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Navigating your way through the RFID jungle

Introduction

With the explosive growth surrounding radio frequency identification (RFID) technology, it isn't surprising that there is so much confusion about the different RFID standards. There continues to be tremendous innovation in RFID, RF and Near Field Communications (NFC), making it difficult to understand what each has to offer, especially when newer technologies are being positioned as better than older, slower technologies.

The truth is, there is no one RF technology that is best-suited for every application. Depending upon the needs of the application, one of the "older, slower" RFID technologies might prove to be the most reliable and cost-effective solution. The market is even seeing converged applications which combine two RFID technologies such as low frequency (LF) and active ultra-high frequency (UHF). Furthermore, as RFID gains inroads into new applications, highly integrated devices are becoming available to accelerate time to market and lower cost, such as RFID technology integrated with wireless charging and energy harvesting capabilities.

To help engineers navigate their way through what can seem like a jungle of standards and buzzwords, this white paper will explore the key RFID technologies, including their primary characteristics and typical applications. An in-depth discussion of the key selection criteria will show readers how they can select the right RFID technology to match the specific requirements of their application. Finally, the paper offers a detailed look at the wide range of hardware solutions, software and tools available to developers.

The many flavors of RFID

There are four basic types of RFID technology available today:

1. LF Passive
2. HF Passive
3. UHF Passive
4. UHF Active

LF and HF Passive RFID use magnetic coupling to transfer power and data. UHF Passive and Active RFID are based on e-field coupling. The type of coupling affects factors such as read distance, data rate and environmental robustness. **Table 1** shows a comparison of key characteristics for each technology, as well as typical applications. **Figure 1** shows how the four standards relate to each other in terms of radio frequency and read range. Note that Near Field Communications (NFC) is a subset of RFID and defines a specification-based on HF passive technology for a specific selection of applications. NFC is an important technology and will be covered separately in this white paper.
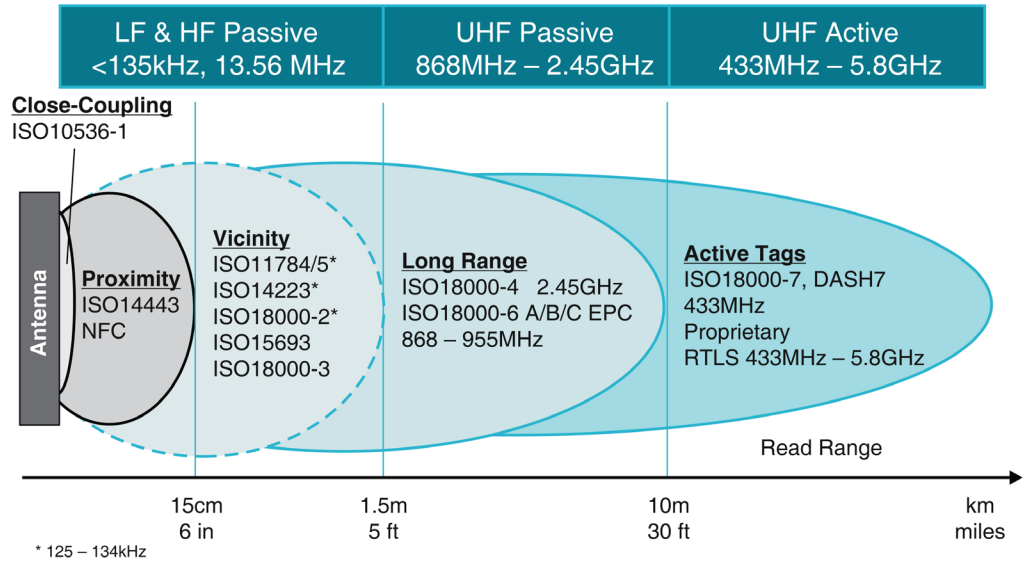
Parameter	Technology			
	LF Passive <135 kHz	HF Passive 13.56 MHz	UHF Passive 868 – 950 MHz	UHF Active 433 – 5.8 Ghz
Read distance	high	low - medium	high	highest
Data rate	4 kbps to 8 kbps	6.7 kbps to 848 kbps depending on protocol	Freq/1, LF/2, LF/4, LF/8*	Freq/1, LF/2, LF/4, LF/8*
Multi tag reading	10s	100s	1000s	1000s
Form factor flexibility	high	high	medium	low
Environment				
Tissue/Water Metal	No absorption controllable	Lim. absorption controllable	Strong absorption reflection	Lim. absorption controllable

Table 1. Technology characteristics   **EPCGen2 spec in the hundreds of kHz or less*

Passive LF	Passive HF	Passive UHF	Active UHF
(125 – 134 kHz)	13.56 MHz	868 – 950 MHz	433 MHz - 5.8 GHz
Livestock and pets	Public transport	Retail	Asset/Inventory management
Access control	Smart tickets	Logistics, roll cages	Toll collection
Vehicle immobilizers	Books	Asset/Inventory management	Logistics, container tracking
Waste management	Medical	Medical/Health care	Fleet management
	Assets/tools	Air baggage and cargo	
	Passports	Access control	
	NFC applications	Waste management	

Table 1. Application areas

LF & HF Passive <135kHz, 13.56 MHz	UHF Passive 868MHz – 2.45GHz	UHF Active 433MHz – 5.8GHz

Close-Coupling
ISO10536-1

Antenna

Proximity
ISO14443
NFC

Vicinity
ISO11784/5*
ISO14223*
ISO18000-2*
ISO15693
ISO18000-3

Long Range
ISO18000-4   2.45GHz
ISO18000-6 A/B/C EPC
868 – 955MHz

Active Tags
ISO18000-7, DASH7
433MHz
Proprietary
RTLS 433MHz – 5.8GHz

Read Range

| 15cm 6 in | 1.5m 5 ft | 10m 30 ft | km miles |

* 125 – 134kHz

Figure 1. The four different types of RFID technology available today are defined by different standards and offer varying read range.

One of the key differences between RFID and other wireless technologies is passive tag reading. Passive tags do not require either batteries or a power source to operate. Rather, when a tag is within range of an RFID reader, either magnetic or e-field coupling provides sufficient power for the tag to transmit its data to the reader. Specifically, power is coupled to the transponder by an AC field produced by the reader via a loop antenna tuned to the center frequency of the field. In contrast, active tags have access to a power source, enabling them to operate over greater distances.

Tags can operate in either Full Duplex (FDX, FDX-B) or Half Duplex (HDX) mode. An FDX-based system has data and energy traveling at the same time. This differentiation is valid for technology in the LF 125kHz to 135kHz range but not for HF or UHF passive technologies as not used here. **Figure 2** shows the reader and tag signals during a transmission. Note that both the reader and tag transmit at the same time. This is because for the tag to be powered so it can transmit data, the reader must be transmitting energy, as well.

READER   **TRANSPONDER**

CONTROL

RX/DECODE

POWER   CODE

Reader signal
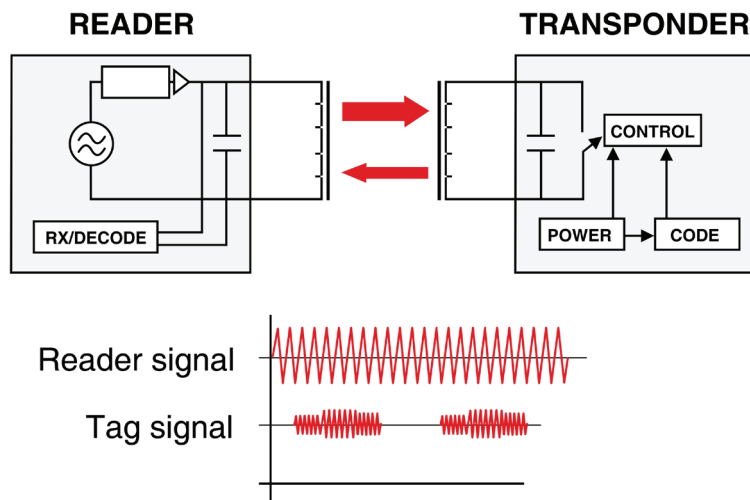
Tag signal

Figure 2. While a full duplex (FDX) based system can support data traveling in both directions at the same time, the reader must employ complex decoding algorithms to separate the tag signal from the reader

signal and ambient noise.

With an HDX-based system, either the reader or tag is transmitting, but not both (see **Figure 3)**. TI's HDX-based tags have an integrated charge capacitor in the transponder. When the reader first connects, it charges the capacitor. When the reader stops transmitting, the transponder is then powered by the charged capacitor and is able to transmit the requested data to the reader.
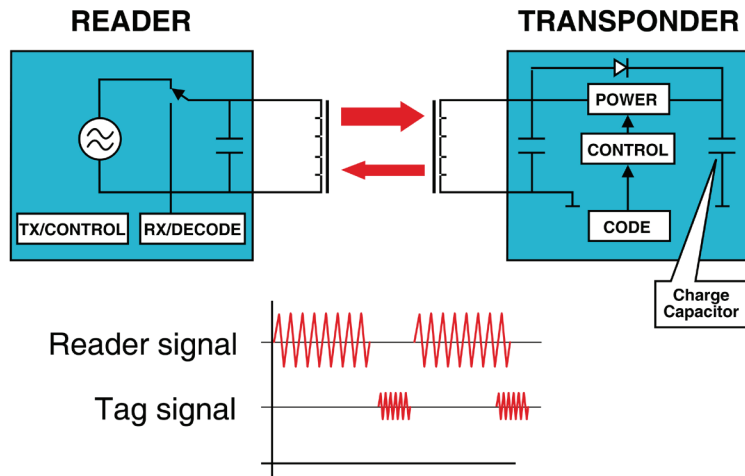
Figure 3. TI's half duplex (HDX) tags integrate a charge capacitor that allows tags to be charged by a reader and then transmit the requested data while the reader is not transmitting. This results in a better: significant improvement in performance (i.e., ~1.5X read range) with higher reliability and lower cost compared to FDX readers since an HDX reader can employ simpler decoding techniques.

TI's HDX tags provide a better: significant improvement in performance compared to FDX tags, which can be observed as a 1.5x increase in read range. This difference arises from the increased complexity required for an FDX-based reader. Consider that during an FDX transmission, the reader must separate the tag signal from its own transmission and any ambient noise. With an HDX-based tag, because the tag does not have to compete with the reader's transmission, the reader can use simpler decoding techniques. The result is higher reliability, greater range, and lower reader cost.

Near Field Communications (NFC)

The Near Field Communications (NFC) specifications are based on HF RFID ISO and ECMA standards. You can learn more from the NFC Forum (www.nfc-forum.org) designed to be used with a wide range of applications. One of the goals of the NFC specifications is to enable seamless interoperability between vendors to help drive adoption of NFC-based equipment and applications.

Specifically, NFC is based on 13.56 MHz, HF passive RFID/contactless card technology and provides a bidirectional link between devices. The NFC Forum standard supports short range transactions up to 10 cm, depending upon reader as well as tag antenna geometry and reader output power. It is used for applications like public transportation ticketing and electronic payments but also for connection handover of an alternative carrier and as service interface.

NFC offers three operating modes: Peer-to-peer, reader/writer and card emulation. In peer-to-peer mode, either device can initiate communications, enabling simple sharing of data, such as between two smartphones. In reader/writer mode, a reader/writer NFC device can read data from, and write data to, NFC / RFID and contactless smartcards. Card emulation mode enables an NFC device to behave like a contactless smartcard. A single NFC device can emulate more than one card. This is ideal for touch-to-pay applications.

NFC is an established technology: ABI Research reports that 345 million NFC-enabled devices were shipped in 2013, and more than double this number are anticipated for 2014. As such, NFC has a tremendous installed base, estimated on the order of 5300 million smartphones alone. Because of its expanding market penetration, NFC-based smartphones can be used as a universal display and entry device,

potentially reducing user interface costs in end equipment (see Sidebar, Autonomous Sensors). This allows users to easily access equipment logs, change configuration data, initiate and observe diagnostic tests, and even perform firmware updates downloaded through the smartphone/NFC enabled device. Applications for NFC include consumer electronics (printers, tablets, routers, cameras, wireless audio), automotive (info-tainment system pairing, access control, wireless and battery-less sensors), medical (diagnostics, fitness, bio med patches), smart grid (eMeters, flow meters, home automation gateways), and retail (point of sale, product authentication).

One of NFC's primary features is that it can be used to eliminate complicated wireless set up in consumer devices. It achieves this through "tapping," where devices are able to quickly pair without requiring complex configuration by users. This enables devices to be used with much greater convenience than with tradi-tional wireless devices pairing. Therefore, NFC is also being used to enable pairing of Bluetooth® and Wi-Fi devices without requiring manual setup by users.

Selecting the right RFID technology

There are several key factors to consider when selecting an RFID technology. Note that the priority of these factors depends upon the application. For example, reliability will be tantamount for a medical application while a point-of-sale application requires robust security.

- Cost
- Reliability
- Security
- Compliancy
- Read/Write range
- Read/Write speed
- Multi-tag capabilities
- Environment

When comparing the various differences between RFID technologies, cost is often one of the most important. It can also prove to be one of the most difficult to evaluate. The tendency for original equipment manufacturers (OEMs) is to focus on the basic point of cost: the tag. However, because of the variation in cost between tags and readers, as well as reader range and sensitivity, OEMs need to consider the total system cost when evaluating a possible implementation. The details of the use case become critical, as fac-tors such as tag size, reader performance, reader antenna and environmental conditions all affect system cost.

For example, because passive UHF foil tags are less expensive than LF wire wound coil tags, it may seem clear which technology to employ. However, the ratio of tags vs. readers/infrastructure needs to be taken into account, as well. For example, if a small number of tags need to be read at many reading points, then multiple readers will be required, increasing infrastructure cost. Would UHF passive be a better choice, with its low tag cost but higher cost for readers? Or would more complex UHF active tags that can be read by a lower cost reader? To answer this question, the total number of tags to be read needs to be compared to the total number of readers required to perform the task reliably.

The operating environment also should be considered early in the evaluation process. For example, both LF and HF passive tags can be read through water while UHF tags offer only limited capabilities under the same circumstances. The choice, then, is clear for tracking a product, such as fish implanted with tags or if tracking must be done in the presence of liquid or high humidity.

Temperature is another key environment factor when determining cost. If the tag must survive in a harsh environment, an LF tag may cost more per tag but offer greater reliability, as well as cost savings for readers. In general, short-range readers will be less expensive than long-range readers.

One exception to this rule of thumb is when the reader itself needs to operate under harsh conditions. Consider a production plant that needs to track products through a heat tunnel. HF passive tags provide excellent short range performance. However, in this application, if a short-range reader is used, it will have to

be placed inside the tunnel. As a result, the reader will need to be designed to be robust enough to operate continuously in extreme heat, and hence, be more expensive. By employing a longer range reader instead, tag cost will increase, but then the reader could be placed outside of the heat tunnel, enabling a less expensive design. Again, the optimal implementation depends on how many tags need to be read and whether these tags are single use or will be recycled.

These examples clearly illustrate the fact that one RFID technology cannot provide the ideal implementation for every application. It is also important to note that few applications are limited to a single technology. To determine the best fit for an application, the specific advantages and disadvantages of each technology need to be considered carefully for the specific implementation. Other factors that may influence technology selection include:

- **Consistency**: Consistency refers to the ability of the RFID implementation to reliably read tags as required by the application. Factors such as read distance/range and data rate/speed need to be matched to the requirements of the environment. For example, tiny tags can be implanted in products and animals but larger tags provide greater range and reach. Alternatively, a larger reader can be used to increase range. A higher data rate will improve reliability as well, but at a higher cost. Future needs might be evaluated as well; if the number of tags to be read is expected to increase in the near term, this will require readers with a higher data rate and may shift which RFID technology is best-suited for the operating environment.

- **Antenna:** The RFID antenna impacts both read/write range and footprint. LF tags offer high flexibility as the antenna can be designed to include a ferrite core. Thus, a tag the size of only a few mms can achieve inches of range. UHF passive, in contrast, has restrictions on tag construction such as the antenna cannot be wound around a ferrite core, so UHF tags need a larger footprint to deliver good read range.

- **Battery-powered:** Range, as well as the integrated processing capabilities of a tag, can also be increased by selecting an active tag over a passive tag. Passive tags are powered by the transmitted energy received. Thus, they have limited range, up to 30 feet under good operating conditions and cannot process data while not engaged with a reader. In contrast, active tags have a battery-powered transmitter that enables them to achieve up to miles of range. This makes them useful for applications, such as container or vehicle toll tags where there may be limited control as to how close the reader can be situated relative to the tag. The presence of a battery also provides the opportunity for a tag with an integrated MCU to perform limited processing tasks. These could include logging of periodic monitoring even when a reader is not present or partial processing of data before transmission.

- **Absorption:** The presence of metal can potentially block or reflect RFID signals, significantly impacting range and reliability. For example, a tag behind a metal door may not be able to be read. Conversely, a metal door could act like a repeater, enabling a tag in front of the door to be read at a much greater distance. Increased range is not always desirable. For example, a tag in one loading bay that is reflected may be visible to a reader in an adjacent bay. This could cause the tag to be counted twice or associated with the wrong outgoing dispatch.

LF and HF passive absorption can be controlled by how far the tag is from the metal surface. These technologies have a well-defined read range of just a few feet, and metal only blocks signals, so reflection is not an issue. Alternatively, the field of a UHF tag is not homogeneous, so as the reader approaches the limits of the tag's range, reading may become less reliable in the presence of metal; sometimes the tag will be read, sometimes it will not.

Metal in the operating environment should be considered when deploying a new system. However, thought must also be given to how the environment might change. For example, a loading dock may occasionally be filled with large, metal appliances. Tag and reader limitations need to accommodate such situations.

Similar issues can arise with water as water absorbs the UHF RFID signal, completely blocking it out. Thus a container filled with liquid may not be read when the contents of the container are positioned between the container's tag and the reader. If UHF tags are used (because of other application requirements), other measures must be taken, such as guaranteeing the orientation of the container, placing multiple tags around the container or using readers at different angles. UHF tag antennas can be designed though to also read through water, but the read/write range is then reduced to passive HF tag ranges, still bearing the higher reader cost.

Options for every application

TI is dedicated to helping OEMs go to market with the right technology for their application. To enable OEMs to have full freedom to choose the technology of their choice, TI leads the market with a broad range of RFID, NFC and RF standalone devices. These solutions are built upon TI's expertise based on decades of innovation and helping thousands of OEMs successfully bring RFID-based systems to market. TI is also committed to driving standardization to ensure seamless interoperability across the RFID industry. **Table 2** offers examples of various applications and TI devices that are well-suited for the particular design issues involved.

Application	Key requirements	TI technology
LF Passive 135 kHz Applications		
Reader/Writer	Reliability Range	TI-STU-251B RI-RFM-00xB TMS3705B
Livestock/Pets	Reliability Range	TRPGx40ATGx RI-INL-0xxx
Automotive	Security	TMS37145 RF430Fxxx
Industrial	Reliability	TRPGR30ATGx RI-TRP-xxx
Waste Management	Reliability	TRPGR30ENATGA RI-INL-W007
Sports Timing	Reliability	TRPGR30Axxx RI-INL-R9QM
Access Control	Security Range	TMS37145 RI-TRP-BFOB TRPGR30ATGx
HF Passive 13.56 MHz Applications		
Reader/Writer	Reliability Speed	TRF7960A TRF7964A TRF7970A
Medical	Safety Reliability	RI-I1x-11x RF-HDT-AJLx
Payment	Security Speed	TRF796x TRF7970
Access Control	Security Reliability	RI-I1x-11x RF-HDT-AJLx
Product Authentication	Security	RI-I1x-11x RF-HDT-AJLx
Public Transport	Security Speed	RI-I1x-11x RF-HDT-AJLx
Passport/ID	Security	TRF796x TRF7970

Application	Key requirements	TI technology
UHF Passive 868 to 950 MHz Applications		
Reader/Writer		CC1101 CC12xx
NFC Applications		
Consumer	Wi-Fi or Bluetooth pairing through NFC	Dynamic NFC Interface/Tag: RF430CL330H
Automotive	Pairing with infotainment system	Dynamic NFC Interface/Tag: RF430CL330H NFC Transceiver IC: TRF7970A
Industrial	Device configuration firmware upgrade	Dynamic NFC Interface/Tag: RF430CL330H NFC Transceiver IC: TRF7970A, TRF7964A
Medical	Sensor transponder (medical patch)	NFC Sensor Transponder: RF430FRL152H
Smart Grid	Service interface to meters	Dynamic NFC Interface/Tag: RF430CL330H
Retail	Contactless reader/writer for point of sale	NFC Transceiver IC: TRF7970A, TRF7964A

Table 2. RFID application reference guide

For example, for NFC-based designs, TI offers the TRF79xxA platform of low-cost transceivers that supports all popular 13.56 MHz air-interface-based protocols, standards and specifications in use around the world. Pin-to-pin compatibility across the family enables true scalability to match specific application or end equipment requirements. The TRF796xA transceiver provides HF RFID reader/writer functionality for both proximity and vicinity applications. The TRF7970A transceiver adds card emulation and peer-to-peer capabilities.

TI's Tag-it HF-I family of transponders, offered as inlays, encapsulated devices and wafers, are compliant with ISO/IEC 15693 global open standards recognized by Android-based systems as NFC Tag Type V. TI's patented laser-tuning process provides consistent read performance and devices undergo complete functional and parametric testing to provide the highest quality performance.

Also available is the Dynamic NFC Transponder RF430CL330H, which provides low-cost, secure and simplified NFC connectivity to a broad range of applications, including enabling dynamic pairing to eliminate complex set up for traditional wireless connectivity. Dynamic tags offer several benefits compared to static tags. Their flexibility enables OEMs to quickly adapt to market feedback, meet new requirements and support security updates or SSID changes. Dynamic tags also eliminate the need for pre-programming and matching of devices during production. Furthermore, they support dynamic data transfers to and from other NFC-based devices.

Figure 4 shows how the Dynamic NFC Transponder RF430CL330H can interact with a smartphone to serve as a bridge for passing setup parameters for Bluetooth and Wi-Fi. This configuration also saves power by enabling the Dynamic NFC Transponder RF430CL330H to wake up the applications processor and/or Bluetooth/Wi-Fi radio out of standby mode. In addition to supporting an NFC Type 4 tag interface, other key features of the Dynamic NFC Transponder RF430CL330H includes embedded memory, an integrated MSP430™ MCU-based processing unit and an I2C/SPI interface (see **Figure 5**).
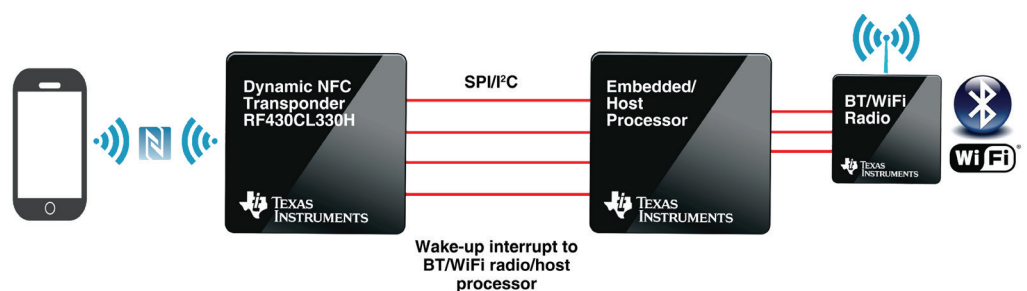
Figure 4. TI's Dynamic NFC Transponder can interact with a smartphone to serve as a bridge for passing setup parameters for Bluetooth and Wi-Fi. It can also wake up the applications processor and/or Bluetooth/Wi-Fi radio from standby mode.
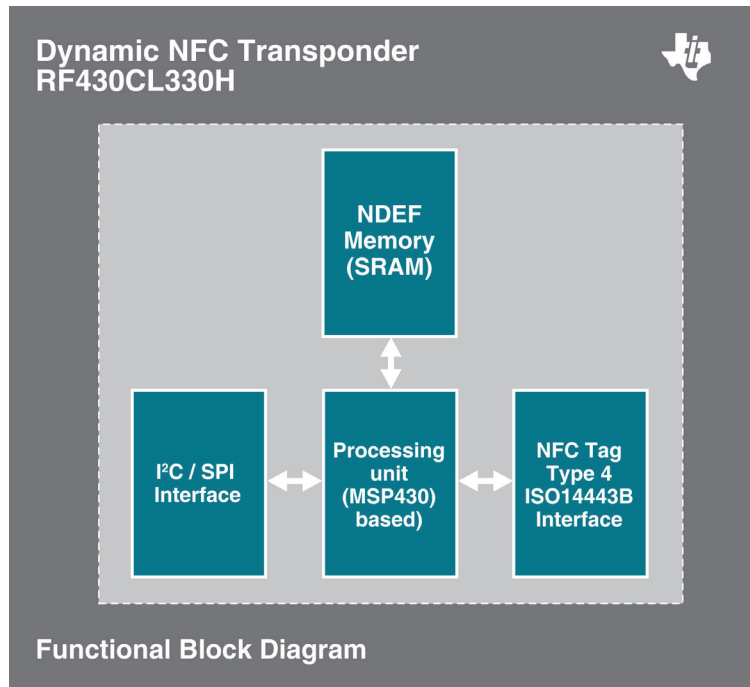
Figure 5. For advanced RFID tag processing, TI's Dynamic NFC Transponder has an integrated MSP430-based processor, embedded memory, and dual interface.

Accelerating time to market

TI does not just observe the convergence of technology. As a leader in the electronics industry, TI helps drive innovation by investing in a diverse variety of technologies that complement each other. By drawing from its experience in car access, NFC and RF integration, TI continues to develop the key technologies OEMs need to bring next-generation products to market. For example, TI has an extensive range of MCUs, processors and DSPs with TI analog on-chip or sold separately for compatibility. These parts can be used for data conversion, power management circuitry and transceivers. Part of TI's roadmap is to continue to provide highly integrated solutions, such as its SoCs with integrated MSP430 MCUs and CC Class radio. TI will continue to expand its RFID product lines by building upon its vast portfolio of innovative technology:

• System on chip (SoC) integration
• Integration of RFID/RF into microcontrollers
• Free programmable RFID/RF microcontrollers
• Energy harvesting
• Efficient battery charging
• Security
• Ultra-low-power microcontrollers
• Advanced FRAM memory technology with low write power

To further accelerate time-to-market, TI provides support beyond just silicon. For example, the NFCLink software library simplifies and streamlines the development of all NFC operation modes for TRF79xx NFC transceivers across TI's entire embedded processing portfolio of MSP430 MCUs, Tiva™ C Series MCUs and application processors. The NFCLink library also includes firmware to ease pairing with other TI hardware.
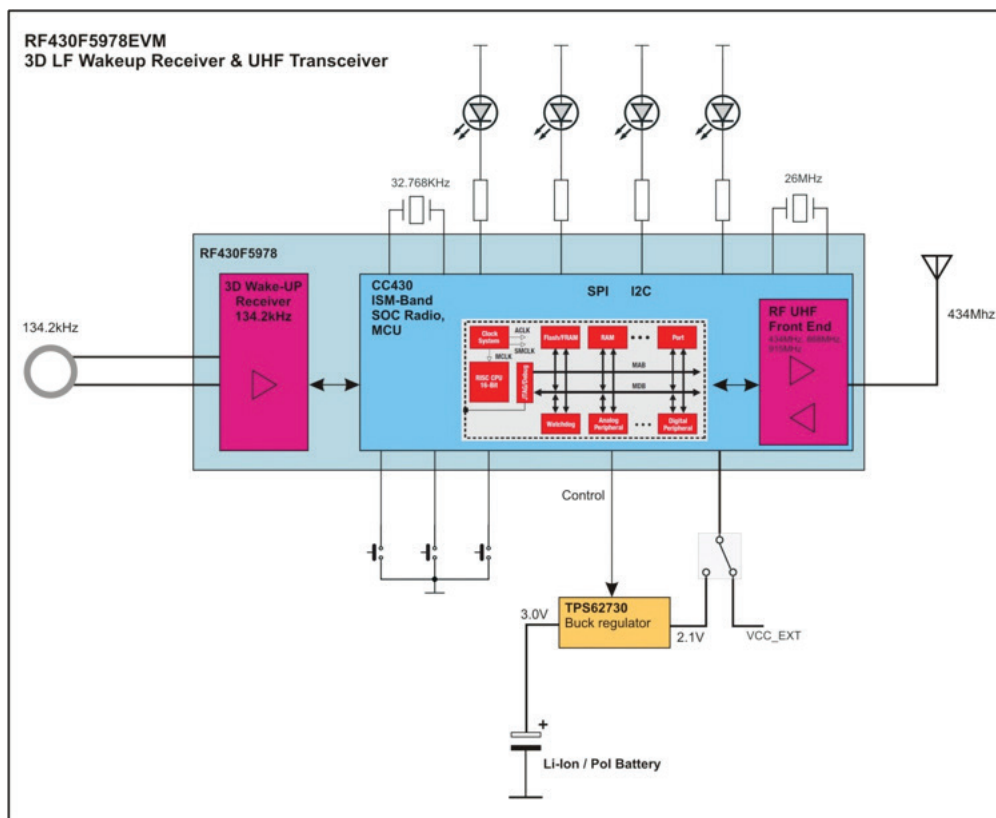
Figure 6: the RF430F5978EVM

References

TI also has a lot of mixed technology parts. You can see from Figure 6, the RF430F5978EVM is capturing data from different sensors over a long period by a LF wake up interrupt starting to transmit the stored data to an AP434 access point. The RF430F5978 combines a TPS62730, CC430F6137 ultra-low-power MCU system-on-chip with integrated 434MHz transceiver cores consists of several devices featuring different sets of peripherals targeted for a wide range of applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications.

Built on proven technology from Stollman E+V GmbH and Kronegger GmbH, the modular stack can be tailored to meet specific application requirements and minimizes the in-depth protocol and device knowledge required to build robust NFC applications. Various operating system drivers are supported, including Win8, Win7, Linux and Android. In addition to NFCLink , other tools available to developers include:

- Dynamic NFC Transponder Evaluation Kit
- NFCLink Evaluation Kit
- TRF970AEVM Standalone Demo
- MSP430Ware™ software for no-OS software development
- Code Composer Studio™ IDE version 5
- Goggle Store apps
- NFC Player
- Microreader LF Evaluation Kit

TI and its partners offer global support, including on-demand video training, in-person workshops and 24/7 support via the E2E online community and forums. OEMs can also get expert design services through TI's extensive ecosystem, including industry leaders Keil, IAR Systems, Stollmann, Green Hills Software and freeRTOS.

Making sense of the RFID jungle does not have to be difficult. While there is no "one size fits all" approach to RFID design, developers often have more than one technology option available that can effectively meet the requirements of their target application. By closely examining the particular use case and the specific advantages and disadvantages of each RFID technology, selecting the best technology can be a straightforward decision.

General information on RFID/NFC technology from TI, including data sheets, technical reference manuals, applications notes, software and tool downloads, and development kits: **www.ti.com/RFID**

General information on NFC technology: **www.ti.com/nfc**

NFC Training Videos: **www.ti.com/nfc-videos**

Engineer 2 Engineer Support Forum: **e2e.ti.com/support/low_power_rf/f/667.aspx**

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