RFID goes UHF

Standards, regulation, pitfalls

Dr. Michael E. Wernle (Germany)

Radio frequency identification (commonly known as RFID) is a generic term used to describe a system that transmits the identity (in the form of a unique serial number and data) of an object or person wirelessly, using radio waves. These wireless systems allow for non-contact reading and are effective in manufacturing and other hostile environments where traditional identification technologies such as bar code labels could not survive. Having its radio origins in LF and HF bands like 135 kHz and 13.56 MHz, RFID is now rolled out to UHF, too.

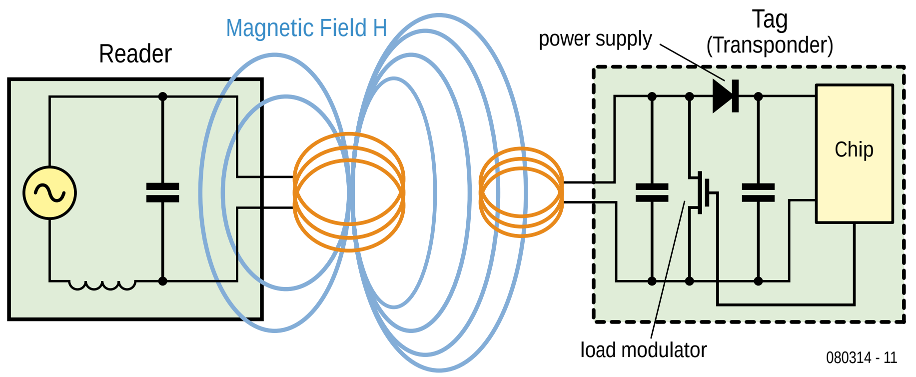

Figure 1. Principle of inductive coupling between RFID reader and transponder (or 'tag').

Unlike bar codes, line-of-sight is not required for RFID, even on UHF. RFID is one of the few technologies where paint, dirt, grease, packaging, etc. do not interfere with the collection of data. For many decades, Auto-ID technologies have been used to reduce the amount of time and labour needed to input data manually and to improve data accuracy. RFID by its own is the most advanced representative of this technology today. The basic components of an RFID system are the *transponder* or *tag* as the electronic data carrier, and a read/write device, called *reader* or *interrogator* to transfer the data received from the transponder in digital form to a host computer or microcontroller for further data processing.

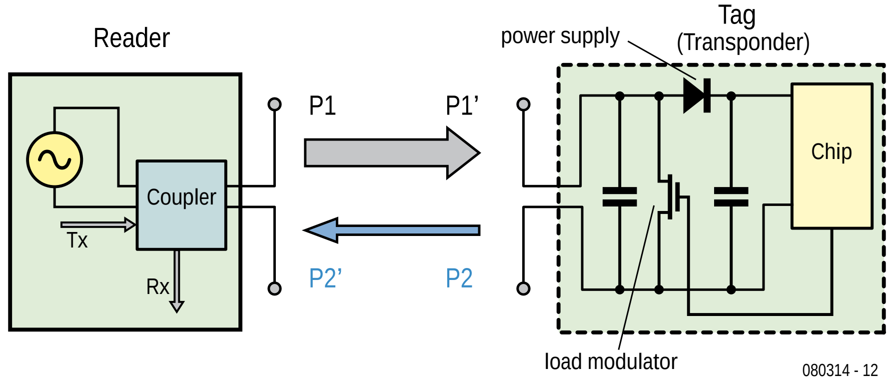

Figure 2. Backscatter coupling is the dominant mode of coupling at UHF.

RFID advantages

RFID offers very specific features not available with other advanced Auto-ID technologies. Although not all systems offer all features, some common features of RFID may be listed.

- Non-contact reading and writing
- Non-line-of-sight reading and writing
- Virtual immunity from obscuring paint, dirt, grease, etc.
- Permanent identification or read/write capabilities
- Read range from several inches to several feet (depending on the system)
- Extremely high data integrity and access safety

RFID applications

RFID meanwhile is a well established technology in various mass applications for more than 15 years. Theses applications are currently used in (but not limited to) access control, car immobilisers, asset tracking, animal (livestock and domestic) identification, flexible manufacturing (tracking and control), laundry tracking, vehicle identification, electronic toll collection, supply chain & logistics tracking. Since the beginning of the early 90's low cost RFID systems entered the market in the above mentioned applications based on highly integrated chips for transponders and read/write devices. Today's main carrier frequencies used are 125 kHz, 135 kHz and 13.56 MHz. Recent developments since 2000 showed up new approaches based on higher frequencies in the 865-950 MHz range (UHF). A main driver for this development is the logistics and supply chain industry after acceptance of the fact that HF will not realise reading distances of 2-3 m minimum, even in the far future as required by these applications. Because of the importance of these new applications and the fact that LF and HF systems already got wide coverage in Elektor in refs. [1] and [2]), this article concentrates on RFID based on UHF frequencies.

RFID components and coupling mechanisms for UHF

It is necessary to understand some fundamentals of RFID technology before you are able to build real world scenarios with RFID components available in the market. Especially the important difference between LF/HF systems on one side and UHF on the other side is a key to properly working scenarios. If you are new to the laws of electromagnetism at higher frequencies you may find some basic statements on this issue helpful [3].

Passive RFID tags (which are the most utilised) are 'asleep' (i.e. do not emit RF signals) until they enter a read zone created by an antenna connected to the RFID tag reader. The size and shape of this zone is dependent on both antenna design and operating frequency. In this zone the RF energy field emitted by the reader 'wakes up' the tag and supplies it with power to transmit its data to the reader, or write data to the tag if it has read/write capability. This exchange of energy and information uses different coupling mechanism depending on the frequency of the basic carrier signal.

An important differentiation is the near field/far field boundary — a good approximation is the formula

$$l = c / (2 \pi f)$$

for antenna coils and

$$l = (2a^2 f) / c$$

for dipoles, where c is the speed of light, a the dimension of the dipole and f the frequency [4,5]. For LF (125 kHz) and HF (13.56 MHz) RFID systems, the resulting value is approximately 382 m and 3.5 m respectively. Below these values, inductive coupling is the process of transferring energy from one coil to another through a shared magnetic field by virtue of the mutual inductance between the two coils of reader and transponder, as shown in **Figure 1**. Here we concentrate on UHF systems, mainly between 865 and 955 MHz. For these frequencies the assigned near field / far field boundary is between 18 and 20 cm. It is obvious that a different coupling mechanism takes place, see **Figure 2**. The reader antenna emits electromagnetic energy (radio waves) but no electromagnetic field is formed. Instead, the tag gathers energy from the reader antenna, and the microchip uses the energy to change the load on the antenna and reflect back an altered signal. This is called *backscatter coupling* [6].

Based on the nature of the coupling a coil is no longer a reasonable antenna concept. The simplest antenna for UHF is a dipole with a length of $\lambda/2$. The disadvantages are well known in the HF community: physical dimensions and low bandwidth [7]. Now we have to take into consideration that two antennas are required, one for the transponder, the other one connected to the reader device.

For transponders used in the logistics industry there are some limitations caused by the dimensions of barcode labels used today — typical extremes for the length are approx. 100 mm. Because of this limitation the ideal dipole has to be folded to create shorter antenna structures. Meander Structures (**Figure 3**), Folded Dipole (**Figure 4**), PIFA (planar inverter F antenna) are just a few expressions for highly sophisticated antenna designs and it is a must to refer to appropriate literature [5,7].

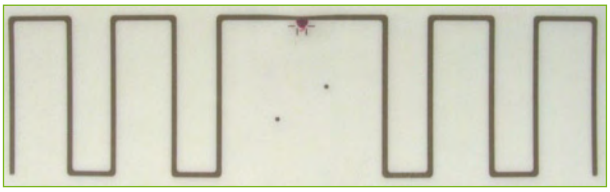

Figure 3. An open dipole made from a meandering PCB track.

Figure 4. Combination of a closed dipole and meandering tracks.

For UHF reader antennas the situation is much easier to handle. Antennas for fixed mounted long range RFID readers are typically based on the well known concept of patch antennas; the typical size is a square of 25 to 35 cm to meet the frequency requirements. For low power output of the reader, in Europe nearly each shape of an antenna is accepted by the ETSI radio regulations [9]; for transmit powers higher then 500 mW there are certain limitations like a maximum beam width of ±35 degrees. Especially the form of the antenna's main loop has to taken into consideration during the design of a long range RFID application like an antenna gate for forklifts and similar.

Physical behaviour of RFID systems depending on frequency

The main differences in RFID systems caused by the frequencies used are shown in **Table 1**.

Table 1. Comparison of RFID band characteristics	
Frequency	**Characteristics**
LF (low frequency) 125–134 kHz	In use since mid 1980s Read range up to 1 m Deep penetration Works best around metals and liquids Slow data rate and no anti-collision Costlier tag antennas because of wound coils
HF (high frequency) 13.56 MHz	In use since mid 1990s Read range up to 1 m Good penetration Widest application worldwide Most progress on standard definitions worldwide High Security transponder chips available Simultaneous read capability @ 50 tags
UHF (ultra high frequency) 865-955 MHz	In use since late 1990s Read range 4-7 m Fast data rate Susceptible to attenuation by liquids and metals Potential to offer lowest cost tags Simultaneous read capability @ 500 tags

Regulations and Standards

Fortunately, RFID is an area of technology with increasing standardisation for the benefit of the users based on more certainty for important investment decisions in Auto-ID infrastructure. We have to separate standards for the application and the technical functionality itself; here we concentrate on the technology side. All frequencies for RFID are out of the ISM bands (Industrial Scientific and Medical bands) and can be used globally without a license. Ultra-high-frequency RFID transponders unfortunately cannot be used globally at one single frequency as there is no single global standard today. The ITU (International Telecommunications Union) has divided the world in three regulatory regions:
- Region 1 includes Europe, Africa, Middle East and the former Soviet Union — see **Figure 5**;
- Region 2 includes North America, South America and the Pacific Region east of the dateline — see **Figure 6**;
- Region 3 includes Australia, Asia and the Pacific Region west of the dateline.

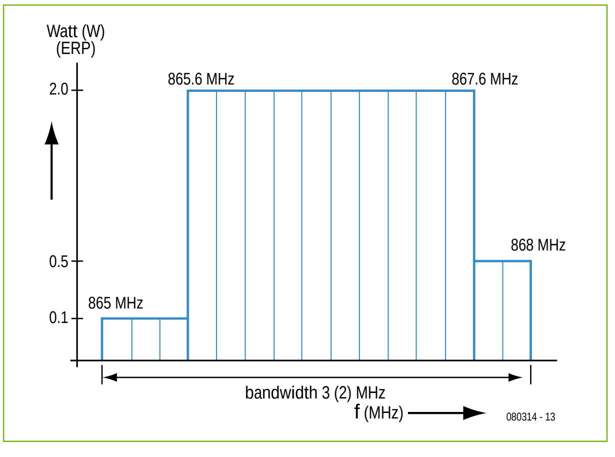

Figure 5. RFID frequency allocation for Region 1 (chiefly Europe).

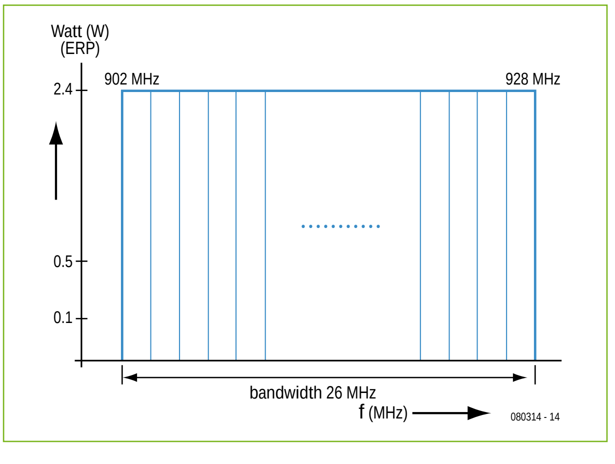

Figure 6. RFID frequency allocation for Region 2 (chiefly USA).

In the USA, unlicensed use of RFID (subject to equipment type approval) is allowed in the frequency range from 902 to 928 MHz with restrictions for the maximum transmission power (FCC CFR Title 47, Part 15). In Europe, RFID and other radio applications are regulated by ETSI recommendations EN 300 220 [8] EN 302 208 [9] and ERO recommendation 70 03 [10], allowing RFID operation with somewhat complex band restrictions from 865–868 MHz. RFID Readers are required to monitor a channel before transmitting ('Listen Before Talk'); this requirement has led to some restrictions on performance, the resolution of which is a subject of current research.

Table 2 presents some information such as main regulatory organisation, allocated UHF band and maximum output power emissions.

In general, the performance of UHF systems in the FCC regulatory region is higher than in ETSI regions, caused by the larger bandwidth and the significantly higher number of channels available.

EPC Number

The Electronic Product Code is an extended form of UPS (Universal Product Code) used in barcode systems and was originally developed at the AutoID centre located at the Massachusetts Institute of Technology (MIT) in Boston, USA during the late 90's. This code has the approach to number all goods in the worldwide logistic transport chain starting at the manufacturer's site till to the consumer. In the basic meaning EPC is not linked to RFID, any electronic media

Table 2. Radio band regulatory organisations			
	Region 1	**Region 2**	**Region 3**
Regulatory Organization	European Conference of Postal and Telecommunications (CEPT)	Federal Communications Commission (FCC) for the USA	various organisations depending on country
Frequency band	865 – 870 MHz	902-928 MHz	around 950 MHz
Maximum radiated power	2 W ERP = 3.28W EIRP	4 W EIRP	various
Bandwidth for high power application	2 MHz	26 MHz	depending on country
No. of channels	10 @ 200 kHz	up to 130	–

is possible to handle these codes. But RFID is the logic carrier of this numbering scheme, especially RFID within the UHF frequency range is heavily linked to EPC in the public opinion.

Today EPCglobal [11], a joint venture between GS1 and GS1 US, is working on international standards for the use of mostly passive RFID and the EPC. One of the missions of EPCglobal was to simplify the various protocols prevalent in the UHF RFID world caused by the first dilettante EPC definitions. Two tag air interfaces (the protocol for exchanging information between a tag and a reader) were defined by EPCglobal, these protocols, commonly known as Class 0 and Class 1, saw some commercial implementation till 2005. In 2004 a new protocol was created, the 'Class 1 Generation 2 interface', which addressed a number of problems that had been experienced with Class 0 and Class 1 tags. The EPC Gen2 standard was approved in December 2004, and is likely to form the backbone of passive UHF RFID tag standards moving forward. The EPC Gen2 standard was adopted with minor modifications as ISO / IEC 18000 Part 6C [12]. Today, it is the main, worldwide accepted standard for UHF RFID in the 865-955 MHz range.

The EPC itself today includes the following number fields:
- Header: defines data type; indicates code partitions; used to partition sub-domains.
- Header: identifies the length, type, structure, version, and generation of the EPC.
- EPC Manager Number: entity responsible for maintaining the subsequent partitions.
- Object Class: identifies a class of objects.
- Serial Number: identifies the instance.

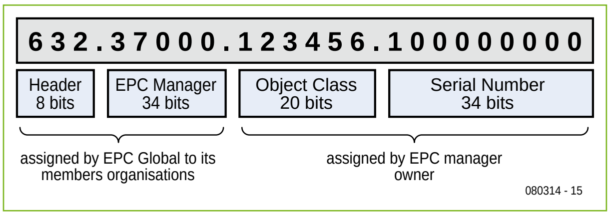

Figure 7.
EPC 96 numbering scheme.

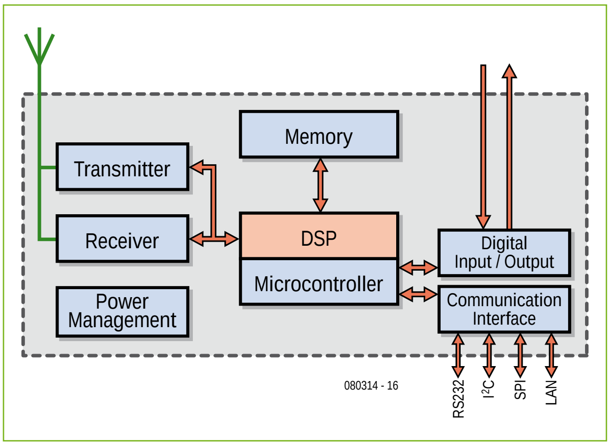

Figure 8. Block diagram of an UHF RFID reader.

Figure 7 shows a simplified version with one header. The EPC number is stored on the transponder and transmitted to the host system by the RFID reader. Based on the number, the host system is able to collect additional information about the object scanned by using the so called Object Name Service (ONS). The ONS matches the EPC of a product to information about that product. As soon as the host software, often called RFID middleware, receives EPC data, it can query an ONS server to find out where more detailed product information is stored. This concept has a famous role model: the high performance Domain Name System (DNS) used in the Internet.

Commercially available RFID UHF products

For UHF transponders a wide range of silicon is already available. Suppliers are the usual companies in the RFID market like NXP, Texas Instruments and ST Microelectronics plus some new fabless chip suppliers like Impinj. Numer-

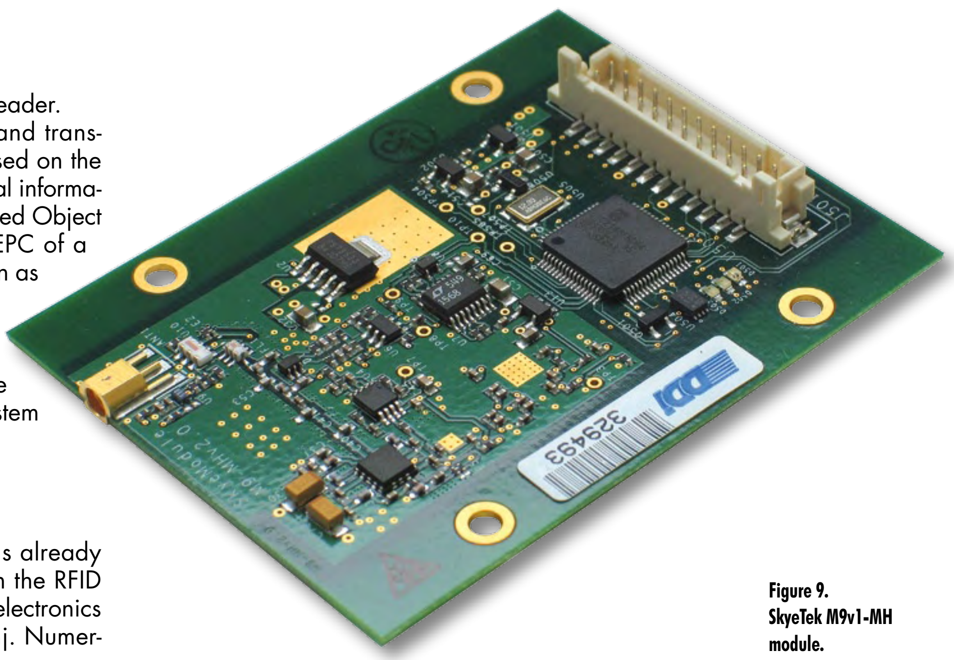

Figure 9.
SkyeTek M9v1-MH module.

ous suppliers around the globe produce transponders using this silicon — it is possible to identify a market for manufacturers of flexible labels like UPM Raflatac, X-Ident and numerous others, and Wisteq, for example, for transponders embedded in a hard case.

For UHF readers the situation is different. For HF there is a wide range of high integrated reader circuits available — the user just adds microcontroller functionality, an HF amplifier if needed and (often underestimated) firmware to design a complete HF reader. For UHF there is till now only one real working high integrated reader chip available,

Figure 10. SkyeTek M9v3-MH module.

originally developed by Intel and just recently (July 2008) sold to Impinj. On one side this chip gives a shorter time to market, on the other side the reader designers lose flexibility during the design process, especially the integration of advanced transponder chip features beyond the bounda-

Figure 11. Sirit UHF EPC long range reader.

ries set by the ISO standards. These chips like the new NXP Gen2 chips UCODE G2XM and G2XL just recently entered the market require high skilled features and require as a result a very flexible reader design like offered from suppliers like SkyeTek (**Figures 9** and **10**), Sirit (**Figure 11**), Motorola, Intermec and a few others.

A reader device consists out of the basic functions transmit, receive, modulation, demodulation and baseband. The block diagram in **Figure 8** shows the typical elements in conjunction with support functionality like digital I/O interface and communications interface like RS232, I²C, SPI (mainly for small low power reader modules) and LAN interface (fixed mounted long range readers).

On a dedicated website, two RFID UHF Reader systems are presented in detail with screenshots of the development environment including some short explanations [13] to give a concrete example of a ramp up.

Conclusion

RFID using UHF is significantly more complex than LF and HF RFID. This is not only caused by the technology itself, handling frequencies close to one gigahertz, but by different radio regulations and application standards.

In a future issue of Elektor we'll describe how to handle some commercial available products to ramp up a small RFID UHF application using ISO 18000-6C / EPC GEN2 compatible RFID components.

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