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# Recent Advances in Passive UHF-RFID Tag Antenna Design for Improved Read Range in Product Packaging Applications: A Comprehensive Review

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**ABSTRACT** Radio frequency identification (RFID) is a rapidly developing technology, and RFID sensors have become important components in many common technology applications. The passive ultra-high frequency (UHF) tags used in RFID sensors have a higher data transfer rate and longer read range and usually come in unique small and portable application designs. However, these tags suffer from significant frequency interference when mounted on metallic materials or placed near liquid surfaces. This paper presents the recent advancements made in passive UHF-RFID tag designs proposed to resolve the interference problems. We focus on those designs that are intended to improve antenna read range as well as scalability designs for miniaturized applications.

**INDEX TERMS** RFID, UHF-RFID, microstrip antenna, PIFA, metallic.

## I. INTRODUCTION

### A. BACKGROUND

Radio Frequency Identification (RFID) is a technology that utilizes electromagnetic field or radio waves to passively identify a tagged object. An RFID tag consists of a radio receiver and a transmitter (attached to an antenna) combined into a radio transponder [1]. When the tag receives a radio wave or pulse from a nearby RFID reader device, it automatically transmits digital information back to the reader. This information can be an inventory number of a product or package used for tracking. Unlike a barcode, an RFID tag does not need to be within the line of the reader's sight. Generally, to identify objects using RFID, several methods can be used; however, the most common method is storing the ID or serial number on the RFID tag to identify a specific product [2].

RFID tags can be broadly classified into two types: passive and active tags. Some other classifications are possible, including semi-passive and semi-active tags. A passive tag is powered internally by energy derived from the reader's incoming radio wave. An Active RFID tag, on the other hand, is powered by an internal power supply or battery which increases its read range to hundreds of meters [3]. Unlike the active RFID tag, the passive tags' lack of an onboard power supply makes them relatively small and thus more easily portable for many applications. For example, they are easily implanted in a sticker or under the skin, thus giving them the

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advantage of being suitable for wider applications. Passive and active RFID tags can also be classified or subdivided by the frequency band within which they operate, that is low frequency (LF), high frequency (HF), and ultra-high frequency (UHF) [4]. Electromagnetic radio signals behave uniquely at each of these frequencies, and there are merits and demerits associated with each. For example, LF passive RFID tags have a slower data read rate due to their low frequency, but has high capabilities to read near or on metal or liquid surfaces [5]. HF and UHF passive RFID tags, on the other hand, have faster data transfer rates and longer read ranges that increase with their operating frequencies, but they are also highly sensitive to radio wave interference caused by metals and liquids in the embedded environment [6]. Resolving the interference problem for higher frequencies or ultra-high frequency (UHF) RFID sensors has remained a significant challenge till date. However, there are recent technological advancements, and this review presents the recent efforts made in ultra-high frequency (UHF) passive RFID sensors that are applicable around metals and liquids. This review is meant to benefit researchers, engineers, and manufacturers in the field and offers an in-depth overview of portable passive RFID with improved read range for accelerated application in product packaging.

### B. TERMINOLOGY CLARIFICATION

An RFID system typically consists of a tag and a reader. In this section, we clarify on the use of some common terminology used in connection to RFID sensors.

RFID tag: An RFID tag is a device or microchip similar to a barcode or smart label that is placed on an item to uniquely track it. It consists of three main parts: a micro-chip to store and process information, a substrate, and an antenna for receiving and transmitting signals (via radio waves) that enables it to communicate with an RFID reader.

RFID reader: An RFID reader is a device or component of the RFID system used to collect information from an RFID tag via radio waves.

RFID antenna: An RFID antenna functions as a receiver and transmitter (or a transponder) of the RFID tag.

## II. ULTRA-HIGH FREQUENCY RFID SENSORS

The UHF band lies in the range 300MHz to 1GHz. Passive UHF-RFID sensors with a read range of (860 – 960 MHz) are the most popular as they require small antenna dimensions [7]. Typical examples of the antenna in this category are Microstrip antenna, Dipole, and Planner antennas. The 433 MHz UHF range is usually preferred when it comes to achieving maximum read range; however, to guarantee the radiation efficiency in this frequency range, large antenna dimensions are required, which limits the use of this frequency (i.e., 433 MHz) to certain domains.

The reading interval of passive UHF-RFID sensors can be significantly affected by liquids and metallic materials located near a reader or label [8]. A strong reflective signal can be generated by liquid and metallic surfaces. Depending on the phase difference of the signal (i.e., compared to that of the transmitted one), it can influence the intensity of the transmitted signal either constructively or destructively [9], [10]. In constructive influence, the reading interval can be extended due to the reflection, while in destructive influence, it can be significantly reduced by the reflection [11]. In all cases, higher impacts are obtained when the interfering materials are very close to the RFID reader or label and are relatively large [12]. The standard recommendation is for RFID sensors to be operated far away from liquid surfaces and metallic materials [12]. Multiple UHF-RFID antennas have been suggested to enhance spatial diversity and improve connection reliability with extended reading interval [13].

## III. METHODS TO MINIMIZE THE EFFECT OF METALLIC SURFACES

Several methods are commonly used to reduce the effect of the metallic surfaces on passive UHF-RFID tags. One of the prominent methods involves incorporating a conductive ground plane underneath the RFID antenna to form a patch-like structure [14]. This is based on an elliptical PIFA design as proposed in [15]. Other methods include adjusting the substrate's thickness [16] by using an EBG material to insulate antenna from metallic surface [17], [18] and adding a large structure known as capacitive tip loading at the dipole end [19], [20]. A comprehensive overview of the shapes and sizes of metallic objects as well as an analysis of the distance of RFID tag are presented in [21]. This section presents a comprehensive review of the recent methods for reducing the effect of metallic object on passive UHF tags. The section is organized according to the common UHF antenna types: Microstrip antenna, Dipole, and Planner antennas.

### A. TECHNIQUES APPLIED TO MICROSTRIP UHF TAG ANTENNA

#### 1) LARGE TAG MICROSTRIP ANTENNA

Mounting a UHF tag antenna on metal is challenging as its radiation efficiency can be significantly reduced [15]. This is because introducing a metallic surface or object beneath a current-fed antenna produces an equal surface current with opposite phase, which causes cancellation of the radiation in the far field [22]. A novel passive 930 MHz RFID large metal tag antenna which is mountable on metallic surfaces was proposed by [10]. The overall dimension of the proposed antenna is 46.1 mm × 28.58 mm × 6 mm which resulted in a maximum reading distance of 7 m when placed on a metallic surface.

Another large antenna that is mounted on a metallic plate of 300 mm × 250 mm is proposed by [23]. The total volume was 104 × 31 × 7.6 mm, and the antenna produced a maximum reading range of 14.6 m at 905 MHz. Another large antenna (size = 75 mm × 20mm × 3 mm) and gain of about 3.3 dBi is proposed by [12]. The antenna consists of two layers, a radiating patch with slots printed on the upper dielectric substrate, and a bottom dielectric substrate surrounded by metal strap with slots. The measured identification distance is 3.8 m. A T-shaped antenna structure with overall size of 80 mm × 80 mm × 1.635 mm, slotted with metallic rectangular patch and T-slot and suitable for mounting objects was proposed by [24]. Another antenna design with rectangular patch and balanced feed which operates in the 915 MHz frequency was proposed by [25]. The antenna has a size of 68.4 mm × 75.1 mm and comes in a simple structure which allows for low-cost and easy fabrication.

### 2) SLOT-TYPE METALLIC PLATE ANTENNA

A capacitive coupling multi-feed slot tag antenna is presented in [26], which consists of a small dipole and slot radiator. The tag is designed to function appropriately with three different RFID microchips and widely varying impedances where it was possible to achieve a conjugate impedance match for the RFID tag. A unique advantage of the design is that it requires no redesign for different RFID chips. Also, its I direct coupling mechanism can help solve certain issues that arise during mass production. The experimental study was conducted incorporating different chips, namely TI, Alien-H2, and Alien-H3 chips which achieved maximum read ranges of 1.2 m, 2.8 m, and 4.2 m. Both simulation and experiment showed good agreement when using an FID reader of 0.5 W of EIRP.

Another slotted type antenna with a linearly polarized groove matrix is presented in [27]. The antenna consists of slots fed in series by a microstrip line where the bottom part of the line is short-circuited to the ground floor. This is a unique UHF-RFID shelving application with a unique U-shaped slot antenna element fed by a traveler. The permanent current wave formed in the left microstrip line short end. The gain of the 3 × 6 matrix antenna is designed to be about 4 dBi with fractional return loss bandwidth ($<-10$ dB) which is almost 5.5% at frequency of 920 MHz.

### 3) PATCH-TYPE TAG ANTENNA

A proximity-coupled radiating patch broadband RFID microstrip antenna for identification of labels on metal surfaces is presented in [20]. The design comes with an innovative power supply structure coupled by proximity. The direction of the feeding line of the microstrip is designed to be parallel to its resonance length (in the radiant zone), with one end of the supply line short circuited to the ground. The proposed design was tested by simulation and experiment. An approximately 49 MHz bandwidth was achieved, which extends over the bandwidth required in North America (i.e., 26 MHz).

Another contribution in this context is a label antenna designed to identify metallic objects in the UHF European band of 865–868 MHz [18]. The antenna is designed with a dipole mounted on the surface of a tiny dielectric that connects two short-circuit patches mounted on the FR4 substrate. The total label size was 73 mm × 25 mm × 3.2 mm. Full-wave simulations showed that this label can reach a reading range of 9.5 m when joined with a metal.

An RFID tag antenna (in the UHF band) that can be mounted on metal surfaces was also proposed in [28]. It is designed with a feed loop hosting two short stubs. The structure is designed with two symmetrical radiating patches shorted to the ground plane. Overall, the antenna showed good performance when mounted on metals with an impedance bandwidth of 8% at 858–929 MHz to achieve a reflection coefficient below −7.36 dB (VSWR < 2.5).

Another miniaturized patch-type RFID-tag antenna mountable on metallic surfaces was proposed in [29]. The antenna is designed with two rectangular patches connected through vias to a ground plane. It also come with an inductive layer to enable it to be mounted on metallic surfaces, and an inductive layer to increase the capacitive reactance of the tag antenna. Overdesign ensured a low resonant frequency and a small size. The testing of the antenna showed an improved read range of 1.5 m despite the metallic surface.

Another type of patch RFID tag antenna for application involving metallic materials was presented in [26]. The antenna consists of two unconnected capacitive loads and two rectangular shaped patches that are connected to form an antenna suitable for assembly on metal objects. The experimental test with the antenna showed a maximum reading range of 2.3 to 2.5 m when placed on a metal object. A folded microstrip patch antenna designed for passive RFID objects with metal sheets was proposed in [30]. The antenna's design makes it possible to be integrated inside or outside packages. A read range of 1 m was obtained when integrated in cigarette cartons and wrapped in aluminum foil. When two labeled boxes were placed side by side, the reading intervals of the antenna decreased due to the coupling effects between the labels. The antenna worked well when integrated in packages containing conductive film. The performance was shown to be excellent even if the conductive material was not present.

A Planar patch-type UHF-RFID antenna for metallic applications is proposed in [31]. In the design, three patches of different shapes were coupled inductively to a triangular loop to form a high impedance bandwidth for application at 860–960 MHz. The antenna is designed with a flat profile to provide ease of manufacture and cost reduction for mass production. A simulation study was conducted on the antenna by means of a software based on FEM-Ansoft HFSS. A measured and simulated impedance bandwidth between 113 MHz and 117 MHz with a return loss greater than 6 dB was obtained which extended over the UHF-RFID worldwide operational frequency band.

A similar UHF patch-type antenna for application on metallic environments is presented in [7]. The antenna consists of T-Match Red and double symmetrical radiant patches. It exhibits an average bandwidth of 11.4% on open air extending over a significant segment of the UHF-RFID band, and an improved radiation characteristic with cross polarization performance. The conducted test showed that it could perform in open air and on metal surfaces in the UHF-RFID band.

Another antenna for metallic environment was proposed in [32]. The metallic antenna is designed with a high impedance surface and rectangular patches connected via tracks to a ground plane. Experimental tests on the antenna produced a maximum reading range of approximately 3.1 m. Overall, the antenna was significantly thinner than most of the other microstrip antennas.

Another patch-type antenna mountable on metal surfaces is presented in [33]. The antenna consists of a microcircuit short circuit line in the ground plane with a proximity coupling power supply structure. Using the power supply structure, the antenna impedance —including the real and imaginary part—can be almost independently controlled, and directly matched with the label chip. Overall, the antenna achieved an impedance bandwidth of 13 MHz, a radiation efficiency of 56%, and a reading range of 5 m to 6 m on metal surfaces.

#### 4) FOLDED-PATCH TAG ANTENNA

A folded patch antenna (size = 30 mm × 30 mm × 3 mm) was proposed for metallic surfaces. This antenna can be read from 3.5 m on dielectric materials with permittivity 1–12. It is also able to achieve a range of 7 m when attached to metal [34]. A similar antenna that has tolerance to metallic material was shown to have a high read range of 6.1 m and 14.1 m on metals and dielectrics respectively [35]. Another similar microstrip antenna on a substrate of FR-4 (dielectric constant = 4.4 and thickness = 1 mm) is proposed in [36]. For implementation of this type, the dielectric is one of the most expensive components to achieve. In [37], a miniaturized patch antenna with a Dumbbells-defected ground structure is presented. The antenna size was miniaturized to operate at a frequency of 868 MHz.

A folded patch coplanar feed type UHF tag antenna is proposed in [38] for mounting on metal surfaces (size = approx. 25 mm × 40 mm × 3 mm. The tag could achieve a read-range of 5 m on dielectrics but attain more than 10 m when mounted on metals [39]. Another similar on-metal antenna was presented by [40]. The tag is an electrically small antenna sized 24.8 mm. The device could achieve a read range of 9 m.

A Microstrip folded tag antenna is presented in [41]. The antenna operates at 902–928 MHz frequency band and has a folded arm with total size of 33 mm × 67 mm × 3 mm. Another low profile folded-patch antenna (size = 30 mm × 30 mm × 3 mm) with an E-shape and frequency at 912 MHz is proposed in [42].

#### 5) FOLDED-PATCH TAG ANTENNA

A Microstrip with slots on the ground plane and patches above the antenna is proposed in [43]. Another similar antenna for Microwave Band is designed in [44]. Another miniaturized antenna is achieved in [25] by inserting an I-shaped slotted patch. This helped to expand the antenna to 68.4 mm × 75.1 mm; however, with some changes to the resonant frequency. Another similar antenna design (5.8 GHz) is presented in [45]. A slotted patch antenna with an Inset-feed technique is proposed in [46]. In the same context, a dual-band slotted patch antenna (size = 26 mm × 28 mm × 1.6 mm) is presented in [47]. With inherent properties like high data rate, low power consumption, and simple configurations, the UWB antennas offer superior designs and features for several applications [45].

Another compact slotted microstrip patch antenna (CSMPA) is presented in [43]. It operates at 2.40–2.45 GHz. It is fabricated with a Flame Retardant 4, FR4 substrate, which has 4.5 dielectric constant and 1.6 mm thickness. The overall design achieved a 50% reduction in size with a gain of 2.5 dB at 2.415 GHz.

A miniaturized slotted patch RFID antenna for metallic objects (size = approx. 33 mm × 16 mm × 3.2 mm) is presented in [48]. The design incorporates 2-coplanar metallic patches. The overall antenna inductance is enhanced using multiple slots on metallic patches, and between the ground and the patches a non-connected metallic plate is placed. The antenna's input impedance can be varied by varying the slot length without a change on the antenna's dimensions. The overall structure produced a read range of 80 cm on metallic surfaces.

#### 6) ELECTROMAGNETIC BAND GAP (EBG) TYPE

Electromagnetic band gap (EBG) materials exhibit a unique band gap at a certain frequency. This offers the possibility to solve some of the shortcomings of UHF-RFID for liquid and metal surface applications. In [49] an RFID tag antenna using EBG material is proposed to isolate the tag from its back so that the label can work on metallic surfaces. The antenna was designed to operate at about 915 MHz, and the simulation test showed a reading range of about 9 m on metallic surfaces.

A multiband dual polarized circular microstrip antenna with circular and rectangular slot is presented in [50]. Another similar circular microstrip antenna is designed in [51] with a circular patch fed by an RT Duroid 5870. A comparative investigation of circular monopole and rectangular-shaped microstrip patch-type antennas is presented in [52]. The simulation results showed that the circular patch antenna offers higher bandwidth, although the rectangular patch-type gives a higher return loss. Another new design approach to circular microstrip antenna presented in [53]. The design is meant to enhance the circular polarization of the antenna and incorporates a pair of triangular metallic strip on a radiating patch.

### B. TECHNIQUES APPLIED TO DIPOLE ANTENNA

A miniaturized microstrip dipole antenna (size = 141 mm × 60 mm) operating at a central frequency of 920 MHz is presented in [54] for passive UHF-RFID sensors. A similar antenna design with a long thin metal structure serving as a near field is proposed in [55]. The antenna can detect metal mountable tag up to a read range distance of 30 m through taking advantage of the metal structure. A major objective of the RFID antenna is to achieve both miniaturized design and good performance in applications involving metal surfaces [56]. Several techniques have been suggested to overcome this challenge. Another similar dipole antenna with enhanced features for metallic environment is proposed in [40]. It was possible to achieve an antenna size of 25 mm × 20 mm × 1.6 mm at 5.8 GHz. To achieve such a small-size design, it was also necessary to take into account the thickness (1.6 mm) of the FR4_epoxy substrate [57].

In the same context, another antenna composed of a modified dipole UHF-RFID antenna designed for metal objects is proposed in [19]. The antenna is built with a T-Match network and radiant patches in the upper part and a ground floor on the lower part. By inserting capacitive peak loads at the ends of the two radiant patches, the miniaturized design was achieved. This was to raise the antenna's capacitive reactance in such a way that 915 MHz approached the automatic resonance. The antenna bandwidth was found to be about 80 MHz and covered two main frequency bands [58]. The main aim of its design was to distinguish metallic objects in the European UHF band (865–868 MHz). The module is composed of a dipole that connects to two short patches mounted on the FR4 substrate mounted on a Slim dielectric. For experimentation, the total size of the label used was 73 mm × 25 mm × 3.2 mm. Full-wave simulations showed that the label could reach a read range of 9.5 m when connected to a metal.

The proposed metal surface in [21] cause changes to their resonance frequency, radiation efficiency, input impedance, radiation efficiency, and radiation pattern. The relationship between the distance from the metal surface and the mark can be found to account for these changes and explained through detailed theoretical study.

In [59], a meander (printed) monopole antenna was developed. The antenna consists of the structure of an artificial magnetic conductor (AMC) used as its reflector. In [60], a multi-band compact-notched circular monopole antenna was provided with a deficient ground surface. In the radiation patch and feed line, the antenna contains three U-slots and one I-slot. By inserting two inverted U-shaped slots into it the ground plane is deformed. A dipole antenna was designed in [54]. The cuts in the antenna structure reduced its size without changing the materials' high dielectric permittivity, which consequently reduced the cost of the antenna.

### C. TECHNIQUES APPLIED TO PLANAR INVERTED-F ANTENNA

Another type of antenna that can be installed on metallic objects is a planar inverted-F antenna (PIFA) as proposed in [61] for the 920–925 MHz band. The antenna consists of a radiating U-slot patch and holes. A low-profile in-metal UHF-RFID tag with radiating element is printed on a copper-clad Alumina (Al2O3) substrate ($\varepsilon r$ = 9, $\tan\delta$ = 0.0003), 23 mm × 23 mm × 1 mm in size and including two PIFAs. In [62], a metal-mountable UHF tag antenna is proposed (size = 32 mm × 35 mm × 1.6 mm). The antenna is composed of two side-by-side PIFAs. Two shorting stubs are used to attach the F-shaped patch vertical arms to the ground plane at a visible distance (6.8 m). The antenna consists of two PIFAs placed side by side. Two shorting stubs are used to connect the vertical arms of the F-shaped patches to the ground plane with detectable distance of (6.8 m).

An antenna which uses ceramic material to label metal objects is designed in [33], with the antenna RFID tag incorporated into the metal object. The diameter of the antenna label measured 34 mm and 5 mm. It is shown that an antenna with an appropriate built-in label can be made by two PIFAs using horizontal slits in the metal object. The proposed design was verified by simulation and measurements. The built-in label antenna was shown to work satisfactorily on the metal object. A UHF-RFID antenna of European band (866–868MHz) is designed in [63]. It may also operate in the North American UHF band (902–928MHz) and the ISM microwave band (2.4–2.45GHz). A planar inverted F-structure and a parasitic inverted L-structure made up the planned antenna. In case of the antenna, both structures created a compact, simple and cost-effective architecture specifically tailored for regular use as a credit card with a length of 85 mm and a width of 54 mm. The antenna was built on a polyethylene substrate (r = 2.35, tan = 0.002) that gave all bands of interest a return loss of less than −10 dB. In all the measured frequency bands, the antenna was shown to have strong impedance stability and omni-directional far-field patterns.

An IFA antenna for passive RFID tags attached on metal objects is designed in [64]. The antenna performance was studied and optimized with several FEM simulations. Two different substrate materials were compared. The two-layer substrate was found to improve metal-related characteristics by isolating the antenna from the metal surfaces. This is because the metal surface functions as a reflector and thus provides extra energy. The antenna's relatively thin structures (3,153 mm and 6,455 mm) allow it to be attached to many metal objects without any performance degradation. PIFA as proposed in [65] is popular for portable wireless devices due to its compactness and low profile. In this study, a structure of three grooves in the radiant patches were incorporated. The PIFA was optimized by testing the parameters, which showed that it was possible to achieve a reduction in scale. Computational and experimental test results for PIFA (with and without slots in the patch) were reported. A PIFA antenna that is mountable on metal surfaces was proposed and implemented in [33]. It suggested a method of adjusting the impedance with various microchip impedances and the possibility of being mounted on metal surfaces.

In [66], a PIFA structure is suggested with an overall dimension of 48 $mm^3$–46-2 $mm^3$. The undesirable influence of metallic artifacts may be minimized by the antenna. In [30], a folded patch antenna was suggested. Two triangular patches and a ground plane consist of the antenna laminated on both sides of a square with a length of 30 mm and an RO4003C substrate of thickness h = 1.524 mm. Another PIFA type antenna (length = 85 mm and width = 54 mm) was designed in [63] with the size of a credit card. The PIFA antenna was produced with a permissibility of 2.35 on a polyethylene substratum.

Another PIFA-type UHF tag antenna is proposed in [67]. The overall size of the antenna was 72 mm × 40 mm. A PIFA for passive UHF-RFID is presented in [68]. The antenna was designed to work at 868 MHz. The overall antenna size was l = 23.7 mm, w = 20.4. A two planar PIFAs placed side by side is proposed in [69]. The antenna of the size 32 mm × 35 mm × 1.6 mm could resonate at 920 MHz. A multi-element PIFA antenna resonating at 915 MHz is presented in [70]. The antenna is made of single-element fractal PIFA, produced on a ground plane of 90 mm × 90 mm [71]. The PIFA-type array antennas for UHF band RFID tags is shown in [72]. Mounted on metallic objects, the array antennas are designed to work at 902 MHz to 928 MHz (size = 45mm × 65 mm). Another low-profile PIFA antenna for metallic objects is presented in [73]. The antenna is designed to operate in the 902 MHz to 928 MHz band and placed on a metal plate (size = 200 mm × 200 mm). Another PIFA type antenna that operates in the 920 MHz to 925 MHz band is presented in [65]. The antenna (size = 40 mm × 20 mm) is designed for mobile devices in the UHF frequency band used in China.

### D. TECHNIQUES APPLIED TO OTHER STRUCTURES

An inductive coupling technique for antennas is proposed in [74]. The concept of applied power consists of two U-shaped symmetrical structures arranged opposite to each other to form a radiant body. This is an easy choice to balance the impedance of the antenna with the impedance of the chip by flexibly increasing the corresponding radiant body inductance. A better output for the antenna size (50 mm × 70 mm × 1.6 mm) is offered by the proposed antenna feeding system. Under this operating frequency, the maximum gain of the antenna for the label adopted is 2.5 dBi. Among traditional antennas, this is a higher value. A good impedance matching characteristic at 904 MHz to 937 MHz and a power reflectance coefficient better than −3 dB were seen in the results of testing the antenna. The capacity of the antenna to increase the overall performance of label antennas was demonstrated in a further comparison between the simulation results and the measurement.

A miniature antenna was created for a passive RFID tag in [75] for the UHF band. The CST Microwave Studio software based on the Finite Integral Technique was used for a simulation test. Using a two-port VNA, VNAs were also assessed. Calibration was not the result of the calibration process. A simple structure and a low profile, which is easy to manufacture, were provided by the proposed antenna. The concept loop antenna is presented in [76], which involves distribution of the metal on the antenna. By adjusting the thickness of the separation, the reflection of the electromagnetic wave improves the antenna gain and field strength.

A boxes and cavity backed model was designed for labeling metal objects [77]. The electromagnetic properties of the cavities and the passive tag of the RFID circuit AKTAG are included in the suggested tag. In addition, the architecture distinguishes the physical connection between the RFID chip and the antenna. The authors demonstrated the feasibility of creating a hidden label by embedding the existing metal cavity in the object structure. When the mark is inside the cavity, a reading interval of 5.5 m is measured in the anechoic chamber. A reading interval of 7.7 m is also achieved when the cycle label is coupled directly to the crack.

A triple-supply Y-shaped antenna RFID tag for metallic environment is presented in [78], which can be integrated directly into plates or metal structures. Its unique feature is that three RFID chips with different impedances operate with the tag. A possible advantage of this design is that it is not required to redraw the tag to work with various RFID chips. Its unusual architecture, complementary to an asymmetrically driven dipole antenna, is based on an asymmetrical slot configuration. An antenna built to work with an input impedance chip of 8.2-j61 Ω is suggested in [59]. To derive optimal power transfer between the chip and the antenna, a T-Matching technique was implemented. In free space and when linked to a metal, a label was evaluated for the antenna by experiment. The results showed a maximum readable range of 10 m for placing the label in free space, and 8.3 m for placing the label on a metal surface. A T-shaped antenna modified to the application of UHF-RFID tags is presented in [79]. To obtain a strong conjugate matching between the antenna and the chip label, four semi-circle patches were inserted. At both ends T-monopoles were connected. The overall free-space reading interval was found to be 7.5 mm, with the addition of a 3 mm thick foam substrate between the metal plate and the label antenna. For near-field UHF-RFID applications, a circular loop antenna is presented in [80]. Having the shape of a bracelet, the antenna can be directly integrated into clothes. This makes it easy to identify small passive UHF tags. A SAR simulation was performed on the antenna to ensure that it operates in line with the regulations while giving a good read range. A deformation effect on the antenna was also conducted for practical application.

The design of a coplanar type antenna is presented in [58]. The main design is a capacitive bent slot powered with a waveguide (CPW) at 2.4 GHz for RFID applications. The antenna consists of a 30 mm × 30 mm substrate. The results obtained from simulation and laboratory measurement indicated a bandwidth of 1.7%. The radiation patterns were bidirectional, which suggests its suitability for use as RFID tag.

In the HF-RFID (13.56 MHz) and UHF-RFID (920–925 MHz) applications, the dual band label antenna type intended for glass objects is proposed in [49]. The size of the antenna tag is the same as that of a credit card (i.e.,147 mm × 73.5 mm × 8.3 mm). The purpose of the antenna project was to implement RFID to track roads and toll systems. The label antenna has been designed on a FR-4 substrate of 0.3 mm and 3 mm thickness, respectively. The EBG structured tag antenna, is constructed on the basis of the loop (spiral) to achieve the double band feature, the serpentine structure with double T, and the mushroom as a structure of EBG for HF, UHF-RFID and EBG, respectively.

RFID labels for a meander antenna design are presented in [81]. The sensitivity of the manufacturing process and the contents of the box were analyzed.

A folded patch is used in [82] where the design was placed on a metal object and digital serration was added to the edges of the radiator to fine-tune its resonant frequency efficiently. Another folded-patch configuration is proposed in [39], while [37] proposed a dumbbell shaped type to miniaturize the size of the antenna. A T-shaped antenna tag is proposed in [24]. The antenna consists of a rectangular metallic patch consisting of a rectangular slot and a T slot. A structure derived from bending a thin sheet of aluminum into a polystyrene foam-filled U-shape is proposed in [20]. For metal uses in [35], an E-shaped folded-patch antenna is proposed. Alternatively, two coplanar metallic patches attached electrically to the ground plane by means of copper are presented in [48]. Another Microstrip folded tag antenna was proposed in [83], which is produced on a 33 mm × 67 mm × 3 mm low-cost FR4 substrate. A 302 cm long thin metal structure that serves as a near-field antenna design for a passive UHF-RFID application is proposed by [55].

In [84] a dual-band semi-Yagi reader antenna is presented, which is worn in a glove on the hand and incorporated onto a stretched fabric. The results showed that it could be read at 868 MHz using COTS-RFID, and the radiation patterns were measured at 2450 MHz. The comparison was also made for a reading range from 7 cm. A RFID is presented on the basis of a quasi-Yagi antenna in [85] which is based on the reflection of the radioactive material upward from the head of a user in the form of a dipole antenna. The display mode method was used without increasing the size of the antenna, and a built-in role surface was placed with a 2 × 2 grid with square rings, which in turn facilitated the emission of waves and the strengthening of the beam for the quasi-Yagi antenna. This pattern was fitted to the head with a semi-Yagi pneumatic folding method. A reading range of 5 m to 6.8 m was achieved for both dipole and quasi-Yagi.

A passive radio frequency ID (RFID) dependent radio sensor system is developed in [86] to detect the surface corrosion of a health facility. The two-dimensional label-type antenna is designed with a new configuration of the circular three-phase arm (CTA) to act as the UHF-RFID sensor marker acting on the steel surface. The antenna is designed with a new configuration of the three-phase circular element (CTA) to act as a high-frequency (UHF) RFID sensor marker acting on the surface of steel samples. A parasite component is added to the CTA as a sensor to improve power factor transmission as it leads to the determination of the resonant frequency. The results show the corrosion detection ability of the proposed system up to a distance of two meters with a UHF-RFID meter and a bandwidth of 13 MHz. Three different antennas of UHF- RFID unfolded, folded, and T shape are proposed in [87] for designing a steel antenna sensor applicable in corrosion sensing. This design is based on an antenna structure with zigzag using microstrip line theory, which in turn, determines the tag threshold. The antenna is shaped on a T-socket to improve the sensitivity of the sensor. The outcomes showed that the corrosion can be characterized by generating a midline structure which in turn enhances the sensing sensitivity. Also, the antenna size can be reduced by using the folding method, which in turn enhances the spatial resolution while decreasing the sensor sensitivity. The result of checking the unfolded antenna and the T-shaped antenna showed the correctness of the corrosion sensor. However, in reference [88], the characteristics of transient responses with an in-phase quadrature (IQ) instead of a received signal strength indicator (RSSI) were used to enhance the robustness and sensitivity of the UHF-RFID. The transient responses to the IQ signal were analyzed by using the skew feature for the various defects. The investigational outcomes showed that IQ-based deflection increase the vulnerability and strength of fault characterization compared to former RSSI and RCS approaches.

A chip-less RFID sensor system is proposed in [89] to detect rust by combining features with frequency selective surface (FSS). A three-resonance generation method with a 2–6 GHz band was used with the FSS pattern design. The results showed that the three resonant frequency characteristics make a powerful sensor by relying on RFID with FSS to detect rust while using the corrosion coatings. It was confirmed that the sensor sensitivity was enhanced when using confidence weighted average (CWA) with the integration of the features.

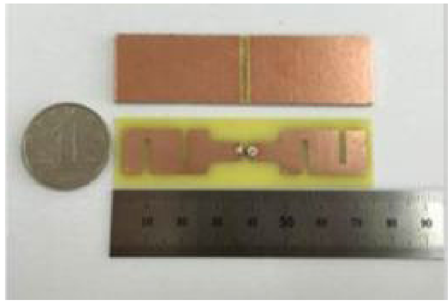
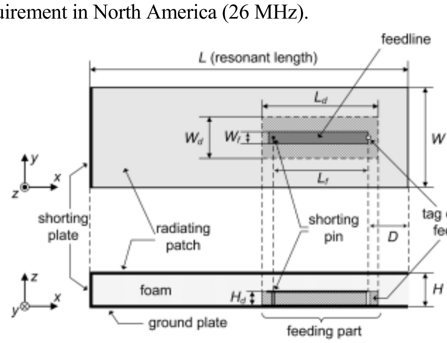
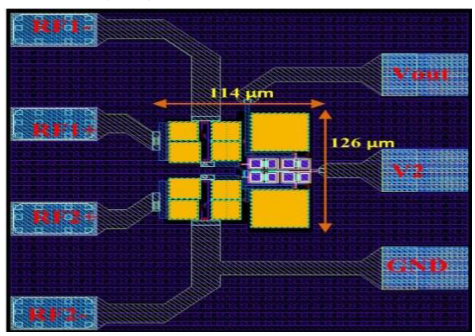
#### 1) LARGE TAG MICROSTRIP ANTENNA

An antenna with an improved read range is proposed in [40]. The antenna has a complementary split-ring resonator (CSRR). An overall read-range of 15.5 m was achieved at 920 MHz (size = 50 mm × 50 mm) for the antenna. A UHF-RFID passive tag with an overall size of 182 mm × 25 mm × 17 mm is presented in [90]. This antenna could be identified at distances up to 14 m. A UHF-RFID at UHF (865–960 MHz) for smart shelf applications is proposed in [91] and could be identified at distances of 50 cm. The structure has a dimension of 200 mm × 550 mm and a thickness of 2.6 mm. Another UHF band (860–960 MHz) antenna with overall dimensions of 84 mm × 100 mm is proposed in [92] which has a read range of 2.7 m. A UHF-RFID antenna with a read range of 8 m is proposed in [93]. The antenna operates at 860 MHz to 960 MHz. A dipole reflector array antenna is designed in [94]. To achieve 110 mm at 5.15 GHz, the dipole length (λ/2) was fixed at 29.1 mm.

#### 2) EFFECT OF SUBSTRATE

A magneto-dielectric substrate [MDS] technique is introduced in [95]. Based on this design, a 77% size reduction is achieved compared to conventional antenna. A microstrip patch flexible antenna with a rubber substrate was designed in [96] for ISM band in the range of 2.4–2.5 GHz. A Microstrip operating at 3 GHz frequency is designed in [97] for various substrate materials such as FR-4, Polystyrene, Ceramic, Quartz, Styrofoam and Glass-Pyrex. Maximum bandwidth of 82 MHz was achieved when Polystyrene substrate was used. In [98], a low temperature co-fired ceramic (LTCC) substrate is proposed combined with a single patch

**TABLE 1.** Some studies of recent advances on passive RFID tag antenna design for improved read-range in product packaging applications.

| | Title & References | Study purpose and Method | Year | Result Evaluation & Prototype |
|---|---|---|---|---|
| 1 | A new structure of UHF-RFID tag antenna mountable on metallic surface using double slits [10] | Novel passive 930 MHz RFID large metal tag antenna which is mountable on metallic surfaces; overall dimension of the antenna is (46.1 mm × 28.58 mm × 6 mm) | 2017 | Maximum reading distance of 7 m when placed on metallic surface.  |
| 2 | Compact broadband UHF-RFID tag antenna for metallic objects [12] | Large antenna of size 75 mm × 20 mm × 3 mm and gain of about 3.3 dBi; the antenna consists of two layers: a radiating patch with slots that is printed on the upper dielectric substrate and a bottom dielectric substrate surrounded by metal strap with slots. | 2017 | The measured identification distance is 3.8 m.  |
| 3 | Small UHF-RFID tag antenna for metallic objects [18] | Label antenna designed to identify metallic objects in the UHF European band (865–868 MHz); with a dipole mounted on the surface of a tiny dielectric that connects to two short-circuit patches mounted on the FR4 substrate. The total label size is 73 mm x 25 mm x 3.2 mm. | 2015 | Full-wave simulations show that this label can reach a reading range of 9.5 m when joined with a metal.  |
| 4 | Low-cost, wideband RFID tag antenna on metallic surfaces using proximity-coupled feed [20] | Proximity-coupled radiating patch broadband RFID microstrip antenna to identify labels on metal surfaces; innovative power supply structure coupled by proximity; direction of the microstrip's feeding line is e parallel to its resonance length; one end of the supply line short-circuited to the ground. | 2009 | Approximately 49 MHz bandwidth which extends over bandwidth requirement in North America (26 MHz).   |
| 5 | Rectenna series-association circuits for radio frequency energy harvesting in CMOS FD-SOI 28 nm [23] | Large antenna mounted on a metallic plate of 300 mm × 250mm; total volume 104 mm × 31 mm × 7.6 mm. | 2017 | Maximum reading range of 14.6 m at 905 MHz.   |

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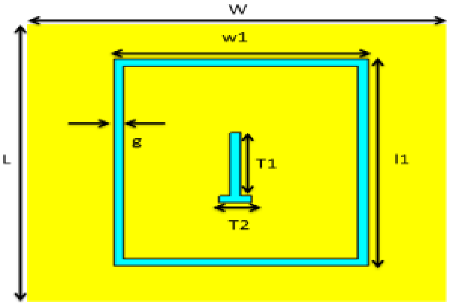
<td>6</td>
<td>T-shaped tag antenna for UHF-RFID applications [24]</td>
<td>T-shaped antenna structure with overall size of 80 mm x 80 mm x 1.635 mm; slotted with metallic rectangular patch and T-slot; suitable for mounting objects</td>
<td>2018</td>
<td>Maximum reading range of about 6.14 m; good performance over other materials like plastic and cardboard.<br>


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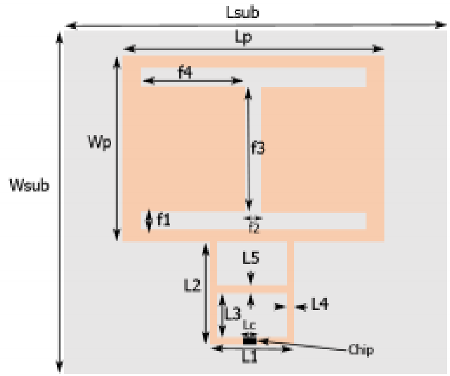
<td>7</td>
<td>Miniaturized microstrip patch antenna for passive UHF-RFID tag [25]</td>
<td>Antenna design with rectangular patch and balanced feed which operates at 915 MHz; the antenna has a size of 68.4 mm × 75.1 mm; simple structure; suitable for low-cost and easy fabrication.</td>
<td>2017</td>
<td>Miniaturized antenna with size reduced to 68% of the premier design.<br>


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<td>8</td>
<td>Low profile RFID tag designed for metallic objects [26]</td>
<td>Capacitive coupling multi-feed slot tag antenna; with small dipole and slot radiator; tag functions appropriately with three different RFID microchips; widely varying impedances.</td>
<td>2009</td>
<td>Experimental study incorporating different chips: (TI, Alien-H2, and Alien-H3); maximum read range of 1.2 m, 2.8 m, and 4.2 m; simulation and experiment showed good agreement; using FID reader of 0.5 W of EIRP.<br>


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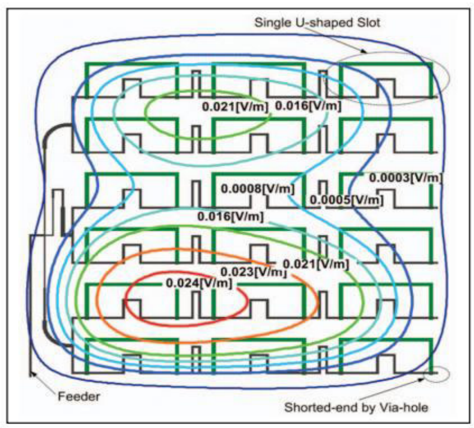
<td>9</td>
<td>U-shaped slot-array antenna for RFID shelf in the UHF [27]</td>
<td>Slotted type antenna with linearly polarized groove matrix; antenna consists of slots fed in series by a microstrip line; bottom part of the line short-circuited to the ground floor; unique UHF-RFID shelving application with a unique U-shaped slot antenna element fed by a traveler; permanent current wave formed in the left microstrip line short end.</td>
<td>2011</td>
<td>3 x 6 matrix antenna with 4 dBi gain and fractional return loss bandwidth (<-10 dB), almost 5.5% at frequency of 920 MHz.<br>


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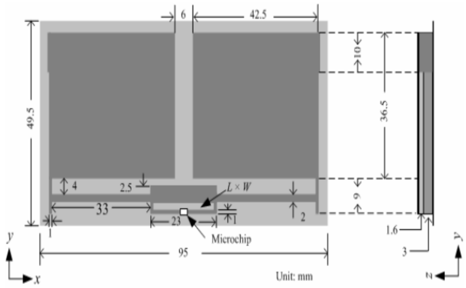
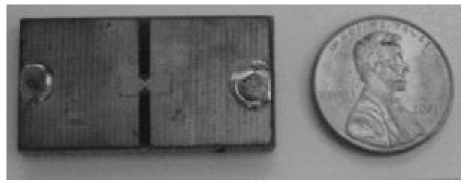
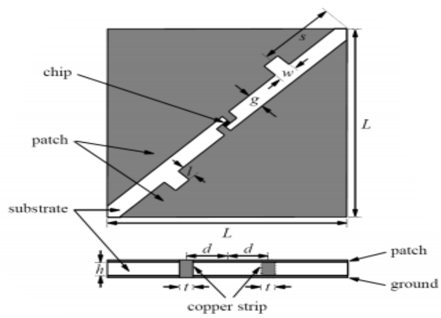
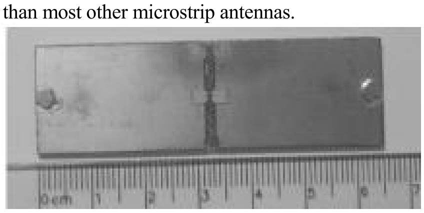
| 10 | Novel UHF-RFID tag antenna with shorted stubs mountable on metallic objects [28] | RFID tag antenna (in the UHF band) mountable on metal surfaces; with feed loop hosting two short stubs; two symmetrical radiating patches shorted to the ground plane. | 2008 | Good overall performance when mounted on metals; impedance bandwidth of 8% at 858–929 MHz to achieve a reflection coefficient below -7.36 dB (VSWR < 2.5).   |
| 11 | Miniature RFID tag antenna design for metallic objects application [29] | Miniaturized patch-type RFID-tag antenna mountable on metallic surfaces; two rectangular patches connected through vias to a ground plane; inductive layer to be mounted on metallic surfaces and increase capacitive reactance. | 2009 | Overdesign for a low resonant frequency and small size; improve read range of 1.5 m despite the metallic surface.  |
| 12 | Compact folded patch antenna for UHF-RFID [30] | Folded microstrip patch antenna designed for passive RFID objects with metal sheets; can be integrated inside or outside packages; read range of 1 m when integrated in cigarette cartons wrapped in aluminum foil; reading intervals decreases if two labelled boxes placed side by side due to coupling effects. | 2017 | Works well when integrated in packages containing conductive film; excellent performance even if conductive material is not present.   |
| 13 | A planar wideband inductively coupled feed patch antenna for UHF-RFID tag [31] | Planar patch-type UHF-RFID antenna for metallic applications; three patches of different shapes coupled inductively to a triangular loop to form a high impedance bandwidth for application at 860–960 MHz; designed with a flat profile for easy manufacture and reduced cost (mass production). | 2013 | A simulation study is conducted on the antenna by means of a software based on FEM-Ansoft HFSS. A measured and simulated impedance bandwidth between 113 MHz and 117 MHz with a return loss greater than 6 dB was obtained which extends over the UHF-RFID worldwide operational frequency band.  |
| 14 | Slim RFID tag antenna design for metallic object applications [32] | Antenna for metallic environment; designed with high impedance surface and rectangular patches connected via tracks to ground plane. | 2008 | Maximum reading range of approximately 3.1 m; significantly thinner than most other microstrip antennas.  |

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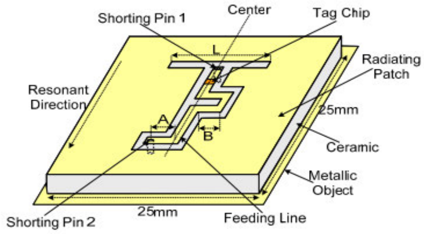
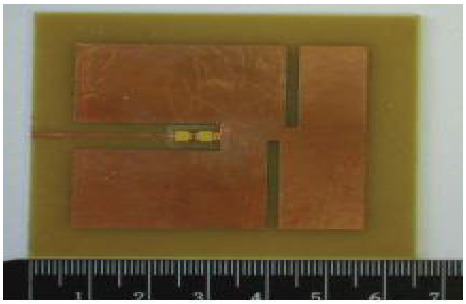
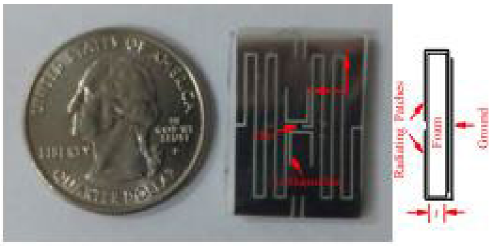
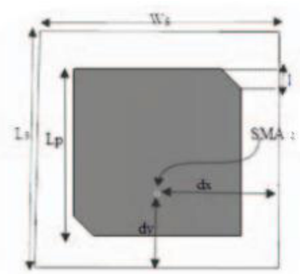
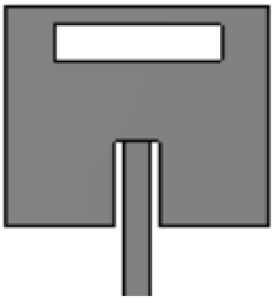
| 15 | Small RFID tag antenna for metallic surface [33] | Patch-type antenna mountable on metal surfaces; consists of microcircuit short circuit line in ground plane with proximity coupling power supply structure; controllable impedance (real and imaginary part); can be directly matched with the label chip. | 2008 | Impedance bandwidth of 13 MH;, radiation efficiency of 56%; reading range of 5–6 m on metal surfaces.   |
| 16 | Compact broadband patch antenna for UHF-RFID tags [46] | Square patched-type antenna for RFID tags; increased bandwidth through internal power technique and two asymmetric grooves incorporated by two non-radiations deep edges in the patch, including two resonances; two slots influence size of patch; insertion power supply can enable application for incoming reactance (correspondence). | 2009 | A prototype of the antenna was verified experimentally which showed that a half bandwidth of the antenna could extend over the UHF band. The reading interval was found to be more than 2m on a metal surface.  |
| 17 | Miniaturized dipolar patch antenna with narrow meandered slotline for UHF tag [34] | Folded-patch antenna of size 30 mm x 30 mm x 3 mm for metallic surfaces. | 2017 | Antenna can be read from 3.5 m on dielectrics materials with permittivity between 1–12; achieves 7 m when attached to metal.   |
| 18 | Miniaturized circularly polarized patch antenna for RFID System [37] | Miniaturized patch antenna with Dumbbells-defected ground structure. | 2018 | Miniaturized antenna size to operate at frequency of 868 MHz.   |
| 19 | Multiband and Broadband Microstrip antenna for wireless systems [38] | Folded patch coplanar feed type UHF tag antenna for mounting on metal surfaces; size about 25 mm x 40mm x 3 mm. | 2014 | Tag could achieve a read range of 5 m on dielectrics; exceeded 10 m when mounted on metals.  |

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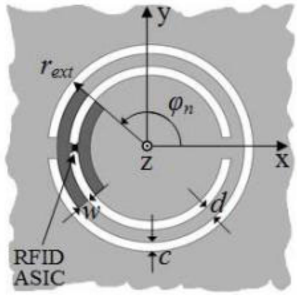
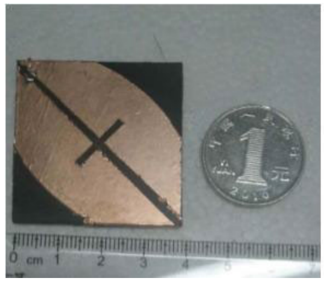
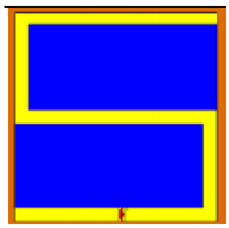
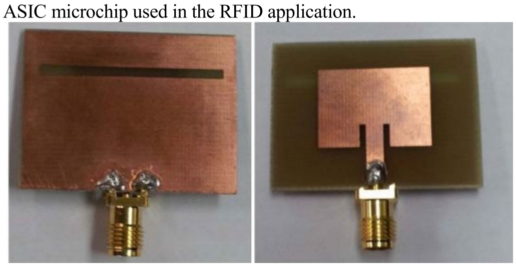
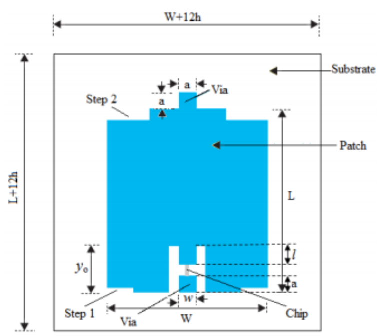
| 20 | Novel design strategy for small on-metal UHF-RFID tags with long read range based on complementary split ring resonator (CSRR) [40] | An on-metal antenna was presented. | 2018 | Electrical small antenna of size 24.8 mm; achieves a read range of 9 m.   |
| 21 | Circular polarized RFID tag antenna with characteristic mode analysis [41] | Microstrip folded tag antenna. | 2019 | Operates at 902–928 MHz frequency band; folded arm; total size of 33 mm × 67 mm × 3 mm.  |
| 22 | Compact planar inverted-S antenna with embedded tuning arm for on-metal UHF-RFID tag design [42] | Low profile folded-patch antenna (size = 30 mm × 30 mm × 3 mm) with E-shape and frequency at 912 MHz. | 2019 | Able to read from 11.9 m; if size is 15 mm x 15 mm can read from 7 m.  |
| 23 | Compact slotted microstrip patch antenna for RFID applications [43] | Microstrip with slots on the ground plane and patches above the antenna. | 2013 | Produces gains of 2.5 dB; overall size of antenna35 mm x 26 mm x 1.67 mm; passive single band dipole tag when it integrated with ASIC microchip used in the RFID application.  |
| 24 | Passive RFID tag antenna at 2.45 GHz for mounting on various platforms [44] | Antenna for microwave band. | 2011 | Produces 2.5 dB at size 35 mm x 26 mm x 1.67 mm; single-band passive bipolar tag when combined with ASIC microchip used in the RFID application.   |

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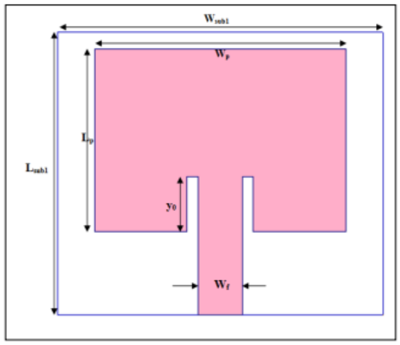
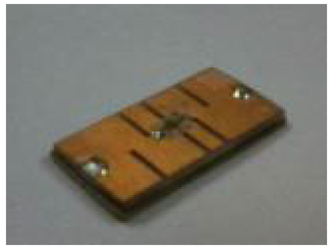
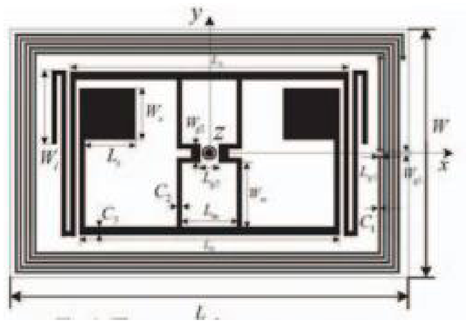
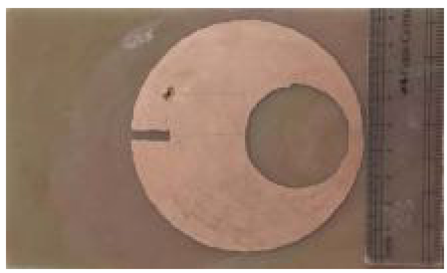
| 25 | Two elements rectangular Microstrip Patch Antenna at 5.8 GHz for RFID reader applications with high directivity and gain [45] | Antenna design (5.8 GHz). | 2018 | Inherent properties like high data rate, low power consumption, and simple configurations; better design and features for several applications.  |
| 26 | Miniature slotted RFID tag antenna for metallic objects [48] | Miniaturized slotted patch RFID antenna for metallic objects equal to 33 mm x 16 mm x 3.2 mm; incorporates 2-coplanar metallic patches; overall antenna inductance enhanced using multiple-slots on metallic patches; non-connected metallic plate between ground and patches. | 2011 | Input impedance adjustable by varying slot length without a change on the antenna's dimensions; overall structure produced a read range of 80 cm on metallic surfaces.  |
| 27 | Dual-band RFID tag antenna with EBG for glass objects [49] | RFID tag antenna using EBG material to isolate tag from its back; operates at about 915 MHz. | 2015 | Reading range of about 9 m on metallic surfaces.  |
| 28 | Rectangular slot cut circular Microstrip antennas [50] | Multi-band dual polarized circular microstrip antenna with circular and rectangular slot. | 2016 | Produces wide, dipolar radiation pattern at all frequencies; against variable aperture position and radius, proposed CMSA results in frequency ratio of 1.0 to 1.15 and 1.7 to 2.0 over four resonant positions; due to loss of substrate, the multi-band design gives gain of less than 0 dB; improved suspended designs with wide gain of over 4 dB per frequency.  |
| 29 | Rectangular and circular microstrip patch antennas in X Band [52] | Circular- and rectangular-shaped microstrip patch-type antennas. | 2014 | Offers higher bandwidth, although rectangular patch-type gives higher return loss. |

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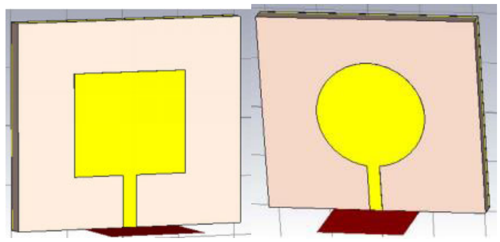
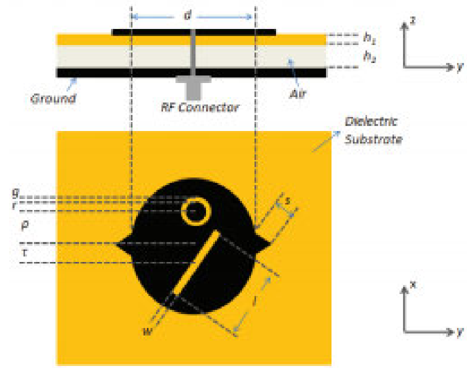
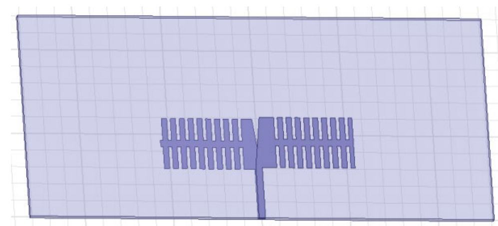
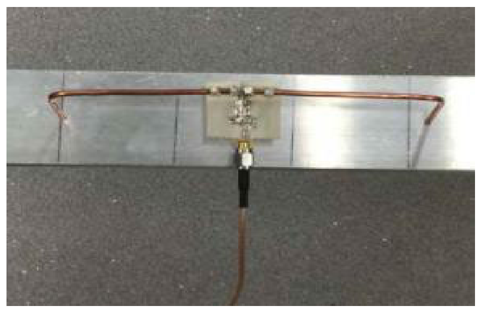
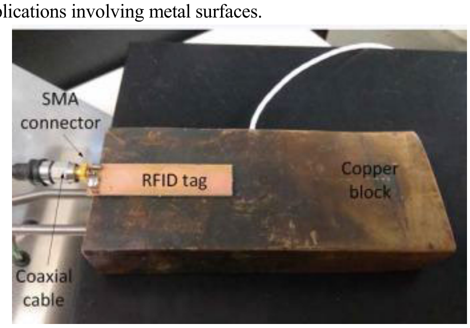
| | | | |  |
| 30 | New design approach to improve circular polarization characteristics of a microstrip antenna [53] | Circular microstrip antenna to enhance circular polarization; incorporates pair of triangular metallic strips on radiating patch. | 2018 | Improved frequency corresponding without simulating bandwidth; improves 5% with effective CP bandwidth.   |
| 31 | Microstrip dipole antenna with reduced dimensions and cutouts [54] | Miniaturized microstrip dipole antenna (141 mm x 107 mm) operating at central frequency of 920 MHz for passive UHF-RFID system. | 2018 | Boom length can be reduced by about 40mm with 920 MHz frequency.  |
| 32 | Large metal objects as near field UHF-RFID antenna [55] | Antenna design with long thin metal structure acting as near field. | 2017 | Can detect metal mountable tag up to a read range distance of 30 m.  |
| 33 | Self-tuning RFID tag; new approach to temperature sensing [56] | New concept for UHF radio frequency identification (RFID) sensor tag operation. | 2018 | Achieves both miniaturized design and good performance in applications involving metal surfaces.   |

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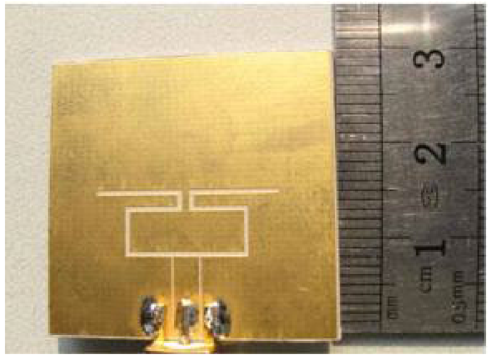
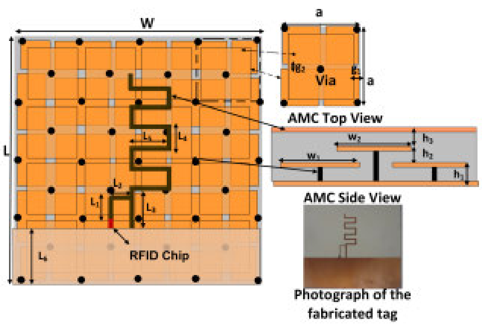
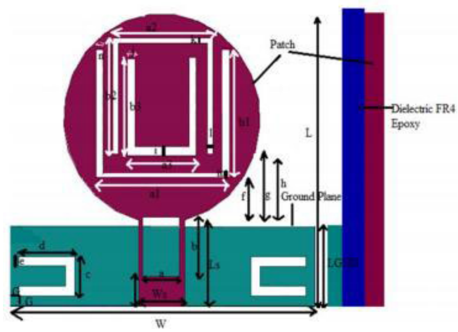
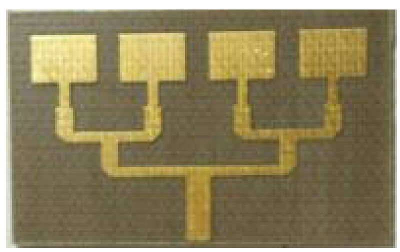
| 34 | Compact slot antenna for 2.4GHz RFID tags [58] | Antenna bandwidth about 80 MHz; covers two main frequency bands; distinguishes metallic objects in the European UHF band (865–868 MHz); module composed of dipole connecting to two short patches mounted on FR4 substrate mounted on Slim dielectric. For experimentation, the total size of the label was 73 mm x 25 mm x 3.2 mm. | 2009 | Full-wave simulations showed that the label can reach a read range of 9.5 m when connected to a metal.  |
| 35 | Passive UHF-RFID printed monopole tag antenna to identify metallic objects [59] | Meander (printed) monopole antenna consisting of artificial magnetic conductor (AMC) used as reflector; built to work with an input impedance chip of 8.2-j61 Ω. T-matching technique for optimal power transfer between chip and antenna. | 2012 | Maximum readable range of 10 m for label in free space, and 8.3 m for label on metal surface.   |
| 36 | Compact band notched monopole antenna with defected ground plane for UWB applications [60] | Multi-band compact notched circular monopole antenna with deficient ground surface; three U-slots and an I-slot in the radiation patch and feed line. | 2018 | Improved antenna gain, efficiency, return loss, radiation patterns, and VSWR.   |
| 37 | Microwave photonic antenna for fiber radio application [61] | Can be installed on metallic objects; planar inverted-F antenna (PIFA) for the 920–925 MHz band; consists of a radiating U-slot patch and holes; low-profile in-metal UHF-RFID tag with radiating element printed on copper-clad Alumina (Al2O3) substrate (εr = 9, tanδ = 0.0003); size = 23 mm × 23 mm ×1 mm; two planar inverted-F rectangular antennas (PIFAs). | 2018 | The optical antenna provides a good performance that can be applied to the networks of future mobile communication.  |
| 38 | Compact Z-slotted patch antenna for UHF metal-mountable tag [62] | Metal-mountable UHF tag antenna of size 32 mm x 35 mm x 1.6 mm; composed of two side-by-side, planar inverted-F antennas (PIFAs). | 2018 | Two shorting stubs to connect vertical arms of the F-shaped patches to the ground plane with detectable distance of 6.8 m. |

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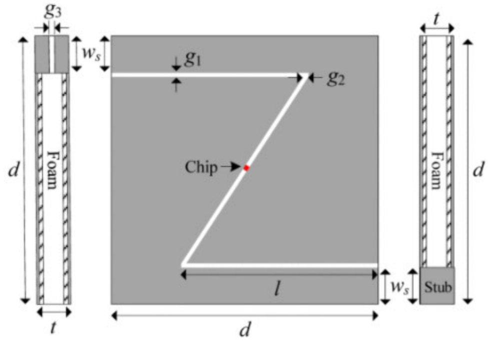
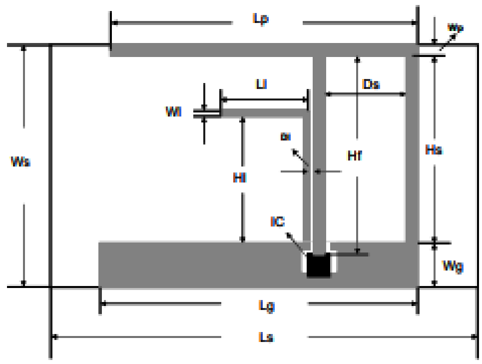
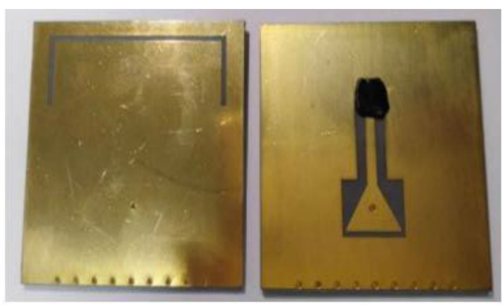
| | | | |  |
| 39 | Dual-band RFID tag antenna using coplanar inverted-F/L structure [63] | UHF-RFID antenna of European band (866–868 MHz); can operate in the North American UHF band (902–928 MHz) and ISM microwave band (2.4–2.45 GHz); planar inverted-F and parasitic inverted-L structure; both structures create compact, simple, and cost-effective architecture tailored for regular use as credit card with length of 85 mm and width of 54 mm. | 2010 | Built on polyethylene substrate (r = 2.35, tan = 0.002) that gives all bands of interest return loss of less than -10dB; strong impedance stability and omni-directional far-field patters is.  |
| 40 | Effect of slots on PIFA performance [65] | Popular for portable wireless devices due to compactness and low profile; structure of three grooves incorporated in the radiant patches; optimized by testing parameters; achieves reduction in scale. | 2016 | Computational and experimental test results for PIFA, with and without slots in the patch.  |
| 41 | Novel UHF-RFID tag using a planar inverted-F antenna mountable on metallic objects [66] | PIFA structure with overall dimensions of 48 mm x 46 mm x 2 mm. | 2018 | Undesirable influence of metallic artifacts can be minimized.  |

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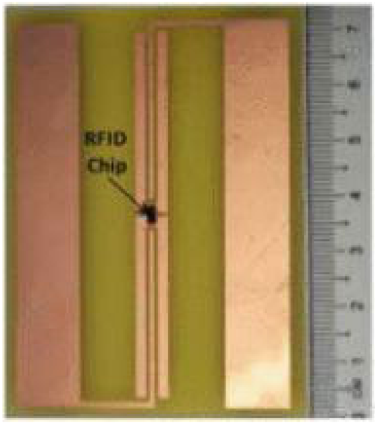
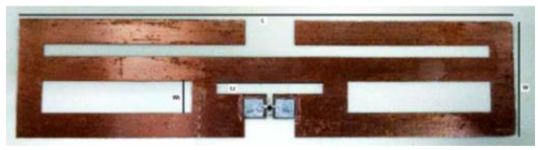
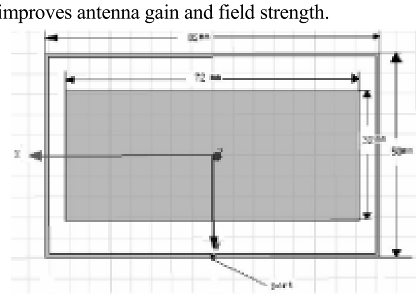
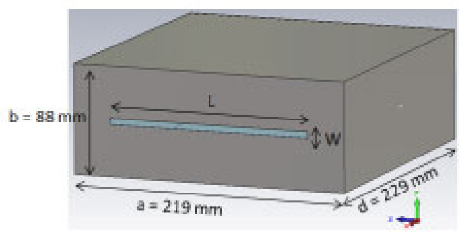
| 42 | U-shaped inductively coupled feed RFID tag antenna for gain enhancement [74] | Inductive coupling technique for antennas; applied power through two U-shaped symmetrical structures arranged opposite to form a radiant body; balances the impedance of the antenna with the impedance of the chip by flexibly increasing the corresponding radiant body inductance; better output for the antenna size (50 mm x 70 mm x 1.6 mm; maximum gain for label adopted 2.5 dBi; high value antenna. | 2013 | Good impedance matching characteristic at 904–937 MHz; power reflectance coefficient better than -3 dB; capacity to increase overall performance of label antennas demonstrated in comparison between simulation results and measurement.   |
| 43 | T-Matching variation effect of RFID tag antenna for 915 MHz [75] | Miniature antenna for passive RFID tag for UHF band; CST Microwave Studio software, based on Finite Integral technique used for simulation test; two-port VNA, calibration not the result of the calibration process. | 2014 | Simple structure and low profile; easy to manufacture.  |
| 44 | UHF-RFID tag antenna mounted on metallic objects [76] | Concept loop antenna; distribution of metal on antenna. | 2008 | Adjusted thickness of separation; reflection of electromagnetic wave improves antenna gain and field strength.  |
| 45 | New concept of UHF-RFID tag for metallic object tracking with embedded cavity [77] | Boxes and cavity backed model designed for labeling metal objects; electromagnetic properties of cavities and passive tag of RFID circuit AKTAG included; architecture distinguishes physical connection between RFID chip and antenna; demonstrated feasibility of creating hidden label by embedding existing metal cavity in object structure. | 2014 | Reading interval of 5.5 m is measured in the anechoic chamber when mark inside cavity; reading interval of 7.7 m when cycle label coupled directly to the crack.   |
| 46 | Free and on metal modified T-shaped tag antenna for UHF-RFID applications [79] | T-shaped antenna modified for the application of UHF-RFID tags; for strong conjugate matching between antenna and chip label, four semi-circle patches are inserted and T-monopoles connected at both ends. | 2015 | Overall free-space reading interval found to be 7.5 mm, with added 3 mm thick foam substrate between metal plate and label antenna. |

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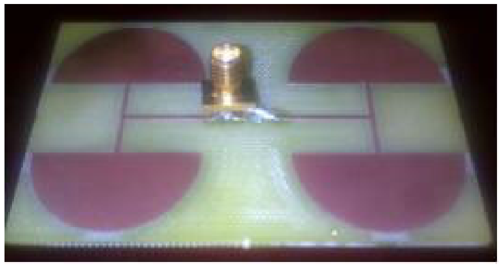
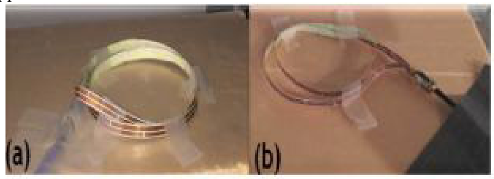
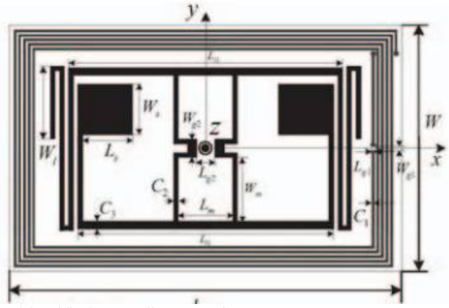
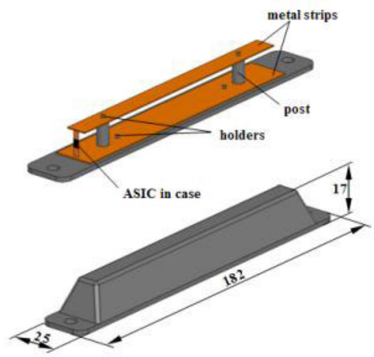
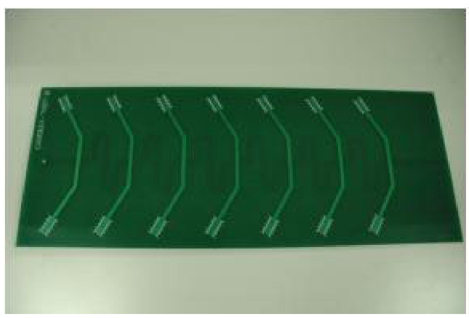
| | | | |  |
| 47 | Design of near field UHF-RFID reader antenna integrated into clothing [80] | Circular loop antenna for near-field UHF-RFID applications; bracelet shape can be directly integrated into clothes; easy to identify small passive UHF tags. | 2014 | SAR simulation to ensure that it operates in line with regulations; good read range; deformation effect conducted for practical applications.   |
| 48 | Dual band RFID tag antenna with EBG for glass objects [49] | Dual band label antenna for glass objects; for HF-RFID (13.56 MHz) and UHF-RFID (920–925 MHz) applications; credit card size (147 mm x 73.5 mm x 8.3 mm). | 2016 | Output power of 4W EIRP reader; can be read from 11.9 meters;15 mm x 15 mm mark reading range rated minimum of 7 m.   |
| 49 | Passive UHF-RFID tag with increased read range [90] | UHF-RFID passive tag with overall size of 182 mm × 25 mm × 17 mm. | 2008 | Can be identified up to distance of 14 m.   |
| 50 | Novel design of UHF-RFID near-field antenna for smart shelf applications [91] | UHF-RFID at UHF (865–960 MHz) for smart shelf applications. | 2013 | Can be identified at distances of 50 cm; structure with dimensions of 200 mm x 550mm and thickness of 2.6 mm.  |

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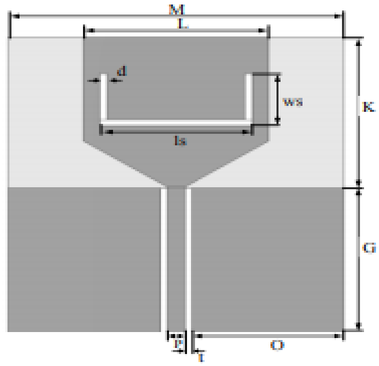
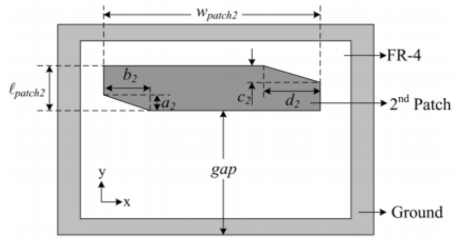
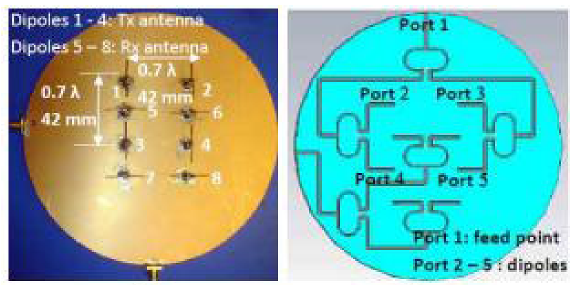
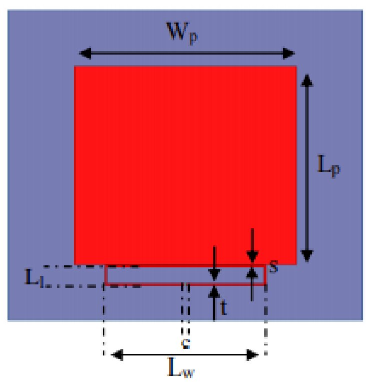
| 51 | Modeling microstrip antenna for UHF-RFID tags [92] | UHF band (860–960 MHz) antenna with overall dimensions of 84 mm x 100 mm. | 2017 | Read range of 2.7 m.   |
| 52 | Circularly polarized tag antenna for increased reading range [93] | UHF-RFID antenna with short plate and truncated patch. | 2009 | Operates 860–960 MHz; reading range from 8 m.   |
| 53 | Antenna performance on read range improvement of chip-less RFID tag reader [94] | Dipole reflector array antenna operating 860–960 MHz. | 2010 | Achieves 110 mm at 5.15 GHz; dipole length (λ/2) fixed at 29.1 mm.   (a) (b) |
| 54 | Miniaturized microstrip patch antenna using magneto-dielectric substrate for RFID applications [95] | Magneto-dielectric substrate [MDS] technique. | 2019 | 77% size reduction of conventional antenna.   |
| 55 | Effects of different substrates on rectangular microstrip patch antenna for S-band [97] | Microstrip operating at 3 GHz frequency for various substrate materials such as FR-4, Polystyrene, Ceramic, Quartz, Styrofoam, and Glass-Pyrex. | 2016 | Maximum bandwidth of 82MHz achieved with Polystyrene substrate. |

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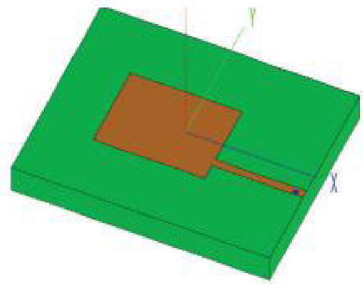
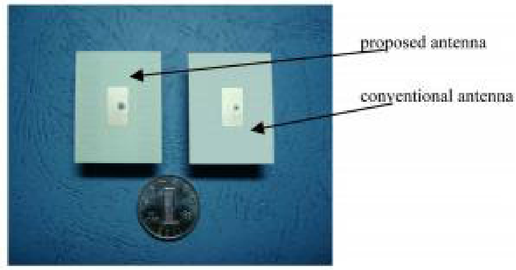
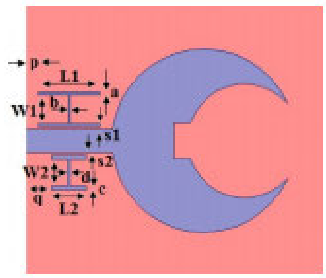
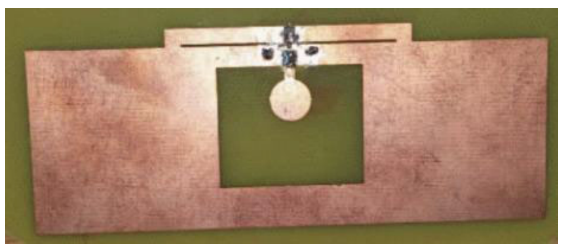
| | | | |  |
| 56 | Gain enhancement for microstrip antennas using negative permeability metamaterial on low temperature co-fired ceramic (LTCC) Substrate [98] | Low temperature co-fired ceramic (LTCC) substrate combined with single patch antenna for gain enhancement. | 2013 | Antenna gain increased by negative permeability obtained from metamaterial substrate with SRRs.  |
| 57 | Dual-band notched wide-slot UWB antenna for low-cost RFID applications [100] | Notched UWB wide-slot antenna. | 2018 | Antenna (size = 40 mm x 40 mm) spans UWB (3.1–10.6 GHz).  |
| 58 | UWB/UHF-RFID tag [107] | Two-port antenna for hybrid UHF/UWB. | 2015 | Slot resonates over full FCC UWB band (3.1–10.6 GHz).  |
| 59 | UHF-RFID system for wirelessly detection of corrosion based on resonance frequency shift in forward interrogation power [86] | Passive radio frequency ID (RFID) dependent radio sensor system to detect surface corrosion; two-dimensional label-type antenna designed with new configuration of circular three-phase arm (CTA) to act as UHF-RFID sensor marker on steel surface; new configuration of three-phase circular element (CTA) to act as high-frequency (UHF) RFID sensor marker on steel surfaces; parasite component added to CTA as sensor to improve power factor transmission and determine resonant frequency. | 2018 | Corrosion detection ability up to a distance of 2 m with UHF-RFID meter and bandwidth of 13 MHz. |

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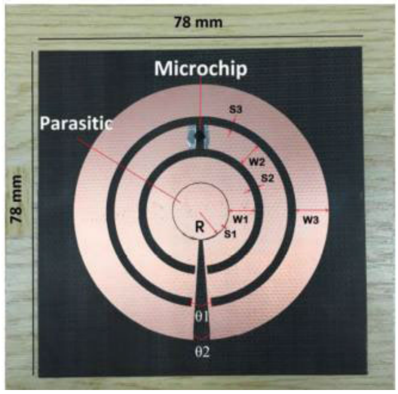
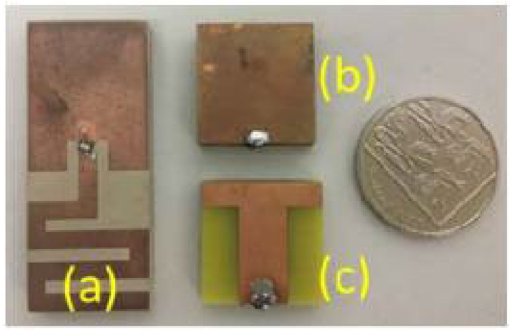
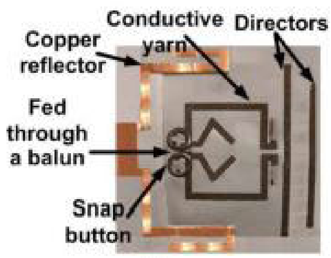
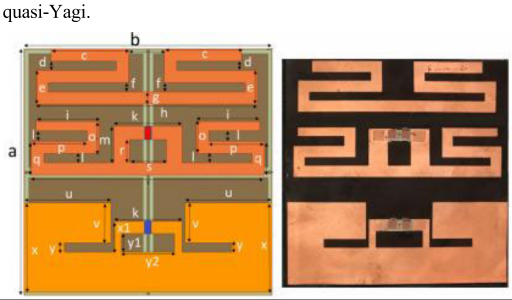
| | | | |  |
| 60 | Miniaturization of UHF-RFID tag antenna sensors for corrosion characterization [87] | Three different antennas of UHF- RFID unfolded, folded, and T-shape for designing steel antenna sensor for corrosion sensing; design based on antenna structure with zigzag using microstrip line theory; determines tag threshold accurately; shaped on T-socket to improve sensor sensitivity. | 2017 | Corrosion characterized by generating midline structure to enhance sensing sensitivity; antenna size can be reduced by folding method to enhance spatial resolution; sensor sensitivity decreases; correctness of corrosion sensor by checking unfolded antenna and T-shaped antenna.  |
| 61 | Wearable dual band Quasi-Yagi antenna for UHF-RFID and 2.4 GHz applications [84] | Dual band semi-Yagi reader antenna worn in glove and incorporated onto stretched fabric. | 2020 | Can read at 868 MHz using COTS-RFID; radiation patterns measured at 2450 MHz; comparison made for reading range from 7 cm.  |
| 62 | Dual-ID RFID tag for headgear based on quasi-Yagi and dipole antennas [85] | RFID based on quasi-Yagi antenna; reflection of radioactive material upward from user head in form of dipole antenna; display mode method used without increasing antenna size; built-in role surface; placed with a 2 × 2 grid with square rings, which facilitated emission of waves and strengthening of beam; pattern fitted to head with semi-Yagi pneumatic folding method. | 2020 | Reading range of 5 m and 6.8 m achieved for both dipole and quasi-Yagi.  |

antenna for gain enhancement. The antenna gain is increased by negative permeability obtained from metamaterial substrate with SRRs. A patch antenna operating in the 2.48 ism band is designed in [99]. The antenna was fabricated with a different height of RT-Droid substrate. The substrate exhibited the lowest dielectric constant. Results show that a better gain is achieved with increased height.

#### 3) ULTRA-WIDE BAND RFID (UWB-RFID)

A notched UWB wide-slot antenna is shown in [100]. This antenna (40 mm × 40 mm) spans the UWB (3.1 GHz to 10.6 GHz). A U-slot resonator with defected ground structure (DGS) was presented in [101]. The antenna size and resonance frequency are 24 mm × 30 mm and 5 GHz respectively. Based on the traditional rectangular patch, the patched shapes were constructed. In order to reduce its overall length, two of the patches were meandered [31]. This also made it possible for the antenna to resonate at 113 MHz to 117 MHz. A two-port antenna for hybrid UHF/UWB is proposed in [102]. The slot was able to resonate over the full FCC UWB band (3.1–10.6 GHz). Another offset circular slot monopole antenna with two steps for application in the UWB-RFID is proposed in [103]. The overall antenna size is 23 mm × 31 mm. An integrated microstrip with slot cross-shaped resonators having stub is presented by [104] for the UWB application. Circular patch antenna for UWB with interference rejection is presented in [105]. The antenna bandwidth was enhanced by cutting L slot into the patch. Another antenna (size = 30 mm × 30 mm × 6.9 mm) is presented in [106]. The structure was intended for application in the frequency band of 6–8 GHz.

Table 1 indicates some studies that have used the passive RFID tag antenna design for improved read range in product packaging applications. In this table we highlight the designs that are intended to improve the antenna read range as well as scalability design for miniaturized applications.

This study highlights that radio frequency identification (RFID) is a widespread and rapidly developing technology. Passive ultra-high frequency (UHF) signal plays a major role in transferring development from the stages of theory and laboratories to the market for practical applications. However, the primitive application of this technology still presents several challenges, such as the quality of the delivery materials, the packaging materials, the thickness of the solid materials, and the determination of the average reading distance to determine the identity using UHF-RFID. In the past years, many studies have been conducted to try to improve the performance and characteristics of the antennas for all applications, mostly improving the quality of materials to achieve lower cost, smaller size, and lower distance reading rate. This research presents an overview of major studies and discusses the features and results of each previous study proposal, including size and average reading distance. This study is hoped to provide the stimulus to learn more about the background of antenna research and compare their approach and result.

## IV. CONCLUSION

RFID sensors are currently the main component of many applications. Ultra-high frequency (UHF) tags used in RFID sensors offer a higher data transfer rate and a longer reading range and usually come in a unique compact in the applications. This paper reviewed the developments in the designs of UHF-RFID tags proposed to solve interference problems, either by improving the antenna's readability range or designing the scalability of the widget. Moreover, this research presents an overview of major studies and discusses the features and results of each previous study proposal, including size and average reading distance. This information can be an inventory number of a product or package used for tracking applications. For future work, the research can be extended to classify and compare the proposed prototypes based on the read range and size.

## ACKNOWLEDGMENT

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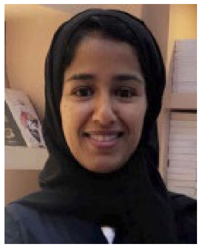

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