

Printed Antennas for Combined RFID and 2D Barcodes

Steven J. Simske and Jason S. Aronoff, Hewlett-Packard Labs, 3404 E. Harmony Rd., MS 36, Fort Collins CO 80528, USA
Bobby Duncan, Hewlett-Packard Company, 2501 Technology Circle, Suite 15, Bentonville AR 72712, USA

Abstract

The adoption of RFID and Near Field Communication (NFC) Devices, while slower than the optimistic projections of several years back, is nevertheless relentless, to the effect that large retailers such as Wal-Mart are willing to place RFID labels costing roughly \$0.10 per package on products which retail for less than US \$7. The advantage of the RFID adoption is initially in inventory management (“just in time” stocking) and re-ordering, sales analytics, etc. However, by combining the printing of the RFID antenna with the printing of other consumer features, significant cost benefits can result. We have tested combining an RFID antenna with the printing of a 2D barcode, and demonstrated that we can replicate the 96-bit GSI SGTIN (Serialized Global Trade Item Number) information of the RFID chip in the 2D barcode, while using the reference (“L” shaped outline of two of the four sides of the 2D barcode) of the 2D barcode for the RFID antenna. Properly crafting the antenna can result in a significant increase in RFID reading range (up to 100X in our experiments), and the antenna can also be crafted to fit the form factor of the product tag. Our paper will discuss some of the implications this work has on hybrid (printing + sensors) smart labels and tags and their use in various retail, industrial, government and manufacturing workflows.

Introduction

One of the most important functions in any process is tracking. We keep track of our objects, our appointments, our links to others (friendships), our duties, our responsibilities, and our overall day-to-day, year-to-year schedules. All of these tasks have direct analogies in the supply chain and logistics areas:

- (1) Objects = Individually-tagged items
- (2) Appointments = Send/receive timestamps
- (3) Links = Inference
- (4) Duties = Regulations
- (5) Responsibilities = Logging, other regulations
- (6) Day-to-day = Tracking
- (7) Year-to-year = Provenance

While the analogies are not exact, they do serve to illustrate—and emphasize—the magnitude of track and trace and product logistics. Effectively used, track and trace and the system of services surrounding it provide—or integrate into—all product intelligence. This is highly important, because we are living at the onset of the “information age”—meaning real-time, relevant information at any time about any product is expected, even demanded, by all parties involved (manufacturer, distributor, retailer, and consumer).

With that in mind, the means to access track and trace information—and use it to point to other information of relevance—is of crucial importance. This is one reason why radio

frequency identification (RFID) technologies (Figure 1) are important—when no line-of-sight is available, RFID provides a means to access the track and tracing information associated with the product.

However, RFID adoption has been slower than anticipated worldwide. The world economic slowdown, the ubiquity of barcode readers and the associated massive adoption of 2D barcode tagging, and the seeming difficulty of integrating RFID systems into existing enterprise systems are factors in this. In addition, cost is certainly a prime factor for many products—and is of high importance to large retailers, for which cost sensitivity is always significant. Driving down the costs of RFID not only improves the adoption rate, but is also an advantage for sustainability—the lower cost RFID chips use less material.

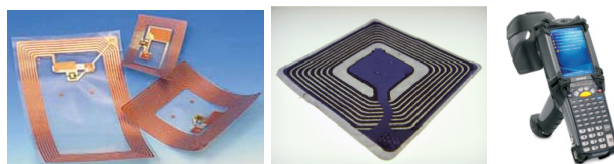


Figure 1. Sample RFID foil (left), label (center) and reader (right)

Manufacturing, distribution and retail industries (MDRI) benefit from lower cost RFID, however, if and only if the lower cost is tied to better—or at least equivalent—ease (and efficacy) of use. Since product identification is—and likely will be for some time—tied to printing, MDRI benefits from the seamless integration of printed marks at the point of sale (e.g. 1D barcodes), at the display (e.g. 2D barcodes) and on the cartons, pallets and shipping containers with the RFID chips used for point-to-point analytics such as track and trace. The relationship between these marks—from pallet to package—is called inference, and optimizing inference approaches is currently an important topic for research and development in supply chain management, visibility and analytics.

Integrating printing—used for product identification, consumer information, brand protection, security, point of sale, consumer/product interaction, and other purposes—with RFID provides a proof point for other next-generation printing applications, such as when printed batteries, sensors and electronics are combined with the visual aspects of the printing. A logical bridge between printing and RFID is printing some or the entire RFID sensor itself. The logical first target is the primary element of the RFID (by area and mass); namely, the antenna. Further integration of the RFID chip within the printing processes can then be provided by the inference model—which is the logical relationship between the data in the RFID, bar codes, etc., on the shipping containers, pallets, cartons and unitary items, as defined above. In general, inference requires advanced printing and

imaging (for inspection) and information technology (IT) infrastructure to coordinate information across all logical units of products. The track and trace requirement originally slated for 2009 by the California Board of Pharmacy was delayed until 2015 [1] in part on the basis of the argument that inference was too difficult to implement across the pharmaceutical supply chain. Inference is particularly problematic when re-packaging (typical for the pharma industry) or cross-docking (breaking pallets down and shipping the cartons or boxes within the pallets to different end destinations, which commonly occurs in retailer warehouses) occurs.

However, inference is a golden opportunity for combined printing, RFID and supply chain logistics provision. Inference—the high-value data that drives supply chain analytics—is agnostic to its implementation, and can be accomplished through any combination of printing, RFID and other possibly novel carrier technologies. The owner of the inference data, therefore, holds the key to connecting printing, RFID, logistics and production data.

In order to encourage and support inference, using printing to address some of the cost concerns with RFID is a logical starting point. We show in this paper how some of the cost of RFID can be reduced through printing.

Methods and Materials

In order to benefit both the large retailers and their myriad suppliers, we needed to use printing to reduce the costs of the other technologies—RFID and logistics—that are the downstream target. However, in accord with Clayton Christensen's advice on “disruptive” technologies [2], it is better to create a situation in which profitability was assured even during the first stage of the product. The opportunity identified was to use printing of RFID antenna to allow consumer packaged goods providers to consider purchasing only a single type of RFID—and one without large (quarter-wavelength) antenna—and thus to benefit from the incredible (approximately 8¢/RFID chip at the time we originally performed the analysis in 2009) savings concomitant to such a scale of purchasing (of a less expensive chip to manufacture). In order to provide this printing, we considered both variable data printing such as that provided by thermal inkjet (TIJ) printing and traditional antenna printing (flexo, gravure, offset, foil, etc.).

As a starting point, we initially attempted to drive conductive TIJ printing costs to a level competitive with foil (approximately 75¢/m²). These metallic effects use as little as one-sixth the silver (Ag) concentration of the high-conductivity formulation using for RFID antenna printing (with obvious implications on improved environmental and recycling concerns). Thus, conductive ink costs are \$4.50/m² or less. For apparel tags, in which the antenna are typically 10 cm x 0.5 cm (or 0.0005m² in area), the conductive ink costs therefore are estimated at 0.225¢/tag, well under the 8¢/tag cost differential opportunity. In fact, the cost of printing a 1.0 cm² variable, SGTIN-compliant variable 2D barcode with appropriate structural pre-compensation [3] with *the same conductive ink needed to create the RFID antennas* is at most an incremental 0.0225¢/tag, bringing the entire variable ink cost to 0.25¢/tag, which can provide direct integration of barcode based point-of-sale, customer/brand interaction and supply chain track and trace with the RFID supply chain track and trace. In addition, this approach helps bring important aspects of RFID printing to a digital printing world—allowing options for customized short or

even medium runs—as opposed to flexo, gravure, offset, foil finishing, etc.

Results

The development of the conductive ink has progressed over the past four years, with the team in HP Labs working with third party providers such as Methode [4] to optimize the ink and finishing characteristics. We used the same ink chemistry approach for the metallic (lower conductivity) ink development, affording the opportunity for independent focus on two different product aspects (reflective properties and conductivity). We have tested the ability of the 0.0005m² antenna to improve the reading distance of several near-field RFID chips (originally produced by removing the original external antennae with a Exacto knife) using the Motorola MC9190 Mobile Computer [5]. We have readily increased the read rate by a factor of 25 (e.g. from less than 7.5cm to more than 240cm).

Next, we considered the simultaneous printing of a 2D barcode and a RFID antenna. Our tests have shown that 2D DataMatrix [6] and Aztec [7] bar code symbologies are robust to overprinting with RFID antenna loops – that is, even when overprinting with conductive ink traces up to 30% as thick as the individual bar code modules such as shown in Figure 2. These “loop” antennae can be used to enhance the amount of flux available to an RFID or related—e.g. Near Field Communication [8]—device (please see [9] for a good overview of the physics involved).

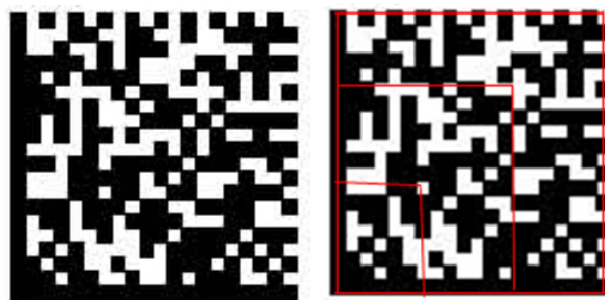


Figure 2. Example of loop antenna (left)

Extending the RFID antenna printing to a specific product segment, we considered apparel tags. Here, the RFID antennae can simply be an extension of the calibrating indicia – that is, the elements of the bar code that are non variable and are used to identify the bar code type, calibrate the bar code image for contrast, skew and other affine distortions, warp and other non-affine distortions, etc. One such test print is shown in Figure 3 (see right image), where the RFID antenna traces are shown in red (mid-level gray to color challenged readers or if your copy of this paper does not have color). The improved readability of near-field RFID chips using the antennae was validated by Wal-Mart's physicist and Senior Systems Engineer, Bruce Wilkinson, who remarked that the samples were useful in building an apparel tag. “The apparel hang tag I built using one antenna that you sent and the [RFID chip provider] tag performed as [well] as either the [of two commercially available] tags.”[10]



Figure 3. Example of apparel antenna (right)

The combined 2D bar code and RFID antenna printing can be implemented in one of several ways:

- (1) Two distinct inks, both the same (or visibly the same, at least) color, are used for the conductive antenna (the red in Figure 3, right) portion and the non-conductive bar code data portion.
- (2) The same pre-conductive ink is used to print the entire 2D bar code, and only the parts to be used for the antenna are activated. Activation approaches include heating, UV annealing and laser annealing.
- (3) The entire 2D bar code is printed in conductive ink (or pre-conductive, with the entire barcode being activated) and thin breaks are made to isolate the antenna portion from the data portion.

Of these approaches, (1) is the preferred method, if possible. However, it involves the printing of two different inks, which might require two passes with excellent registration between passes. Method (2) offers the advantage of using a single ink, but requires an activation step – with good registration at that. Method (3) offers a solution with a single ink and a single, broad activation. However, registration is still required for “breaking” the conductivity between the antenna and data portions of the 2D bar code.

However, there is an option that involves a single ink and no registration. In this approach, we print the entire 2D bar code with conductive or pre-conductive and subsequently activated ink. We slightly undersize the black (ink) tiles so that there are “open circuits” at the corners. This variant of (2) and (3) above greatly reduces the “eddy induction” that would otherwise decrease the efficiency of the antenna. A related option is to simply print the bar code with a whitespace “break” between the antenna and data portions. However, one must take care that the resulting “broken” bar code is still readable.

Discussion and Conclusions

This results presented above provide validation of the overall approach. More importantly, however, it is validation of the value, or utility, of the approach. Large retailers, who must always be sensitive to cost, have carefully considered where to begin investigation of the use of conductive inks. The apparel industry faces shrinkage—meaning loss of inventory due to theft—as a large and growing problem. Providing item-level RFID can be used to simultaneously manage stock and reduce shrinkage – provided the tag cannot be easily removed from the

product/packaging before the customer walks out the door with it! As a consequence, the apparel industry is interested in the adoption of GTIN (global traceability identification number) data, a standard maintained by GS1 (which includes the former EPCglobal, or “electronic product code” global), as part of its standards portfolio [11]. GS1-compliant barcodes and RFID tags enable the standardized writing and reading of GS1 identification keys and other data for products and associated documents, independent of the manufacturer or shipper. An EPC identifier can thus be written in the form of a DataMatrix (or other 2D barcode) or in the form of a radio frequency tag.

There are many track and trace systems, including the 18-digit SSCC (Serial Shipping Container Code), as described in [12]. EPCglobal has ratified the EPC Network standards which codify the syntax and semantics for supply chain events and the secure method for selectively sharing supply chain events with trading partners. The specific data encoding that goes on the tag is defined by EPCglobal, and the corresponding EPCIS specification [13] defines how to capture all this item level information, how to store it in a repository, and then how to share it with trading partners.

Current approaches include the use of an RFID-only track and trace solution, in which different RFID chip/antenna combinations are used based on the product form factor, cost, and level in the inference model. The mean cost of an RFID chip under these circumstances is, according to our 2009 data, 8¢/chip higher than the cost if only a single, near-field only (no appreciable length of antenna attached) RFID chip is sourced *en masse*. Another approach is to provide an overall provenance model involving non-variable (flexo, gravure, offset, etc.) printing of the antennae along with RFID as in our variable-data printing solution. Based on the current estimated cost of the TIJ ink, however, we believe that the additional benefits of variable data printing (e.g. GTIN-compliance and inference at item level where RFID is not required, cost-effective and/or feasible) significantly improve the “break even” run size for which digital printing is at least as cost effective as traditional printing.

Regardless, we have formulated an initial cost model that suggests the 8¢/chip cost opportunity is more than sufficient to result in a profitable, positive path forward for the print service provider, brand owner and RFID provider with a single industry, the apparel industry, as the target. At bulk costs, the RFID chip provider and the print service provider can both make margin off the sales of the RFID chips directly into the multi-billion tags/year apparel business. The overall model estimates printing costs as 50% of the 8¢/tag differential, for which the ink costs are less than 20%. The additional printing costs depend on the conductive/pre-conductive ink used. Simply speaking, the integrated printing, RFID and supply chain services (such as track and trace and ePedigree—and downstream authentication, analytics and other data-driven services) are the driver for the potentially even larger business of data analytics and services that come from hosting the data associated with these suppliers.

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Author Biography

Steve Simske is an HP Fellow and the Director and Chief Technologist of the Document Lifecycle & Security Printing & Imaging portfolio in Hewlett-Packard Labs. Steve is currently on the IS&T Board. He is also an IS&T Fellow and a member of the World Economic Forum's Global Agenda Council on Illicit Trade. He holds more than 40 US patents and has more than 250 peer-reviewed publications. He holds advanced degrees in Biomedical, Electrical and Aerospace Engineering.