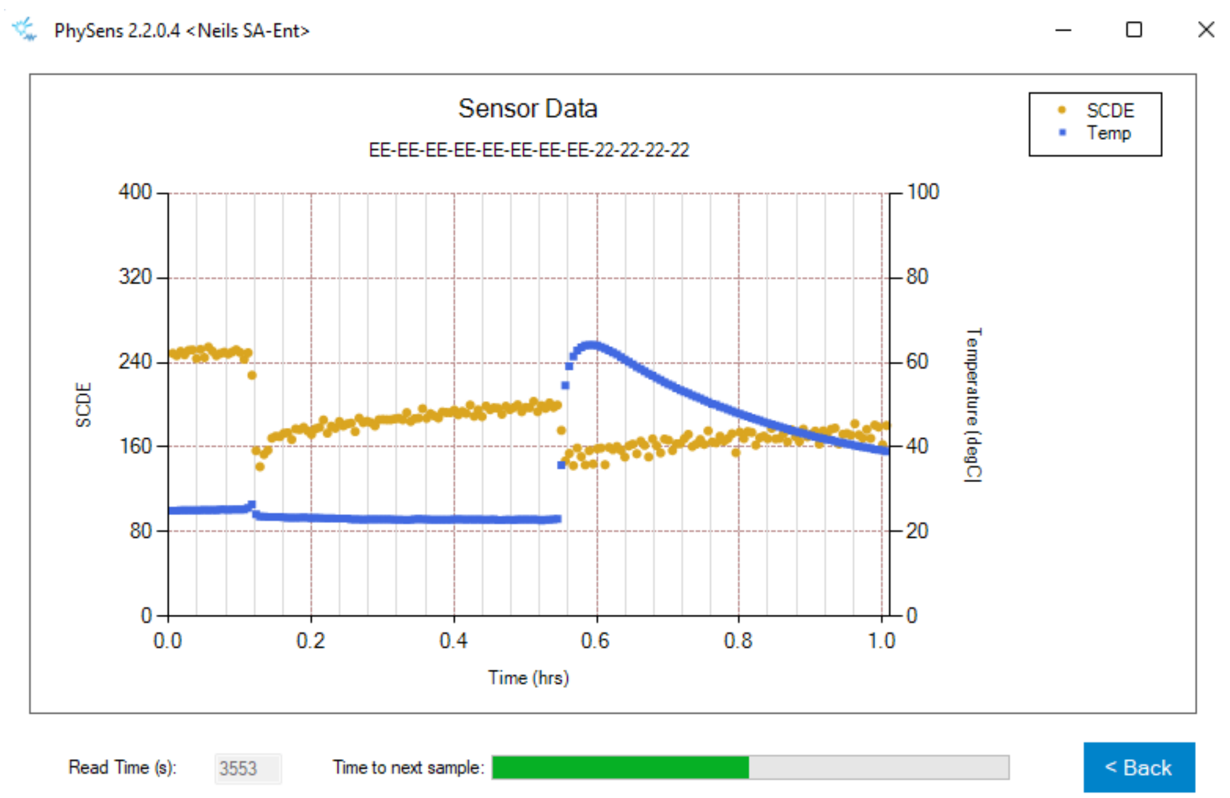
Water Leak Detection Using RFID

PRACTICAL USE OF PASSIVE SENSORS



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Caution

Reader antennas should be positioned so that personnel in the area for prolonged periods may safely remain at least 31 cm (12.2 in) in an uncontrolled environment from the antenna’s surface. See FCC OET Bulletin 56 “Hazards of radio frequency and electromagnetic fields” and Bulletin 65 “Human exposure to radio frequency electromagnetic fields.”

Vorsicht

Reader Antennen sollten so positioniert werden, dass das Personal im Bereich über einen längeren Zeitraum kann sicher bleiben mindestens 31 cm (12.2 Zoll) entfernt von der Antenne Oberfläche, in einer unkontrollierten Umgebung. Siehe FCC OET Bulletin 56 "Gefahren der Radiofrequenz und elektromagnetische Felder" und Bulletin 65 "Human Exposition gegenüber hochfrequenten elektromagnetischen Feldern."

Revision History

Version	Author	Date	Changes
1.0	J. Major	Feb 2023	Initial Document

Table of Contents

Terminology

Term		Description
Sensor terms	Die	RFID sensor semiconductor chip
	Inlay	RFID die + RFID energy harvesting antenna
	Tag	Inlay on a substrate (often PET plastic)
	Label	Tag embedded inside a printable encapsulation
Other	RF	Radio Frequency (transmission and/or reception)
	RFID	Radio Frequency Identification.
	UHF	Ultra-High Frequency (in the context of RFID ~860-960MHz)

Introduction

This document describes the use of RFID, a stable and mature technology, to interact with a passive sensor capable of detecting moisture.

A passive sensor requires no batteries or wires. An example of this would be a solar powered sensor using a cellular connection to stream data to a user. The sensors discussed in this document can detect wetness in contact with the sensor and/or humidity surrounding the sensor. The sensors are quite low cost, physically small, and in many cases paper thin.

This application note focuses upon the detection of leaks and moisture using UHF RFID (also known as RAIN RFID) equipment tailored to interrogate or read passive sensors utilizing specialty RFID die. However, much of the general discussion of using RF radiation to interrogate passive sensors is applicable to the broader class of sensors that interact with RF sources.

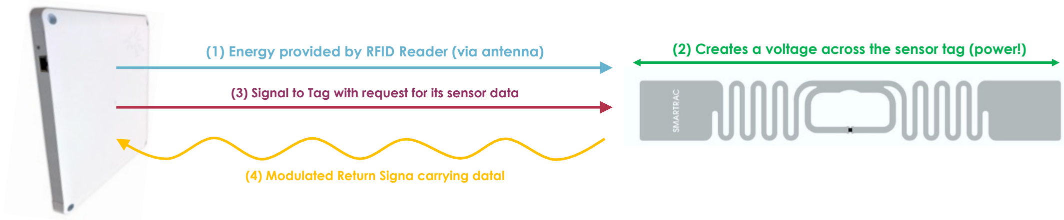
Basic Operation

The sensors use energy harvesting from a nearby transmitter to power themselves and transmit information back to the same antenna sending power to it.

In more detail. a reader is connected by an RF cable to one or more antenna, each transmitting RF power (and some instructions for the sensor) . Each sensor receives power from the RF field generated by one of the nearby antenna, energizing the sensor. Once active, the sensor measures and stores the sensor data in volatile on-board memory. The reader, using the same antenna, sends a sequence of commands that instructs the sensor(s) to send the identification number of the sensor and its sensor measurements back to the reader. The sensor reflects the energy received back to the readers antenna (the same one sending the RF power) and encodes the sensor data on the reflected signal in a manner the reader can interpret.

Since the sensor data is stored in volatile memory on the sensor, the sensor data is lost when the RF power being delivered to the tag is turned off. The sensors do not function (capture data) unless the RF field is operational.

The system can interrogate a high number of sensors simultaneously (e.g., tens, hundreds . . .). Further the system can interrogate different types of sensors. Thus, a single reader can provide information from many locations within an environment and can collect a wide variety of sensor data, including temperature, wetness, relative humidity, light, pressure, strain, etc. – all at the same time. Most readers support 4 antenna allowing a single reader to interrogate a larger area than a single antenna system (and hence more sensors).



The Reader and Antenna:
a) Send power to the sensor tag
b) Send a request to "interrogate" the sensor tag
c) Receive sensor data back
d) Sends that data to the server, cloud or computer

Sensor tag contains:
a) Energy harvesting antenna
b) A microchip
c) A backscatter transmitter
But NO battery!

Figure 1 - RFID Reader Antenna Energizing a Passive Sensor

Contact Detection vs. Humidity

Humidity simply describes the storage of water in air. Relatively humidity (RH) describes the amount of water in air compared to the maximum water that can be stored in air. Generally, RH is described as a percentage. Since the amount of water that air can hold increases with temperature, RH is a function of both the amount of water in the air and temperature. Specifically,

RH(%) = (water stored in the air/maximum water that can be stored in air at this temperature)

All the moisture sensors supported by SensThys will detect changes in humidity. Generally, these sensors can show trend data on humidity. However, the AS3213-RH relative moisture product from Asygn provides percent relative humidity, properly adjusted for temperature, as a reader output.

In leak detection applications, however, the leaks are generally small enough that the relative humidity around the sensor doesn't change. To detect small leaks, the water must physically touch the sensor.

Fortunately, these sensors are quite sensitive to water and can detect as little as 100 mL of water in contact with the sensor. That is just 1/5 of a drop of water!

However, surface tension can prevent water from a leak from reaching the tag rendering that leak non-detectable. This can be mitigated (see later in this document) by applying a wicking material to draw the water to the sensor making even small water leaks detectable.

Leak Detection Methodology

For successful sensor applications, there are conditions that must be met.

SENSOR: An appropriate sensor must be used. Selecting the right sensor involves a series of decisions, including

(1) Which sensor die should be used?
(2) What is the physical environment where the sensor will be located?
(3) What kind of inlay is required to function in the environment?
(4) What kind of label is needed and what information is required and how will that information be collected in operation?

PHYSICAL CHANGE: The second condition is that the sensor be situated so that it detects the physical change. Specifically, the application needs to align with the physical behavior of the sensor, here are some examples:

(1) A leak detector works by water physically touching the tag - the tag will be blind to water near the tag but not physically touching the tag.
(2) Strain gauges are linear devices – they will not detect strain in a direction orthogonal to the axis of the sensor.
(3) Sensors that are sensitive to physical changes must be placed in a region where the properties of the material change.

READ: The sensor must be located such that it can be successfully powered up and interrogated by an antenna connected to the reader. The workable distance from the antenna depends upon the antenna and sensor chosen and can range from 1 to ~10 meters. Within this range, the RF can generally pass-through non-conductive materials, such as fiberglass, foam, fabric, and dry wood In addition, RF can also pass through materials that are *partially* blocked by metal, effectively passing through the openings in the metal. An RF beam that passes through material generally loses some power reducing the read range.

Sensor Overview

These sensors are comprised of several parts. The first is the sensor die. These sensor die are complex integrated circuits that combine the functionality of RFID with sensing capabilities. The sensor die is shown in Fig. 1. In this case, the sensor is a strain gauge from Asygn, mounted onto an inlay from Tageos.

Figure 2 - The sensor die. For scale, the word “ASYGN” is 7 mm across.

The die is mounted onto a layer that contains the basic electrical structure allowing the die to operate. This is called an inlay. An inlay from Smartrac (Avery-Dennison), with an Axzon die, is shown in Fig. 2. The patterned aluminum forms an antenna to receive and reflect RF power from the antenna connected to the reader. The dimension of this inlay is 3.5 in x 1 in (9.6 cm x 2.6 cm). When the die is married to the inlay, the sensor becomes functional.

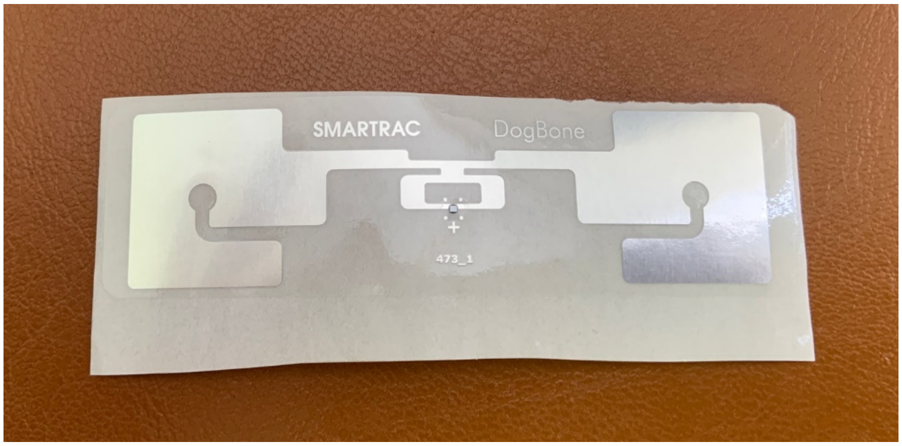


Figure 3 - The sensor die mounted onto the inlay.

An inlay is often provided with an adhesive on the backside and referred to as a “wet inlay”. In usage, this allows a “peel and stick” mounting practice. Fig. 3 shows the inlay being separated from the backing material. After removal, it is ready to be stuck in place! When used as a final product, this combination is referred to as a tag.

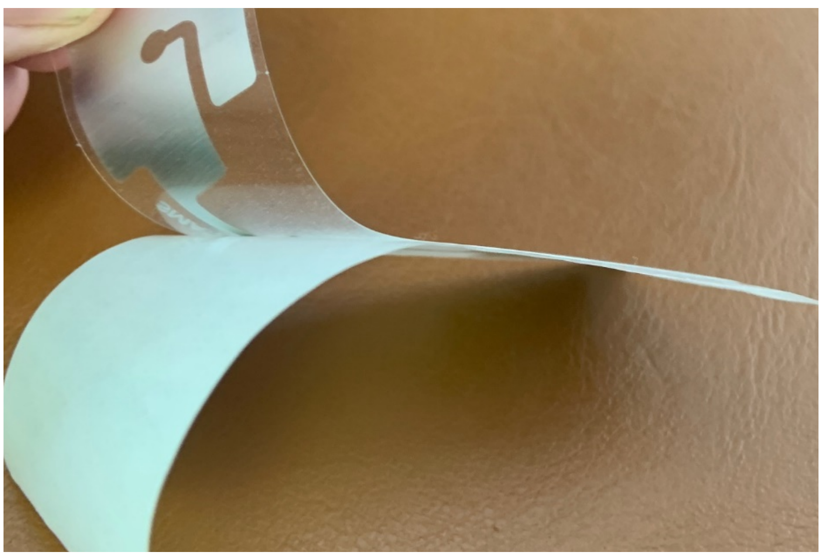


Figure 4 - The inlay, with an adhesive on the back being removed from the backing material.

The inlay (tag) *may* be further laminated between additional materials (paper or plastic), typically with information printed to provide human and machine readable information. Often a “serialized” barcode is also provided. The cover can be printed with black or full color ink. Collectively this is termed a label.

The unique electronic identifier of the sensor, called the "Electronic Product Code", or EPC, is generally linked to the location of the sensor in the automotive, equipment, or physical plant. EPC's provide more information than a traditional bar code. Bar code normally identify a type or SKU (e.g. blue socks) but not an individual item (blue socks, pair 32,587). This makes identification of a leak or moisture trivial since each sensor has a unique EPC to all other sensor tags. The information printed on the label is generally linked to the information stored in memory on the label and is customized to meet the needs of the customer.

A key advantage of these passive sensors is that, unlike a barcode, the EPC may be programmed or written to. This allows custom encoding to be used to identify a location, e.g. Brand X, Model Y, B-pillar, right-hand side.

Figure 5 - The sensor with a front label. The label can include information stored on the tag and information helpful in the customer environment.

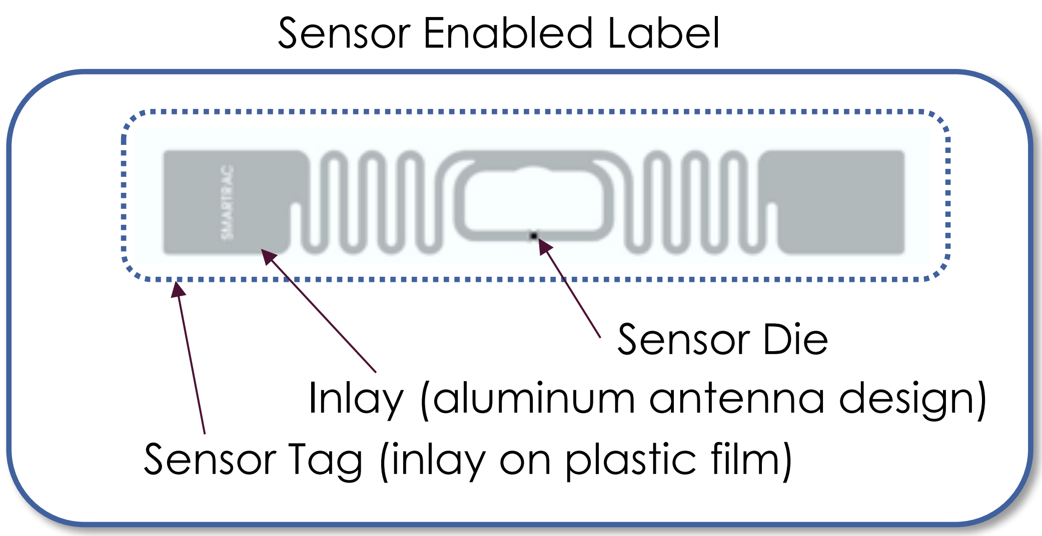


Figure 6 - Sensor label components

It is critical to understand that there are many choices available when selecting a sensor. Each sensor type has different capabilities. In this note, we have provided only a cursory overview to help you start selecting your sensor. Please contact SensThys for a more comprehensive recommendation.

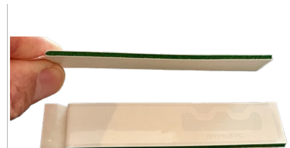
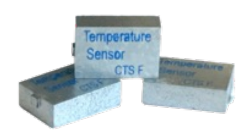
	Conventional	On-metal	Ceramic
			
Construction	Peelable film strip (flexible plastic film with aluminum antenna)	Longer strip wrapped around an insulating layer	Sealed ceramic package
Thickness	Paper thin	Dollar coin thickness (2mm / 0.08")	2 or 3 coins stacked (3 - 5mm / 0.1" - 0.2")
Other dimensions	¼" x 2" to ¾" x 4"		14 - 24mm x 10mm ½" – 1" x 0.4"
Cost	Low	Medium	High
Use	Non-conducting surfaces e.g. cardboard, wood, plastics, glass	Conducting surfaces e.g. metal and carbon fiber	Any surface
Temperature	-40C - +85C	-40C - +85C	-40C – +250C

Figure 7 - An overview of basic sensor types

For standard leak detection, sensors can be designed to operate on insulators and on conductors. In addition, the sensor can simultaneously acquire both a moisture reading and temperature. We offer a variety of sensor tags utilizing Axzon and Asygn die for these applications.

The selection of the right sensor is hard. This selection process begins with the sensor die, but then covers a wide variety of topics spanning the material properties surrounding the sensor, inlay characteristics, data integrity, and the information required for the specific use case. Please contact SensThys so that we can assist with this.

Wicks: Water to the Sensor

Our focus in this note is leak detection. The physical change detectable here is water touching the sensor. However, in most situations the actual location of the leak isn't precisely known, so how do you get the water from a leak with unknown position to the sensor?

A fabric wick, or wicks, is ideal for transporting water from leak(s) to the sensor.

The wicks used in this application are ~5mm wide. They have an adhesive on the backside. The fabric is designed to transport liquids from a water source to a second location, here the leak and the sensor, respectively.

We use the unit of ml (10^-3 Liter) as our unit to describe leak volume. To aid the reader, one ml is approximately twenty drops of water.

1 drop = ~50 x 10^-6 Liter = 50 microliter = 0.05 ml

The sensors are quite sensitive. Figure 8 shows the change in the sensor code of the tag following the application of 0.025 ml, only ½ of a drop of water. A clear change in the sensor code is observed. Fig. 6 is an example of the real-time graphing capability of the SensThys software platform. This figure is simply a "cut and paste" out of that application.

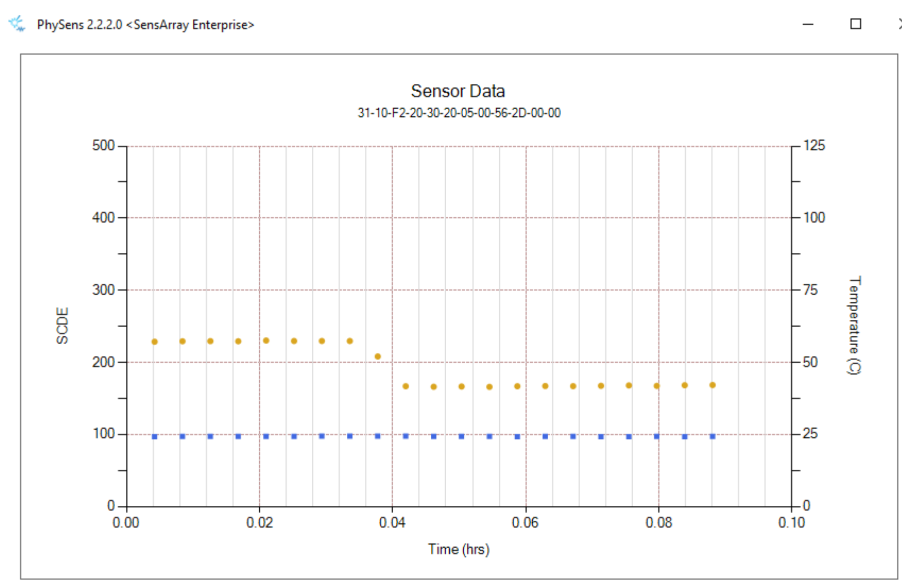


Figure 8 - The sensor detects 10 microliters of water.

Key Point: Sensors can detect water sources on the order of 0.01 ml (10 microliters)

We now examine the performance of the wick. The typical application is unidirectional, from the leak to the sensor. Fig. 7 shows the progression of the water from a liquid source. The water source is varied from 0.025 ml to 0.4 ml.

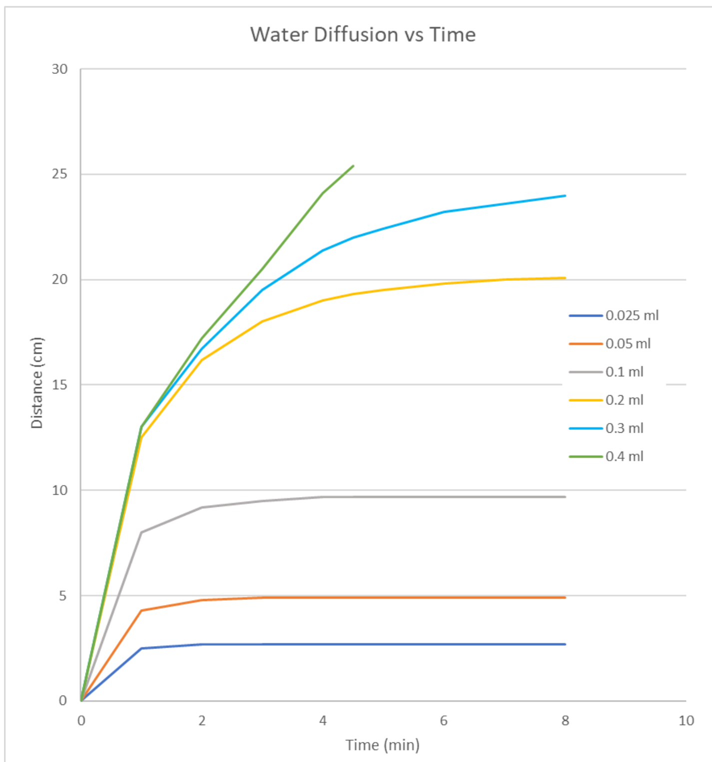


Figure 9 - The diffusion of water in the wick vs. water volume and time.

With a water volume of only 0.1 ml, the wick can transport the water 9 cm within 2 minutes. As the volume increases, the distance increases. At a volume of 0.4 ml, the wick can transport the fluid 25.4 cm in 4.5 minutes.

Key Point: The wick can extend the range of detection for the sensor by ~25 cm.

At this point, the combination of the sensor and wick are shown.

A wick of 23 cm is placed on a sensor. 3 cm of the wick is placed on top of the sensor, leaving 20 cm of wick. 0.4 ml of liquid is placed at the end of the wick about 1 minute after the experiment starts. The liquid moves to the sensor in approximately 3 minutes at which point the sensor clearly indicates the presence of the liquid.

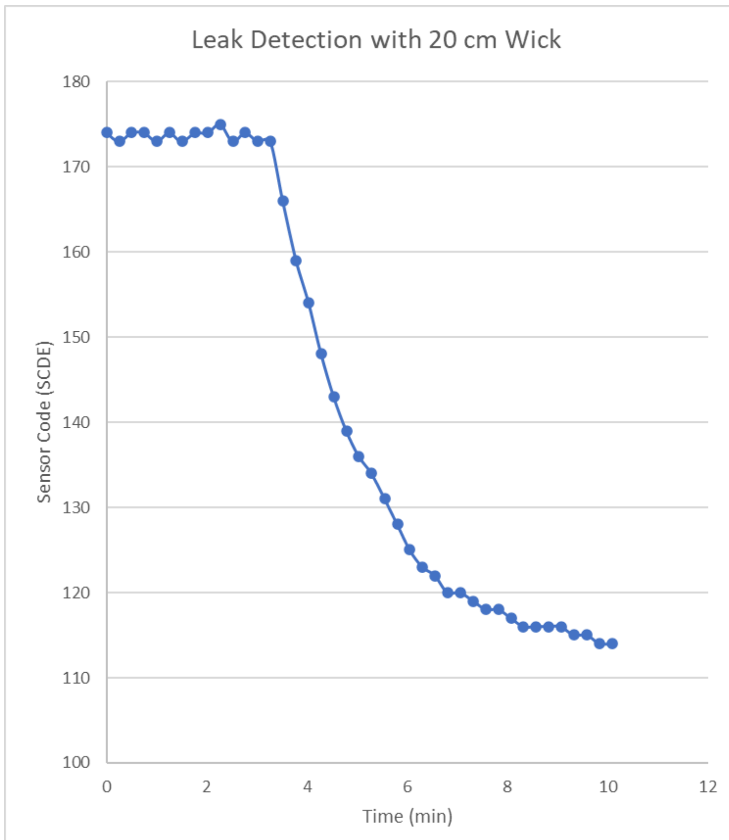


Figure 8 A wick guides the water from a leak to a sensor 20 cm away. The leak is clearly observed by the sensor.

Wick placement

We now discuss how to use the wick in manufacturing situations. The function of the wick is to transport the water from potential locations of water ingress to the sensor for detection. We suggest that the location of leak be worked through carefully. If the region is visible, then simply observing the origins of water and the path of water is perfect. If not visible, an alternative is to use a boroscope or similar camera system to inspect the region during water ingress.

Key Point: Wicks can transport water horizontally or vertically down.

A wick will not pull water up a significant distance. Thus, the wick should be used to pull the water “across to” or “down to” the sensor.

Many leak detection applications require that the tags be mounted to metal. These are called “on-metal” tags.. Let’s examine this type of sensor and how to mount the wick to this type of sensor.

Figure 10 shows the top view of an on metal tag. From the top, it looks like an ordinary sensor.

Figure 10 - The front label side of an on-metal tag, the AZN3110

Figure 11 shows the back side of the on-metal tag. The back of the tag is clearly a metallic layer. This is quite different than the appearance of a sensor intended for mounting to a non-conductive surface.

Figure 11 - The back of the on-metal sensor. The back of the on-metal sensor is primarily metal.

On-metal sensors have a foam layer separating the back metal layer from the front of the sensor. This can be seen clearly in Figure 12. The left image shows the front and side, while the right image shows the back and side. The black foam layer is clearly visible.

Key Point: The wick will need to be placed near the end with the foam visible.

Figure 12 - The foam layer as seen from the top (left) and bottom (right) of the sensor.

Many on-metal sensors have regions where the bottom metal is connected to the top part of the tag. This is seen in Figure 13, which shows the other end of the sensor from the top (left) and the bottom (right).

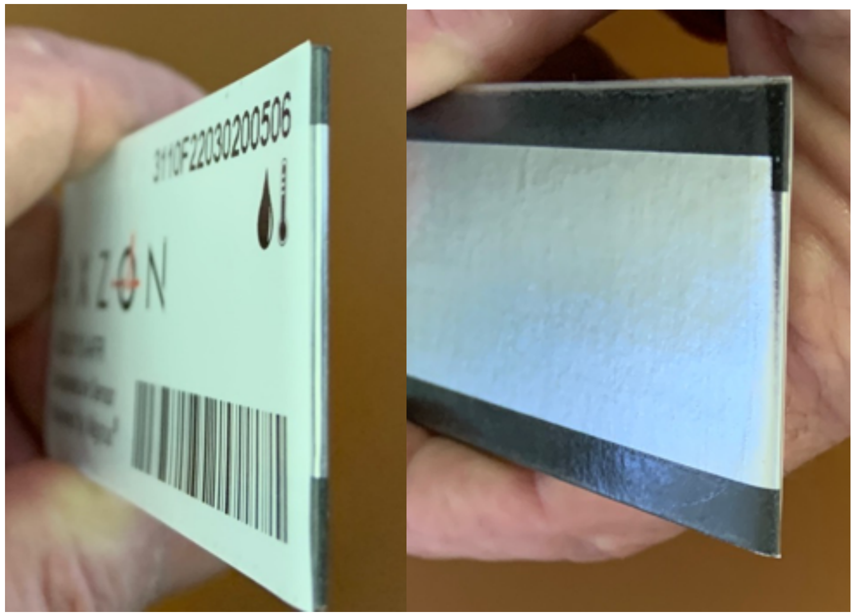


Figure 13 - The other end, showing the bottom metal in contact with the top portion. This is the "shorted end". Shown from the top (left) and bottom (right).

Key Point: Do NOT put the wick close to the shorted end.

To place on-metal sensors, first remove the protective layer on the back of the sensor, exposing the adhesive. Then simply press the sensor into place so that the adhesive makes good contact, holding the piece in place.

Next, remove the backing of the wick and place the 2-3 cm of the wick onto the end region of the sensor which shows the black foam. Provided that 2-3 cm of the wick is on the sensor, the exact orientation of the wick does not matter. Further, multiple wicks can be applied to a sensor to expand the area of sensitivity for the sensor.

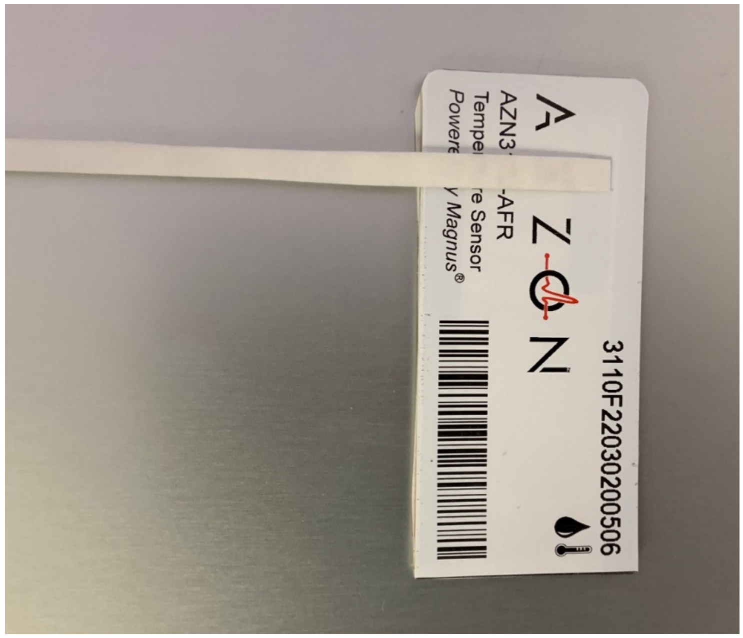


Figure 14 - An example of how to place the wick upon the sensor. The wick is on the "foam" end of the sensor.

Reading the Sensor

Reader Antenna

Since there are no wires and no batteries, these sensors **receive power** from and **transmit** their status back to an antenna, which is also referred to as a read point. A single reader can support many "read points".

The RF power emitted from the antenna emerges from the flat polycarbonate surface of the antenna at about a 140-degree angle. Tags sitting beside or behind the antenna will receive much less power and may not be read.

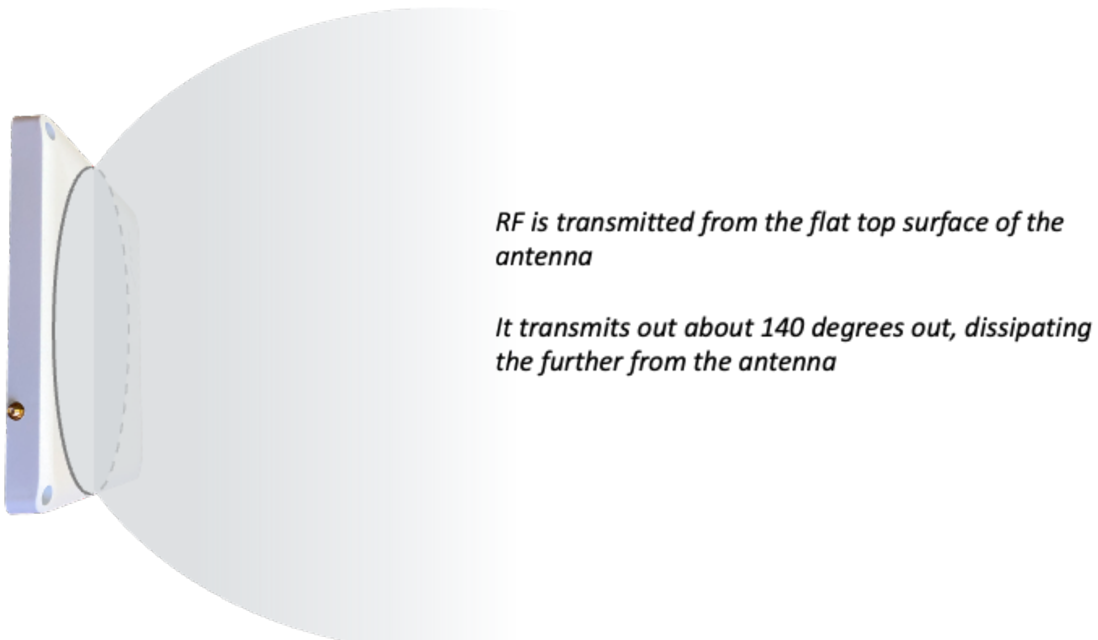


Figure 15 - Showing the RF power transmitted by the antenna.

The top surface (white plastic) of the antenna should be clear of foreign objects. Putting any object on top of the antenna will change the performance. High index materials, such as a piece of plastic or a book, will detune the antenna. Placing conductors, including liquids, carbon fiber and all metals on top of the antenna will dramatically decrease antenna performance.

Certain materials, such as an empty cardboard box, are fine, but a good general rule is not to put things on top of an antenna.

Key Point: Don't put items on top of the antenna.

Next, antennas have a region called the "near field". Inconsistent reads can happen in the near field. To avoid this, please avoid having materials, including sensors, closer than the width of the antenna. This is shown in the following figure.

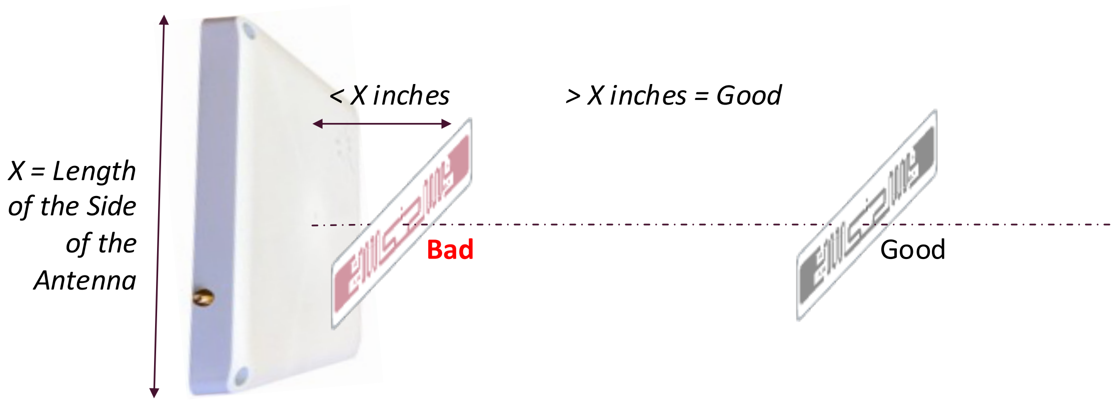


Figure 16 - Showing acceptable read distance from the antenna.

Key Point: The sensor should be at kept a distance at least equal to the dimension of the antenna away from the antenna.

Sensor Orientation

The sensor includes its own antenna – and the performance of this antenna is dependent upon the orientation of the antenna in the RF. For these sensors, we recommend that the antenna be flat in the same plane of the antenna. In addition, we strongly recommend that that primary axis of the antenna not be perpendicular to the plane of the antenna, as this orientation will deliver minimum power to the sensor.

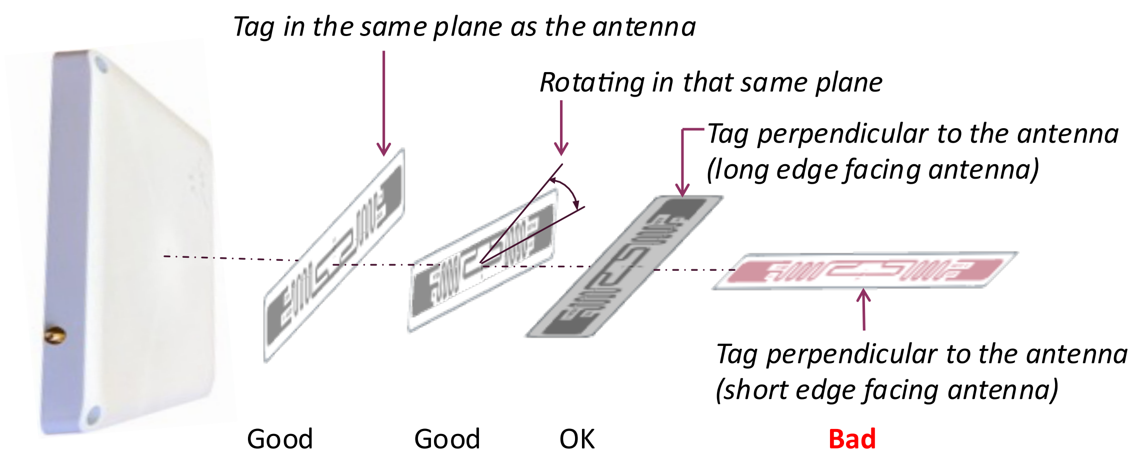


Figure 17 - Showing the orientation of the sensor to the antenna.

Key Points:
Have the plane of the sensor parallel to the plane of the reader antenna.
Don't have the long sensor axis perpendicular to the plane of the reader antenna.

Material Interactions

These sensor tags are powered by radio energy delivered by the antenna and communicate back to the same antenna using that power. Generally, the RF power can pass through non-conductive material – wood, fiberglass, plastic, cloth, oil, leather. However, the RF power cannot pass through conductive materials, including conductive liquids, carbon fiber, metal, etc.

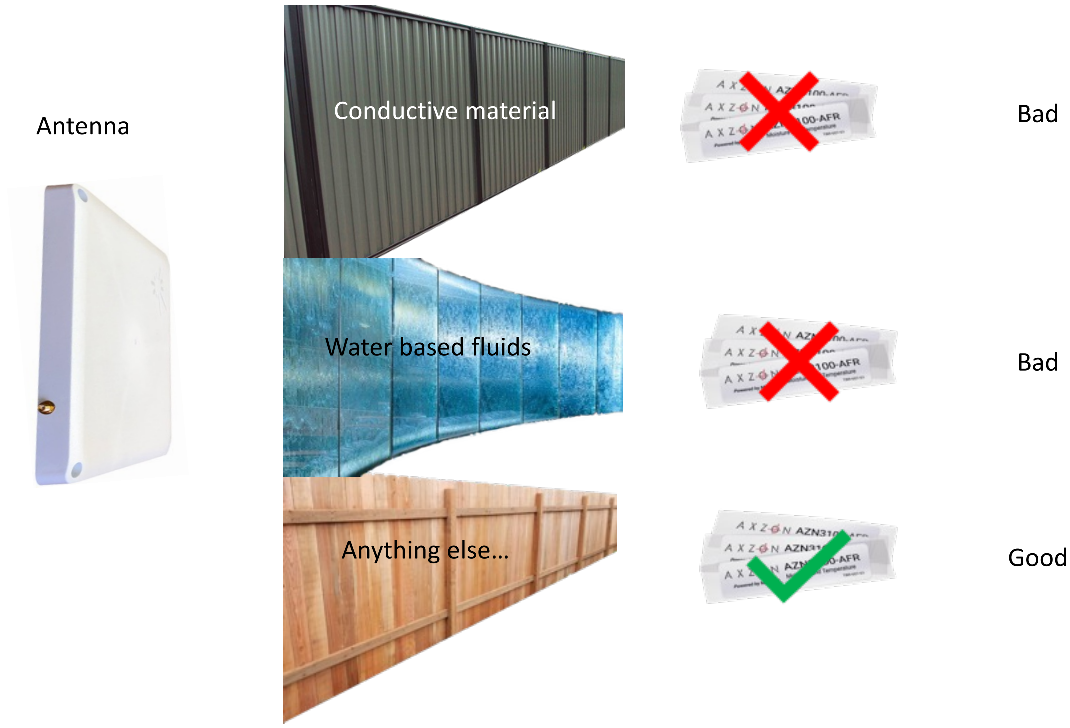


Figure 18 - Showing what materials are compatible with RF transmission.

The RF power can often go through metallic objects that have holes. An example of this is a metal fence.

Figure 19 - RF power can often pass through conductive structures with significant openings such as a chain link fence.

In practice, getting reliable high-quality data from RF sensors is almost always achievable. However, it is often the case that expert on-site support is required for complex situations. In the case of leak detection, one example of this complexity in the automotive world is finding leaks behind extensive wiring harnesses and trim panels.

Calibration

For moisture/wetness, the sensor code (SCDE) of the tag is reviewed. The following discussion will focus upon results from the Axzon 3110, however, much of this discussion can be generalized to the wider category of moisture detection.

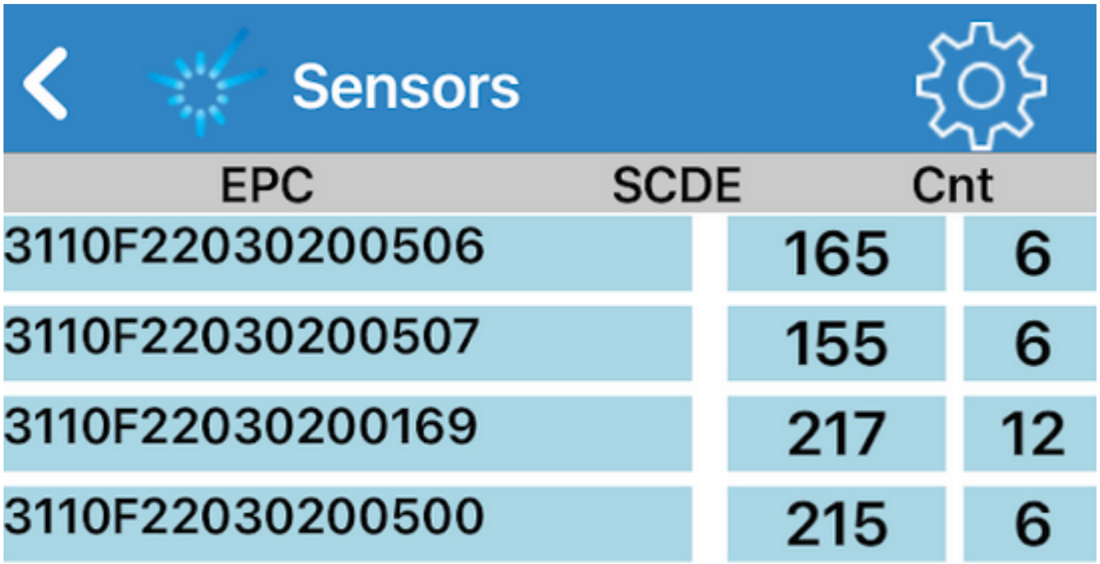
Generally, moisture or wetness, from humidity or from direct contact with water, drives down SCDE (sensor code). A totally dry tag may have a starting SCDE of 400, while a tag simply exposed to a humid environment might have an SCDE of only 180.

Thus, an SCDE reading of 200 might simply show humidity, or with a dry environment, a reading of 200 (where the sensor would naturally show SCDE of 400) would show water being delivered to the tag.

Key Point: To understand if a tag is receiving water from a leak requires that you know the SCDE of the tag prior to being exposed to the leak. Leak checking in a manufacturing line requires a "before" calibration.

Key Point: In environments where SCDE is continuously monitored, the arrival of water will be clearly observed as an abrupt change in SCDE. In applications of continuous monitoring, calibration is not required.

For leak checking in a manufacturing line, our software supports a seamless calibration step that reads all the starting SCDE values for the various locations being tested. The following figure shows the calibration data for four tags.



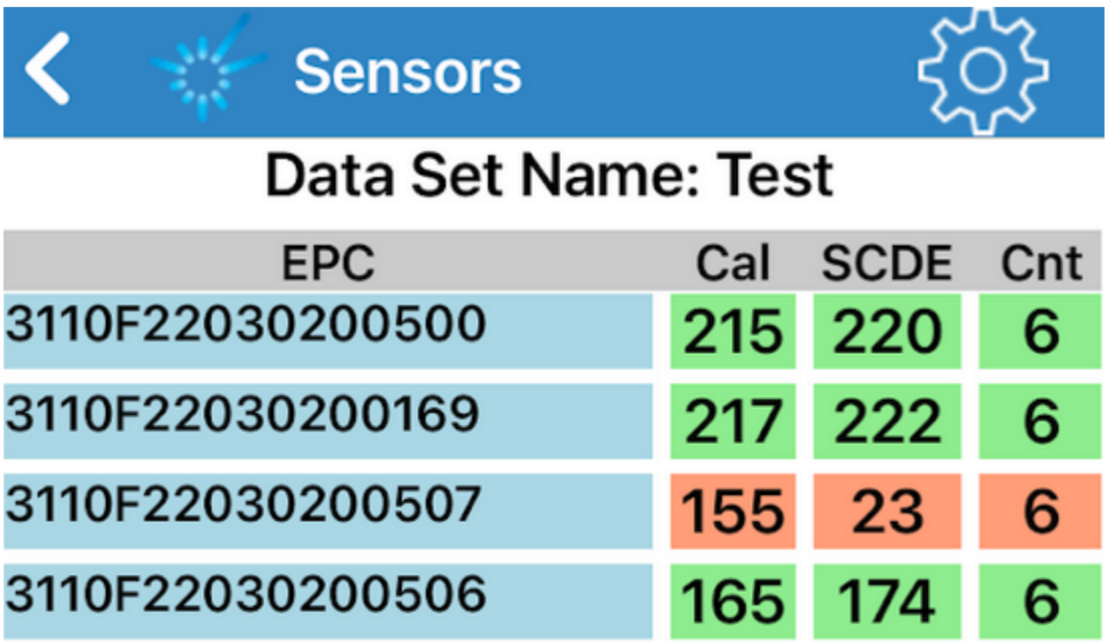
EPC	SCDE	Cnt
3110F22030200506	165	6
3110F22030200507	155	6
3110F22030200169	217	12
3110F22030200500	215	6

Figure 20 - The data from four sensors before being exposed to the possible leak.

Measurement

After the sensor is calibrated in the factory environment, the sensor is taken through the leak discovery process. After that process is completed, the sensors are read, and the software highlights leaks that have been discovered.

The application clearly shows the leak, and its EPC, thus letting the user know both that a leak has occurred and where the leak is located. Fig. 14 shows the measurement information of the tags of Fig. 13 after being exposed to potential leaks.


Sensors

Data Set Name: Test

EPC	Cal	SCDE	Cnt
3110F22030200500	215	220	6
3110F22030200169	217	222	6
3110F22030200507	155	23	6
3110F22030200506	165	174	6

Figure 21 - The sensors of Fig. 16 after being exposed to potential leaks. Sensor ending in 507 has been exposed to water ingress.

High Integrity Data

Some sensors are negatively impacted by RF noise. In general, sensors that use RF techniques to detect environmental changes are sensitive to RF noise. Electronic noise confuses these sensors and negatively impacts the observed measurements.

RF noise can come from many industrial sources, including motors, transformers, RF equipment, arc welder, etc. In addition, the sensors themselves produce RF signals that may interfere with other sensors – we recommend a minimum distance of 25cm (1 ft) between sensors.

Detecting and mitigating RF interference is beyond the scope of this document and generally outside of the expertise of most sensor customers. SensThys will survey the installation site for RF noise and directly interrogator sensor output to ensure that the output data from these sensors is free from artifacts due to RF noise. In areas where RF noise is a problem, we will guide customers to find factory-workable solutions to get high data quality.

SensThys employs proprietary methods to both detect and proactively filter results in noisy environments to provide optimum data integrity.

Conclusions

Passive sensors can detect very small amounts of water when configured properly. Key points to focus upon include proper use of wicks to guide the water to the tag, proper use of the antennas in the manufacturing environment, and attention to the details of sensor configuration, including die, inlay, tag, and labeling choices.

We are focused upon IoT sensing and have the expertise to guide your firm through this process to ensure the delivery of solid sensor data. We can help you see within.