

Understanding Gen2 Readers' Receive Sensitivity Requirements

By Dan Ratner

Introduction

ThingMagic, as a rule, doesn't publish a single number for reader receiver sensitivity for three reasons:

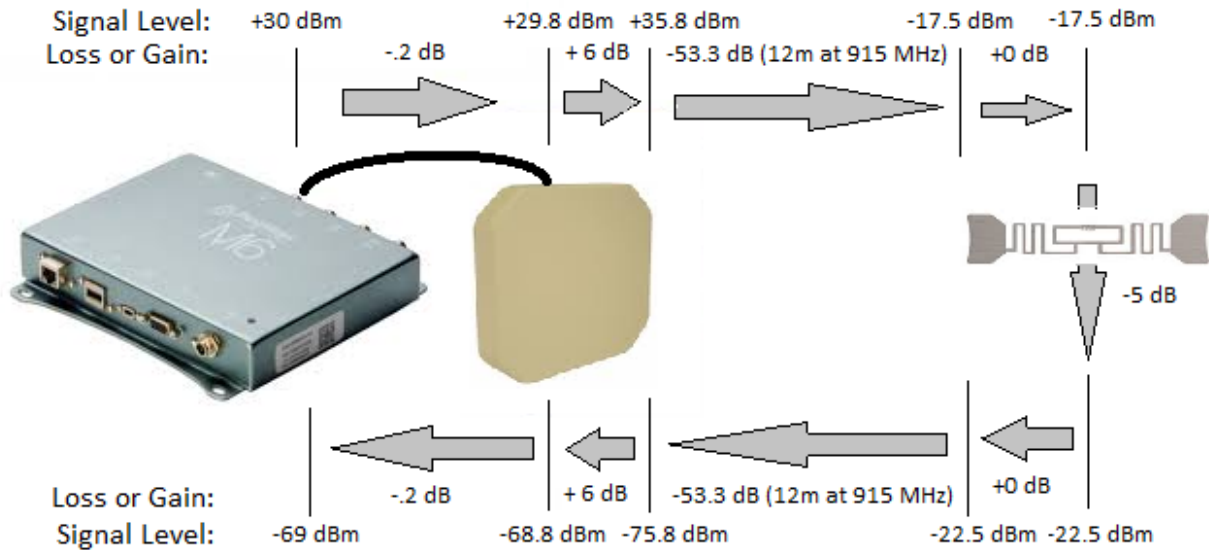
- (1) There is no standard method for measuring receiver sensitivity - vendors who want to show a very low number can do so using methods that are valid in a laboratory test environment, but not relevant for real-world applications.
- (2) The definition of reading "success" is application dependent, so even when the sensitivity is measured properly, one number does not give all the information required to make an informed decision.
- (3) The role of receive sensitivity in achieving desired system performance is not well understood by many system designers (and we hope to help correct that with this Whitepaper!). For many applications, increasing¹ receiver sensitivity beyond a minimum required value has no significant additional benefit for performance metrics, such as read distance.

In this whitepaper, we will discuss these caveats, provide the sensitivity values for all our products, and then explain how to interpret these values to optimize reading performance and success rate in your application.

How Receive Sensitivity Affects Read Distance

First, let us explain why increasing receiver sensitivity only increases read distance until a threshold level is reached, then has little impact. When a signal is transmitted to a tag, a reply is not returned to the reader until the tag is powered up sufficiently to operate. For most tags, by the time the tag receives enough power to respond, it will return signal levels well above the reader's sensitivity threshold. The diagram below illustrates the calculation that confirms this assertion:

¹ We try to avoid terms like "lower" or "higher" receive sensitivity, because it might be unclear to the reader whether we are referring to the numerical value or relative merit of two sensitivity levels, since a lower numerical value indicates a more sensitive receiver.



This illustration shows the signal loss - and gain - throughout the entire journey of the signal. Note that the elements in the path affect the signal twice, once in the forward direction and once in the reverse direction. Following the signal path from the upper right to the lower left from reader transmitter to reader receiver:

1. The transmitter launches a signal at +30 dBm (a very common value because this is the highest signal level permitted by many regulatory requirements).
2. A short piece of cable connects the reader to the antenna. Its loss is little more than the loss of its connectors, about -0.2 dB.
3. The antenna adds 6 dB of linear gain².
4. Over a 12 meter distance, the signal loses 53.3 dB. This distance is very close to the maximum for a UHF RFID system using the latest passive tags, based on the published sensitivity of these tags.
5. The inlay antenna of a typical tag with dimensions of 10 cm by 1 cm tag is around 0 dB, so the signal level into the inlay is the same signal level delivered to the tag IC: -17.5 dBm. (Larger tags will typically have more antenna gain, smaller tags will typically have less.)
6. The tag IC receives -17.5 dBm of signal based on all our assumptions. This is the lowest signal level that can power up state-of-the-art UHF RFID tags.
7. The tag reflects the signal back to the reader while modulating it to transfer information, losing around 5 dB of signal in the process.
8. The return signal, shown as arrows from right to left, loses or gains exactly the same amount of signal as for the forward path, resulting in a received signal level of -69 dBm at the reader.

² Linear gain, not circular gain, is used for this calculation because most tags have linear antennas and therefore only receive the portion of the transmitted signal that is aligned with their antenna – approximately half of the total.

This calculation determines the minimum required receive sensitivity of the reader for best performance, but there is little benefit to exceeding this sensitivity. In this example, there is no advantage to having the reader be able to decode signals lower than -69 dBm as long as the tags cannot power up at levels below -17.5 dBm. If any factor, such as increased distance, decreases the signal to the tag, the tag will remain dormant and not return any signal at all to the reader.

Factors that Impact Receive Sensitivity

It is difficult to compare receive sensitivity among published specifications from different vendors due to wide variation in measurement methodologies, which can include:

- Whether the transmitter is actively transmitting or not when the receive sensitivity is measured, and, if so, whether the transmitter is at its maximum output level
- Whether the tag-to-reader distance is adjusted slightly to give the best sensitivity.
- The success rate that is deemed acceptable.
- Whether the receive sensitivity is measured at the highest tag data rate or the lowest tag data rate (receive sensitivity is best at the lowest tag data rate).
- The RF frequency at which the measurement is taken, for example whether the reader is operating within the FCC region of 902 to 928 MHz or around the EU region of 865 to 868 MHz.

We are more conservative than many vendors when we do our measurements. Our sensitivity figures are based on:

- Transmitter operation at full power for the module.
- Measurement made across the full range of phase values to simulate the best and worst-case small distance variations.
- Receiver sensitivity is recorded for 90% or higher tag read success rate.
- Measurements made for all supported tag response encoding methods (“M” values) and data rates (“BLF”).
- Individual measurements are made at multiple frequencies for all regions.

Transmit Output Level

UHF RFID readers rely on knowledge of the signal they transmit to the tag in order to optimize decoding of the signal reflected back to them from the tag. For this reason, the most accurate receive sensitivity test procedures must use a signal sourced by the reader, not one that is externally generated by an artificial source. In order to not have the receive sensitivity measurement limited by the sensitivity of the tag (which we just explained will occur in real-world applications), receive sensitivity test beds must allow the signal attenuation from the reader to the tag to be adjusted separately from the signal attenuation from the tag to the reader (by routing the signal to the tag via cables with variable attenuators rather than over the air). Ideally, the signal level received by the tag will be kept constant while the signal level returned to the reader reduced until the reader can no longer detect it, so that the

level and quality of the signal as it leaves the tag remains constant and only the signal level reaching the reader is changed.

What is not immediately obvious is a further configuration factor that can significantly affect sensitivity: the signal level transmitted out of the reader. What we mean by this is that even if the signal reaching the tag is constant, the sensitivity of the reader will be lower if the test bed combines a high transmit level with high attenuation (in the signal path to the tag) rather than a low transmit level combined with low signal attenuation. This is because, in all UHF RFID readers, some amount of transmit power always gets reflected into the receiver, decreasing its sensitivity. These reflections occur inside the reader and at the reader antenna. Some vendors measure their receive sensitivity using very low transmit signal levels. Although measuring the receiver sensitivity while the transmitter is almost off will give a perfectly valid value for receive sensitivity, this has little relevance for real-world systems where the transmitter will almost always be at its highest level in order to achieve the greatest possible read distance. For one example of the impact of this effect, look at the sensitivity charts (starting on p. 8) for the various modules and note that our Compact module, the simplest of our modules with a maximum output power level of +23 dBm, has the best sensitivity of all our modules – as low as -86 dBm in the EU region. Our more sophisticated modules do not show sensitivity levels that low because they transmit at much higher levels. Their additional circuitry allows them to counter the expected dB-for-dB sensitivity reduction as the transmit level increases. The M6e transmits at levels 7 dB greater than the Compact, but its sensitivity is only a few dB less than the Compact.

Phase Variation

The signal received by the UHF RFID reader is its own carrier signal reflected back to it by the tag, along with data the tag has added by amplitude modulating the signal. The tag accomplishes this modulation by rapidly making its antenna more absorbent or more reflective to the carrier signal received from the reader. The reader must ignore the large amount of carrier reflected back in order to detect the small amount of signal variation that represents the message from the tag. The reader does this in part by relying on the knowledge that the common part of the signal is essentially the same carrier signal it transmitted, but delayed due to the time it takes the signal to travel to the tag and back. This time delay shifts the phase of the received signal relative to the transmitted signal, whereupon it combines with the locally reflected transmit signals mentioned earlier to create a combined signal that the reader must decode.

The receiver must detect small variations in reflections from the tag in the face of multiple sources of reflections from multiple sources inside and outside the reader. The phase of the returning signal from the tag relative to that of the outgoing transmission determines whether noise sources cancel each other out, resulting in greater receive sensitivity, or combine, resulting in less receive sensitivity. The carrier's wavelength at 915 MHz is 33 cm (a little over a foot). Because the signal travels both to and from the tag, changing the distance from the reader to the tag by half that amount – 16.5 cm – will represent the entire range of phase values, including the favored ones.

This is one reason why keeping tags moving with respect to the reader (or readers moving with respect to the tags) in your application will nearly always result in increased read success. If it is impossible to move the tag relative to the reader, which is the case in many applications (such as reading stationary items on a shelf with a fixed-mounted antenna), then a reduced receiver sensitivity figure should be used for performance calculations. ThingMagic measures the sensitivity across the entire range of phase variation, so both the best and worst sensitivity values are measured. (Other vendors will only measure the sensitivity at the distance that represents the ideal phase difference.)

Tag Encoding and Data Rates

In the Gen2 protocol, the reader instructs the tag how to encode the data it sends back and also the rate at which it should send that data. With this pre-determined knowledge of the tag's signaling rate, the reader sets up narrow receive filters for low data rate signals or wide receive filters for high data rate signals. The narrower filters (for lower data rates) let in less noise and therefore result in increased receive sensitivity. The encoding method and rates that we support, in order of decreasing tag read rate (but increased sensitivity) are shown in this table:

← Higher Sensitivity	Encoding ("M" value)	Backscatter Link Frequency (BLF)	Max Read Rate
	FM0	640 kHz	800 tags per second
	FM0	250 kHz	400 tags per second
	M=2	250 kHz	300 tags per second
	M=4	250 kHz	200 tags per second
	M=8	250 kHz	100 tags per second

The maximum tag read rates are approximate, but they will help you determine how to trade off lowering read rate to raise sensitivity.

How We Measure Receive Sensitivity

Our receive sensitivity testing is very rigorous. We make 50 read attempts at each power level, in 1 dB increments, and at 20 degree phase increments from 0 to 360 degrees. We record the success rate for each combination of phase and signal level. Note that there is approximately a 5 dB difference between the level that the tag can occasionally be read, and the level when it achieves the high level of success we consider acceptable. Other vendors who aren't so conservative as we are will only publish these better sensitivity figure, which may not be relevant to your application if there is a limit to the amount of time a reader has to read tags.

A/P	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
-48	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-49	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-51	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-52	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-54	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-55	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-56	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-57	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-58	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-59	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-60	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-61	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-62	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-63	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-64	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-65	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-66	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-68	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-69	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-70	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-71	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-72	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-73	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
-74	100	100	100	100	98	100	100	100	98	100	100	100	100	100	100	100	100	100	100
-75	100	100	100	100	98	100	100	100	96	98	96	100	100	100	100	100	100	100	100
-76	100	98	100	98	88	98	100	94	92	90	92	94	100	98	100	100	100	100	98
-77	94	96	98	88	92	90	96	92	88	74	74	82	94	92	96	100	100	100	98
-78	98	92	94	78	84	94	82	80	58	42	54	76	86	90	92	98	98	100	94
-79	80	70	76	42	50	78	72	50	26	8	46	28	64	54	84	84	88	88	80
-80	60	28	34	20	2	40	24	26	4	0	8	18	40	28	58	80	58	64	50
-81	42	8	6	2	0	20	10	0	0	0	0	2	12	4	6	42	20	34	20
-82	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	4	4	2
-83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Receive Sensitivity for Modules at All Relevant Settings

The charts that follow provide are our measured sensitivity levels for all modules at each of the relevant Gen2 transmitter settings, both for North American (NA) and EU regions³.

Our fixed readers all are designed around our modules. If you are using one of our fixed readers, use this table to determine which module is in your reader and use data for that module:

Reader	Module
USB Plus+ and original USB reader	Compact
Vega and original Astra A("A5") reader	M5e
M6 and Astra-EX ("A6") reader	M6e

Four sensitivity values are given for each combination of settings, which correspond to four common application environments:

1. If the tags and reader are moving slowly with respect to each other (so that the optimum phase will be experienced), and a 10% success rate will still result in a successful read, use the column "Tags or Reader Slow Moving"
2. If the tags and reader are moving quickly with respect to each other, then you will want a higher success rate, over 90%, to ensure that the tag is read while it is in the field of the reader. For this use-case, use the column "Tags or Reader Fast Moving".

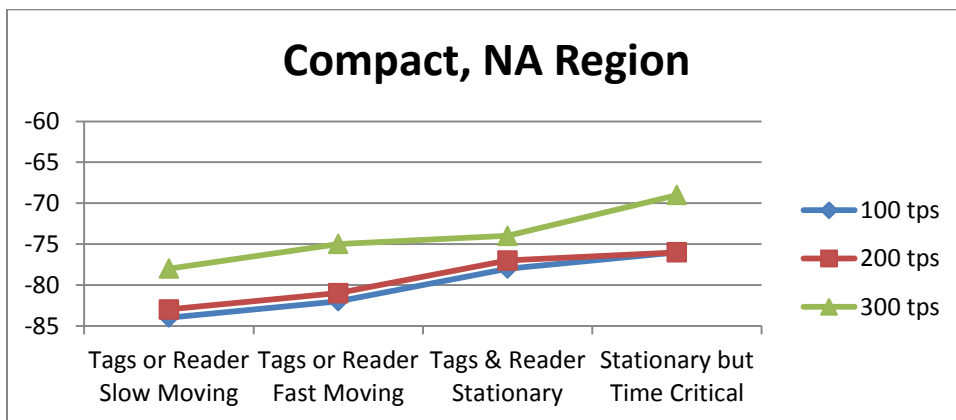
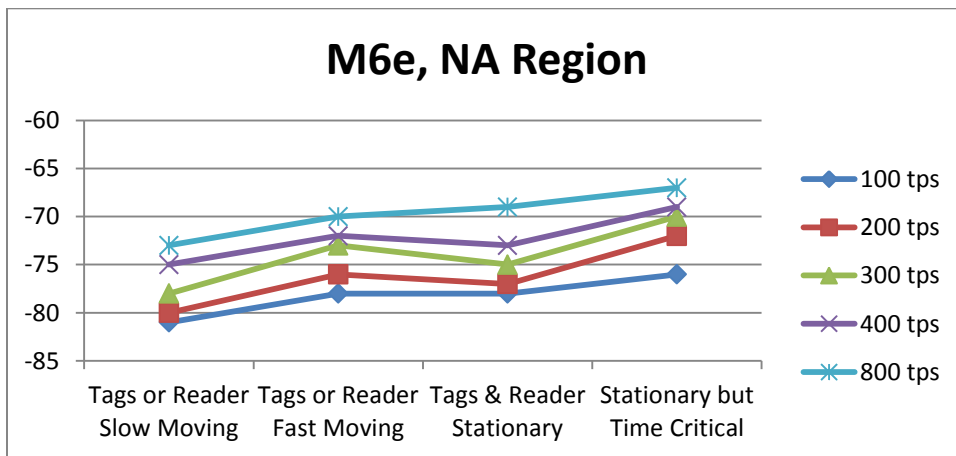
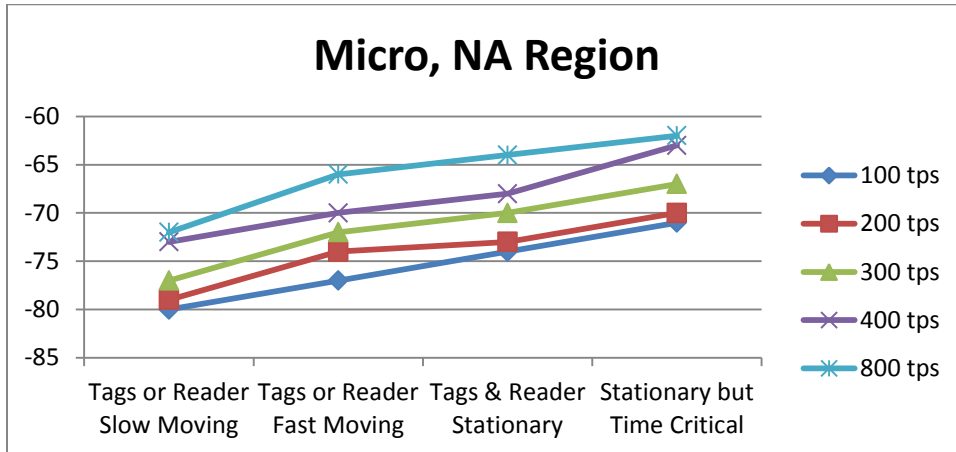
If the tags and reader are moving quickly with respect to each other, you will need to consider the read rate as well as the success rate. If it takes the reader 10 tries to read a tag, this is the equivalent to decreasing the read rate to a tenth of its actual value.

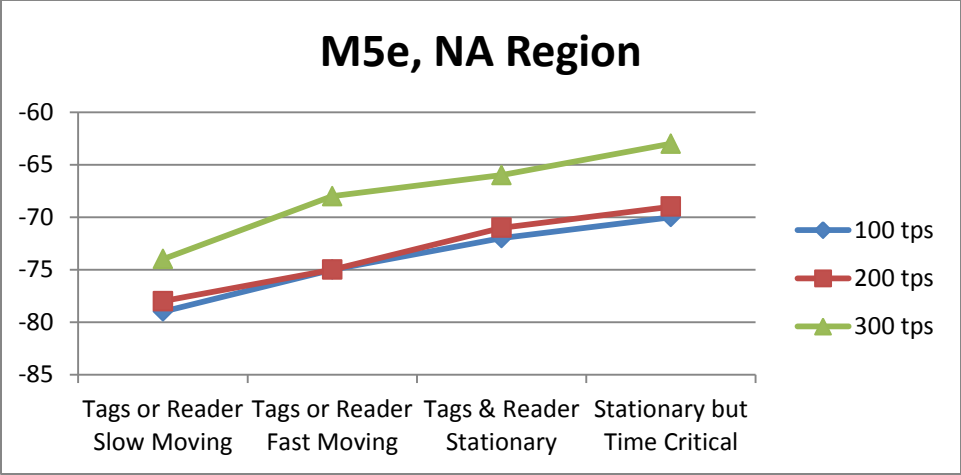
3. If the tags and reader are stationary with respect to each other (so that there is no phase optimization) but 10% success rate is acceptable, then select "Tag & Reader Stationary".
4. If the tags and reader are stationary with respect to each other (so there is no phase optimization), but read time is critical (so a 90% success rate is required), select "Stationary but Time Critical".

³ We offer several options for operation in the EU region. These measurements were made for the "EU3" setting, which conforms to the most recent ETSI standard.

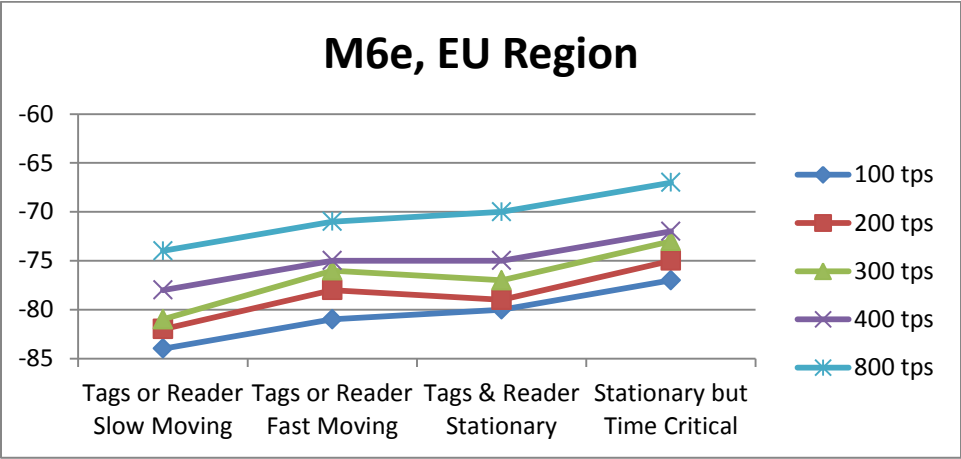
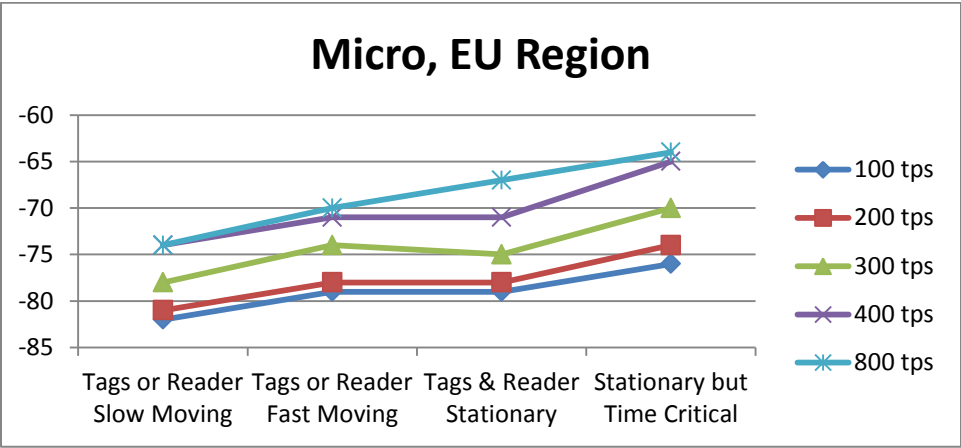
North American Region

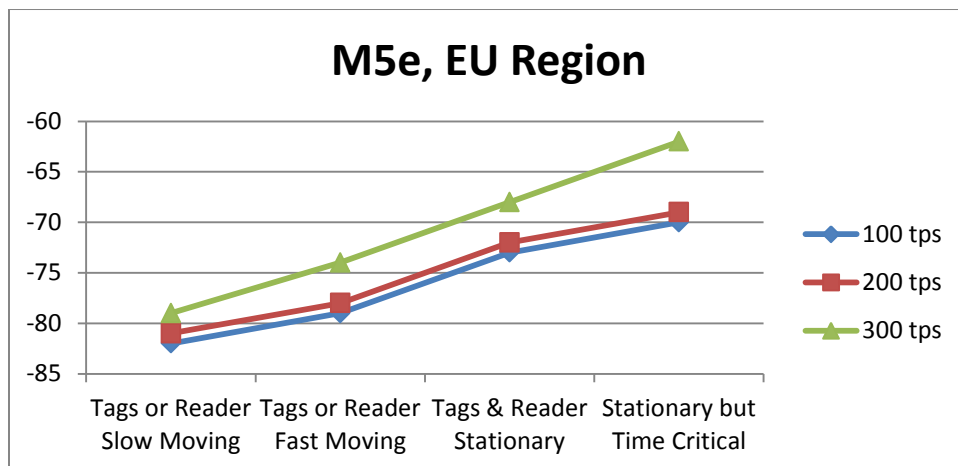
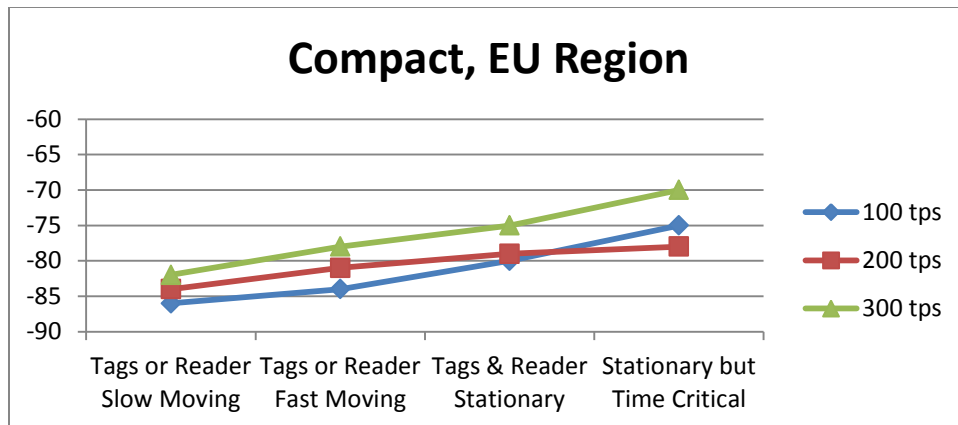
In the following charts, sensitivity, in dBm, is given on the vertical axis. Each colored line represents the combination of Gen2 settings that yield the data rates shown. Each line contains 4 data points, representing the four application environments described above.





EU Region (“EU3” setting in API)





Summary

Receive sensitivity is affected by many factors, both internal and external to the reader, and cannot be described by a single “best case” number, as some other vendors do. Furthermore, increasing receiver sensitivity only increases performance (i.e. read distance) until tag sensitivity limitations become the determining factor; after that, no increase in performance will be evident.

Optimizing a UHF RFID reading system to meet your distance and read rate requirements requires a relatively simple calculation to determine the signal level that will reach the tag, to confirm that this level is sufficient to power the tag so it will respond. Once you know the minimum signal level at the tag, you use a similar calculation to determine the minimum signal level at the receiver of the reader. This level is the reader’s receive sensitivity requirement for your application. Once the required receive sensitivity level is known, you are free to adjust other reader settings for optimum read rate and success rate (using the charts we have provided) as long as you observe the constraint of the minimum reader sensitivity requirement.

For more information, visit www.thingmagic.com.