The Global Language of Business

Retail's RFID Evolution: Front-of-Store Applications

Jointly written by GS1 US and MIT Auto-ID Laboratory

Executive Summary

Retailers are under extreme pressure. There's intense competition from e-commerce, inflation, higher-wage demands, and labor shortages stemming from the Great Resignation. Inflation is at its highest in four decades, and the labor market is still 1.2 million jobs below where it was pre-pandemic. Retail earnings reports show that profits are down 30% from last year.[1]

Technology and automation can help relieve some of these pressures, and retailers have been looking at emerging trends, such as the Internet of Things (IoT), contactless interactions, and omni-channel fulfillment, as solutions to deploy. Larger companies, such as Amazon with their Amazon Go stores, are using shelf and cart sensors, machine vision, and artificial intelligence (AI) to detect user-product interactions, purchases, and changes in stock on shelves. Although these solutions can be effective, the technology is challenging to scale, and deployment costs can be up to $1M per store.[2] As a result, they pose a major barrier to entry for small and midsize companies. Retailers who fall behind in automation may have to pass the cost of inefficiency on to consumers and risk losing business to their larger, more technologically advanced competitors.

Radio Frequency Identification (RFID) technology has long been considered a promising solution—but it requires all items be tagged, and this has created a stop-and-go dynamic over the last decade. Recently, there has been renewed interest in using RFID in retail, including at the store's front end.

The technology has evolved considerably over the past 20 years—UHF passive RFID tag and reader costs have plummeted, read range has increased, reader and inventory accuracy has increased, infrastructure for connecting readers wirelessly has become ubiquitous, and both tags and readers are now available in a large number of sensitivities and form factors. This has unlocked the viability of long-awaited applications such as intelligent shelves, dynamic pricing displays, and store layout optimization.

Because many retailers already use RFID technology in their supply chain and back-end logistics, there is opportunity for those companies to extend RFID solutions to their front-end operations more easily and with less expense than they could with technologies like AI-powered computer vision. To that end, it is worth understanding the current state of the technology, as well as how retailers and the GS1 community could leverage one of their core technologies, with greater impact into the future.

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The Current State of RFID Technology

An RFID system consists of a reader, antennas, tags, and the physical space between them.

RFID Tagging Technology

Cost and read range are two of the most important attributes of RFID tags. Over the past 20 years, costs of RAIN RFID (passive UHF technology) tags have reduced from 75 cents per tag[3] to as low as four cents per tag[4] in bulk quantities. At the same time, RAIN RFID–tag read ranges have increased from an average of 10-12 feet in 2010 to 30 feet or higher today,[5] which can improve the ability to read inventory data across large areas and spaces where products and boxes may be high up on shelves or in unreachable spaces. The increase in read ranges also can improve the accuracy of the reader.

The versatility of tag form factors has also increased in the past decade. For instance, tags that can be deployed in metal or liquid-dense environments—such as pharmaceutical fridges or the refrigerated sections of grocery stores—without significant loss of performance are now available.[6] Tags with very small form factors of 1.25 square millimeters have also been developed.[7] Tamper proof tags,[8] embedded tags,[9] and tags that operate at multiple frequencies and use different protocols, such as UHF/Gen2v2 and HF/NFC, have also emerged.[10] The list presented here is not exhaustive but meant to be illustrative of the fact that tagging technology has been moving to address applications beyond simple labeling.

Finally, integrating sensing functionality into RAIN RFID-tag integrated circuits (ICs)[11] has also emerged as an area of focus in the industry in the past five years and has been used in applications such as tilt, impact,[12] and moisture sensing[13] in logistics and manufacturing. Some applications may need battery-assisted tags to improve transmission range of the tag or operate the sensor inside of the tag.

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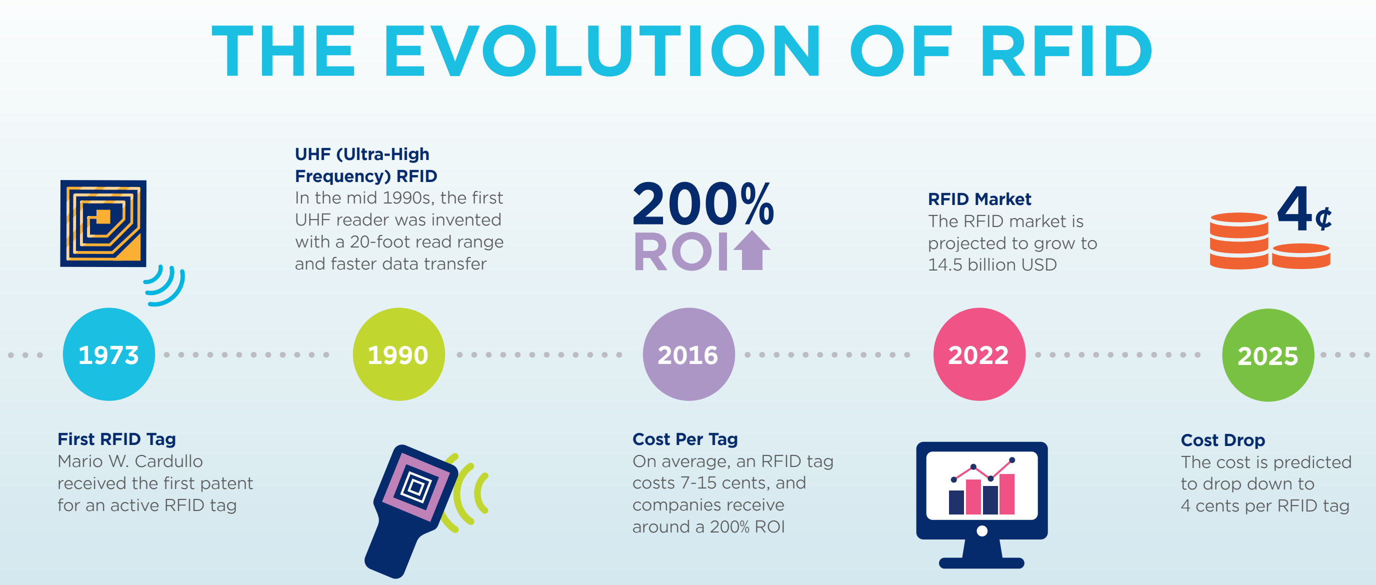

Figure 1: The Evolution of RFID

RFID-Reader Technology

RFID readers have also benefited from technological advancements of the past decade. Several noteworthy improvements are highlighted below.

First, reader transmit power is better optimized to account for losses in antenna cabling. This allows more power to reach the tag, improving read range without violating FCC regulations. Second, the processing power and on-board memory are also increasing, allowing for rapid switching between different antennas. This reduces missed reads and improves performance. Third, the emergence of gigabit ethernet allows the reader to handle and transfer a large amount of data without latency. Finally, sensitivity improvements enhance the correspondence between a reader and a tag. They also allow for improved read range for battery-assisted RFID tags and RFID tag sensors.

RAIN RFID reader costs have also decreased in the past decade without significant trade-offs in performance. It is possible to obtain enterprise-level readers in the $500 to $800 price range, which is at least 50% less than reader prices in the 2010s.[14] RFID readers have different form factors, such as fixed readers, portal readers, tunnel readers, overhead readers, mobile readers and readers compatible with mobile phones,[15] and wearable readers.[16] Many vendors offer reader module chipsets for customizing RFID readers in different form factors.[17]

Finally, several unique reader-antenna solutions have emerged. Systems that can capture RAIN RFID tags in a larger zone, such as a warehouse;[18] work on logistics units, such as forklifts; or detect the location of tags, whether in a corridor[19] or on a conveyor belt,[20] are now available. Specialized portals for monitoring dock doors[21] and precision race-timing antennas that can detect movement speeds of up to 135 miles per hour are also on the market today.[22] These examples show the broad range of applications in which RFID hardware solutions are being deployed in industry.

Improvement	Result
Transmit power optimized	Better read range
Processing power & on-board memory increased	Better performance
Gigabit ethernet emerged	Better data handling (no latency)
Reader sensitivity enhanced	Better read range

Air Interface Protocol and RFID Standards

RFID technology has also seen an evolution in standards and frequency allotments:

1. A GS1 initiative, EPCglobal®, innovated and developed industry-driven standards for the Electronic Product Code (EPC®) to support the use of RFID and allow global visibility of items in today's fast-moving, information-rich trading networks. Air interface and reader protocol standards were developed (and have been maintained), including the UHF Gen2 v1 and v2 protocol for RAIN RFID tags, Low Level Reader Protocol (LLRP) for readers. In addition, there are standards for capturing a context with the data from these reads with the EPC Information Services (EPCIS) standard. After EPCglobal completed its original mission, the RAIN RFID Alliance[23] was created in 2014; RAIN is an RFID industry consortium that works toward the adoption and use of Gen2 technology across end users. Similar to the NFC Forum and Wi-Fi Alliance, which are based on underlying standards such as ISO/IEC 18000-3 and IEEE 802.14.x, the aim was to promote the technology, to ease the use and adoption of the technology, and to envision a future in which RAIN RFID could be used as a key component in IoT.
2. The recent addition of the upper EU frequency bands allows for additional bandwidth for UHF RFID operations in Europe[24] and is indicative of the continued growth of RFID technology in an era of digitization.
3. The EPC UHF Gen2 Air Interface Protocol version 2 (Gen2v2) standard,[25] launched in 2014, addresses security issues, including anti-counterfeiting, improved chip memory organization, access control, and user privacy. These improvements have enhanced both the applicability and the trustability of RFID. For example, when a RAIN RFID reader reads a RAIN RFID tag, it prompts the tag to encrypt a message using a secret key. If the reader can decrypt the tag's data, it means the tag is genuine. This feature will help ensure that tags cannot easily or scalably be faked or spoofed.

The UHF Gen2v2 standard improved on the previous version of Gen2 with additional functionality and security, and in doing so has enabled solution providers to develop more-advanced products for end users.

GS1 formed the Modernisation of EPC Industry discussion group in 2021 for an enhancement of EPC encodings and the air interface protocol. The group's output will serve to optimize alignment between EPC encodings and barcoded GS1 element strings, with the goal of improved performance of EPC and RFID implementations, as well as increased cohesion across GS1's Identify and Capture layers.

One of the major objectives from this workgroup is to envision the next version of EPC UHF Gen2 Air Interface Protocol (a possible version 3, which might be referred to as Gen2v3).

The key objectives of this new version will be to:

- Improve air interface filtered inventorying to help focus on tags of interest
- Support sensor tags that can monitor the environment
- Improve inventory reliability and read rates
- Simplify yet generalize access to additional data stored in the User Memory bank of the tag

In addition, GS1's EPC Tag Data Standard (TDS), which defines the constructs of an EPC, also received a major update in the form of TDS 2.0. TDS specifies data that is carried on EPC-encoded RAIN RFID tags, including the GS1 identifier (EPC), User Memory data, control information, and tag manufacture information.

Relevant features in the update include:

- Introduction of new "EPC+" schemes to simplify encoding and decoding that improves barcode-RFID interoperability
- Optional encoding of automatic identification and data capture (AIDC) data after the EPC within EPC or unique item identifier (UII) memory bank

TDS 2.0 support for encoding of AIDC data in EPC/UII memory, as an alternative to User Memory, enables Gen2 Inventory backscatter of AIDC data, satisfying use-case requirements for optimized capture from RAIN RFID tags. Interoperability with barcode-encoded GS1 element strings and GS1 Digital Link URIs is boosted by not needing to know the length of the GS1 Company Prefix for new EPC+ encodings.

RFID in Retail: A Revisit

The technological advancements and the emerging challenges in retail have led to a resurgence of interest in RAIN RFID technology. In a 2021 survey, 80% of retailers had a positive view of RFID and have seen a substantial improvement in ROI, particularly in the last two years.[26] In fact, Walmart, one of the early adopters of RFID, recently announced that they will be mandating the use of RAIN RFID tags for items beyond apparel, such as home goods, sporting goods, electronics, vehicle tires, and toys.[27]

Interestingly, while RFID is well established as a tracking technology in back-end operations in stores, there has been growing interest in deploying it in front-end operations. The motivations are both increased productivity and enhanced customer experience.

There are two well-established models for 100% item tagging:

- RAIN RFID is being used by some retailers for speedy customer self-checkout. At Decathlon,[28] a major sporting goods retailer, this approach has raised revenues by 2.5%.[29] Chanel has been using tags on garments to give customers personalized recommendations and information nuggets about their potential purchases while they're in smart dressing rooms. Different radio frequency technology is also being discussed; for example, HF RFID applications could enable proximity-based dynamic pricing to entice customers to make a purchase while they are near a product.[30]
- Inditex has a different model, where anti-theft tags have RAIN RFID. When a product is sold, the anti-theft device is removed, and the attached RFID tag is read at that point. These tags are then recycled.[31]

Both models expand the value of RFID on the shop floor.

Low-Cost, Embedded Shelf Intelligence

As mentioned earlier, many automated retail applications make use of cameras and shelves enhanced with sensors. These solutions work well but are expensive and suffer from scalability problems.[32] It may be possible to reduce costs by expanding the use of RFID technology in smart shelving.

For example, RAIN RFID tags could be embedded in the shelves or placed on the walls behind the shelving. Figure 2 shows a UHF RFID enhanced pressure pad. Here the pressure pad can be calibrated to a controlled change in the signal properties (RSSI, frequency, phase, etc.) of the tag so that when an object is placed on the pad, the weight can be detected by a commercial off-the-shelf reader. The pressure pad could be integrated into the shelving and could be used to help detect events such as:

- **A customer interacting with an object:** A pressure pad could detect whether a customer picked up an object and how long they interacted with it. This could be used to provide directed context cues to camera systems and may be used to address the scalability and privacy issues associated with camera tracking today.
- **Misfiled items:** A sudden change in weight might suggest the empty slot from a recently purchased item was filled with an incompatible or wrongly filed item.
- **On-demand inventory visibility:** Empty slots on shelves could give store personnel a better view of where store inventory is missing. This would help reduce stock outs and better coordinate the movement of inventory between a store's front and back end, which is a key feature in an omni-channel retail environment.

Figure 2: RFID enhanced pressure pad for weight detection

Recently, researchers have been developing RAIN RFID tags enhanced with gas sensors that can detect chemicals such as volatile organic compounds,[33] ethylene,[34] and ammonia.[35]

Deploying these tag-based sensors on the shelves or walls near perishable foods (see Figure 3) could enable the detection of ripeness levels and spoilage. Additionally, TDS 2.0 allows for a simplified and easy capture of an expiry date encoded into RAIN RFID tags, which can also help reduce waste. Either of these methods could be used to discount items close to expiry and discard those past expiry.

The deployment of RFID sensor tags presents standardization opportunities as well. For example, right now, there is no defined way to infer whether a tag is a product tag, gas sensor tag, or pressure sensor tag based on EPC data capture.

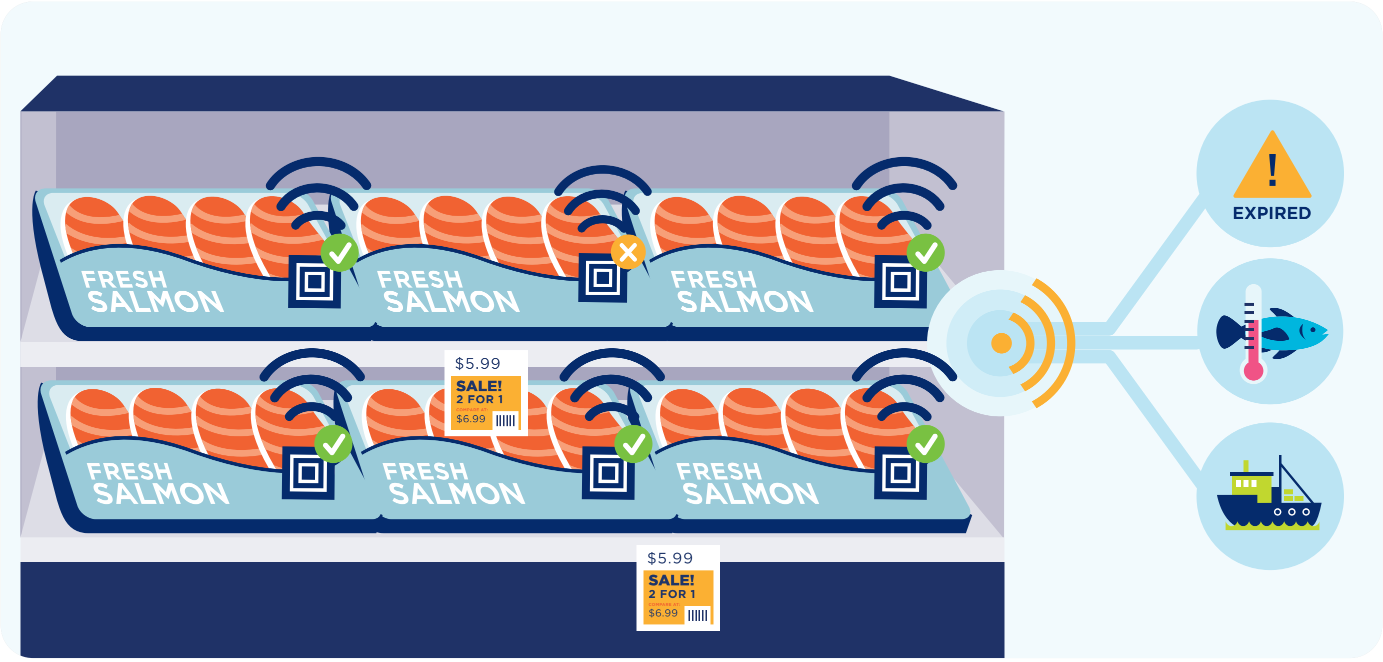

Figure 3: Detecting the presence of expired perishable foods using shelf-embedded RFID tag-based gas sensors

Figure 4: Example of digital price tag in a supermarket

Better Dynamic Pricing

There has been interest in using digital price labels in stores so that prices can be updated more easily for sales and promotions. Figure 4 shows an example. At the moment, there is no connection between the digital label and the item under or above it. There is a pressing opportunity to use data from the aforementioned RFID tag-based shelf sensors to enhance the utility of these digital labels.

For example, items that are seeing no interaction (based on RFID weight sensor data) could be progressively discounted over several days. Similarly, an interaction cue could trigger a short-time reduction in price to entice a customer to make a purchase.

Carts and shopping baskets fitted with RAIN RFID tags could track the flow of shoppers through a retail store that already has RFID readers deployed.

Store Layout Optimization

Carts and shopping baskets fitted with RAIN RFID tags could track the flow of shoppers through a retail store that already has RFID readers deployed (see Figure 5). This could be used to test different store layouts as well as understand likely areas where high-value items could be placed to maximize their chance of being noticed—and purchased—by customers.

These are just a few examples of applications that could be enabled by deploying RFID infrastructure in the store's front end. Since many retailers are already using the technology for store back-end operations, extending the infrastructure to the front end should not be as costly to set up as a fresh installation.

Furthermore, the same infrastructure enables multiple applications. For example, the same network of readers deployed throughout the stores to read shelf sensors could also be used to track shopping carts for layout optimization.

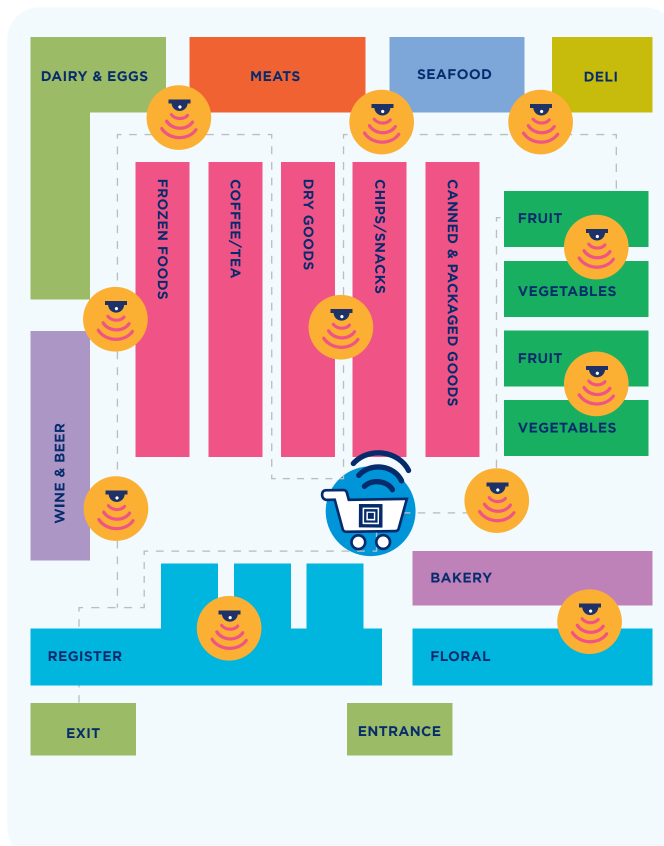

Figure 5: Store layout optimization based on understanding of traffic flow using RFID-tagged shopping carts

Automated Retail: Current Approaches and Challenges

For the past decade, brick-and-mortar stores have been losing revenue to digital commerce. This has been exacerbated in the last two years by the COVID-19 pandemic. In response, many retailers have looked to technology not only to improve the customer experience but also to improve productivity.

There are several areas of focus in automated retail. One example is frictionless commerce, where retailers use automation to overcome labor shortages and improve the customer experience, especially the checkout process.[36] Cashierless checkout is an area of rapid innovation within frictionless commerce that has more than 150 solution providers with a range of offerings.[37] Some solutions are as simple as assigning additional lanes for self-checkout, while others make use of sensors and AI to detect customer shopping interactions or even build a profile of a customer and use that to personalize the shopping experience.[38]

Omni-channel retail, and its impact on order fulfillment and inventory visibility, is another focus area. Different shopping techniques such as in-store, BOPIS (buy online, pick up in store), curbside delivery, and pickup service all tap into the store inventory, requiring better inventory visibility,[39] management, and forecasting data.[40] Dark stores and micro-fulfillment have also emerged as areas of development, with many solutions employing robotics and other automated picking solutions.[41, 42]

While technology has great potential to boost efficiency and customer experiences, there are many challenges to adoption. First, retail has small profit margins, and it is often difficult to justify the investment of those profits into new technology.[43] Technology deployment costs can be as high as $400 to $800 per square meter. As a result, mature technology deployment may be out of reach for all but the largest retailers.[44, 45]

There is disparity in revenue as a function of store size for small-size retailers vs. larger players like Amazon Go.[46] While cashierless checkout clearly generates more revenue, the large up-front setup costs can make it hard to justify the investment. Besides cost, customer profiling, facial recognition, and tracking can also have privacy implications that have not yet been adequately addressed.

In order to be able to compete, smaller retailers need to deploy cost-effective sensing and data-capture technologies to add value to their business processes without breaking the bank. One possibility is to reuse technologies that have already seen widespread adoption in retail, such as RFID or barcodes, in creative new ways.

RFID technology is reportedly used in supply chain logistics by 93% of North American retailers,[47] and this is especially true of retailers embracing omni-channel shopping experiences.[48] There is, therefore, a good opportunity to bring the benefits of this technology to the store front end with less additional setup cost.

If you are interested in discussing the use cases mentioned here or joining a proof of concept for future RFID work, please contact us at innovation@gs1us.org

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About MIT Auto-ID Laboratory

The MIT Auto-ID Laboratory traces its roots back to 1999 with the founding of the Auto-ID Center, which laid much of the groundwork for the standardization of RFID technologies, the introduction of the Electronic Product Code (EPC), and coining the term "Internet of Things." It continues to research RFID systems, applications, and extensions to RFID technologies, including RFID-based sensors.

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