AND9211/D

Smart Passive Sensor Measurements

ON Semiconductor®

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APPLICATION NOTE

Introduction

ON Semiconductor’s Smart Passive Sensor tags powered by a Magnus®−S integrated circuit (IC) produce a Sensor Code which gives information about the sensor tag’s environment. To maximize the precision of sensor measurements, the user should understand and account for effects related to the reader transmission frequency and the amount of power received by the sensor tag. This note describes those effects and discusses strategies for addressing them.

Frequency Effects

Legal regulations governing ISO 18000−6C communication forbid readers to transmit on a single frequency for an unlimited time. Before a specified maximum period of time elapses, readers must either turn off or – more commonly – switch to a different frequency within a predefined set of frequencies. Readers can transmit again at the initial frequency after a specified minimum time. When frequency-hopping, readers move between channels in a non-sequential, random-looking order. A Magnus−S IC detects changes in antenna impedance, which can be caused by factors the sensor tag is designed to sense, such as moisture, or the proximity of something metallic. But impedance also depends on frequency, which means that Magnus−S can report different Sensor Codes when it is read repeatedly, as the reader changes its transmission frequency.

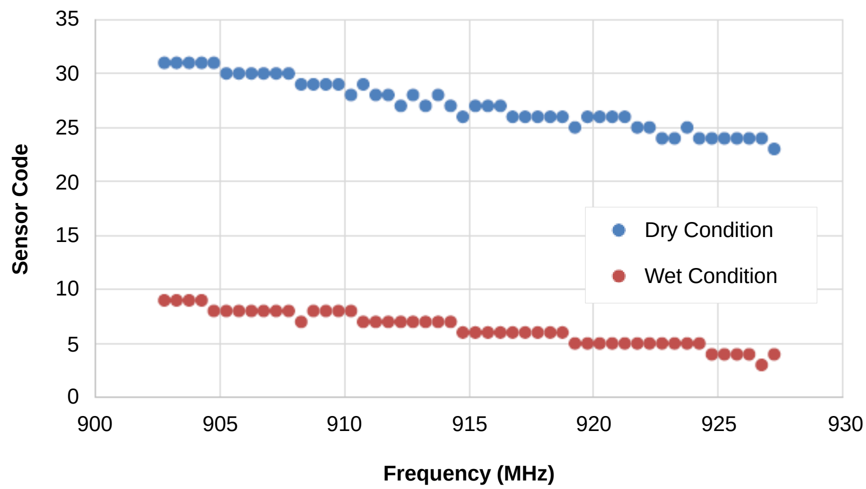

Figure 1. Sample Sensor Code Results for a Moisture Sensor in Dry and Wet Conditions

Typically, the Sensor Code will vary approximately linearly with frequency, and the line will shift up or down in response to a change in the sensing stimulus. For example, Figure 1 plots the measured Sensor Code as a function of frequency for a smart passive sensor tag designed to sense moisture.

It is possible for Sensor Codes to saturate at their extreme values of 0 or 31. It is a good idea to ignore readings at these extremes to ensure that only data within the dynamic range of the sensor are used in the measurement. Saturation is more likely for sensor tags which exhibit a Sensor Code vs. frequency plot with a large slope (Figure 2). Sensor tags designed to be placed on metal often have this feature.

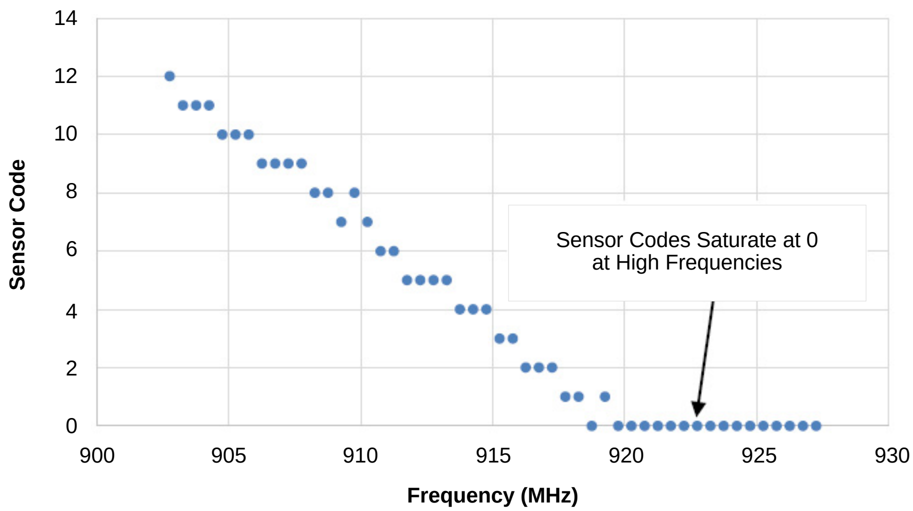

Figure 2. Example Sensor Code Results Showing Saturation at High Frequencies

Summarizing a Set of Measurements

When the Sensor Code is plotted against frequency, it is straightforward to visually recognize a change in sensor condition. However, it is often preferable to condense the data to a single number which eliminates frequency dependence and focuses entirely on the sensor environment. Combining results from different frequencies can also average out random noise and improve precision. Table 1 describes three possible approaches to dealing with frequency-dependence and reducing a series of readings to a single number.

Table 1. TECHNIQUES FOR DEALING WITH FREQUENCY DEPENDANCE

Technique	Pros	Cons
Use Sensor Code value from one frequency only	• Simplest to implement	• Regulatory requirements prevent continuous transmission at a single frequency; compliance will limit the sample rate • Lack of averaging reduces precision
Use the average Sensor Code value over the entire frequency band	• Simplest to implement • Averaging over frequency improves precision and reduces numerical noise	• Must collect enough data to ensure that the frequency range is adequately and evenly sampled to avoid biasing the results
Use regression analysis to fit the Sensor Codes to a line, then take the value of the line at some fixed frequency. (See Appendix for details)	• Regression process improves precision and reduces numerical noise • Can achieve good results even when sampling only a fraction of the frequencies in the band	• More complex to implement

Note that different regulatory regimes have significantly different numbers of frequency channels in them. For example, in North America there are 50 frequency channels, each 500 kHz apart, between 902 and 928 MHz. Under the European ETSI EN 302 208 specification, there are only 4 channels between 865 MHz and 868 MHz. So the time required – and precision gained – by reading the Sensor Code at every channel before producing a result depends significantly on regulatory requirements.

Received Power Effects

When a Magnus−S IC is receiving a low amount of power, the Sensor Code it generates is fairly independent of the precise power level. Once the received power increases beyond a certain threshold, the Sensor Code tends to show an inverse relationship with received power: higher power levels produce lower Sensor Code values. Figure 3 shows a sample plot of the relationship between power and the Sensor Code value, averaged over frequency. Keep in mind that power received by the sensor tag depends on many factors such as distance and antenna gain, not just reader output power.

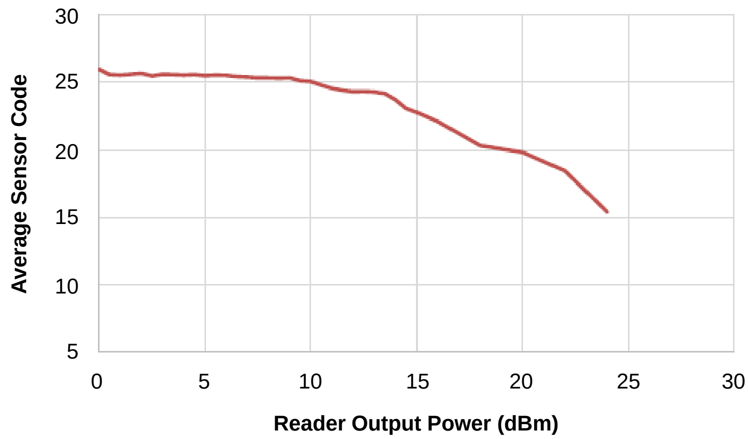

Figure 3. Sample Sensor Code vs. Reader Output Power Plot for a Magnus−S2 IC

For applications using low-gain antennas, low-power readers, large minimum separations between sensor tag and reader, or when high sensor precision is not needed, this effect may not be a concern. But in some cases, it will be desirable to ensure that the sensor tag does not receive enough power to significantly affect the Sensor Code. This can be achieved readily by making use of the On-Die RSSI Code.

The On-Die RSSI Code is a 5-bit value (0−31) which can be read from Magnus−S and gives an indication of the amount of power it is receiving. Larger values correspond to higher power. If the On-Die RSSI Code is above the recommended upper threshold given in Table 2, the reader power should be reduced to avoid affecting the Sensor Code.

It is also desirable to avoid delivering very low amounts of power to Magnus−S, mainly because this increases the chance of reading at some frequencies but not others. This is more likely to occur with readers and/or antennas which exhibit non-uniform radiated power across frequency. In some cases, very low power may also pull the Sensor Code lower, but by a maximum of only about 1 code value. If the On-Die RSSI Code is below the recommended lower threshold given in Table 2, the reader power should be increased, if possible.

Table 2. RECOMMENDED RANGES FOR MEASURED ON-DIE RSSI CODE

Recommended On-Die RSSI Values	Magnus−S2	Magnus−S3
Upper Threshold (to avoid affecting Sensor Code)	21	TBD
Lower Threshold, if Achievable (to reduce the chance of missed reads)	16	TBD

In some applications, the power received by the sensor tag can be kept fairly constant (by fixing the placement of the sensor tag and reader and controlling interference in the transmission path). In those cases, the reader power can be preset to a level which achieves the codes in Table 2 and held constant. But often, the reader will be programmed to search automatically for a desirable power level and periodically adjust itself to account for changes in the environment that affect received power.

As noted earlier, higher On-Die RSSI Codes correspond to more received power, up to a maximum code of 31. However, if Magnus−S is receiving very large amounts of power, the power-detection circuitry can become overwhelmed, resulting in unpredictable On-Die RSSI values. This should only occur when the reader is transmitting near the upper EIRP limit allowed by regulations, and only when the sensor tag is within a few feet of the reader. But for this reason, when searching for a desirable power level, the reader should start at a lower power and increase if necessary, rather than beginning at maximum power.

APPENDIX

Review of Linear Regression Analysis

Linear regression analysis offers a straightforward way of summarizing a series of Sensor Code readings taken at different frequencies. Linear regression finds the slope and y-intercept of the line that best fits the measured data, and does not require calculating anything more complicated than an average.

Consider a set of N readings, where f_i indicates the i^{th} measurement frequency s_i and indicates the i^{th} Sensor Code value. Simply calculate the following set of averages:

$$\bar{f} = \frac{1}{N}\sum_{i=1}^{N} f_i \qquad \bar{s} = \frac{1}{N}\sum_{i=1}^{N} s_i$$

$$\overline{fs} = \frac{1}{N}\sum_{i=1}^{N} f_i s_i \qquad \overline{f^2} = \frac{1}{N}\sum_{i=1}^{N} f_i^2$$

The line which fits the data points is given by

$$s = mf + p$$

$$m = \frac{\overline{fs} - (\bar{f})(\bar{s})}{\overline{f^2} - (\bar{f})(\bar{s})} \qquad b = \bar{s} - m\bar{f}$$

Once the slope (m) and y-intercept (b) of the line are calculated, the value of the fitted line at some fixed frequency (such as the center of the band) can be used to represent the overall measurement.

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