TEXAS INSTRUMENTS

Application Report
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RFID Technology Selection for Waste Management Applications

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ABSTRACT

This document is intended to assist those involved in the waste management industry to make short and long term decisions about RFID technology as it pertains to that industry.

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1 Scope

This document will cover the benefits of RFID for waste management and highlight key available readers, tag technologies and system performance differences.

2 References

- http://www.ti.com/rfid/shtml/apps.shtml
- ISO 11784:1996, ISO 11785:1996
- ISO 15693-2:2006, ISO 15693-3:2001
- ISO 18000-6c:2004

3 RFID Usage Concepts for Waste Management

With costs rising at all points in the waste management process, RFID technology can enable those involved in the industry to improve the efficiency of their waste operations.

It all starts with an RFID transponder (or tag), which should be in a rugged plastic housing or embedded in the container to protect it from the environmental conditions that exist in the waste application.

The tag is attached or embedded to/in the waste container. An RFID reader and antenna integrated into the waste vehicle and connected to a host controller reads the tag’s unique serial number as the waste container is emptied.

This unique number can be linked with a date/time stamp, type of container, weight of the container, and customer information, and that information can be sent directly to a server using wireless connectivity, stored in the reader or on the vehicle’s onboard host controller and transferred later to a central waste management system.

Tags can also be used to identify the waste vehicles themselves to automate the hauler, landfill or recycling station operations. The vehicle mounted tag can be read as it passes over an in-ground antenna as it arrives or departs a facility.

Unlike barcodes, which require direct line of sight to be read and are easily scratched or damaged in the harsh waste and recycling environment, RFID tags do not require line of site, and available RFID tags, readers and antennas are already robustly designed, making them a more permanent form of unique identification that is superior to barcode technology is this application.

Taking advantage of an RFID system’s ability to reliably identify individual receptacles, waste haulers can benefit from the automation of waste collection, container management and provide verification of service. In addition, this information can be used to optimize truck usage and routes.

A truck based waste management system based on RFID versus a manual method streamlines the driver tasks/hauler operations and customer billing processes. For these reasons, RFID technology is a wise investment for the waste management professional.

4 Passive RFID Technology Overview (LF/HF/UHF)

Globally accepted passive RFID technology occupies three frequency bands: low frequency (LF), high frequency (HF), and ultra-high frequency (UHF). These frequency bands are regulated by the respective country or region one is operating in. For example, in the US, the FCC maintains regulatory control, in Europe it is the ETSI organization. These regulatory agencies have allocated certain frequencies for RFID technology to be employed. For LF it is 134.2 kHz, for HF it is 13.56 MHz and for UHF it is 902-928 MHz (in the US). These same regulatory agencies also set other restrictions on the use of these frequencies, such as power output, deviation from the allowed frequencies, and the testing for radiated and conducted emissions in other bands. All of which are important to keep in mind as we go deeper into the system details.

Passive RFID transponders depend entirely upon the energy generated by the reader antenna for power. LF and HF reader systems utilize inductive coupling (a magnetic field) to power the transponders. UHF reader systems utilize capacitive coupling (an electric field) to power the transponders.

The user experience or relative observed result is that LF and HF systems have very defined and controlled read zones whereas a UHF system, while perhaps having a longer range, has less control over the read zone.

This is the first important distinction that has implications for the waste management application which at the most basic level requires 100% accurate service verification. LF and HF RFID provide the user with a defined, controlled read zone while UHF RFID provides longer range read, but less control over the read zone.

5 Passive LF RFID (Technical Detail)

Power is coupled to the transponder by an AC field produced by the reader and its associated tuned loop antenna and the magnetic field has a center frequency of 134.2 kHz. When sufficient power is received by the transponder, it is able to respond to commands sent from the reader. The reader sends commands to the transponder by modulating the powering field and the transponder responds back in one of two ways, depending on the type of transponder. In this technology type, there are two types of transponders that conform to the ISO standard. One type is referred to as full duplex (FDX, FDX-B) and the other is referred to as half duplex (HDX). While they both comply with the ISO standard, there are some key technical differences between the two that result in about a 2x performance advantage when the HDX technology type is used.

An FDX system has data travelling in both directions at the same time (see Figure 1). It superimposes the response data on the 134-kHz carrier signal using amplitude modulation (AM).

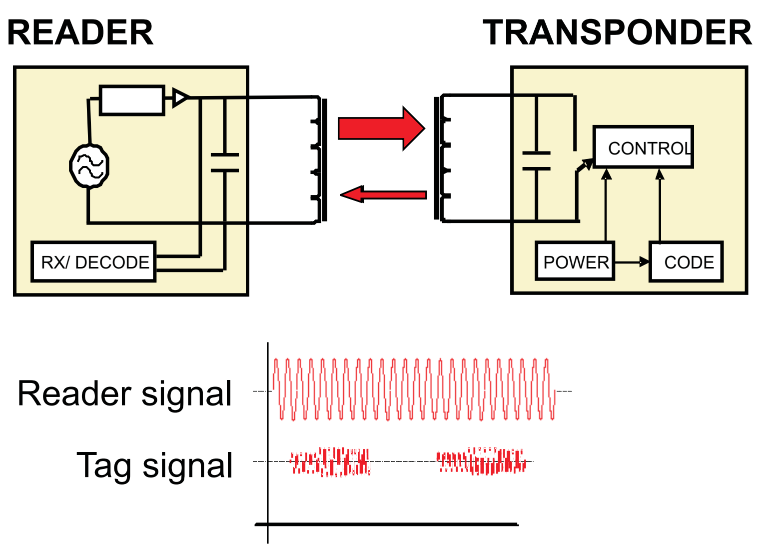


Figure 1. FDX System

In an HDX system data is only travelling in one direction at one time (see Figure 2). The energy stored in the transponder's charge capacitor is used to return the data using FM modulation.

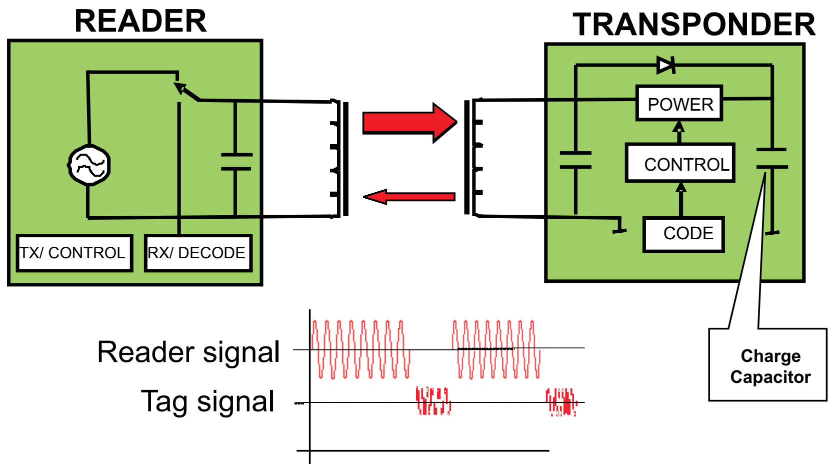


Figure 2. HDX System

Figure 3 and Table 1 summarize the key differences between the two methods and compares the key technical differences.

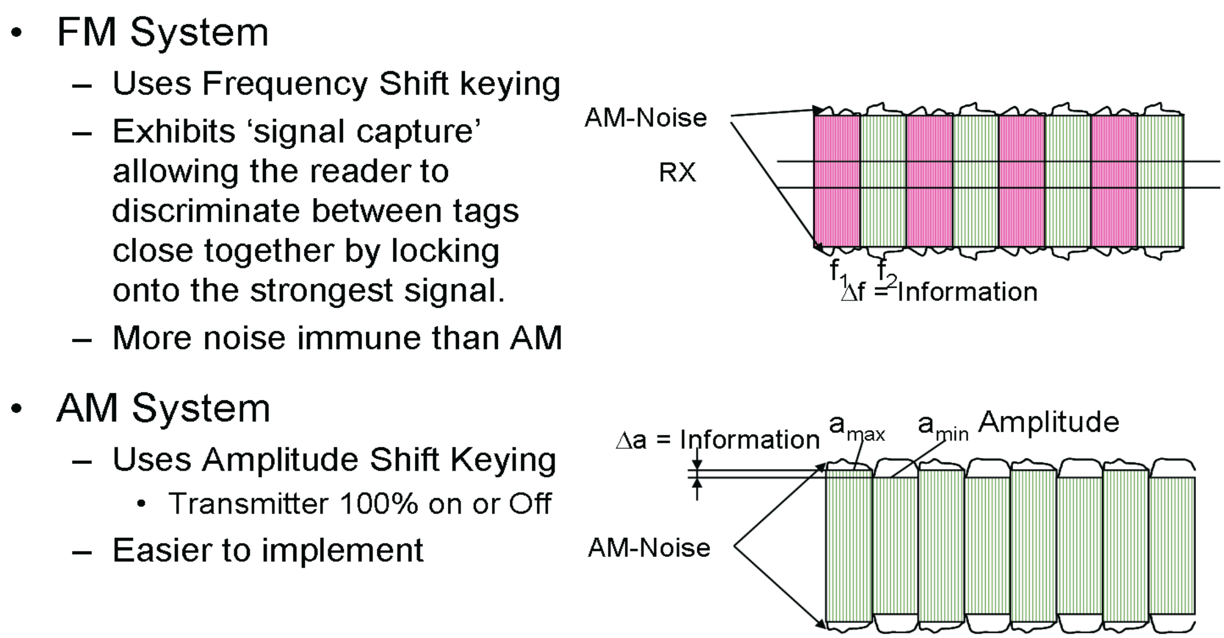


Figure 3. FM and AM Sytem Differences

Table 1. Full Duplex and Half Duplex Differences

PROTOCOL	FULL DUPLEX (FDX OR FDX-B)	HALF DUPLEX (HDX)
Modulation	ASK	FSK
Frequency	129 - 133.2 kHz	124.2 kHz = 1
	135.2 - 139.4 kHz	134.2 kHz = 0
Channel code	Differential biphase	
Symbol time	0.23845 ms	0.1288 ms 1
		0.1192 ms 0
Telegram (bit)	128	128

The end result of the technical differences between the two techniques is that the FDX (or AM) system's reader receive/decode side is very complicated because it has to "pick" or discriminate the transponder response from any ambient noise as compared to the HDX (or FM) system which has much simpler readers and also has a superior performance over the FDX systems which can be observed in read range (about 2x over FDX). A direct analogy many can relate to is the difference between the way broadcast AM radio sounds versus the way broadcast FM radio sounds. FM radio is noticeably better and is not affected by the AM noise that could be present.

6 Passive HF RFID (Technical Detail)

Power is coupled to the transponder by an AC field produced by the reader and its associated tuned loop antenna. The magnetic field has a center frequency of 13.56 MHz and is one of the industrial, scientific and medical (ISM) frequencies available for worldwide use. When sufficient power is received by the transponder, it is able to respond to commands sent from the reader. The reader sends commands to the transponder by modulating the powering field and by using a modulation system known as pulse position modulation, whereby the position of a single pulse relative to a known reference point codes the value of a byte of data. This allows the transponder to draw the maximum energy from the field almost continuously. Transponders, which have no power source, can be energized at ranges of up to 1 m from a reader that can only transmit power within the limits permitted by international radio frequency (RF) regulations.

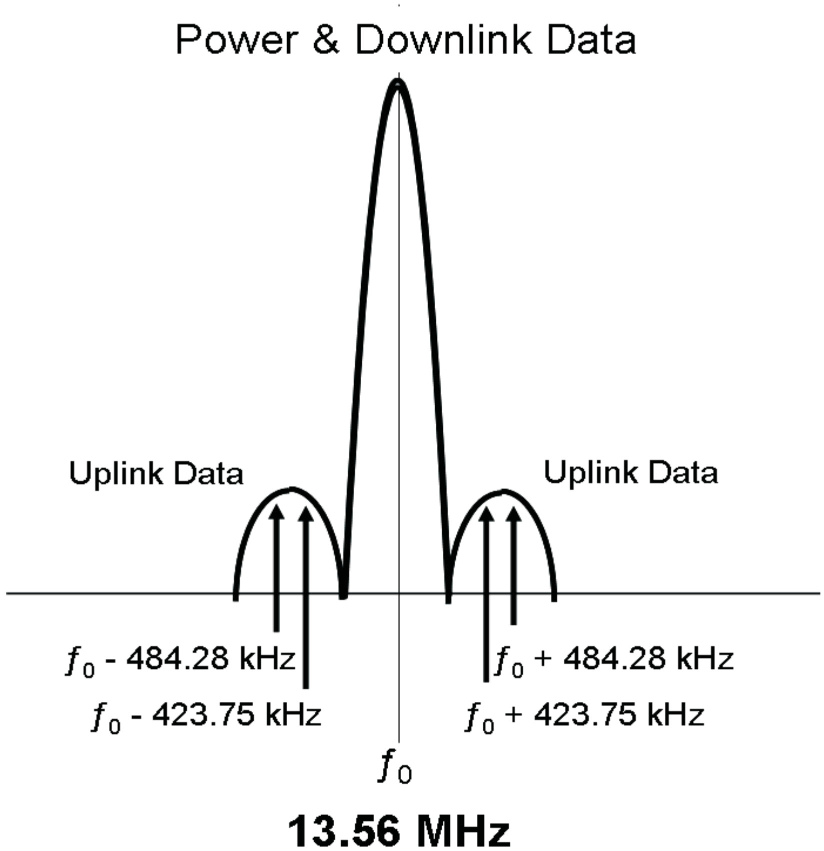


Figure 4. HF Power/Downlink Carrier Frequency and Uplink Frequencies (Response Sidebands)

A transponder only responds when it receives a valid command that selects a single transponder from a possible collection of transponders within range of the reader. This process of collision detection and selection, also known as anti-collision, is made possible by detecting the unique identification number encoded into every transponder. Anti-collision and the commands used are defined in ISO/IEC 15693-3. The transponder responds to the reader by drawing more or less power from the field and generates one or two sub-carriers of around 424 kHz or 484 kHz. These are switched on and off to provide Manchester-encoded data that are then detected by the reader.

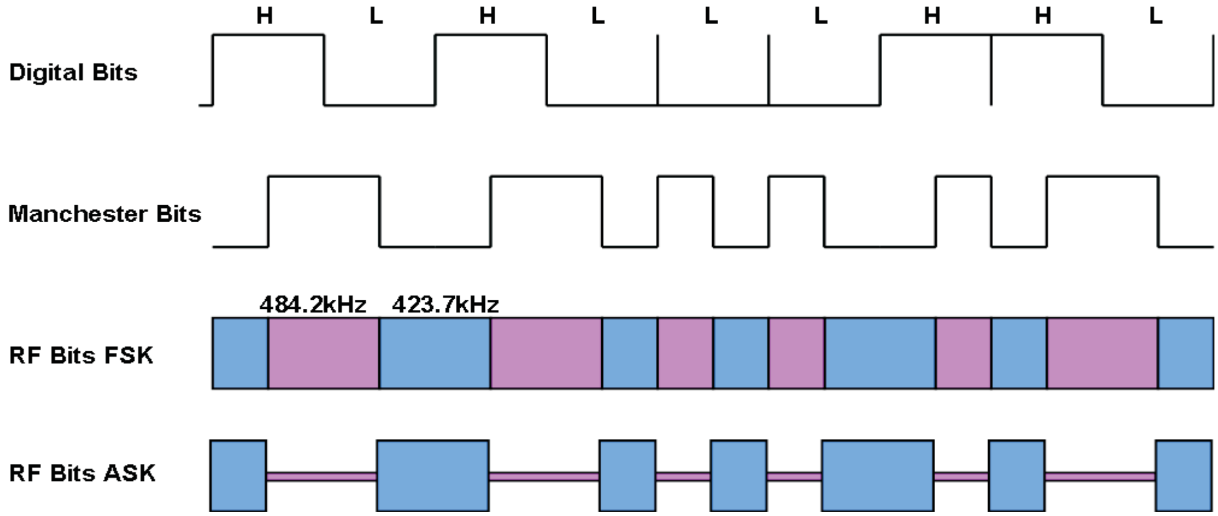


Figure 5. Communication from Inlay to Reader (ASK and FSK compared)

Thus both power and bi-directional communications form the air interface between the transponder and the reader. It is the flexibility of the interface to select one or two sub-carriers when communicating from transponder to reader, while also using slow or fast data rates from the reader to the transponder, that allows systems to be tuned to suit different operational requirements ranging from use with high RF noise at short range to low RF noise at long range.

7 Passive UHF RFID (Technical Detail)

Power is coupled to the transponder by an AC field produced by the reader and its associated tuned patch antenna; the electric field is centered in the US at 915 MHz and centered on other frequencies in other parts of the world. Unlike LF and HF, with UHF there is no global standardization/harmonization on the frequencies used or the power output limit. At UHF frequencies, longer reading distances are achievable. The data rates are much higher, but the signals don't pass through materials as well as they do at the lower frequencies and while reflections can extend the read range, this system characteristic makes the reading zone less well defined (such as ghost readings from labels thought to be out-of-range).

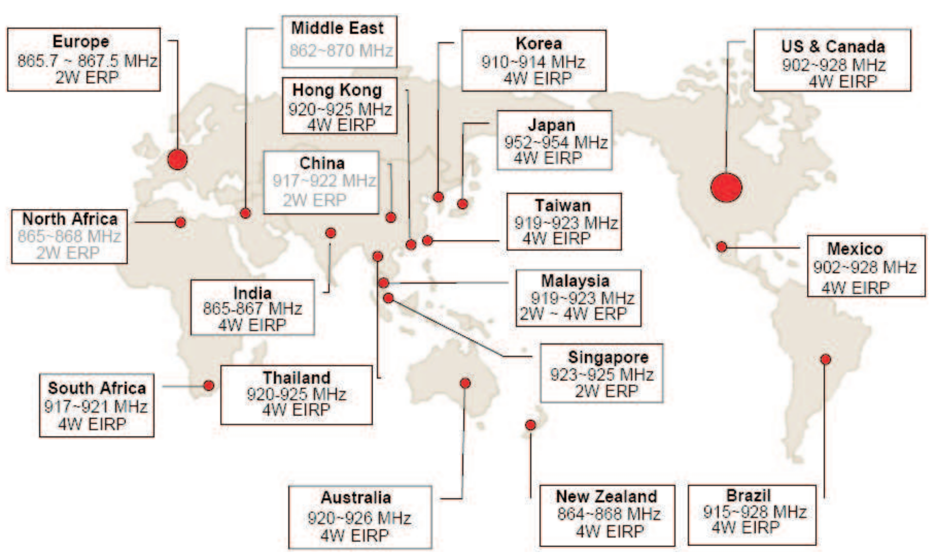


Figure 6. Allowed UHF Frequencies and Power Levels from a Global Perspective

When sufficient power is received by the transponder, it is able to respond to commands sent from the reader. The reader sends commands to the transponder by modulating the powering field and by using a modulation system known as amplitude shift key (ASK) with pulse interval encoding, whereby the data is passed to the tag by pulsing the carrier wave at different time intervals to indicate the ones and zeros in a bit stream.

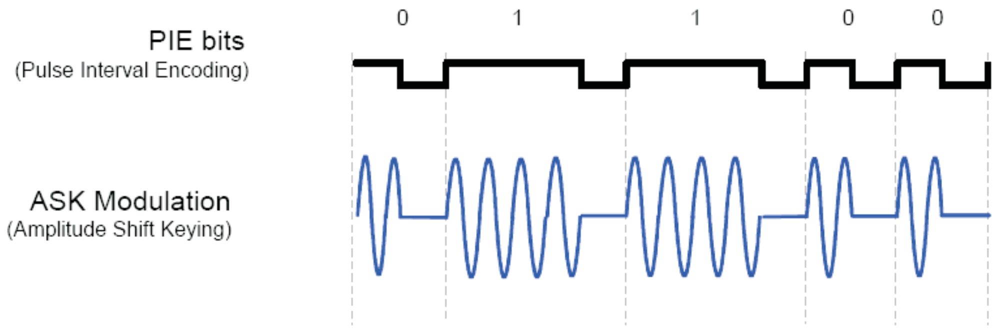


Figure 7. Passive UHF Reader to Tag Modulation

The tag uses backscatter modulation to respond to a reader. It does this by switching the reflection coefficient of its antenna (using a shunt circuit) from a matched load where the incident RF signal is absorbed, to a short at the antenna terminals where the maximum reflected RF signal is created. It is energy reflected in a direction opposite to that of the incident e-field waves.

Think about a RADAR system analogy where a RADAR station on the ground is tracking an airplane. The RADAR transmits waves of RF energy toward the target and the target reflects these waves of energy back. The amount of energy reflected back is dependent upon the surface area of the target that is exposed to the incident RF waves. A larger surface area equates to more energy being reflected back. With RADAR, the determination of target size is determined indirectly through the amount of signal reflected back. With passive UHF RFID, the tag can (by the use of a shunt) appear larger (Digital 1) or smaller (Digital 0).

The reader instructs the tag which method of data encoding to use when sending its data back (either Miller Subcarrier encoding or FM0 Baseband encoding. The tag can use either of two modulation formats, which the tag manufacturer selects (either ASK (Amplitude Shift Keyed) or PSK (Phase Shift Keyed)).

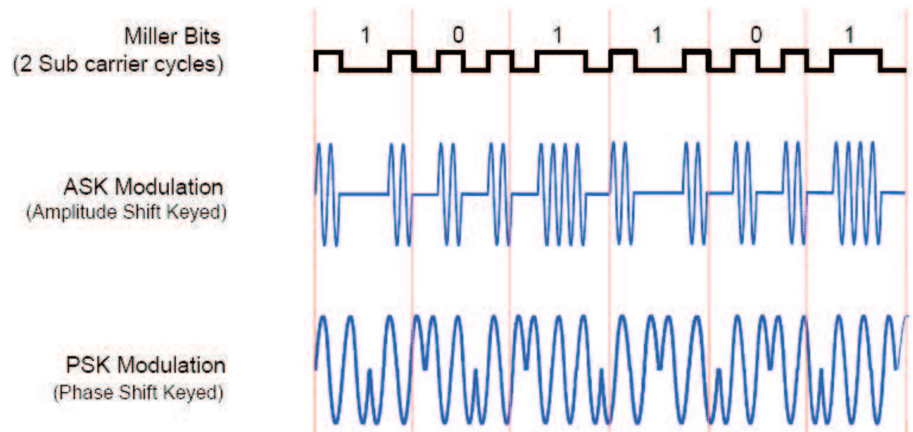


Figure 8. Passive UHF Tag to Reader Modulation

8 Passive RFID Transponder Overview (Form Factors)

Below are images of passive RFID transponders – LF, HF and UHF.

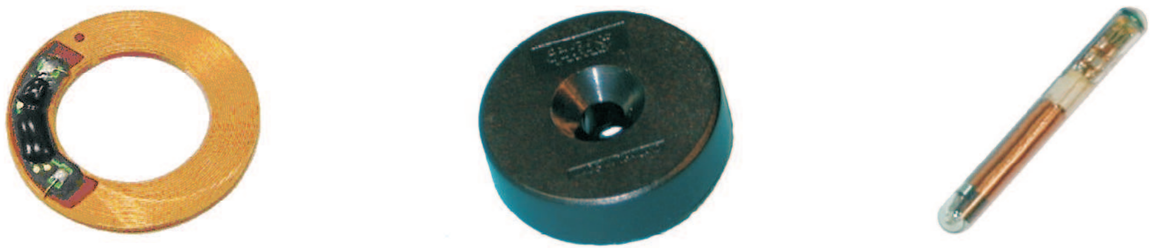


Figure 9. Low Frequency Transponders for Waste Management (24-mm Inlay, 30-mm Eencapsulated, 32-mm Glass)

Figure 10. High Frequency Transponders (PET Based Inlays, 22-mm Encapsulated)

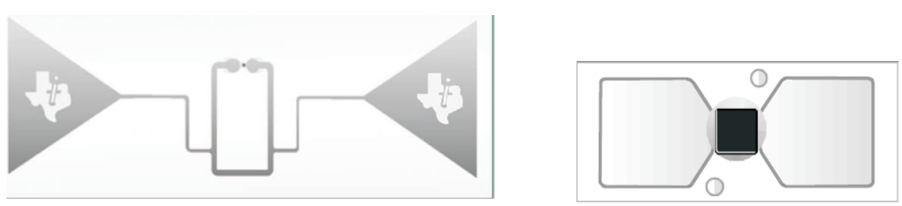


Figure 11. Ultra-High Frequency Transponder and Strap (PET Based Inlay, PET Based Device With Antenna Attachment Points)

9 Passive RFID Reader & Antenna Systems Overview

9.1 LF

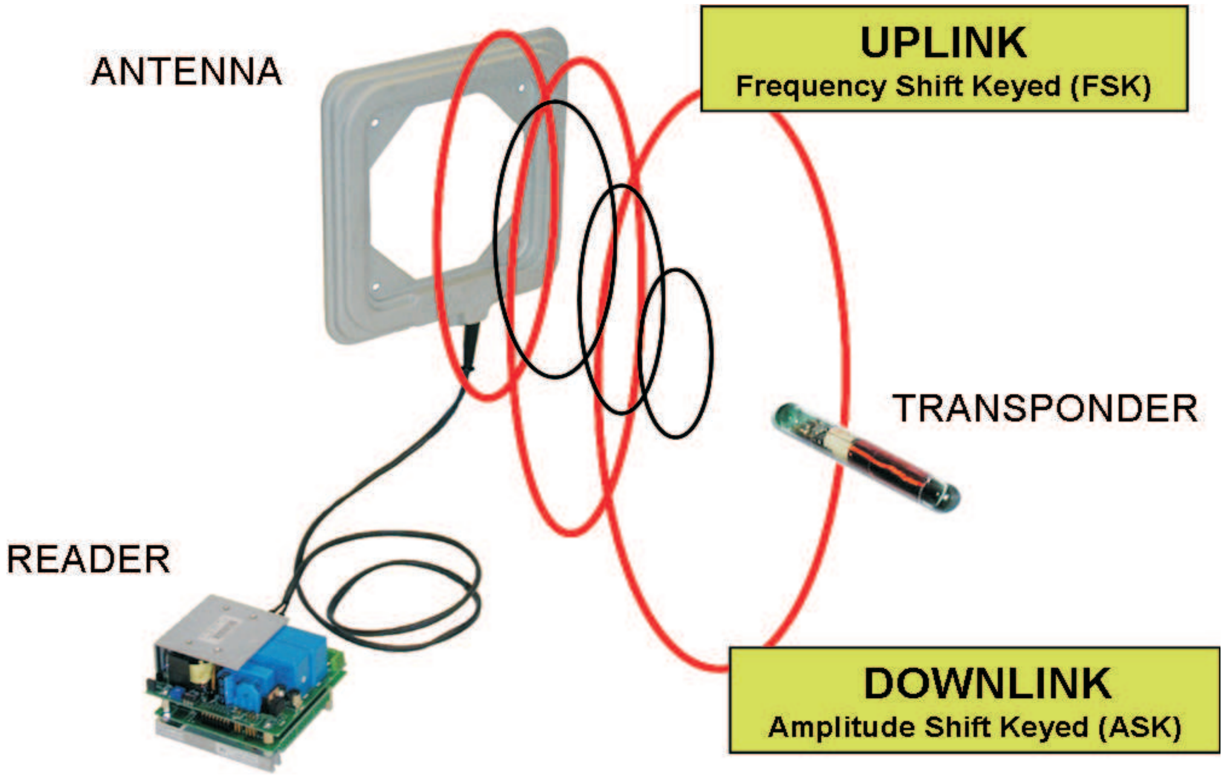


Figure 12. LF Reader/Antenna System for Waste Management

LF readers use the magnetic component (H-field) of the electromagnetic wave to transfer energy from the reader's antenna to the tag's antenna. This can be compared to the way a transformer works but using air in place of a ferrite core.

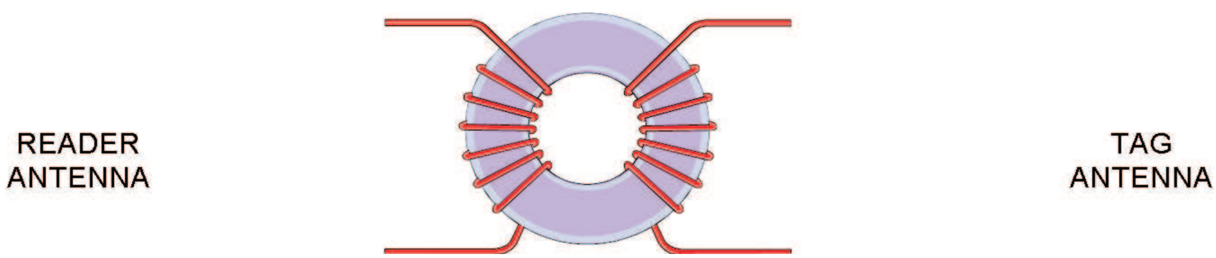


Figure 13. H-field

The reader's antenna induces a voltage in the tag's antenna and the frequency used (134.2 kHz) has a long wavelength (λ = 2.2 km). Because of this long wavelength, this RFID system has an ability to read through materials, is unaffected by water, and because of the system design, has a well defined magnetic field; all of which bias this technology for use in the waste management application, where the hauler cannot control what is disposed of or the daily ambient conditions.

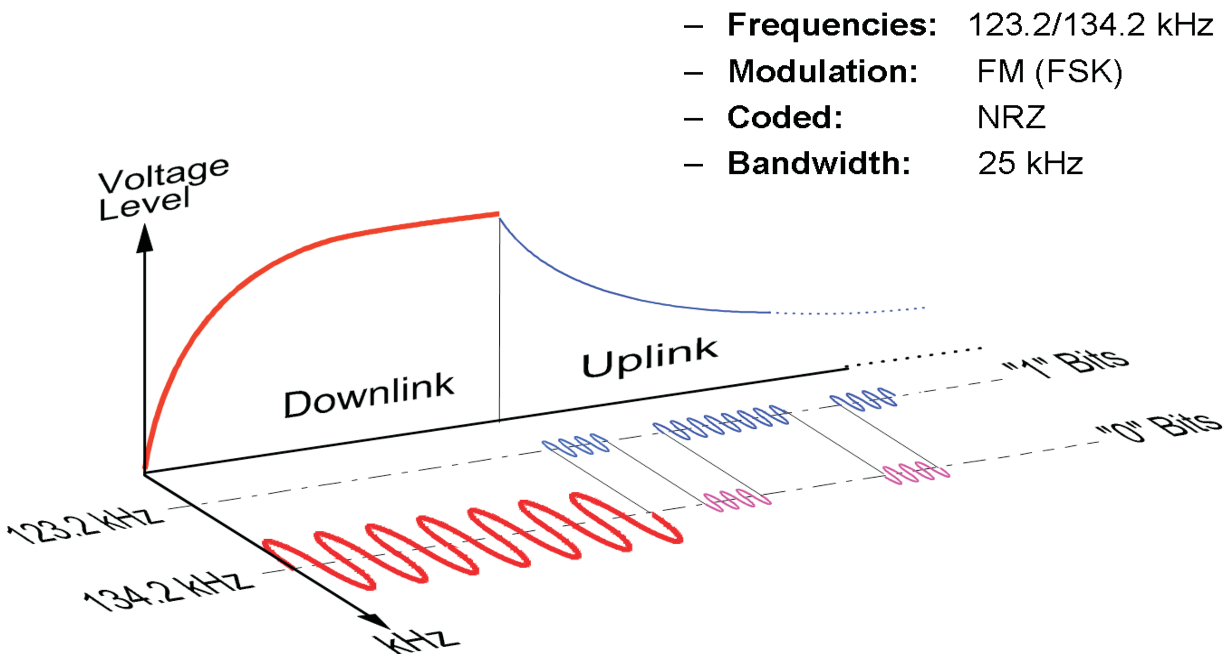


Figure 14. LF HDX RFID Read Cycle Representation in Voltage, Time/Frequency, and Resulting Digital Bits

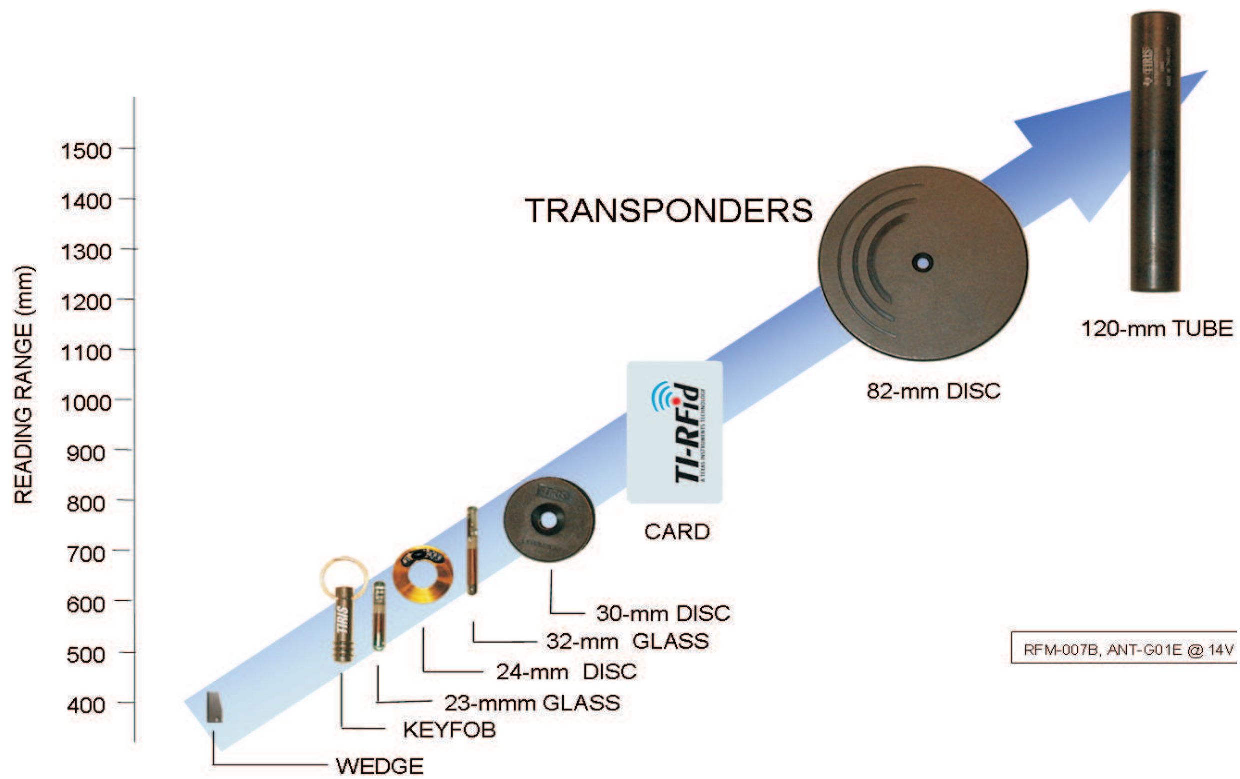


Figure 15. Typical Passive LF RFID Transponder Read Ranges (With Reader at ~1/2 Power)

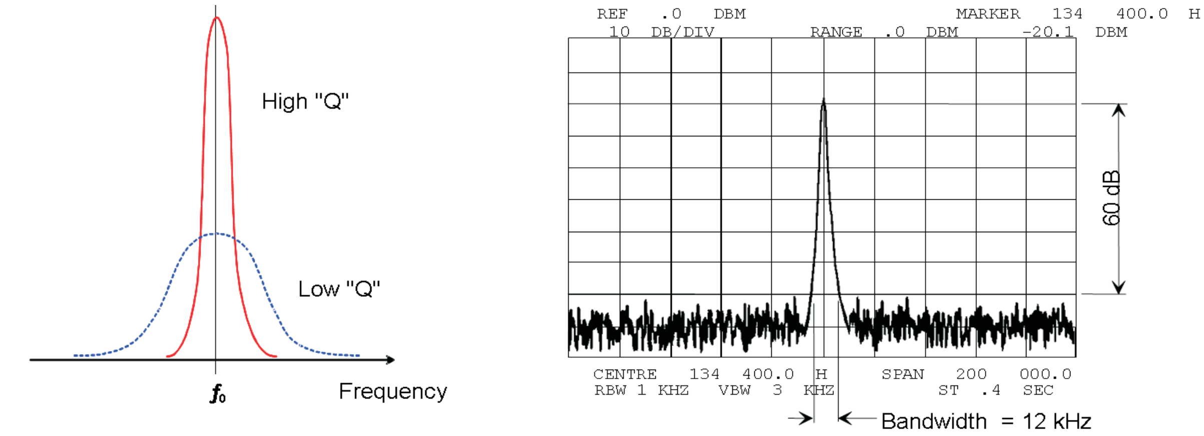


Figure 16. HDX LF Reader Antenna Has Greater Performance and Better Immunity to Noise

The quality (Q) factor is a measure of the effectiveness of an antenna. A high Q antenna will output a higher field strength than a low Q antenna for the same input power. A high Q antenna is also a filter and will reject signals outside the bandwidth. Unfortunately, the higher the Q, the more easily the antenna is de-tuned by the presence of metal. However, within reason, the antenna can be re-tuned for existence in a metal environment with a little separation from metal.

Reading distance is related to tag's antenna size, the bigger the antenna, the greater the range. The tag has to have a 6-dB stronger signal than the background noise to be detected. Writing performance is 1/2 to 3/4 of the reading distance, and the antenna to tag orientation makes a difference, as shown in Figure 17.

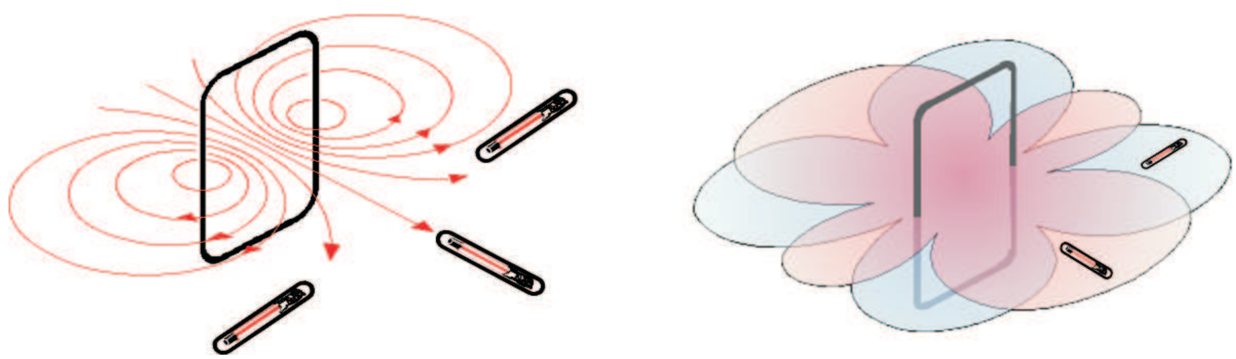


Figure 17. Reading Distance

Low frequency HDX achieves a longer range because the powering phase is independent of the read phase. Unlike LF FDX technology, it does not have to operate in the presence of a strong carrier signal, nor is the weak tag response masked by noisy sidebands. Increasing the power increases the range, without an increase in noise. The receiver is optimized - there is no compromise with higher power. FM is used for the tag response, and the narrow receiver bandwidth gives good noise rejection. There is no technical reason to ever use FDX for any LF RFID application, and especially in the waste management application, where the purpose of the use of the technology is to provide 100% service verification.

9.2 HF

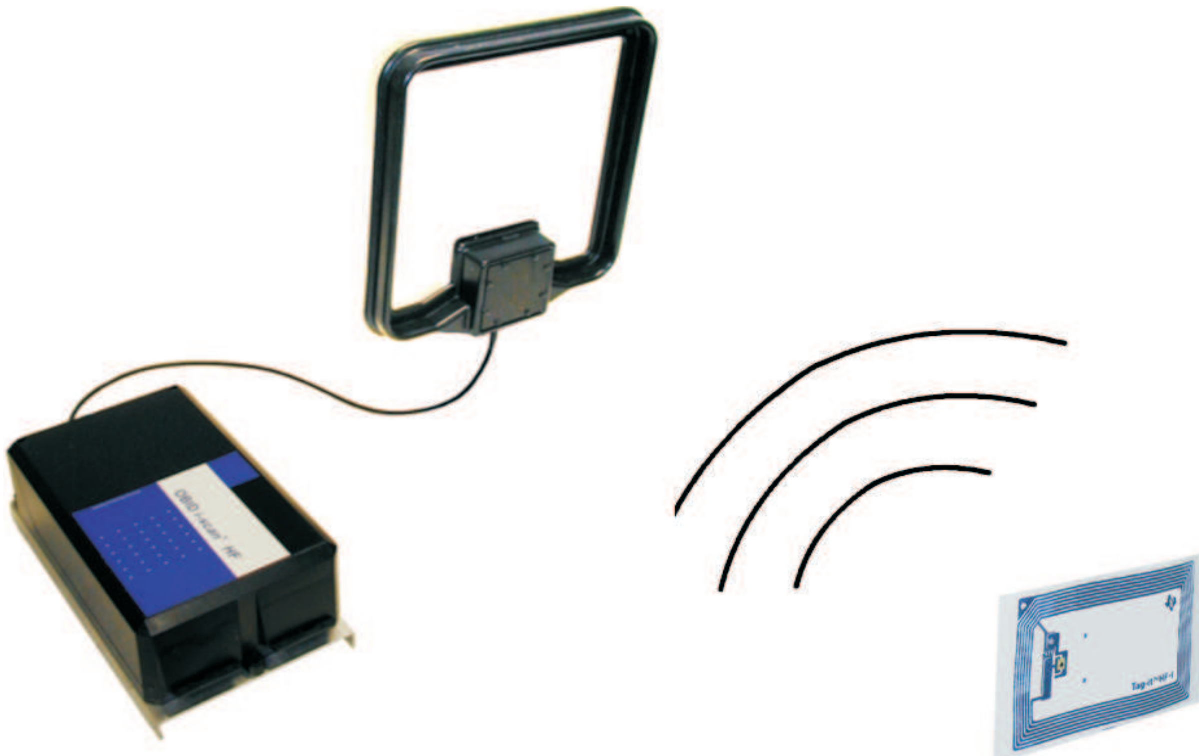


Figure 18. HF Reader/Antenna System

HF readers use the magnetic component (H-field) of the electromagnetic wave to transfer energy from the reader's antenna to the tag's antenna (in the same manner that LF readers operate). While LF and HF systems share the fundamental concept of magnetic field power transfer from the reader to the tag, they differ in some respects.

The reader's antenna induces a voltage in the tag's antenna and the frequency used (13.56 MHz) has a shorter wavelength (λ = 22 m). Because this wavelength is shorter than the LF wave, this RFID system is more affected by some materials, such as metal, PVC, water, but it still has a well defined magnetic field that can be very controlled.

In applications where free space operation is involved or inlay to antenna orientation is known and controlled, this is a great technology to utilize.

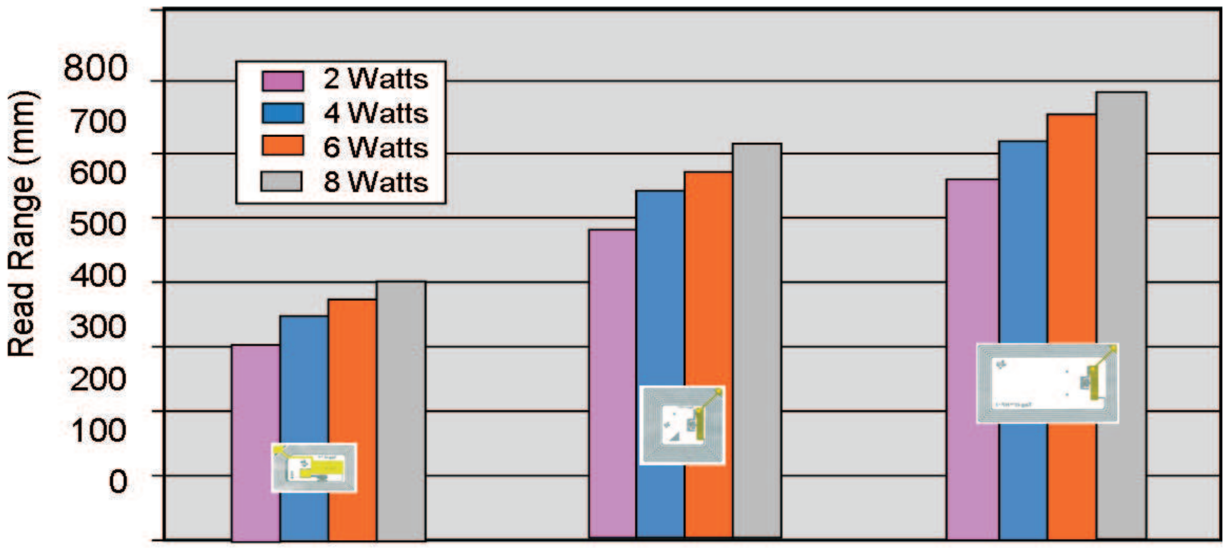
The mention of free space operation brings up an important discussion point for this section, and that topic is dielectric constants and how they relate to the tuning of transponders and the net effect this has on the readability of transponders in RFID systems.

All RFID tags are tuned circuits. As the frequency goes up, the makeup of the materials that the tag comes in close proximity to become factors as they have specific dielectric constants that begin to and in some cases completely detune the transponders to the point where they cease to operate. This statement just made goes all the way back to the work of Ampere, Faraday and Maxwell, specifically the electromagnetic wave equation, whereby the propagation of electromagnetic waves through a medium or in a vacuum is described mathematically. It can be written in terms of an electric field or a magnetic field.

The importance of this set of equations is that one term, c (the speed of light), is used. The speed of light in a vacuum is defined, but it varies with the material medium it is exposed to. This is important because tag designers, especially UHF tag designers, go to great lengths to match the impedance of the silicon to the rest of the circuit in order to properly tune it for maximum performance, and usually with free space in mind or something close to it.

This is where the frequency dependence comes into play, since a material cannot polarize instantly to an applied electric field and must be delayed by the dielectric constant (or electric permittivity) and thus the electric susceptibility of the material is exposed to be what it is, at frequency.

To the layman – what this means in plain terms is that because HF and UHF tags operate at a much higher frequency than LF tags, it is much more of a challenge to create a robust tag that will be as immune naturally to materials/environment that exist in the waste management industry. The exact same rules also apply to the reader antennas. It is of course not impossible, but the odds are that any UHF tags made to truly compete from a durability and readability standpoint will end up being the same cost as LF tags or even higher, while still having the same issues outlined in the points above and not addressing the application properly.



Note: LR2000 Reader with RI-ANT-T01A Antenna (300 x 300 mm)

Figure 19. Typical Passive HF RFID Read Ranges (With Varying Transponder Size and Reader Output Power)

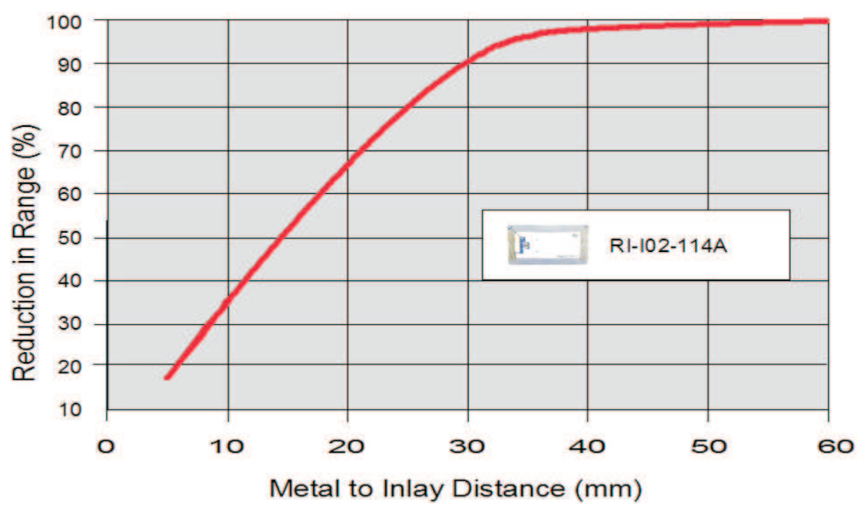


Figure 20. Readability Affected by HF Transponder Proximity to Metal

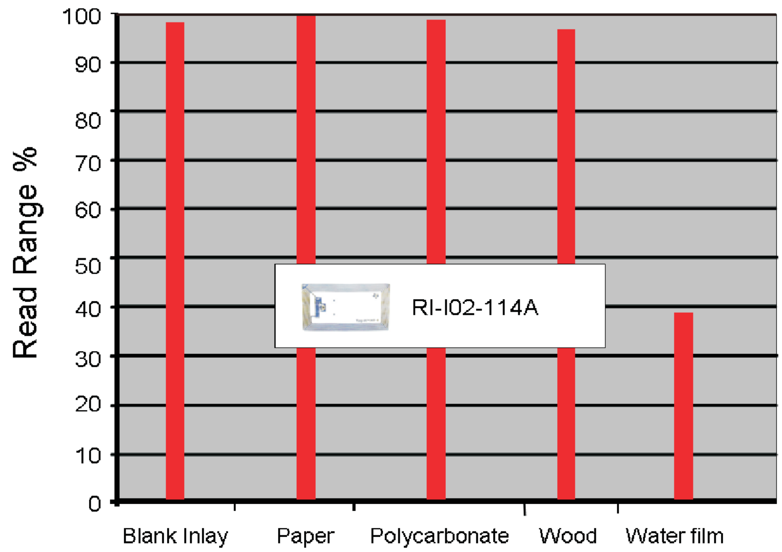


Figure 21. Readability Affected by HF Transponder Proximity to Other Materials

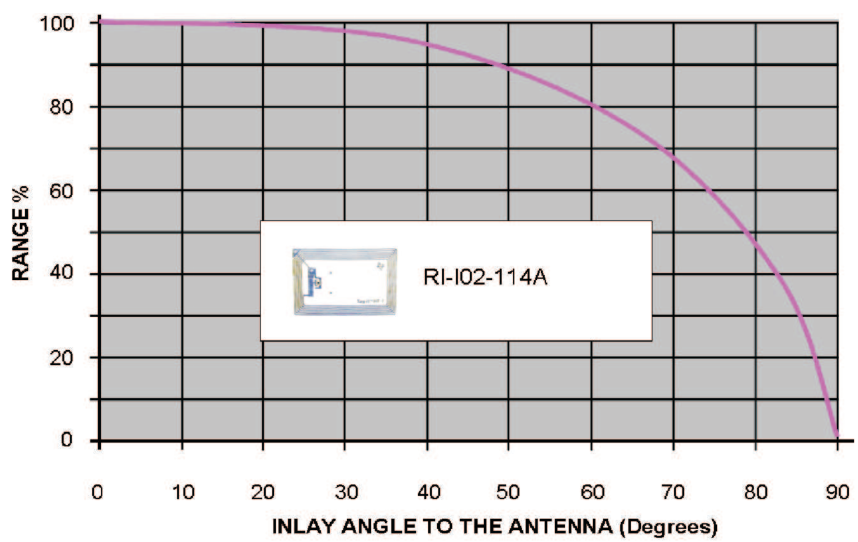


Figure 22. Readability Affected by Orientation of HF Transponder to Reader Antenna

9.3 UHF

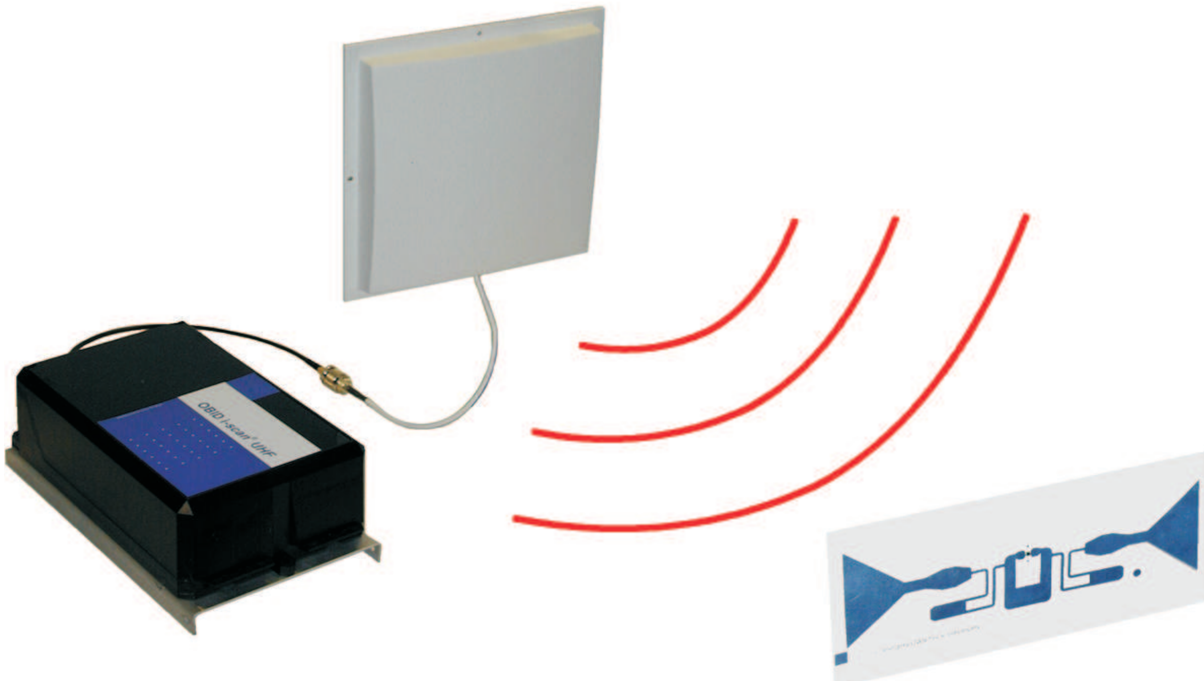


Figure 23. UHF Reader/Antenna System

While the LF and HF systems share the fundamental concept of magnetic field power transfer from the reader to the tag, UHF systems use the electric component (E-field) of the electromagnetic wave to transfer energy from the reader's antenna to the tag's antenna. This is same electric field concept used by cell phones, for example.

The reader's antenna induces a voltage in the tag's antenna, and the frequency used (centered on 915 MHz) has an even shorter wavelength (λ = 32.8 cm). Because this wavelength is so much shorter than the LF and HF waves, this RFID system is greatly affected by almost all materials, water, plastic and especially metal. Additionally, when a linear antenna is used in an attempt to control read field, tag orientation is crucial and when a circular polarized antenna is used, the field is not very controlled at all. This technology was specifically designed to track hundreds of items at a time, at high speed, and the industry acceptable read metrics (tag misses) are well below 100%.

In applications where free space operation is involved, and many items are passing by at high speed, this is a technology to use as a replacement for a barcode vision system as this is what is was designed for. This is also a great technology to use as a barcode label replacement on circuit boards that need to be tracked through a manufacturing process or have the potential for return for upgrade, warranty repair, etc. using a packaged UHF tag IC surface mounted on the PCB, with a fractal, dipole or slot antenna designed around it.

It is important to mention again that tag designers, especially UHF tag designers, go to great lengths to match the impedance of the silicon to the rest of the circuit in order to properly tune it for maximum performance.

This is where the frequency dependence comes into play, since a material cannot polarize instantly to an applied electric field and must be delayed by the dielectric constant (or electric permittivity) and thus the electric susceptibility of the material is exposed to be what it is, at frequency.

The most important tag performance characteristic is read range—the maximum distance at which an RFID reader can detect the backscattered signal from the tag.

Because reader sensitivity is typically high in comparison with tag, the read range is defined by the tag response threshold. Read range is also sensitive to the tag orientation, the material the tag is placed on, and to the propagation environment. Tag designers start a design with free space in mind first and then tune for other materials.

To begin, one must understand a little something about dielectric constants and the relationship they have with the speed of light and the resulting wavelength change they are responsible for when used in an RF application.

The dielectric constant is a measure of the influence of a particular dielectric on the capacitance of a capacitor. It measures how well a material separates the plates in a capacitor and is defined as the ratio of the capacitance of a set of electrodes with the dielectric material between them to the capacitance of the same electrodes with a vacuum between them. The dielectric constant for a vacuum is 1 and for all other materials it is greater than 1.

Table 2. Dielectric Constants

PTFE	2.1
FEP	2.0 - 2.1
PFA	2.1
PVDF	> 5.6
ETFE	2.4 - 2.5

In this example application, we will be making an RFID tag that is made for use on a container made from PTFE. We must take the materials being used in the application into account always and this will show how critical it is with this frequency band (more so than with HF or LF RFID technologies). According to Table 2, the dielectric constant of PTFE is 2.1.

The speed of light, c, in free space is 299.79667268 x 106 m/sec or 983.58488412 x 106 f/sec. It is calculated by the formula:

$$c = \sqrt{\frac{1}{\varepsilon_0 \mu_0}} \quad (1)$$

Where:

$\varepsilon_0 = 8.8542 \times 10^{-12}$ (permittivity of free space constant)

$\mu_0 = 1.2566 \times 10^{-6}$ (permeability of free space constant)

When a dielectric is inserted, the permittivity of the space is what is altered and can be expressed and used in the following manner:

$$\varepsilon = \varepsilon_0 K_e \quad (2)$$

Where:

K_e is the dielectric constant of the material (in this case 2.1 for PTFE) .

Now we can replace a term in the original formula and come up with the actual velocity of propagation through the material, which after calculated, can be used to determine the wavelength of an RF signal through the medium due to the velocity of propagation.

$$c_{(VOP\ PTFE)} = \sqrt{\frac{1}{\varepsilon \mu_0}} \quad (3)$$

Therefore (using 2.1 as the dielectric constant):

$$c_{(VOP\ PTFE)} = \sqrt{1/(18.59382 \times 10^{-12})(1.2566 \times 10^{-6})}$$

$$c_{(VOP\ PTFE)} = \sqrt{1/23.364994212 \times 10^{-18}}$$

$$c_{(VOP\ PTFE)} = \sqrt{42.799069023 \times 10^{-15}}$$

$$c_{(VOP\ PTFE)} = 206.87935862 \times 10^{6} \text{ m/sec} \quad (4)$$

Now that we have determined the speed of light in the medium (velocity of propagation), we can determine two things that will be helpful, the velocity factor (expressed as a percent) and the electrical delay in nanoseconds. Often these values are published, but as an OEM it is always good to double check published results with low level calculations.

The velocity factor is determined by the following formula:

$$V_{FACTOR} = (c_{(VOP\ PTFE)} / c) \bullet 100 \quad (5)$$

In this example: V_{FACTOR} = 69%

The electrical delay is calculated by the formula:

$$d = L / (c \bullet V_{FACTOR}) \quad (6)$$

Where:

d = delay in nanoseconds

L = length of antenna in feet

c = velocity of light in free space

V_{FACTOR} = velocity of propagation expressed as percent

To determine the length of the antenna needed in this application, the following formula can be used:

$$L = \lambda \bullet V_{FACTOR} \quad (7)$$

Where:

L = physical length in inches

λ = wavelength (in free space), ($\lambda = c / f$)

V_{FACTOR} is expressed as a percentage.

In Equation 8, with this material, using 915 MHz (center of the band of interest in this application) as the frequency:

$$\begin{aligned} L &= (12.899\ inches)\ (69\%) \\ L &= 8.90\ inches \\ 1/2\ L &= 4.45\ inches \\ 1/4\ L &= 2.225\ inches \end{aligned} \quad (8)$$

This is a very significant calculation and result, especially as it relates to the waste management application. Notice that the material is responsible for actually slowing down the speed of light and then causing the antenna to become shorter as a result. This same calculation would have to be repeated for each new material's dielectric constant that the UHF tag might be affixed to or come in close proximity with.

The point is that you cannot take an off the shelf UHF tag and expect it to work in this application without failure, like the LF solution has been proven to do. There are many different container materials, and there are many other materials that will be in the container and affect the tag in similar ways and cannot be accounted for and therefore will drastically affect the robustness of the system. This is sensitivity to materials is a weakness in the UHF RFID technology that makes the passive LF RFID technology superior in the waste management application.

To build further on the passive UHF RFID facts, long read range is the goal of these systems. This read range can be calculated, simulated and then designed to and measured, but as mentioned before, the designer will start with free space calculations.

The read range can be calculated using the free-space formula (Friis) given as:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \quad (9)$$

Where λ is the wavelength, P_t is the power transmitted by the reader, G_t is the gain of the transmitting antenna, G_r is the gain of the receiving tag antenna, P_{th} is the minimum threshold power necessary to provide enough power to the RFID tag chip, and τ is the power transmission coefficient given as:

$$\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2}, \quad 0 \le \tau \le 1 \tag{10}$$

where $Z_c = R_c + jX_c$ is the tag IC impedance and $Z_a = R_a + jX_a$ is the tag antenna impedance.

It is very important to note that one of the terms in the equation is τ (the transmission coefficient), and the relation of this term to the fact that the tag can truly only be tuned to one frequency, but must cover a band (in the US) from 902 MHz to 928 MHz (a 26-MHz spread). Charts Figure 24 through Figure 26 (with the example showing the tag tuned for 915 MHz) show the theoretical free space read range spread across the frequency band to be covered, and changing the tag gain from chart to chart. As you can see, the tag gain plays a very important role and there is not a uniform read range because the tag has to be tuned to a frequency (in this case 915 MHz) and the resulting transmission coefficient (on either side of the center frequency) is lower than one. In this example, the transmission coefficient was stepped in 0.05 increments away from 1 and 915 MHz.

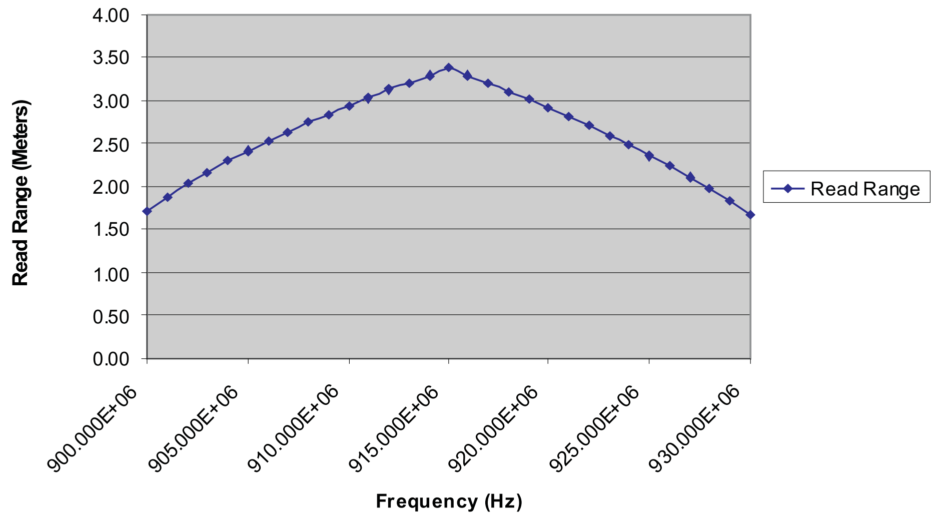


Figure 24. Calculated (Theoretical) Read Range Example with Gain of Tag = 0.5 dBi

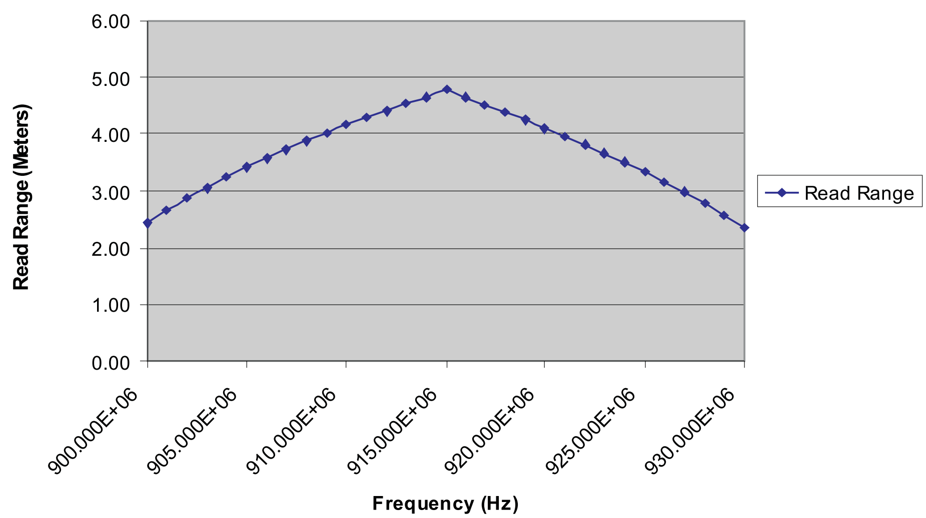


Figure 25. Calculated (Theoretical) Read Range Example with Gain of Tag = 1 dBi

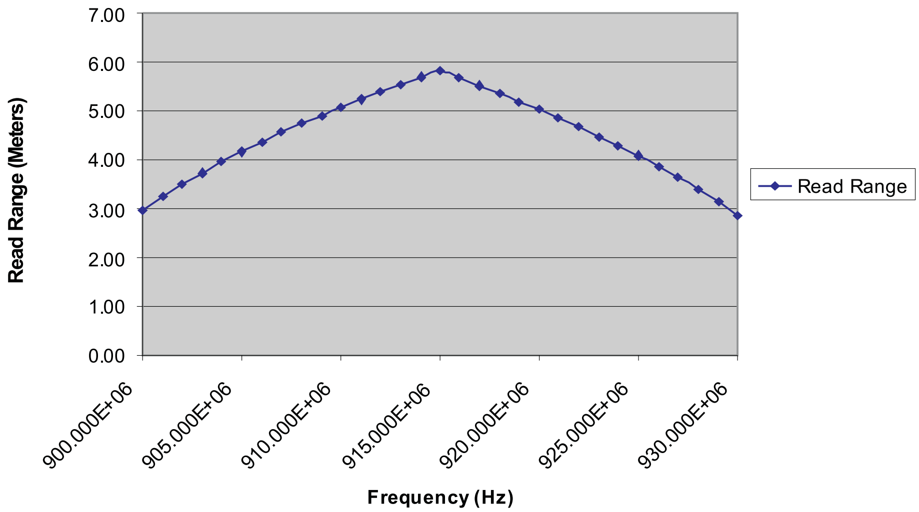


Figure 26. Calculated (Theoretical) Read Range Example with Gain of Tag = 1.5 dBi

The preceding charts show the theoretical free space read ranges for the passive UHF RFID technology, with the reader operating at full power (US) and the tag gains set for three different (but acceptable) values and varying the transmission coefficient as we move away from the 915-MHz center frequency. This is the fantasy world that is being sold in the market today as the miracle of UHF RFID.

Figure 27 is another simulated example of these equations that illustrates the reduction in read range that occurs because of various dielectric constants and the effect this has on the term G_r. One can see that the tag read range is greatly affected as it encounters materials other than free space.

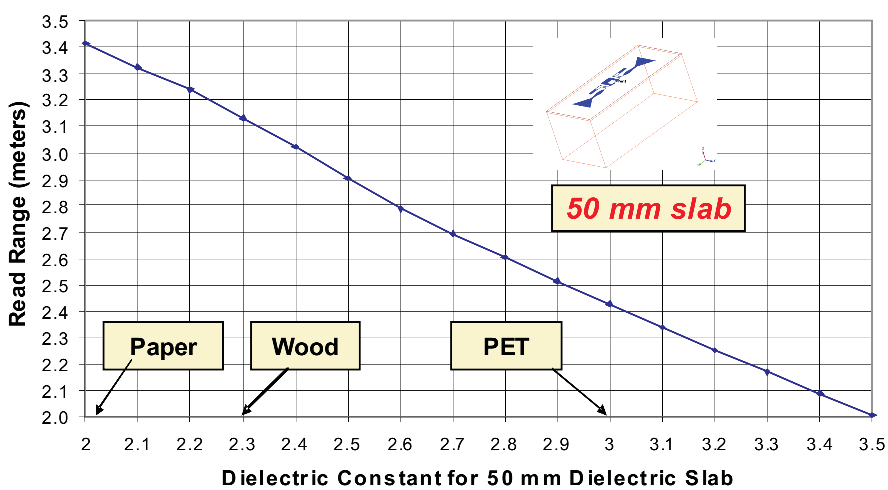


Figure 27. Read Range vs. Dielectric Constant

The point here is that because of the higher frequency = heightened sensitivity of the UHF tag antenna, a UHF tag designer has to know exactly what the materials in the application are and then design a tag with those details in mind. Furthermore, just as with LF and HF the polarization of the tag and the corresponding read range are also details to be considered.

Figure 28 shows the resulting read range (simulated) as the tag nears metal.

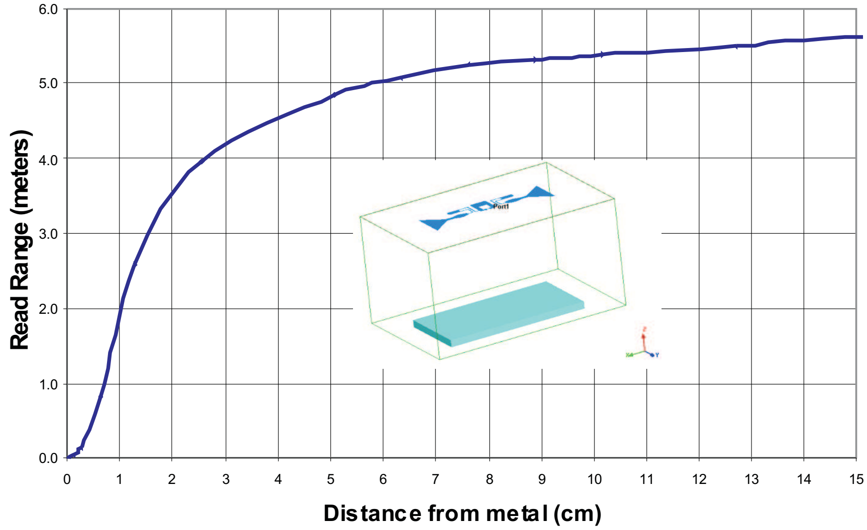


Figure 28. UHF Read Range

10 Review and Conclusions

Why use low frequency half-duplex for waste management? Choosing the right technology such as high, ultra-high or low-frequency (LF) radio frequency identification (RFID) technology for automated waste management usually comes down to the requirements of the application. Factors to consider when making the decision include: how the RFID tag performs in the environment where it is being applied, its read-range and its signal strength.

10.1 Performance

UHF read performance around cell towers, wireless DOT cameras, and other licensed and legal UHF ISM band transmitters is greatly affected in the areas where they might co-exist. That spectrum is full of licensed transmitters that will not be shut down if they interfere with a passive RFID application.

The RFID readers are unlicensed intentional radiators. Licensed transmitters have the right to “step on” them whereas the reverse is prohibited. There are very few if any licensed low frequency transmitters in residential areas whereas the reverse is true in the 902- to 928- MHz band. If there are devices in the application that “step on” the LF RFID readers, (for example in the waste vehicle), they can be easily identified and shielded.

The UHF tag 96 bit EPC code can be duplicated or copied; LF tags cannot be duplicated or copied. Furthermore, if LF read only (R/O) transponders are used in the waste management application and a read/write (R/W) transponder is used to copy the R/O serial #, it (the R/W transponder) still would return a specific start byte to the reader indicating that it was an R/W and be caught as a fake immediately at the point of read.

UHF tag range is very long and geared towards reading as many tags as possible and cannot be singulated easily. In the waste management application, this is not thought to be a desired quality. The application out in the field demands a controlled, homogenous read zone that reads one tag at a time for service verification.

All RFID tags are tuned circuits. As the frequency goes up, the makeup of the materials that the tag comes in close proximity with become factors as they have specific dielectric constants that begin to and, in some cases, detune the transponders completely to the point where they cease to operate.

To the layman, what this means is that because HF and UHF tags operate at a much higher frequency than LF tags, it is much more of a challenge to create a robust tag that will be as immune naturally to materials/environment that exist in the waste management industry. The exact same rules also apply to the reader antennas. It is of course not impossible, but the odds are that any HF UHF tags made to truly compete probably will end up being the same cost as LF tags or higher, while still having the same issues outlined in the points above.

Additional reasons why LF HDX is the right choice of the wise waste management professional:

It's been in the trenches. TI LF applications are tried and tested with well over a decade of field experience in cattle, automotive, petroleum refinery, payment and waste applications.

The form factor for LF transponders already exists with a family of inlays, rigid over-molded and glass tags that are compatible with waste disposal units. It really is a rugged, field-proven technology. The animal tracking industry, rife with uncontrollable variables such as weather, unpredictable terrain and other obstacles, has used LF technology for more than 18 years with great success.

Listen before you speak: An LF air interface communication scheme called half duplex frequency modulation means the reader pauses during the tag's response to retain signal strength. Other LF products transmit and respond at the same time (a full duplex frequency system), thereby weakening the signal strength. Consider that the motor and the control lines of the garbage truck can also interfere with the reader and transponder, and the need for a strong signal becomes apparent.

LF works well around a metal environment. LF signals are magnetic, small and direct, meaning they don't bounce off the truck's metal walls, and they don't interfere with the signal between the LF tag and reader which creates very accurate reads.

LF has a suitable read range especially in communities where trash disposal units are lined up in close quarters. In the applications where UHF was deployed for waste management, about a 17% failure rate was seen, and those systems were subsequently replaced with LF HDX systems, which have proven to be the correct replacement and provide 100% read rates. Additionally, a UHF RFID system's longer read range will mean that in a multiple container environment or in a cul-de-sac, all the containers will be read at once (or not singulated) and eliminate the benefit that the RFID system was installed for in the first place. It's already hard enough to keep up with them without help from the inaccurate readings the UHF RFID will give in the waste management application.

10.2 Ease of Installation / Cost of Ownership

TI-RFID low cost LF reader systems are made to be mobile, UHF fixed readers are made to be fixed in a warehouse, not to necessarily endure the repeated stresses/shocks and environmental (temperature/humidity) swings they will experience during a waste vehicles service lifetime.

TI-RFID LF readers offer a wide input voltage range and can be operated off the vehicle voltage bus, while commercially available UHF readers require their own custom power source that would need to be connected then to an inverter in order to operate off the vehicle voltage bus.

TI-RFID LF reader/antenna systems are easily installed, tuned, operated, and are a relatively zero maintenance component when properly installed, whereas the installer of a UHF reader system might need some very specialized knowledge and equipment to ensure performance was optimized. Additionally, periodic maintenance might be required for a UHF installed system to sweep the cables, the antennas and check the reader output power.

Texas Instruments offers a wide range of field tested standard form factor LF tags that can "drop in" to the waste application and meet a wide variety of requirements from memory size to read distance. UHF tags are fixed memory and any tag created and put in to service would more or less burden the installer with being a pilot. There are several examples already of UHF being deployed in the field for waste management and failing to go the distance that LF tag and reader systems can and have done.

The LF system antennas can be custom made and fabricated very inexpensively by the layman using our application notes and leveraging our applications staff – HF and UHF reader antennas cannot be – it takes very special knowledge and expensive equipment to make and tune HF and UHF reader antennas. Our applications staff knows, we have experience will all three frequency bands, but for the waste management professional, we feel obligated to recommend the correct technology for this application – LF HDX.