Getting Around the Technical Issues with Battery-Assisted UHF RFID Tags

Battery-assisted Passive (BAP) tags fill the gap between purely passive tags and the more costly active tags.

By Simon Müller, EM Microelectronic Marin SA

RFID tags are produced in vast quantities and are particularly cost-critical to ensure return on investment (ROI). This is why most RFID tags are passive, i.e., do not require a battery to operate. A passive UHF tag IC rectifies the RF signal emitted by the RFID reader and captured by the tag antenna to supply its circuitry. At the same time, the main drawback of passive UHF RFID tags is the limiting factor for the read range. A passive tag IC working in the UHF (900 MHz) band usually requires between -7 and -14 dBm power to operate which corresponds to a read range between 4 and 9 m at a reader power of 36 dBm EIRP. However, for some applications more range or link margin is needed, especially in environments with metals and water in which electromagnetic waves experience strong attenuation. More link margin leads to better reading reliability and better interference control in harsh environments. Moreover, it would enable higher speed applications as the tags are read earlier in the field.

One way to overcome the read sensitivity limitation of passive tags is to add a battery to supply the IC. The RF signal is now only used to carry the information not to supply the IC. Of particular interest are the so-called battery-assisted passive (BAP) tags, also known as semi-passive tags. These tags retain the reverse link of passive tags, i.e., communicate back to the reader by modulating the RF signal that is reflected by the tag antenna. BAP tags fill the gap between purely passive tags and the more costly (battery-powered) active tags.

Semi-Passive Tags

Battery-assisted passive (BAP) tags, also known as semi-passive tags, offer some of the advantages of active tags such as increased read range and permanent power supply, but at a reduced complexity and price. Due to their simple architecture, power consumption can be minimized such that printable low-cost batteries offer enough capacity for a battery lifetime of 1 to 5 years. However, as the BAP market is emerging, it is crucial for reader manufacturers to improve the reader sensitivity.

Active UHF Tags

Active UHF tags, similar to radio transceivers, use a transmitter to communicate with the reader. Thus active tags do not rely on the presence of a reader to broadcast information which enables, for example, tag-to-tag communication. The transmitter converts battery power into RF transmit power in order to gain in reverse link sensitivity and range respectively. To avoid a bottleneck in the forward link (i.e. reader-to-tag link), usually a simple diode detector that is used in passive tags is not sufficient. A detector-based architecture may allow for up to -50 dBm sensitivity in a clean environment. To achieve more sensitivity, the signal needs to be amplified prior to down conversion, typically by using a low-noise amplifier (LNA). To keep up the sensitivity in real-life, i.e. interference-prone and noisy environments, the diode detector is typically replaced by a heterodyne receiver to achieve better frequency selectivity and interference rejection. The result is a complexity similar to that of radio transceivers. The increased chip area, the need for more battery capacity and the additional off-chip components lead to a tag price typically greater than $10US.

Battery-assisted Passive (BAP) UHF Tags

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Figure 1 is a diagram of a basic BAP tag in a simple single-

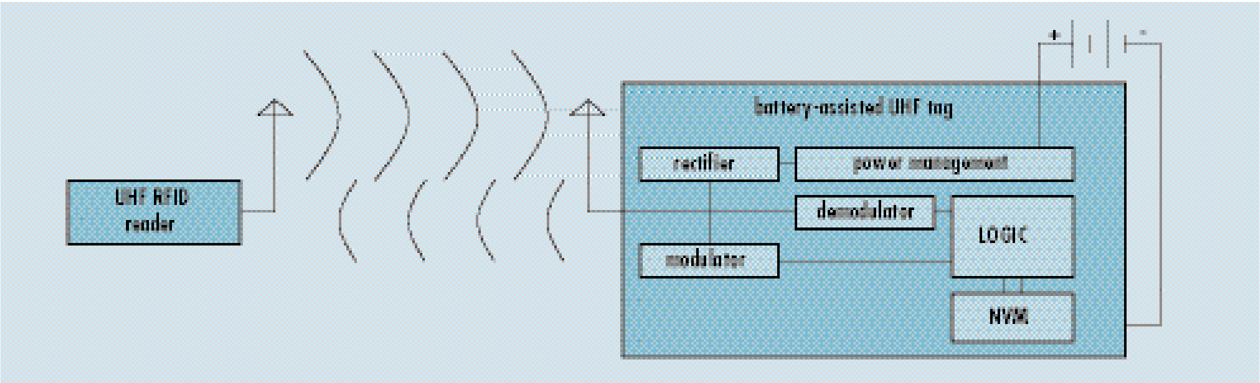

Figure 1. Diagram of basic BAP RFID system.

Equation 1

$$P_{R\_RX} = P_{R\_TX} \underbrace{G_R G_T \left(\frac{\lambda}{4\pi r}\right)^2}_{\text{forward link}} \cdot \left|\Delta\Gamma^2\right| \cdot \underbrace{G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2}_{\text{reverse link}}$$

Equation 2

$$\alpha = G_T^2 \cdot \left|\Delta\Gamma^2\right|$$

reader single-tag application. The only difference in the diagram compared to a purely passive tag system is the connection of the battery to the power management block. The main challenge for the power management is to run the IC in a power save mode during most of the tag's life when there is no RFID reader present in order to maximize the battery lifetime.

To achieve the desired sensitivity in the forward link the demodulator requires some signal amplification after down conversion; typically for passive tags a simple data slicer is enough. The rectifier is optional; however, its main advantage is to operate as a backup power supply when the battery is empty. An empty battery will not kill the tag, but only decrease its performance.

The link budget in Equation 1 (above) can be derived from the Friis equation. The link budget is visualized in Figure 2 for a typical passive case and a possible BAP case at the sensitivity threshold. The reader is assumed to transmit at a power of 30 dBm and is connected to an antenna with 6 dB antenna gain. This results in the maximum allowed EIRP power of 36 dBm, according to FCC regulations for unlicensed readers. Most of the power loss in the forward path occurs in the near field region close to the reader antenna (r<<30 cm) where the power drops off at a rate of $1/r^3$ (which is not described by the Friis equation). The same holds for the reverse path near the tag antenna.

For convenience α was defined in Equation 2 to include the tag antenna gain G_T and the differential reflection coefficient ΔΓ between antenna and chip. Factor α gives a measure for the tag backscatter efficiency. Figure 2 shows that the reader receiver sensitivity quickly becomes the bottleneck for the BAP case. For a tag sensitivity of -29 dBm (resulting in around 48 m read range) and assuming α=-3 dB, a reader sensitivity better than -91 dBm is required to detect the tag backscatter reply. However, most currently available UHF readers achieve a sensitivity between -60 and -80 dBm and would considerably reduce the read range in the BAP example. Designed for passive applications, these readers may not exploit the full potential of the technology. As the BAP market is emerging, it is crucial for reader manufacturers to improve the reader sensitivity. Few reader manufacturers specify sensitivity numbers around -95 dBm. In our example, a reader with -95 dBm sensitivity is left with only 4 dB margin before reaching the sensitivity threshold and becoming the link bottle neck.

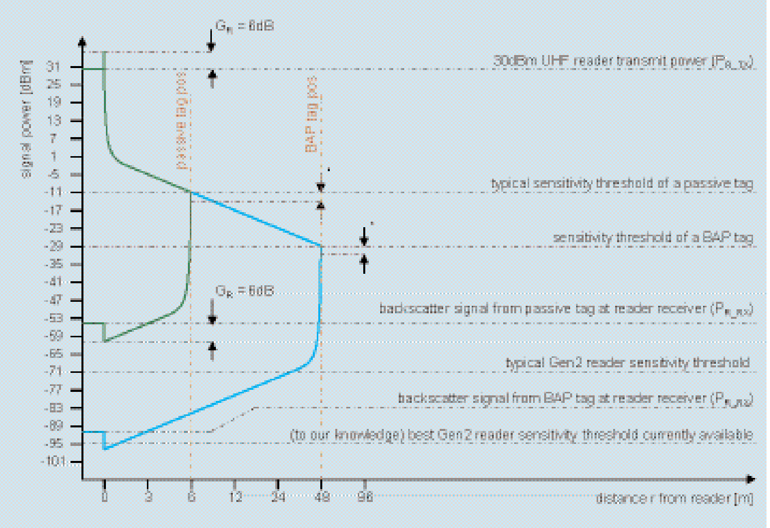

Figure 2. Visualized link budget example for a passive and a BAP tag.

On the tag side a challenge is to optimize the tag backscatter efficiency α. The backscatter efficiency in Figure 2 was assumed to be the same for the passive and the battery-assisted case for the sake of simplicity. α can be increased by optimizing chip and antenna design. For maximum backscatter efficiency, both the differential reflection coefficient $|\Delta\Gamma| = |\Gamma_{ON} - \Gamma_{OFF}|$ and the tag antenna gain need to be maximized. Γ_{OFF} is the reflection coefficient during modulator-off state and describes the power reflected between tag antenna and IC when the tag is not modulating and is given by $\Gamma_{OFF} = (Z_{IC\_OFF}\ Z_{ANTENNA})/(Z_{IC\_OFF}+Z_{ANTENNA})$. Γ_{ON} is the corresponding reflection coefficient for the modulator-on state. In this article, the tag is assumed to use ASK modulation which is the most common backscatter modulation scheme. Thus, the antenna is usually power-matched to the IC ($Z_{IC\_OFF} = Z^*_{ANTENNA}$) when the modulator is off resulting in $|\Gamma_{OFF}|$ close to the theoretical limit of 0. When the modulator switch is turned on $|\Gamma_{ON}|$ is theoretically 1. However, in practice, $|\Gamma_{ON}|$ is below 1. To maximize $|\Gamma_{ON}|$ a strong modulator switch (resulting in a low $|Z_{IC\_ON}|$) and a high $|Z_{ANTENNA}|$ are needed.

An interesting option is tags supporting a Tag-Talks-Only (TTO) protocol. In this mode, the tag starts backscattering as soon as it enters the reader field; no forward link is required. Thus, the chip and tag antenna can be optimized for the reverse link and high values for |ΔΓ| can be achieved. A de facto TTO protocol standard is IP-X™which has been implemented in EM4122 (passive) and EM4232 (BAP).

How well BAP tags will be adopted not only depends upon resolving the technical issues above, but also upon maintaining compatibility with existing (passive) RFID installations. Some of the most common RFID standards in the UHF range today are ISO 18000-6, EPCglobal C1 G2 and IP-X™. The second generation IP-X™called IP-X™ Gen2 is currently under development to ensure harmonization and co-existence with the other standards. The EM4324 chip is fully compliant to ISO 18000-6C / EPC C1 G2 and can operate both battery-assisted and passive in order to allow for a maximum range of applications.

A drawback of passive tags is that the IC is powered down whenever the tag is outside the read/activation range. In contrast, the battery allows permanent operation of the IC. This opens a range of new applications that rely on continuous operation, such as continuous sensor data logging. Currently, efforts are being made in ISO and EPCglobal to include battery and sensor support in the UHF RFID air interface standards.

Conclusion

BAP tags fill the gap between passive and active tags, thereby offering a lower price than active tags and more read range and read reliability than passive tags. Since BAP tags don't actively transmit RF power back to the reader, a major challenge is to maximize the backscatter efficiency on the tag side and most of all, to provide a high sensitivity on the reader side. As experience has shown in the past, a close collaboration between reader, tag and IC suppliers is needed to optimize the RFID system.

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About the Author

Simon Müller is an RFID IC design engineer for EM Microelectronic Marin SA, Sors 3, CH-2074 Marin Switzerland.