The Gen 2 Story:
Charting the Path to *RFID that Just Works*™

The recently ratified EPCglobal™ Gen 2 RFID standard—the new state of the art in supply chain technology—has raised the bar for competitive RFID systems worldwide. Unfolding in tandem with recent well-publicized retailer and DoD mandates, it would seem that the timing of the new standard couldn't be more opportune. But like the promise of a great western frontier, getting there might require the crossing of a few uncharted mountains and deserts… easy, but only if you have the right guide.

While the theory behind practical, widespread RFID deployment is sound enough—perhaps even proven—one would still do well to regard the words of Yogi Berra: "In theory, there's no difference between theory and practice. In practice there is." Impinj's Dr. Chris Diorio, a significant contributor to the Gen 2 spec development effort, agrees. "A spec is a *framework* on which you build a solution, not a solution in and of itself. Even though the Gen 2 spec represents a huge technological advancement compared with current Gen 1 RFID systems, and offers a solid foundation upon which to build an RFID system, fielding a working Gen 2 system is still a big step beyond the spec."

Deployment hurdles notwithstanding, Gen 2 offers a worldwide standard for RFID systems operating in the UHF band. A remarkable achievement, it was crafted with the cooperation of more than forty participating companies and driven by a shared vision of cross-vendor compatibility, worldwide interoperability, and significant improvements in performance, cost, and reliability over predecessor UHF protocols. Furthermore, it offers a roadmap that extends well into future generations, as future UHF standards will be built upon the Gen 2 foundation. All of which tills the ground for fertile investment in a technology that will redefine a critical element of commerce: the supply chain. The specification is so widely endorsed that it is now under the wing of the venerable ISO organization, where it is slated for early 2006 ratification as ISO 18000-6C.

So what's it all about?

Standards are wonderful; there are so many to choose from!

Presently deployed Gen 1 UHF RFID systems are based on a number of competing protocols, most notably Matric's Class 0 and Alien Technology's Class 1. The problem? The current incarnations of these protocols are proprietary. Beyond that, they lack the features, reliability, and horsepower to adequately serve a growing number of applications—particularly when taking worldwide operability into account. And because they're not upgradeable, their shortcomings, in many cases, mean that they have already hit the wall.

MIT's Auto-ID Center recognized the problems of these proprietary RFID standards early on. More importantly, they also recognized that provincial protocols would impede the development and large-scale deployment of RFID technology. Their solution? A single open standard that 1) would create an environment of interoperability and international regulatory compliance, and 2) would raise the bar on RFID system performance in a significant way. These two values formed the backbone of what they proposed as the next generation of UHF RFID—the precursor to the Gen 2 standard. With a single worldwide specification in place, UHF RFID-based systems would become faster, easier to use and less costly to field, more robust, and provide a multi-supplier path going forward.

The Auto-ID Center "kicked-off" the Gen 2 effort in June of 2003, at a seminal meeting in Zurich, Switzerland. They would eventually transfer the responsibility for development and commercialization of the evolving standard to EPCglobal™, who, in December of 2004, finally ratified the standard as "Generation-2 UHF RFID Protocol for Communications at 860 MHz – 960 MHz." Or more simply, Gen 2.

At the center of this activity was UW Professor Chris Diorio. Working with the renowned Dr. Carver Mead—the father of digital VLSI—Diorio had previously developed a low-power nonvolatile memory (NVM) technology that would make possible long-range, field-rewritable RFID tags. This work caught the attention of MIT Professor Sanjay Sarma, the Auto-ID Center's Chairman of Research, and in turn led Diorio to join the Auto-ID Center. With Dr. Diorio's background in communications, semiconductors, and standards work, he was soon appointed co-chairman of the Hardware Action Group and project editor for the Gen 2 specification, roles that would continue with Auto-ID's technology transfer to EPCglobal™.

Diorio, who with Mead had founded Impinj, Inc., became a point man in the effort to develop the Gen 2 specification, with Impinj performing much of the systems engineering and analysis to prove the essential technological elements.

In the early stages, Gen 2 faced significant resistance, as it became apparent that it would obsolete all of the existing UHF RFID standards. But Diorio, the end users, and dozens of technology companies persevered, convinced that Gen 2 held the greatest promise for proliferating UHF RFID. Says Diorio, “Gen 2 is the first worldwide RFID standard that's backed not only by the technology providers, but by the end users as well.” In time, the momentum behind Gen 2 made it unstoppable, and all parties (including those who were initially opposed to the effort) joined in the final push to the goal line. And Gen 2 was born.

Twelve Ways Gen 2 has Redefined RFID

The spirit of innovation that led to 802.11 wireless radios, and to cellular phones, is very much in evidence throughout the pages of the Gen 2 specification, the objective of which was to bring harmony out of the cacophony of competing and otherwise incompatible standards. With that in mind, consider the following twelve key qualities that position Gen 2 at RFID's center stage:

1. Superior Tag Population Management

The protocol in a nutshell.

If the Gen 2 development effort had a mission statement, its cornerstone would have been the efficient and accurate management of RFID tag populations. To that end, Gen 2 defines the interactions between readers and tags over a robust air interface with three primary command-driven procedures: *Select, Inventory,* and *Access.* Let's take a closer look.

Select – Prior to conducting an inventory, a user may wish to first conditionally isolate only those tags that exhibit, say, a particular date code, manufacturer code, or other variable of interest. By targeting *only* that segment of the tag EPC memory that contains those particular kinds of descriptive bits, the reader can quickly narrow down the field, making for a more efficient inventory operation. The *Select* command offers a quick sorting of the tag population, where the reader (using union, intersection, and negation operators on a set of user-defined selection criteria) chooses a subpopulation of the tags within its field.

Inventory – The *Inventory* operation—the real workhorse of the Gen 2 protocol—identifies tags, one at a time, resolving conflicts among tag responses, and sets an appropriate "inventoried" flag within each of the tags as they're counted.

Access – Available only following an *Inventory* operation, *Access* involves more than simply sorting and counting tags; *Access* commands allow the reader to write individual tag memory fields directly (with EPC and/or password data), set the desired memory lock bits, or kill the tag.

2. Robust Signaling Protocol

A vastly more reliable RF link protocol, Gen 2 slays a Gen 1 nemesis, ghost reads.

Consider the way a Gen 2 reader uniquely identifies a single tag within a population. When a reader issues a *Query* command, the tag must respond within an extremely narrow window—just 4-millionths of a second wide. If the tag does not respond within that timeframe, the reader assumes that no tag is present, and issues another *Query* command. The reader continues to poll in this manner until it receives a valid response. This tight window represents the first hurdle in a series of "communication qualifiers" designed to eliminate false triggering on noise and other spurious emissions. When a tag does respond, it does so with a *preamble*—a distinctive waveform that the reader is able to reliably discern and identify, even in noisy environments. If the reader does not recognize the preamble as the leading part of the tag's response, it is ignored.

As data begins to flow from tag to reader in the form of well-defined symbols, memory retained in the waveform is used to identify bad sequences, or alternatively, to make decisions on ambiguous bits and fix them. Diorio illustrates with an example. "If you were to hear the phrase, 'a stitch in time saves *pine*,' you would know that, based on the history of that set of words, that it should read, 'a stitch in time saves *nine*.' In the same way, through the signaling scheme described in Gen 2, information contained in sequential symbols allows the reader to correct errors as it goes along."

Once the transmission is complete, the reader reviews the waveform and checks the PC (Protocol Control) bits at the top of the transmission, used to compare the number of bits it received with the number of bits the tag says it sent. If the two numbers match, then the reader can be fairly confident of a valid transmission. But not so fast. The reader then compares the CRC (cyclic redundancy check) at the end of the transmission and verifies its integrity. Only then is the reader satisfied that it has read a valid EPC.

Says Diorio, "True Gen 2 readers, implementing these checks properly, will have an astronomically low probability of seeing ghost reads. In fact, with a properly implemented Gen 2 system, end users should simply not tolerate ghost reads."

3. Dense-Reader Operation

Can you hear me now?

Any truly practical vision of RFID deployment will require the fielding of many readers, all of which might be operating simultaneously, blasting away at full volume, and in fairly close proximity to one another. Faint-voiced tags will have little, if any, hope of being heard above such a din; the noise and interference resulting from of all that shouting will surely bury them. Unless they're Gen 2 tags.

Gen 2 gets around the problem of "dense" readers by isolating tags and readers through a frequency channelization scheme, best illustrated by analogy:

Think of the UHF spectrum as a highway, where readers are semi trucks, and tags are bicycles. Dense-reader spectral planning effectively divides the UHF frequency band—the highway—into multiple lanes. Trucks are allowed to use certain lanes, while bicycles are permitted to use other lanes. In any case, trucks and bicycles do not *share* lanes. Furthermore, trucks are required to remain within the boundaries of their respective lanes, as sideswiping or drifting into the bicycle lanes would prove disastrous (particularly for the bicycles!). In similar manner, if a reader's signal (which is many orders of magnitude greater than that of the tags) were to leak into adjacent tag lanes, it would mask the tags' low-power transmissions, burying them in RF noise, and preventing other readers from seeing them at all. By restricting reader transmissions to occur within strictly delineated lanes (or channels), tags can be heard clearly, even though as many as 50 active readers might be operating simultaneously in 50 available channels.

The fact is there is a limited amount of spectrum allocated for UHF RFID (this is particularly true in Europe). A Gen 2 system incorporating *only* dense-reader capable readers is best able to exploit that space efficiently, and it does so to great effect.

4. Cover-Coding of the Forward Link

Masking information transmitted from the reader to the tag prevents unwelcome snooping.

Maintaining a secure link between reader and tag is essential to safeguard data transmitted over an air interface. It's especially critical in the reader-to-tag direction, because reader transmissions occur at substantially higher power levels than those of the tags, who effectively whisper their responses back to readers. Here's how Gen 2 goes about the enciphering:

The reader requests a random number from the tag. The reader then mixes that random number with its data before transmitting the result to the tag. The tag decodes the mixing (reversing the operation) and extracts the original information. A simple scheme, but it effectively protects both data and password transactions by obscuring data transmissions in a purely random manner.

5. A 32-bit Kill Password

Unauthorized kills are dead in the water.

Incorporated to address privacy concerns, the kill command permanently disables a tag from talking back to a reader, rendering it useless. The ability to kill a tag, though, exposes the network to the possibility of unauthorized kills. To thwart such mischief, a password protection scheme was adopted. In earlier UHF RFID versions, though, it didn't amount to much. Class 1's 8-bit kill password, for example, left it exposed to only 256 possibilities—hardly a password at all. While Class 0 improved things significantly with a 24-bit password, Gen 2 raised the hacker's bar to 32 bits—more than 4,000,000,000 possibilities.

6. Sessions Dramatically Boost Productivity

RFID tag to multiple readers: "Take a number"

Capitalizing on the enabling power of the dense-reader mode, Gen 2 also introduces the concept of *sessions*, where as many as four different readers may access the same population of tags through a time-interleaved process. That's an extremely useful capability. Consider the case where a shelf-mounted reader in the midst of a counting operation (assigned to, say, session 1), is interrupted by another reader entering the field—possibly a handheld reader—to perform its own inventory operation (in session 2, perhaps). Dock door and forklift readers, assigned to sessions 3 and 4 respectively, might also jump in for a round. Because Gen 2 tags maintain a separate "inventoried" flag to keep track of each of these various random and independent sessions, they're able to seamlessly resume their participation in the previous (pre-interruption) inventory round, picking up right where they left off, and never miss a beat.

7. Significantly Faster Singulation Rates

Tag, you're it.

Readers and their associated tag populations have a lot of business to transact. At least one throughput-gating parameter is the effective data rate, which also determines the time it takes to singulate, or identify, a single tag within a population. Typical Gen 1 data rates run from 55 to 80 kbps. Pretty fast. Gen 2, though, provides for data rates as high as 640 kbps (a throughput of 1600 tags per second). That's on the order of a ten-fold performance improvement over Gen 1.

8. Variable Read Rates

Faster is better—sometimes.

The rate of data flow between reader and tag is governed by a number of factors: environmental conditions (including noise level and physical structures), region of operation, the number of active readers in the area, and even the speed of tagged materials moving through the distribution center. A very adaptable system, Gen 2 allows the fine-tuning of the RFID network—including the varying of data rates—to optimize performance across all possible combinations of operating conditions. Whether the need is for fast reads of pallets moving through a dock door, or slower reads in a noisy environment of dense readers, Gen 2 is able to flex.

9. Greater Configuration Control

Flexible communications formats allow the tailoring of the Gen 2 system to its specific operating environment.

The modulation and data encoding schemes of choice, like the selection of data rates, also depend on a set of environmental considerations. As such, Gen 2 provides options in both reader-to-tag link and tag-to-reader link directions, allowing performance calibration of the Gen 2 system to the demands of its operating environment. Gen 1 systems, on the other hand, are limited to a fixed communication format, where one size may not necessarily fit all.

10. Worldwide Operation

Gen 2 RFID plays on the world stage.

Both Gen 1 and Gen 2 systems cover the 860 to 960 MHz operational band—the superset of international frequencies—but the way the two standards deal with that spectrum is worlds apart. As far as Europe is concerned, Gen 1 doesn't deal with it very well. Compared with North America's fairly wide frequency allocation of 902 to 928 MHz, Europe's is pretty slim—just 865 to 868 MHz. As such, European RFID deployments tolerate much less interference, and require much tighter spectral control than Gen 1 systems can deliver. Gen 2, on the other hand, takes the European standards fully into account; it works well in North America, Japan, Europe, and elsewhere, making Gen 2 a truly international standard, hence its strong advocacy within ISO.

11. Improved Manufacturability

Better, faster, smaller, cheaper.

Gen 2 tag IC design lends itself well to very large scale integration. The new standard exhibits a greater emphasis on digital logic; as Moore's law continues to shrink fabrication geometries, Gen 2 tags will get ever smaller still.

12. The 12th Man

The whole is greater than the sum of the parts.

While each of the foregoing features represents a significant performance improvement over Gen 1 offerings, when taken together, they leverage much more. Further, as Gen 2 systems are fielded, it will become apparent that perhaps the greatest lever of all is the communications systems engineering expertise behind the specific implementations. This is where the Gen 2 standard is forged into proven elements that comprise a working system solution.

Standard, but Viva la Difference

The ability to deliver standards-compliant products is only half the story. Says Impinj's Dr. Chris Diorio, "Anyone can meet a spec. Both economy cars and Formula-1 race cars are drivable, but in terms of performance, as everybody knows, there's no contest." And therein lies to the key to Impinj's continued RFID market leadership.

"Being required to meet a standard," Diorio continues, "says nothing about performance. While meeting the letter of the standard, Impinj tags have demonstrably greater range, lower power consumption, superior noise rejection, and are more reliable in the field as compared to competing products. In other words, they're more likely to be read, and be read well. But beyond those sorts of parameters, there's the bigger question of how well you can engineer a working RFID *system*—a system comprising all the essential Gen 2 elements that work together in a seamless manner. And that includes tag silicon, antennas, inlays, labels, readers, and software."

To that end, Impinj has rolled out its GrandPrix™ Solution, a fully integrated, high-performance Gen 2 architecture. By virtue of Impinj's communications systems engineering expertise—to say nothing of its leadership position within the organization that crafted the standard—it seems only natural that Impinj would also be first to market with Gen 2-certified products.

"We did our homework," says Diorio. "We have an exceptional understanding of how Gen 2 works, and now we're making it work in the field for end users. The bottom line is, if it's Impinj GrandPrix™, it's RFID that just works. Plug it in, turn it on… it just works."

Reading is Fundamental

If there is anything that Chris Diorio laments with regard to the Gen 2 specification, it is the allowance for non-dense-reader capable readers. "The original intent," says Diorio, "was for the fielding of only dense-reader mode capable readers. We felt that the spectral purity forced by the dense-reader mode was essential for optimal system performance and integrity. But we encountered objections from reader vendors who were already fielding product that couldn't meet the dense-reader requirement. So we compromised by specifying separate reader classes to cover the three typical environments: dense-, multiple-, and single-reader."

Furthermore, while tags are required to support all mandatory Gen 2 features, readers have only to support a sufficient subset of the standard to singulate conformant tags. "As a result," adds Diorio, "readers can be very simplistic and actually *not* implement many features of the Gen 2 standard—and still theoretically be Gen 2-certified. For people planning Gen 2 deployments, this is an important distinction."

Diorio further notes that legacy readers that have been upgraded to support the minimum set of Gen 2 features could prove problematic. "If you've got an environment full of dense readers," he explains, "and you introduce just one single-environment reader, it can ruin everybody's day. So getting past legacy readers that implement some Gen 2 features, but really don't perform any better than the old readers, is probably one of the industry's biggest hurdles."

Impinj's response to the issue is the development of its Speedway™ multi-protocol reader platform. A key element of the Impinj GrandPrix™ Solution, the reader was designed from the ground up to support the Gen 2 standard in its entirety, while also providing backward compatibility to the legacy standards. Says Diorio, "Speedway™ implements the dense-reader modes, supports the 640 kbps tag backscatter data rate—the highest rate specified by the Gen 2 standard, and it contains all the hooks required to solve the ghost-read problem. With Speedway™, we've created a reader reference design that exploits the full power of the Gen 2 standard, and all the integrity that that brings to RFID deployed in the field. It is far and away the best-performing reader platform available, and we anticipate that end users who adopt it will experience the capabilities and strengths of a Gen 2 system."

Getting Onboard

If you don't know where you're going, you might end up somewhere else.

Whether you're investigating RFID systems by choice or by mandate, the first step in the process is education. Says Impinj's Chris Diorio, "Getting educated on the benefits of RFID, the risks of RFID, as well as the ROI considerations, is absolutely vital. And it's essential to work with vendors that guarantee delivery of credible, field-proven Gen 2 products. Working with Impinj-certified partners will make all the difference. Impinj's GrandPrix™ Solution is the best way to get there. In fact, our motto at Impinj is, 'RFID that just works.' As an end user, that's what you've got to demand from your suppliers."