Technology Brief 16
RFID Tags and Antenna Design

RFID Applications

Radio-frequency identification (RFID) uses electromagnetic fields to transfer identifying information from a small electrical ID circuit to an external receiver. These are commonly used for identifying or tracking animals, packages and goods, smart cards, tags, etc. (**Fig. TF16-1**). RFID circuits are injected in pets to help identify and return lost or stolen animals, attached via ear tags to livestock to identify their whereabouts and activities (how much time they spend eating or drinking), attached to athletes via wrist bands to track and verify their progress in a race, affixed to consumer goods and packaging to track, locate, and maintain inventory, and prevent theft. RFID tags can be based on either static, unchanging data (such as the ID number for a dog or cat), or their data can be changed by either an internal circuit (monitoring and reporting temperature of a refrigerated shipping container, for instance) or an external circuit (such as marking the last time a box was inspected).

When combined with other circuits, the information provided by RFID tags can be used in a myriad of ways. For instance, credit-card sized RFID tags attached to valuable art or other one-of-a-kind objects contain a unique ID number, as well as circuits detecting tilt and vibration. This information is continuously transmitted to receivers on the ceiling of a museum to create a security system that constantly monitors their location and status, and generates alarms if they are moved. RFID tags permanently installed in new guitars can help track them throughout their lives, and those installed in vintage guitars can help prevent fraud and theft. RFID tags are in most access-monitoring cards today, and can uniquely identify a person and his/her time of entry and exit. If other items are also tracked (sensitive documents for instance), an RFID reader can also identify what he/she is carrying and can generate an alarm if documents are leaving a room (or books leaving a library) that shouldn't be. RFID tags can be used in numerous medical applications to identify a person and identify and track the drugs or treatments he/she receives.

RFID and bar code scanners can be used for similar applications, but work in very different ways. Bar code scanners require direct visual access for a laser to read

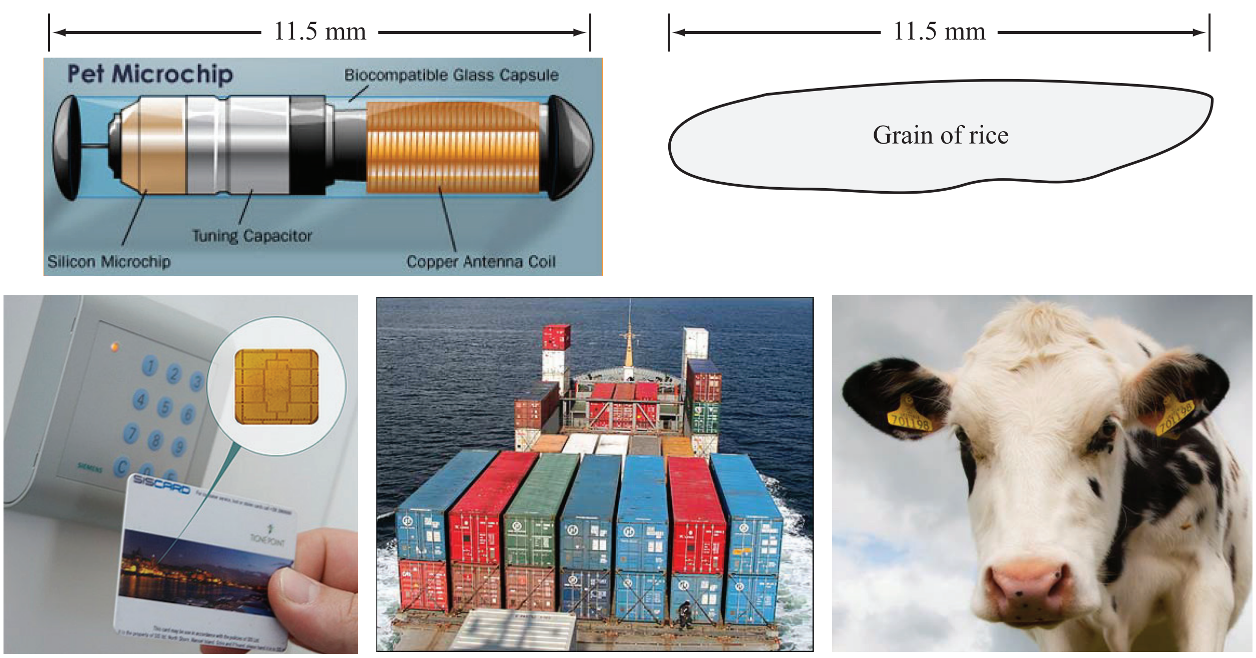


Figure TF16-1: RFID examples.

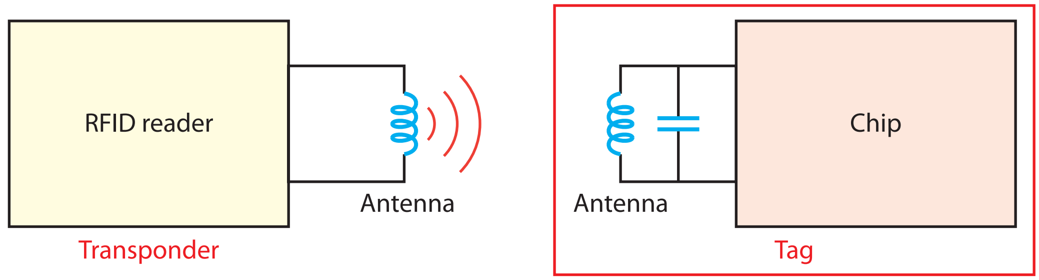


Figure TF16-2: RFID system.

the bar code. RFID circuits can be out of sight (inside a pet or package) as long as the wireless electromagnetic signal can penetrate the external packaging. Bar codes are ***read only***. RFID systems can be *read only* or ***read-write***. Bar codes are printed directly on packaging, or stickers affixed to packaging. RFID systems require an external antenna and a (tiny) computer chip. The antenna can be printed, but the chip must be somehow affixed. The entire system is often implemented in a sticker or card. Bar codes are essentially free (printed), whereas RFID tags cost 15 US cents and up.

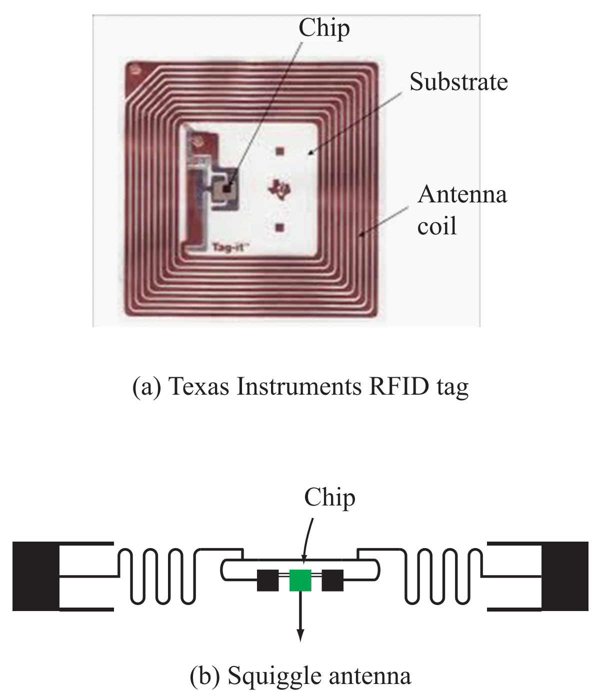
RFID Operation

In a ***passive RFID*** system, an external transponder transmits a wireless signal to the RFID circuit (**Fig. TF16-2**), which “wakes up” and receives power from the signal through inductive coupling or other power harvesting methods. It then transmits its coded ID information back to the transponder, through the inductive link. The advantage of passive RFID systems is that they can be very small, not much bigger than a grain of rice, and can last for decades without maintenance as they do not require an internal battery to power the circuit. But the transponder must be within a short distance (less than 1 m) of the RFID circuit in order to receive the ID information. ***Active RFID*** systems have a battery to power the internal RFID circuit and can therefore transmit much further, up to 200 m.

RFID systems consist of an RFID transceiver with a sinusoidal source and (typically) a loop antenna, through which the current flows, creating a magnetic field. The magnetic field is part of an electromagnetic wave that travels a short distance through the air to the RFID tag. The RFID tag has another (typically) loop or loop-like antenna to receive the magnetic field and convert it back to a current, and an RF circuit to convert it to a small voltage that can be used to power the data circuit in the chip. Frequencies used for RFID and some of their applications are listed in **Table TT16-1**.

RFID Antennas

Two examples of RFID antennas are shown in **Fig. TF16-3**. Both are printed 2-D antennas containing an inductor, in either a coiled design as in part (a) or in a “squiggly” design (yes, it really is called a squiggle tag),



(a) Texas Instruments RFID tag

(b) Squiggle antenna

Figure TF16-3: RFID antennas.

Table TT16-1: RFID frequency bands.

Band	Regulations	Range	Data Speed	Remarks	Approximate Tag Cost in Volume (2006) US$
120–150 kHz (LF)	Unregulated	10 cm	Low	Animal identification, factory data collection	$1
13.56 MHz (HF)	(ISM) band worldwide	10 cm – 1 m	Low to moderate	Smart cards (MIFARE, ISO/IEC 14443)	$0.50
433 MHz (UHF)	Short-range devices	1–100 m	Moderate	Defense applications, with active tags	$5
865–868 MHz (Europe), 902–928 MHz (North America) UHF	ISM band	1–12 m	Moderate to high	EAN, various standards	$0.15 (passive tags)
2450–5800 MHz (microwave)	ISM band	1–2 m	High	802.11 (WLAN), Bluetooth standards	$25 (active tag)
3.1–10 GHz (microwave)	Ultra wide band	1 to 200 m	High	Requires semi-active or active tags	$5

which is often printed on a sticker label for consumer products.

Antenna design is a subspecialty of electrical engineering. Antenna designers consider ways to either convert current and voltage to electric and magnetic fields in the air (for wireless transmission) or to collect those fields in the air and convert them back into currents and voltages. In general, the same antenna can be used to receive and transmit the RFID signals. Antenna performance is governed by the shape of the antenna and its size relative to the wavelength λ of the electromagnetic (EM) wave it radiates or intercepts. The wavelength, in turn, is related to the signal frequency f by $\lambda = c/f$, where c is the velocity of light in vacuum. Hence, the size of an antenna usually is chosen to match the EM frequency that the RFID is intended to use. The ratio of electric to magnetic field is called the impedance of the antenna, and it needs to be matched to the same ratio of voltage and current that are produced or received by the circuit (the impedance of the circuit). The impedance of the circuit is controlled by the capacitors, resistors, inductors, and other elements at the input or output of the circuit. The impedance of the antenna is controlled by its shape and size. Coils tend to be more inductive, which means their impedance is more like an inductor (has a positive imaginary part). Antennas shaped like plates tend to be more capacitive (having a negative imaginary part). Most antennas are a combination of inductive and capacitive, and can be modeled in circuit analysis as circuits containing both inductors and capacitors. Circuit elements are called ***lumped elements*** because their capacitance, inductance, and resistance are built from individual components, whereas an antenna is a ***distributed element*** whose capacitance, inductance, and resistance are spatially distributed along the length of the antenna. Taking all of these design factors into account at once is fairly daunting, so computer software is used extensively in antenna design, leading to creative designs such as the squiggle antenna and beyond. Antenna designers sometimes say they are “painting with copper” to describe the creative artistry of their field.