

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

**ESD.290 Business Impact of Auto-ID and RFID
Spring 2005**

Description of Assignments 4 and 6

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1. Assignment 6: Paper

Write a 10-page report with a forecast on how RFID will transform a given industry. It is essential to provide an estimate on the dollar impact and a justification for it. Consequently, this assignment will be graded on a 100 point scale, according to the following criteria:

- 50 points: \$ estimate calculations and associated justification
- 20 points: description of RFID technologies and appliances that will be necessary for your forecast to materialize
- 20 points: description of business processes that will be affected
- 10 points: overall description and writing style

Each team should submit three deliverables:

1. Deliverable 1: Paper proposals, each 1 – 3 paragraphs long. Please submit up to 3 proposals. This deliverable is due February 17th.
2. Deliverable 2: Final papers including at least: a) Industry forecast overview and key impacted business processes, b) Industry \$ value estimate and associated rationale, and c) RFID technologies necessary for the forecast to unfold.
3. Deliverable 3: Final presentation in class on March 17, 2005.

The following key dates should be observed:

Date	Event
February 17	Teams present proposals for term paper (Deliverable 1). Up to 3 ideas per team.
March 10	RFID Kit Assignment due
March 10	Final Paper due (Deliverable 6-2)
March 17	Final presentation given in class. (Deliverable 6-3)

2. Assignment 4¹: RFID Appliance Kit Project

At the end of the RFID Kit Assignment, students will have to turn in the following deliverables:

A written report, consisting of the answers to all the questions found in this assignment, with the necessary explanations, calculations, equations, and plots. It is probably a good idea to use a spreadsheet to note all the results, perform all calculations, and plot all data required to answer the questions. That way, discovering a mistake in an earlier step will not mean you have to redo all your calculations. Spreadsheets make excellent lab notebooks. They are also pretty good plotting and charting tools.

The reader system, consisting of the reader module, power source, antenna and tags, accessible by a PC via an RS232 serial cable. To test the reader system independently from the developed application, the S6350 Utility Software provided in the course folder will be used.

Detailed specifications to the above deliverables are provided in the rest of this document.

This assignment will be graded on a 100 point scale, according to the following criteria:

- 50 points: the written report
- 40 points: the reader system
- 10 points: overall performance

¹ Assignment 4 was the original idea of Prof. Brian Subirana and Prof. Sanjay Sarma. Most of the development of the questions and the design of the kit has been done by Prof. Rafael Pous with input from Prof. Brian Subirana and Prof. Sanjay Sarma. Chad Eckes also provided useful input all along the way.

Materials

The students will be provided with the following materials:

- A protoboard on which to setup all the connections and circuits required to build the reader system, plus red and black electric cable.

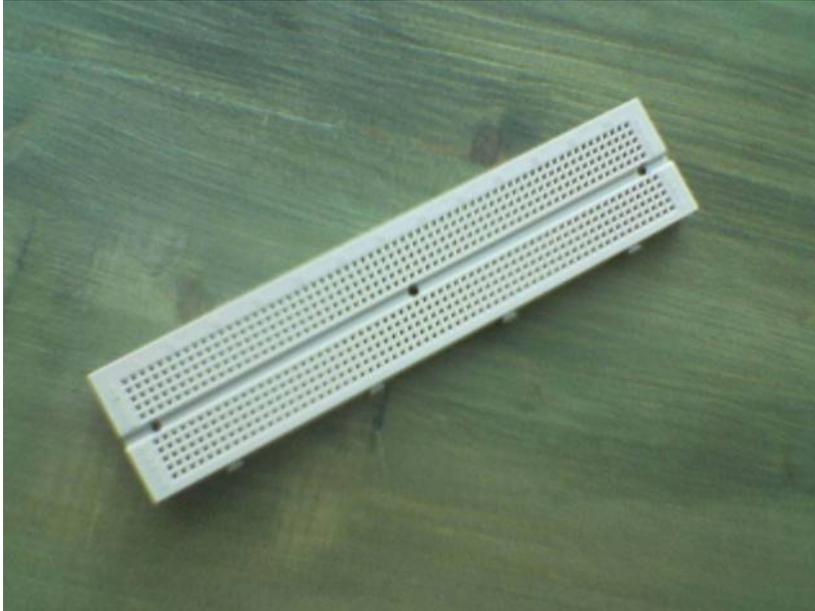


Figure 1 Top view of the protoboard. All connection points in the same 5-point vertical strip are connected, so all wires or component legs placed in the same strip are connected to each other.

- An HF mid-range RFID reader module, that when placed between the PC and the reader antenna is the main component of the reader system, except for the tags themselves.

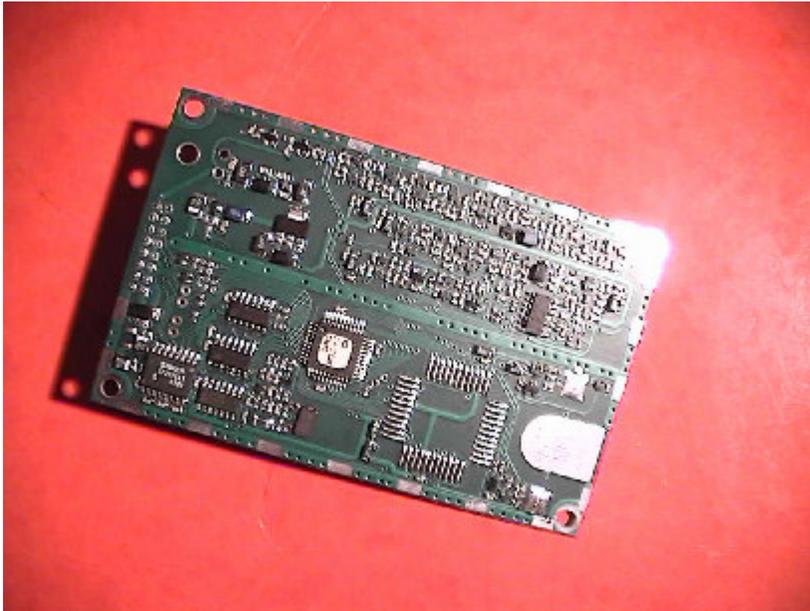


Figure 2 The S6350 HF reader module (component side).

- The necessary materials to build the power source
 - 9V 6LF22 battery (rectangle-shaped)
 - Battery connector for the above battery type
 - 5V L7805CV voltage regulator
 - Two 100 μ F electrolytic capacitors (cylinder-shaped)

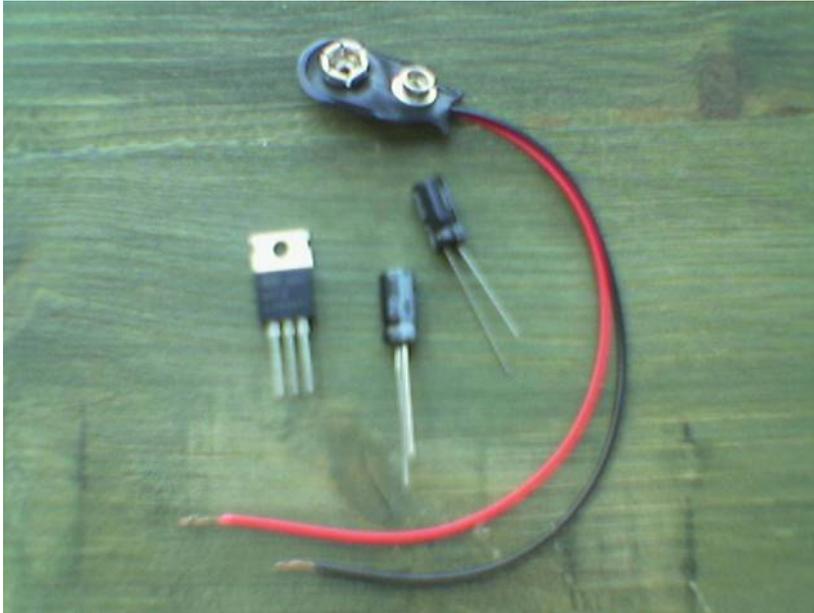


Figure 3 Power source components.

Note: One 9V battery may not be enough, since the reader tends to drain the battery fairly quickly. The TA will have at least 3 9V power supplies on hand, which can be requested and checked-out on an as-needed basis.

- The serial connection from the PC serial port to the reader:
 - An RS-232 female serial port connector
 - An RS-232 male-female serial cable



Figure 4 Serial data connection components.

- The necessary materials to fabricate and tune a coil antenna
 - Electric cable
 - 8 connector pipes to connect the cable to the reader module
 - Resistors of 15 k Ω , 18 k Ω and 22 k Ω (components with color-coded bands)
 - A color chart to interpret the values of the above resistors
 - Two 27 pF capacitors (lentil shaped, marked “27”)
 - One 220 pF capacitor (lentil shaped, marked “221”, which means 22 plus one zero)
 - One variable capacitor from 3 to 40 pF (3-legged component)



Figure 5 Antenna fabrication and matching components, and connecting pipes.

- 3 RFID tags, also known as transponders (Tag-it HF-I Transponder Inlays, Large Rectangle shape)

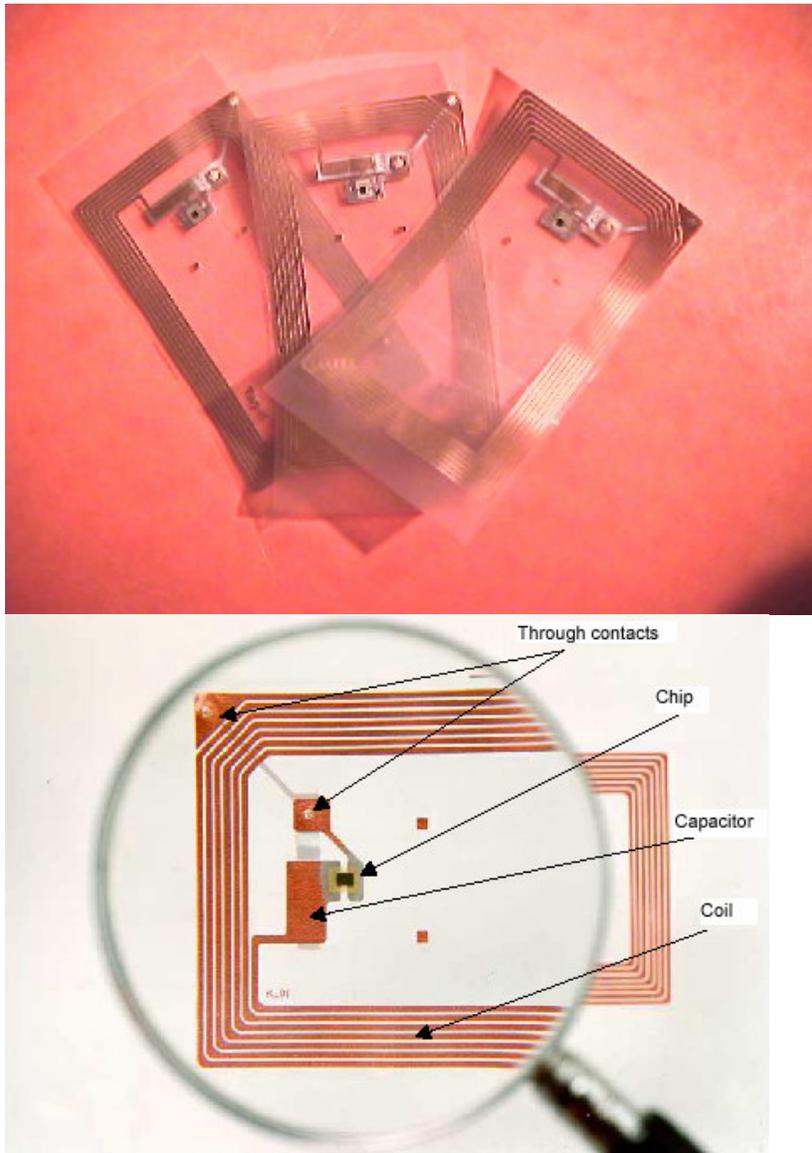


Figure 6 Detailed view of one of the supplied RFID tags.

The following documentation (available at <http://www.ti-rfid.com>):

- Tag-it HF-I Transponder Inlay Reference Guide
- S6350 Midrange Reader Module RI-STU-TRDC-02 Reference Guide
- HF Antenna Design Notes Technical Application Report

The following software (found in MIT Server.):

- S6300 Demo Software (a Windows application that allows to send one request at a time to the reader, and check the response from it)
- S6350 Utility Software (a Windows application that allows configuring the reader and perform most operations with it via a GUI)

2.1. Description of Tasks

The following is a step-by-step description of the activities that you need to carry out during the assignment. In the following you will find the following two types of activities:

Tasks: marked as **Task nn**, are activities that require some action on your part, whether it is finding some information on the documentation, building a circuit, connecting a module, installing software, or similar activities.

Questions: marked as **Question nn**, to be answered in writing in the assignment written report, including the logic to the answer, mathematical derivations if any, graphs, or any other relevant information. Questions labeled as “extra credit”, will only be used to compensate for credit lost elsewhere, and will not penalize your grade if left unanswered.

2.1.1. Setting up and testing the PC to reader serial data connection

Setting up the power source

Task 1 Look at the protoboard (see Figure 1). It is used to develop electronic circuit prototypes. It consists of a set of connection points on which you can connect a cable (remember to remove the plastic coating of the cable section you will use to make the connection), or electronic components. These connection points are grouped in vertical strips. All connection points in the same 5-point vertical strip are connected, so all wires or component legs placed in the same strip are connected to each other. When you need to make a connection between two cables, component legs, or a cable and a component leg, stick both on connection points in the same strip, this way they will be electrically connected.

Task 2 Go to pages 12 and 13 of the “Reader Module Reference Guide”, and take a close look at the reader module (see Figure 2). Identify the 0 and +5 Volt pins on the reader module. Note that the component side is where electronic components are attached, precisely the opposite from which the reader module pins are accessible, so when you are making the connections to the reader module, you should be using a mirror image of the figure on page 13. Using a red cable, connect the +5 Volt pin to one strip in the protoboard. Using a black cable, connect the 0 Volt pin to a different strip in the protoboard.

Note: You should be using the 8 connector pipes to connect your cables to the pins on the reader. You'll see that one end of the pipe is tailored to slide over the reader pin, and the other is where you connect the cable. There are two ways to connect the cable to the pipe: 1) Thread the cable into the pipe, pinching the clasps of the pipe around the cable to make it snug, or 2) peel about 2 cm of the cable and wrap it around the connector pipe. Method 1 is preferable, as you reduce the chance of the cables touching each other, which causes the system not to work.

Task 3 Go to your electronic component set, and find the of the 5V L7805CV voltage regulator (see Figure 7). If you go to section 2.1.2 of the “Reader Module Reference Guide”, you will see that the reader module operates at 5 Volts DC, with a tolerance of half a Volt. Since we want to power the system using batteries and there are no 5 Volt batteries, we need to use a 9 Volt battery, and the voltage regulator to bring down the tension to 5 Volts (tension is a synonym of voltage). The way the regulator works is the following. A tension that may be higher than 5 Volts, and possibly unstable (with fluctuations over time) is applied between the input and ground pins. The regulator will then supply a constant stabilized 5-Volt tension between the output and ground pins (note that the ground pin is common between the input and the output). To further stabilize the voltage, capacitors are usually placed both at the input and the output (a capacitor acts as a sink for time-varying tensions). To build the power source, make the following connections:

Connect the power regulator to the protoboard, with each pin on a different strip of connection points.

Connect the red (positive) cable of the battery connector to the input pin of the regulator, by sticking it in a connection point in the same strip as the input pin of the regulator.

Connect the black (negative) cable of the battery connector to the ground pin of the regulator.

Connect one of the 100 μ F electrolytic capacitors (cylinder-shaped) to the regulator input by connecting the short (negative) leg to the ground pin of the regulator, and the long (positive) leg to the input pin of the regulator.

Connect the other 100 μ F electrolytic capacitor (cylinder-shaped) to the regulator output by connecting the short (negative) leg to the ground pin of the regulator, and the long (positive) leg to the output pin of the regulator.

When you need to use the reader, connect the 9V 6LF22 battery (rectangle-shaped) to the battery connector. Make sure you disconnect it when not in use to avoid using it up unnecessarily.

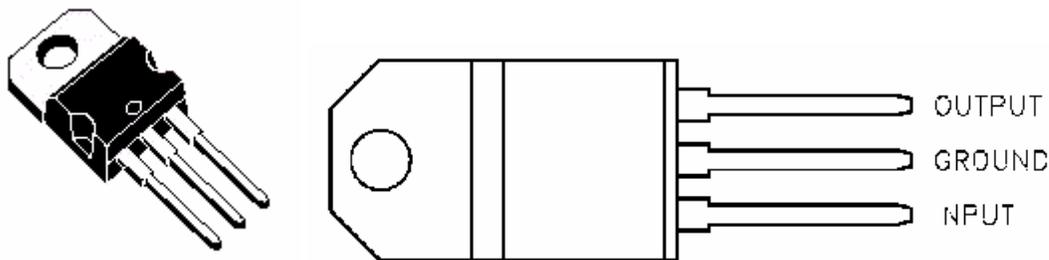


Figure 7 Top view (left), and pin assignment from the top view (right) of the 5V L7805CV voltage regulator. Note that the actual regulator is a bit different than the one shown in this diagram.

Task 4 The last step in powering the reader is to connect the power source to the reader module. For this, make the following connections:

Connect the output pin of the power regulator to the +5 Volt pin of the reader module, by connecting a red cable between the protoboard strips where each of the two are connected.

Connect the ground pin of the power regulator to the 0 Volt pin of the reader module, by connecting a black cable between the protoboard strips where each of the two are connected.

Figures 8 and 9 below show one way the components used in tasks 1 – 4 could be put into the protoboard.

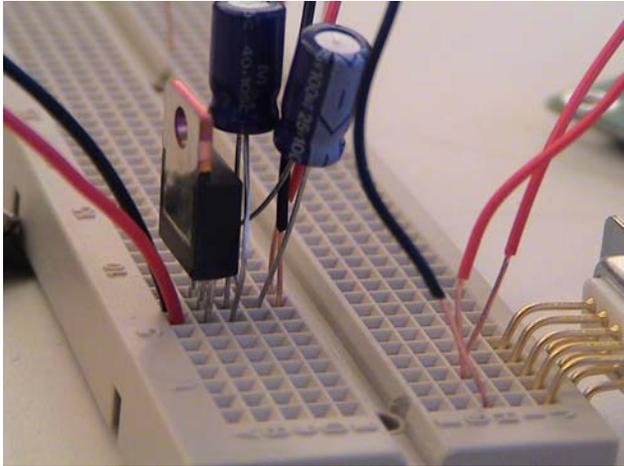


Figure 8

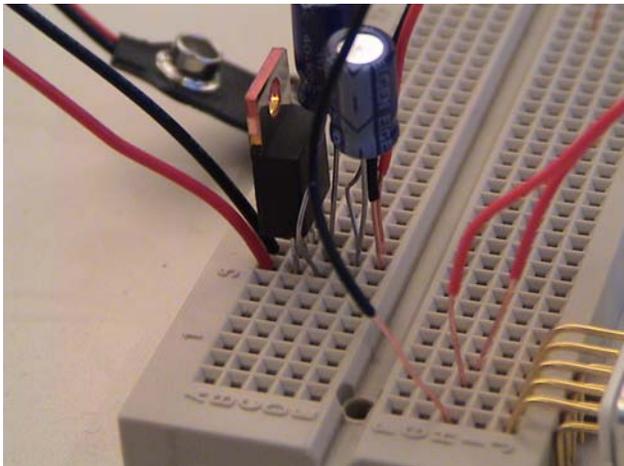


Figure 9

Question 1 What is the voltage at a household electric outlet in the U.S.A.?

Question 2 Besides the voltage and the available power, another difference between the power source you just built and the electrical outlet is that the power source is DC, that is, a voltage constant with time, and the voltage of the electric outlet is AC, that is, varies with time according to:

$v(t) = V_p \cdot \cos(2\pi \cdot f \cdot t)$, where $v(t)$ is the instantaneous voltage at a given time, V_p is the peak (or maximum) voltage, and f is the frequency, that is how many times per second the voltage goes through a full cycle in its variation. Frequency is measured in “time per second”, also called Hertz (Hz). What is the frequency of an electric outlet in the U.S.A.? And in Europe?

Optional: In the U.S.A., how long does a cycle last (this is called the period of the voltage, and is represented by T)?

Question 3 The nominal voltage that you answered in

Question 1 is actually not V_p , but is what is called the “effective” or RMS voltage, which in the case of AC

voltages is related to V_p by $V_{ef} = \frac{V_p}{\sqrt{2}}$. What is V_p in the U.S.A.?

Setting up the PC to reader data connection

Task 5 The PC to reader data connection uses a special protocol named RS232, which you do not really need to understand in detail. It has several modes of operation, and the one we will be using in this assignment is the simplest, in which one wire is used to send data in one direction, and another wire to send data in the other direction. Then, of course, there is the ground wire, which is shared by both data communication directions. Go to pages 12 and 13 of the “Reader Module Reference Guide”. Identify the output from reader pin (RS232 TxD – i.e. transmission –), the input to reader pin (RS232 RxD – i.e. reception –), and data ground pin (RS232 ground) on the reader module. Note that the component side is where electronic components are attached, precisely the opposite from which the reader module pins are accessible, so when you are making the connections to the reader module, you should be using a mirror image of the figure on page 13.

Task 6 Connect the female RS232 connector to the protoboard. See Figure 10 for its pin assignment. You will not be using pins 6, 7, 8 and 9, so you can bend the connecting legs for these 4 pins if they get in the way when connecting it to the protoboard. Identify the transmitted data, received data, and signal ground pins.

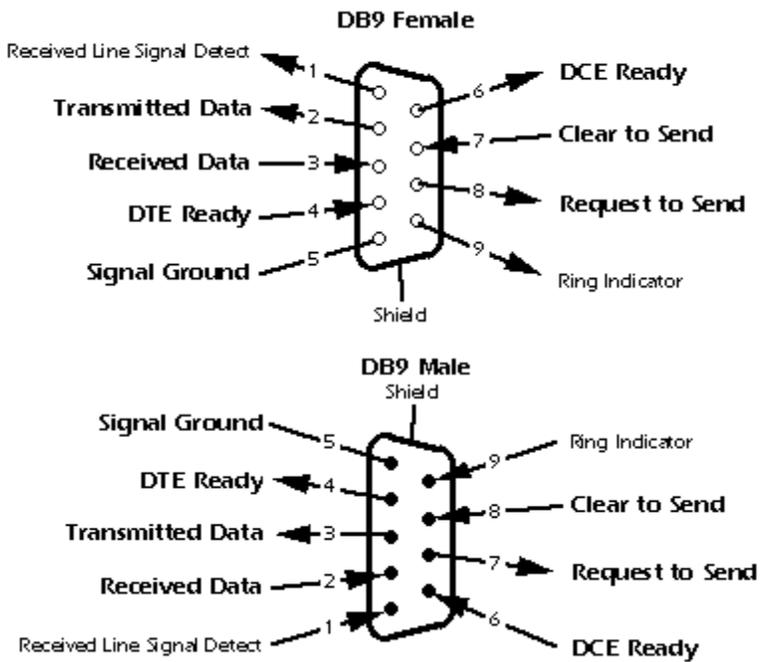


Figure 10 Pin assignment of the female and male RS232 connectors.

Task 7 Now connect the reader module to the RS232 female connector. Make the following connections:

Using a black cable, connect the RS232 ground pin of the reader module to the signal ground pin of the RS232 female connector.

Using a red cable, connect the output from reader pin of the reader to the transmitted data pin of the connector.

Using a red cable, connect the input to reader pin of the reader to the received data pin of the connector.

Figures 11 and 12 below shows two ways the components used in tasks 1 - 7 could be put into the protoboard.

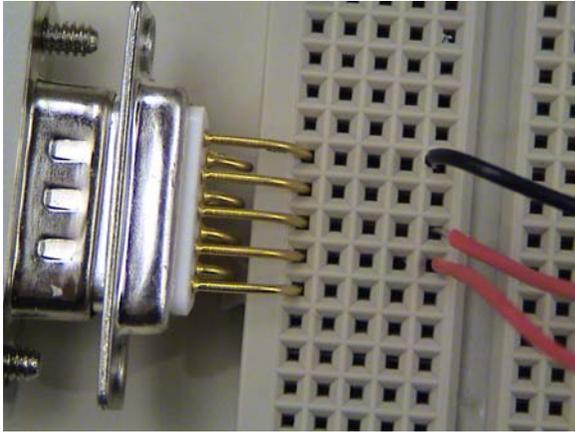


Figure 11

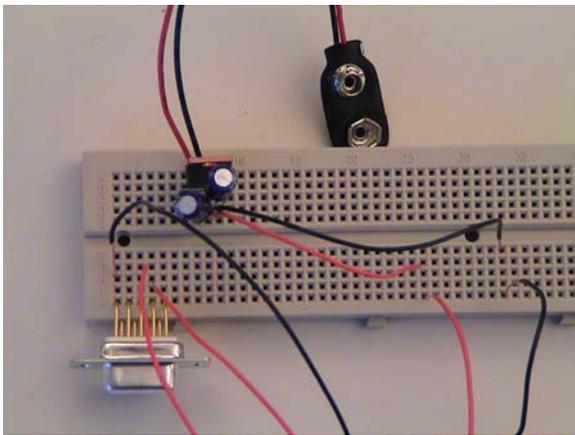


Figure 12

Figure 13 below shows how the entire kit should look after tasks 1 – 7.

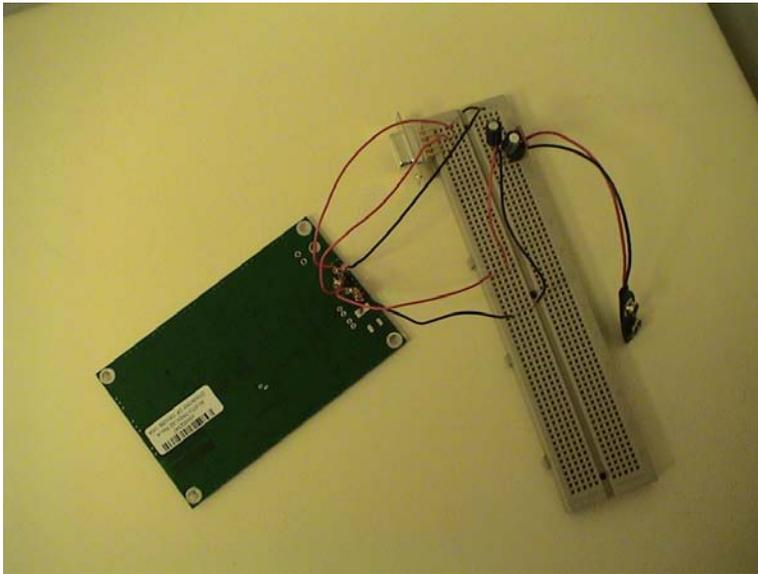


Figure 13

Question 4 In Figure 10, note that when male and female connectors are connected, pin 1 connects to pin 1, pin 2 to pin 2, and so on. All pin numbers have the same assignment in both the male and female versions, except for 4 pins. Which are these 4 pins, and why is there such a discrepancy?

Question 5 In the RS232 data transmission mode we just set up, the two devices communicating send data to each other at any moment, without previous notice. This means that they both need to be listening constantly, or that one of the two is in control of the situation, and the second one only replies to requests from the first one. Another mode in which the RS232 protocol operates is what is called the “handshake” mode. In this mode, the two devices exchanging data request permission to do so, and wait for the permission to be granted before they send the data. Using Figure 10, can you identify two of the extra pins that would be used in handshaking mode?

Testing the PC to reader connection

Task 8 The reader still has no antenna, but first, you will test that the connections you just made are correct. Connect the serial cable from the female connector on your protoboard to the male connector on your computer. The RS232 male connector on computers used to be utilized to connect the mouse or the modem. A special mouse connector or USB connector are now typically used instead.

Task 9 Next copy the demo application “S6300 Demo.exe” from the software directory of the course CD to your computer’s desktop. Run the demo application by double clicking on it. The software has successfully launched when you see the following window:

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This simple application sends a low-level request to the reader and shows the reader's response (more on this later). The default request, the "Get Reader Version" request ("010900000000F0"), simply asks the reader to identify itself, and needs no antenna or tag to be present to work. This is why you use it to test the reader at this point. Remember to connect the 9 Volt battery to the battery connector.

Troubleshooting Tips: When attempting to launch the S6300 Demo software, you may at first get an error message complaining about a missing "Mscomm32.ocx" file. If that is the case, be sure to try all of the following troubleshooting tips:

Copy the "Mscomm32.ocx" file from the software directory of the course CD to C:\WINDOWS\SYSTEM32 (or equivalent in your computer), and try again.

If you still get an error message, go into an MS-DOS prompt, type the following command: `regsvr32 c:\windows\system32\mscomm32.ocx`, and hit <Enter>.

If you still get an error message, it may be because your RS232 male connector on your computer is being used by another process. If you have a special mouse, PDA or cell phone you connect to the male connector, there may be software running in the background that is utilizing that port (which is typically the COM1 port), even though you don't have your device plugged into the port. A typical example of this is the Palm Hot Sync software that is often running. Anyhow, be sure to exit/close all applications that utilize that port.

Task 10 Press the "Send" button, and you should get the following response:

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If instead, you get the following:

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check that the battery is connected, or go back to Task 1 and check all steps and connections. If you have been successful, **congratulations**, you have made it through the most difficult part! Remember to disconnect the battery when you are done.

Question 6 The response given by the reader is in hexadecimal format. Allowed characters are 0 to 9 and A to F. The meanings of each of these characters in decimal and binary formats are:

0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100

D	13	1101
E	14	1110
F	15	1111

Note that each hexadecimal character represents a number from 0 to 15, and is represented with 4 bits in binary format. In most cases, these characters should be interpreted in pairs, each pair forming a byte (that is 8 bits). How many bytes long is the response you obtained from the reader?

Question 7 The binary format of the byte is obtained by simply substituting the characters by their binary representations, resulting in an 8 bit representation of the byte. To get the decimal equivalent, you need to multiply the decimal equivalent of the left character by 16, and add the result to the decimal equivalent of the right character (in our normal decimal system, things work the same way, except that only characters 0 to 9 are allowed, and 10 is used instead of 16). For example, the byte 3C in binary format is 00111100. Its decimal equivalent is $3 \times 16 + 12 = 60$. What are the decimal equivalent of all bytes in the response?

Question 8 Sometimes, to represent larger numbers, two bytes are used, the LSB (Least Significant Byte) and the MSB (Most Significant Byte). The decimal equivalent of the byte pair is calculated by multiplying the MSB by 256 and adding the result to the decimal equivalent of the LSB. The length of the response in bytes is given as a two byte pair. As you can read in page 16 of the reader's reference guide, the LSB is byte 2 of the response and the MSB is byte 3 (it is fairly common to send the LSB before the MSB). What is the decimal equivalent of the byte pair representing the length of the response? Does this value coincide with the answer to Question 6?

Question 9 In page 23 of the reader's reference guide, you will find an explanation of the request and response dialog you just performed. You asked the reader about its firmware version. Which firmware version does the reader have, according to the result of Task 10?

Question 10 What the reader and the PC are exchanging are bits, that is, 1's and 0's. The speed at which these bits are exchanged is known as the baud rate. One baud is 1 bit per second (also known as 1 bps). Look up in page 7 of the reader's reference guide the baud rates at which the reader can be configured. What are the maximum and minimum baud rates of the reader? The first version of the EPC (Electronic Product Code) proposes to use 96 bits for each tag. Later you will learn about the many factors that affect the speed at which the reader can read tags. For now, let us assume that the only factor is the reader's baud rate. At the minimum and maximum rates, how many EPC tags per second can a reader detect? If a pallet contains 100 boxes, each with an EPC tag, how long would it take to inventory the whole pallet?

Question 11 (Extra credit) The last two bytes of both the request and the response are the LRC (Longitudinal Redundancy Check). These bytes are used as a test to make sure that the message did not suffer any errors. The LRC can be calculated from the rest of the message, so the reader and the tag compute it, compare it with the LRC received, and if there are any discrepancies they request the message to be resent. The LRC used in this protocol is actually very simple. The first of the two LRC bytes, is the cumulative "exclusive or" operation of all bytes in the message, except for the LRC itself. The "exclusive or" operation between two bytes (represented by the symbol \otimes) is actually very simple. The two bytes are compared bit by bit, if they are equal, the result is 0, if they are different, the result is 1. For example $10011011 \otimes 00010110 = 10001101$. So the first byte of the LRC is the result of applying the "exclusive or" operation to the first two bytes of the message, then the result with the third one, and so on. The second byte of the LRC is simply the opposite of the last one, that is, is like the last one, but substituting ones by zeros and vice-versa. Compute the LRC of the "Get Reader Version" command, and check if it is the same as the one calculated by the demo program. (Hint: a spreadsheet can be a very convenient way of calculating this).

2.1.2. Setting up and testing the reader to tag radio frequency connection

Building your own antenna

Task 11 Take a piece of black cable at least 1,5 m long, Build a loop antenna, 10 cm on the side, with 5 turns, like the one shown on Figure 14.



Figure 14 Square loop antenna built with 5 square loops of regular cable. Note the twisted leads.

Task 12 Until now, we have dealt with voltages (a.k.a. tensions). A voltage is the potential energy associated with the electric force applied to a unit charge. When a voltage is applied to a charge, and the charge is free to move (e.g. the charge is in a conductor, like an electric cable), the charge moves. The measure of the charge traversing a certain point in a cable in a second, is called current. Voltage is measured in Volts (V) and is represented by v . Charge is measured in Coulombs (C) and represented by q . Voltage and currents are the fundamental magnitudes in electronic circuits. Current is measured in Amperes (A) and is represented by i . One Ampere is the current equivalent to one Coulomb traversing a certain point in one second.

There are three fundamental circuit components that relate current and voltage in the following way:

$$v = R \cdot i$$

$$v = L \cdot \frac{di}{dt}$$

$$i = C \cdot \frac{dv}{dt}$$

The circuit element that relates voltage and current in a linear way is called the resistor, and the linear constant is called resistance, is represented by R and is measured in Ohms (Ω).

The circuit element that relates voltage and the time derivative of current is called the inductor, is represented by L and is measured in Henrys (H).

The circuit element that relates current and the time derivative of voltage is called the capacitor, is represented by C and is measured in Farads (F).

The antenna loop you just build behaves mainly as an inductor. Find the formula to calculate the inductance of the antenna in page 11 of the HF antenna design notes. This expression refers to a single loop square antenna.

Question 12 The inductance of an N-loop antenna is N^2 times higher. What is calculated inductance in μH of your antenna? (Note that LN represents the natural logarithm function, and you can approximate the wire diameter to be 0.5 mm).

Question 13 The task of matching is not only to convert the inductance of the antenna into a resistance, but at the same time maximize the current in the antenna, and to make sure that the behavior at frequencies slightly higher and lower than the resonant frequency is similar, so that the antenna works with signals that have time variations that are not exactly sinusoidal. You will use the balanced capacitor matching circuit of page 28 of the antenna design notes. Following the steps in page 29, which are the values of $R_1 = R_{par}$, C_{1A} , C_{1B} , and C_2 ? (Note: you may want to use a spreadsheet to setup your calculations, so is you need to change one value, all others are recalculated automatically).

Task 13 Choose the closer resistors and capacitors from the provided elements, and build the matching circuit on the protoboard, as specified on page 28 of the antenna design notes. (Also see Figure 14 below.) Connect the terminals of the antenna loop to the matching circuit (one to each terminal of R_1). Notice that the antenna and matching circuit are symmetrical, so now you can connect the two antenna connections of the reader module to the two terminals of C_2 in any order you wish. Also note that by connecting two resistors in series, you get a resistor with the sum value of the two. You add the values of the capacitors, when you connect them in parallel.

The following are the values for capacitors C1, C1a and C1b: $C_1 = 221 \text{ pF}$; $C_{1a} = C_{1b} = 22\text{pF}$

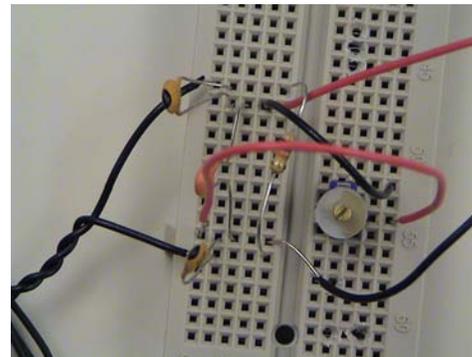
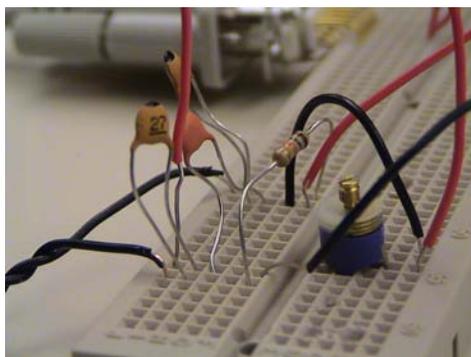


Figure 15 – Capacitors and resistors in the protoboard, for matching the circuit for the antenna

Question 14 Look in page 9 of the reader's reference guide. What is the typical output power of the reader into a 50Ω resistance? What are the input voltage and current into the resistor?

Question 15 (Extra credit). When the reader is supplying the typical power, what is the current going through the antenna? For this assume that the voltage at the input is the voltage found in Question 14, and remember that when a voltage is applied to several impedances in series, the voltage is divided among the different impedances proportionally to their impedance values. (Note: it is probably a good idea to do this calculation using a spreadsheet).

Question 16 All the above calculations relate to High Frequency (HF) RFID technology at 13.56 MHz. More recently, Ultra High Frequency (UHF) technology is starting to be used. As opposed to HF antennas, that use magnetic fields to communicate with the tags, UHF antennas use electromagnetic radiated waves, which are a combination of electric and magnetic field that couple to each other, decouple from the antenna, and travels in space. Light, radio and TV signals, and microwaves, are all examples of electromagnetic waves.

When waves propagate, they vary both with time and space. The expression of a propagating voltage wave propagating along the x axis is $v(x,t) = V_p \cdot \cos 2\pi \cdot (f \cdot t - \frac{x}{\lambda})$, where λ is the “space period” of the wave, called the wavelength. Such a wave moves at a speed $v = \lambda \cdot f$. Electromagnetic waves in space, which are the type of wave that UHF RFID antennas produce, travel at the speed of light, $c = 3 \cdot 10^8$ m/s. In the U.S.A., UHF RFID technology uses 915 MHz. What are the period and the wavelength of electromagnetic waves at this frequency?

Question 17 (Extra credit) A UHF reader operates at 915 MHz. A tag is placed on a box in a conveyor belt, travelling at a speed of 5 m/s towards the reader. What is the frequency shift as seen by the tag due to the Doppler Effect? Is it relevant? (Note: the Doppler Effect is a shift of frequency as perceived by the observer, due to the relative velocity of the observer and the source. When the observer and the source are approaching, the perceived frequency is higher. When they are moving away from each other, lower.

The perceived frequency is $f' = f \cdot \left(\frac{v \pm v_o}{v \mp v_s} \right)$ where the velocities of the observer and the source are considered positive when in the direction of approaching the other).

Question 18 Most of the time, dipole antennas are used for UHF. A dipole is nothing but a straight wire of approximately half a wavelength in length, cut at the center, and fed at this point with a voltage. What is the approximate length of an RFID UHF dipole?

Question 19 Compared to the wavelength of a WiFi network, which operates at about 2.4 GHz, how much longer is the wavelength of an HF reader? And a UHF reader?

Task 14 Now we will do a quick test of the whole setup. Place one (only one) tag inside the antenna loop. Start the Demo program, and in the request field, type the following command: “010D00000006011070100”, and press the “Send” button. The following shows the screen sequence you should see before and after pressing the “Send” button.

Image removed for copyright reasons.

If you get a response similar to the above, **congratulations**, you have assembled an operational RFID reading system. The above response is when a tag with a unique identifier UID=E0070000017A70CE is placed near the reader's antenna. The response to your request will be different, since the UID of the tag you used is different.

Question 20 The request you just sent to the reader is the ISO "Inventory Command", which is used to get a list of all the tags within the antenna range. Go to page 30 of the reader's reference guide, where you will find a description of the format of this request and its response. Note that the ISO command is actually embedded as the data section of a proprietary command of the reader (the "60" command, (more details on page 28 of the reference guide). Look at the request byte sequence. Which are the second and third bytes of the sequence? These two bytes are the LSB and MSB of a two-byte number. What is its decimal equivalent value? This value is supposed to be length in bytes of the request, including the LRC section. Is this the case?

Question 21 Now look at the response byte sequence. Following the explanation on pages 30 and 31, answer the following questions. How long in bytes is the response sequence? Does it match with the value given by bytes 2 and 3 of the response sequence? What are the LSB and MSB of the "Valid Data Flags" of the response sequence? What is the binary expression of these data flags? Though you may not yet be familiar with the concept of a time slot or a collision in RFID systems, you can answer the following questions: In which of the 16 time slots was data received? Did collisions occur?

Question 22 Note that the bytes of the tag's RFID are sent in reverse order. The last two bytes are the LRC section of the response (used only for error detection in the transmission). The first byte of the tag's UID is the 3rd starting from the end (E0 in the above example), and the 8 byte tag UID (72 bits), is formed by reading 8 bytes backwards starting with this one (E0070000017A70CE in the above example) The following two bytes, that complete the 10 byte data section contain additional information about the tag. What is the UID of the tag you just read?

Question 23 Now place another tag near the antenna and reissue the “Inventory” command. What is its UID? Repeat the operation with the third tag. You will need this 3 UID’s later in the assignment.

Question 24 At this point, place 2 tags on top of the antenna, and send the “Inventory” command. Explain the meaning of the different sections of the request response you obtain.

2.1.3. Exploring the reader to tag connection and the different commands available

Installing the utility software

Task 15 In the software section of the CD course, you will find the file S6350_utility_v1-10.zip. Extract its contents to a folder, and double click on “setup” to install the S6350 Demo Program, which is utility software for controlling the reader. Check that it works by double clicking on the “S6350 Demo Program” icon. Once installed, check if the previous demo still works. If it complains about an outdated `mscomm32.ocx` file, go to the directory where the utility program is installed (usually “C:\Program files\TI-RFID\S6350 Program”, and substitute the file `mscomm32.ocx` with the one in the software section of the course CD. Now both programs should work fine. The following is a screen shot of the utility software:

Image removed for copyright reasons.

Figure 16 Screen shot of the S6350 Utility Program

Start the S6350 Demo Program. It is a program that allows you to issue all sort of commands to the reader in a much more user-friendly way than the other demo program you have used so far. In the “Main” section of the menu, activate the “View Comm Data” option. This will show at the bottom the request/response byte sequences of each command issued by the utility. In the “Host Protocol” section of the menu, choose “ISO”. The tags supplied to you respond to ISO commands, although the reader is able to communicate both with the ISO and the proprietary Tag-it protocols.

Make all the connections to have an operational reader system (battery, RS-232 cable, and antenna), and place one tag on the antenna.

Issue the inventory command. Check that the UID of the tag coincides with the one you had previously read.

Reading in continuous mode

Task 16 Now use the “Start Continuous Mode” button with the “Inventory” command selected, to have the reader permanently check for tags. Add one or two more tags and see what happens. Experiment with

different combinations. Press the “Stop Continuous Mode” when your are done.

Image removed for copyright reasons.

Figure 17 Screen shot of the utility software running the “Inventory” command in continuous mode.

Question 25 Name one situation in Supply Chain management in which the “Inventory” command would be useful. Be specific.

Telling a tag to be quiet

Task 17 Choose the “Stay Quiet” command in the utility software. Note that this command operates only in the “addressed” mode. That means that the command is sent to a specific tag. Place one tag on the antenna, and select its address in the address selection box (to the right). Now send the command. Note that the tag does not respond to this command. Now reissue the inventory command, and notice that the tag does not respond anymore.

Question 26 Name one situation in Supply Chain management in which the “Stay Quiet” command would be useful. Be specific.

Reading data from a tag

Task 18 Now that you can identify the presence of a given tag, it is time to access its data. Go to page 10 of the “Tag-it HF-I Transponder Inlays Reference Guide”, and look at the memory organization of the tag. Note that besides the 8-byte UID, there are 64 4-byte blocks, the IC (Integrated Circuit) version, the AFI (Application Family Identifier) byte, and the DSFID (Data Storage Format Identifier) byte (this last two bytes are the first two bytes of the 10 byte data portion of the response to the “Inventory” command that you tested in

Question 23). Using the utility program, issue the “Read Multiple Blocks” command to read the first 8 blocks of the tag (usually set to 0 unless the tag has been previously used). Note that the software shows the 4 bytes contained in each block. Now try the “Read Single Block” command.

Question 27 Name one situation in Supply Chain management in which the “Read Multiple Blocks” command would be useful. Be specific.

Question 28 Name one situation in Supply Chain management in which the “Read Single Block” command would be useful. Be specific.

Writing data to a tag

Task 19 Similar to the read single and multiple block commands, there are “write” commands for single and multiple blocks. This version of the utility software only allows single block writes. Take one tag and write the decimal number 183 in byte 3 of block 5. Check that it worked with one of the read commands. Set the byte back to 00. Check again.

Question 29 Name one situation in Supply Chain management in which the “Write Multiple Blocks” command would be useful. Be specific.

Question 30 Name one situation in Supply Chain management in which the “Write Single Block” command would be useful. Be specific.

Sending request to a specific tag

Task 20 Until now, you have issued read and write commands on a single tag. All read and write commands can be run either in “unaddressed” mode (that is, to all visible tags), or in “addressed” mode (that is, to a specific tag identified by its UID). Place several tags on the antenna, and issue an “Inventory” command (this way the utility software will memorize the UID’s of the tags). Then experiment the different combinations of single/multiple, read/write, addressed/unaddressed commands, and see how they behave.

Question 31 Name one situation in Supply Chain management in which the “Read Single Block” command would be useful in addressed mode. Be specific.

Question 32 Name one situation in Supply Chain management in which the “Write Single Block” command would be useful in addressed mode. Be specific.

Locking data in a tag

Task 21 Individual blocks can be locked with the “Lock Single Block” command, so they can be read, but not written again. Locking is irreversible, so do not get carried away experimenting with this command. Write decimal value 205, into byte 2 of block 7 of one tag. Then lock it. Use the “Get Multi Block Security Status” command to see that the block has effectively been locked. Try to set the block back to 0 and see what happens. Also remember that blocks can be locked at manufacturing.

Question 33 Name one situation in Supply Chain management in which the “Lock Single Block” command would be useful. Be specific.

2.1.4. Exploring the antenna reading range

Making magnetic field calculations

Task 22 Nature has many wonders. One of them is that when we place a compass needle near a wire in which charges are moving (i.e. an electric current is present), the needle moves. This is because electric currents create magnetic fields. We could spend chapters with mathematical derivations of Quantum Electrodynamics trying to get to the bottom of why this happens, but sooner or later, before we get a rational explanation of why this happens, we would be faced with having to accept one fact: nature has many wonders, and we have no explanation for their origin.

Magnetic fields can be thought of as closed lines along which compass needles align themselves. The earth produces magnetic fields that go roughly from the South pole to the North pole (this is why a compass is useful to indicate the North). A current in a wire, creates magnetic fields in the form of circles centered around the wire, which decrease proportionally to the distance to the wire. Magnetic field strength is represented by H and is measured in A/m (Amperes per meter). The value of H as a function of the current in the wire and the distance to the wire is:

$$H = \frac{I}{2\pi r}$$

where I , is the current, and r is the distance to the wire. Remember that the field forms circular lines around the wire, so the field times the length of each circle is $H \cdot 2\pi r = I$, which is independent of r . This is sometimes explained as saying that the “circulation” of the magnetic field around a wire equals the current of the wire, no matter what path we take to go around the wire.

When instead of a single wire we have a more complicated current pattern, such as a 5-turn square loop, we use a great principle of nature: the principle of superposition. This principle (which, like all principles, cannot be proven) says that the magnetic field due to a set of currents, is the addition (superposition) of the fields created by each current, when the others are not present. This and approximate formulas or numerical calculations using computers allow us to actually determine the field configuration of all sorts of current distributions.

Go to page 5 of the “HF Antenna Design Notes” to see a picture of the field created by rectangular loop.

Question 34 What is the value of H in A/m 30 cm away from a wire carrying a 12 mA current?

Question 35 Magnetic fields and in general all magnitudes in electronic circuits can have values spanning many orders of magnitude. To make it easier to deal with such numbers, logarithms are used. We define a “decibel” (represented as dB), as 10 times the decimal logarithm of the relationship between two magnitudes representing some kind of power. When we say an airport produces a 120 dB noise, we mean that the power of the sound waves is 10^{12} times the threshold power of the human ear (that is the softest sound that we can hear). The 120 dB as calculated as $10 \cdot \log_{10}(10^{12}) = 10 \cdot 12 = 120$. Since in the case of magnetic fields, power is proportional to the square of fields and currents, dB are calculated as 20 times the decimal logarithm of magnetic fields (since logarithms have the following property:

$10 \cdot \log(x^2) = 20 \cdot \log(x)$). We can express the magnetic field in units of dB μ A/m as 20 times the

decimal logarithm of the relationship between the value of H and a field of $1 \mu\text{A/m}$, that is $H[dB\mu\text{A/m}] = 20 \cdot \log_{10}(10^6 \cdot H[A/m])$. What is the value, in $\text{dB}\mu\text{A/m}$, of the magnetic field you calculated in Question 34?

Question 36 Go to page 18 of the tags reference guide. In Table 5, find the typical value of the magnetic field required to activate the tag when reading. What is the value of this field in A/m ?

Plotting the antenna reading and writing zones

Task 23 Now time for some experimental work. Take a $50 \text{ cm} \times 50 \text{ cm}$ rigid cardboard piece, and draw a grid of vertical and horizontal lines spaced 2 cm from each other (you should end up with a 25×25 grid). Now take one tag and draw a circle at its center. Take the antenna loop and place it in the middle of the grid. Now start the reader in continuous mode with the inventory command. Now place the tag in the center of the grid and the antenna. The reader should be reading the tag continuously. Now slowly move the tag away from the antenna until the reader stops seeing it. Prepare a spreadsheet similar to the following, to note the areas where the tag can be read and where it cannot be read:

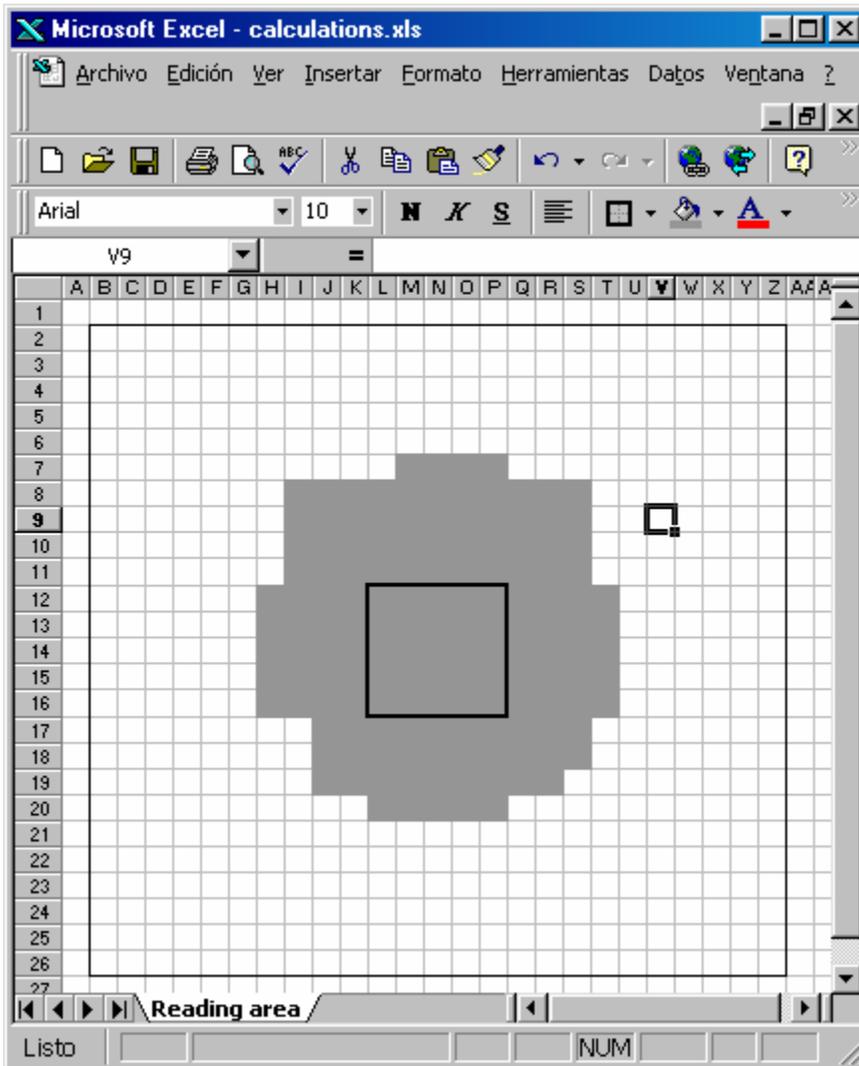


Figure 18 Spreadsheet used to represent the reading area measured.

Task 24 Plot the reading area of the antenna when the antenna is placed lying on the grid and the tag is parallel to the grid and lying on it.

Task 25 Plot the reading area of the antenna when the antenna is placed lying on the grid and the tag is perpendicular to the grid and lying on it.

Task 26 Plot the reading area of the antenna when the antenna is placed perpendicular to the grid and the tag is parallel to the grid and lying on it. For this it is better to put the antenna on the table, and hold the grid vertically on top of the antenna.

Task 27 Plot the reading area of the antenna when the antenna is placed perpendicular to the grid and the tag is perpendicular to the grid and lying on it.

Question 37 Go to page 6 of the antenna design notes, and check whether your plots for the grid perpendicular to the antenna are similar to those in the figure. Go back to page 5 and look at the shape of the field lines. Can you explain the shape of the reading zones for the two tag orientations?

Question 38 A UHF reader radiates 8 dBm of total power, but receives only -100 dBm. Where did the rest of the power go?

Testing the influence of different materials in the antenna environment

Task 28 Put the tag flat on the center of the antenna, and make sure it is being read. Now put a stack of paper sheets between the antenna and the tag. Keep adding paper, until the reader stops being able to read the tag. Has the distance been reduced with respect to the same tag orientation without the paper in between? Now try other materials like plastic, wood, metal, liquids, and describe what happens.

Task 29 Place the tag on the surface of a can of soda. Experiment with different orientations and distances between the tag and the can. Explain your conclusions.

Task 30 Place two tags together in different orientations. Describe what happens.

Task 31 Make another antenna loop, identical to the one you are now using, but connect the two leads together, instead of connecting it to the reader. Place the new loop above the antenna, and the tag in the middle between the two, parallel to both. Is the maximum reading distance affected? How?

2.1.5. Further understanding the signals between the reader and the tag

Coding

Task 32 When the reader wants to send data to the tag, first, it needs to code the binary sequence into a continuous signal. There are several ways to do this, which is called coding. Coding usually implies working with two voltage levels, high and low, and a fixed signal duration for each bit. NRZ coding is the obvious choice: high level for 1's, and low level for 0's. It turns out that electronic circuits are much better at detecting transitions between levels than levels themselves. The Manchester coding uses a transition from high to low level for each 1, and a transition from low to high for each 0. Note that for the sequence 11 the signal must go back to high in between to allow the second transition (similarly for the 00 sequence). The Miller coding creates a transition (high to low or low to high) for each 1, and no transition for each 0.

Draw the coded signal for the binary sequence 00101011 using NRZ, Manchester, and Miller codings.

Modulation

Task 33 Once we have the binary sequence coded in a signal (called the baseband signal), we must modify some characteristic of the RF wave (13.56 MHz for HF and 915 MHz for UHF) to send the information from antenna to antenna (antennas do not work unless the voltages are of high enough frequency). Our 3 choices are: the amplitude (ASK, amplitude shift keying), the frequency (FSK, frequency shift keying), or the phase (PSK, phase shift keying). Go to page 10 of the reader's reference guide. What modulation scheme is used by the reader? And by the tag?

Task 34 When talking about ASK modulation, the index of modulation refers to the fraction by which the amplitude for the low level is reduced with respect with the amplitude for the high level. For instance, a 30% ASK modulation means that the amplitude for low is 70% of the amplitude for high, and 100% modulation is actually switching off the signal during the low levels. Draw the modulated HF signal for the sequence 00101011, using NRZ and 50% ASK modulation at the maximum baud rate of the reader. Annotate all significant time scales.

A common FSK modulation is 2 FSK, where high and low levels are created by switching between two RF generators with different frequencies, on slightly lower and the other slightly higher than the nominal frequency. The average of the two frequencies should be the nominal frequency. . Draw the modulated HF signal for the sequence 00101011, using NRZ and 2 FSK modulation (assume $13.56 \text{ MHz} \pm 200 \text{ kHz}$ frequencies) at the maximum baud rate of the reader. Annotate all significant time scales.

Anti-collision protocols

Task 35 What happens when there is more than one tag in the reader's are of influence? How can the reader distinguish the signals that come from the different tags? If two tags respond at the same time, the signal will be unreadable. The only way is for a single tag to respond at a time, at least for the inventory command. Later, once the UID's are known, the reader can send addressed commands and collisions can be avoided. One common approach is to trust in statistics, and have the tags respond at random times, with a calculated probability of each tag having responded by itself at least once. If the response times are slotted, that is, there is a preset set of instants at which the tags can respond, the probability of success increases.

Run the following simulation: in a spread sheet, each row will represent a tag, and each column a time slot. Now use a random number to generate a 1 in each cell with probability p , a 0 otherwise. A 1 in a cell means that the tag responded in the given time slot. Now add up each column. A total value of 0 means no tag responded. A value of 1 means one tag responded successfully. A value greater than 1 means that there was a collision, and the message of all tags was lost.

Run the simulation for $N = 3$ tags, and $p = 0.25$. How many time slots did it take for all 3 tags to communicate successfully with the reader? Repeat for $N = 10$ tags and $p = 0.5$. Experiment with different combinations.

To calculate the probability of success we use the "offered load" (G) parameter, which is the total "busy time" of the system. In the above case, for N tags and probability p of a slot being used by each tag, the offered load is $G = N \cdot p$. The throughput S of the system is the total "collision-free" transmission time, which it can be proven to be:

$$S = G \cdot e^{-2G}$$

and the probability of success, that is the probability that a given tag communicates successfully in a given time slot is:

$$q = \frac{S}{G} = e^{-2G}$$

Question 39 When the above scheme, with a set of M time slots, and each tag choosing one random time slot to respond, the scheme is known as the ALOHA procedure. In the ALOHA procedure the “offered load” is $G = \frac{N}{M}$, where we assume that the tag is using the entire time slot to respond.

To reduce collisions, the ALOHA protocol has a “REQUEST” and a “SELECT” command. The “REQUEST” command is used to inventory the tags, and the “SELECT” command is used to communicate with a tag whose UID is known. This is what you have previously seen as the “unaddressed” and “addressed” modes of the reader commands.

For 4 tags, and a each tag responding randomly in one of 16 available time slots, which is the probability of success? If we want 99% reliability for each tag, how many 16-slot sequences must we repeat? What if there are 8 tags? And 16? And 32?

Question 40 Go to page 16 of the tag reference guide. What is the maximum number of tags per second that can be read by the reader? Does this number fit your previous calculations?

Congratulations! You have built a fully-operational RFID system, hardware and software included.