RADIO FREQUENCY IDENTIFICATION (RFID) EXPERIMENTAL WORK IN ENGINEERING TECHNOLOGY PROGRAMS

by

Albert Lozano-Nieto, PhD
Engineering Technology and Commonwealth Engineering
The Pennsylvania State University
Wilkes-Barre Campus
a-lozano@psu.edu

Abstract: *The goal of Engineering Technology programs is to produce highly qualified graduates serving industry and the society. They need to provide students with not only practical and hands-on experience, but also with the critical thinking and technical skills to solve the problems and challenges that graduates will face in their professional careers. Engineering Technology programs need then, to anticipate the future needs of industry in order to be abreast of the ever-changing market in technological fields.*

The experience teaching in Electrical Engineering Technology, together with recognizing the changes in society, technology and industry indicate that the concepts related to Radio Frequency Identification (RFID) will be prevalent in tomorrow's environment if not in today's. We can expect an increase in the need of engineers and technologists who are aware of the main techniques and approaches used for RFID The goal of this paper is to analyze different options at the time of incorporating RFID experimental work in Engineering Technology programs and courses. The approaches presented in this paper range from the practical characterization of complete systems to the observation and analysis of the different signals in the components that make up the RFID system, thus allowing to develop experiences at the appropriate level for different courses or programs.

I. Introduction

Engineering Technology programs are designed to produce highly qualified professionals to solve the problems faced by industry and society. These programs are aimed at training future professionals in the maintenance, repair, acquisition and management of electronic equipment. However, as industry and technology are undergoing major changes, the training of these future professionals needs to be reviewed and updated. In particular, Electrical Engineering Technology programs should respond to the needs of today's industry, as well as to anticipate what will be required from professionals in the upcoming years.

Radio Frequency Identification (RFID) is having a more prevalent presence not only in trade magazines and journals specialized in electronics, computers and networking but also in the mass media. The mandates by the public sector agencies -for example in the US Department of Defense- as well as the private sector such as stores like Wal Mart requiring that all their suppliers use RFID for inventory of the goods they receive, has been the main force that drove the maturity of this new technology. In turn, these mandates have permeated to a large number of large and medium size businesses as a tool to reduce costs and increase revenue. Moreover, we are seeing reports on a weekly basis that indicate how small companies are also incorporating these approaches into their business operation [1].

RFID is here to stay and will play a prevalent role in how business operate in the future. It is hard not to make a parallelism between the development of this technology with the evolution of the penetration of personal computers in the market. While twenty years ago the use of computers was mostly constricted to large and medium size enterprises, it is impossible today to imagine a successful business of any size that does not employ computers. The United States Department of Commerce has forecasted the market size of RFID technology between $2.0 billion and $4.2 billion in 2008 [2] with some private companies forecasting as high as $7 billion for 2008.

As the market size for RFID technologies continues to increase, the number of engineering technology graduates who will be involved in the deployment of this technology or in its evaluation will also increase. To respond to this future increase demand on knowledge and skills in RFID, it is now the time to cover these concepts in our engineering technology programs. By doing this, we will not only contribute to enhance the skills of our students and therefore help them to become more competitive in the global market, but we will also help them understand the real uses, applications and limitations of this technology and dispel the myths that abound regarding the use of RFID.

The introduction of new technologies is always accompanied by fears and claims of potential threats. The last most recent controversy peaked about ten years ago with claims that linked the use of cellular telephones with several types of cancers [3]. Although this connection was never scientifically proven, it nevertheless haltered the expansion of cell repeaters and towers due to alarmed and concerned citizens. Fifty years ago it was the penetration of microwave ovens in the American households that was perceived as a potential health threat until these claims disappeared as they could not be proven [4]. Even though we use microwaves for cooking without giving it any second thought, there is still a reminiscence of those days in the popular culture, as for example the use of the term *"to nuke"* to refer to cooking using a microwave oven, when it has no relation whatsoever to nuclear radiation. Even the introduction of electricity in households at the beginning of the century was met with fears of health effects due to the potential "leakage" of electricity [4]. Today, it is the turn for RFID to be subjected to fears, paranoia and misunderstanding as it can be seen by some of the publications and websites that exploit the societal fears of a "*Big Brothe*r" government spying on its citizens and similar ideas [5]. The concerns on the security of the information sent by the transponders and the transponders themselves is not taken lightly by the different groups and agencies involved in this technology [6] and are currently several approaches being investigated to increase the safety of this technology [7, 8].

As technology educators, it is also our job and responsibility to help students to be aware of the implications of new technologies being developed from an objective point of view. With this, future graduates can use their knowledge to educate and help the general population in dispelling the myths associated with technology and at the same time to assert their real benefits and drawbacks.

The goal of this paper is to explore the available possibilities and develop a framework in which we can bring the concepts used by RFID into our classes and laboratories. The focus of the paper is not to outline a curriculum to teach in our courses but to explore options that we can use for the experimental learning in this area. The level of detail and depth in which these concepts are covered will depend on each institution and the needs of each academic program. Depending on their goals and mission, some academic programs may decide to develop a specific course in RFID, while other academic programs may cover these concepts in existing communication courses. For this reason, this paper will not offer any specific curriculum but instead, it will explore the available options for developing experimental laboratories focused on RFID.

II. Basics of RFID

RFID is a technology that uses radio frequency for communication between a tag – also known as the transponder- and a reader – also known as the interrogator-. The transponder carries a unique identification number that is sent to the interrogator every time that the transponder is queried. The identification number can then be referenced against a database to retrieve additional information on the object that was tagged. RFID technology is in this way, functionally similar to the bar codes that appear in almost all products marketed in the United States and a large number of countries. They differ in the way that the information is read: by optical means in the case of bar codes and by radiofrequency in the case of RFID.

Although the widespread use of this technology is recent, it was first developed during World War II in order to identify friend or foe aircraft. The first work exploring RFID is a paper by Harry Stockman that has become the landmark for the future development of this technology [9]. After several years, and following the advances in the development of personal computer, personal communications and microelectronics in general, the technology is now mature enough to be mass-marketed at competitive costs.

A RFID system consists of four different parts:

- The tag or transponder that is affixed to the item being tracked.

- The reader or interrogator that is the system that writes information to the tag or reads information from the tag. The basic structure of an interrogator is shown in Figure 1. There are different types of interrogators depending their characteristics:

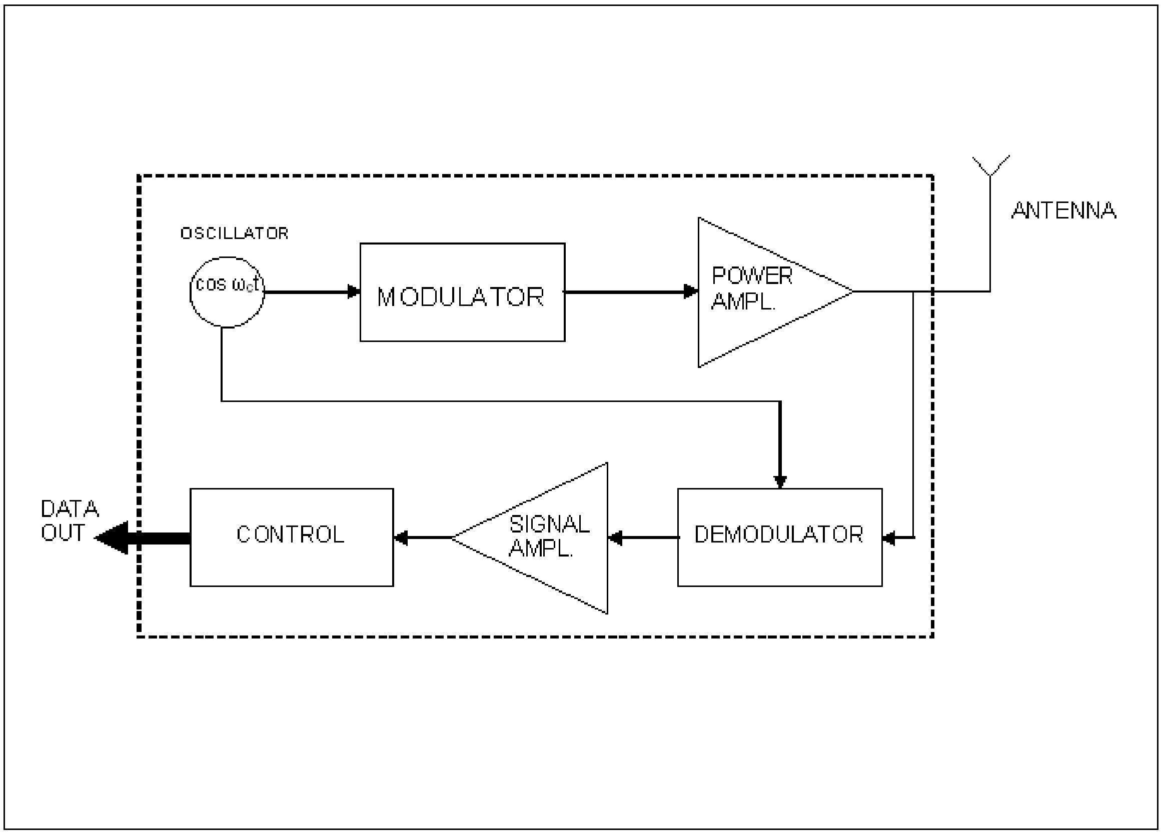

FIGURE 1. Basic structure of a RFID interrogator

  - o Fixed Interrogators are the types used in warehouses and other large facilities where these are mounted on walls, doors or other structures. These types of interrogators need an external power source and can accommodate several antennas.

  - o Handheld Interrogators, that are much smaller, have an antenna built into the unit and are battery operated. Some of these interrogators can also read barcodes, increasing their functionality. The communication between handheld interrogators and their main system can be either tethered or by wireless methods.

  - Mobile Interrogators that can be connected to a laptop port, PDAs or cellphones, or even mounted in forklifts or clamp trucks. These interrogators usually have wireless connections and are powered by their host.

- The antenna that is used to couple energy between the transponder and interrogator.

- The database that manages the information sent by the transponder.

The tags (transponders) themselves can be classified attending to different parameters. While it is not the goal of this paper to produce an extensive review of RFID systems and classifications, it will describe the most used classifications of transponders as they originate very RFID systems with very different properties.

One of the most common methods for classifying tags or transponders is based on how they obtain the source of power necessary for establishing communication. Tags are therefore classified as three different types:

- Passive tags. These tags do not contain any source of power and therefore they are the most simple and least expensive tags. When a passive tag enters the electromagnetic field created by the interrogator, the energy of this field is captured by the antenna in the tag. The tag then uses this energy to power its microchip that contains the code that is transmitted back to the interrogator. These methods of communication are known as backscatter communication or inductive coupling and are mostly used by low-frequency and high-frequency transponders as shown in Figure 2. The read range for these tags is the lowest of all, 10 feet at the very best, but they are also the less expensive tags.

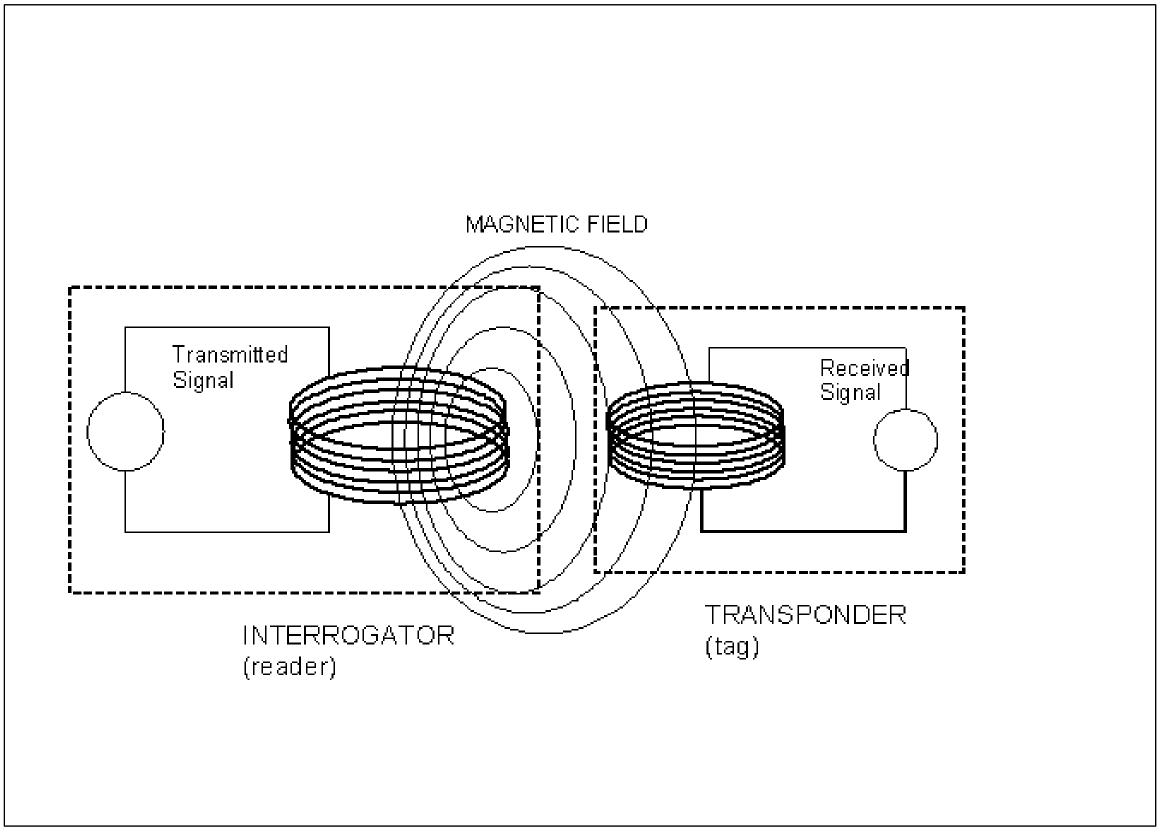

FIGURE 2. Principle of inductive or magnetic coupling used in passive RFID tags. In the configuration shown here, the reader powers the tag through its magnetic field generated. Afterwards, the tag will transmit a digital signal that will be read by the reader.

- Semi-passive tags: These tags contain batteries that are used to power its microchip in order to gather information from several transducers, for example to log temperature, but the batteries are not used to transmit the information to the interrogator. The information is sent back to the interrogator using the backscatter of inductive coupling technique, similar to passive tags, therefore having a similar read range [10]. Because of the increased complexity and reduced use, these tags are quite more expensive than passive tags. While passive tags can be produced for less than 5 cents, semi-passive tags still cost $20 or more.

- Active tags contain batteries that are used to communicate with the interrogator. In this type of tags, the communication can be initiated even when the tags is far away from the interrogator, 100 feet away or more. These tags can be produced for around $20 a piece. While passive tags have an ideally infinite life, the life of the active tags is limited to the life of their batteries.

It is necessary to stress that with the exception of very specific applications (like for example the E-Z pass system for toll payment in highways that use active tags in order to have a useful read range), the great majority of RFID systems today employ passive tags.

Another type of tag classification is by looking at their ability to read and write data. With this classification scheme, the most common types of tags are:

- Class 0: These tags can only be read by the interrogator. The data in these tags is an alphanumeric identification string, preprogrammed by the manufacturer. The RFID system can not overwrite or modify this code.

- Class 1: The identification string from these tags can be programmed by the manufacturer or by the RFID system, but it can only be written once. Once the data is written it cannot be overwritten or modified. These tags are known as WORM tags (Write Once Read Many).

- Class 2: These tags can be re-written by the interrogator many times. A typical application would be in a production line in which the tag is updated after each step of production is completed. These tags have more memory and can hold more information that Class 0 and Class 1 tags.

There are also tags Class 3, Class 4 and in which the information that they contain is more complex and sophisticated. We will not address these types of tags in the paper as we are only concerned with the basis of the RFID technique. One last classification of RFID systems and their tags is based on the frequency of the signal used by the interrogator to query the tag. Therefore RFID systems can be classified based on frequency in:

- Low-Frequency (LF) RFID systems, operating in the 125 kHz to 140 kHz range. These tags, shown in Figure 3 are used by a large number of systems as the technology for this frequency range is well developed and so it has a low cost.

FIGURE 3. Several tags that operate in the LF range. These tags are available in different shapes and sizes, but because of the requirements in the 125 kHz to 140 kHz frequency range, all the tags require considerable wire length for to make their antennas efficient. The length of cable required can be seen in the transparent tags. In these same tags, it is also possible to see the chip that is connected to the antenna.

- Because LF waves work well around metals or objects with high water content, one of the main applications of this frequency range is its use for tracking animals (cattle, pets, etc.) or even implanted in humans. Figure 4 shows two different transponders that can be implanted in animals for livestock tracking and control. The two main drawbacks associated to the use of LF is that the transmission speed has to be low because of the frequency of the carrier signal and the size of the tags is relatively large because of the requirements of having larger antennas to be effective at these frequencies.

FIGURE 4. RFID tags in the LF range suitable to be implanted in animals. The length of these tags is 1” and 1.5”. In this close up it is easy to observe the coils that make the antennas for these tags.

- High Frequency (HF) systems, operating at 13.56 MHz. This frequency is also well developed and therefore HF systems present a low cost, comparable to LF systems. These systems are less sensitive to noise than LF systems, support a higher transmission speed and the antennas –and therefore the tags- can be smaller than tags used for LF system. Figures 5 and 6 show examples of HF tags designed to be attached to the objects being tracked. These systems however, do not work well if the tags have to be attached to metallic objects or used in materials with high water content. Both LF and HF systems have a limited read range of below 10 feet because they only use passive tags.

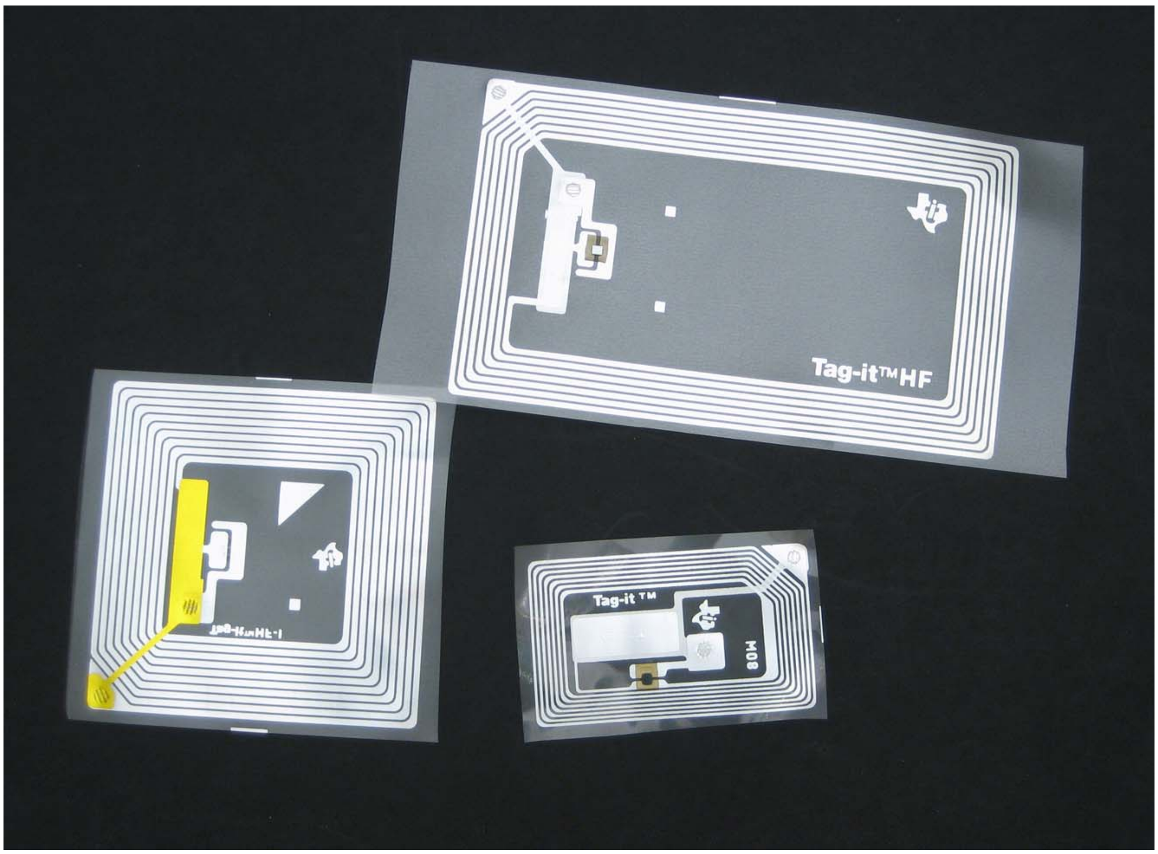

FIGURE 5. RFID tags from Texas Instruments for HF systems at 13.56 MHz. In this picture it is possible to observe how the length of the antennas is considerable shorter than for tags in the LF range.

- Ultra-High Frequency (UHF) systems that operate in the 860 MHz to 930 MHz frequency range. Because tags in this frequency range can be active tags, the effective read range can be as high as 60 feet, with a higher communication speed. However, because of the attenuation due to water content, these systems do not work well in moist environments, and because of wave reflections they do not work well around metallic objects either. UHF systems are slowly growing in their commercial use as new generations of UHF RFID systems can read up to 1,500 tags per second in good conditions.

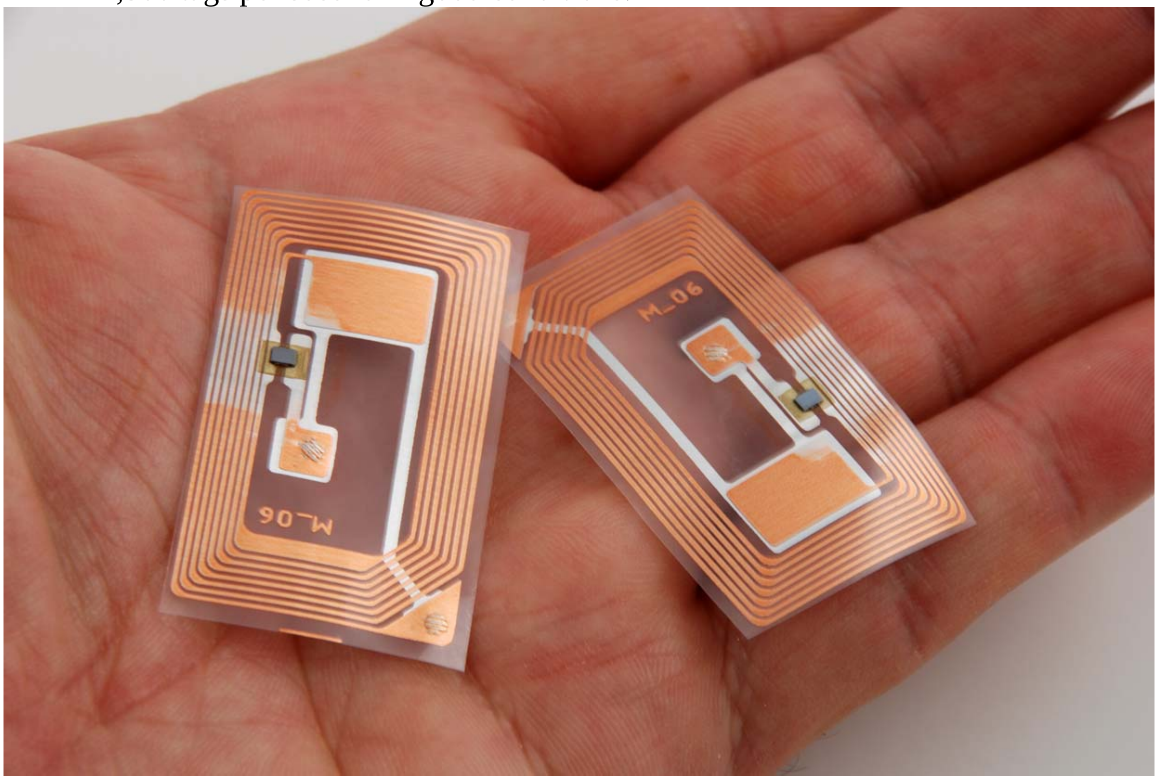

FIGURE 6. RFID tags operating in the HF range. In these tags it is possible to see the microchip connected to the antennas.

- Microwave systems operating at 2.45 GHz and at 5.8 GHz. These systems support much higher read speeds and a read range slightly below UHF systems. Their main drawback is the higher attenuation by atmospheric moisture and the interference from other devices in this unregulated frequency. These systems are still under development and we should see more of them being introduced commercially in the next years.

III. Creating Experimental Labs in RFID: Equipment Options

Commercial RFID systems, suitable for deployment in different types of industry are expensive, can be complex and cumbersome to use by non-experts and therefore they are not the best choice for creating experimental activities in engineering technology courses. In this paper, we will analyze low-cost and simpler alternatives that do not have the capabilities required for industrial use such as reduced number of transponders that they can handle, limitations in antenna connectivity etc. However, these low-cost alternatives are nonetheless valid and appropriate for developing experimental learning in our courses focused in proof of concept and help students to become familiar with this technique.

With the equipment discussed and described in the next sections, students can experiment and learn the basic concepts associated to the RFID technique such as reading range, effects of antenna orientation, collisions, attenuation and absorption of different materials, types of antennas, required time for reading, etc. These activities will allow students to understand the basic concepts associated with RFID and carry out basic experimentation to further understand it. The list of equipment described below does not pretend to be exhaustive; it is just a sample of low-cost and basic RFID systems that are suitable to bring RFID into the engineering technology labs.

a) RFID Reader Module and tags: Parallax Inc.

The RFID reader from Parallax [11] was the first available low cost system –below $40 for a single reader-, as it was designed towards the hobbyist and educational markets. This RFID system, shown in Figure 7, is a passive system operating in the low-frequency range (125 kHz) that opened the possibility of experimentation and design of small RFID systems that otherwise was not possible due to the cost and complexity of commercially available systems that were designed for larger scale operations.

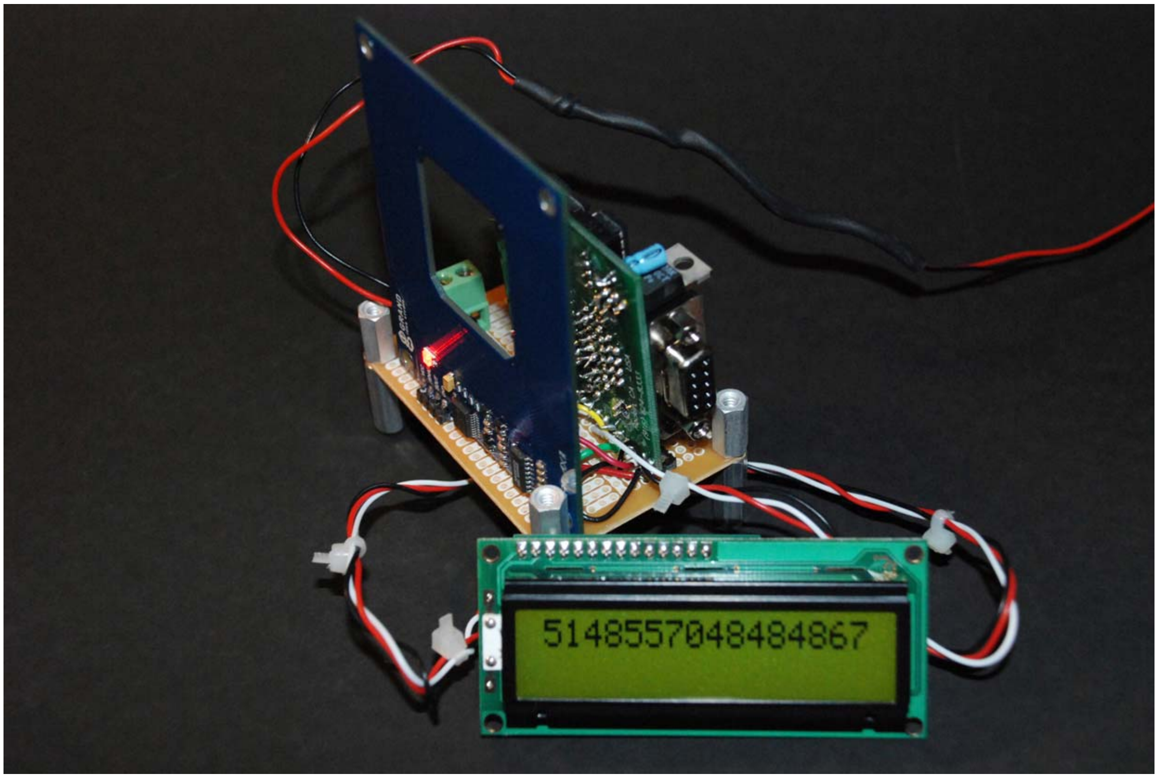

FIGURE 7. Parallax RFID reader system with interface and display developed by the author. The RFID reader is the blue module that has the antenna imprinted in its PCB. The green PCB is one of the Basic Stamp modules that is used for control in this example. They are all linked by the horizontal PCB with the LCD display that displays the last identification string received from a tag.

There are four signals that connect the reader module with the external world. These signals are the power supply (5 V_{DC}), ground, an Enable input to enable or disable the reader, and the Serial communication output at 2400 bauds, TTL logic. The connection of these signals is through four pins, spaced 0.1 inches, therefore making it compatible with the space of breadboards, and allowing for easy experimentation. Parallax also supplies several types of tags that can be read with the system.

A low-cost system will always have some limitations that need to be considered at the time of developing experimental work for our courses. These are:

- Passive system, therefore limiting the read distance to few inches.

- The serial output is the raw data from the reader and therefore it needs to be processed before being able to be displayed, normally using a microcontroller for this processing. Parallax supplies a basic code that can be used with their Basic Stamp family, although any microcontroller can be used. For example, in Figure 7, the RFID reader is the blue module, while the rest of the system is a Basic Stamp microcontroller that handles the data from the reader and outputs it to the LCD display. Depending on the background of the students and the goals and objectives for the course where this activity is being held, instructors can provide the code to them, students may have to write it from scratch or we can give them a basic structure that needs to be completed by the students.

- Unidirectional communication: The communication only flows between the reader module and the microcontroller. All the low-cost systems and the majority of medium-cost systems support only tags that have already been written by their manufacturer and the information they contain cannot be modified or even killed (WORM tags). The only communication between the controller and the reader is the Enable control to allow or disallow the reader to be active.

- Readable tags: The Parallax system can only work with a specific family of tags (EM Microelectronics-Marin SA EM4100). Therefore, the RFID system will not be able to read or detect the presence of transponders that follow different standards.

- The operation frequency for this system (125 kHz), although it is within the range of allocated frequencies for RFID systems, is not as common as other frequencies in the LF band. As a result, the interrogator and transponder in this system cannot interact with other interrogators and transponders available for other systems.

- No protection against data collision. This system will only be able to respond to a single tag. If more than one tags are within its range for reading, the collisions will confuse the reader.

Despite all these limitations, this system from Parallax has the advantage of its low cost, allowing to be used in our classrooms and laboratories for demonstrations and more importantly, experimentation by our students. Parallax also supplies additional information on the communication protocol that they use. This fact, linked with the code for the external Basic Stamp microcontroller allows to deploy a basic RFID system in a very short period of time. Furthermore, the forums in the Parallax website provide an excellent resource from experts that can help with troubleshooting questions that may arise, not just for the RFID system but for any questions related to the interface, code, etc. [12].

One final advantage of the Parallax RFID Reader Module is that the electronic components are easily accessible, so it is possible to visualize the signals with an oscilloscope at the different pins of the integrated circuits. With this, we can develop experimental activities that will help the students understand concepts such as power consumption when the reader is active or inactive, cycle timing for the reader, serial communication, etc. In addition to the previous activities, this module can also be used to perform the basic characterization for a RFID system, measuring its responds to tag and antenna orientation, the absorption of different materials, interference due to reflected waves, read and response time, etc.

b) RFID Reader and tags: Phidgets

Phidgets USA, a division of Trossen Robotics sells several RFID readers and tags [13]. These readers have a similar physical configuration that allows the visualization of signals from the pins of the integrated circuits used, making them also suitable for this component-level characterization of the RFID readers. However, Phidgets USA has three three types of readers compared to a single one from Parallax. These readers are:

- Phidgets RFID. This is a read-only system operating at low-frequency (125 kHz). Its performance, configuration and physical layout are very similar to the system from Parallax.

- APSX RW-2110. This is a high-frequency systems (operating at 13.56 MHz) that can read and write the HF tags that support multiple rewrites (not all the HF tags will support being written more than one).

- APSX RW-3110. This system is similar to the previous one (read/write system in the HF range) but allowing a larger read range.

The cost of these interrogators is $60, $55 and $126 respectively. The output of all these interrogators is TTL level or RS232 level depending on the type of kit chosen. Figure 8 shows a picture of one of these readers with a direct connection to a computer by means of a USB connector.

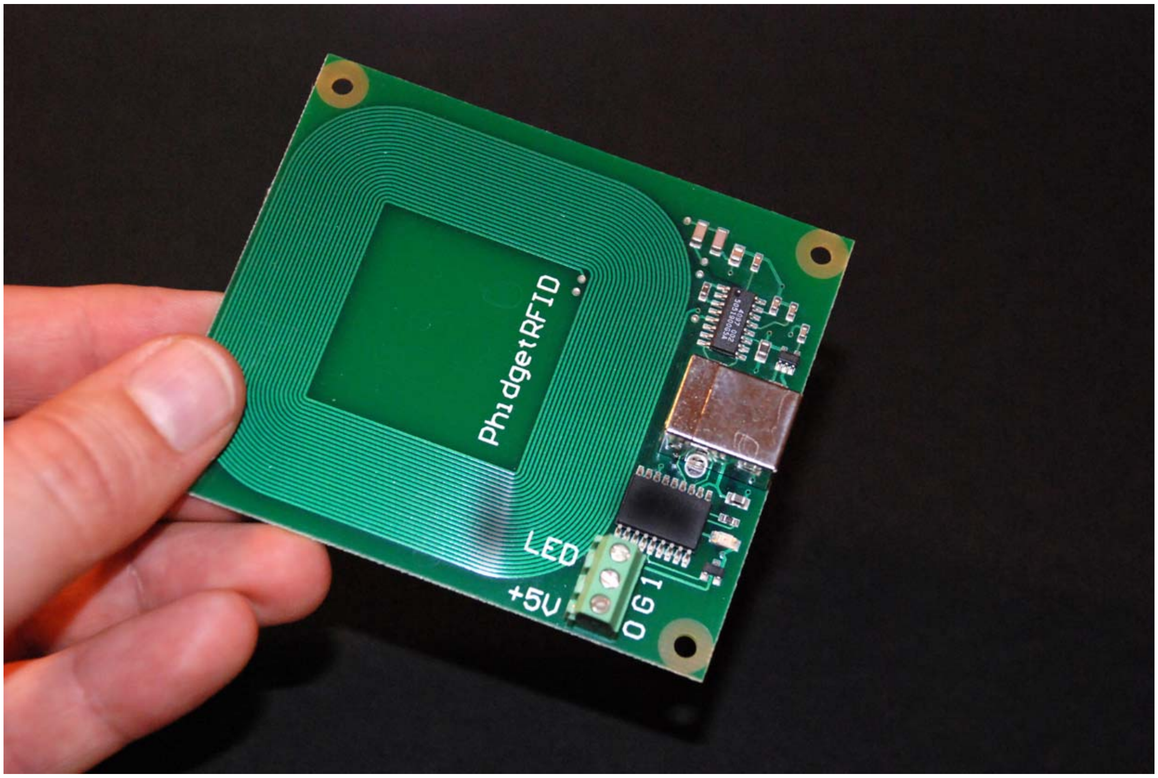

FIGURE 8. Phidgets RFID module operating in the LF range with USB connection. This picture shows clearly the imprinted antenna in the module and how the different integrated circuits and other electronics are easily accessible.

The same type of academic activities suggested for the RFID reader from Parallax can also be performed with these transponders because the connections and pins are also easily accessible. In addition to those lab exercises, using the APSX RW-2110 or APSX RW-3110 will allow for additional experiences. Students can learn the process of rewriting tags and evaluate that they have been written correctly. More importantly, however, is the possibility to compare the performance of RFID systems that work in the HF range with systems in the LF range. Because of the different characteristics of electromagnetic waves at these frequencies, students can compare the absorption effects of different materials at these two frequencies, the requirements for antennas, the effects of interference, etc. Using this approach, it is possible to create laboratory work in which the students need to make a decision on what frequency to use (LF or HF) based on a series of experimental measurements that they can carry out following some predetermined constrains.

c) AVEA Access control and RFID Modules

The RFID products from AVEA are distributed in North America by Quality Kits [14]. Their three basic kits are all RFID interrogators working in the LF range. The core of these kits is the hybrid module with an embedded microcontroller as it can be seen in Figure 9. Because of being an open configuration, all the pins for these modules as well as the kits are easily accessible, making it possible to visualize in an oscilloscope the different signals at the different locations of the kits as described earlier for other systems.

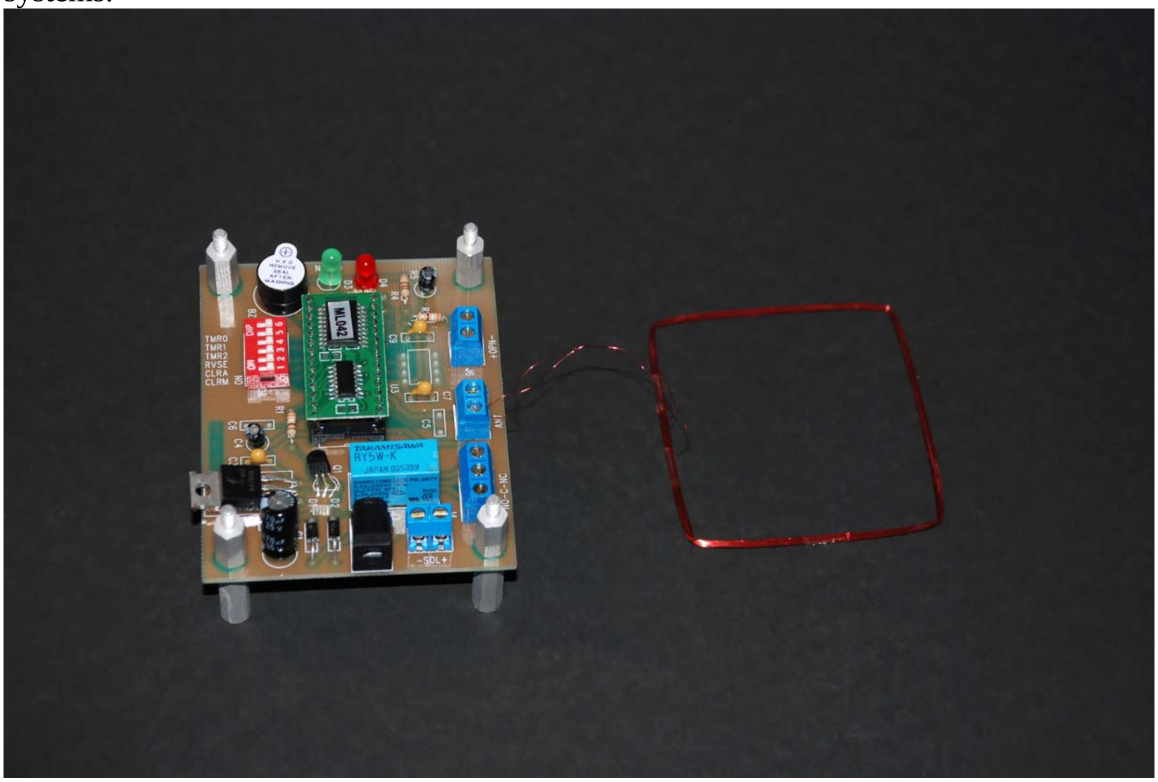

FIGURE 9. RFID module from AVEA. The picture shows the connectors for the antenna, allowing to experiment with different antenna types, sizes and configurations. The picture also shows the reader module (green PCB) immersed in the whole kit that contains the interfacing electronics.

It is interesting to note that while in the Parallax and Phidgets systems described earlier the antenna is imprinted in the same Printed Circuit Board as the electronics, in the products from AVEA the antenna is a separate unit. The antenna for these systems is a squared loop antenna made from wire and tuned to the operating frequency. This antenna can be easily connected and disconnected from the reader, therefore allowing experimentation with different types of antennas as they can be easily built in different configurations. For example, students can evaluate the effect of detuning the antenna on the read range, the effect of substituting the antenna with another antenna with different dimensions, the effect of placing the antenna around different materials, etc. Therefore, this module gives students the opportunity to experiment with modifications and changes in the antennas that is not possible with the other systems described in this paper.

One of the kits is the typical RFID interrogator that will read the information sent by the transponder and will send it to the host computer. However, a more interesting kit has been designed as an access-control module. This kit contains Normally-Open or Normally-Closed relays that will be activated responding to 42 different that can be programmed by the user as “allowed” cards. This makes it very easy to implement security access systems. All the kits come completely disassembled and must be assembled by the user. This can represent an advantage as they can be used for high school demonstrations, summer camps and other outreach activities in order to increase the interest of youth in electronics, technology and engineering. In a very short period of time, these young students can learn how to solder, they can have a grasp of the basics of electronics, learn how to read schematics and finish a project that will illuminate a light bulb or will make a siren go off depending on the type of target being swiped. For all these reasons, these kits provide a unique and different perspective that other basic RFID systems reviewed in this paper do not have.

d) RFID Evaluation Modules: Texas Instruments

Texas Instruments is one of the major semiconductor companies who has played a leading role in the development and research on RFID since their inception. They provide solutions at different levels, from complete systems down to the integrated circuits that are the core of any RFID interrogator as well as the chips used in transponders. For the academic purposes outlined in this paper, the main focus will be on their line of evaluation kits that can serve as small RFID systems suitable to be configured in our academic labs. These evaluation kits do not have the complexity and associated costs necessary for the deployment of large-scale systems, and at the same time they do not require the level of expertise necessary to design RFID systems at the component level.

Texas Instruments offers evaluation modules in the LF and HF range [15]. In the HF range, the TRF7960 Evaluation Module consists of a whole RFID system at the standard frequency of 13.56 MHz. This evaluation module supports interaction with transponders using four different protocols, and four additional transmission speeds (from 106 kbps to 848 kbps) thus making it suitable to work in different environments. The system connects to a personal computer that is used for configuring the interrogator as well as for receiving the data from the different transponders that are being read. In the LF frequency range, Texas Instruments offers one evaluation module operating at 134.2 kHz, in two different versions that differ in the read range (6” or 15”). These modules are similar in their approach and configuration to the modules described earlier in which a personal computer is used for interfacing. In addition to the interrogator, antenna and necessary connections all these modules from Texas Instruments come with a variety of transponders for the frequency of interest. Because all the modules support reading transponders that operate following several standards, the number of tags that we can use is much larger than for the other systems mentioned previously. Therefore, using any of these systems students can experiment with different tags and their properties at the time of being place on a product, their physical configurations, etc.

One of the main advantages of these systems compared to the previously described systems resides in their modularity and being complete, so they can be operational in a very short period of time. Also, they do not require any additional circuitry to interface with the host computer. Their modularity can also be seen as their main drawbacks as being enclosed in their modules they do not allow direct access to the different integrated circuits in order to visualize the signals in an oscilloscope as shown in Figure 10. Furthermore, because they don't need any additional circuitry, students may not learn in as much detail about the different interconnections and signals that are being transmitted inside the interrogator.

FIGURE 10. Evaluation RFID module from Texas Instruments. These modules can operate at LF and HF frequencies.

These evaluation modules can become a useful tool for our classes at a relatively low cost of approximately $200 for the HF system and $300 for the low-power LF system. They are most suitable for the first exposure of students to RFID as there is almost no development that needs to be done before they become operational. Once the students are familiar with RFID systems, reading tags, etc., we can move to a more electronics approach using the Parallax, Phidgets and AVEA modules that require some electronics interfacing, code writing and offer the possibility to visualize the different signals in the system.

It is also important to mention that in addition to these evaluation modules, Texas Instruments also offers the interrogators and transponders separately, so it can be possible to build the same systems with these off-the shelf components by using the appropriate interfaces. For example, the RI-STU-251B is a reader (interrogator) in the LF range that only requires to be connected to an antenna at the front-end and a suitable interface for the bit stream at the back end. This will require for the students to learn in deeper detail the different communication protocols that are used, that are documented in the products offered by Texas Instruments. This type of activity is suitable for students more experienced in the design of complex digital systems, embedded systems, etc., as it requires to design a complex interface.

e) Component-level RFID devices

Depending on the type of courses taught, the goals for a specific academic program, or even the personal interests of our students, for example at the time of developing a senior design project, it may be possible to work with RFID systems at the component level, including the design of a basic system. While a major part of such a system will be the digital subsystem with the microcontroller and associated interface, in this paper we will only focus on the specific RFID parts.

Texas Instruments offers several types of antennas that can be used in RFID interrogators [16]. The models RI-ANT-S01C and RI-ANT-S02C are stick-type of antennas suitable to be used in LF interrogators at the 134.2 kHz with a cost of around $70. They also offer gate antennas of three different sizes for the LH range (RI-ANT-G01E, G02e and G04E) and one for the HF range of 13.56 MHz (R1-ANT-T01) with costs ranging from $120 to $200. All these antennas are commercial grade and therefore able to support day-to-day operation, this being the reason for their higher cost. The stick antennas have been designed for portable interrogators and they are able to work in harsh environments. The gate antennas are designed for use in warehouses and other applications that require them to be stationary while being physically robust against contact from workers, forklifts and other machinery normally operating in these conditions.

At the hybrid level, the RI-STU-MRD1 from Texas Instruments is a 30-pin hybrid module that provides the RF and control functions to communicate transponders in the LF range. The module RI-RFM-003B is another RF module also from Texas Instruments with similar performance. As all these modules need to design some circuitry around them and develop the software to communicate by means of different protocols, they are perfectly suitable for example, to be used in a semester-long student project.

Microchip, a manufacturer of integrated circuits mostly known for their family of PIC microcontrollers has also a division dedicated to RFID IC's. The integrated circuits MCRF 355 and MCRF 360 of integrated circuits are the core of RFID interrogators in the HF range. The product line MCRF45X is also a family of integrated circuits for RFID purposes in the HF range. Microchip also offers several application notes and design guide that can be used for advanced students to design and develop their own RFID system at the component level [17, 18]. An added advantage is that all these chips from Microchip are available in the standard DIP package, making it much easier to work with them in the classroom laboratories.

IV. Conclusion

This paper has explored several low-cost, basic systems that are adequate to bring RFID into the classrooms and laboratories of our Engineering Technology programs. While the systems described here are just a sample of products available in the market, they can be seen as a representation of products available that can be used to fulfill these academic needs as the number of manufacturers and vendors who provide RFID solutions is increasing every day. The goal of the paper was to review products that because of their simplicity and low cost they are a good choice to use in our programs. For the same reasons of low cost and simplicity, this paper has not evaluated RFID systems in the UHF or microwave range, nor active or semi-active tags.

An additional advantage of the in the approach followed in this paper is that instructors can tailor the activities for the students to different levels of complexity and also to the different approaches for different courses. Some instructors may prefer to study the RFID system considering it as a whole entity and evaluate its performance in different conditions. In some other cases, it can be necessary to focus on radio frequency transmission or the different electrical signals in the system. Some other courses may put their emphasis on the interface between the RFID system and the microcontrollers or even in the software for communication between the interrogator and the host computer, including database management. Because of their simplicity and openness, the majority of the systems described in this paper are suitable for all these approaches, therefore being an attractive choice to work with in engineering technology courses.

In any case, and independently of the products used or the approaches chosen for specific courses, it is necessary to expose students, at least to the basic principles of RFID and give them opportunities to work with this technology in the laboratories. RFID is a new technology with an increasing presence in industry, and for this reason we need to help students understand it and use it correctly in order for them to become competitive in the global marketplace once they graduate.

References

[1] RFID: The state of Radio Frequency Identification (RFID), 2005. White Paper IEEE-USA White Paper,

[2] US Department of Commerce, 2005. Radio Frequency Identification: Opportunities and challenges in Implementation.

[3] Foster, K., 1996. "Electromagnetic field effects and mechanisms". IEEE Engineering in Medicine and Biology, July-August p. 50-55

[4] Adair, E. 1996. "Electrophobia" IEEE Engineering in Medicine and Biology, July-August p. 91-101

[5] Spychips: www.spychips.com

[6] Information Security. Radio Frequency Identification Technology in the Federal Government. Report to Congressional Requesters. United States Government Accountability Office. May 2005

[7] Fishkin, K.P , Roy, S. and Jiang, B, 2004: . Some methods for privacy in RFID communication. In 1st European Workshop on Security in Ad-Hoc and Sensor Networks (ESAS 2004)

[8] Juels, A., 2004 "Yoking-Proofs" for RFID Tags, Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications Workshops, p.138, March 14-17, 2004

[9] Stockman, 1948. "Communication by means of reflected power". Proc. Of the IRE, pp. 1196-1204.

[10] Philipose, M., Smith, J.R., Jiang, B., Mavishev, A, Roy S. and Sundara-Rajan, K. 2005. Battery-Free Wireless Identification and Sensing. IEEE Pervasive Computing, Jan-March 2005, 37-45

[11] Parallax RFID Reader: http://www.parallax.com/detail.asp?product_id=28140

[12] Parallax Forums: http://forums.parallax.com/forums/

[13] Phidgets USA RFID readers: http://www.trossenrobotics.com/RFIDhome.aspx

[14] AVEA RFID solutions (http://www.avea.cc/. RFID kits distributed in North America by Quality Kits: www.qkits.com

[15] Texas Instruments RFID site: http://www.ti.com/rfid/

[16] Texas Instruments - Antennas http://www.ti.com/rfid/shtml/prod-ant.shtml

[17] Microchip MCRF45X Reference Design:
http://ww1.microchip.com/downloads/en/AppNotes/21654b.pdf

[18] Microchip 13.56 MHz RFID System design guide:
http://ww1.microchip.com/downloads/en/devicedoc/21299e.pdf