Chameleon™ Technology Enables Low-Cost Sensors[1]

Background

RFMicron's Magnus™ integrated circuit (IC) family offers the industry's only self-tuning capability, called Chameleon™ technology. Implemented in an on-chip analog signal processing circuit, Chameleon technology automatically adjusts the input impedance of the IC to optimally tune the tag every time it is accessed.

Tags based on conventional chips can be detuned by a variety of external factors, most commonly by proximity to liquids or metals. Such factors can change the impedance characteristics of a tag's antenna. When the tag chip has a fixed impedance, a mismatch between the chip and the antenna results, reducing the tag's performance. Chameleon technology maintains the chip-antenna match as conditions change, resulting in more consistent tag performance. A detailed discussion of impedance matching and Chameleon technology is available in RFMicron's white paper on Chameleon Self-Tuning (document #WP-001).

Wireless Passive Sensors Enabled by Chameleon Technology

A wireless passive sensor is an RFID tag composed of an antenna and a Magnus S sensor die (Figure 1). The Magnus S die includes a bank of tuning capacitors between the antenna ports and the EPC Class-1 Gen2 RFID engine (Figure 2). The Chameleon Engine dynamically adjusts the chip's input impedance by switching capacitors in or out of the circuit to maximize the power delivered to the RFID engine. In the Magnus S die, the bank of capacitors has 32 capacitance states represented by a 5-bit sensor code that is the tuning setting. The sensor code can be accessed from a Magnus S chip using a standard Gen2 READ command.

The sensor code provides a measure of the tag antenna's impedance. Should the antenna's impedance change between reads of the tag, the sensor code will also change because the Chameleon Engine adapts the bank of capacitors to match the antenna impedance at the time of each tag read. The change in the sensor code then indicates a change in the antenna impedance, so the

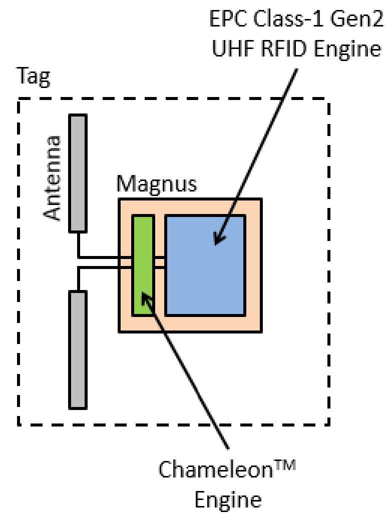

Figure 1. Sensor consisting of an antenna and a Magnus S die.

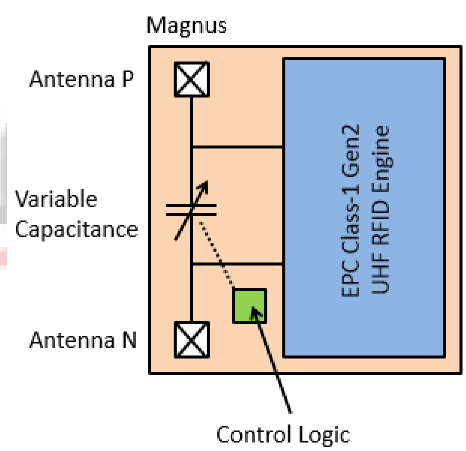

Figure 2. Magnus S sensor die with EPC Class-1 Gen2 RFID engine and adaptive front end called the Chameleon Engine.

sensor code reflects that the antenna environment has changed.

If the tag antenna is designed to respond to a change in environment in a known way, the sensor code can provide a quantized measurement of the change in the environment. In a real way, the sensor code enables the tag to become a wireless passive sensor.

The use of the Chameleon Engine as a sensor is demonstrated with the moisture tag shown in Figure 3. The tag consists of a typical meandered dipole antenna with the addition of an interdigitated capacitor, which forms the sensing area, and Figure 4 shows the sensing area with a water droplet applied. Figure 5 shows the sensor codes read by a standard RFID reader using the standard EPC READ command, and it is clearly seen that the presence of the water is easily detected with this wireless passive sensor.

Simple and Inexpensive

The Magnus S chip enable a new class of low cost and capable passive sensors not available today. Like conventional Gen 2 passive tags, a Magnus S sensor consists of a single IC on an antenna, with no additional components required. Sensor cost can thus be similar to that of other Gen 2 passive tags. Further, Magnus S sensors do not require batteries, so they are maintenance free.

Magnus S sensors enable a degree of sensor-based monitoring where no practical solution was previously available, such as installations requiring very low cost, wireless access, very large numbers of tags, long maintenance-free lifetimes, or very small/thin form factors.

By utilizing the EPC Class-1 Gen2 standard, Magnus S enables fully passive and wireless sensing using existing low-cost UHF RFID equipment that is readily available and widely deployed.

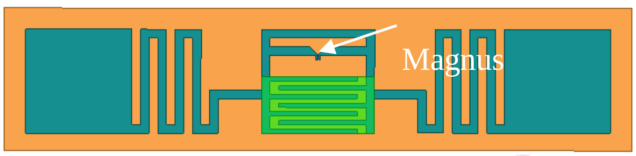

Figure 3. A capacitance-based moisture sensor.

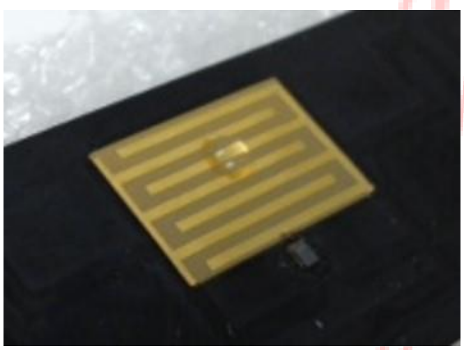

Figure 4. A water droplet applied to the sensor capacitor of the moisture sensing tag.

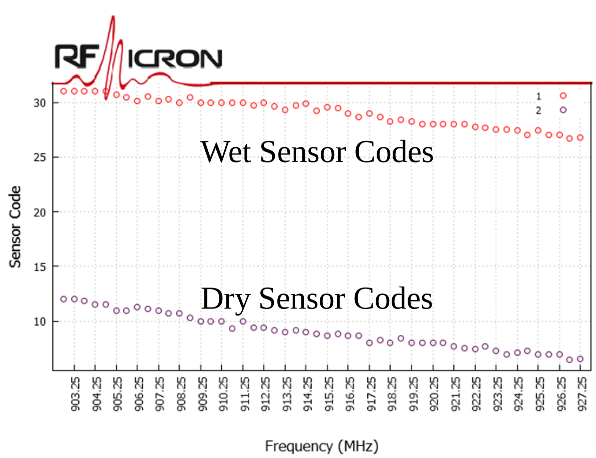

Figure 5. Sensor code movement indicating the presence of the water droplet.

System Considerations

The key to passive sensors using Magnus S chips is the design of the antenna to convert the environmental variable to be sensed into an impedance change that the Chameleon Engine can then convert into a sensor code as it dynamically matches the antenna impedance to the die impedance.

At its most fundamental, an antenna behaves as a resistor/inductor/capacitor (RLC) tuned circuit. Any one of these or a combination of the three can be exploited to enable an antenna to sense its environment.

The sensor designer must choose a physical mechanism and design the antenna to maximize its impedance change to that mechanism. The number of physical mechanisms is essentially unlimited, so it is easiest to describe by way of example.

The sensor in Figure 3 measures the presence of water where the tag actually becomes wet. Water has a very high dielectric constant of ~80, so the interdigitated capacitor experiences a large change in capacitance depending on whether it is dry or wet. The dipole antenna experiences an impedance change depending on the amount of water on the capacitor, and the Chameleon Engine converts this into a sensor code that indicates the amount of water present. The sensor code is then an indication of the amount of water on the tag.

In general, inductance and capacitance can be exploited by using materials with properties that are affected by the environment or by using physical changes in dimension. Resistance can be exploited by taking advantage of the fact that resistive losses pull the resonant frequency of a tank circuit. The advantage of using inductance or capacitance is that these mechanisms generally do not affect read range. Exploiting changes in resistance will result in some loss of tag read range due to power dissipated in the resistance.

Resolution

The Chameleon Engine is an analog-to-digital converter (ADC) converting impedance to a number with 5 bits of resolution. If sampled in a single RFID channel, the maximum resolution of a sensor is 5 bits. Lower resolutions occur if the sensor uses a subset of the available codes.

The US RFID band has 50 channels spanning 902-928 MHz, a fractional bandwidth of just 2.8%. Such a small change in frequency means that the measurements in each channel mostly capture the same information, so measurements across all 50 channels is a form of oversampling.

Analog-to-digital converters (ADC) often use oversampling and averaging to increase resolution. Several constraints must be met:

1. Noise in the conversion must approximate white noise.
2. The noise amplitude must be large enough to move the sampled impedance by at least one code.
3. The impedance has an equal probability of taking any value between two codes.

Sensors using the Chameleon Engine generally meet these conditions.

Oversampling and averaging increases the effective number of bits of resolution, N, when

$$Z_{os}=4^N Z_s,$$

where Z_{os} is the number of oversampled channels, and Z_s is the number of sampled channels before oversampling. $Z_s=1$ since that is the minimum number of samples to read the sensor.

When using all 50 US channels, the effective increase in resolution is $50=4^N$ producing N=2.8. If all 32 Chameleon Engine states are used in a sensor, then the maximum effective resolution is 5+2.8=7.8 bits. Should fewer states be used, then the effective resolution decreases. For example, if a sensor only utilizes 8 codes, then the maximum effective resolution is 3+2.8=5.8 bits. With 10 channels in the EU band, the maximum resolution is $10=4^N$ producing N=1.7 for a total maximum of 6.7 bits.

Applications[1]

The application space for using Chameleon Engine sensor code readings to implement fully passive sensors is virtually unlimited. Any physical effect that affects capacitance, inductance, resistance, or antenna loading can be exploited to make a sensor. Because of sampling at multiple frequencies, resolution can be as high as 7.8 bits.

Applications involving moisture abound, including water vapor detection, sensing of wet material stock when wetness causes product loss or deterioration, sensing of wetness in applications sensitive to mold or corrosion, and detection of leaks in hard-to-access locations.

Solid state films react to a variety of gases with a change in resistance and enable the construction of sensor tags that respond to industrially significant gases such as CO, CO_2, NO_x, H_2S, O_2, and Cl_2. Thin films deposited onto an interdigitated capacitor can produce sufficient change in circuit Q to build wireless passive sensors readable through the sensor code.

Proximity at micron resolution is detectable through inductive changes created by eddy currents on nearby metal surfaces. These can be used to detect movement or to build pressure sensors.

Physical distortion of the antenna itself causes a change in resonant frequency of the antenna, and the Chameleon Engine will adjust the sensor code to accommodate the change. Applications are possible for alarms, stress detection [such as for bridge integrity monitoring] and inflation of flexible objects.

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