MHz for each bit associated with.

Considering the drawbacks of Backscattering chipless RFID tags, the frequency band should be in the UWB frequency range to accommodate a high number of bits. The transmission power should also be in the spectral mask for the UWB signal as authorized by the concerned authorities. However, the detection of weak backscattered signals in the spectrum might be difficult caused by these restrictions and noisy environments. An identification algorithm is required on the reader's side to detect these signals without an error.

Two L-shaped slot resonators chipless tags [46], as presented in Fig. 9, allows the incorporation of orientation

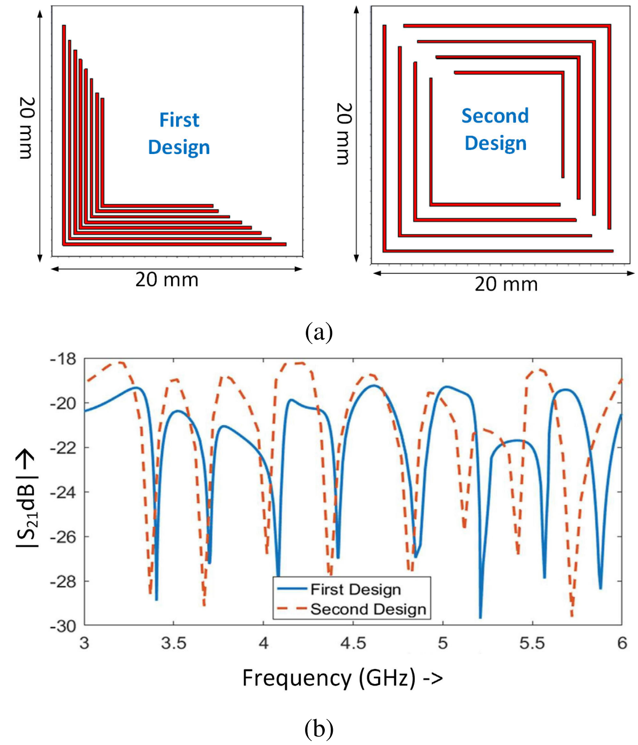

FIGURE 9. **(a) L-resonator based backscattering based chipless tags design (b) Measured S_{21} response of both types of chipless RFID tags.**

independent with compact size. It operates in the frequency range of 3-6 GHz and the ability to be read irrespective of the receiver's position.

Other reported chipless tag designs that, in principle, can be made reconfigurable and can potentially enable the reuse of chipless tags [47]. For example, an individual's ID card can be reused for another individual by a simple change in the bit patterns by using the reconfigurability approach. However, one standard limitation of the reported chipless RFID tags is the feeding line's disturbances while providing reconfigurable functionality.

The earlier phase of some other types of chipless RFID tags like image-based and hybrid tags are also presented in the literature. The hybrid chipless tag [34] uses frequency and phase-based information for bit encoding. The image-based chipless RFID tag [48] illuminates a particular area for decoding of the tag instead of the whole tag.

IV. CHIPLESS RFID IN THE CONTEXT OF IoT

The chipless RFID tags do not require any microchip to store data in transponders, and this aids in reducing the cost substantially when compared to the chip-based RFIDs [49]. Due to the absence of microchips, the chipless RFIDs are free from any delay, which existed in the conventional chip-based RFIDs. This delay-free system led to enhanced sensitivity and response time, having the potential to strengthen the IoT system's performance. Chipless RFID can help object identification, feel the object as a sensor, and think about the

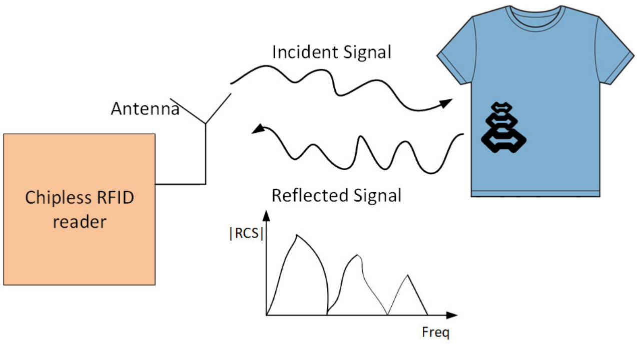

FIGURE 10. Chipless RFID system for clothing management.

object as an intelligent chipless RFID system, enabling IoT technologies. As an example of on A sewn chipless tag [50] Fig. 10 can be significant for clothes as an anti-theft system for clothing brands or in an automatic laundry system for cloths identification. Chipless RFID system opens a window for innovation in services relying on information related to identity, status, location of the objects and devices, and new societal services to improve living standards. It can be used as sensor for different sectors such as food, agriculture, biomedical, health, [51]–[60], localization field [61], [62].

With the advancement of IoTs and deployment in the market, the sensors have gone through remarkable growth in recent years. For instance, the UC San Diego Jacobs School of Engineering and the Center for Wireless Communications announced their chipless RFID technology that works on WiFi signals in August 2018. The chipless RFID tag developed by them is in metal tags made from copper foil printed on thin, flexible substrates, like paper. [12] The chipless RFID sensors have the potential to enable systems to track objects, understand their status, and communicate and take action to create "real-time cognizance". RFID sensors can monitor environmental parameters like gas pressure, humidity, temperature, and other related properties [63]. Chipless RFID works on the direct variation of the backscatter signals, making RFID sensors more secure from a malicious alteration of sensor information by attackers. Chipless RFID sensor has some advantages over other sensors, like longer storage life, less radiated power, and robustness [64], [65].

Chipless RFIDs are a promising solution when it comes to item-level tagging and object tracking, even without contacting the object. The given representation in Fig 11, describes the different scopes of chipless RFID. In the contemporary scenario, when COVID-19 has been a sensitive issue globally, chipless RFID ensures secure and safe tracking and management for any object. Chipless RFID tags do not require any power supply like other tracking methods like WiFi, Bluetooth, and WSN; thus, it is easy to install in any substance and object. It saves power with less requirement for the overall system, which aids in IoTs' applications. The other advantages of Chipless RFIDs are that they can be printed as a miniaturized circuit on a low-cost and loss substrate. Circuit

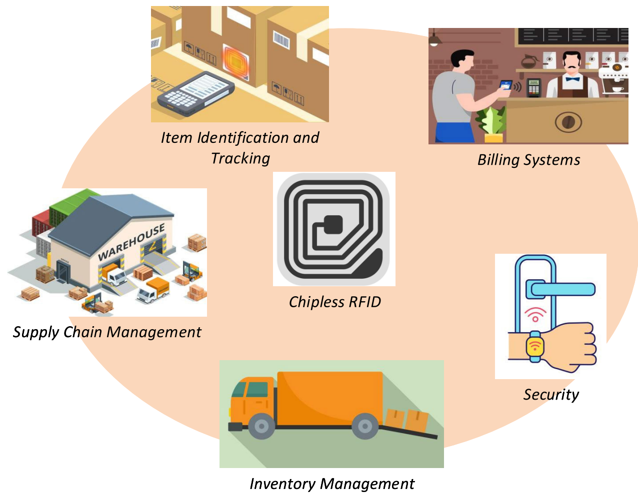

FIGURE 11. Representation of different chipless RFID applications.

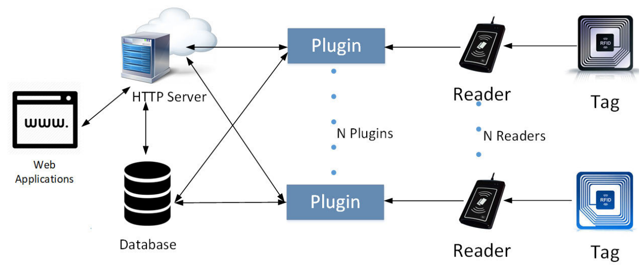

FIGURE 12. An IoT-based framework for tag management.

fabrication can be done on a fragile substrate or paper using inkjet printing technology [66] to replace barcode technology easily. Now, it can also be printed on metal containers, and liquid bottles [39]. Additionally, the cost of a Chipless is also significantly less, leading to the depreciation in overall cost.

A proposed chipless RFID framework [67] integrates tags and readers in the system to a greater extent, as displayed in Fig. 12. This model enhances the existing models concerning integrity, security, transparency, and unification of the IoT system and can be incorporate with multiple applications involving chipless RFID with IoT in 5G.

V. EXPLORATION OF CHIPLESS RFIDs IN THE FIELD OF IoTs

The following section analyzes the chipless tags on the different parameters for IoTs applications. It can also help in the optimization and development of tags in the real-world environment.

A. TAG SIZE AND COST

In item tracking, the tags' cost is an essential factor to take into account. The cost of the final object is associated with the tag. The Chipless RFID has been used as a low-cost alternative with the reference of other tracking devices and chipped RFID. The tag's size is lesser and easy to reconfigure, affecting the tag's final cost and further managing the object's

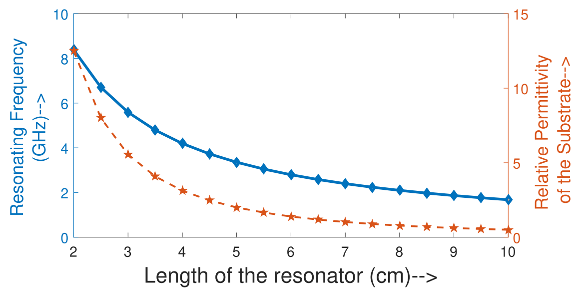

FIGURE 13. **Variation of operating frequency and relative permittivity of substrate with the resonator length of the chipless RFID tag.**

overall cost. The tag's cost also depends on the material and production cost. At lower resonating frequency, the resonator length is high, which implies the size of the chipless tag, as presented in Fig. 13. As given in (1), chipless RFIDs are being used in Ultra high-frequency band to lower the tag's size. On the other side, decreasing the length of the resonator requires a high relative permittivity substrate, which creates more noise in the signal.

$$f = \frac{c}{2L_x}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

where f is the resonant frequency, c is the speed of light in free space, ϵ_r is the relative permittivity of the substrate, and L_x is the length of the resonator.

B. READING CAPABILITIES

Distant Reading is a critical parameter in industries and other IoT applications. Facilitating that need, Chipless tags can detect objects at high speeds, such as conveyor belt at 80 m/min [68]. Input power is a significant factor in the reading range of the chipless tag. An experiment has been conducted to see the variation of received power at logic-0 (peak) and logic-1 (notch) format at two input power levels, i.e., 0dBm and 20dBm, as mentioned in Fig. 14. The response explains that the received power drops in the higher reading range and lower input power level. It also indicates that it is difficult to identify and track the tag, particularly with lower received power from the reader's side.

The measured response of chipless RFID in Fig.14 and Fig. 15 shows that the operative range of chipless RFID depends mainly on input signal strength and type of chipless RFID. Other factors that affect the chipless RFID range are losses in the substrate of the tag, noise in the environment, obstacles, and their types in the chipless RFID reading path. Distortions in the reading of the chipless RFID can be improved using applicable RFID reader algorithms [69], [70]. Lower permittivity substrate like rogers 5880 provides lesser losses in the backscattered signal; however, it affects the length of the chipless tag as given in Fig.13. Chipless tags assure that they can survive in a dynamic environment. Contrary to that, chip tags may not survive at high temperatures and pressure conditions. Chipless tags provide a low-cost solution for tagging objects in the retail

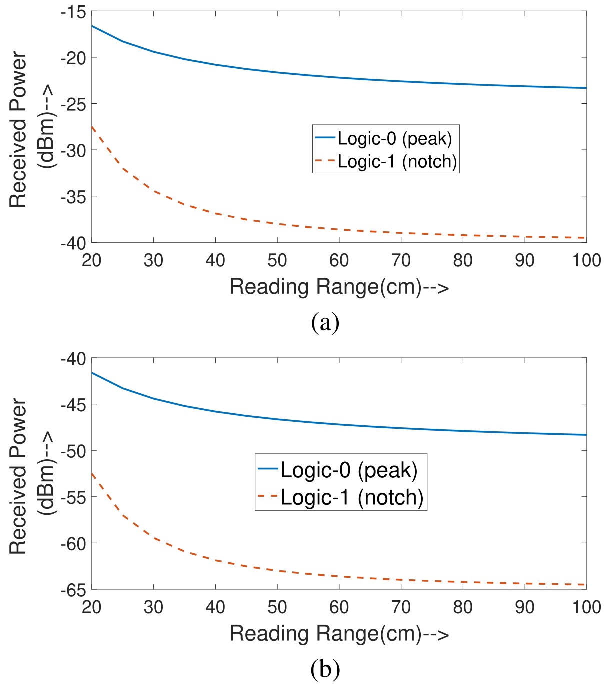

FIGURE 14. **Reading range of the chipless tag as a function of the received power at 4 GHz (a) input power level at 20dBm, (b) Input power level at 0dBm.**

environment. Perhaps, the RCS of the metal surface in the moving environment can hinder the RCS of the chipless tag.

C. SENSITIVITY TO THE ENVIRONMENT

In a harsh environment, it may not be easy to track objects because of frost's deposition, but apparently, chipless tags are a good alternative for tracking the objects for short-range applications for the same harsh environment. The printed chipless tags overcome corrosion, and such tags can be deployed in agricultural technologies [71]. It can work as a sensor to detect environmental changes, as the backscattering response reflects the environmental condition. Environmental issues can significantly change the tag's reading ability, but these issues can be resolved by calibration of the reader according to the environment.

D. MODE OF OPERATION

FDR-based chipless RFIDs have capabilities in both near- and far-field applications at higher frequencies. It also enables the development of electrically small structures for IoT applications. With the help of tags' antennas, retransmission-based chipless tags can be utilized to track long-distance items. The reading capability depends on the reader transmitter antenna's power and the reader antenna's reflected power. A comparative analysis of the retransmission and backscattering-based chipless tags having the same bits of information have been done to analyze the different aspects of the received signal strength indicator (RSSI), as shown in Fig. 15. It unfolds the fact that retransmission-based tags have the upper hand in the form of received power. In contrast,

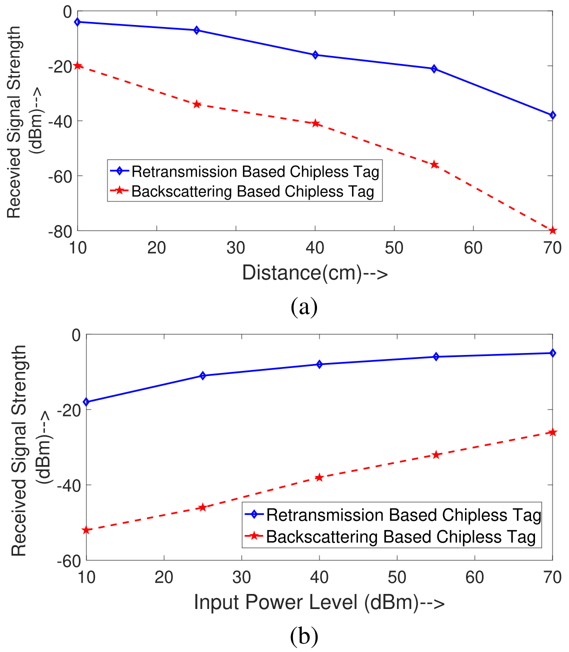

FIGURE 15. Received signal strength for both types of chipless tags (a) varying distance keeping input power level at 10dBm (b)Varying input power level at a distance of 30cm.

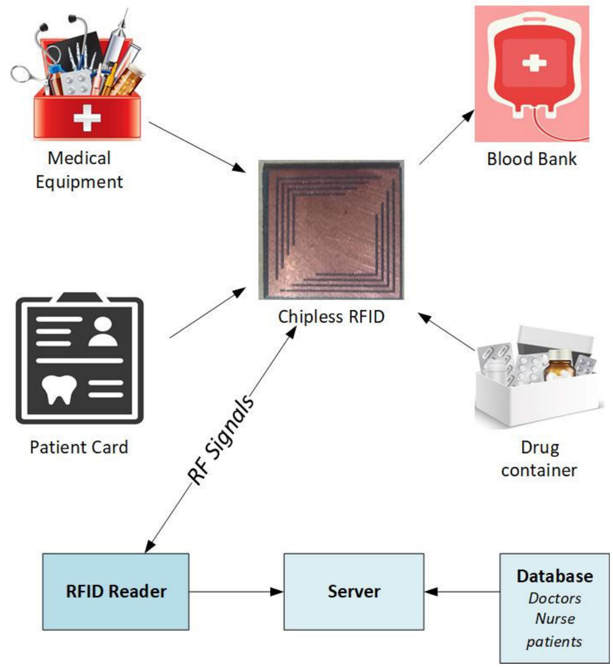

FIGURE 16. Health sector management using chipless RFID.

backscattering tags have the area's advantage, where the area implies the cost of the tag and the object associated with it.

VI. FUTURE DIRECTIONS

Some technical challenges need to address in the field of chipless RFID before diving into universal item-level identification and tracking. The immediate future of chipless RFID research and development (R&D) focuses mainly on three primary directions, large coding capacity, compact size, and configurability. The compact size of chipless tags enables it on small-sized objects such as a book or small packing boxes and reduces the object and system overall cost. The configurability provides an approach to reuse and recycle chipless RFID tags, thus lowering the cost per time. Additionally, it provides coding configuration flexibility of the tag according to the requirement in real-world applications.

In the future, massive growth of Chipless technology is expected in the health and retail sector. Various companies in retail already accepted RFID technology due to its high accuracy and cost-effectiveness. Chipless technology gives a new dimension of power-efficient management in the retail sector. In the health sector, shown in Fig. 16, RFID is used to track and manage medical instruments and blood banks. Compared to chip-based, the high bit density of chipless enables more information in the tag by lowering the cost. High coding capacity chipless RFID [72]–[74] and spatial chipless RFID [75]–[77] are new steps in the growth of chipless RFID, increasing the coding capacity of the tag without increasing the cost of the system.

The Institute of Electrical and Electronics Engineers (IEEE) estimated that more than 50 billion objects would be networked by 2021, of which many will use chipless RFID. The supply chain across the pharmaceutical, manufacturing, and other logistics industries markets can be uplifted using IoT and Chipless technology. Some preliminary work discussed in this article shows the high possibility of improving the directions mentioned above. Further research and optimization of chipless technology are expected to make high volume development in localization and tracking. The printing of chipless RFID on a low-cost substrate such as low grading packaging papers need to analyze and test. It will open a new aspect of reducing the cost of localization and tracking in IoT. The research on the accuracy, range, and noisy environment reading of chipless RFID will improve the chances of proper adoption in the IoT scenario.

VII. CONCLUSION

In the present world, where communication is the need of society, IoT has drawn the attention of so many researchers to facilitate both industry and academia. Advancement in information and communication has promoted IoT as a more promising and reliable technology. Today on a larger scale, companies are using RFID technology to track the products' inventory and their movements. Chipless tags can be benefited in large-distance along with the nearby fields of IoT applications. It can be used in payment transactions, security, logistics, supply, distribution, health care, and asset tracking. Particularly in inventory and warehouse management, it can be very significant to achieve optimum storage conditions, locate an item, eliminate human error, and improve security facilities. The food industries can be helpful while indicating expiry dates, food storage, and transport management. Additionally, it can be accommodated with health care services to track patients' records, medicine storage, expiry indication of medicines, biosensors, surgery instruments tracking, and many more.

Still, the challenges and limitations open a window for future research and development in RFID and chipless tags. Future research can focus on polarization, size of the tags, and reading range specific, and many more in that direction. Additionally, an extended capacity of more than 100 bits for higher data applications can be explored. The noise and interference are also critical problems to be considered in the future for the wide use of chipless in IoT applications. In the end, we can state that Chipless tags have been very crucial research in the information and communication sector to facilitate the need for the contemporary modern world.

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