RFID: An evolution of change, from World War II to the consumer marketplace

William Lumpkins

CAPTAIN AMERICA INFINITY FIGURE COURTESY OF DISNEY

An older technology that was first used during World War II for various communication protocols became what we now call radio frequency identification (RFID), which has become deployed almost worldwide now to track valuables and personal assets as well as for safety reasons. Bob Violino writing for the *RFID Journal* notes:

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Mario W. Cardullo claims to have received the first U.S. patent for an active RFID tag with rewritable memory on January 23, 1973. That same year Charles Walton, a California entrepreneur, received a patent for a passive transponder used to unlock a door without a key. A card with an embedded transponder communicated a signal to a reader near the door. When the reader detected a valid identity number stored within the RFID tag, the reader unlocked the door. Walton licensed the technology to Schlage, a lock maker, and other companies.

The hotel industry embraced RFID slowly at first, and now it has become the standard.

What is RFID?

RFID is remote/self-powered asset tracking technology (see Fig. 1). It uses an antenna with an F_{co} of the resonance field that generates a charge to a microprocessor that sends encrypted bits of data back and forth to the reader or field generator. The microprocessor, antenna, and encryption protocol are called an RFID tag. This is used to monitor important assets like shipping containers, high-value items that are prone to theft, even vehicles. The great thing is that this technology uses radio frequency waves like frequency modulated (FM) radio waves, similar to what you would listen to on your car radio. As such, they travel invisibly through glass and the air, though they have trouble penetrating thick clothing or walls. The number one use of RFID tags in North America is as toll tags for vehicles—cars do not need to stop at a toll booth but just pass through and their accounts are debited directly.

RFID tags are easy to hide. They can be inserted into software game packages and book bindings, printed on boxes, and in some very

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advanced applications even embedded in clothing, though the cost factor tends to be prohibitively high. As you may know, most of the latest credit cards and loyalty cards have embedded RFID technology like Apple Pay, Google Pay, American Express, and some very new Visa/MasterCards, as most RFID tags get their power from the RFID field generators or readers, they do not need batteries. With no parts to wear out, they can transmit secure asset location information virtually indefinitely.

As an added benefit, RFID readers can be hidden, and there are various plans at a multitude of retailers to embed them in floors, doorways, ceiling tiles, and store shelves. The biggest issue is the cost of the readers or field generators, which is why they tend to be limited to handheld readers or at store entrance/exits. The RFID tag can cost as little as US$0.05 in multimillion units of volume, but the readers tend to cost about US$800 for a handheld and just over US$2,000 for a store entrance unit. Retail logistics departments try to justify the costs with the reduction in overall theft and the time savings of allowing sales associates to quickly check inventory by waving the reader in an aisle versus checking every single item individually.

The largest expense is the back office software needed to track all of the RFID asset tags and how it incorporates into the inventory management software. These systems tend to be made by companies like SAP and cost in the range of US$300,000–$500,000. Marketing departments would love to develop software for tracking the movement of the product once it leaves the store, but there is no way to do so, as most RFID tags use a proprietary encryption protocol and different readers cannot read them. I could envision a future when all RFID tags use a similar system but, though I like the fantasy of intercorporate cooperation, that is not likely to happen any time soon. That is why there is a current industry push for another old idea made into a new marketing buzz word, the *Internet of Things*, the premise being that more and more items will be able to connect to the Internet and the "cloud" for ultimate connectivity with enhanced security and enable us to find lost children, ensure that thieves to not abscond with our property, and make our lives easier and safer.

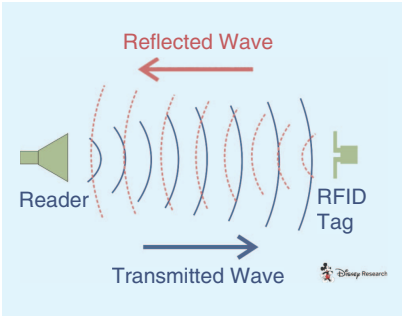

FIG1 An RFID block diagram. (Image courtesy of Disney Research.)

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Get in the game

Activision was the first large-scale gaming company to include RFID in its game. Activision created a virtual ecosystem, or story, for *Skylanders* (Fig. 2) by investing in cartoons for children on Saturday mornings as well as a massive ad campaign in multiple children's magazines and gaming outlets. Through these activities Activision's Skylanders has surpassed US$2 billion in lifetime sales as of January 2015.

The *Skylanders* figurine has an embedded RFID chip in the base, which is placed on a "glowing" RFID reader called the "Portal of Power" (Fig. 3). The figure then shows up in the game world of the *Skylanders* program. Players use game controllers to direct the in-game character on many adventures, as they pass certain levels or acquire in-game wealth, the information is stored in the figure via the Portal of Power (RFID reader). This allows the player to take his/her figure and visit a friend who has the game and join in. This creates a sense of rivalry between the friends in which they want the same figures and work to increase the advancement levels of each character. As different figures enter the gaming world, specialty quests become activated, which enhances game play by encouraging players to play together. This keeps a sense of social interaction alive in a time when game systems are criticized for the lack of activity for young players.

FIG2 *Skylanders*. (Image courtesy of Activision Inc.)

Disney saw how much money Activision was making with its RFID-based gaming and, as it had just completed a major overhaul putting RFID tracking systems into all of its amusement parks, it decided it was time to move into the active gaming

space with *Disney Infinity* (Fig. 4). Utilizing the same RFID supplier, NXP, as it used in its amusement franchise, it was able to integrate the NXP RFID chip into the base of the *Disney Infinity*, oddly just like Activision's *Skylanders*. But Disney decided it didn't just want to copy the *Skylanders* experience but expand upon it, and thus it incorporated elements of other popular gaming systems like *Minecraft* (originally created by Markus Persson) and *LEGO Online*.

This allowed Disney to leverage the successes of three popular gaming experiences into its "Toy Box." The Toy Box concept from Disney allows the player to create a unique universe by purchasing in-game content and turning on special features when different Disney figures enter the *Infinity* universe. Disney realized that in-game purchases only really target users with parents who are not paying attention to their children's use of their online account or older players who have the disposable cash to fund their fantasy creation, thus the *Disney Infinity* power disc was born. This disc sits under the figurine and allows new content to be added. Depending on the figure, special combinations can unlock unique content.

The *Disney Infinity* system is unique in that it does not need to create a storyline like Activision did with Skylanders, as it already has hundreds of storylines, from its franchises including Mickey Mouse, *Pirates of the Caribbean*, and *The Incredibles*, as well as a slew of Marvel superheroes including Spider-Man. In the two years of gaming operation, it has surpassed US$2 billion in sales as well as boosted its movie rentals and purchases. As the children play with the figures in the gaming world, they ask their parents to re-watch the stories that they are playing, and the money keeps printing itself for Disney.

FIG3 *Skylanders*' Portal of Power. (Photo courtesy of O & S Services LLC.)

Mobile payment systems

The exchanging of goods for a recognized symbol of value called currency has occurred on our planet for tens of thousands of years. The concept has stayed the same: an object represents a set value that is exchanged for goods and services. The object is then reused for other goods and services, the object's value is designated at the local or international level by a group of individuals who set the value through a complex mix of value or trust factors. At one point in time precious metals were used, like gold and silver, then we progressed to paper money (specialized paper notes issued by a regulatory body) and then checks (paper notes that referenced a local bank) or credit cards (plastic cards with identifiers that represent banks or credit-issuing institutions and the individual borrower of the credit). The inherent problem still existed that if the paper money, checks, or credit card were lost, stolen, or copied that individuals would lose the value or net worth of their economic buying power. Multiple ideas have been pursued to strengthen the security of exchanging of these trust-based tokens of material wealth.

RFID has been used for many years for real-time location services as well as for mobile payment in many forms. One early implementation of this was the ill-fated Fairchild e-commerce project of the mid-1980s. Fairchild Semiconductor, along with Motorola, Texas Instruments, IBM, and now-defunct DEC, were experimenting with RFID-based monetary systems. Fairchildvissued press releases stating that paper money, checks, and credit cards could become monetary containers of the past by injecting an RFID sensor into the hand (Fig. 5) and having it tied to an individual's bank or credit institution.

FIG4 The *Infinity* base station. (Photo courtesy of Disney.)

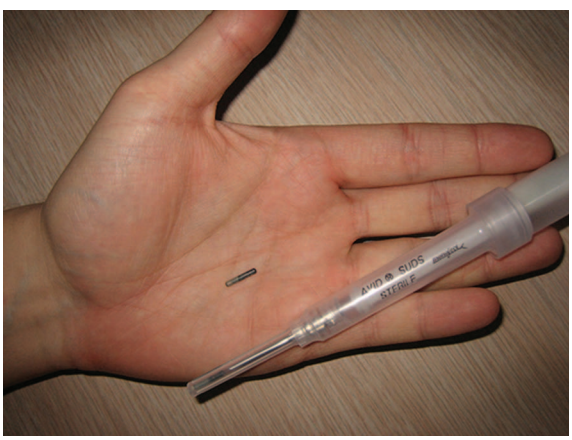

FIG5 An RFID sensor can be injected into a hand.

Great idea, poor market research. Fairchild did not consider that fact that in the United States at the time, there had been a resurgence of "end-of-the-world" fears. Some fanatical religious groups touted the new technology as a sure indication of the end of times as indicated in the Bible in Revelations 13:16-18 "… a mark on his right hand or forehead, so that no one could buy or sell unless he had the mark … of the beast." These groups very vocally squashed the idea, and Fairchild decided against releasing a product at that time.

Interestingly enough, the patents were purchased by various companies and have been very successful as "pet tagging," which involves inserting or embedding RFID tags into pets for enhanced security in case the animals are lost. Figure 6 shows an example of a veterinarian injecting a RFID tag into a pet. Animal shelters now have a scanner that can scan the identification chip and contact the owner. If a company creates an environment or the impression that a product is needed, consumers will buy it. "Love" is a great motivator as any sociologist or psychologist will tell you.

FIG6 Pet tagging. (Photo courtesy of the Pawfect Pets Newcastle Inc.)

Near and far (East)

RFID has many names, one of which is near-field communication (NFC). One could mke the case that RIFD is the physical embodiment of NFC, and NFC is just the communication protocol. Either way, it tends to be used interchangeably among technologists. Arguably, RFID/NFC was developed in the United States as an eavesdropping device for the dark recesses of the U.S. government and then quickly morphed into e-commerce applications. But it did not take off for predominate use in North America.

The Japanese/Hong Kong marketplace widely deployed RFID/NFC use with the Sony Corporation's FeliCa communication standard. FeliCa is rumored to be a reconfiguration of the Felicity Card first used in Hong Kong by Sony Corporation for Hong Kong's mass-transit system. FeliCa uses the underlying antenna/field generator (reader/writer) of RFID; then it incorporated a proprietary communication protocol including encryption for use as a mobile payment system. This early version of FeliCa used 13.56 MHz as the field frequency with a communication rate of 212 or 424 kb/s. Figure 7 shows one of the common uses of FeliCa card systems.

NFC is derived from communication technology specified by the international standard ISO/IEC 18092 (NFCIP-1). After the establishment of NFCIP-1, NXP Semiconductors N.V. (formerly Philips Semiconductors), Nokia Corporation, and Sony Corporation founded an industry standardization group called the NFC Forum in March 2004. The NFC Forum has developed a set of specifications that, in addition to NFCIP-1, considers the compatibility with existing contactless integrated circuit (IC) cards.

FIG7 A student uses FeliCa with a soda machine. (Photo courtesy of Zytronic Inc.)

FIG8 NFC enables kiosks for McDonalds. (Photo courtesy of Mark and Freda, Australia.)

The NFC Forum has also set up a certification program allowing device manufacturers to certify that their products conform to NFC Forum specifications. In the NFC Forum specifications, the Type-A and Type-B communication technologies specified in the contactless IC card international standard ISO/IEC 14443 are called NFC-A and NFC-B, respectively. The FeliCa communication technology, based on the Japanese Industrial Standard JIS X 6319.4, is called NFC-F. The NFC Forum develops specifications for realizing global compatibility and equally handling these technologies.

Related to NFC, there is also the international standard ISO/IEC 21481 (NFCIP-2). This standard covers NFCIP-1, ISO/IEC 14443, and ISO/IEC 15693. Although ISO/IEC 15693 uses the same frequency as the other standards, it is mainly applied to RFID tags used for products and logistics management. ISO/IEC 15693 is not included in the specifications defined by the NFC Forum at the moment.

Food for thought

An interesting social concern at the moment is the issue of a low minimum wage for fast food workers around the world. There is a general consensus that the wage that fast food workers, such as those at McDonalds, make is too low for them to support a family. Thus, many fast food companies are finding ways to automate many of the less-needed functions (order takers) that require human intervention, like payment systems, and only requiring human interaction for the creation of the food product. Kiosks (Fig. 8) are becoming a more common sight around the world.

Of course, not only does this help alleviate the worker issue, it tends to reduce lines

for the consumer and it speeds up the entire process so consumers can "consume faster." As companies are able to "outsource" more of the redundant employee base, they are able to increase the wages of the human workers and create both a socially viable economic structure as well as a profitable bottom line. Hopefully, robotic systems will not advance enough to replace volunteer writers otherwise, I might find myself out of a job.

The Toy Box concept from Disney allows the player to create a unique universe by purchasing in-game content and turning on special features when different Disney figures enter the Infinity universe.

Pay it forward

Google Wallet is a free digital wallet that securely stores your credit cards, debit cards, gift cards, loyalty cards, and offers. With Google Wallet, you can shop in stores, buy online, and send money. You can shop and save in stores by storing all of your cards and offers on the Google Wallet app. Consumers can also purchase in stores using the Google Wallet Card or NFC tap and pay if they have an NFC-enabled Android device. Google Wallet can be used to make purchases on Google Play and on select Android apps and sites, wherever the "Buy with Google" button is posted. Money can be sent or requested to or from anyone in the United States with an e-mail account through Gmail or the Google Wallet app. People who don't have a Google Wallet already can create one to send and receive money. In addition, you can track your online purchases, get shipping notifications, and view detailed order history.

Google Wallet exists either on the user's NFC-enabled Android device or as a separate NFC-encapsulated plastic card that looks like a credit card. As I do not have an NFC-enabled Android phone (just an Apple-based NFC phone that Google does not support at the moment), I ordered a Google Wallet card. In theory, like all NFC solutions, it is supposed to replace consumers' credit cards, though, I am not sure that I am willing to cut up my credit cards anytime soon. There is still the issue of trust that always exists with new technology and payment systems.

Another payment system that has come out is the Apple Pay mobile payment system. Apple Pay is designed to protect the user's personal information. It doesn't collect any transaction information that can be tied back to a user, and payment transactions are between the user, the merchant, and the user's bank. Apple doesn't collect your purchase history, so when you are shopping in a store or restaurant, Apple doesn't know what you bought, where you bought it, or how much you paid for it. Actual card numbers are not stored on the device, instead, a unique device account number is created, encrypted, and stored in the secure element of the device. The device account number in the secure element is walled off from iOS and not backed up to iCloud.

Apple Pay supports credit and debit cards from the three major payment networks, American Express, MasterCard, and Visa. In addition to American Express, Bank of America, Capital One Bank, Chase, Citi, Wells Fargo, and others who announced their support in September 2014, more than 500 new banks from across the country have signed on to Apple Pay. Users can make purchases in stores and within apps, with credit cards issued by many of the leading banks nationwide, which make up 83% of credit card purchase volume in the United States. Apple Pay in stores is fast and easy to use. Simply hold the iPhone near the contactless reader while keeping a finger on Touch ID.

Both Apple Pay and Google have the very real restriction that they are currently both U.S. centric, which is mostly due to the fact that the level of security that the rest of the world requires for banking and credit card transactions has oddly never been implemented in U.S. systems. Both Apple and Google will need to beef-up their encryption and security protocols to operate in the worldwide arena, just as Japan/China has with Felica and the European Union has with the Smart Card ICs.

Energy harvesting

An exciting aspect of this old technology is the renewed interest in renewable energy. Just like Nikolai Tesla from the early to late 19th century, wireless power is re-emerging. As we know, an RFID tag gets its energy from radio waves, so why not take the unused energy from all of those pesky Wi-Fi hotspots that lurk in every creak and crevice of our modern lives. From Starbucks to the hospital to the local elementary school, Wi-Fi is everywhere. As Wi-Fi operates at 2.4 GHz, all we need are antennas that have an F_{co} at 2.4 GHz and RFID tags can reuse the extra radio waves and recharge devices like cell phones, tablets, and toys.

The implementation of energy harvesting is simple in concept, more complex in implementation, as is most technical marvels (see Fig. 9). Working backward in Fig. 9, the load could be a standard mobile battery or microenergy cell (MEC). These exist today, with one example being Infinite Power Solutions' Thinenergy® MEC

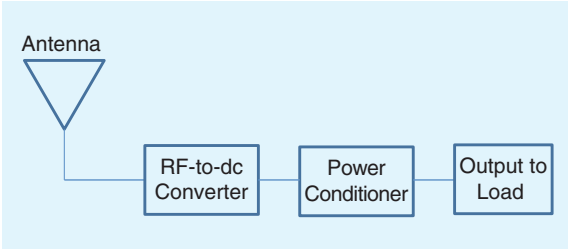

FIG9 An RFID energy harvesting block diagram.

201 solid-state, flexible, rechargeable thin-milm Micro-Energy Cell, with storage capacities up to 1 mAh. The next stage working backward is the power conditioning block, this stage regulates the power to the MEC and cleans up the potential spikes of current that could damage the load. David Squires, vice president of business development for Infinite Power Solutions, has stated, "In energy harvesting applications, a key enabler is the quiescent current drawn by the power-management IC." Squires added, "The MAX17710 has an unprecedented 1 nA battery current draw when a harvesting source is not present. The Max17710 is one of many solutions that could be chosen."

The final two blocks of Fig. 9 are where magic happens. The power conversion block may seem simple but remember its function is quite complex—it must "sense" or "read" the receive signal strength indicator of a wide range of frequencies, pick the strongest signal, and then have the antenna reconfigure itself for the optimum voltage standing wave ratio (VSWR). After a period of time, it needs to rescan the band to find out if the antenna is configured correctly or if it needs to be reconfigured. I call this *adaptive antenna frequency modification*, which is not a new or revolutionary idea, and it has been used since World War II by the allies' (United States and British) top-secret communication stations. Its use was not for energy harvesting but to extend their range of communication at sea during inclement weather and sunspot activity. This was done by manually changing out or switching out, by mechanical means, large capacitor, inductors, and or resistive components to change the center frequency F_o (see Fig. 10). Today this will need to be done by changing out varying gates of submicron material to achieve the same effect, in a much smaller form factor for mobile devices.

Finally, the antenna block, designing an antenna for a specific frequency like 2.4 GHz for Wi-Fi or Bluetooth, is not very difficult for the Global System for Mobile Communi-

$$\lambda_{\text{uppercutoff}} = 2 \cdot a$$

$$f_{\text{lowercutoff}} = \frac{c}{2 \cdot a}\ (\text{GHz})$$

a = Dimension of Broad Wall (cm)
c = Speed of Light (29.979 cm/ns)

FIG10 The cut-off frequency of an antenna waveguide.

cations or long-term evolution. there are many companies out there that have these now but designing a low-cost antenna that can "pull" or receive an adequate amount of energy (think low VSWR 1:1 from a frequency range of 2.4–80 GHz) is quite a challenge. Why is such a large range needed? This goes back to the concept of usable spectrum. Currently, 2.4 GHz is being broadcast everywhere, from microwave ovens, access points, cell phones, tablets, remote controls, portable headsets, ear buds, and so on. But there will be a shift in the near future to move out of this band to 5 GHz and beyond. IEEE 802.11ac at 5 GHz is already moving into the mainstream with IEEE 802.11ad close behind and operating at 60 GHz. Also, at 5.9 GHz is IEEE 802.11p WAVE (wireless access in vehicular environments) for intelligent transportation systems and dedicated short-range communications, allowing vehicles to intelligently receive warnings from smart infrastructure on the nation's highways and inter-urban traffic systems. Another new technology that is quickly emerging is automotive RADAR.

California passed SB 1298, which sets up procedures and requirements for determining when the cars are road-ready as autonomous vehicles. Self-driving cars sounds a bit scary, but the law still requires a human to sit behind the wheel. How does this relate to energy harvesting? With the advent of the new self-driving laws, 60–80 GHz will be prevalent RADAR frequencies used by these vehicles, which means an overabundance of "free" RF energy, ready to be "consumed" by energy-harvesting products.

A relevant example of an existing energy-harvesting IC is the Power Harvester Receiver P2110 from PowerCast Corporation. The PowerCast Corporation boasts that their tuning range is from 1 MHz to 6 GHz, but they do not have a circuit that swings the entire range; their circuit is currently only tuned for a center frequency of 915 MHz, which is perfect for 3G/4G cell phones. A designer that wants a frequency other than 915 MHz would need to license the frequency range IP from PowerCast to create a specific MASK read-only memory for that frequency like 2.4 GHz with an appropriate antenna with the desired cutoff frequency. PowerCast reports that the RF-to-dc conversion efficiency is as high as 70% in some scenarios. PowerCast estimates the range of their device from a suitable RF power source to be 40–45 ft (12–14 m). A nice video of the Power Harvester in action can be found at http://www.youtube.com/watch?v=uox8Rmm9_c4.

Apple doesn't collect your purchase history, so when you are shopping in a store or restaurant, Apple doesn't know what you bought, where you bought it, or how much you paid for it.

While we may see induction chargers like Power Mat and Qi in the near future at Starbucks and other convenient cash-consuming locales, just over the horizon lies the true future of energy-harvesting technology, a day when a consumer doesn't need to charge his/her portable communication device but rather simply change out a battery when it quits recharging. Interestingly enough, we will not have to wait long; currently the research and development divisions of Samsung, Intel, Qualcomm, and Texas Instruments, to name a few, are hard at work trying to make this a reality. They all know the first

to market with a viable solution will create huge amounts of goodwill (and loads of money). This will also create new marketplaces as power cables disappear (or just get very thin/light) and wireless sensor networks take off.

With no need for wired power, this will help to enhance our world and the environments of countries with poor infrastructure and or failing power systems. The power grid may be stable at your home or office but everyone will be talking on their cell phones or driving their vehicles, which will be broadcasting RF and be recaptured by energy-harvesting devices to power themselves. Perhaps someday we will even have a true "perpetual motion machine," with energy harvesting of the Earth's magnetic fields.

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What's old is new

This exciting old technology that is finally making it into the mainstream is changing rapidly. I have had the honor during these past two years to be the chair of the IEEE Committee on RFID (CRFID). The CRFID is composed of ten technical Societies of the IEEE that focus on different aspects of the technology space: IEEE Antennas and Propagation Society, IEEE Circuits and Systems Society, IEEE Communications Society, IEEE Consumer Electronics Society, IEEE Engineering in Medicine and Biology Society, IEEE Intelligent Transportation Systems Society, IEEE Microwave Theory and Techniques Society, IEEE Solid-State Circuits Society, IEEE Systems, Man, & Cybernetics Society, and the IEEE Vehicular Technology Society. The CRFID holds two major conferences every year with the *RFID Journal* Live! (Industry Forum), where scientists, researchers, students, industry professionals, and technologists gather to discuss issues and share research. Our next upcoming conference is 16–18 September in Tokyo, Japan, (see http://2015.ieee-rfid-ta.org/ for more information). We welcome all interested parties to attend and join in the future of RFID.

The CRFID also has an online newsletter as well as a virtual journal on RFID, which can be accessed at http://www.ieee-rfid.org/ieee-rfid-virtual-journal/. The *RFID Virtual Journal* brings together in one place the best work in RFID technology, systems, and applications. For each quarterly issue, the associate editors of the virtual journal, representing a diverse group of IEEE Societies, highlight the best work available in the field from across IEEE journal and conference publications. These high-impact, peer-reviewed publications provide the highest quality information available about this rapidly evolving field. The editorial content focuses on timely topics and draws together emerging research and commercial trends to provide a comprehensive perspective on RFID and its emerging impact on society.

How do I enable myself?

It's not easy to get the newest RFID products nor is it easy to get them to interoperate. The good news is that we've been trying to engage all interested parties in the early stages while there is still time to encourage businesses in putting these awesome ideas into practice. Here's what you can do.

1) Educate yourself about RFID. Sign up for both the IEEE *RFID Virtual Journal* and the free RFID newsletter at http://www.ieee-rfid.org/.
2) Help us spread the word about the upside of RFID and energy harvesting. Share this article with friends, coworkers, and loved ones. If we work together and let stores know that we won't tolerate not having free wireless power and the need for a greener planet, they'll have to honor our collective buying power. Support RFID and wireless power and technology for a better tomorrow and a greener planet.

Read more about it

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About the author

William Lumpkins (xillia@ieee.org) is the vice president of engineering at O&S Services, an engineering services company specializing in consumer product development. He earned his B.S. degree from New York University, Albany, in 1996. He is the past chair of IEEE Council on RFID, the current IEEE Sensors Council Standards chair, and a Senior Member of IEEE.