ELEKTOR RFID Reader

For MIFARE® and ISO 14443-A cards

Gerhard H. Schalk

RFID cards are becoming increasingly popular in many fields where previously barcodes and chip cards were used. They open up many new possibilities, such as applications in travel cards or even banknotes. As befits a premier electronics magazine, *Elektor Electronics* is offering its readers with this issue not only a free RFID card but also a professional RFID reader for your own applications. The design described here can both read from and write to all types of RFID card that are compatible with the MIFARE and ISO 14443-A international standards.

In developing the *Elektor Electronics* RFID reader we have aimed to make the device as universal as possible. So, for example, the reader can be used in conjunction with a PC over a USB connection, or in stand-alone mode using its liquid crystal display. It is very simple to use the free PC-based program 'MIFARE Magic' to read and write all kinds of MIFARE cards without installing special software in the reader.

Specifications

***Elektor Electronics* RFID reader:**

- Near-field reader for 13.56 MHz RFID cards
- Compatible with MIFARE and ISO 14443-A cards
- Allows both reading and writing
- USB interface for connection to PC
- Ready for immediate use without programming
- Free PC-based software available
- Stand-alone (including portable) operation using LCD module
- Dedicated MF RC522 reader IC
- Dedicated microcontroller on reader board
- SPI and I²C interfaces
- Spare 8-bit microcontroller port
- Buffered switching output
- Available as ready populated and tested SMD circuit board
- Can be modified for user applications
- Programming tools available

MF RC522 reader IC:

- Highly-integrated single-chip reader for ISO 14443-A and MIFARE cards
- Supports contactless data transmission at 106 kbit/s, 212 kbit/s and 424 kbit/s
- 50 mm approx. read/write range (depending on antenna)
- Integrated MIFARE Classic cryptography
- Programmable over UART, I²C or SPI
- 64 byte transmit and receive FIFO buffer
- Programmable reset and power-down modes
- Programmable timer
- Internal oscillator allows direct connection of 27.12 MHz crystal

MIFARE Magic directly supports a range of contactless 13.56 MHz MIFARE cards, including the Philips MIFARE UltraLight, MIFARE 1K and MIFARE 4K. The MIFARE Magic window (**Figure 1**) also offers the facility to send individual commands to the card with a click of the mouse. This allows you to determine the characteristics of different cards very easily. Examples of compatible cards include the MIFARE UltraLight RFID card supplied with this issue, and described in more detail in a separate article, and smart cards used on many public transport systems all over the world — for example, the London Underground Oyster card

In stand-alone operation, for example in an access control application, the reader can be used directly with the firmware we have developed. On switch-on the reader immediately looks for cards within the range of the antenna (a few centimetres) and reads any cards it finds in that area. The LCD (if connected) then shows the card type along with its serial number, and the switching output of the reader is activated.

The reader is constructed around the newest Philips reader IC type MF RC522 and a type LPC936 microcontroller. Since the reader IC is only available in an HVQFN32 package, we have decided to solve the problems of mounting and soldering by making available ready populated and tested reader boards fitted with pre-programmed microcontrollers.

The *Elektor Electronics* RFID reader is naturally ideal for experimenting with the free MIFARE UltraLight card. The system includes a powerful microcontroller and I²C, SPI, UART and USB interfaces, and free development tools are available. This makes it suitable for developing dedicated applications such as door and gate openers, membership card systems, storing passwords and configuration data, payment systems, security for domestic appliances such as televisions, video recorders and PCs, monitoring battery

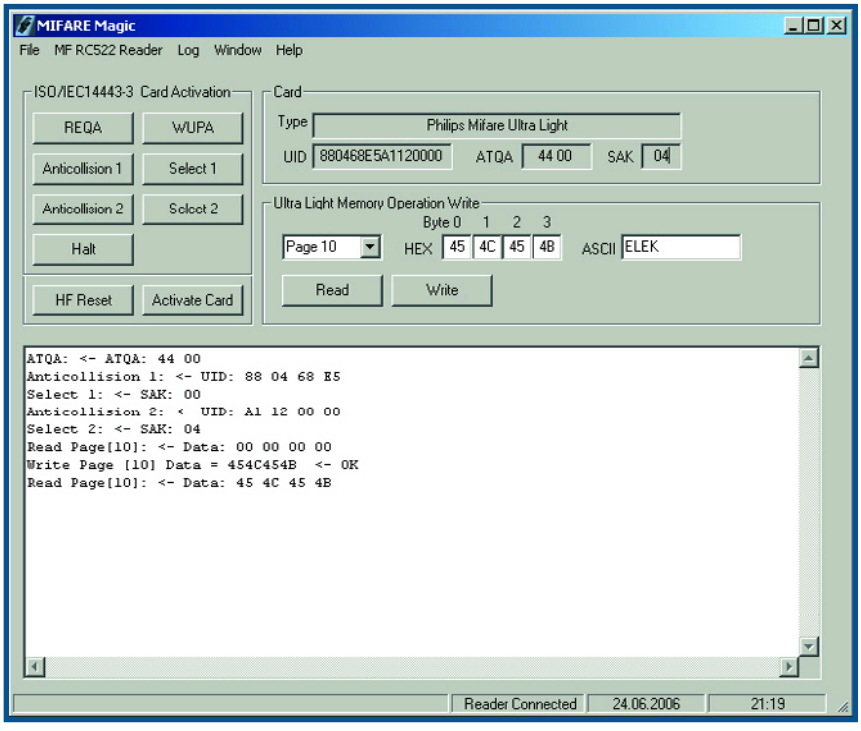


Figure 1. The MIFARE Magic program developed for the *Elektor Electronics* RFID reader allows MIFARE and ISO 14443-A RFID cards to be read, written and programmed.

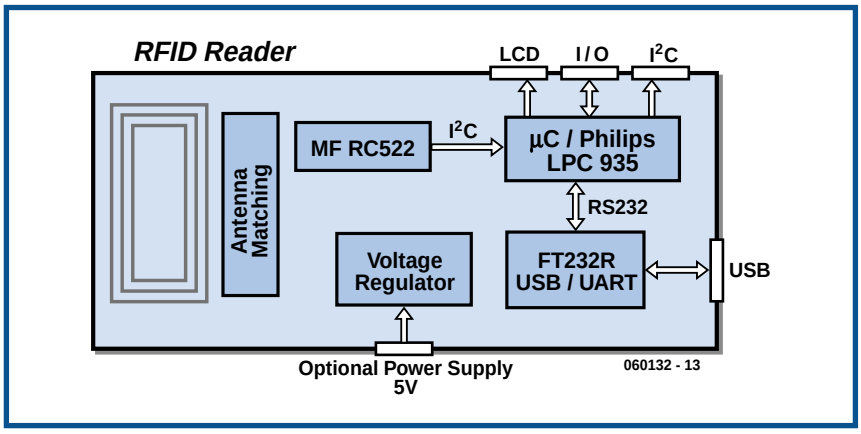


Figure 2. Block diagram of the *Elektor Electronics* RFID reader.

packs and much more besides. The combination of secure identity, data storage and contactless interface opens up many opportunities for novel applications.

Reader hardware

Figure 2 shows the block diagram of the reader. The basic reader functions, including the creation of the HF magnetic field, modulation and demodulation, and the generation of the ISO 14443 data stream, are carried out in the MF RC522. It is simplest to think of the MF RC522 as a contactless UART driven directly by the microcontroller. In the *Elektor Electronics* reader we have used an 8051-compatible LPC936 microcontroller from Philips. The CPU takes only two cycles per instruction and is clocked at 16 MHz. This speed and the 16 kbyte Flash memory are sufficient for an enormous range of possible applications. Programs for the microcontroller can be simply written using any 8051 compiler. Communications with the PC are handled by an FT232R USB/RS232 interface chip from our friends at Future Technology Devices (FTDI).

The full circuit diagram is shown in **Figure 3**. When connected to a PC, power is taken from the USB via mini-connector K1. The FT232R USB interface chip is configured to report the reader as a high-power device when the bus is initialised (during 'enumeration'). As a bus-powered device the reader can then draw a current of up to 500 mA. When enumeration is complete the /PWRNEN signal on pin 11 of IC1 changes state, making P-channel MOSFET T2 conduct. The 5 V supply is then passed through to voltage regulator IC5. The output of the LM2937 provides the 3.3 V supply for the LPC microcontroller (IC3) and the MF RC522 (IC4). Red LED D6 shows when the 3.3 V supply is present. If 5 V power is not provided via the USB connector Schottky diode D4 allows an external power supply to take over automatically. Either four AA-size cells (the enclosure suggested in the parts list will accept these) or a 5 V mains supply capable of delivering at least 300 mA can be used.

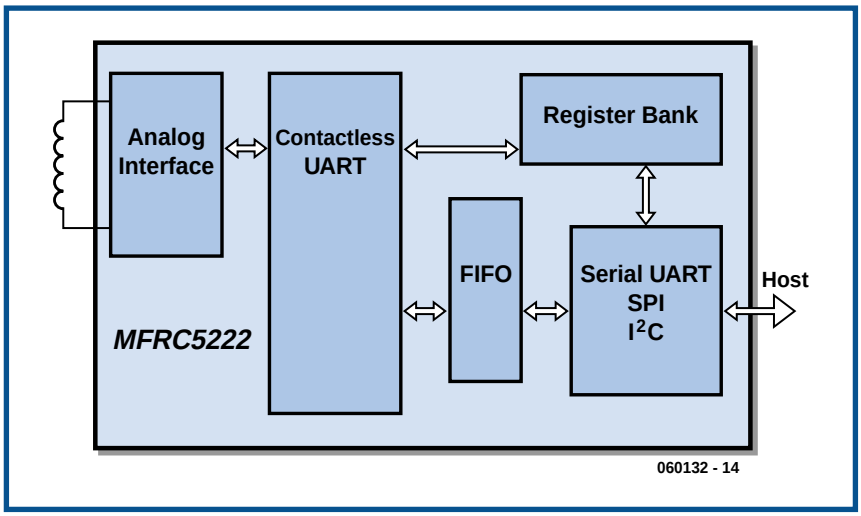


Figure 4. Block diagram of the Philips MF RC522 reader IC.

Figure 4 shows an overview of the internal functions of the MF RC522 reader IC in the form of a (greatly simplified) block diagram. The output drivers of the device allow direct connection of transmit and receive antennas without external active amplification circuitry. A few passive components provide the essential matching to the antenna characteristics. The analogue interface handles demodulation and decoding of the reply data sent by the card. The digital block is responsible for constructing the ISO 14443A or MIFARE protocol frames and accompanying error detection (parity and CRC). The FIFO buffer allows 64-byte blocks to be sent and received in ISO 14443 mode ('T=CL' protocol). In MIFARE mode the largest data blocks exchanged are at most 16 bytes long, and so there is no need for the microcontroller to split up the command packets. The registers of the MF RC522 can be programmed over the SPI, asynchronous serial or I²C interfaces. Since the LPC936 microcontroller only has one asynchronous serial interface, and this is required for communications with the PC, the I²C interface is used to talk to the MF RC522.

If desired an LCD module can be connected to port P0 of the LPC936 via connector K2. P0.0 is buffered by a transistor and provides a switched output, and the SPI and I²C interfaces of the microcontroller afford plenty of opportunities to expand the reader by adding extra hardware. For example, a real-time clock could easily be added to allow for time monitoring, and the switched output could control a door opener; see also the pages about the RFID reader on the *Elektor Electronics* website.

Get started

The double-sided printed circuit board for the *Elektor Electronics* RFID reader is shown in **Figure 5**. It is only possible to reflow solder the reader IC, and so we are making the board available

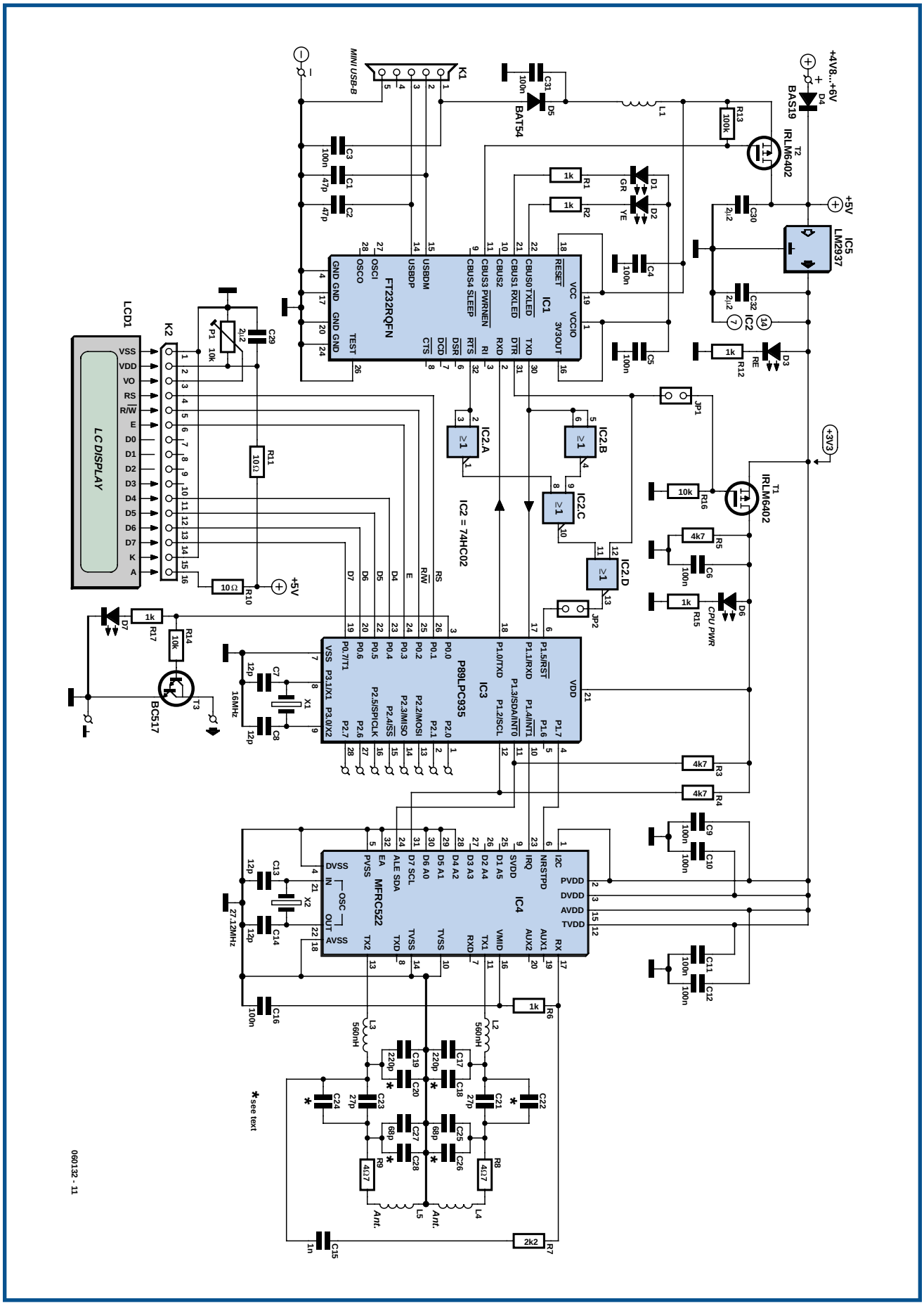


Figure 3. Complete circuit diagram of the reader, which can operate either in stand-alone mode, using the LCD module, or in conjunction with a PC using the USB interface.

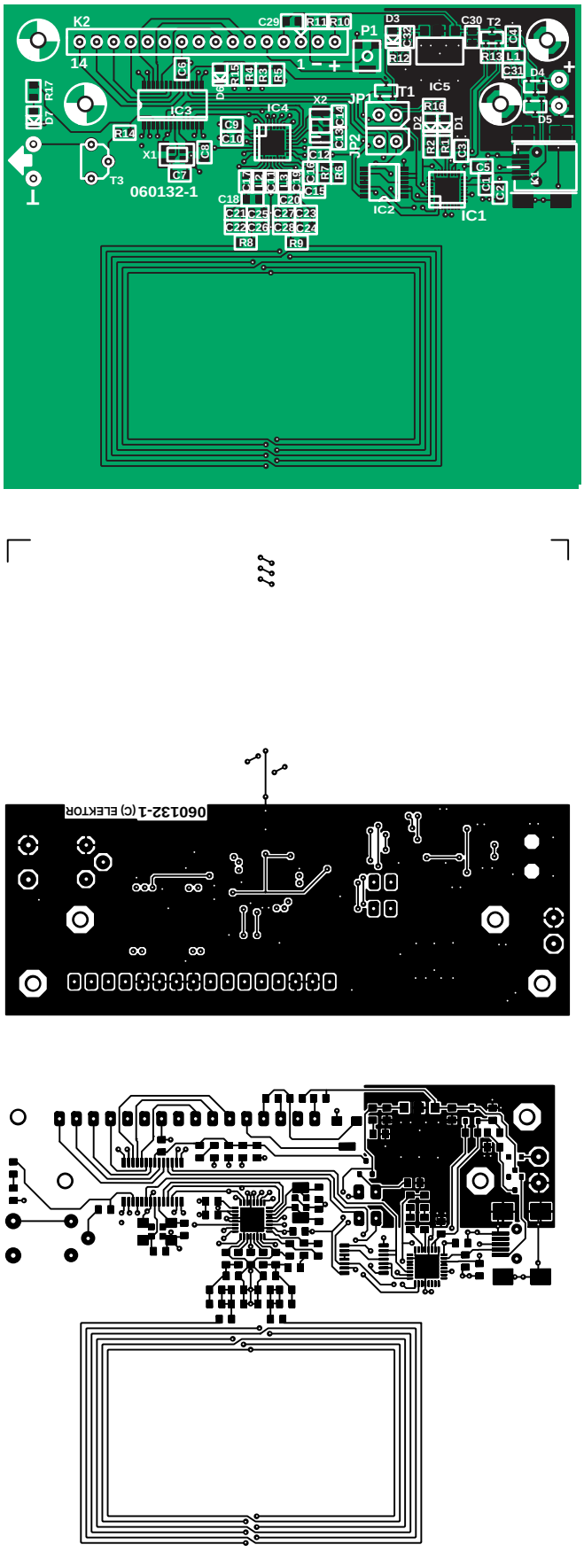


Figure 5. The double-sided printed circuit board incorporates the antenna. The reader IC is not suitable for hand soldering and so the board is available ready populated and tested.

ready populated and tested. Instructions are also provided for building the unit into the suggested enclosure, which we can also supply.

The two jumpers on the reader board (JP1 and JP2) are not fitted for normal operation. Assuming the LCD module is connected to the reader board, the unit is ready for operation as soon as power is applied, and the serial number of any RFID card within range of the reader's antenna will appear on the display. If the display appears blank, the contrast should be adjusted using P1.

To use the reader with a USB connection to a PC, the free CMD-FDTI-USB driver must be downloaded from the *Elektor Electronics* website. This particular driver is required because the FT232R contains the *Elektor Electronics* Vendor ID and Product ID.

When the RFID reader is connected to the PC using the supplied USB cable Windows will automatically detect the new USB device. The freshly-downloaded driver should be selected for the unit. If problems arise, the 'Installation Guide' on the FTDI website (www.ftdichip.com) can be consulted for assistance: this guide is also applicable to the modified driver.

Installing the CMD-FTDI driver installs both the 'D2XX' (direct) and 'VCP' (virtual COM port) drivers. The VCP driver allows the USB link to be treated from the point of view both of the PC and of the microcontroller as an ordinary RS232 connection.

The D2XX driver is required if it is desired to modify the unit in a way that requires changes to the internal configuration data stored in EEPROM in the FT232R. This can be done using the PC-based program MPROG, available as a free download from the FDTI website: MPROG will work only with the D2XX driver.

MIFARE Magic

Once the driver has been installed, MIFARE Magic, a specially-written PC-based program for the *Elektor Electronics* RFID reader, can be run. This is also available as a free download, from www.elektor-electronics.co.uk. After downloading the program the contents of the ZIP file must be copied into a subdirectory of your choice. Start the program with a double-click on MifareMagic.exe, with the reader already connected to the USB port. This allows MIFARE Magic to find the reader automatically. There is no need

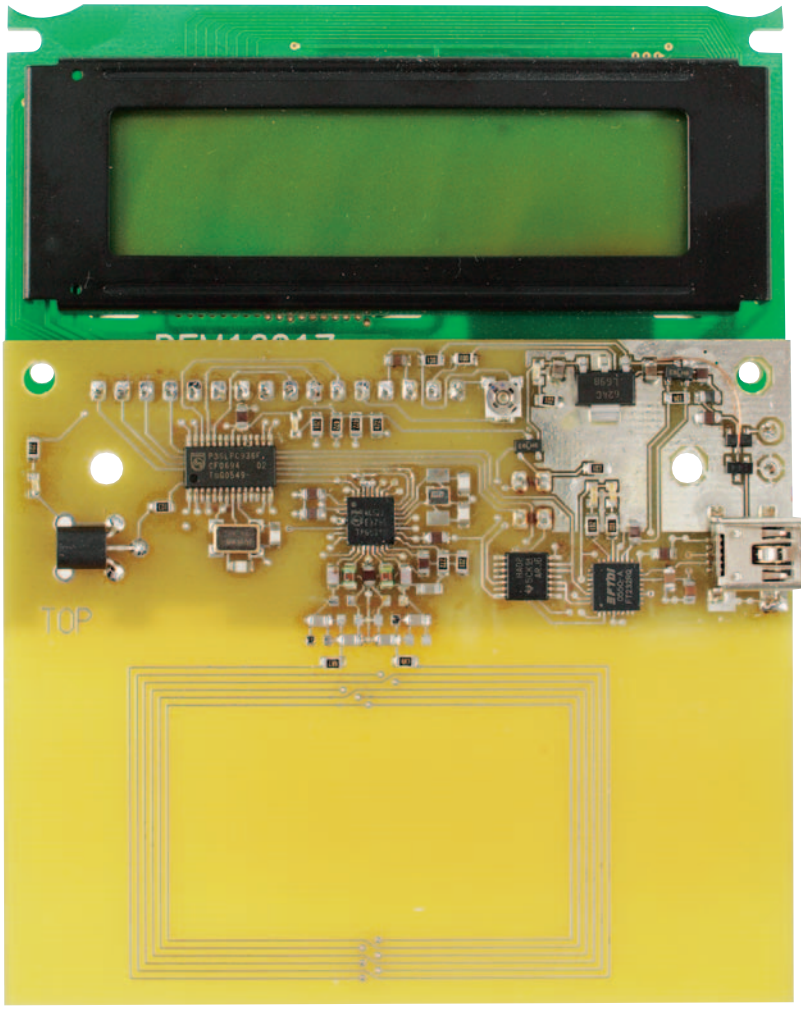
COMPONENTS LIST

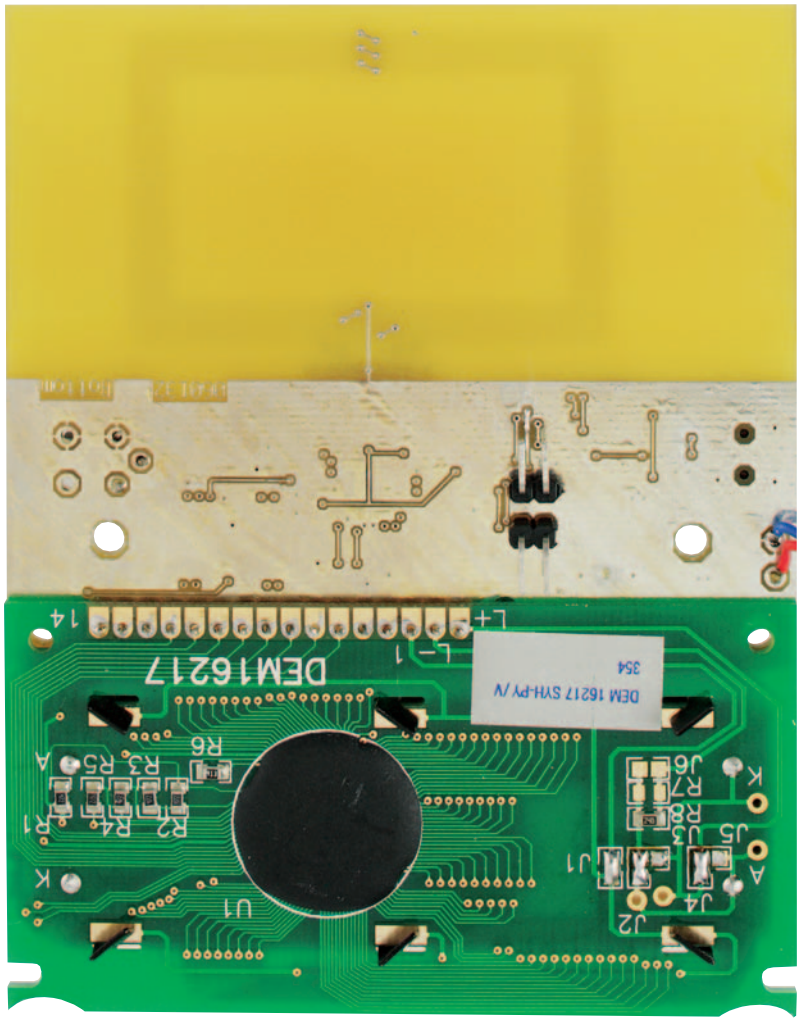
Resistors
(all SMD case 0805, 5%)
R1,R2,R6,R12,R15,R17 = 1kΩ
R3,R4,R5 = 4kΩ7
R7 = 2kΩ7
R8,R9 = 4Ω7
R10 = 270Ω
R11 = 10Ω
R13 = 100kΩ
R14,R16 = 10kΩ
P1 = 10kΩ-preset, SMD, 4 mm SQ

Capacitors
(all SMD case 0805, 16 V, ceramic)
C1,C2 = 47pF NP0
C3,C4,C5,C6,C9,C10,C11,C12,C16, C31 = 100nF
C7,C8,C13,C14 = 12pF NP0
C15 = 1nF NP0
C17,C19 = 220 p NP0
C18,C20 = not fitted
C21,C23 = 27pF NP0
C22,C24 = not fitted
C25,C27 = 68pF NP0
C26,C28 = not fitted
C29,C30, C32 = 2µF2

Semiconductors
D1 = SMD LED (0805) green, low-current
D2 = SMD LED (0805) yellow, low-current
D3,D6,D7 = SMD LED (0805), red, low-current
D4 = BAS19 (200 mA; SOT23)
D5 = BAT54S (30V / 300 mA; SOT23)
T1,T2 = 6402 (p-channel MOSFET, 20V / 3.7A; SOT23)
T3 = BC517 (npn Darlington; TO92 case)
IC1 = FT232RQFN (QFN32 case, FTDI)
IC2 = 74HC02 (TSSOP14 case; NOR gate)
IC3 = P89LPC936FDH-S (SSOP28 case; Philips)
IC4 = MFRC52201HN1 (HVQFN32case; Philips)
IC5 = LM2937 (low-drop, 3V3, SOT223 case)

Miscellaneous
X1 = 16MHz quartz crystal (18pF parallel capacitance; 5·3.2mm)
X2 = 27.12MHz quartz crystal (18pF parallel capacitance; 5·3.2mm)
K1 = miniature USB-B socket, SMD, 5-way
L1 = SMD ferrite (1.5 A; 0805 case)
L2,L3 = 560nH SMD inductor (0805 case)
JP1,JP2 = 0.1-in. jumper (see text)
LCD1 = LCD module with 2x16 characters and backlight
Enclosure, dim. 146x91x33 mm with LCD window and battery compartment for 4 AA bateries
PCB, order code **060132-91** (populated and tested, including USB cable; see Elektor SHOP pages and www.elektor.com)
Compatible LC display (see Elektor SHOP pages and www.elektor.com)
89LPC936 source & hex code files; free download from www.elektor.com
Mifare Magic PC software incl. source code; free download from www.elektor.com





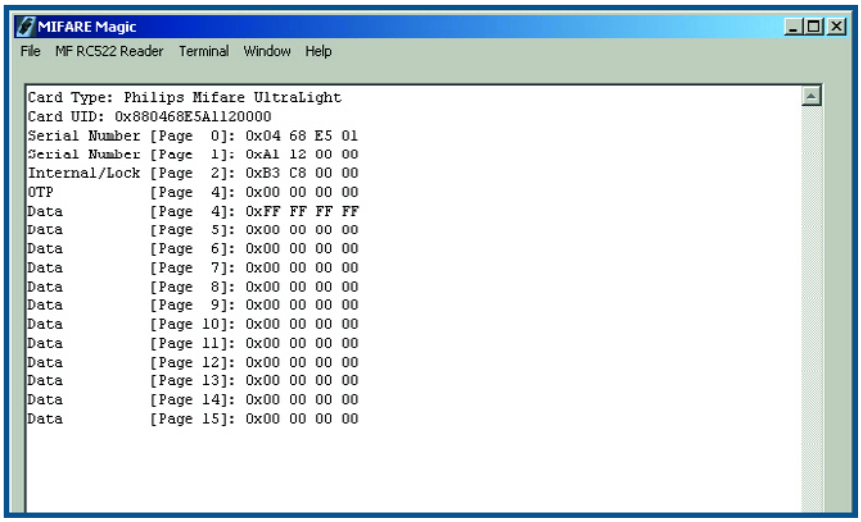


Figure 6. The 'Terminal' view of MIFARE Magic shows all the characters sent by the reader over the USB interface.

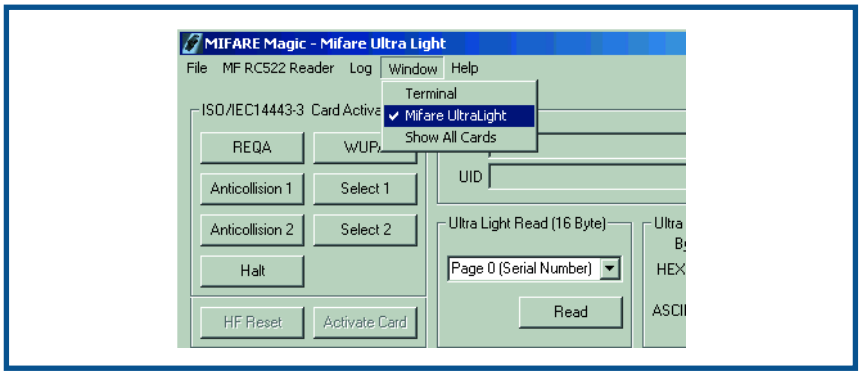


Figure 7. The 'MIFARE UltraLight' and 'Mifare Standard' windows allow simple programming of the RFID card.

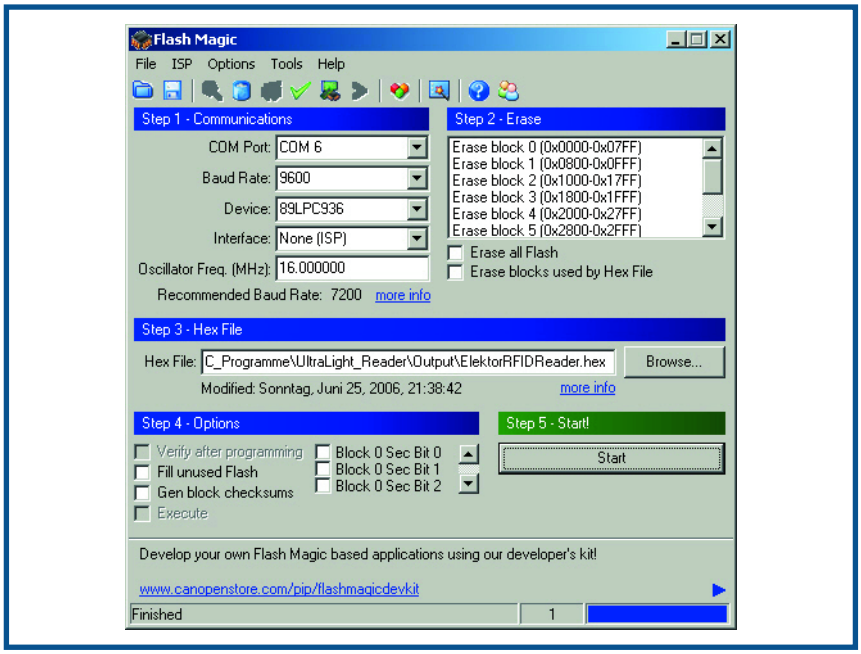


Figure 8. The free PC-based Flash Magic program can program the LPC microcontroller over the USB interface of the *Elektor Electronics* RFID reader.

to select a COM port, as MIFARE Magic uses the D2XX driver internally. **Figure 6** shows the 'Terminal' view of MIFARE Magic. This mode emulates a VT100 terminal and displays all the characters sent by the LPC microcontroller over the FTDI interface.

The firmware in the LPC microcontroller defaults to 'terminal' mode on power-up. As soon as the reader detects a new card within its field it activates the card. The reader determines whether the card is a MIFARE UltraLight, MIFARE 1K or MIFARE 4K. The entire memory contents of the card are read out and displayed on the MIFARE Magic terminal. For MIFARE 1K and 4K cards the standard MIFARE key is used. If the card uses a different key the data stored in certain sectors will not be readable. To use a different terminal program instead of MIFARE Magic (such as HyperTerminal or the built-in terminal in the LPC Flash Magic programming tool), the VCP driver must be used and the terminal program must be told the number of the relevant COM port. The parameters for the port are as follows: 115200 baud, no parity, 8 data bits and one stop bit.

The 'Window' menu allows MIFARE Magic to be switched between the 'Terminal' view, the 'MIFARE UltraLight' and the 'Show All Cards' views. The 'MIFARE UltraLight' window (see **Figure 7**) allows various card commands to be executed with a click of the mouse. This makes it easy to program a MIFARE UltraLight card, such as the sample supplied free with this issue. When this window is opened the firmware in the LPC microcontroller on the reader board switches from terminal mode into PC reader mode. Here the microcontroller waits for a card command from the PC and calls the corresponding function in its software. This mode is useful when developing applications on the PC.

The 'Show All Cards' window displays the serial numbers of all cards currently detected by the reader. This is useful for testing reader range and the capacity of the reader to deal with multiple cards simultaneously.

Program-it-yourself

For dedicated applications it is possible to modify or completely rewrite both the firmware in the LPC936 and the software running on the PC. Any updates to the reader firmware will also require reprogramming the

LPC936. The most up-to-date software will always be available on the *Elektor Electronics* website for free download. Updates will be reported on the news pages of the website and in the magazine under 'Corrections and Updates'.
The LPC on the reader board can be programmed directly over the USB port using the free PC program 'Flash Magic' (see **Figure 8**). This program, from Embedded Systems Academy (www.esacademy.com) and sponsored by Philips (www.semiconductors.com) supports a range of Philips microcontrollers.
Both jumpers JP1 and JP2 must be fitted on the reader board before the LPC microcontroller can be programmed. Interested readers will find a detailed discussion of how to program the device on the *Elektor Electronics* website along with a list of all the MIFARE UltraLight reader and card commands.
The reader firmware was developed using the Keil mVision3 C compiler for the LPC microcontroller. All the commands necessary for developing dedicated applications are made available as functions and so it is not necessary to deal directly with the individual registers of the MF RC522.
The listing shows the code necessary to activate a MIFARE UltraLight card and read a data block. The data will be transmitted using the serial interface of the microcontroller.
As mentioned above, the PC reader mode of the LPC firmware allows a PC application to invoke card functions. Using this mode function invocation is done using a very simple serial protocol to communicate with the program running in the microcontroller. When the function has been executed the response is returned to the PC. The naming and parameters of the functions are identical in the PC software and in the microcontroller firmware.
The source code for the PC-based MIFARE Magic program and for the microcontroller software can be downloaded for free from the *Elektor Electronics* website.

(060132-1)

Listing

```
while(1)
{
   status = ISO14443_Request(WUPA, &bATQ);
   if(status != STATUS_SUCCESS)
     continue;

   status = ISO14443_Anticoll(Level1,0,&abSNR[0]);
   if(status != STATUS_SUCCESS)
     continue;

   status = ISO14443_Select(Level1, &abSNR[0], &bSAK);
   if(status != STATUS_SUCCESS)
     continue;

   // Check if UID is complete
   if((bSAK & 0x04) == 0x04)
   {
     // UID not complete
     status = ISO14443_Anticoll(Level2,0,&abSNR[4]);
     if(status != STATUS_SUCCESS)
       continue;

     status = ISO14443_Select(Level2, &abSNR[4], &bSAK);
     if(status != STATUS_SUCCESS)
       continue;
   }

     // Read UltraLight Block 0..3
     status = Read(0,abDataBuffer);
}
```

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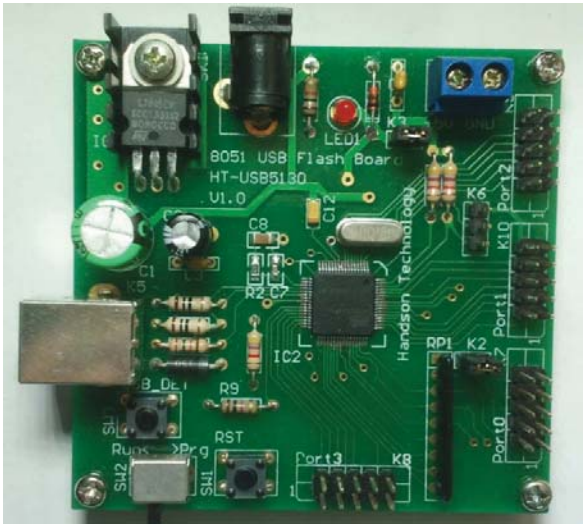

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