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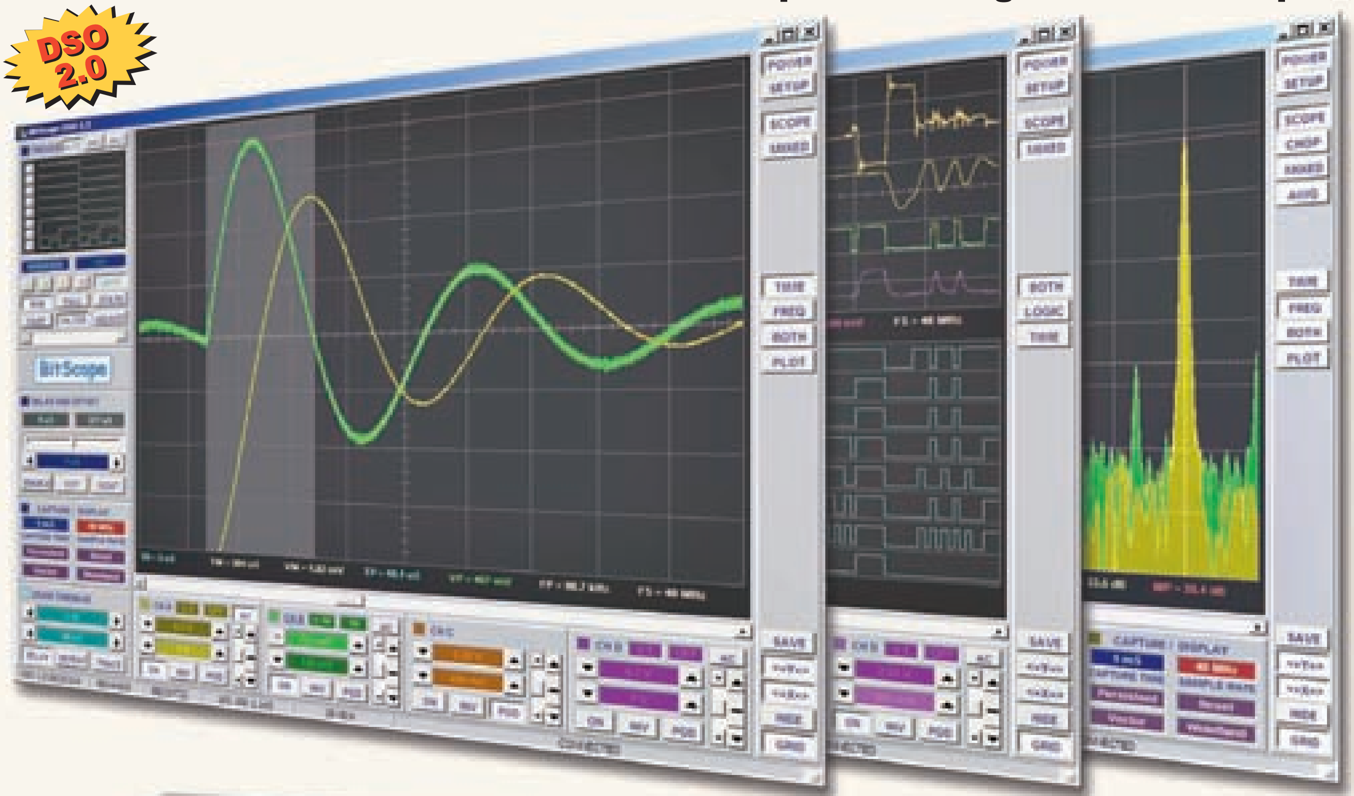

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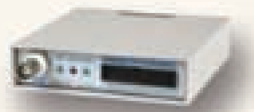

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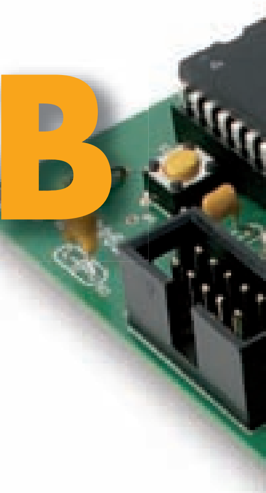
Microcontrollers all over the place

When browsing this month's issue you will have a hard time finding editorial pages not covering microcontrollers in one way or another. It's intentional. A quick look at my pagination map for this month (an A3 sheet showing 88 rectangles with article titles and production numbers pencilled in and more rubbed out) tells me that *Making Waves* (page 20) and *Scale Deposit Fighter* (page 70) are the only articles not directly linked to the wonders of the modern microcontroller. Even *Retronics* covers a micro – and a famous one it still is. *Hexadoku*, we are told, can be solved with an ARM microcontroller doing all the hard thinking – no, I cannot tell you where the program may be found. But then, I suspect that a surprisingly high number of the function generators kindly supplied to us for the purpose our test and market overview does contain some form of machine code chewing little monster, if only for the user interface. Compare that to the bewildering array of controls on an old HP benchtop function generator of the 1970s and it's hard to argue that there is no advantage in designing in a microcontroller, not just to make the instrument simple to use, but also to avoid 'silly' settings that are possibly harmful to connected equipment.
Elektor is liked for its coverage of a wide variety of microcontrollers, each with its own strengths and weaknesses, be it 8051, 6800, R8C, ARM, PIC, AVR, Freescale, FPGA, you mention it! However, the very same diversity on our pages is also criticised on occasions by readers bewildered at the choice of devices on the market. To these readers I can only repeat that Elektor is an independent magazine. Also, having a wide range of devices to choose from is a fact of life – just do it. This month also marks the return of *Mini Projects*, see page 70. The pages are for the benefit of a younger audience we would like to see enjoying electronics too. This month the 'star component' in the project is none other than a 4049 IC from the junkbox suitably marked *Microcontrollers – None Inside*.

Jan Buiting, Editor

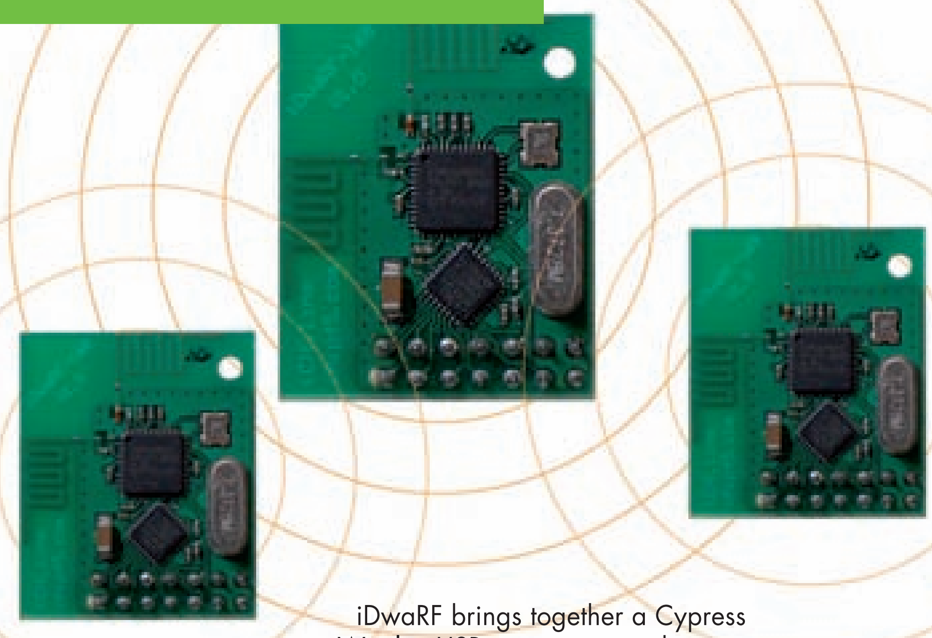
AVR Drives USB



Here we present a USB I/O board based on a standard AVR microcontroller – without any special USB chips!

Elektor CD-ROM 2006 page 12

48 Wireless USB in Miniature



iDwaRF brings together a Cypress WirelessUSB transceiver and an Atmel AVR microcontroller to create a networkable 2.4 GHz radio module featuring a free protocol stack and development environment.

CF Card Crypto Puzzle

fanstastic prizes, page 61

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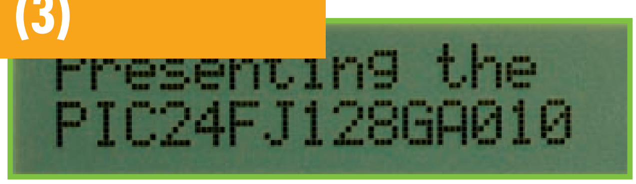
16 Attack of the SpYder

This month you'll get to know Freescale MC9S08's cronies called SpYder, a USB plug-in programmer/debugger and CodeWarrior, the associated software suite. The two are contained in our SpYder Discovery Kit, which sells at just £ 6.45 including a sample of an MC9S08 8-pin PDIP micro.

58 Explorer-16 (3)



More advanced (but still 100% free) simulation this month with a VSM model for media storage card devices added to our PIC24F system (all virtual, of course).
To cap it all, solve a CF card crypto puzzle and win fantastic prizes sponsored by Microchip and Labcenter.

elektor electronics — leading the way

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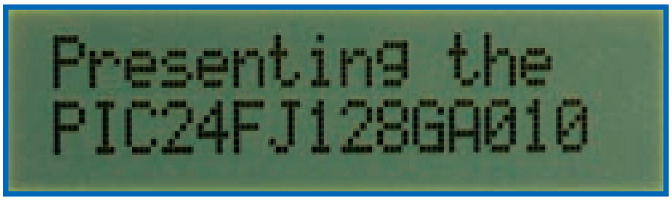


Explorer-16

Hi Jan — very interested in the new series featuring the Explorer-16 project (January & February 2007, Ed.). In the summer I went to a Microchip 1-day seminar on the PIC24 and dsPIC devices. It cost me from memory, just over £90 and included refreshments, buffet lunch and a free Explorer-16 board plus PIC24 and dsPIC33 mounted PIMs. The presentation and demos were very good. They also gave out a voucher for 20% off Microchip products.
Spurred on by the new series I have ordered an ICD 2 Debugger and have already uninstalled my MPLAB IDE to update to the latest version.
One small erratum, on the inset panel on p.25, step 5 refers to the selection of Build All from the Debugger menu. I think that should be the Project menu.
Looking forward to the next article, with thanks for an interesting magazine. I am a deserting Electronics (Wireless) World reader! I stopped my subscription because the format changed completely and concentrated on 'waffle' articles.
I am part professional, part amateur electronics engineer. I manufacture industrial modems for the railways and utilities, slow speed 1200 baud FSK V23 protocol and 300 Baud Dial up V21 duplex types. My interest in Microchip was to produce a firmware version based on a dsPIC. Microchip have already made the software available as a download but it is for another platform. Some work to do there!

Andrew Binning

Thanks for the feedback Andrew and hope you also enjoy Explorer-16 instalments 2 (February 2007) and 3 (this issue). We confirm the error in the text; a correction is published on the Explorer-16 project page on our website. Fortunately it does not seem to have deterred too many readers from successfully running the first simulation.

ECG using a Soundcard

Hi Elektor — I've read the article in Elektor October 2006. The project looks simple and I want to build it. However, the software looks daunting. I downloaded the zipped files and when I opened them, there are many things inside. How do I make a start? I am familiar with Delphi, C++, Visual Basic, but have not tried out Java. Please advise.

Norman Kim (Australia)

Martin Klaper replies:
Hi Norman, thanks for your e-mail from Sydney, Australia.
For a jump start, I recommend using the precompiled version, i.e. double-click on the EKG-MonitorV1.0.jar file. The only prerequisite is an installed JAVA runtime environment (JRE). Usually this is already on your computer. In case you need to install it, go to www.java.com/de/download/index.jsp and download the JRE.

Here you can download the Java development environment (JDK): http://java.sun.com/javase/downloads/index.jsp.

If you are familiar with Delphi, Visual Basic and especially C++, it should not be too difficult to learn a fourth programming language. My project is structured in three parts: IO, GUI and signal processing, so it should be possible to concentrate on one or another aspect. A good entry point to Java is www.BlueJ.org, although many other excellent Java tutorials and books are available in bookstores and on the net. Some useful web links are in my Elektor article and on the Elektor website.
A circuit board is available from Elektor, see the project page on their website.
[foto als NL mailbox 2/2007]

Help batteries through the winter

Dear Editor — I've a small question about the charger for sealed lead-acid batteries. Can I use this circuit as a charger for ordinary lead-acid batteries as used in vehicles? I mean the variety you can top up with distilled water. Or should I go for the lead-acid battery charge controller? The battery involved is a 12-V type for my motorcycle, and I really need a circuit to help the battery survive the winter period during which it is not used on the bike. Consequently it has to remain on the charger constantly over a period of about three months, will that be a problem?

Roy (by email)

A motorcycle battery is best used in combination with our Motive-Battery Charger from the October 1994 issue as that circuit takes into account the lower capacity of a motorcycle battery as compared with a car battery. To prevent sulphation, you could connect the Lead-Acid Battery Revitaliser from the September 2001 edition of Elektor in parallel. This circuit will charge the battery every few seconds with a short but strong pulse that serves to destroy sulphate crystals on the battery plates. Best results are obtained, we believe, by first charging the battery with the charger and then allow the Revitaliser to improve the condition. Inevitably, this circuit will draw a little current from the battery to build up the energy for the pulses. If the battery is in danger of going flat, you charge it again using the charger.

Nixie clock parts sourcing

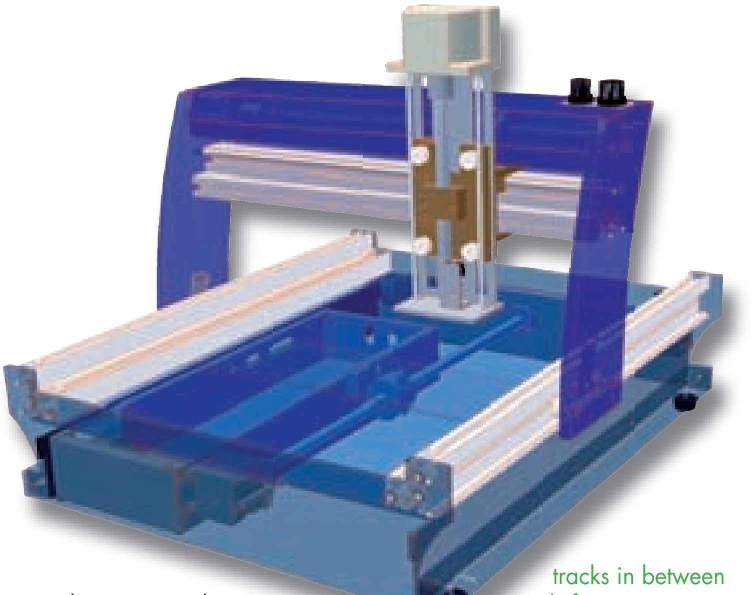
Dear Jan — I am happy to inform you that that those rare birds, the 74141 TL ICs for the Sputnik Timer Machine clock (January 2007, Ed.), are available from us under order number HLT0579. Suitable Nixie tubes like the types Z590M and B5870 are also in stock.

Further offers relating to Nixie clocks are found on the website http://www.askjanfirst.com/r5.htm which is also the source of the picture showing the acrylic glass Nixie clock with blue socket lighting.

Jan Wüsten, Ask Jan First GmbH & Co. KG (Germany)

Profiler (3)

The 'Profiler milling machine from a kit' publication in our January 2007 edition has given rise to a number of questions that are asked repeatedly, by email or through our forum. Among these questions: whether or not aluminium can be milled with this machine? The answer is: yes it can. Milling harder materials is not recommended



however as the construction of Profiler is not up to handling, say, steel. Another important aspect to keep in mind is the speed and force specification of the spindle motor you intend to use. The Ferm spindle motor contained in the kit is a basic tool that's definitely not up to high requirements.

The circuit board inside the machine are supplied ready populated and tested. A suggestion received from a number of readers to switch the drill and the vacuum cleaner on and off under control of the electronics has been forwarded to the kit manufacturer. At the time of writing, this option is not yet available.

Another frequently asked question covers accuracy, as the milling bits have to be changed by hand. A calibration method is available for this, allowing the bit to be fully inserted into the tool and then secured. Next, the software performs a calibration for the milling depth. This allows the spindle motor and/or the milling bit to be accurately positioned on the surface to be milled, — the tip of the bit just touching the surface. This position is stored as a reference, so replacing worn bits is not a problem during a milling job.

For the sake of completeness we once more summarise the main specs of the milling machine.

What can be done with Profiler

- milling PCBs, including tracks in between pads for DIL IC pins.
- milling aluminium front panels (using a suitable milling bit).
- milling ABS enclosures.
- milling ABS and wooden parts for modelling.

What cannot be done with Profiler

- milling PCBs with two tracks in between pads for DIL IC pins.
- milling hard materials like steel plate.

The functionality of the user interface is limited to controlling the machine. Other software is required to create designs. Although Autocad is commonly used (DXF format) for 2D and 3D objects, CorelDraw is likely to do the job too. Almost any PCB software can be used to design printed circuit board artwork. See our 'E-CAD' DVD (free with the November 2005 issue). The exported files (Gerber & Excellon) can be read by the conversion program comprised in the Profiler user interface. Other file formats required the use of an add-on software tool called RAMS.

Spy Radio Stations

Dear Editor — I was interested to read the article 'Spy Radio Stations' in the December 2006 issue. However I was a little bemused by the author's suggestion that Number Stations may be replaced by the Internet — will Security Services really send out e-mails which, when intercepted, carry the agent's email address at the start of every packet? Or will the agents give out the same information by logging onto a spy website?

The advantage of using H.F. transmission is that the agent may be anywhere in a region covering about 1/3 of the globe.

Sebastian Linfoot (UK)

Thanks for writing in Sebastian. Your interpretation of the article text is fairly wide and to be honest we do not see a suggestion by the author that Internet may replace radio for spy number transmission. None the less, it is intriguing to know how alternative methods could be made to work. The Enigma 2000 organisation mentioned in the article is probably the best source of relevant information.

Solution to Hexadoku January 2007

F	7	E	B	8	A	2	6	3	5	0	C	9	D	4	1
1	0	4	8	9	5	3	E	6	D	7	B	2	F	A	C
2	D	3	6	4	7	C	F	A	1	9	8	5	0	B	E
9	A	5	C	0	D	B	1	2	4	E	F	8	3	7	6
8	B	A	0	6	F	4	7	C	2	5	3	E	1	9	D
6	5	2	1	D	0	E	B	7	9	8	A	4	C	3	F
7	9	C	E	3	1	5	2	D	B	F	4	A	6	0	8
3	4	F	D	A	C	8	9	E	6	1	0	7	B	2	5
0	2	9	F	1	8	7	D	B	3	4	6	C	E	5	A
B	8	6	7	2	4	A	5	1	C	D	E	0	9	F	3
E	3	1	A	F	B	6	C	5	0	2	9	D	4	8	7
5	C	D	4	E	9	0	3	8	F	A	7	6	2	1	B
4	6	B	2	7	3	1	8	0	A	C	D	F	5	E	9
A	F	0	3	C	E	D	4	9	8	B	5	1	7	6	2
D	E	8	5	B	2	9	0	F	7	6	1	3	A	C	4
C	1	7	9	5	6	F	A	4	E	3	2	B	8	D	0

Corrections & Updates

MP3 Preamp

February 2007, p. 40-45, ref. 060237-1

The circuit diagram shown in Figure 2 should be corrected to reflect that the negative terminal of capacitor C3 is connected to junction R10/R18/T2 base, i.e., not to the emitter of T2 as printed. The same applies to C12 and T6. The printed circuit board design (Figure 4) is correct.

Also in the circuit diagram, the indication with connection point 'C1' should be moved one level down, i.e., from GND1 down to the same level as C9.

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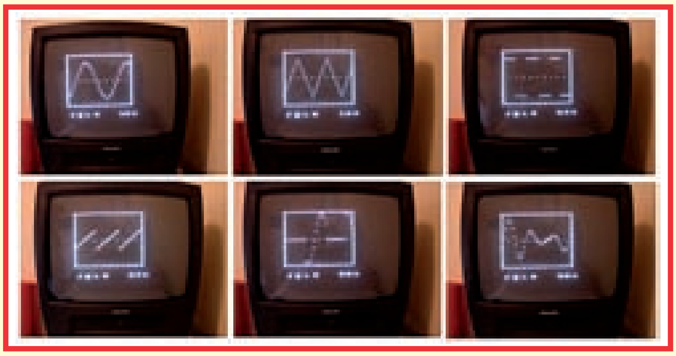
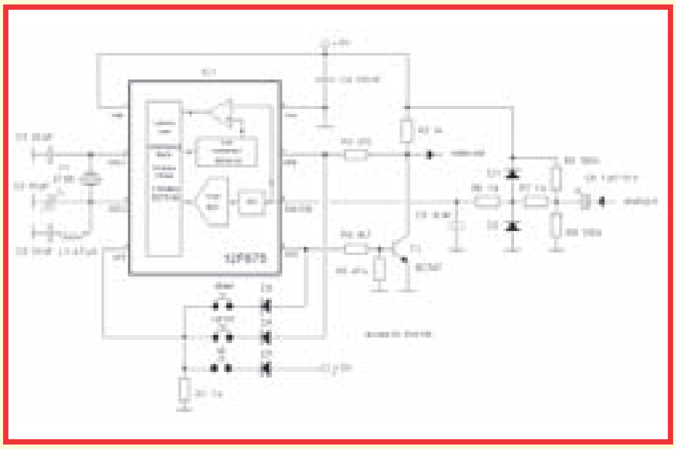
µScope





It is often said that the oscilloscope is the most useful piece of test gear that the engineer can possess. Over the years 'scope' design has improved tremendously; they are now more portable, reliable and offer far better performance than their predecessors. More recently we have seen the introduction of the 'USB scope' which digitizes the analogue input signal and displays it on a laptop or PC screen, these offer a good range of features at a reasonable price. For the last 25 years the cost of even a low-spec scope has been beyond the reach of the average electronics enthusiast. During this period many designers with an ambition to own their own scope have risen to the challenge and produced their own design. Many of these home brew scopes appeared in the electronics press in the 1960s and 70s, most of them used valves but in 1975 the fully transistorised (excluding the CRT of course) 'Elektorscope' was published in Elektor Electronics. Despite the success of the design many people were put off by the cost of the CRT and special mains transformer. Way back in October 1978 Elektor Electronics addressed this problem by publishing the 'TV scope'. This design used a standard black and white TV set to display the waveforms while the input signal was sampled and stored in a 'bucket brigade' memory chip. One feature of the design was that the X axis (time) was drawn vertically on the screen. With the technology available at that time and an emphasis on a low cost solution it was still a rather complex project and required a number of PCBs containing many ICs. Thanks to progress in microprocessor technology it is now possible to produce the complete 'TV scope' concept using just a single 8-pin microcontroller.

A brief scrutiny of the data sheet was sufficient to determine that the PIC 12F675 microcontroller contained all the components necessary to build a modern day equivalent of the TV scope which we have called the 'µScope'. The aim of the exercise was to implement all the features of the original design in the controller's firmware.

The 12F675 is one of the smallest members of the PIC controller family from Microchip. The 14-bit processor has a 1024 word flash memory, 64-byte RAM together with a 128-byte EEPROM. Included with the built-in standard peripherals are timers and a watchdog. The 12F675 also has a 10-bit A/D converter with a sample and hold function, a voltage comparator and an adjustable voltage reference all of which can be configured by software.

As we know there is no such thing as a free lunch, here the very simple hardware approach means that the software must be more complex. The processor needs to work hard just to produce a real-time video signal, when you take into consideration the oscilloscope functions and the user interface the processor has hardly any spare capacity at all. The on-chip memory is also barely enough; at 64 bytes the RAM is actually too small but luckily Timer 1 is not used so its two registers are employed as additional RAM space. The limited memory and chip clock speed call for some unconventional solutions to ensure success in this design application. It would of course be much simpler to use a higher-spec controller but then the project would be far less interesting and challenging. With so little hardware it goes without saying that the cost of the design will be absolutely minimal and the complete circuit can be accommodated on a small piece of solder-pad prototyping board. Software for the PIC 12F675 was written using the 'tait style' programmer. Communication with the PC is performed using the parallel computer (printer) interface and the software runs by starting the 'PP06' program. Current consumption of the complete circuit is less than 10 mA so it is possible to use battery power. The sensitivity of the scope can be improved by adding some amplification to the input signal; the µScope is not a wide-band instrument, it has a bandwidth of only a few kilohertz so it is sufficient to use a standard specification opamp as an amplifier. Those of you who feel confident enough to alter the software can experiment by writing a program to generate signals for display on the scope. The assembler program EXAMPLE.PIC draws a white rectangular border and a dashed line on the screen. All of the relevant software can be freely downloaded from the Elektor Electronics website. The software is well documented and the operating principle is quite easy to understand so it shouldn't be too long before you are able to make the necessary modifications to produce your own signals. The resulting waveforms can also be recorded onto a VCR if necessary.

Ronald Dekker (Netherlands)

(060278-11)

The software for this project (060278-11.zip) can be found on the Elektor Electronics website under magazine/2007/March/Mailbox.
The author's website also contains a more detailed description (in English) of the project: http://members.chello.nl/r.dekker49/

See the EXPLORER-16 Hands-On PIC24F Design Series on page 58!

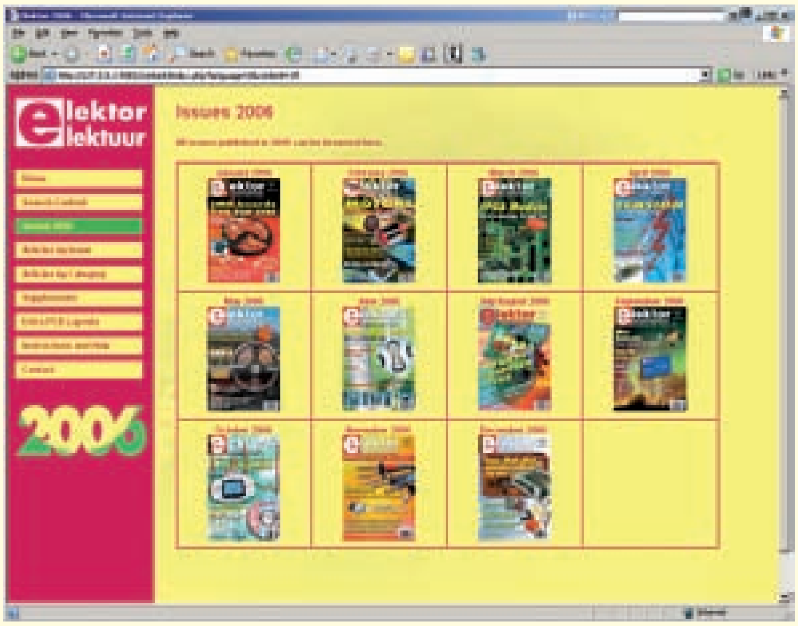
Elektor CD-ROM 2006

Harry Baggen

New version has HTML user interface

The Elektor Volume 2006 CD-ROM that's published along with this March 2007 issue has a rather different look and feel than previous editions — it's gone through a makeover in more than one way.

Elektor year volume CD-ROMs have appeared since 1996 and become a well-established product, eagerly awaited every year by thousands of our readers.
In early years (1996 and 1997) a homebrew user interface was applied for lack of a suitable standard for reproducing magazine articles on digital media. As of the 1998 edition, Adobe pdf was used and thanks to its general acceptance it has remained the standard ever since. Articles are displayed using the well-known Acrobat Reader program from Adobe, of which a current version was supplied on every Elektor annual CD-ROM. A user interface written to match Acrobat Reader was included to ensure simple and uncluttered operation while also providing a search function for subjects and keywords.



During the past ten years the user interface on Elektor year volume CD-ROMs was modified quite a few times to meet the requirements of computer users and, of course, new Windows versions introduced over the years. Still, problems occurred very now and then due to incompatibility issues. Also, installing multiple year volumes on hard disk proved complicated at times. During recent years, the DiskMirror utility was supplied on our CDs to help users get it all organised in a simple manner.

Starting with the 2006 edition, we switch to a completely new user interface based on HTML and employing the default web browser installed on every reasonably modern PC. In this way we hope to offer better, simplified control of the program while at the same time preventing hardware-related problems.

A little getting used to

The new user interface for the 2006 CD-ROM may look a bit unfamiliar initially if you're used to the previous versions, and may require some time to get comfortable with.
Provided Autostart for CDs is enabled on your PC, the 2006 CD-ROM will launch automatically when inserted in the drive. If not, you will need to run the program *Server2Go.exe* found on the CD. The computer will start a webserver application (actually, an Apache webserver and a MySQL database). Depending on the computer's speed, this may take some time to load and complete. Next, your PC's default web browser is started and the welcome page of the Elektor 2006 CD-ROM appears. Here you can select from four languages followed by a number of menu options. Most texts, options and prompts are self-explanatory to the extent that no further advice is needed: an overview of the 11 magazine issues, all articles per issue, all articles by heading and of course a search function across the entire CD contents, also allowing multiple search arguments (with an AND/OR selection). One click on an article title is sufficient to open a new browser window in which the relevant pdf document will appear.

All free, printed, supplements our readers got last year, like the Visual Basic, C and i-Trixx booklets are also contained on the CD — they are found under *Supplements*. Printed circuit board artwork that was not printed in the relevant magazine issues (due to lack of space) are found under *Extra PCB layouts*. Finally, the CD also contains all News & New Products items published in 2006.
Typically, less than 5 minutes worth of clicking around are needed to get the feel of new system.

Putting it on the hard disk

The new version is extremely easy to use from hard disk. All you have to do is create a new folder on your hard disk and give it a suitable name (like Elektor2006). Then copy the complete CD contents to that folder. Next, create a shortcut in the Start menu or on the desktop, to point to the application program *Server2Go.exe* in the folder. Future editions of the Elektor year volume CD may be added in this folder and are automatically included in the general overview.

The only disadvantage of the new system is its incompatibility with the previous one — older year volumes are inaccessible, hence cannot be searched, directly from the new menu. It's a sobering thought however that the PC world is changing so fast you have to say goodbye to a system at a certain stage and make a fresh start.

We hope you like the new layout. If you have requirements or remarks, or you wish to discuss the new CD with other readers, please feel free to do so in the special topic created on our Forum at www.elektor-electronics.co.uk.

(070057-I)

Vinculum IC speeds USB flash drive connectivity to microcontrollers

By Fred Dart (MD, FTDI)

Although this media has been readily available for a number of years, use of USB flash drives has, to date, been restricted to platforms with adequate processing power such as PCs and 32-bit embedded systems. FTDI has now opened up the use of USB flash disks to microcontrollers with the introduction of their Vinculum series of intelligent USB host controllers.

The **Vinculum VNC1L** IC provides USB host interface and data transfer, and supports the most popular device classes; mass storage, printer and human interface device (HID). HID class devices typically include USB keyboards, joysticks and mice. When interfacing to flash drives, Vinculum manages the file allocation table (FAT) structure by using a straightforward command set. The device has an 8-bit core together with a 32-bit co-processor, dual DMA controllers, 64 k embedded flash and 4 k internal SRAM memory. Vinculum features two USB 2.0 low and full speed, host and slave ports, universal asynchronous receiver transmitter (UART), serial peripheral interface (SPI) and parallel first in first out (FIFO) interfaces. It also has two PS2 legacy ports for keyboard and mouse, and up to 28 general-purpose input output (GPIO) pins depending on configuration. The current Vinculum handles both low and full speed USB 2.0, which provides data link at up to 12Mbytes/s and will interface to all USB2.0 peripherals, as well as older USB1.1 devices. This is more than sufficient for USB flash drive applications and is deliberately targeted to keep the size, cost and power down to a level that is acceptable for embedded applications. Power consumption is 25 mA for the 3.3 V core and the 5-V-safe I/O interface.

Vinculum provides USB host capability to microcontroller-based products that previously did not have the hardware resources available. A wide range of consumer and industrial products, such as intelligent domestic appliances, meter readers and vending machines, can now incorporate USB peripheral connectivity. For product designers this is now greatly simplified by the availability of FTDI's new **VDRIVE2 module**. Packaged in a neat snap-in enclosure (**Figure 1**), VDRIVE2 consists of a Vinculum IC, USB "A" socket and a few support components. Only four signal lines plus a 5V supply and ground are required. By using the Vinculum Disk Interface Firmware Specification (DIFS) the I/O interface can be selected between the serial UART and SPI using the on-board jumper pins. A bi-colour led provides power and status indication.

Figure 1. The VDRIVE2 snap-in module.

Adding a PIC microcontroller and a few other components, the VDRIVE2 module can be turned into a flash disk based data logger. **Figure 2** shows the schematic of a simple application. The AC signal input is connected to the 10-bit analogue to digital converter on board the Microchip PIC. The PIC code takes a predefined number of samples and then writes the corresponding ASCII values to a comma separated value (CSV) file on the USB flash disk attached to the VDRIVE2 module. Vinculum's DOS like ASCII commands simplify the task of file handling. An extended ASCII command set is designed for use with a terminal during test and development, whilst a shortened hexadecimal version is used with a microcontroller. Currently, Vinculum's command set has five categories: Directory, File, Power management, Debug and Miscellaneous. **Table 1** illustrates some example commands.

(070014-I)

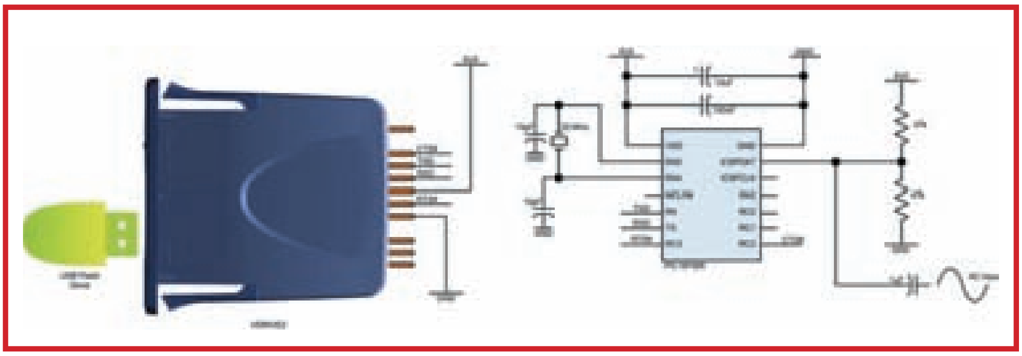


Figure 2. Connecting the VDRIVE2 to a PIC micro is as simple as this.

Table 1. Vinculum — command monitor system examples.

Extended ASCII command for terminal mode	Hexadecimal command for microprocessor mode	Command function
Directory examples		
DIR<cr>	$01,$0D	Lists the current directory
MKD<cr>	$07,$20,<name>,$0D	Make directory
CD<sp><name><cr>	$02,$20,<name>,$0D	Current directory is changed to the new directory <name>
File examples		
RDF<sp><size in hex (4 bytes)><cr>	$0B,$20,size in hex(4 bytes),$0D	Reads the data of<size in hex> from the current open file
OPW<sp><name><cr>	$09,$20,<name>,$0D	Opens a file for writing with the command WRF
Power management examples		
SUD<cr>	$15,$0D	Suspend the disk when not is use to conserve power
WKD<cr>	$16.$0D	Wake disk

MPLAB® REAL ICE™ emulation system

Microchip announces the MPLAB® REAL ICE™ emulation system to support the development of applications that use Microchip's PIC® microcontrollers and dsPIC® Digital Signal Controllers (DSCs). The MPLAB REAL ICE offers low-cost, next-generation emulation support, including faster memory interfacing and longer distance, higher speed target connections.

The new emulation system is fully integrated into the free MPLAB Integrated Development Environment (IDE) used for writing code, building projects, testing, verification and programming. Within MPLAB, the new system supports a wide range of debugging facilities, such as complex break points, application code trace and data logging, code execution stopwatch, and real-time variable monitoring. Microchip developed the MPLAB REAL ICE emulation system alongside its next-generation microcontrollers and DSC devices to ensure tightly coupled emulation integration. On-chip resources support the emulation features for full-speed debugging, with real time variable monitoring. High-speed data interfaces rapidly upload large trace records, offering quick monitoring and instant adjustment of application parameters.

The MPLAB REAL ICE emulation system offers the following advanced features:

- Full-speed, Real-Time Emulation.
- Portable, USB-Powered, and CE and RoHS-Compliant
- Trace Execution and Analysis:
  - Multiple execution trace and application logging features
  - Real-time watch and data capture
  - Trace data streamed via parallel or serial interface
- Rugged Probe Interface:
  - Protection circuits guard against power surges from the target
- Legacy and High-Speed Connectivity:
  - Backward compatibility with the MPLAB ICD2 in-circuit debugger, or
  - A driver/receiver pair for high-speed, noise-tolerant communications, supporting cable lengths up to 3 metres.
- Logic Probe for External Triggers:
  - 14-pin header connects to logic probe for external triggers
  - Can also trigger an external logic analyser or oscilloscope

The MPLAB REAL ICE in-circuit emulator (part number DV244005) is available now for $499.98 or the local equivalent excluding local tax. In addition, the MPLAB REAL ICE Performance Pak (part number AC244002) is available now for $159.98, and includes two plug-in high-speed driver boards to enhance communications between the unit and target.

The optional Processor Extension Paks, available shortly, will provide an extension board that plugs directly into the target socket and releases debugging pins for use within the application.

For additional information visit Microchip's Web site at www.microchip.com/realice

(077029-II)

Class-D chipset cuts parts count and board size by 50%

International Rectifier recently introduced a new Class D audio chipset comprised of the IRS20955 200-V digital audio driver IC and the IRFI4024Hx series of digital audio MOSFETs. Compared to typical designs, the new IC reduces PCB board space by 50 percent for Class-D audio amplifiers up to 500 W, while the MOSFETs reduce power switch part count of the Class D stage by 50 percent for the entire mid-voltage range of mid- and high-power amplifiers for home theatre applications, professional amplifiers, musical instruments and car entertainment.

The IRS20955(S)(TR)PBF IC reduces external component count by up to 27 components and features a unique floating, 3.3V/5 V logic-compatible, PWM input that eliminates seven external level-shift components for Class D audio applications using a half-bridge topology and dual power supply.

Greater protection is achieved with an integrated programmable bi-directional current-sensing feature with self-reset function that allows the high-voltage IC to sense the exact point of the switching cycle. Current is sensed at the correct moment allowing the IC to optimize the over-current protection circuit. In addition, this offers considerable space-saving benefits with the elimination of a large current-sense resistor. The IC has built-in protection control logic that eliminates 11 components and shrinks board footprint, compared to existing audio IC reference designs.

The new audio IC has preset internal deadtime generation to enable accurate and stable gate switch timing, while delivering optimum deadtime settings for improved total harmonic distortion (THD) performance and high noise immunity. In addition to simplifying design, this deadtime feature reduces part count by as much as eight external components, and reduces board space by eliminating large package types. Operating up to 800 kHz, the IRS20955 digital audio IC is also suitable for single-supply, full-bridge designs.

In addition to low on-state resistance, the series of half-bridge N-channel MOSFETs provide optimized gate charge, body-diode reverse recovery and internal gate resistance to improve key Class D audio amplifier performance parameters such as efficiency, THD and EMI. For example, the IRFI4024H-117P features a typical $R_{Ds(on)}$ of 48 mOhms for high efficiency, and a typical Q_g of 8.9 nC and Q_{sw} of 4.3 nC for improved THD.

www.irf.com

(077029-V)

Weatherproof LED data display

Lascar Electronics has introduced the EM32-4-LED, a 4-digit LED data display well suited for use in microcontroller based applications. The display area comprises four 7-segment LED digits and three decimal places, each of which can be individually addressed using serial communication. The low-power red LEDs provide a vivid display that can be easily read in most lighting conditions whilst drawing just 20mA at 5V. Connection to the EM32-4-LED is via a 12-pin DIL connection with industry standard 2.54mm (0.1") pitch.
The EM32-4-LED is housed in an attractive round metal alloy and glass enclosure that provides environmental protection to IP-67 when correctly mounted.
The EM32-4-LED is available immediately from Lascar Electronics with prices starting at £24.95 (£14.97 at quantities of 250+ pcs).

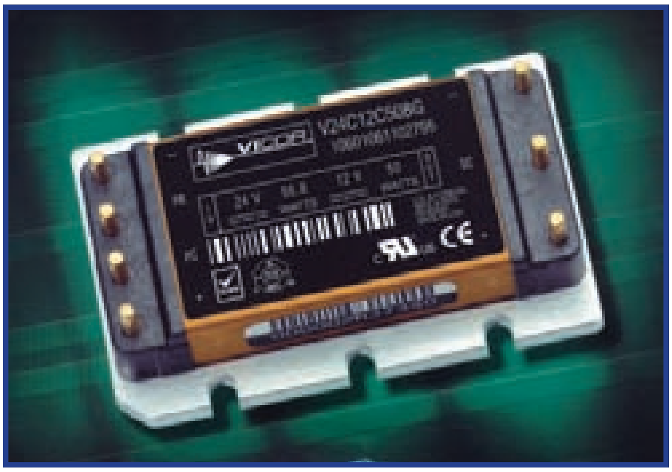
For further information regarding this product, or to discuss a potential application please contact the Lascar sales team on

+44(0)1794 884567 or by e-mail: sales@lascar.co.uk or from the Lascar website www.lascarelectronics.com.

(077029-IV)

Cost-effective mid-power 24Vin micro modules

Vicor announces the addition of seven mid-power Micro DC-DC converters to the 24Vdc input family: 50W models at 3.3, 12, 15, 24, 28, and 48Vout. The modules — which incorporate Vicor's patented low-noise Zero-Current and Zero-Voltage Switching (ZCS/ZVS) — are appropriate for power system applications in industrial and process control, distributed power, medical, ATE, communications, defence, and aerospace.
The addition of these modules doubles the size of the high-power density 24Vin family, which previously consisted of 75W at 3.3Vout and 100W at 5, 12, 15, 24, 28 and 48Vout. The converters operate from 24V nominal input, with an input range of 18V to 36V and will operate down to 16V after startup. Efficiencies range up to 89% for the higher output voltages.



These models, which are RoHS compliant (with F or G pin option) are 57.9 x 36.8 x 12.7 mm in size with a height above board of 10.9mm.
These mid-power products provide customers a cost-effective solution for applications that do not require the full-power capability of the Micro module, but would benefit from the low-noise performance and full-feature set provided by te Micro platform.

Vicor's comprehensive line of power solutions includes modular, high-density AC-DC and DC-DC modules and accessory components, fully configurable AC-DC and DC-DC power supplies, and complete custom power systems.

www.vicorpower.com

(077029-I)

Current sensors for automotive battery-monitoring applications

LEM has introduced two new members of its IT family of current transducers to address high-current applications. The IT 400-S and the IT 700-S are specified respectively for 400 and 700 A_{RMS} nominal. As with other members of the family, they offer very high accuracy, based on resolution better than 0.05 ppm, linearity better than 3 ppm and an initial offset between 30 and 50 ppm. Thermal offset drift is extremely low, at only 0.5 ppm/K.

Featuring galvanic isolation, the IT 400-S and IT 700-S can be used for current measurement of any kind of waveforms (including DC, AC, mixed and complex). They have been designed to operate from a bipolar ±15 V DC power supply and will accommodate round primary conductors of 26 and 30 mm diameter respectively.

In addition to their normal current output, the transducers offer an additional output indicating the transducer state (opened or closed contacts), and an external LED showing the normal operation.

With an operating temperature range of +10 to +50°C, the transducers will find applications in high-precision power supplies and high-performance gradient amplifiers for MRI (Magnetic Resonance Imaging), as well as medical equipment such as medical X-Ray imaging, but also calibration test benches in laboratories and test departments. They can also be used as interfaces for power analysers when high accuracy is required.
The transducers are CE marked and supplied with a two-year warranty.

www.lem.com

(077029-III)

Attack of the SpYder

Discover Freescale's MC9S08 micro, SpYder and CodeWarrior

Jan Buiting & Luc Lemmens, in cooperation with
Inga Harris (Applications Engineer, Freescale Semiconductor Inc.)

In this short series of articles we add Freescale's powerful MC9S08 device to the diverse and colourful palette of 8-bit microcontrollers that have graced our pages these past two or three decades! This month you'll get to know MC9S08's cronies called SpYder and CodeWarrior; next month we have a nice application project for you to build. For your benefit we're going to use a micro housed in an 16-pin DIP case!

Freescale Semiconductor ranks among the market leaders in microcontrollers — yet their tool set and distribution networks were unattainable to the hobbyist market until 2006 as their tool solutions, both hardware and software, were price inhibitive. Since breaking off from Motorola they have placed a strong focus on the mass market and with the recent addition of an e-commerce site, free samples, free of charge compilers and debuggers and low cost hardware tools Freescale's microcontroller families are now accessible to all. *Elektor Electronics*, in exclusive cooperation with Freescale, is happy to be instrumental in this. The latest tool, the SpYder, manufactured by SofTec Microsystems with a normal resale price of about £ 20 (30) is another strong step into this marketplace.

Where it all came from

The roadmap shown in **Figure 1** shows how Motorola/Freescale's cores have evolved. The HC05 and HC11 8-bit cores were introduced in the 1980s and were widely used by all kinds of developers. In the late 1990s the HC08 (8-bit) and HC12 (16-bit) cores were introduced but were never widely adopted by the mass market. In very early 2000's the HCS12 16-bit core followed by the HCS08 8-bit core were introduced with the key new feature on the Background Debug Module (BDM).

The 8-bit HCS08, and — introduced last year — the RS08 microcontrollers contain a single-wire background debug interface, supporting in-circuit programming of on-chip non-volatile memory and sophisticated non-intrusive debug capabilities. It is this module which enables the development of these low cost, easy to use tools. The BDM connection will also be present on the 32-bit microcontroller 68K/ColdFire™ V1 core products which will be available later this year.

SpYder is a bug eating, MCU spying tool for 8- and 16- legged microcontrollers

BDM: do-it-yourself or buy one

In 2005 *freegeeks.net* (now integrated in www.freescale.net) provided the HCS12 microcontroller community with an open source tool named TBDML, and with 1454 downloads in the first 12 months it was hailed a great success. Now the equivalent tool for their 8-bit BDM enabled microcontrollers is available in two forms. You can choose the OSBDM for the HCS08's which you can find details of on the Freescale forums [1]. This self build tool has a BOM (bill of materials) of under $10.

Alternatively, you can buy a ready made SpYder which supports MC-

9S08QG, MC9S08QD and MC9RS08KA 8-bit microcontrollers to date, and as more microcontrollers are announced this list will grow.

The SpYder Discovery kit will be sold through Elektor as of this magazine issue.

OSBDM and SpYder essentially do the same thing. They interface between your development environment (Windows PC based) and your target microcontroller as shown in **Figure 2**. The key aim of these tools is to provide a tool which is cheap and easy for enthusiasts, students etc. to use.

More about SpYder and BDM

The 2*g* accelerometer we'll describe in part 2 of this series is controlled by Freescale's MC9S08QG8 MCU and the SpYder Discovery Kit.
The Kit is a new USB-to-BDM development tool for Freescale's MC9S08QG, MC9S08QD and MC9RS08KA 8-bit microcontrollers (**Figure 3**). For those of you unfamiliar with BDM, it is Freescale's version of ICD, debugWIRE, JTAG etc., used on their recent 8- and 16-bit products.

The BKGD (BacKGrounD) pin on these devices provides this single-wire background debug interface to the on chip debug modules. See the Development Tools chapter of any HCS08 or RS08 datasheet for more information about these debug modules and how

MC9S08QG4/QG8 features

- 4-8k Flash, capable of EEPROM emulation
- 512bytes of RAM
- Internal Clock Source (ICS)
- Up to 10 MHz bus
- On-chip oscillator
- Frequency locked loop to generate the CPU clock from the internal oscillator.
- External crystal support (16-pin only) up to 10MHz bus
- 2% accuracy over full operating range
- Power saving modes
- Serial Communication
- I²C (synchronous), SPI (synchronous), and SCI (asynchronous) Timers
- 2-channel Timer/PWM Module (TPM)
- An 8-bit modulo timer module (MTIM) with 8-bit prescaler
- Analogue Modules
- 8-channel, 10-bit ADC, including temp sensor
- Analogue comparator
- Development Tools: SpYder08 & CodeWarrior Special Edition (free)
- On chip ICE and BDM
- 8-pin packages – PDIP (!), NB-SOIC, DFN
- 16-pin packages – PDIP (!), TSSOP, QFN

Freescale & Elektor

Elektor is proud and glad to acknowledge its exclusive cooperation with Freescale Semiconductor Inc. for the benefit of its readers. The cooperation covers not only publishing articles based on Freescale microcontrollers and other semiconductor devices, but also sales of SpYder kits at a reduced price. There's more in the pipeline so stay tuned.

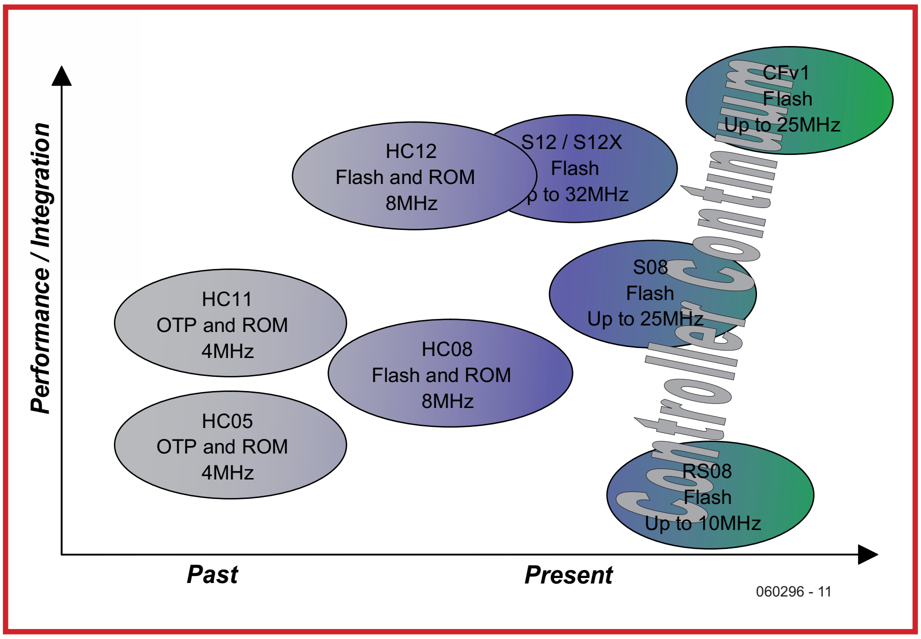


Figure 1. Core roadmap of a selection of Freescale micros released onto the market.

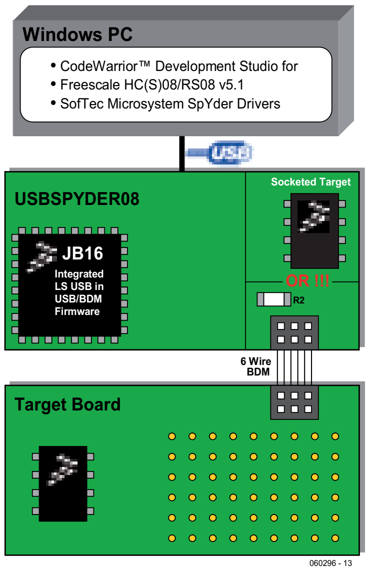


Figure 2. SpYder comfortably seated between the PC's USB and a Freescale microcontroller board with BDM connectivity.

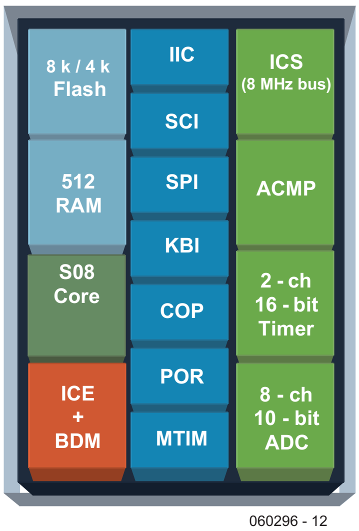


Figure 3. What's inside an MC9S08 micro — globally, that is!

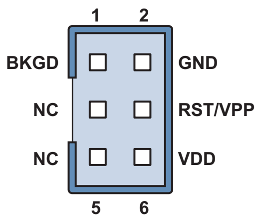


Figure 4. Freescale BDM connector pinout.

to use them. While the interface is single wire, typically a 6-pin connector, a BDM port is used to interface with the target as shown in **Figure 4**.

The primary function of this pin is for bidirectional serial communication of active background mode commands and data transfer. During reset, this pin is used to select between starting in active background mode or by starting the user's application program. Additionally, this pin requests a timed sync response pulse, allowing a host development tool to determine the correct clock frequency for background debug serial communications. BDC commands are sent serially from a host computer to the BKGD pin of the target HCS08 or RS08 MCU. All commands and data are sent MSB-first using a custom BDC communications protocol. With a single-wire background debug interface it is possible to use a relatively simple interface pod to translate commands from a host computer into commands for the BDC.

In the case of the SpYder Discovery Kit, a low-speed universal serial bus (USB) interface is used.

The tool takes the form of a USB Flash Memory Stick.
Together with the CodeWarrior IDE, SpYder provides you with everything you need to write, compile, download, in-circuit emulate and debug user code. Full-speed program execution allows you to perform hardware and software testing in real time. The tool works up to bus speeds of 10 MHz, supports the 3.3 V operation range of the microcontrollers and has on board a socketed target microcontroller which can be replaced with other supported PDIP packaged parts available in small sample quantities FOC from http://www.freescale.com. To increase the flexibility of the tool, it has a BDM connector for off-board debugging of the supported products in other packages, or if you need to develop along with other board components.

MC9S08QG8CPBE is just a long name for an 8-bit micro in a 16-pin PDIP case

Meet CodeWarrior

Freescale's CodeWarrior™ Development Studio for HC(S)08/RS08 with its award winning integrated development environment (IDE) has a quick start guide which eases installation and helps create a first example project, and more than 100 example

What is the MC9S08QG8CPBE microcontroller and how to get one

For next month's accelerometer project you will need to order up an MC9S08QG8CPBE as it will be the main controller in the system. It is a small (8 and 16 pin), fully featured microcontroller device from the Freescale S08 family. The device includes the main features shown in the inset. The datasheet can be found at

www.freescale.com/files/microcontrollers/doc/data_sheet/MC9S08QG8.pdf

You can get hold of free samples of the MC68HCS08QG8 DIP parts from here

www.freescale.com/webapp/sps/site/overview.jsp?nodeId=01098400786959705928692948&tid=FSH

Click on 8-bit microcontrollers and search for MC9S08QG8CPBE, then follow the instructions to receive free samples.

YES it is a 16-pin DIP IC! To place the order simply type the part number specified, click on the Order Sample button and follow the steps required to finalize the order. At any one time you can only order a maximum of four samples.

Note: the supply of free samples is at the discretion and terms of Freescale and not in any way governed by Elektor Electronics

projects are available to assist in your design efforts.
The Project Wizard (**Figure 5**) can be used to create a working project (Assembly or C) in as few as seven mouse clicks, and users can change target microcontrollers and the debug/Flash programming connection in an open project.

The IDE features an intuitive project manager and build system; a highly optimized compiler; a graphical, source-level debugger; integrated profiling capabilities; a full chip simulator and more.

The free 'Special Edition' of the CodeWarrior™ Development Studio for HC(S)08 and RS08 devices can be downloaded from the Freescale web site. It's just not possible to print the exact url here as the file is behind an extensive login procedure. At the time of writing, the download is shown as a 'Featured Tool' on the Freescale 8-bit microcontrollers page [2]. It should be noted that the download is fairly large at about 283 Mbytes. Fortunately, the Special Edition is included on the CD-ROM you get with the Softec SpYder Discovery kit.

Lots more information on CodeWarrior for various Freescale microcontroller families and platforms may be found on [3], including special releases for professional users.
For a number of our readers invariably suspicious about special offers we print that CodeWarrior Special Edition allows projects of up to 64 k to be developed using assembler, and 16 k in C.
An in-depth introduction to CodeWarrior can be found in application note AN2616 [4].

In-circuit debugging can be achieved within the CodeWarrior IDE when your PC is connected to the target application with a BDM cable such as the SpYder.

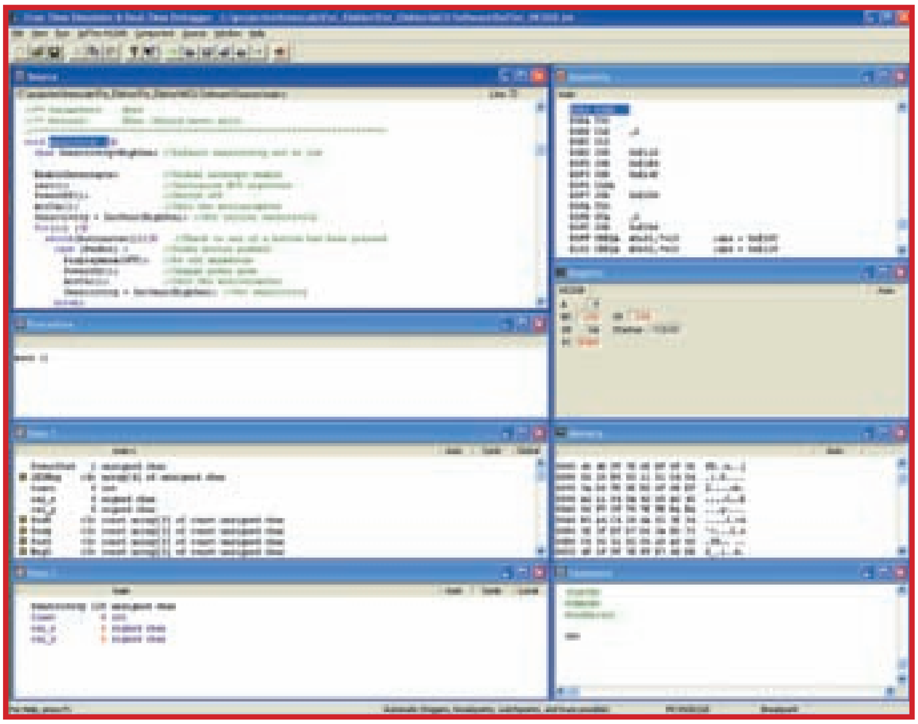


Figure 5. CodeWarrior's Project Wizard in action. Full debugging on a running program can be seen here.

Next month

In a follow-up article we'll discuss setting up SpYder and CodeWarrior for the benefit of our first project, a 2*g*, 2-axis accelerometer with LED readout, based on an MC9S08QG8CPBE microcontroller. The project will be built on two small PCBs which will come with a free gift.

(060296-I)

SpYder Discovery kit

Thanks to a special arrangement with Freescale Semiconductor, the Spyder Discovery kit is a available from Elektor at a price of just £ 6.45 (Euro 9.75 / US$ 12.70) plus postage & packing. SpYder allows you to program and debug code for MC9S08 micros, in conjunction with CodeWarrior Development Studio for RS08/HC08 devices (free download or on enclosed CD-ROM).

It should be noted that the photograph shows an early version of the Softec kit supplied to beta testers. The final version supplied to Elektor customers comes with an 8-pin PDIP MC9S08QG8 sample, and the SpYder plug-in board encapsulated in a plastic housing.

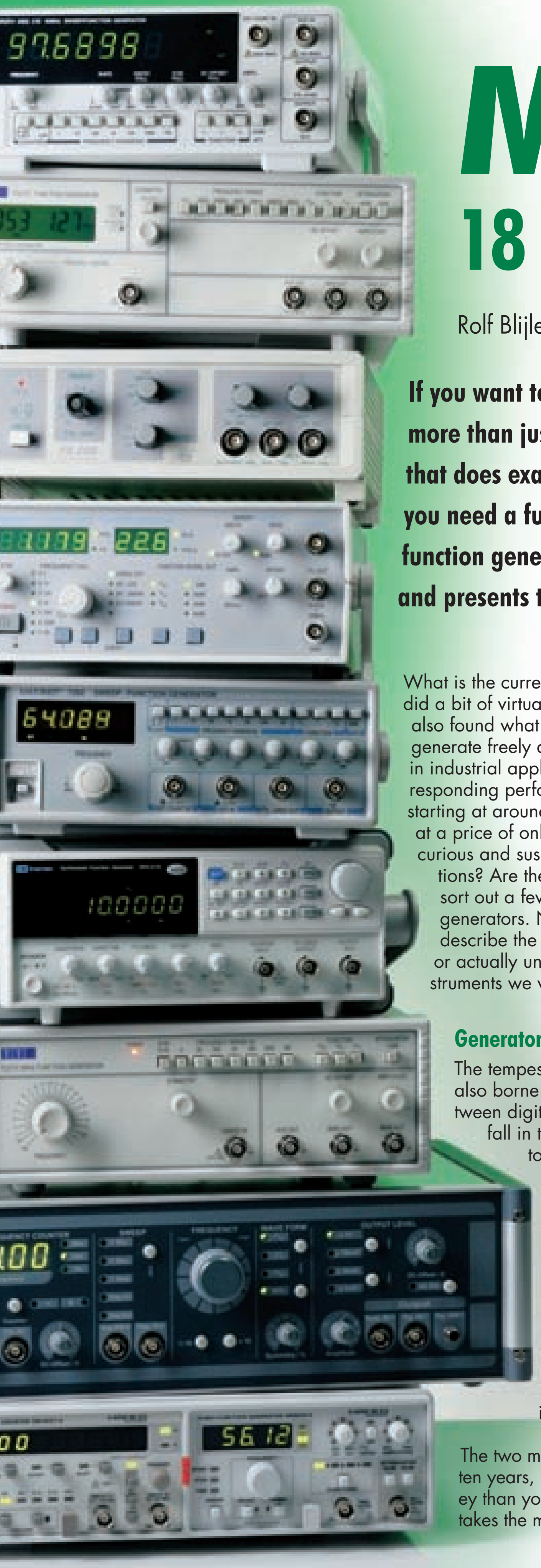
Web links

[1] www.freescale.net/forums and http://forums.freescale.com/freescale/board?board.id=8BITCOMM

[2] www.freescale.com/webapp/sps/site/homepage.jsp?nodeId=0162468449&tid=FSH

[3] www.freescale.com/webapp/sps/site/overview.jsp?nodeId=01272694011860

[4] www.freescale.com/files/microcontrollers/doc/app_note/AN2616.pdf



Making W

18 function generators on

Rolf Blijleven

If you want to know exactly what's happening in a circuit, you need more than just a multimeter and an oscilloscope. A signal generator that does exactly what you want is as least as important. That means you need a function generator. This article describes the technology of function generators, summarises what they must be able to do and why, and presents the results of a critical examination of 18 different models.

What is the current state of the art in signal generators? To answer this question, we first did a bit of virtual shopping on the Internet. Besides 'traditional' function generators, we also found what are called 'arbitrary waveform generators (AWGs), which can be used to generate freely defined waveforms. The latter type of signal generator is frequently used in industrial applications, and it often has a price in the four- or five-figure range, with corresponding performance (see **Figure 1** for an example). Benchtop models are available starting at around £ 65, or you can use the soundcard in your PC to generate waveforms at a price of only £ 20 or less — or even for free. Such a wide range of prices makes you curious and suspicious at the same time: what can you actually do with the cheap solutions? Are the expensive ones perhaps too expensive? In this introduction, we try to sort out a few of these questions. The first thing we look at is the technology of function generators. Next we discuss the basic functions and the more advanced functions. We describe the indispensable features and features that are convenient, not so convenient, or actually unnecessary. Finally, we present the results of our examination of the 18 instruments we were able to obtain for review.

Generator electronics

The tempestuous developments in the semiconductor industry in recent decades have also borne fruit for designers of signal generators. If we make a first distinction between digital and analogue types, we see that the relatively inexpensive instruments fall in the analogue category. This is because nearly complete function generators are available commercially in the form of ICs. Some examples are the Maxim MAX038 and the Exar XR2206. This type of IC is built around a voltage-controlled oscillator (VCO). This is usually a relaxation oscillator (**Figure 2a**) with the feedback resistor R replaced by a controlled current source that charges the capacitor at an adjustable rate in order to set the frequency (**Figure 2b**). The oscillator produces triangular and square waveforms, and the triangle wave is tapped off to a stage that converts it into a sine wave. These three waveforms can be selected at the output.. The distortion and symmetry of the waveform can be adjusted using a potentiometer connected to two pins of the IC, and there is also a TTL sync output. With only a few external components, you can easily achieve a frequency range of 0.2 Hz to 2 MHz. And as we already mentioned, it's inexpensive – the XR2206 sells for less than £ 3 in small quantities.

The two most important techniques in the digital area have scarcely changed in the last ten years, but they have become less expensive. You get more waveform for your money than you did ten years ago. The 'arbitrary waveform generator' (AWG) technique takes the most direct approach. It's actually just a digital storage scope in reverse. **Fig-**

aves
the test bench

Figure 1. The Agilent N5182MXG, a professional signal generator with maximum frequency of 6 GHz.

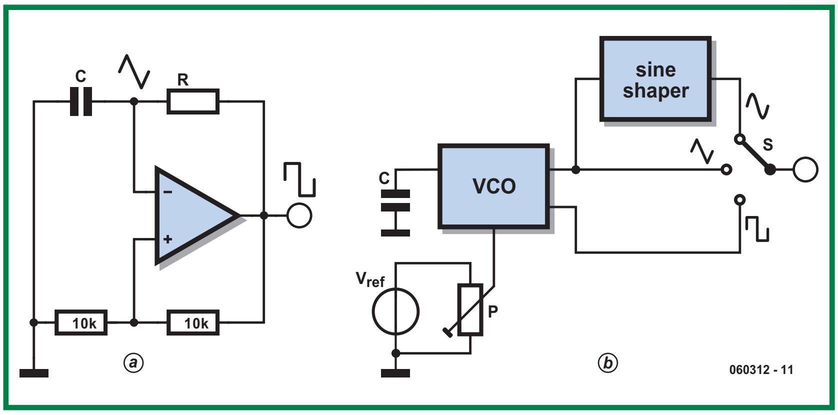


Figure 2. Basic circuits of analogue signal generator ICs.
2a: The simplest circuit consists of an oscillator formed by an opamp, a few resistors, and a capacitor.
2b: The oscillator circuit is used as a voltage-controlled oscillator (VCO) in function generator ICs. The triangle wave is shaped into a sine wave in a separate stage. This yields a choice of three waveforms.

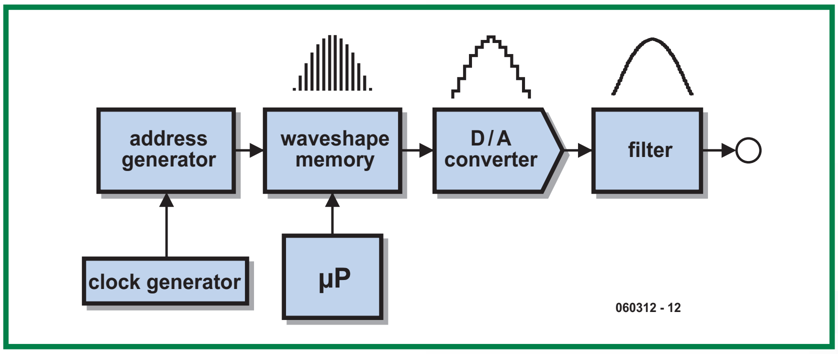


Figure 3. Block diagram of an arbitrary waveform generator, which is actually a digital storage scope in reverse.

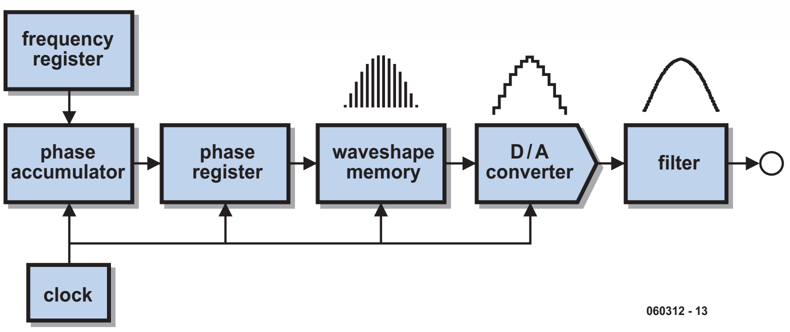


Figure 4. Block diagram of a direct digital synthesis system.

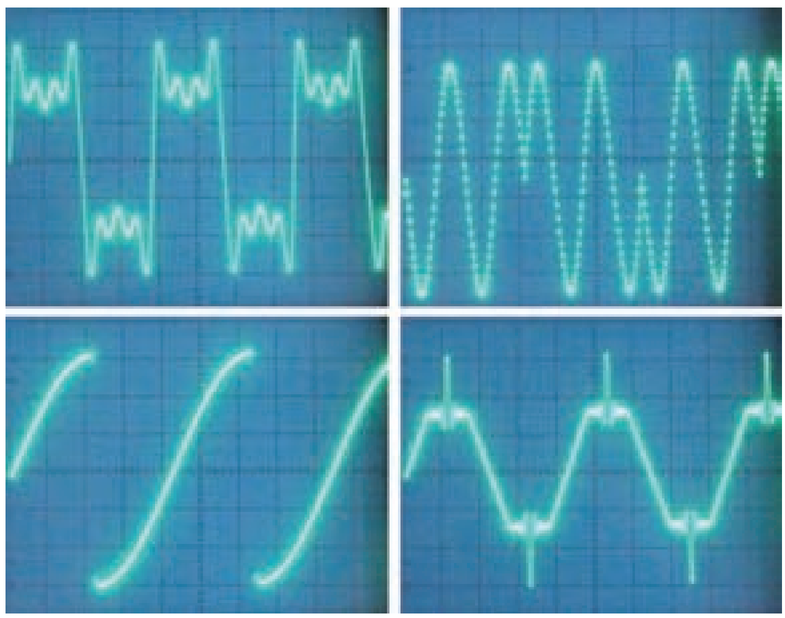


Figure 5. Some arbitrary waveforms produced by the M&R Systems WG-810. See the description of this instrument for details.

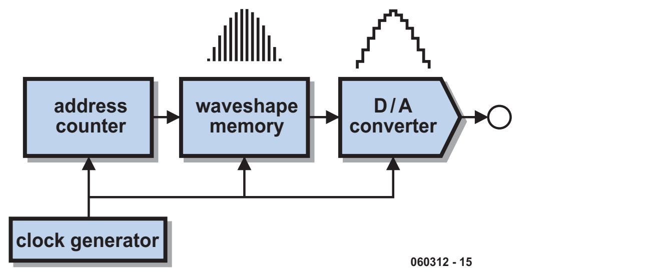


Figure 6. Block diagram of a simple function generator. The variable clock generator block can be based on DDS.

ure 3 shows a typical block diagram. The waveform is stored in a memory that serves as a look-up table. A clock drives an address generator that reads out memory locations. The contents of the memory locations are fed to a D/A converter. Its output signal is smoothed by a filter to eliminate harmonics. The memory can be a ROM for fixed waveforms, but RAM can also be used for freely definable waveforms. In the latter case, there is always a microprocessor or microcontroller in the picture to control the whole works. The number of bits per memory location determines the vertical resolution of the waveform. With 14 bits, each step of the waveform can assume 16,384 (2^{14}) different values. The number of memory locations determines the horizontal resolution of the waveform. Some instruments have clever control logic that allows segments of a waveform to be repeated arbitrarily. A variable clock frequency or sampling rate is essential with this arrangement, since the clock has to run faster at higher frequencies. For very low frequencies, it is fairly common practice to 'freeze' each location for several clock pulses.

The other digital technique is called 'direct digital synthesis' (DDS) (**Figure 4**). If you follow the signal path upstream from the output, the first things you see are the same as in an AWG: a filter, a DAC, and a waveform memory – but it's different when you get to the source. The heart of this system is the phase accumulator. It has two input signals: a clock and a number from a programmable frequency register. It uses them to define a phase angle, which is the step size for stepping through the look-up table. For low frequencies, the number in the phase register is small, so every location (or nearly every location) of the table is accessed. The step size increases with the frequency, so the number of intermediate entries that are skipped on each step increases with the frequency. In theory, the maximum output frequency is one-half of the clock frequency, but at this point all that's left of the waveform is the samples that define the fundamental frequency. The practical limit is thus lower. Depending on the application and the filter than is used, a frequency equal to 40% of the clock frequency can still be achieved.

Phase noise is an inherent aspect of DDS. The problem is that the period of the desired output signal cannot always be an integer multiple of the step size. If you try to fix this by truncation (ignoring the 'extra' portion and starting again at the beginning), you obtain a frequency error: the period is shorter, so the frequency is higher. This isn't what you want in a function generator. Another option is carrying the count, which means skipping a number of samples at the beginning of the table corresponding to the number left over at the end of the table.
Although these issues must be taken into consideration in the design, the DDS approach has considerable advantages. First, frequency changes are very easy to implement with DDS – much easier than with an AWG. Sweeping is simply a matter of gradually increasing the frequency. Large steps and abrupt steps are dead easy (a few examples are shown in **Figure 5**). Second, as

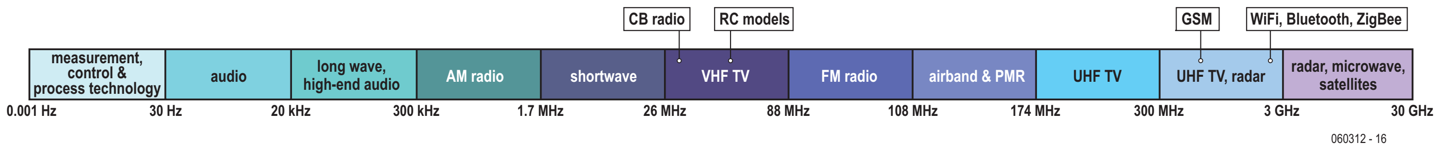


Figure 7. Overview of frequency ranges and related applications.

we already said, you get more waveform for your money nowadays, since everything (including the DAC) fits into a single IC. The smallest member of the Analog Devices AD9800 family is the AD9833. It can handle clock rates up to 25 MHz, is housed in a 10-pin µSOIC package, draws a scanty 30 milliwatts, and costs less than a tenner. Not so long ago, the average electronics enthusiast would have thought you were a bit crazy if you quoted specs like this. There is an abundance of potential applications for DDS ICs, such as the short-wave receiver featured in our December 2006 issue.

It's thus hardly surprising that manufacturers can produce acceptable, inexpensive function generators that use a mixed form of the techniques described above, such as shown in **Figure 6**. Here a DDS-based clock generator drives a binary counter that reads out a fixed table from ROM. Just add a DAC and you're ready to go. Innumerable variants are conceivable. Maybe this would be a good topic for our next design contest?

Basic features

What are the essential features? Every function generator worthy of the name can produce sinusoidal, triangular, and square waveforms. For the sake of completeness, a sine wave is the purest tone possible. In musical terms, it is a fundamental tone without any harmonics. This makes it the ideal waveform for making measurements on filters and determining bandwidths. A triangular waveform is a quick diagnostic aid thanks to its shape. Dips, dropouts, clipping and other forms of distortion are easy to see with a triangular waveform. It's thus a good tool for *detecting* distortion, but *measuring* distortion is a much more complex discipline (see **inset**). A square wave completes the trio. It simply switches quickly back and forth between two DC levels. This makes it suitable for use as a clock for digital circuits, but it is also indispensable for judging the stability of an amplifier stage. An amplifier stage that exhibits overshoot on a square-wave signal has a tendency to oscillate, and that is undesirable. One of the key quality criteria for square waves is the edge steepness: the steeper the better.

Adjustable duty cycle (the duty cycle is how long the signal is high during one period relative to how long it is low) is also handy for all sorts of digital applications.. Many generators incorporate this feature in the form of a **symmetry adjustment**, which you can use to distort the triangle wave into a sawtooth and (in many cases) to make the sine wave 'lopsided'. A variable **DC offset** rounds out the package of basic features.

Extras

In many cases, you need to be able to sweep the frequency between two set frequencies (from low to high or the other way round). Some generators have a built-in sweep function, but many of them have a **VCF input** ('VCF stands for 'voltage-controlled frequency'). The voltage applied to this input determines the frequency. This makes it possible to generate FM and FSK signals. **Precise frequency adjustment** is in theory possible using the VCF input, and otherwise the controls must be suitable for this purpose. In the past, a large-diameter knob was often used for setting the frequency, and this was certainly not without reason. For example, suppose you want to adjust the frequency to exactly 440.0 Hz in a range that extends from 200 Hz to 2 kHz, and further suppose that the adjusting knob has a rotation range of 330 degrees. This means that 1 degree of rotation corresponds to 5 Hz, so your chances of getting it right with a fiddly little knob are just about zero. The **width of the frequency range** is thus also significant. The total frequency range of the instrument is usually divided into several overlapping ranges that can be selected using a switch. A factor of 10 is commonly used for the for each range. For example, in the 100-kHz position you might be able to adjust the frequency from 20 kHz to 200 kHz. However, factors of 100 or 200 are also used. In the latter case, the range in the 10-kHz position could extend from 500 Hz to 100 kHz. The advantage if this is that you can make very broad sweeps, but the disadvantage is that it's difficult or impossible to adjust the output to a specific frequency.

Before you decide on the **total frequency range** of a generator, you have to think about how you want to use it. **Figure 7** presents an overview of the frequency ranges and typical applications in the various ranges. In this article, we describe instruments with ranges extending up to 2 MHz, with a few exceptions than reach to 10 or 20 MHz. Some of them show the frequency on a **display**, and some of the instruments with this feature also allow the frequency counter to be used with external signals.

A few generators also show the **signal amplitude** on the display. Many generators produce a rather hefty signal amplitude. A level of 10 V_{pp} is not uncommon, but this is usually far too much. It must also be possible to reduce the amplitude of the output signal to the millivolt level. A built-in attenuator is convenient for this purpose, with settings such as –20 dB, –40 dB and –60 dB, along with a fine adjustment control.

Now that we've described the technical background and features, it's time to look at the 18 individual instruments.

Golden Oldie

Countless function generator designs have been created using the Exar XR2206 IC. It also forms the basis for several especially popular instruments designed in the Elektor Electronics lab. The first design dates from December 1977, and it was exceptionally popular. We sold more than 10,000 PCBs for this circuit. Several more designs appeared in the following years. A highly improved design appeared in the 1980s as part of our test equipment series, and we still have two working examples of this version in our lab. One of them is shown in the photo. All of the components for this circuit are still available (at least in principle), so you can still build your own copy of this excellent function generator. If you visit our website, you can download a scanned copy of the article from the December 1984 issue at no charge (look under the '18 Function Generators on the Test Bench' article in the March 2007 issue).

H-Tronic FG-200

This is one of the least expensive signal generators in the test. Built around a 2206, this instrument generates sine, triangle and square waves in six selectable ranges extending from 1 Hz to 100 kHz, continuously adjustable from 0.2 to 2.4 times the selected decade value. The frequency range thus extends from 0.2 Hz to 240 kHz. There is only one knob to set the output level, so the adjustment is rather coarse. There are two AC outputs with overlapping ranges extending from 10 mVpp to 12 Vpp, and a DC output with a range of 100 mVpp to 10 Vpp. The DC offset is continuously adjustable from –5 V to +4 V.

All of these measurements correspond exactly to the specs in the user's guide, which only amounts to two pages. The operating instructions are essentially nothing more than 'read what's next the knobs and everything will be obvious'. The distortion spec is 1%. At the upper end of the frequency range, the sine wave is dented and the triangle wave looks like a tent with a strong side wind. Nevertheless, the FG-200 is distinctly better than the only less expensive option (soundcard function generators). If you can manage without luxury, this instrument offers outstanding value for money.

Goodwill Instek GFG-8015G

It looks like something from the former East Bloc with its dark-grey case, sloping edges and hooded panel, but it comes from Taiwan. The user's guide includes not only extensive specifications and an explanation of what the knobs do, but also a detailed description of the schematic.

This is an analogue signal generator with all the standard features. The controls are laid out nicely and show evidence of careful consideration: you can disable the offset instead of just adjusting it to zero, a two-position attenuator with steps of 20 dB enables minimum output levels below 10 mVpp, there is an inversion switch, and there is a VCF input that can be used with an external sweep signal.

A small drawback is that the frequency adjustment is rather coarse, but otherwise this is a very reasonable signal generator at a highly competitive price.

ELV SFG-7002 M

The German user's guide is very extensive and includes all the schematics. That's because this instrument is designed as a kit, and it is also available as such (with a less expensive case) starting at about £ 90. Our test model was the most expensive (£ 138), ready-made version in a metal case. Our first impression was that it has to be located at eye level, since otherwise it's difficult to see what you're doing. It doesn't have any sort of tilt stand. It doesn't have a display, but it does have internal sweep capability in addition to the standard set of functions, as well as symmetry and offset controls. The range switch has four positions that don't do anything, but there aren't any markings on the panel for these positions, so it's probably supposed to be that way. The symmetry knob doesn't affect the sine wave, and the triangle wave turns into a DC voltage when you turn it fully to the right. Nevertheless, this is still a good choice for hobbyists in particular, since it offers a lot of capability at a low price. It is built around the MAX038, which has been discontinued, so don't wait too long.

Voltcraft 7202

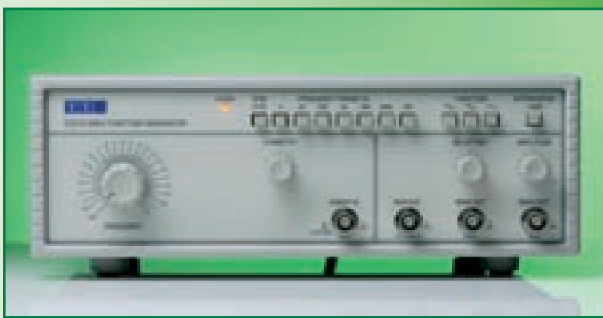
This signal generator makes a rather nice visual impression with its many pushbuttons and knobs, which can be used to set or adjust just about everything imaginable – especially if you look at the price at the same time: £ 152 ex VAT. A five-digit frequency counter provides direct readout of the frequency setting. We needed the spare fuse provided with this Voltcraft 7202, since it didn't do anything at first after we unpacked it (but it worked perfectly afterwards). The price is very competitive considering its extensive set of features (see the table), but on closer examination its specifications are rather weak compared with its closest neighbours in this price class. The square wave looks more like a sine wave in the upper portion of the frequency range, the adjustment is very coarse with a factor of 200 between the minimum and maximum frequencies, and the lowest output amplitude is 125 mVpp, which is rather high. It's made in Korea, presumably in the same factory as the FG8220, the Dynatek DSG 310 and the Voltcraft MXG-9802A. Although this is the best of the four in terms of ease of use, it unfortunately falls a bit short.

Thurlby Thandar Instruments TG210

This is one of the lower-priced signal generators in the TTI product line. Compared with its more expensive brother, the TG513, it has a maximum frequency of 2 MHz instead of 3 MHz, no display, and only a 20-dB attenuator, but it does have a symmetry control, a DC offset control with a zero detent, a sweep input, an Aux output, and signal outputs with two different impedances (600 ohms and 50 ohms). The minimum output level is 20 mVpp with the 20-dB attenuator selected, and it has a small dead zone when the knob is turned all the way to the left, but the knobs are still large enough for decently precise adjustment.

A special feature in comparison with the other instruments is that it can also generate very low frequencies – much lower than specified (we measured approximately 5 milliherz).

For the rest, it's a solid instrument that is pleasant to use and does what it promises plus bit more. In a word, good.



Digimess FG200

It's a bit strange that although the FG200 is less expensive than the Digimess FG100 and has a slightly smaller feature set, it has several nice extras compared with the instruments closest to it in its price class. It has built-in linear and logarithmic sweep functions and a frequency counter that can also be used with external signals. The frequency control is a ten-turn potentiometer, but unfortunately the suggestion of increased accuracy is not borne out in practice. Maybe the problem is with the frequency counter, but the two least significant digits of the four-digit frequency display were almost always flickering back and forth between two values. This was synchronised with the flashing of the Gate LED. The included user's guide is rather precursory. It doesn't say anything at all about the Gate LED, for instance, or about several other features. The instrument does have a lot of LEDs, but that's a matter of taste.

Although it's a reasonably versatile instrument at a reasonable price, it doesn't live up to the legend of German solidity suggested by its name.

Voltcraft MXG-9802A

This instrument is also available under the Metex brand name, and like the previously mentioned FG8220 and DSG 310, it comes from Korea. The four-language user's guide is limited to a brief description of the functions. The instrument has an RS232 port, but unfortunately there's no description anywhere of how to use it. As a function generator, it is reasonably complete with all the standard features and a built-in sweep function, which behaves the same way as the DWG 315 sweep (see the description there). It has a 4.5-turn potentiometer for setting the frequency, which is better than what its companions have to offer and makes quite precise adjustment possible. Unfortunately, the frequency counter is very coarse below 1 kHz and requires a lot of juggling with the gate and reset controls. The longest gate time gives the best accuracy, but then you have to wait around 20 seconds each time you change the frequency before you can read the new value. It has two counter inputs. The high-frequency input works up to 2.7 GHz, but it gets thoroughly confused if the input signal level drops below approximately 1 Vpp. Conclusion: it can do a lot, but it has quite a

M&R Systems WG-810

Modern styling with separate buttons for the basic functions and a menu button, selection knobs, and a rotary knob for navigating through the menus on the LCD screen. Everything is nicely arranged and functional. Besides the standard set of signals, it can generate a sawtooth, noise, and much more: this generator can produce genuine arbitrary waveforms. It has seven built-in extra waveforms, of which two can be morphed (stretched out of shape). One of them is a square wave where you can pull the corners down toward the baseline until it changes into a sine wave, and the other is a sine wave with adjustable phase cut. With 8-bit resolution and an upper frequency of 10 MHz (hence the name), it has relatively modest resolution and distortion (see table), but its real power is hidden behind the rear-panel RS232 connector. In combination with the separately available Spro program or a terminal emulator program available on the Mair & Roher website, you can use it to download your own waveforms.

A very versatile instrument at a competitive price: that's professional!

B+K Precision 4010A

This rather sizeable instrument was designed in the US, but it is made in Taiwan. It has a good front-panel layout. The scale of the frequency adjustment knob covers only half of its range of rotation, so there are 'dead zones' at each end. It has a sync output, which is a relatively rare feature, and it can be switched to CMOS mode. The output level can be adjusted between 4 V and 14 V in CMOS mode. The switching levels of CMOS are 1/3 and 2/3 of the supply voltage, so a lower limit of 4 V is too high if the supply voltage is 5 V or less – which is entirely possible with battery-powered circuits. Maybe it's handy for working with relay control logic, but in our opinion it is of limited use. The INV knob doesn't do anything, which is irritating. The 4010A falls short in comparison with other instruments in the same price class. The specifications are nothing special, the sine-wave distortion is quite high (4% at 1 kHz), and it takes up a lot of space on the bench.

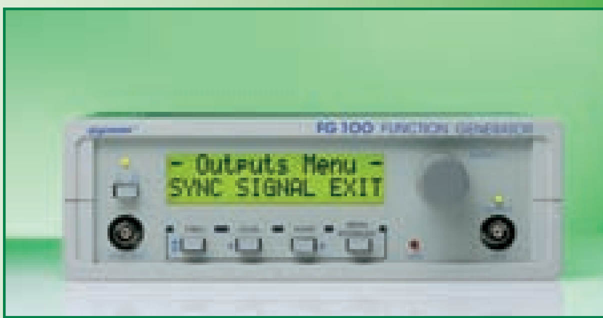
There are cheaper instruments available with better performance.

Thurlby Thandar Instruments TG315

The TG315 is a midrange analogue signal generator from the British firm Thurlby Thandar Instruments. It has a light-beige case and the standard set of waveforms (sine, triangle, and square), with a frequency range of 0.03 Hz to 3 MHz and an amplitude range of 20 mVpp to 20 Vpp. The frequency and amplitude or offset are shown on a numeric display. The frequency can be adjusted over seven ranges, and the fine adjustment knob is where it should be: right below the frequency display. If you push in the symmetry knob, the frequency is divided by 10 and you can use a rotary knob to skew the waveform to the right or the left. This transforms the triangle wave into a sawtooth or adjusts the duty cycle of the square wave. The display shows either the peak-to-peak or RMS value of the output signal (selectable), and it is reliable even at high frequencies. That saves you an extra voltmeter. The amplitude can be attenuated by 20, 40 or 60 dB, and there are separate 50-ohm and 600-ohm outputs. It's a bit of a pity that it requires an external sweep signal, but if you don't especially need sweep capability, this instrument is a good choice if you're looking for professional quality.

Digimess FG 100

The UK firm Vann Draper bought the Digimess product line of Grundig (Germany) in 2000. The FG 100 is also available under that brand name. It has fewer knobs and a smaller case than the Digimess FG 200, but it costs £60 more. For that money, you get a larger frequency range (up to 20 MHz) and an RS232 interface that can be used to control everything from a PC. Software that works with LabVIEW is available separately, but the extensive user's guide (in German and English) also includes a sample program in QBasic. The front-panel user interface is menu-driven and reasonably intuitive, and with a bit of help from the user's guide you can master it in no time. The instrument is DDS-based; the sweep line shows distinct steps. Besides the standard set of signals, it generates rising and falling sawtooth signals, and the duty cycle of the square wave is adjustable. Thanks to the menu-driven interface, it cannot be set outside the specified limits (as is often the case with analogue signal generators). This is a compact, complete instrument, and it can generate complex test sequences under software control.



Dynatek DSG 310

The look & feel of the case, display and knobs is the same as the FG8820, but then it comes from the same Korean factory. To summarise the differences: it costs £ 35 less, works up to 10 MHz, has a fine frequency adjustment, and has only one frequency counter input.

The DSG 310 also has its own peculiarities. It can only sweep from low to high, and the sweep width depends on the selected frequency range. For instance, the range of adjustment with the 10-kHz setting is approximately 500 Hz to 10 kHz, which is rather broad. If you set the generator to sweep mode, it starts at the set frequency and continues until the end of the selected range. In other words, with the frequency knob rotated fully left, it sweeps from 500 Hz to 105 kHz. Naturally, your scope will throw up its hands at some point.

The DG 310 is real do-it-all, but its character traits may not appeal to everybody.

ELV MFG 9001M

The MFG 9001 comes from the German firm ELV and is available with several different cases, either fully assembled or as a kit. The instrument we tested was housed in a solid metal case. The case is rather sizeable, but the broad front panel provides a lot of functions. It has all the standard functions and built-in sweep.

The lower and upper sweep limits can be set precisely, with a maximum width factor of 10. The built-in frequency counter can also be used with external frequencies, and it has a separate offset (a rare feature). It has a sweep output, and remarkably enough, it can output signals at amplitudes down to the low millivolt level.

It lacks a tilt stand, so it must be placed at eye level, and the positioning of the BNC connectors is somewhat cramped, but it is fairly easy to use – we didn't have to consult the user's guide (in German only).

The MFG 9001 has an outstanding price/quality ratio as a ready-made instrument, and it's a good deal better as a kit.

Seintek G5100

This compact instrument is DDS-based, and it has eight programs that you can configure and recall as desired. That's apparently how it is intended to be used: set it up once and then leave it alone. Its capabilities are otherwise rather standard (see table). The user interface is on the difficult side: the twelve buttons for the regular functions and another eight for navigating the menu are inconveniently close together. It also has a rotary knob with clicks, but confusingly enough, only every second click does anything. As a result, selecting and configuring parameters takes a lot of button pushing and knob turning, but absolutely everything can be configured. Too much flexibility can create a maze.

Unfortunately, the software provided with the instrument does not add any functionality. You can't run a sequence of programs, which is truly a missed opportunity – this instrument is ideally suited for use in long-term testing under PC control, which appears to be a more natural habitat for it than a lab bench.

Goodwill Instek SFG-2110

This synthesized function generator has all the standard functions and much more. It is DDS-based, so it the user interface is different from the usual analogue generators. You can set the frequency quickly and precisely by entering the value with a numeric keypad and pressing the appropriate units button. You can also select any digit of the display separately and increase or decrease the value by rotating a knob with a nice click action. It can also sweep, over a narrow or wide range and slowly or quickly. Another handy feature is that you can store up to ten configurations and recall them as desired. The built-in frequency counter can also be used for external signals up to an impressive 150 MHz. It's true that the counter doesn't work properly below 9 Hz, although the specified lower limit is 5 Hz, but that's a minor detail. In terms of functionality, and especially in terms of ease of use, the SFG-2100 stands head and shoulders above the other instruments in its price class. If you don't need an RS232 interface or frequencies above 10 MHz, but you do want to have a frequency counter, this is by far the best choice.

FG-8220

The brand name of this instrument is uncertain. The front-panel logo can mean just about anything, and the user's guide is mum on the subject, but after a bit of detective work we figured out that it is made by the Korean firm Dagatronics. It is at the top end of the price scale, has an upper frequency limit of around 20 MHz, and has reasonably specifications (see table). All the standard features are present, and it can sweep with adjustable with and speed. You can also use it to generate FM and FSK signals: the generator provides the carrier frequency, and you provide the modulation signal at the VCF input. The built-in frequency counter can also be used for external signals, and it has two inputs with separate frequency ranges.. It has a lot of bells and whistles, but we're not all that keen. The fan is noisy, the knobs are too close together, and the controls are rather coarse. The sweep profile is not a clean sawtooth, there is no amplitude display, and the frequency counter readout is instable and changes when you adjust the amplitude. This generator can do a lot, but there are lots of things you will have to get used to if you buy it..

Hameg HM8030-6

Hameg's HM8000 series consists of a power supply (£ 145) in a modular case with room for two user-selected modules. Our test example was configured with a HM8030-6 function generator and a HM8021-4 1.6-GHz frequency counter, but an LCR meter, a lab power supply, and a programmable multimeter are also available. The on/off switch is located on the mainframe, and the frames can be stacked up to 5 high. The user interface of the function generator is clear and self-explanatory. It can sweep downward with a max/min frequency ratio of up to 10, and the sweep period and limits can be set quickly and precisely. The duty cycle adjustment only affects the square wave, so you cannot use it to produce a sawtooth. There are two 20-dB attenuator buttons, and the output signal level is 5 mVpp with the total attenuation set to the maximum value of 40 dB.

The specifications are impeccable, and the modular design is attractive for anyone who needs at least two modules. Of course, quality and robustness rarely come cheap.

Metrix MTX 3240

This instrument at least wins the prize for the most unique styling. It has a rather high, shallow case with a front panel that leans backward slightly. It takes a bit of getting used to, but this shape makes the instrument easy to use and read. It has an especially large, clear display that shows everything at once: frequency, output voltage, offset voltage, and duty cycle. The user interface is limited to small number of buttons with clearly defined functions and a central rotary knob, which makes the instrument easy to use. The only thing that required a bit of puzzling was setting the sweep range. The frequency range is 5 MHz, which isn't especially large, but all the signals (including the square wave) look good right up to the maximum frequency. The duty cycle adjustment can be used skew the triangle and sine waves, as well as to adjust the symmetry of the square wave. There is a connector on the back for an optical RS232 link, but the cable for this is an optional accessory. However, LabVIEW drivers are included with the instrument. Unfortunately, the user's guide doesn't say whether any other parameters can be set or programmed via the PC.

Brand & Model	rrp £ (€) ex VAT	f_{min} [Hz]	f_{max} [MHz]	rise time [1] sq. wave	distortion sinewave to 100 kHz [2]	Asymm.[3]	sweep	VCF in
H-Tronic FG-200	76 (110)	0.2	0.240	n.s.	< 1%	✗	✗	✗
Goodwill Instek GFG-8015G	117 (170)	0.2	2	< 100 ns	< 1%	✓	✗	✓
ELV SFG 7002	138 (200)	0.1	10	< 12 ns	< 1%	✓	lin	✗
Voltcraft 7202	152 (220)	0.2	2	< 140 ns	< 1%	✓	lin	✓
TTi TG210	166 (240)	0.02	2	< 100 ns	< 0.5%	✓	✗	✓
Digimess FG200	176 (255)	0.2	2	< 100 ns	< 2%	✓	lin, log	✓
Voltcraft MXG-9802A	183 (265)	2	2	< 150 ns	< 1% @ 1 kHz	✓	lin, log	✓
M&R Systems WG-810	197 (285)	1	2	< 50 ns	< 2%	✓	lin, log	✓
B+K Precision 4010A	207 (300)	0.2	2	< 120 ns	4% @ 1 kHz	✓	✗	✓
TTi TG315	207 (300)	0.03	3	< 100 ns	< 0.5% in audio range	✓	✗	✓
Digimess FG100	266 (385)	0.5	20	< 15 ns	< 1% in audio range	✗	lin	✗
Dynatek DSG 310	266 (385)	0.1	10	< 35 ns	< 1%	✓	lin	✗
ELV MFG9001M	266 (385)	0.1	20	< 12 ns	0.75%	✓	lin	✓
Seintek G5100	300 (435)	1	156	< 35 ns	< 1.5%	✓	lin	✓
Goodwill Instek SFG-2110	310 (450)	0.1	10	< 120 ns	< -55 dBc to 200 kHz	✓	lin, log	✓
Uni FG8220	341 (495)	0.2	20	< 25 ns	< 1.5%	✓	lin	✓
Hameg MH8030-6	355 (515) [4]	0.05	10	15 ns typ.	< 0.5%	pulse	lin	✗
Metrix MTX-3240	393 (570)	0.1	5.1	< 40 ns	<0.5% to 50 kHz	✓	lin, log	✓

Legend

✓ = present ✗ = not present n.s. = not specified

[1] steepness of square wave

[2] unless otherwise indicated

[3] asymmetry control (duty cycle), pulse = for rectangular signal only

[4] £145 (€210) for mainframe + £210 (€305) for generator

[5] frequency counter input for external signals

[6] pushbutton control for adjustable attenuation of output signal

[7] Output at logic level synchronous with signal. T=TTL, C=CMOS, Cv=CMOS, variable

[8] Displayed value for frequency (f) and amplitude (A) in volts peak to peak (pp) and/or volts effective (rms)

[9] Manual supplied in language: English, German, French, Dutch, Spanish, Italian

[10] B-c = BNC-croc clip cable; B-B = BNC-BNC cable; RS-232 = serial cable; s/w = software

Brand & Model	f-cnt in [5]	DC offset [V]	$Vout_{min}$ [mVtt]	attenuation [dB] [6]	sync out [7]	display [8] f	display [8] A	manual [9]	accessories [10]
H-Tronic FG-200	✗	– 4 ... + 5	10	✗	✗	✗	✗	E	✗
Goodwill Instek GFG-8015G	✗	± 10	n.s.	– 20, – 40	T/Cv	✗	✗	E	B-c
ELV SFG 7002	✗	± 7	n.s.	– 20, – 40	T	✗	✗	G	✗
Voltcraft 7202	✓	± 10	125	– 20	T/Cv	✓	✗	E	B-c
TTi TG210	✗	± 10	20	– 20	T/C	✗	✗	E	B-c
Digimess FG200	✓	± 5	1	– 20, – 40, – 60	T	✓	pp	E, G	B-B
Voltcraft MXG-9802A	✓	± 10	1	– 20	T	✓	✗	E, D, F, D	B-B
M&R Systems WG-810	✓	± 7	5	– 20	T	✓	pp	E, G	mainsadapter
B+K Precision 4010A	✗	± 10	n.s.	– 20	T/Cv	✗	✗	E	B-c
TTi TG315	✗	± 10	2	– 20, – 40, – 60	T/C	✓	pp, rms	E	E
Digimess FG100	✗	± 2,5	10	n.a.	T	✓	pp	E, G	B-B, B-c
Dynatek DSG 310	✓	n.s.	n.s.	– 20	T	✓	✗	E	B-c
ELV MFG9001M	✓	± 5	1	– 20, – 40, – 60	T	✓	✗	D	✗
Seintek G5100	✗	± 7,5	5	– 20	T	✓	pp	E	B-B, RS-232, sw
Goodwill Instek SFG-2110	✓	± 10	24	– 20	T/Cv	✓	✗	E	2 x B-c
Uni FG8220	✓	± 5	n.s.	– 20	T/C	✓	✗	E	B-c
Hameg MH8030-6	✓	± 5	5	– 20, – 40	T	✓	✗	E, G, F, Sp	✗
Metrix MTX-3240	✓	± 10	1	✗	T/Cv	✓	pp	E, G, F, Sp, I	✗

Velleman
USB Function Generator

Velleman did not have any current-model function generators available in its test equipment line at the time of this review, but they indicated that an interesting new instrument would be available soon.

It is a function generator with a USB port that is operated via the PC.

Sample features:
- Frequency range: 0.01 Hz to 2 MHz
- Generator and PC optically isolated
- Low sine-wave distortion (<0.08%)
- DDS generator with an 8192-sample wave table; arbitrary waveforms can be composed on the PC
- Maximum sampling rate 50 MHz

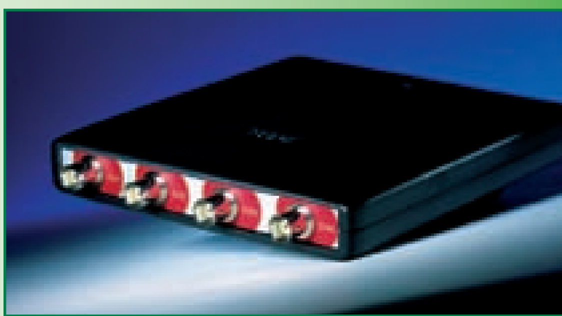
Conclusion

Regardless of whether you want to run a test signal through an amplifier stage every now and then or you spend several hours every day with your signal generator, you usually want to configure the desired signal quickly and then carry on with your work. And even if the specifications of all the instruments are readily available to everyone via the Internet, with the result that you can easily succumb to the temptation to buy based on specifications

Using a PC as a function generator

Do you like to bask in the glow of your PC monitor? You're not alone. With a bit of software, you can also use your soundcard to generate test signals. If you want more than this, you can consider acquiring a USB scope, since some models have a built-in function generator. We'll come back to this shortly, but first let's have a look at what we found: freeware. You can't get frequencies above around 20 kHz from a soundcard, but the nice thing is that you can use the signals directly and you can hear what you're doing via the speakers.
We found a handy little window at www.marchandelec.com, with two channels that can be set individually to output a sine wave, triangle wave, square wave, sawtooth, pulse, white noise, or pink noise. There are just three sliders: Frequency, dB Left, and dB Right. We had a look at the output with a scope. The sine wave maintains its shape nicely up to around 18 kHz, but the other waveforms show all sorts of dents and bumps even at low frequencies (which is something the maker warns about). A particularly handy feature of this program is that the frequency and amplitude are both continuously adjustable, so you can sweep them manually.

Another program that is quite popular, although it isn't freeware, is the Soundcard Function Generator from Virtin (www.virtins.com). The demo version works for seven days, after which you can purchase a licence for $25. Here again you have two channels and the standard set of signals, including two colours of noise. The frequency, amplitude, sweep time, and sweep start and end frequencies are all adjustable. Just set it up and go. It also comes with a simple scope program, but you can't make any adjustments while it's running, although you can play with the display parameters afterwards. However, we quickly decided to use our own scope instead. The sine wave looks reasonably clean, but the amplitude starts to drop significantly above around 10 kHz. The program comes with a library of freely loadable waveforms, such as a realistic EKG pattern and a much nicer square wave than the built-in version. The file format is suitable for DIY modifications: 1024 lines containing a sample number and two Y-coordinate values. All in all, it's actually fairly versatile. If you don't have any objection to a limited frequency range, this is a nice option that costs next to nothing.



On the other hand, if your ambitions are quite a bit higher and you are also interested in acquiring some other test equipment, you should certainly consider a USB scope. We ran a comparative article on USB scopes in our September 2005 issue, but we mention them here because some models have a built-in function generator. The HandyScope HS4 from TiePie Engineering in the Netherlands (www.tiepie.nl) is a good example. It is much more than just a signal generator, since the package also includes a multimeter, oscilloscope (naturally!), transient recorder, and a spectrum analyzer. Measuring distortion according to good engineering practice, as described elsewhere in this article, is thus within the realm of possibility.

The USB scope test article can be downloaded from www.elektor-electronics.co.uk.
Go to the September 2005 contents page.

Measuring distortion

It's surrounded by hype in the audio world, and in the telecommunications world it can make the difference between intelligible conversation and rubbish on the line. Total harmonic distortion (THD) is the complex of distortions experienced by a signal on its way from the input to the output of an amplifier or amplifier stage. You can quantify it by measuring the input waveform and subtracting it from the output waveform. The difference is by definition the THD. This sounds simple, but it's far from easy. You can't do the subtraction honestly unless your measuring set-up can cancel out the effects of the gain and phase shift of the stage being measured. The compensation necessary to achieve this harbours a wealth of measurement error sources, and it is a difficult and above all time-consuming task to get them under control and keep them under control.

Another technique is to employ a sinusoidal waveform as the test signal and use a notch filter to remove its frequency component from the output signal. What's left is THD. Although this approach appears to be very elegant, there are lots of associated pitfalls and gotchas. For instance, the test signal must be a very pure sine wave. The average audiophile turns up his nose at anything more than 0.01% THD, so the test signal must have less than 0.05% distortion. You only find this in the more expensive class of generators.

The modern technique uses a spectrum analyzer: you measure the spectrum of the test signal and run it through a Fourier analysis. Here again, the input signal must have as little distortion as possible, since otherwise the distortion will appear again in the components of the analyzed output signal.

alone, the 'ease of use' parameter is not something you can capture on a datasheet. Nevertheless, it is one of the most important factors – just as with every tool. That's why we focussed so much attention on it in assessing the 18 instruments in this test. How can you judge ease of use? To start with, the layout of the front panel must be logical, and everything must be easily accessible. This may sound obvious, but there are still instruments available where you can accidentally press two buttons instead of one, or with the knobs so close together that you sometimes nudge another one while adjusting the one you want. Next, suppose you have the instrument ready to hand, warmed up and all: how long does it take you to get a 440.0-Hz sine wave at the output? This may sound like a simple test, but the frequency adjustment of some instruments is so coarse that that you'll never get there. With some instruments, it's a matter of seconds, while with others it takes several minutes. The record here is held by the Seintek G5100, which takes an especially long time to configure. However, you can recall the setting in less than 10 seconds once you manage to get it programmed.

We also looked at functionality and quality relative to the price, and at innovative features. The situation here can be described as the history of the electronics industry in the last three decades. The major players have survived by focussing entirely on professional users. They offer outstanding equipment, but with prices that are only suitable for the budgets of captains of industry. We left them out of consideration here. European companies such as Thurlby Thandar Instruments and Metrix pursue the same strategy, but they still offer limited but reasonable functionality at the bottom end of their product lines, with outstanding specifications at an affordable price. Other manufacturers, such as Digimess and ELV, offer more extensive options with acceptable specs, but they keep costs down by outsourcing production to the Far East. This sort of production has a history of more than 30 years in Taiwan. Based on this experience, Goodwill Instek takes a clever approach to filling market niches. As far as we're concerned, its GFG-81015G is a good choice as a basic instrument, with good specs and a very competitive price. The Koreans do not have this long experience yet, but they have an unbridled zest for work. Five of the eighteen instruments in the test come from Dagatronics in Seoul. Four of them are built around the same basic design, and they unquestionably offer a lot of functionality for a low price. They appear to be aimed at beginners, since all four have a user's guide with the same extensive section describing sample uses, and that is certainly very friendly. However, they are pervaded by an air of hasty work: the specs are mediocre and the user interface is not well thought out – you get knobs to adjust things that shouldn't be adjustable. They are also clearly oriented toward mass production: anyone can place an order today for a thousand generators with his own name on them and a few knobs more or less than the standard configuration, and your order will be delivered by aeroplane tomorrow.

We leave the choice of the best instrument up to our readers, since it is ultimately a question of what you want to do with it and how much you're willing to spend. We can conclude with two honourable mentions: the Digimess FG100 and the WG-810 from M&R Systems. They are similar in terms of ease of use: clear and well thought out. The FG100 has slightly better specs, and it can perform quite complex tests under PC control, but what clearly distinguishes the WG-810 from the rest is support for user-defined waveforms, and that at an affordable price. M&R Systems deserves to be better known.

(060132-1)

Manufacturer	Type	Manufacturer web address
B+K Precision	4010A	www.bkprecision.com
Digimess	FG100/FG200	www.digimessinstruments.co.uk
Dynatek	DSG 310	
ELV	SFG 7002/MFG 9001M	www.elv.de
Goodwill Instek	GFG-8015G/SFG-2110	www.goodwill.com.tw
Hameg	HM8001 + 8030	www.hameg.com
H-Tronic	FG-200	www.h-tronic.de
Metrix	MTX-3240	www.chauvin-arnoux.fr
M&R Systems	WG-810	www.mrsys.at
Seintek	G5100	www.seintek.com
Uni	FG 8220	www.seintek.co.kr
TTI	TG210/TG315	www.tti.co.uk
Voltcraft	7202/MXG-9802A	www.conrad.de

AVR drives USB

Design: Michael Odenwald en Michael Keller, Commitor GmbH

Is it possible to use a microcontroller from the pre-USB era to fashion a USB device without using additional ICs? The designers set themselves this question a while ago. Many long evenings later, the answer proved to be 'yes'. As a result, we can now present a USB I/O board based on a standard AVR microcontroller – without any special USB chips!

USB interfaces in embedded devices are commonplace nowadays. A variety of circuits with USB interfaces have already appeared in the pages of *Elektor Electronics*. Particularly with the availability of special-purpose chips from our Scottish friends at FTDI (and other manufacturers), it has become very easy to include a USB interface in a design.

If you are looking for a more tailored solution, you can also take advantage of several microcontrollers that come with built-in USB interfaces. However, this solution requires a rather good understanding of the USB bus. The firmware must process the data packets received from the USB bus and transmit its own packets via the bus. If the device is not a standard USB device, you also need a special device driver – and you will have to write it yourself.

100% soft

It's also possible to fit a USB interface in an FPGA, as we showed in our FPGA Course published as a series of instalments from April 2006 through February 2007. In that case, we put an 8051 microcontroller core with an additional USB interface in the FPGA. This was our first '100% software' USB device.
The device described in this article shows that a standard AVR microcontroller can also communicate via the USB bus with the aid of only three resistors (**Figure 1**). Besides processing the data packets, the microcontroller handles communication at the bit level. The firmware looks after this entirely on its own.

You may be thinking that the AVR has to run at high clock speed to manage all this, but that's not true at all. The microcontroller operates with a 12-MHz clock here, but its maximum rated clock speed is 16 MHz. It thus has room to spare.

USB specifications

The USB specifications [1] clearly indicate that the USB bus uses a serial data protocol. Data is transmitted on two bidirectional lines. These lines (D+ and D–) transmit the data in differential mode. This means that the signals on the D+ and D– lines are opposite to each other. An exception to this rule is made for synchronisation purposes: the signal levels on both lines are set low in that case.
Our device operates in the Low Speed mode, which means the data transmission rate is 1.5 Mbit/s. Communication at the bit level thus places some specific demands on the microcontroller. In physical terms, it must have at least two bidirectional ports. It must also be able to read and process the status of these ports very quickly in software in order to keep pace with the data rate.
There are also numerous other requirements, but for now the only thing you need to know is that each transaction is initiated by the host device (usually a PC). If the host wants to read data from the connected device, the device must respond by sending back the data. The data is transmitted in data packets, which must also comply with various requirements.

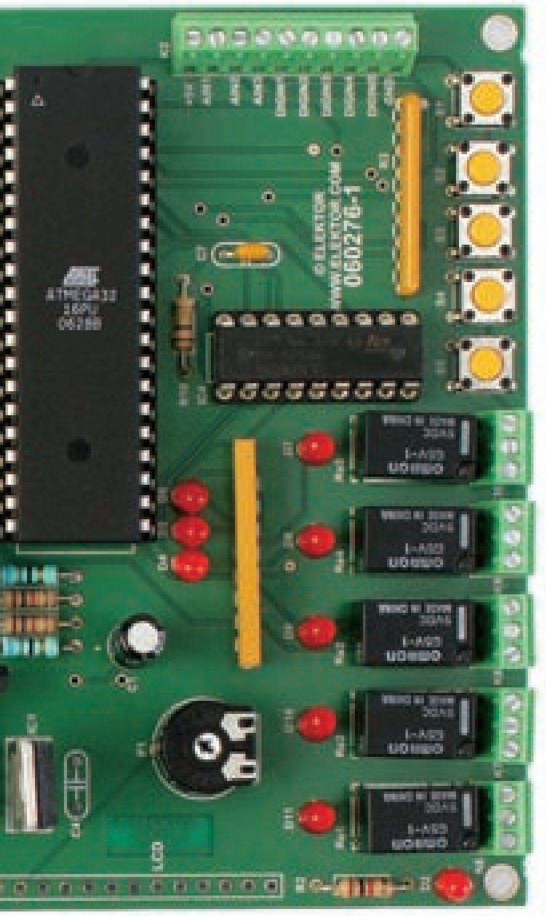
There are also several built-in mechanisms to ensure that the host can detect new USB devices and assign them addresses. This is all related to the 'plug-n-play' concept. The idea is to minimize the actions that users must perform in order to use USB devices.

Electronics

The electronic portion of this design is fairly standard (aside from the USB connector). The AVR microcontroller (IC3) forms the heart of the circuit (see Figure 1). Crystal X1 sets the clock rate to 12 MHz.

The circuit has three analogue inputs and five digital inputs, which are available on connector K2. These lines are routed directly to the I/O pins of the microcontroller, and they are fitted with 100-kΩ pull-down resistors. The resistors prevent the inputs from gen-

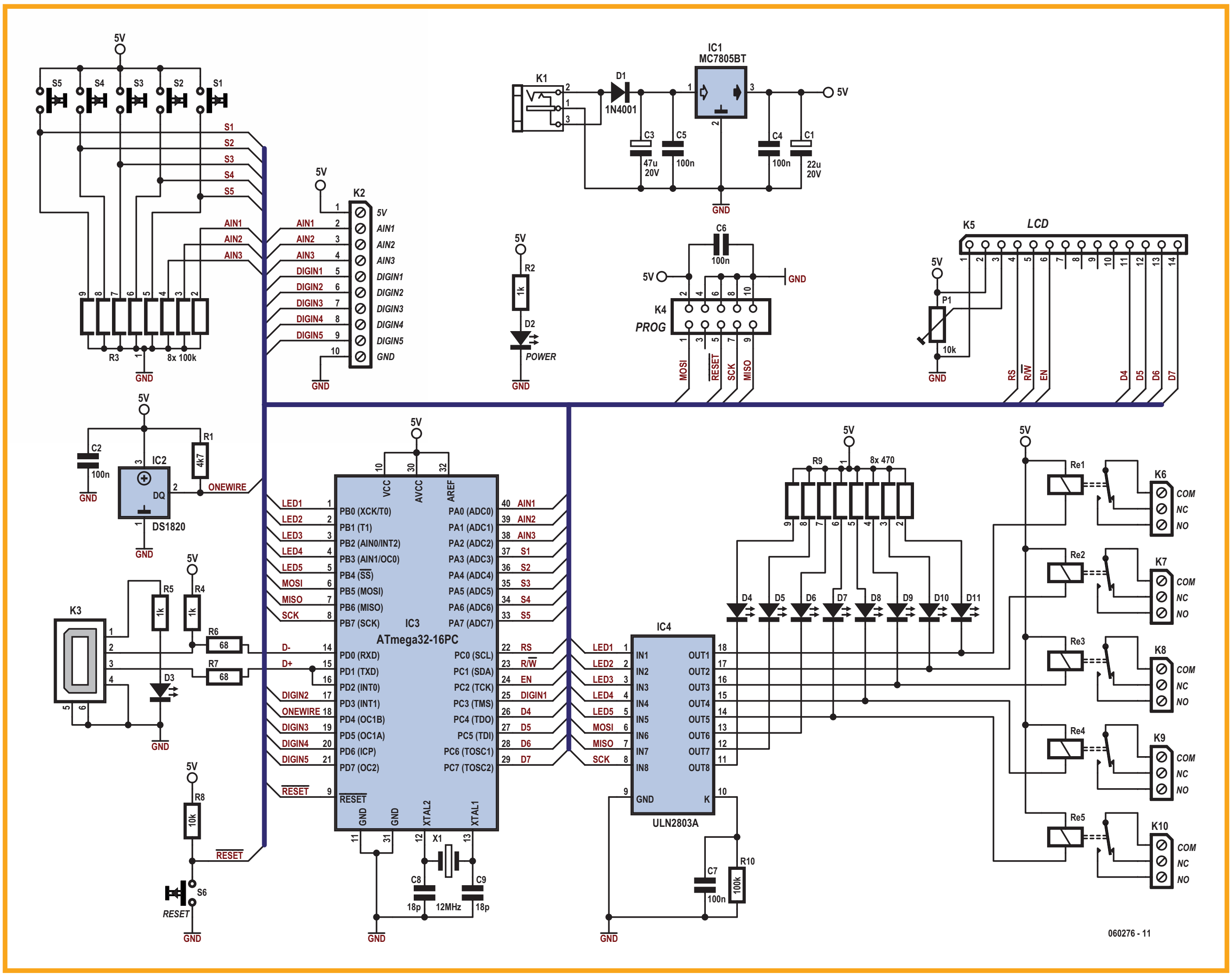
Figure 1. As you can easily see from the schematic diagram, the microcontroller forms the heart of the circuit.

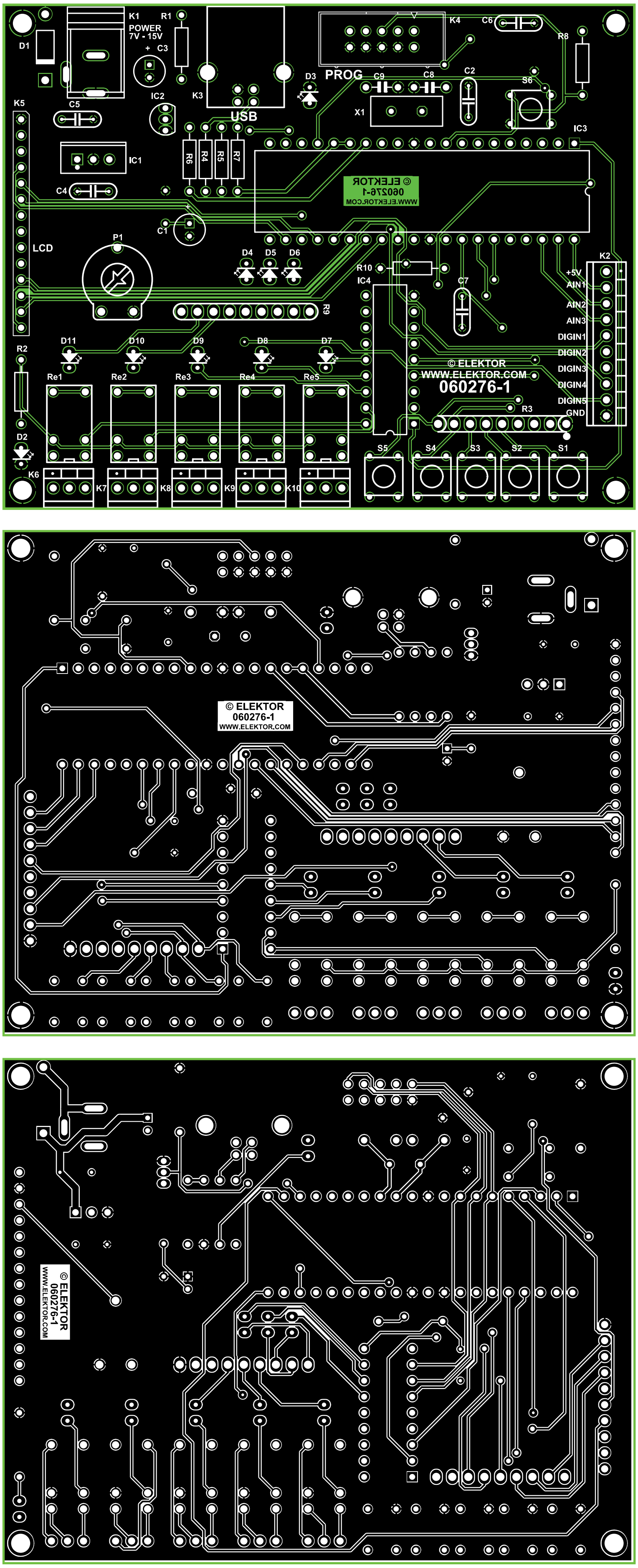


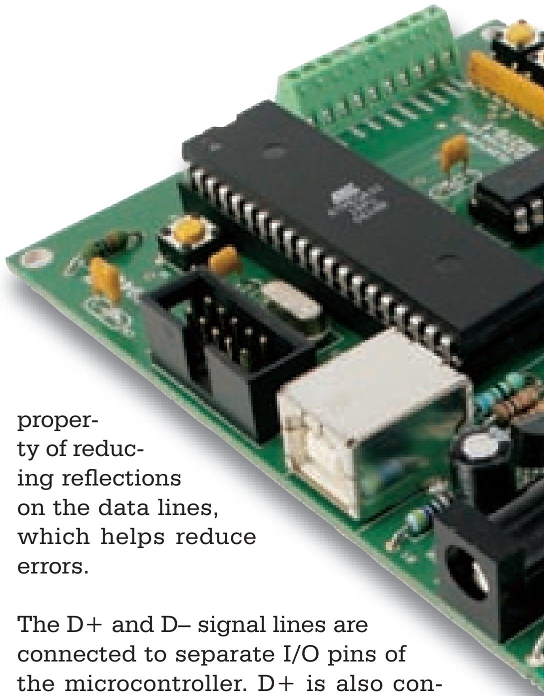
A development board with a software-defined USB interface

erating annoying problems due to static charges if they left open.
The circuit also has a temperature sensor (IC2). This is a '1-wire' chip, which means that only one I/O pin is necessary to use the sensor. The input options are rounded out with five push-button switches.

The circuit is fitted with an LCD that is driven using four data bits and the usual control signals. The microcontroller can also drive five relays. There an LED for each relay to indicate whether the relay is actuated.
The USB port is extremely simply with regard to the electronic components. Resistor R4 causes the host to recognise that a Low-Speed device is connected to the USB port. Resistors R6 and R7 provide current limiting in case of problems. They also have the pleasant







property of reducing reflections on the data lines, which helps reduce errors.

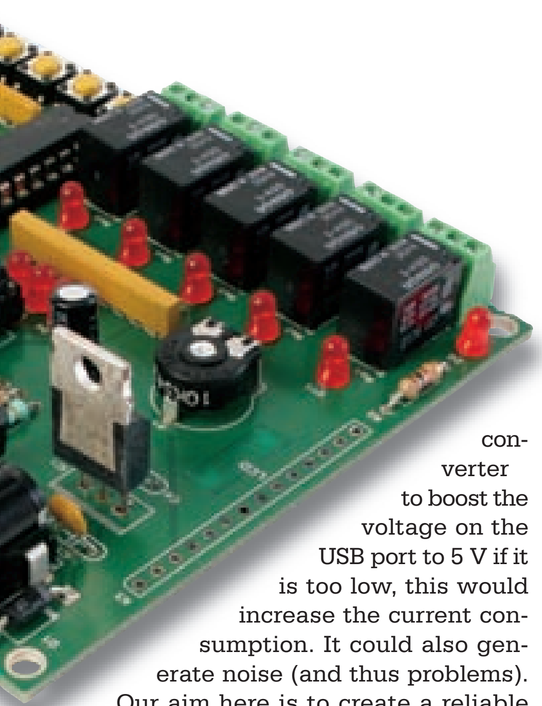
The D+ and D– signal lines are connected to separate I/O pins of the microcontroller. D+ is also connected to the INT0 input of the microcontroller. This makes it possible to generate an interrupt each time the signal level on the D+ line changes. Don't be misled by the fact that the D+ and D– lines are connected to the UART pins of the microcontroller. The software uses these two pins as normal I/O pins. The built-in UART of the microcontroller is not used for the USB interface.
The PCB track and component layouts are shown in **Figure 2**.

Power supply

An AC mains adapter is suitable for powering the entire circuit. In principle, it is also possible to power USB devices from the host, but this option is not suitable here. According to the specifications, the voltage on the USB bus can range from 4.4 V to 5.25 V. However, voltages seen in practice often differ from the specifications. With regard to current consumption, the maximum current a device is allowed to draw before enumeration (see inset) is 100 mA. During the enumeration process, the device states how much current it wishes to draw from the USB port (up to a maximum of 500 mA).

In this case, we need a minimum voltage of 5 V for the microcontroller. Although it would be possible to use a step-up

Figure 2. The microcontroller also occupies the central position on the circuit board.
As you can see, there is a wealth of I/O options.



converter to boost the voltage on the USB port to 5 V if it is too low, this would increase the current consumption. It could also generate noise (and thus problems). Our aim here is to create a reliable DIY design that is also reliable in operation, so we chose the simple solution of a standard power supply using an AC mains adapter. Diode D1 protects the voltage regulator (IC1) against reverse-polarity connection of the mains adapter.

Firmware

Naturally, the driving force of this project is the firmware. The firmware consists of several modules, which are predominantly written in C. Assembly-language code is only used for driving the USB lines, since it is faster.

The device descriptor is located in the usb.h file. During the enumeration process, the host uses the data in the device descriptor to determine what sort of device is connected. If you want to adapt the circuit to your own purposes (or just play with it), this is where you can ensure that the host recognises your device correctly. Of course, this requires a certain amount of knowledge of the USB protocol.

The avr-usb.h file contains a list of requests that are supported by the connected device. The host can send a request to the device, which performs the associated action in response. Some examples of typical actions are clearing the LCD, actuating or releasing a relay, and so on. In some cases, the request requires the device to return data to the host. One example of this is reading the temperature.

COMPONENTS LIST

Resistors

R1 = 4kΩ7
R2,R4,R5 = 1kΩ
R3 = SIL array 8x 100kΩ
R6,R7 = 68Ω
R8 = 10kΩ
R9 = SIL array 8x 470Ω
R10 = 100Ωk
P1 = 10kΩ preset

Capacitors

C1 = 22µF 20V radial
C2,C4,C5,C6,C7 = 100nF
C3 = 47µF 20V radial
C8,C9 = 18pF

Semiconductors

D1 = 1N4001
D2-D11 = low-current LED, red, lead pitch 2.5mm
IC1 = 7805CP
IC2 = DS1820
IC3 = ATmega32-16PC (programmed, E-SHOP # **060276-41**)
IC4 = ULN2003A

Miscellaneous

K1= 2.5mm mains adaptopr socket
K2= 10-way PCB terminal block, lead pitch 2.54 mm (e.g. Phoenix contact # 1725737)
K3= USB-B connector
K4 = 10-way boxheader
K5= 14-way pinheader
K6-K10= 3-way PCB terminal block, lead pitch 2.54mm (e.g. Phoenix contact # 1725669)
Re1-Re5 = 5V relay (e.g. OMRON G5V-1-DC5)
S1-S6 = pushbutton (e.g. OMRON B3F-1002)
X1 = 12MHz quartz crystal, HC49/U case
LCD module, 2x16 characters
PCB, E-SHOP # **060276-1**

Compiling

The complete firmware, including the assembly-language code, can be compiled using the AVR GCC compiler [2], which is a (free) open-source compiler. There is also a downloadable 'make' file, which makes the compilation process a lot easier (see [3]).

The circuit has a programming interface, so you can program new firmware into the microcontroller while it is fitted to the board ('in system'). However, you must set the proper fuse bits for this, since otherwise the entire process won't work. The palmaver site [4] describes a convenient way to determine the proper configuration bytes. You can determine the right settings for this circuit by entering '0x3fDf' in the box at the upper right (see **Figure 3**). This corresponds to programming the BOD-

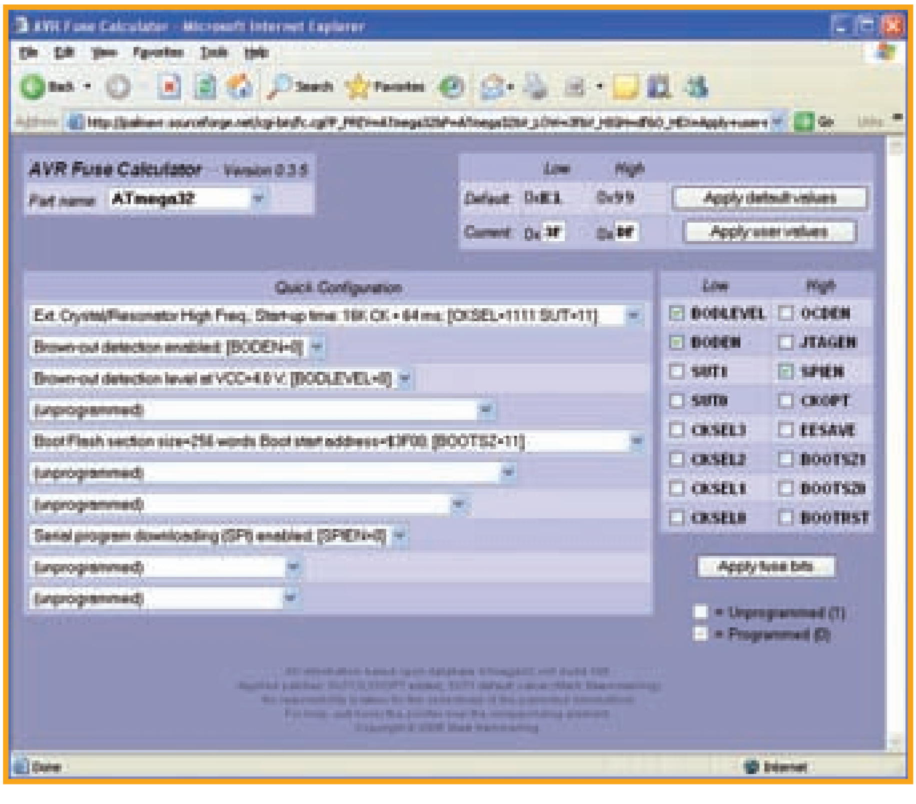


Figure 3. It's easy to determine the right fuse settings with this handy online tool [4].

Enumeration

The host device must perform a process called 'enumeration' before it can use a connected USB device. The first step in the process takes place in he USB device, where a pull-up resistor in the device signals its presence on the USB bus.

In the case of a Low-Speed device (1.5 Mbit/s), the pull-up resistor must pull the D– line to +3.3 V. In the case of Full-Speed (12 Mbit/s) and High-Speed (480 MB/s) devices, the D+ line must be pulled to +3.3 V.

In response to the change in the signal level on the data line, the host uses a predefined protocol to try to determine what sort of device is connected to the USB port. Besides the expected data (such as the VID and PID), the device must also report which class it belongs to, along with other information such as its version number, name, and so on. A USB address is also assigned to the device. The host uses the addresses to distinguish the different USB devices.

The information described above enables the host to determine which device driver it needs in order to use the device.

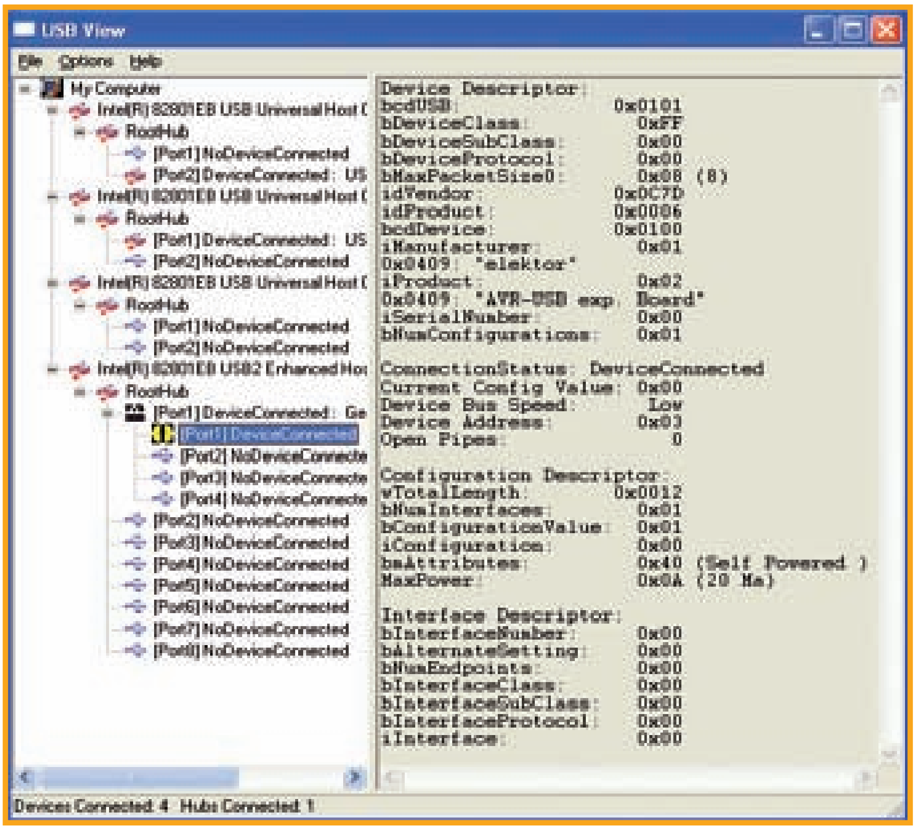


Figure 4. USBview gives you a bird's-eye view of everything connected to the USB.

LEVEL, BODEN and SPIEN bits (setting them to logic 0) and leaving the other bits unprogrammed (logic 1).

Assembly and testing

The circuit should be easy to assemble if you use the accompanying PCB design. The circuit does not include any difficult SMD components, and everything is readily available. The PCB is also available from our E-SHOP [3].

After soldering all the components in place, inspect the results carefully to ensure that all the solder joints are good and you haven't created any shorts. It's also a good idea to double-check the values of the resistors and capacitors and verify that all the ICs are oriented correctly in their sockets.

Once you have completed the inspection, you can start testing the board – cautiously of course! First connect an AC mains adaptor with a DC output voltage of 9–12 V. If everything is as it should be, LED D2 will light up. Next, connect the circuit to a PC via a USB cable. LED D3 should also light up now. Windows (assuming you are running Windows) will then start the enumeration process.

You can skip installation of the driver for now, since you don't yet have a specific driver for this circuit. The driver (which is also open-source software) is described in the 'Universal USB Driver' article in this issue.

USBview

You don't necessarily need a driver to test USB communications. Instead, you can use Microsoft's USBview utility. This program is included in the Microsoft Driver Development Kit (DDK) [5]. You can use it to view the data from the device descriptor of the USB device (see **Figure 4**).

This program works without a device driver. You can test USB communications by viewing the data from your device in the USBview window. All the data you see there comes from the device and is sent to the PC via the USB bus.

If all the test results are positive, the hardware is ready and you can start working on the device driver. Refer to the 'Universal USB Driver' article elsewhere in this issue for the details.

(060276-1)

Web links

[1] www.usb.org/developers/docs.html

[2] winavr.sourceforge.net/

[3] www.elektor-electronics.co.uk

[4] palmavr.sourceforge.net/cgi-bin/fc.cgi

[5] www.microsoft.com/whdc/devtools/ddk/default.mspx

Universal USB Device

Michael Odenwald, Michael Keller and Paul Goossens

Designing your own USB device can be an enjoyable task for electronics hobbyists. The main stumbling block is often the driver for the device. Writing this piece of software can be a bit too difficult for many people. A universal USB device driver, which is also open source, presents the solution!

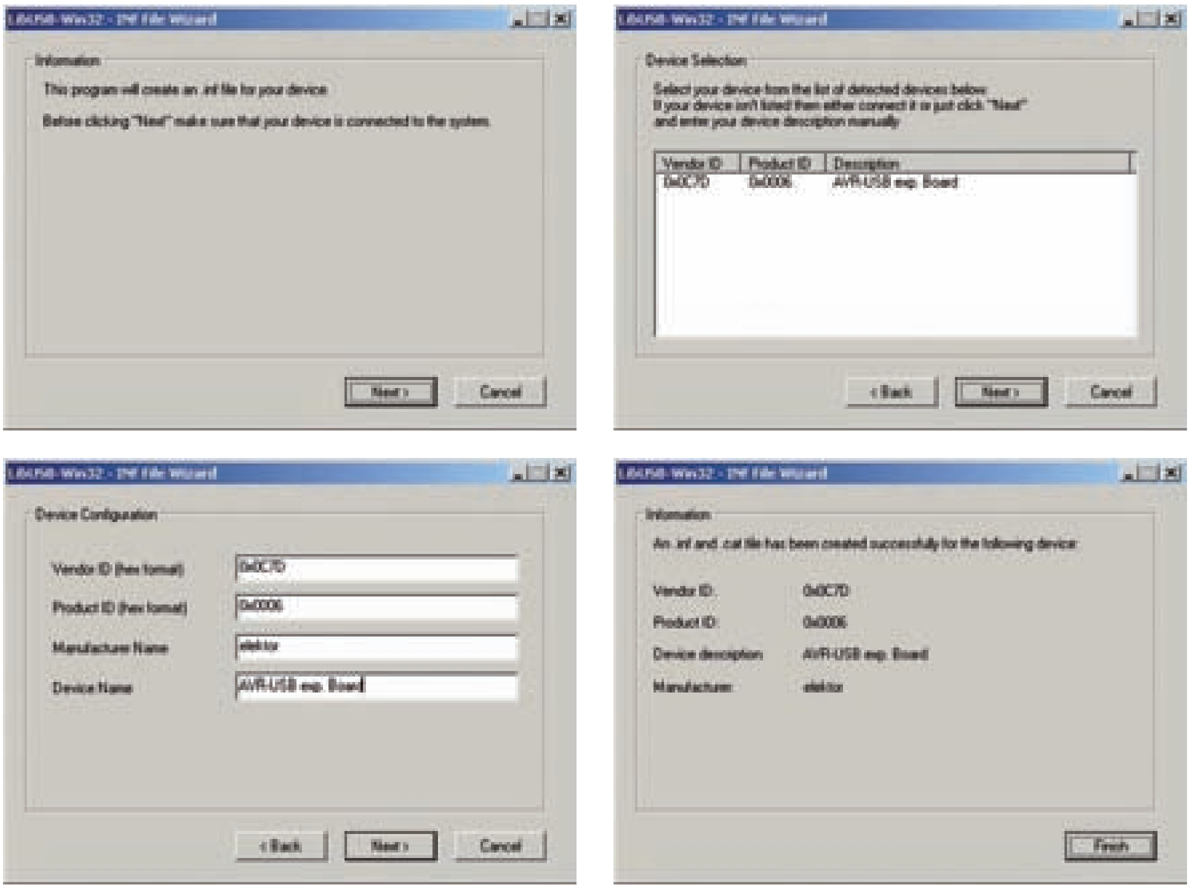


Figure 1. These are the steps you'll come across when creating the INF file for the universal USB driver.

When designing USB devices you also need to write an associated device driver. For many designers this is a very tricky task and many won't even attempt such a project because of this. This is now all set to change! With the help of our AVR USB board we'll show you how we tackle this driver problem, using an existing universal open source device driver program.

Connections

Everything went smoothly as far as the hardware for our AVR USB board was concerned, until we connected it to the PC. Windows (XP) then politely asks us for a device driver, as expected. And this doesn't exist (yet) for our hardware.

To help us out we made use of 'libusb-win32', a universal open source USB device driver [1]. This comes as a DLL and lets Windows applications communicate directly with a USB device. With this we can deal with the (device dependent) data stream in a Windows application and there is no need for a specially written device driver.

Unlike the way a 'normal' device driver functions, libusb-win32 lets us use an API (Application Programming Interface) instead of having to communicate via a so-called IOCTL (Input/Output ConTroL).

Driver Say goodbye to connection problems

Let's get busy!

First we have to download libusb-win32 and extract all files from this ZIP file in their own folder. Before we can use this driver we first have to create an INF file. This file tells Windows which driver belongs to which device.
The creation of this INF file is made very easy by the inclusion of a program in libusb-win32 ('inf-wizard.exe'). The INF file is created as follows: Power up the AVR USB board and connect it to the PC. Windows will now ask for the driver. Click on 'Cancel'. Start the program 'inf-wizard.exe'. In the first window click on 'Next', after which the second window appears. This contains a list of all the connected USB devices. Select our AVR USB board, with a VendorID of 0x0C7D and a ProductID of 0x0006, and click on 'Next'. In the third window we can give the device a different name, if required. This isn't necessary, so we click on 'Next' again. The program now reports that it has generated an INF and a CAT file. Click on 'Finish' to close the program. (**See Figure 1.**)

Initial test

We now have to disconnect the AVR board from the PC and then reconnect it again. Windows will ask for the driver program once more. This time, select the option 'Specify a location' and browse to the INF file that we created with 'inf-wizard.exe'.
If everything goes to plan, Windows will install the device driver. From the Device Manager in Windows you should now be able to see the AVR USB board.

Applications

We can now use the AVR USB board in our applications. On the Elektor Electronics website are a few downloads for this project, which contain several applications (including the source code) for controlling the AVR USB board. These applications have been written in C, .NET and a few other languages. You can use the source code as the basis for your own applications.
The testing of all functions of the AVR USB board is very easy with the program 'AVR-USB-Windows1.exe'. With this you can test all I/O capabilities of the hardware.

A closer look at the source code

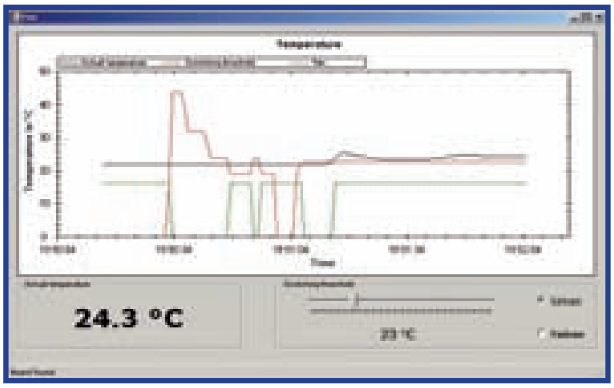
To give you an idea how we can control our USB device from within an application, we'll show you a few parts of the source code. The saying 'a picture is worth a thousand words' also applies to source code!
In **Listing 1** you can see how the application searches for a specific USB device. If it is found, a connection with this device is initiated.
In a for-next loop all of the available USB busses of the computer are interrogated. The VendorID and ProductID of every USB device connected to each bus are requested. When both the VendorID and ProductID have the required values the program tries to 'open' this device. The 'handle' for this device is stored in the global variable 'usb_dev_handle'. The last step is to configure the device according to the USB standard and claim exclusive rights to the use of this device.
When no unexpected errors occur the function will return the value '1' to indicate that everything went well. If anything went wrong the function will return the value '0'.

Listing 1

```
Globale variabele:
usb_dev_handle *usbIODevice; /* The usb device handle */

Funktie:

int searchUSBDevice(int vendorID, int productID)
{
  struct usb_bus *busses;
  struct usb_bus *bus;
  struct usb_device *dev;

  if (usbIODevice != NULL)
  {
    usb_close(usbIODevice);
  }

  usbIODevice=NULL;

  /* Find the device for the given vendorID and
productID*/
  usb_init();
  usb_find_busses();
  usb_find_devices();
  busses = usb_get_busses();

  for (bus=busses; bus; bus=bus->next) {
    for (dev=bus->devices; dev; dev=dev->next) {
      if (dev->descriptor.idVendor == vendorID &&
      dev->descriptor.idProduct == productID) {
        usbIODevice=usb_open(dev);
        if(usb_set_configuration(usbIODevice, 1)) return 0;
        if(usb_claim_interface(usbIODevice, 0)) return 0;
        return 1;
      }
    }
  }
  return 0;
}
```

Hardware control

Controlling the hardware is also very simple. In **Listing 2** you can see how the status of the digital inputs is read. This assumes that the function 'searchUSBDevice' (from listing 1) has previously been called to assign a valid



handle to 'usb_dev_handle'.
With the help of 'sendUSBVendorCmdIn' we send the command 'AVR_USB_READ_DIGITAL'. This command can also be found in the source code of the firmware. With this we also specify from which port we want to read (the second parameter). The result is put into the array 'iodata'. The application can then use these returned values to determine what the status of the relevant digital input is.

Experimenting

The best way to familiarise yourself with this software is to go through the examples. The examples avr-usb1 to avr-usb4 (which can be downloaded from [2]) can all be compiled using GCC [3]. (GCC stands for GNU Compiler Collection, a free ANSI-C compiler with support for K&R C, C++, Objective C, Java, and Fortran.)
The other examples have been written in C#.

With the many examples available, you should be able to write applications for the AVR USB board in other development environments under Windows as well.

And finally ...

For ideas or help when you get stuck you should take a look at the forum for the open source driver [4]. In here you'll find many enthusiastic programmers who pass on useful information, and you can also ask questions.
You can of course also use our own forum on the *Elektor Electronics* website to share your experiences with other readers. For those of you with a grasp of foreign languages it would also be useful to visit the forums of our French, German or Dutch websites. Here you'll undoubtedly find other electronics hobbyists who'll make worthwhile contributions to this project and who in turn would be interested in your experiences.

(060226-I)

Weblinks

[1] http://libusb-win32.sourceforge.net/

[2] http://www.elektor-electronics.co.uk/

[3] gcc.gnu.org

[4] http://sourceforge.net/forum/?group_id=78138

Listing 2

```
int digiportTest(void)
{
  int i;
  int result;
  unsigned char iodata[8];

  printf("digiport: AVR-USB get value from digital input Port:\n\r");

  for (i=0; i<=1000; i++)
  {
    if((result = sendUSBVendorCmdIn( AVR_USB_READ_DIGITAL, AVR_USB_DIGITAL_P1, 0, iodata, 8)) < 0)
printf(„Error sendUSBVendorCmd %d", result);
    printf(„digital in status P1 is %s\n\r", (iodata[0]) ? „close" : „open");
    if((result = sendUSBVendorCmdIn( AVR_USB_READ_DIGITAL, AVR_USB_DIGITAL_P2, 0, iodata, 8)) < 0)
printf(„Error sendUSBVendorCmd %d", result);
    printf(„digital in status P2 is %s\n\r", (iodata[0]) ? „close" : „open");
    if((result = sendUSBVendorCmdIn( AVR_USB_READ_DIGITAL, AVR_USB_DIGITAL_P3, 0, iodata, 8)) < 0)
printf(„Error sendUSBVendorCmd %d", result);
    printf(„digital in status P3 is %s\n\r", (iodata[0]) ? „close" : „open");
    if((result = sendUSBVendorCmdIn( AVR_USB_READ_DIGITAL, AVR_USB_DIGITAL_P4, 0, iodata, 8)) < 0)
printf(„Error sendUSBVendorCmd %d", result);
    printf(„digital in status P4 is %s\n\r", (iodata[0]) ? „close" : „open");
    Sleep(500);
  }
  return 0;
}
```

Wireless

iDwaRF: a network

Dr. Erik Lins and Christian Meinhardt

iDwaRF brings together a Cypress WirelessUSB transceiver and an Atmel AVR microcontroller to create a networkable 2.4 GHz radio module featuring a free protocol stack and development environment.

Besides standard applications such as mobile radio, WLAN and Bluetooth, highly-integrated low power radio devices open up many new possibilities, including wireless sensor networks and even radio-controlled robotic football teams able to orchestrate an offside trap in the blink of an eye! And, with iDwaRF, we can do all this without complex protocols or licensing problems.

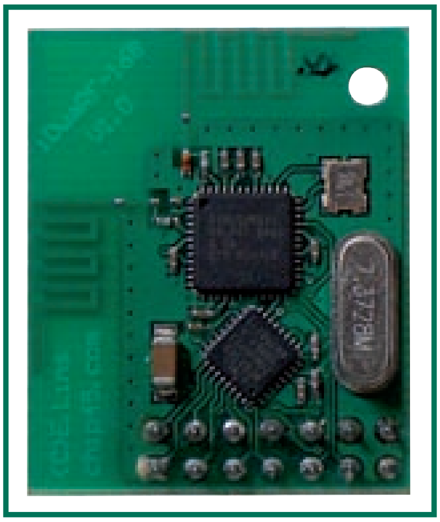


Figure 1. The iDwaRF radio module with 2.4 GHz WirelessUSB transceiver and ATmega168 AVR microcontroller.

An alternative to ZigBee

For wireless sensor network applications ZigBee [1] is often the protocol of choice. The protocol is relatively complicated, and only members of the ZigBee Alliance are permitted to use it in commercial products. Cypress [2] offers a simpler alternative in its WirelessUSB technology [3]. The devices are cheap and the radio protocol makes only moderate demands in terms of hardware and memory in the microcontroller. WirelessUSB supports wireless many-to-one links and is thus ideal for use in wireless sensor networks. The protocol details are freely available and can be used without restriction in combination with Cypress radio chips.

iDwaRF

The iDwaRF-Net software that accompanies the iDwaRF-168 module (**Figure 1**) is a port of the Cypress WirelessUSB protocol to the ATmega168 AVR-family microcontroller [4]. The iDwaRF-168 module can be freely reprogrammed and can equally well play the role of hub or sensor in a many-to-one wireless sensor network. It is easy to add extra application-specific functions.

WirelessUSB operates in the 2.4 GHz ISM band. Each WirelessUSB radio network uses a selection from a total of 79 channels: even when multiple WirelessUSB devices are operating simultaneously the protocol will be able to find a free channel to use.
Transmission uses a robust DSSS (direct sequence spread spectrum) modulation scheme [5]. Even at a 10 % error rate the data can still be received correctly, and if there should be long-term interference the protocol provides for

USB in miniature

able WirelessUSB radio module

an automatic change of channel. Like Bluetooth, WirelessUSB comes in short-range (up to 10 m) and long-range (up to 50 m) versions. The latter is used in the iDwaRF-168 module.

Hub and sensors

An iDwaRF module programmed to act as a hub forms the centre point of a star-topology many-to-one radio network, which can consist of many sensors (**Figure 2**). Normally the hub operates continuously and can be connected to a PC or another microcontroller, acting as a host, using a serial link. For simple applications the iDwaRF module itself can be programmed to carry out the required dedicated host functions.

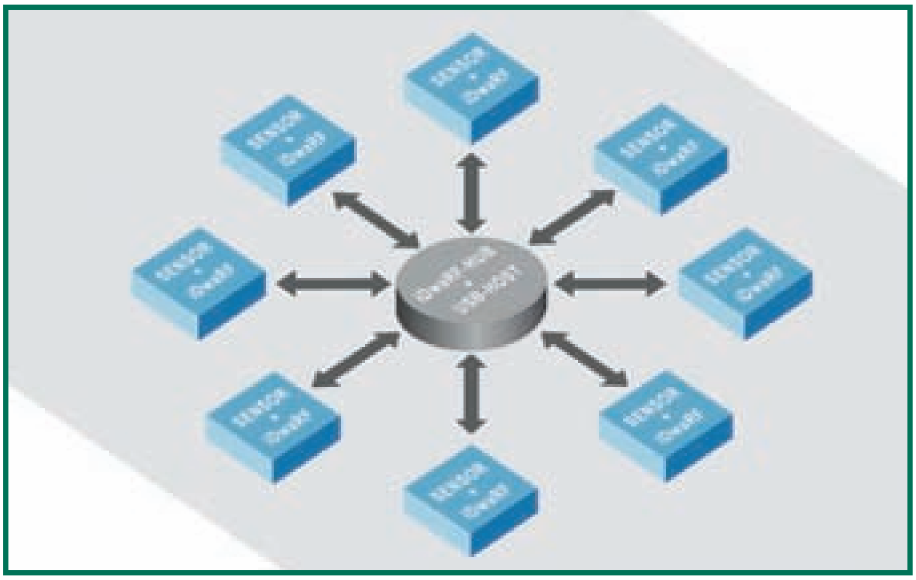


Figure 2. The star-topology radio network consists of a hub and several sensors.

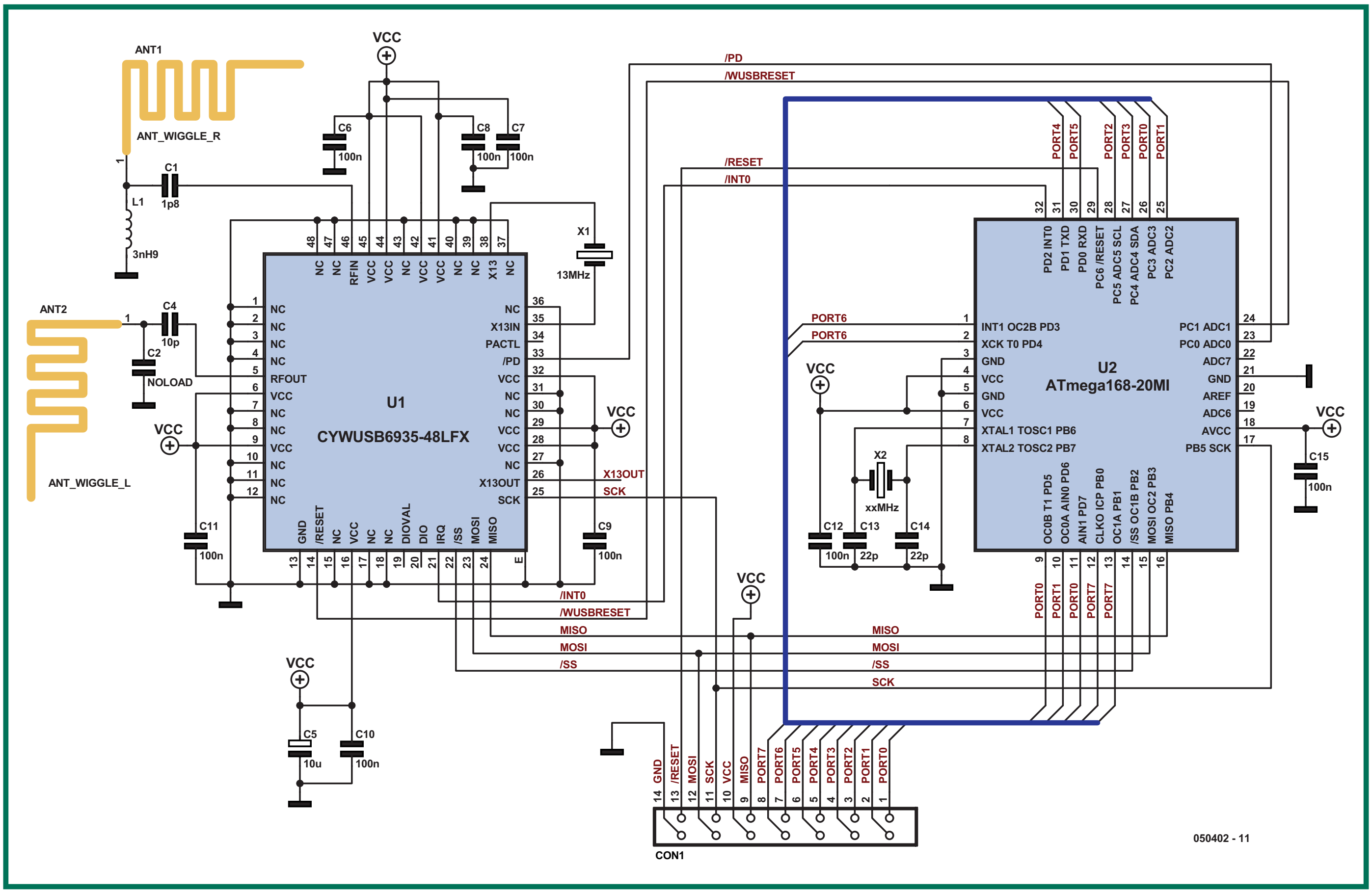


Figure 3. Circuit diagram of the iDwaRF module.

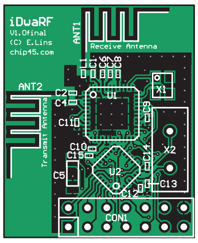


Figure 4. The iDwaRF printed circuit board includes a printed antenna.

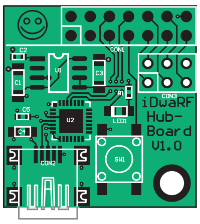


Figure 6. The iDwaRF module is mounted on the hub printed circuit board.

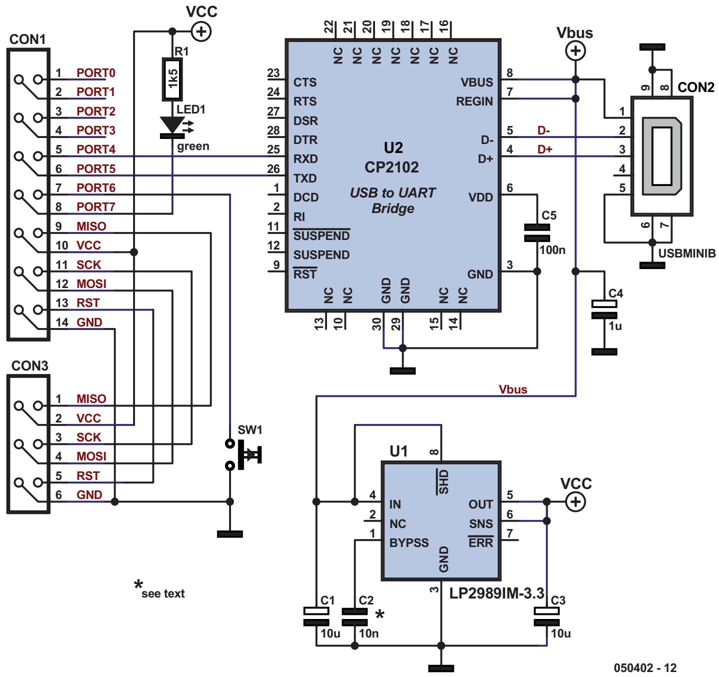


Figure 5. Circuit of the hub board.

A sensor unit consists of a suitably-programmed iDwaRF module with sensors attached. To save power we use the AVR's internal RC oscillator. Also, the module is only activated at intervals (as determined by the 'beacon time'). Communications are initiated by the sensor and terminated by the hub; a reverse channel (transmitting information from hub to sensor) is also available.

Module printed circuit board

Figure 3 shows the circuit diagram of the iDwaRF-168 module. The Cypress CYWUSB6935-LR transceiver is connected to an ATmega168 microcontroller over SPI, using the MISO, MOSI, SCK and /SS (chip select) signals. An interrupt signal (/INT0) from the radio device indicates the reception of data. The ATmega168 can put the radio chip into power-down mode using an I/O pin connected to the /PD signal, and can reset it using the /WUSBRESET signal. The radio chip needs just an external 13 MHz crystal (X1) and decoupling capacitors (C6 to C11) for operation. The transmit and receive antennas are separate from one another and integrated directly into the circuit board layout as meander lines (**Figure 4**). Having separate antennas gives greater range and sim-

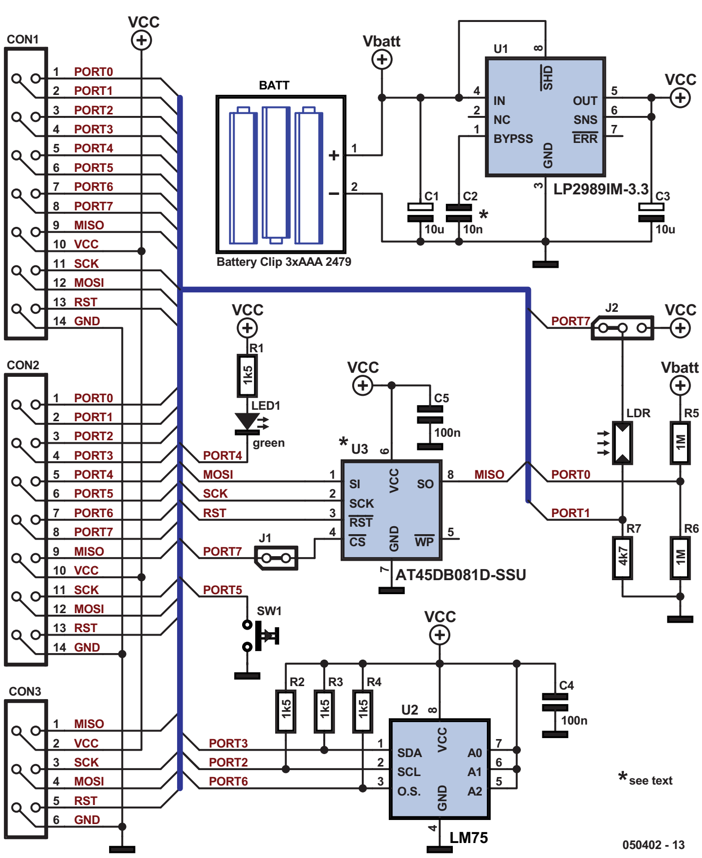


Figure 7. Circuit diagram of the node board with temperature and light sensors.

Table 1. CON1 connection groups

iDwaRF-168 CON1 (port pin)	First connection (ATmega168 pin number)	Second connection (ATmega168 pin number)	Third connection (ATmega168 pin number)
PORT0	OC0B / T1 / PD5 (9)	AIN1 / PD7 (11)	ADC3 / PC3 (26)
PORT1	OC0A / AIN0 / PD6 (10)	ADC2 / PC2 (25)	-
PORT2	SCL / ADC5 / PC5 (28)	-	-
PORT3	SDA / ADC4 / PC4 (27)	-	-
PORT4	TXD / PD1 (31)	-	-
PORT5	RXD / PD0 (30)	-	-
PORT6	INT1 / OC2B / PD3 (1)	XCK / T0 / PD4 (2)	-
PORT7	CLKO / ICP / PB0 (12)	OC1A / PB1 (13)	-

plifies matching (L1, C1 and C4). The antennas are laid out in the manner recommended by Cypress.

The microcontroller is equipped with a crystal in an HC49 package, and so it is straightforward to change it for a different frequency. As supplied the ATmega168 is configured to use its internal RC oscillator.

A 14-way header (CON1) brings out the ISP (in-system programming) signals of the ATmega168 (MOSI, MISO, SCK and /RST), power, and eight spare I/O port pins. Some of the header pins are connected to more than one signal on the microcontroller to allow as many as possible of the peripheral functions of the device to be used. This means that you must ensure that any two microcontroller pins that are connected to the same header pin are never simultaneously configured as outputs, or damage to the microcontroller may result. **Table 1** shows the CON1 pinout and signals in detail.

Application boards

In the simplest wireless network scenario one iDwaRF-168 module is programmed as a hub and one or more modules are programmed as sensors. It is of course necessary to build the necessary interfaces to the sensors themselves and connect them to the modules. To simplify building such systems we have developed three application boards, to each of which can be attached an iDwaRF-168 module: a hub board, a node board and a prototyping board.

The hub board supports the iDwaRF module with a USB interface (the CP2102), a 3.3 V LDO voltage regulator, button and LED (**Figure 5**).

The node board is used to make a sensor unit using an iDwaRF module. The circuit (**Figure 6**) includes an LDR as a light sensor, an LM75 temperature sensor, an (optional) AT45DB801D serial flash memory, a button and an LED. Power is provided by three AAA cells and a 3.3 V LDO voltage regulator.

The two printed circuit boards (**Figure 7** and **Figure 8**) are chiefly populated using SMD components. **Figure 9** shows the boards with iDwaRF-168 modules fitted.

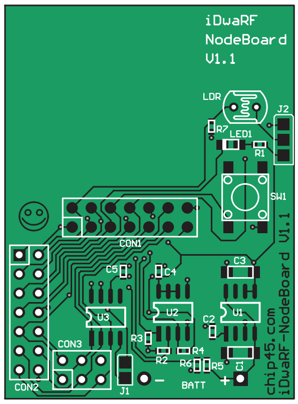


Figure 8. The node board converts the iDwaRF module into a complete sensor unit.

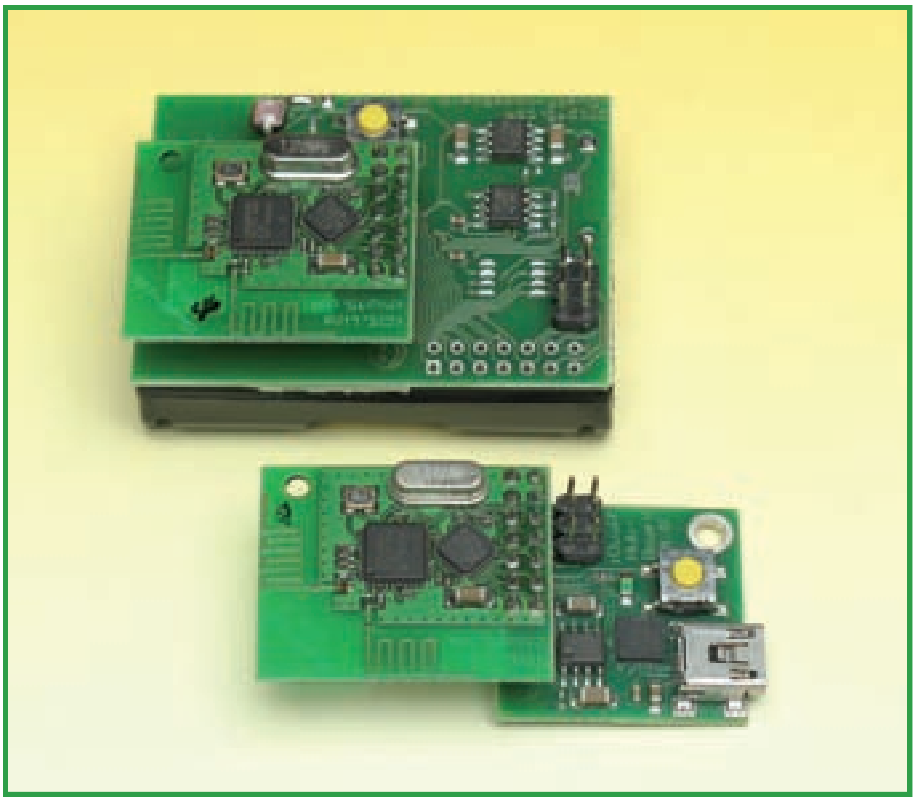


Figure 9. Node board (rear) and hub board (front) with iDwaRF radio modules fitted.

Table 2. Example programs

empty	Empty program: framework for new applications.
chat	Creates a wireless serial connection between two host PCs, allowing 'chatting' between two terminal programs.
tutorial	Example program that switches the LEDs on the hub and sensor modules on and off remotely when a button is pressed. The implementation of this example is explained step-by-step in a separate 'how to' document (see text box).
terminal	This basic sensor network application supports the components on the node board or iDwaRFSensorBox. Data packets (including battery voltage, potentiometer setting, button state and temperature) from several sensors are displayed in plain ASCII text. The terminal program can also send data to individual sensors.
quad_adc	This program reads four ADC channels and transmits the readings to the hub at regular intervals.

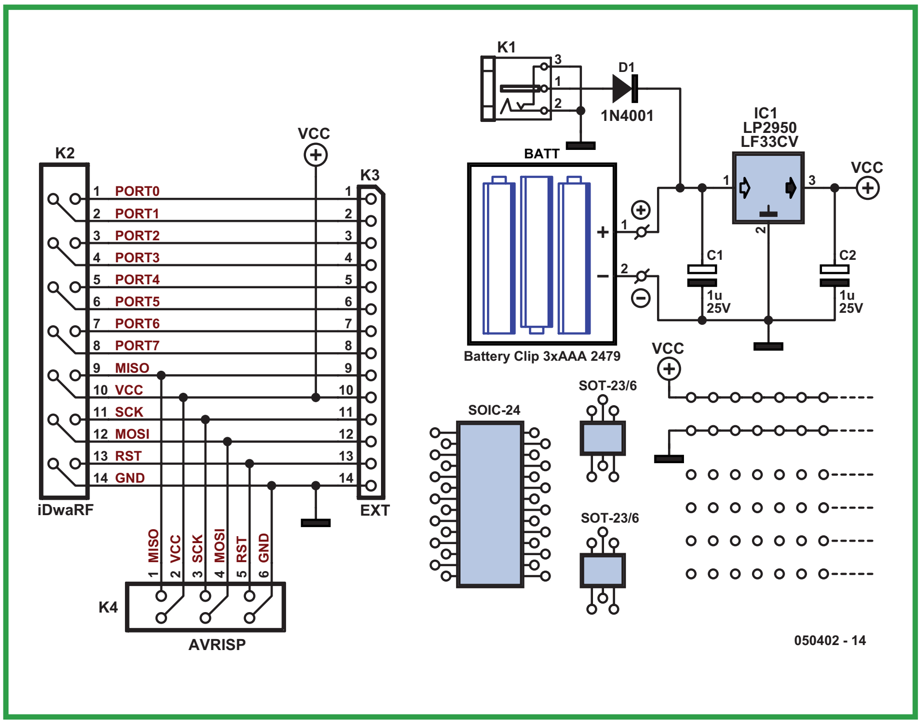


Figure 10. Circuit diagram of the prototyping board for dedicated iDwaRF module applications.

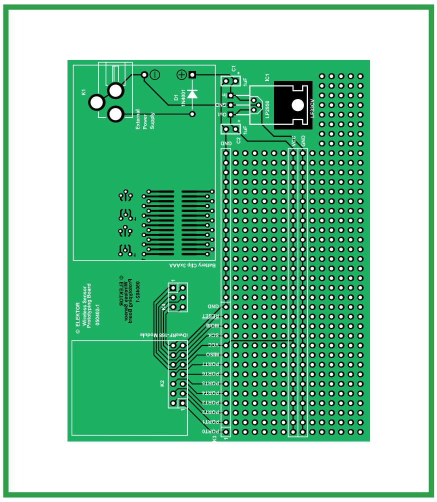


Figure 11. The prototyping board has an experimentation area with SMD footprints on the reverse.

The prototyping board has a generous area for building your own circuits and is suitable for creating more specialised applications using the iDwaRF-168 module. There are SMD pads on the reverse of the board. The only active component in the circuit (**Figure 10**) is the LDO voltage regulator, in a TO-92 or TO-220 package according to the expected current draw. As well as the regulator and socket to accept the iDwaRF-168 module there is an AVR programming connector, a battery holder and, as an alternative, a socket for a mains adaptor with a reverse polarity protection diode. The printed circuit board (**Figure 11**) is half-Eurocard sized and can be used in the place of a node board. For reasons of space we have made the parts lists for the circuit boards and layouts available for download from the *Elektor Electronics* website.

Software

The iDwaRF-Net software package [6] includes a library of firmware for use in hub and sensor modules with corresponding header files (in the 'iDwaRF' directory), along with a few ancillary functions, for example to support serial communications ('USART' directory). There are also four example programs which can either be used as they stand or form the basis for dedicated applications. **Table 2** gives more details of these example programs.

Each example program consists of hub source code (userMain_hub.c) and sensor source code (userMain_sensor.c). The firmware provides the facility to register so-called 'callback' functions, which the firmware calls regularly in the course of normal operation. These functions can be used for application-specific code. The most important callback functions are explained in the text box.

Ready, steady…

Assembling the hardware is relatively straightforward. The SMD printed circuit boards (the iDwaRF module, the node board and the hub board) are available as ready-made units (see the 'Elektor Shop' pages at the back of this issue). A kit of parts is available for the prototyping board. Separately-ordered iDwaRF-168 modules are supplied unprogrammed and without header or crystal fitted in order to give the user maximum flexibility.

The firmware for programming a hub or sensor module is freely available [6]. Modules ordered bundled with a node or hub board come ready-programmed. A crystal is always required for baud rate generation on the hub board (a 7.3728 MHz crystal is supplied as standard), and the microcontroller must be suitably programmed for crystal operation. The correct values for the ATmega168 with a crystal oscillator are: extended byte, 0xF9; high byte, 0xDF; and low byte, 0xFC. It is recommended to use the same values and same crystal frequency for the sensor, and the firmware is currently set up to work on this assumption. If the frequency is to be changed (using a different crystal or the internal RC oscillator) the relevant #define in the firmware must be changed and the code compiled afresh.

The AVR ISP connectors have to be soldered on to the node board and hub board, and the node board also needs to be connected to the battery holder. Finally the iDwaRF module can be fitted and (in the case of the node board) the batteries inserted. The USB connection on the hub board requires the corresponding CP2102 virtual COM port driver to be downloaded and installed [6]. Drivers are available for both Windows and Mac OS X. A CP210x module is provided as standard in current Linux kernels, allowing the iDwaRF module to be used with non-Windows PCs.

The pre-compiled hex files [6] for hub and sensor are downloaded using the six-pin AVR ISP connector. Note that the supply voltage for the iDwaRF module on the node and hub boards is only 3.3 V, and so care must be taken to ensure that the programming adaptor also works at this voltage. Simple STK200-compatible programming adaptors that connect to the PC's printer port, which draw power from the target device, do not always work reliably at 3.3 V. Modern USB programming adaptors (compatible with the STK500-V2) such as the CrispAVR-USB work without problems.

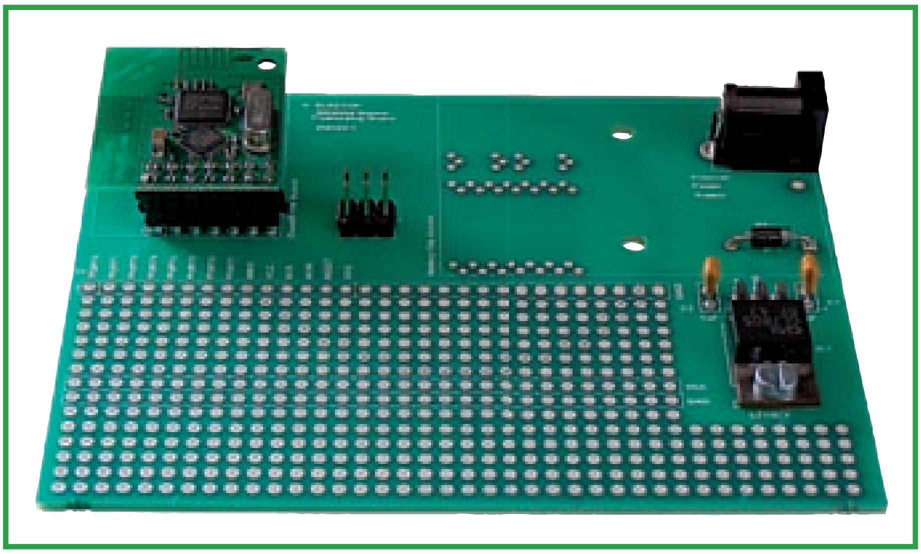


Figure 12. Prototyping board with iDwaRF radio module plugged on.

Table 3. Commands available in 'terminal' program

Command	Description
rst	Restarts the hub firmware. All sensors are unregistered and lose their ID codes, and must register again with the hub.
gps	Returns an internal Cypress firmware state variable.
bon	Activates automatic bind mode on the hub. New sensors are probed for using PN code 0 and channel 0. In normal use automatic bind mode is activated.
bof	Deactivates automatic bind mode. New sensors can no longer register with the hub.
enu	Displays a list of the currently registered sensors on the hub. The list includes the sensor ID assigned during registration and the unique manufacturing ID stored in the radio chip.
cln	Cleans up the hub's list of registered sensors. Sensors which have registered more than once with the hub and which have therefore been assigned different ID codes are removed from the list and only their current ID code remains valid.
cnf	Configures network parameters. There are 8 different PN codes and channel subsets, and this command allows the hub to be switched to a new PN code and channel. The facility to change channel number is for test purposes only, as the channel is changed automatically in normal operation. The PN code, however, remains fixed. The format is cnf <pncode> <channel> where 0 < pncode < 9 and 0 < channel < 80. The cnf command automatically deletes all registered sensors from the list.
snd	Sends beacon time and other data to a sensor. The data packet is buffered in the hub and when the sensor in question next makes a transmission the packet is sent back in the back channel to the sensor. All parameters are given in decimal. The format is snd <sensorid> <beacon time> <data0> <data1> <data2> <data3> ... A beacon time of -1 indicates that the beacon time is not to be changed.
del	Removes a sensor from the list of registered sensors in the hub. The format is del <sensorid>
hex	Causes sensor data to be displayed in hex rather than as plain text.

The principal callback functions

In the hub:

cbSensorPacketReceived(): called when a packet is received from a sensor. Direct access to the current sensor data is possible, although if lengthy processing is to be carried out the data should be copied into a global buffer and the work done in the main program.

cbSerialDataReceived(): called when a byte is received over the serial interface. Usually the byte is simply stored in a global buffer and its reception signalled using a flag, so that more time-consuming processing can be carried out in the main program.

cbProcessRxData(): further processes the bytes received by cbSerialDataReceived(), for example to implement a complex communications protocol with the host PC. In the 'terminal' example the commands entered on the host PC are parsed and processed in this function.

In the sensor:

cbConfigForSleep(): called shortly before the sensor switches into power-down mode. This allows for particular sensor devices to be switched off to reduce power consumption.

cbExitFromSleep(): called when the sensor leaves power-down mode. At this point particular sensor devices can be powered up again.

cbTxProcess(): assembles the data packet to be sent to the hub. At this point sensors can be read and the readings stored in the global transmit buffer. The current data packet is then automatically sent to the hub.

cbBackchannelProcess(): called with data received from the hub in the reverse channel. This can be used to create an output signal on the sensor, or to generate an analogue voltage using PWM. The 'terminal' example switches on the LED when a data packet is received.

... go!

The 'terminal' example program is the best one to use to demonstrate all the important functions of a wireless sensor network. iDwaRF modules programmed as sensors automatically connect to the module programmed as the hub and transfer data. With one node board and a hub board connected to a PC it is possible to see immediately on the PC's screen when light falls on or is shaded from the light sensor, when the button is pressed, or when the temperature sensor is warmed or cooled. Setup proceeds as follows.

Hub board

The virtual COM port driver creates a virtual COM port when the USB cable is plugged in. The number of the port can be obtained from the Device Manager (reached from the Control Panel).

Now we can run a terminal program, set to the relevant port, and talk to the hub in plain ASCII. If there are no sensors there will initially be no reports from the hub. The hub is reset by typing the command 'rst' and pressing 'enter': the hub will then emit its start-up message. It is best to configure the terminal program to expect CR+LF at the end of each line and to enable local echo, as the hub does not echo the characters it receives.

Data format

S5:	ID 0	ldr 212	temp 22.5°C	batt 2.9V	button OFF	(5 6 7 8 9 10)	:	11
a)	b)	c)	d)	e)	f)	g)		h)

Legend:

a) Packet type: S0 (BIND_REQUEST); S1 (BIND_RESPONSE); S2 (PING, hub only); S3 (ACK); S4 (DATA, hub only); S5 (DATA, sensor only)

b) Sensor ID

c) ADC value from the light intensity sensor

d) Temperature

e) Battery voltage

f) Button state (ON or OFF)

g) Six unused bytes displayed as decimal indices

h) Data byte count

The values from c) to g) above form the packet data payload. The standard packet size is set to 17 bytes, of which six are protocol overhead, leaving 11 bytes of payload.

Sensor
If a sensor is switched on the data packets received will be displayed line-by-line in the terminal window. The first packet is called a 'bind request' where the sensor registers with the hub and, in return, receives an ID code assignment and a value called the 'beacon time'. This period, which has a default value of five seconds, is the interval between the transmission of successive data packets. The format of the data packets is described in detail in the text box 'Data format'. A brief flash of the LED on the sensor board shows when it is active; the LED is extinguished when the sensor returns to power-down mode.

If the node board is moved to a warmer location, or if the ambient light intensity changes, the data packets displayed will reflect the new sensor values. If the button on the node board is pressed a data packet is transmitted immediately: this shows that it is possible to react immediately to external events, without waiting for the preset beacon time to elapse.

Command line
Commands can be typed into the terminal window at any time. Typing 'enu' ('enumerate') lists the sensors that are registered with the hub, showing their ID code and unique serial number.

Our first sensor will appear in this list with ID '0'. To send data to this sensor we use the 'snd' command. In its simplest form this has two parameters: 'snd 0 40' sends the value 40 to the sensor with ID code '0'. The first data byte is always interpreted by the sensor as a new beacon time, in units of 125 ms. In this example, the value of 40 corresponds to the default beacon time of five seconds. So, if we type 'snd 0 8' we will set the beacon time for sensor 0 to one second, and data packets from this sensor will be displayed in the terminal window at this rate. The command 'snd 0 40 1' sets the beacon time back to five seconds and also sends an extra data byte with value '1', which will cause the LED on the node board to light. In the terminal example the code in the sensor simply checks whether there is an extra data byte beyond the beacon time or not, and sets the LED on or off accordingly. The actual value of the extra byte is not taken into account. The complete set of commands provided by the hub in the 'terminal' example is listed in **Table 3**.
If now a further sensor is activated another 'bind request' packet will appear among the data packets being received from the first sensor, followed by a series of data packets. The 'enu' command can be used to list the registered sensors, and should now display two entries with ID codes '0' and '1'. We can test the new sensor by adjusting its beacon time: 'snd 1 8' will set it to one second, and we should now receive packets from sensor 1 at five times the frequency of those from sensor 0. If an 'x' is used in place of the ID code in the send command, the beacon times for all sensors are set simultaneously. Using 'snd x 40' we can therefore reset the beacon times for both sensors to five seconds.

If the data packets are to be processed on the host PC, the 'hex' command can be used to switch the display from readable form to pure hex values. These can easily be read by another application, for example using the scanf() function.

Room for expansion

The supplied programs can form the basis of dedicated applications using iDwaRF modules: the possibilities are endless. Often a couple of extra components are all that is needed, for example to make measurements using an ADC, generate PWM waveforms, scan keys or drive an LCD.

The iDwaRF-Net software can in theory work with up to 255 sensors, although at present the limit is 32. For larger sensor networks the xHub is planned, using an ATmega128 with more flash memory and an external SRAM. An external antenna will increase the range of the hub.

Users of the iDwaRF radio module [7] and the iDwaRF-Net firmware can use a forum [8] organised by the author. This is in addition to the forum on the *Elektor Electronics* website. Further example programs will of course appear for download at [6] as soon as they become available.

(050402-I)

References and links:

[1] www.zigbee.org

[2] www.cypress.com

[3] Thomas Biel: 'Wireless USB', Elektor Electronics, September 2004, p. 8

[4] www.atmel.com/avr

[5] Stefan Tauschek: 'Wireless Connectivity', Elektor Electronics, February 2005, p. 14

[6] www.elektor-electronics.co.uk or www.chip45.com/iDwaRF-168_Downloads

[7] www.chip45.com/iDwaRF-168

[8] www.chip45.com/iDwaRF-Net

Very low price

TraceME application areas

Measurement & Control engineering:

Wireless distance control of generators, all equipment with an SPI or RS232-interface. Climate control.

Cold-storage engineering:

Detection of temperatures during cold-storage transport and alarm signals when deviations occur.

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Monitoring transport of organs, stem cells, blood, etc. Ambulances and other transports.

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Busses, cars, lorries, taxis, fire engines, river craft, trailers (also on solar energy)

M2M (machine to machine)

Pilot/control your machines/pumps etc. via the internet without the help of mechanics.

Security/ safety:

Buildings with or without miniature cameras and/or sensors via wireless transmission.

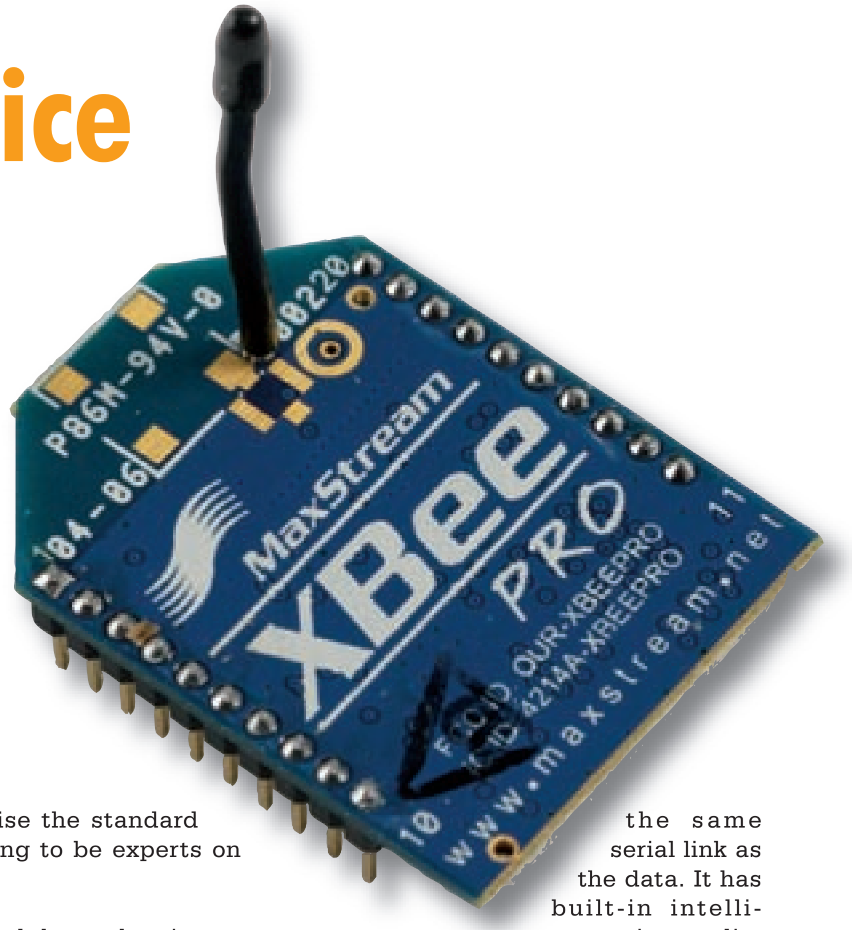
Police:

Various police services have already been equipped with TraceME modules + cameras in various countries.

ZigBee Transceiver

Xbee in practice

Fabrice André



We already introduced XBee in the November 2006 issue. These new wireless data transmission modules developed by Maxstream comply with the ZigBee standard. Now we present a circuit based on the XBee modules to show how they can be used in practice.

As already indicated in the previous article, it's time for a practical application based on the XBee modules. This article describes a ZigBee transceiver for connection to the serial port of a PC, along with a simple control program.

Brief background

Like WiFi and Bluetooth, ZigBee is a standard for wireless data transmission. However, it differs from the first two of these standards in that it is purely intended to be used for industrial applications, and it was specifically developed to satisfy the needs and requirements of the industrial environment. It should thus hardly come as a surprise that ZigBee leaves the competition behind with regard to energy consumption, transmission reliability, and cost. The catchy name us backed up by a whole consortium of large companies, which is known as the **ZigBee Alliance**.

Maxstream, which has a good feel for the importance of wireless communication trends for the industrial sector, has developed its own ZigBee transmission module, christened 'XBee'. Its biggest advantage is that it enables users to utilise the standard without having to be experts on the subject.

The XBee module works via a conventional serial TTL link. Its job is to form the data into packets and send it to another XBee module or another node that complies with the ZigBee standard. The XBee module is easy to configure using several parameters that are sent to the module via the same serial link as the data. It has built-in intelligence so it can distinguish parameters from data.

ZigBee interface

The circuit described here enables two computers to communicate reliably with each other via their COM ports.

Figure 1. A typical RS232/USB converter cable.

Obviously, you will have to build two copies of the circuit (one for each PC) for this sort of link. Here we took the approach of not only establishing a wireless link between two PCs (which isn't especially interesting by itself), but also developing a practical control program that can serve as the basis for an application that meets your own specific wishes.

At this point, some of our readers may be worrying about the compatibility of this circuit with new PCs that may not be equipped with anything as old-fashioned as a serial port. This doesn't have to be a problem, since a serial port emulated by a USB/serial converter(see **Figure 1**) is also perfectly satisfactory. The author checked this out using commonly available converters fitted with chips made by FTDI and Prolific.

Electronics

The circuit can hardly be regarded as complicated. If you've already glanced at the schematic diagram in **Figure 2**, this won't come as any surprise. There are three separate sections, viewed from left to right: the power supply, the transceiver (at the top), and the indicator portion (at the right).

The supply voltage can lie anywhere in the range of 8–20 VDC, and it does not have to be especially well filtered or regulated. Any AC adapter you happen to have lying around is probably more than adequate. The first component the supply voltage encounters is diode D2, which protects the circuit against a reverse-polarity connection. It is followed by a 7805, which provides a regulated 5-V supply voltage, and an adjustable regulator that generates a 3.3-V supply voltage for the XBee module. The output voltage of the LM317 is determined by voltage divider R10/R12. Although 5 V may seem rather low as an input voltage for a 3.3-V regulator, it does not present a problem with this arrangement, and it has the supplementary advantage that very little heat is dissipated in the regulator – in contrast to the 7805, which has to dissipate a considerable amount of heat and must be fitted with a small heat sink. The power supply section has buffer and filter capacitors in various places.

The DB9 connector (K1) is connected to one of the serial ports of a PC via a standard serial interface extension cable. Be sure to use a 1-to-1 cable instead of a crossover (null-modem) cable. Data is sent in both directions via this cable. An RS232/TTL adapter circuit (consisting of R1, R2, D1, T1, and R3) is connected to pin 3.

At the risk of stating the obvious, we must point out that the serial port of the computer work with symmetrical voltages and negative logic (see **Table 1**). This means that a voltage of –

Table 1

Logic level	PC	XBee	TTL
0	+12 V	0 V	0 V
1	–12 V	+3.3 V	+5 V

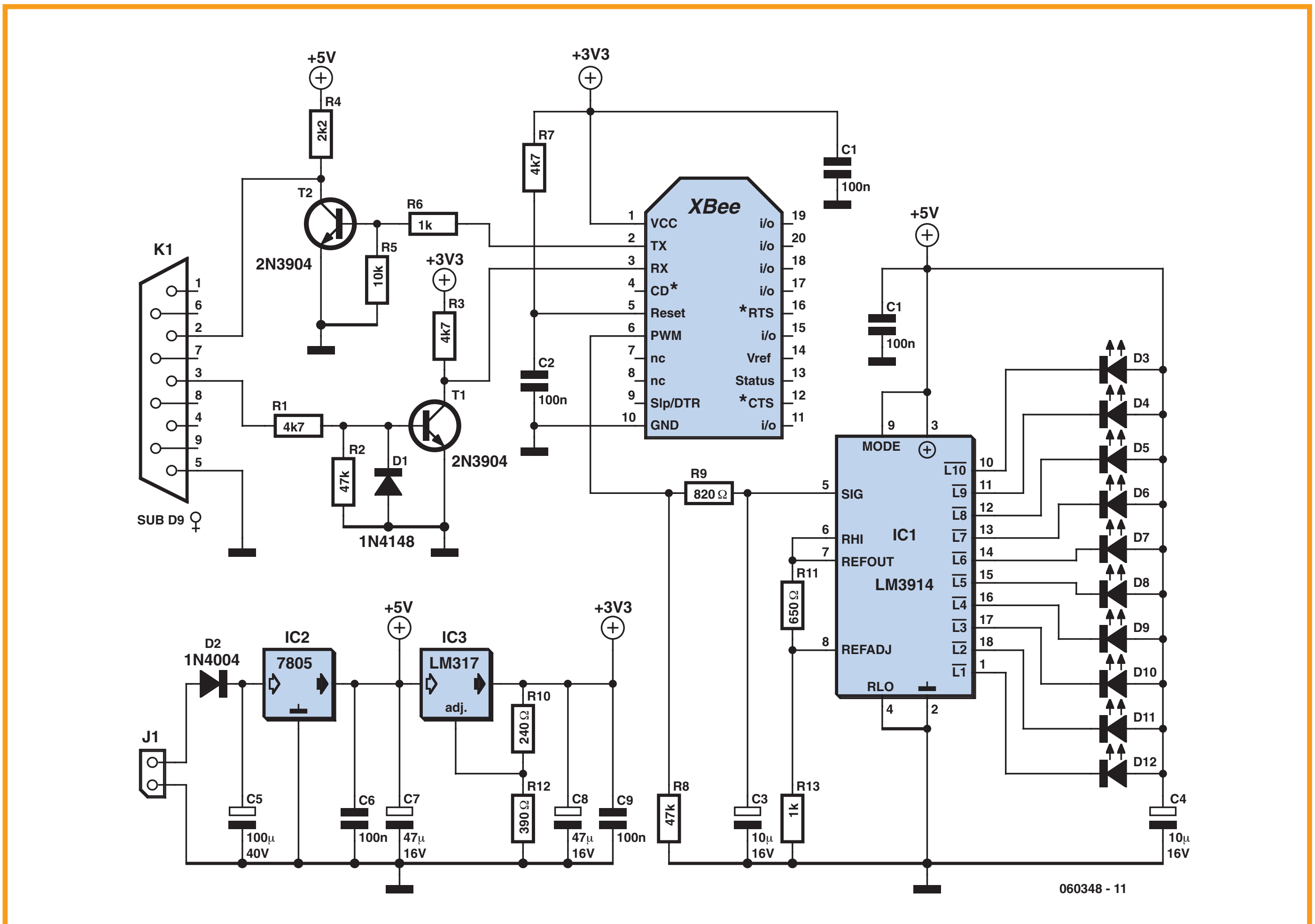


Figure 2. **Schematic diagram of a transceiver based on the XBee module.**

Operation 1

Command	+++	Xbee reply	**ok**	(receive mode enabled)
Command	**ATBD↵**	Xbee reply	**3**	('3' corresponds to 9 600 baud)

Operation 2

Command	+++	Xbee reply	**ok**	(receive mode enabled)
Command	**ATBD4↵**	Xbee reply	**ok**	('4' corresponds to 19,200 baud)

Operation 3

Command	+++	Xbee reply	**ok**	(receive mode enabled)
Command	**ATWR↵**	Xbee reply	**ok**	(all changes stored)

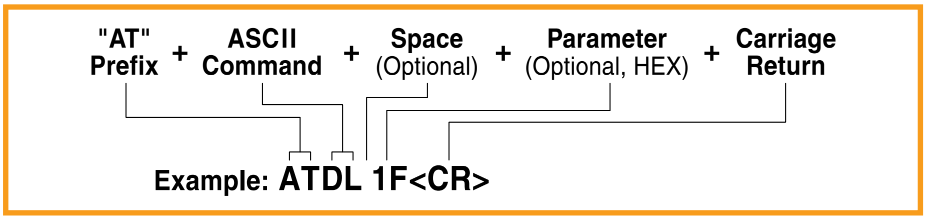


Figure 3. **Command structure.**

12 V appears on the transmit data (Tx) line when the PC puts a logic 1 on the data out line, and that would quickly spell the doom of transistor T1. This is the reason for protection diode D1. It reduces this 'hazardous' voltage to a value of –0.6 V, which the 2N3904 can handle. This voltage causes the transistor to be cut off, so a 'normal' logic 1 at a level of 3.3 V appears on the receive data line of the XBee module (pin 3) thanks to pull-up resistor R3.
The XBee module (which operates exclusively from 3.3 V) also transmits signals to the PC with a voltage of 3.3 V, so these signals must be adapted as well. This job is handled by R6, R5, T2 and R4, with the result that a 5-V signal is sent to the PC. Although this is considerably less than the nominal 12-V level the PC expects, it works perfectly in most cases.

Now let's look at pin 6 of the XBee module, which is the pulse width modulation (PWM) pin. The XBee module uses this pin to indicate the strength of the most recently received signal. The PWM signal is a pulse waveform with a fixed frequency of 120 Hz and a pulse width that depends on the signal strength. Here we use a low-pass filter formed by R9 and C3 to convert the PWM signal into a DC voltage. This network transforms the pulse width into an analogue value in the range of 0–3.3 V. For our mathematically inclined readers, we can remark that the charging curve of a *RC* network is logarithmic. This is ideal for our purpose, since we want to display the signal strength in dBm.

The analogue signal is fed to an integrated LED driver (IC1). This IC (an LM3914) displays the strength of the most recently received signal using ten small LEDs. It is configured in 'bargraph' mode via pin 9. The LEDs do not have separate series resistors to limit the current flowing through them. No resistors are necessary, since each LED output is a current source that is configured by resistors R11 and R13. The current in each LED is thus limited to 18 mA. It's perfectly possible to use other types of LEDs, depending on your taste or what you have in your components drawer. However, it may be necessary to adjust the current in the LEDs according to the following formula:

$$I_{LED} = 12.5 / R11$$

R11 also has another function: in combination with R13, it determines the full-scale voltage of the display, which means the voltage at which all LEDs are lit up (3.1 V in this case). Each time you change the value of R11, you have to calculate a new value for R13 using the following formula:

$$R13 = R11 \times 1.5$$

Data or command?

This brings us to an important topic. The XBee module has a single pin for receiving data and commands. Data is received by the internal UART and output directly via the antenna, while commands must never be transmitted.

The commands form the instruction set of the XBee module. They replace the commands used to communicate with a modem (Hayes or AT [A] [B] commands). The complete list is given in the device data sheet on the manufacturer's website.
Figure 3 shows the structure of a typical command. We are particularly interested in one of these commands: ATBD. It consists of two terms: 'AT", which are the first two characters of every Hayes command, and 'BD', which stands for 'baud rate'. The ATBD command refers the transmission data rate of the XBee module. As this is serial link, standardised data rates such as 1200 and 9600 are used here.

As data must always be transmitted but commands must never be transmitted, the XBee module must be able to tell them apart. This is handled by an in-house protocol devised by Maxstream.

The first thing you have to do is to put the XBee in the 'wait for command' state by sending three '+' characters in a row (+++ in ASCII), followed by the ATBD command and ending with a CR (Return) character to terminate the session. The XBee module analyses every command packet that it 'understands'. If the result is positive, the XBee module replies with a message consisting of 'OK' followed by a number that corresponds to the data communication rate (normally speaking 3, which corresponds to 9600 baud). The data sheet includes a table showing the relationship between the numbers and the data rates (see operation 1).

Here we queried the data transmission rate of the XBee module, but the rate can also be changed using the same procedure. Start by issuing '+++' again as described above, but this time add a data rate parameter between the ATBD field and the CR character (see operation 2).

From now on, the XBee module will operate at 19,200 baud. There's only one thing you still have to do: store this change in the internal memory of the XBee module so the setting will be retained even after power is switched off. Once again, you can do this using the same method as before (see operation 3).

Software

To make things more convenient for you, the author has written a small program in Visual Basic that considerably simplifies working with the XBee module. XBee Terminal (XBT) looks after the entire communication process. You can download the software file (**060348-11.zip**) from the *Elektor Electronics* website (www.elektor-electronics.co.uk). XBT is available in the form of a simple executable file or an installable program. The executable is intended for readers who already have a VB environment on their computers, while everyone else can use the installation program.

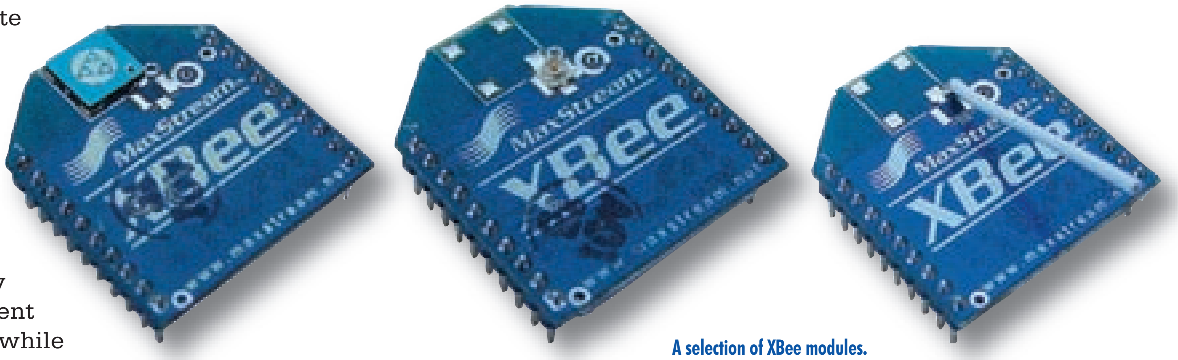
Simply connect the circuit to your computer, switch on the supply voltage, and launch XBT. A message at the bottom of the window will inform you that the serial port that the circuit board is connected to has not yet been opened. You have to open it now. Start by configuring the correct data rate (9600 is OK), and then click the icon at the top of the window corresponding to the port the circuit is connected to.
The serial port will be opened immediately, as indicated by a brief message (otherwise an error message will appear). To close the port, select 'COM' instead of a port number. A short message will also be displayed in this case. Don't forget that you have to close the port before you can change the data rate.
When the 'Opened' message appears, move the mouse pointer to the XBee Firmware dialog window and select 'Read version'. This causes the program to ask the XBee module for the version number of its firmware, which will be shown in the ASCII field immediately afterwards. You will see the previously displayed 'OK' message and a number (probably '106'), which indicates a particular release.
Now you can repeat the process of reading and setting the data rate of the XBee module, which we already described in detail above using commands. Click the 'Baud Rate' window and select 'Read Baud Rate'. XBT will send a read command to the XBee module, and the response will be displayed in the ASCII field. It will normally be '3', since the default setting is 9600 baud.

Next you can chose a different data rate as described in the previous example, such as 19,200 bits/s. Click the 'Baud Rate' window and select '19,200'. If you want to store the change in the XBee module, click the red button.
When you change the data rate of the XBee module, the data rate of the serial port of the PC must also be changed. XBT does this for you.
There are several other windows associated with 'Baud Rate', each belonging to an important command. If the command you need is not included, use 'Send command' or 'Command' with a suitable command, such as 'ATBD'. Leave the parameter field blank for a read command, or specify a parameter for a write command (such as '3' with the ATBD command to select 9600 baud).
If you want to send a message, enter it in the ASCII field and then click the 'Send' button.

Tricks and pitfalls

You may be working with two circuits connected to a single PC. In this case, connect each circuit to a different port of your computer and launch XBT twice. Then link each instance of the program to one of the modules as described above.
If you want to learn more about how XBT works, you're welcome to snoop. Take a female DB9 connecter and wire pins 2 and 3 together. Connect it to one of the serial ports of your computer and start the XBT program. All the commands you send using the XBT program will now be looped back and shown in the ASCII field.
If you decided to use an XBee module with an external antenna (see the previous article listed under 'References'), you may be wondering what sort of antenna is suitable for use with the module. The author recommends Yagi antennas, since they give good results and have a long range. You can also make your own antenna. A quick web search using 'Wifi antenna' as a keyword will turn up innumerable construction plans.

(060348-1)



A selection of XBee modules.

References

[1] ZigBee with XBee, Elektor Electronics, November 2006, pp. 64 ff

Web links

Hayes command set:
http://fan.nb.ca/cfn/info/help/com-prog/modemcommandslist.html
www.modemhelp.net/basicatcommand.shtml

ZigBee:
www.ZigBee.org

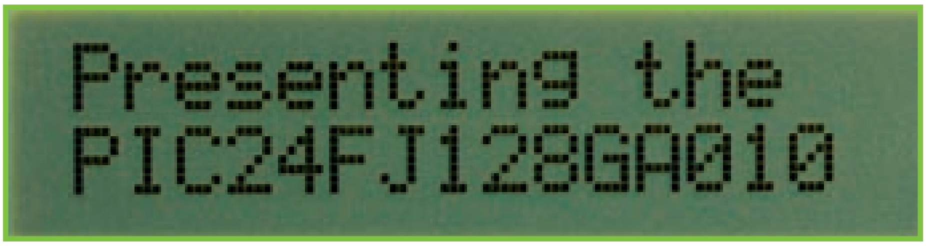
All about WiFi:
http://nl.wikipedia.org/wiki/Wifi

Maxstream:
www.maxstream.net/

Explorer-16 (3)

Part 3: Speaking Thermometer, CF card simulation and Crypto Puzzle

Jan Buiting & Luc Lemmens, in cooperation with Microchip Technology and Labcenter Electronics



More advanced (but still 100% free) simulation this month with a VSM model for media storage card devices added to our PIC24F system (all virtual, of course). To cap it all, solve a CF card crypto puzzle and win fantastic prizes sponsored by Microchip and Labcenter. But let's first revert to last month's Speaking Thermometer project.

Last month's Speaking Thermometer is not just a simulation you can run using three main components: (1) Labcenter's Proteus VSM, (2) Microchip Technology's MPLAB (both from your Explorer-16 CD-ROM) and (3) Elektor's archive file called *Demo2.zip*. All components, by the way, are free, the CD-ROM having come as a gift with the full print run of our January 2007 issue.

If you haven't done so already, please do run the January 2007 'Demo1' simulation of the Explorer-16 board itself. In the virtual environment created by Proteus VSM, press buttons and click away on other controls to your heart's content and see how the system responds with its various indicators.

'Demo2' from the February 2007 issue is funnier to see… and hear in actual use! Particularly if you simulate temperature variations and manage to create your own voice files.
The aim of these simulations is to teach you how both simple and complex PIC24F MCU software can be created and debugged to the highest possible level in combination with hardware devices like sensors and voice output (how's that for an actuator device). The hardware/software interaction can be put through its paces in VSM/MPLAB without having real components cluttering your desk or even appearing on the boss' Project Purchasing sheets. If you need still stronger encouragement: with simulation your PC does most of the design work for you, saving time and money compared to working with hardware components to achieve a design goal.

the simulations teach you how both simple and complex PIC24F MCU software can be created and debugged

While awe stricken with the power of the simulations and the degree of integration between the Labcenter and Microchip Technology products, let's not forget that the Speaking Thermometer design can be made to work in hardware too. For this, all you need to know is how to program the PIC24F PIM on the Explorer-16 demo board that's part of our **Explorer-16 Value Pack**.

Speaking Thermometer

The following is described to help you become acquainted with the hardware contained in the Explorer-16 Value Pack. Extensive product descriptions, user manuals and software installation guides being supplied on CD-ROMs in the Pack (take your time to read it all, it's worth the effort), we can concentrate on our specific requirements. An up to speed description is given assuming of course that you are reasonably conversant with PCs.

1. Plug the Audio PICtail board into the PICtail bus connector on the Explorer-16 board. Check that the PIC24F PIM is fitted on the demo board.

2. Plug the PICkit 2 module onto the 6-way pinheader on the Explorer-16 board **observing that the LEDs are at the side of the Audio PICtail Plus board** (see note supplied with Explorer-16 Value Pack).

3. Apply power to the Explorer-16 board (9-15 VDC at about 300 mA).

4. Install the software that comes with the PICkit 2 from your Explorer-16 Value Pack. Check that version 2.0 or higher is available as earlier versions do not have support for the PIC24F MCU series. If necessary, updates can be downloaded from the Explorer-16 project page on the Elektor website.

5. Plug the USB lead from PICkit 2 into a free USB outlet on your PC. Install the device by responding to the usual prompts and windows that appear. PICkit 2 will be automatically recognised from then on.

6. Run the PICkit 2 software (a shortcut will be available on your desktop). The program will report: 'PICkit2 found', and, importantly, 'PIC Device found' (in this case, the PIC24FJ128GA010 on the demo board).

7. Now click File → Import hex → Demo2.hex. You may need to Browse your system if you can't remember where you put the .hex file (see part 2).

Once the file has been found and selected, the PICkit 2 program says 'Hex file successfully imported' and you'll see the usual controls for a programmer like Write, Verify, Read, Erase. There is no need to activate either of the 'VDD Target' boxes.

8. Now click on Write and the hex file is sent off to the PIC24F target device on the demo board (**Figure 1**). The red LED in the PICkit 2 module will flash to indicate the system is busy. Wait for the process to complete.

9. Remove power from the demo board, wait a few seconds and power on again. The Speaking Thermometer will start and you will hear the "degrees Celsius" message from the mini loudspeaker on the Audio PICtail board. In some cases, the reset button has to be pressed to launch the application.

10. The current temperature can be requested by pressing pushbutton S4 on the demo board.

Explorer-16 project highlights

- **Economic and educational gateway to 16-bit microcontroller technology and simulation**
- **Explorer-16 Value Pack supplied at unbeatable price**
- **Free Proteus VSM, MPLAB IDE and MPLAB C30 supplied on CD-ROM**
- **Free simulation project files with instalments**
- **Explorer-16 demo board accommodates PIC24F/H and dsPIC33**
- **PICkit 2 suitable for PIC baseline / midrange / 18F / 24F/ dsPIC33 (updates available)**
- **PIC24F and dsPIC33 PIM modules available for standalone applications**
- **Written and supported by experts at Microchip Technology, Labcenter and Elektor**
- **Crypto Competition**
- **Interactive support through project page and forum on Elektor**

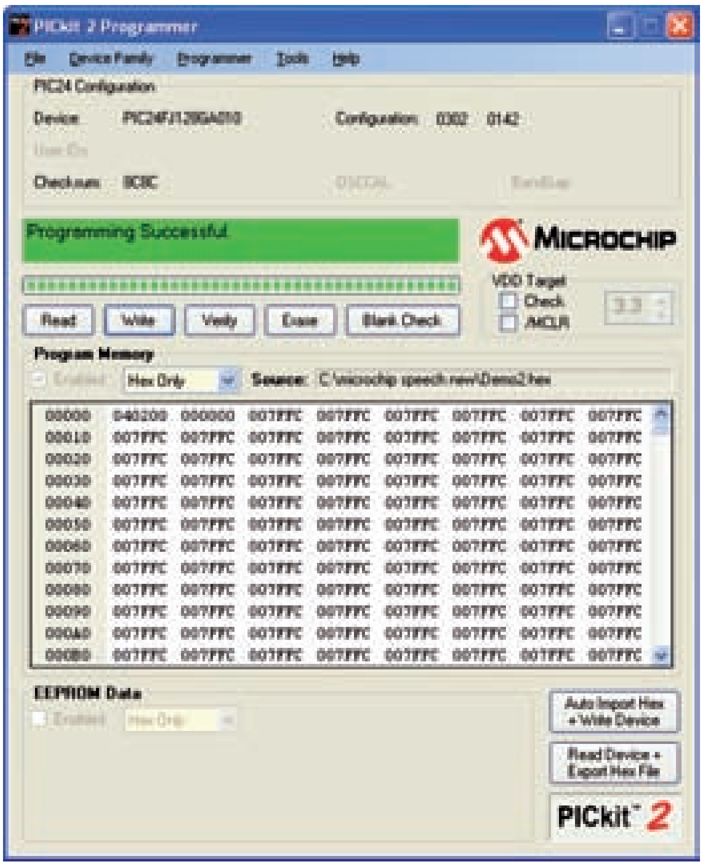


Figure 1. PICKit 2 has successfully loaded the hex object code file for the Speaking Thermometer and is ready to transfer it to the PIC24F target device via the plug-on pod.

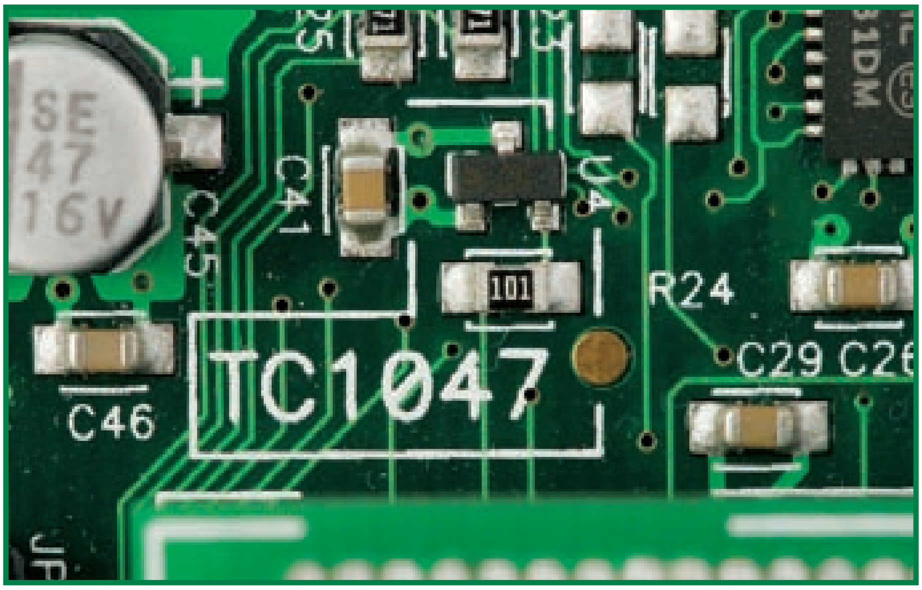


Figure 2. TC1047 temperature sensor on the Explorer-16 demo board. It is fully supported by the system software and easily addressed in C.

Figure 3. Extract of the C source code written for the Speaking Thermometer. Here, the ADC is read and the temperature translated to speech.

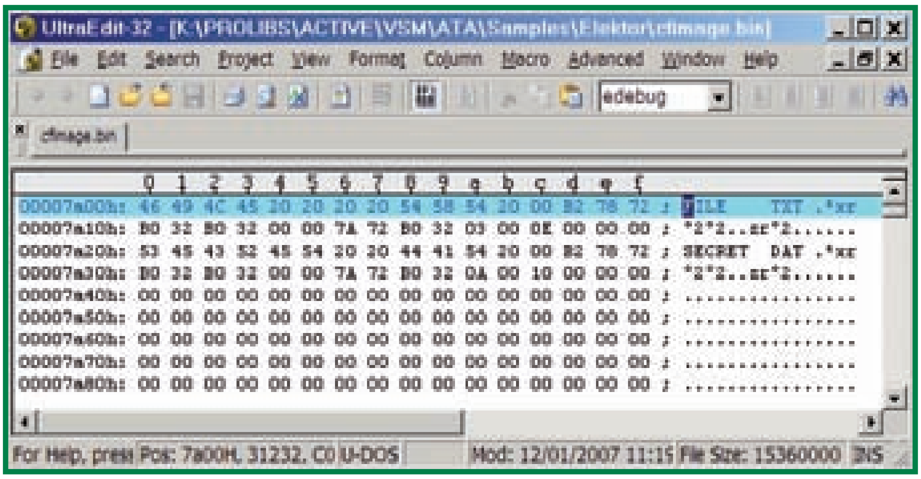


Figure 4. Directory table on a (virtual) Compact Flash card. The location 0x7A00 applies just to this sample image produced using UltraEdit.

For better sound reproduction, connect a set of powered PC loudspeakers to the jack on the Audio PICtail board.

TC1047

So where is the temperature sensor? Although not shown on last month's arrowed floorplan of the Explorer-16 demo board, it is actually near the PIM, see **Figure 2**. The tiny TC1047 device proves the simplicity of connecting sensors to a PIC24F MCU. The TC1047 datasheet is worth examining for your own projects hence it is available from the Explorer-16 project page.

Put your fingertip on the three-pin SMD for about five seconds and press S4 again.

An educational gadget

The Speaking Thermometer may look trivial but has a lot of potential for some really advanced programming in C. A code snippet of the program is shown in **Figure 3**. How about these challenges:

1. change the program to start speaking automatically when a temperature change of more than half a degree C is detected. Ditto, make an alarm sound when a certain temperature is reached.

2. create your own voice files. A tutorial on how to do this will be available from the Free Downloads Area on the Explorer-16 project page. You will find that this requires extra storage memory and the section below on CF cards will prove useful.

As you rise to these challenges you will be making extensive use the C30 compiler, Proteus VSM and the MPLAB environment. Remember, **everything can be simulated**, boosting confidence that the real thing will work spot-on. There is a lot to experiment with — let us know how you get on and post your findings in our online Forum.

Onwards with media storage cards

Now, let's move on to working with media storage cards using the PIC24F MCU and the Microchip Media Storage Library.

The virtual hardware for this part of the article is supplied and designed to be used with the demonstration ver-

CSI Miami needs help

COMPACT FLASH CRYPTO COMPETITION

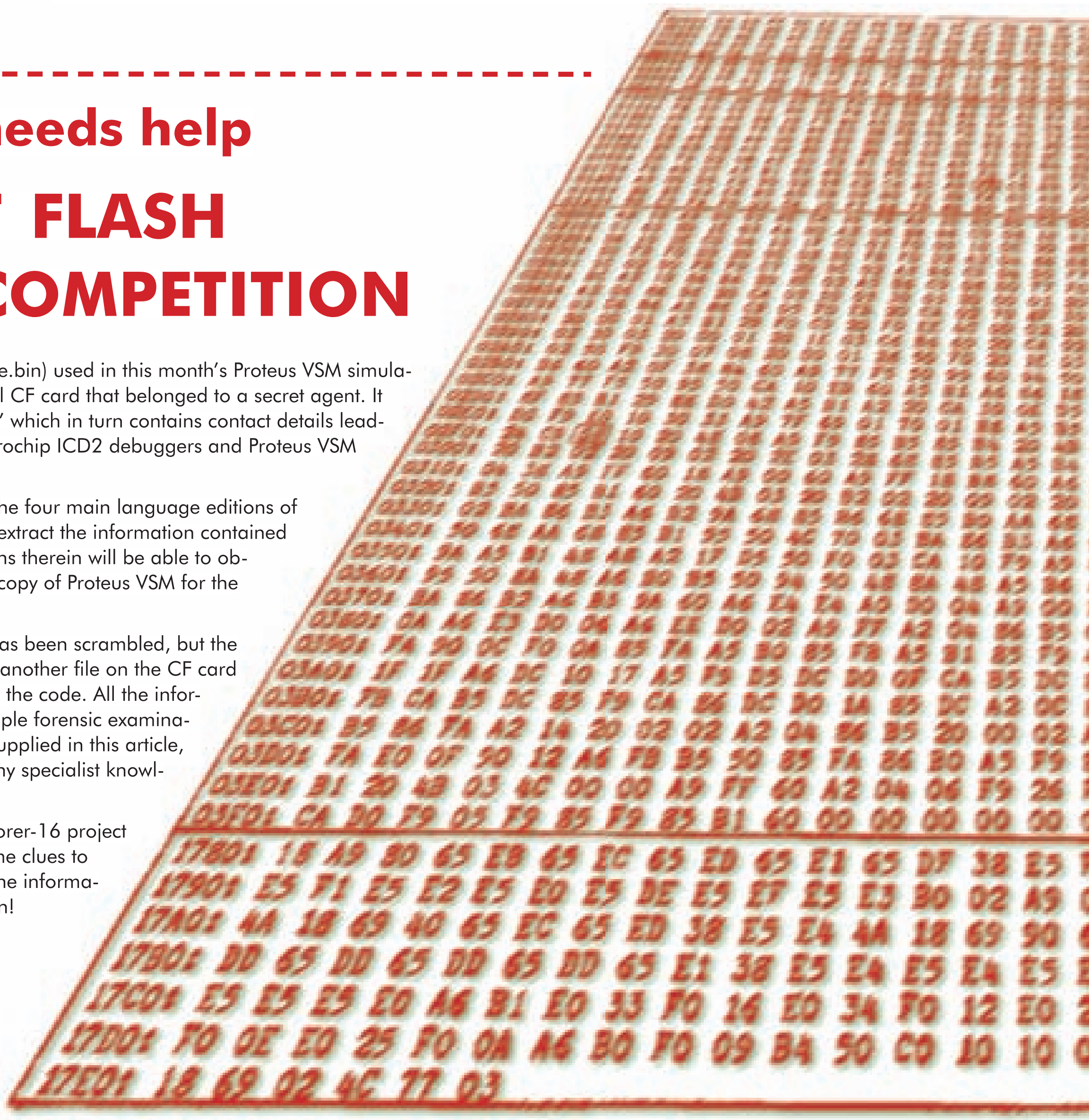
The compact Flash image (cfimage.bin) used in this month's Proteus VSM simulation was actually taken from a real CF card that belonged to a secret agent. It contains file a called 'SECRET.DAT' which in turn contains contact details leading to a limited source of free Microchip ICD2 debuggers and Proteus VSM software.

The first three readers of each of the four main language editions of Elektor (12 prizes in total) able to extract the information contained in the file and follow the instructions therein will be able to obtain a free ICD2 debugger and a copy of Proteus VSM for the PIC24FJ128GA010.*

Of course, the file 'SECRET.DAT' has been scrambled, but the secret agent was careless and left another file on the CF card that may prove helpful in cracking the code. All the information you need to perform a simple forensic examination of the card image has been supplied in this article, and you should not need to use any specialist knowledge of cryptography.

Via the Message Area on the Explorer-16 project page we may or may not post some clues to cracking the code and getting at the information leading to the prizes. Have fun!

Competition not open to employees of Microchip Technology, Labcenter Electronics and Segment b.v., its business partners and/or associated publishing houses.



sion of Proteus VSM supplied on the Explorer-16 CD that came with your January 2007 issue.

The design consists of a PIC24F, a simulated compact Flash card and an RS232 terminal. This is broadly equivalent to plugging in the Compact Flash PICtail plus card into the Explorer-16 demo board, and then attaching an RS232 terminal or terminal emulator to UART2 – in real life.

Also supplied is an example project, DEMO3.MCW, which makes use of the Microchip Media Storage Library. This library provides a simple file I/O API and implements an FAT16 storage structure on the media card. The Media Storage Library can work with both Compact Flash and SD/MMC cards, although in this article we shall be using it with Compact Flash only.

Useful background information on Compact Flash (CF) cards and the FAT16 format may be found in References [1], [2] and [3]. Things you need to know about these media include

- the fact that a CF card is run in ATA mode whereas an SD card is run in MMC mode;
- the Sector organisation of an ATA drive;
- the need for a filing system;
- the basics of FAT16 – directory tables etc.;
- the file CFIMAGE.BIN is a binary dump of the drive sectors.

the secret agent was careless and left another file on the CF card that may prove helpful in cracking the code

Figure 4 shows a hex dump of the directory table at 7A00h. A lot of clues on how the system is implemented in software can be obtained from it. Note that the exact location of the directory table will vary according to the size of a CF card.

Talking to the card in C

Provided you are reasonably conversant with the C programming language, you can review the file FileIO.c contained in **Demo3.zip** for each of the functions listed above. This will tell you how the various technical requirements for CF cards could be implemented for our PIC24F system. It should be noted that the Media Storage Library is still in the development phase at Microchip and the relevant disclaimers should be observed. Although Labcenter and Microchip have worked closely together to be able to of-

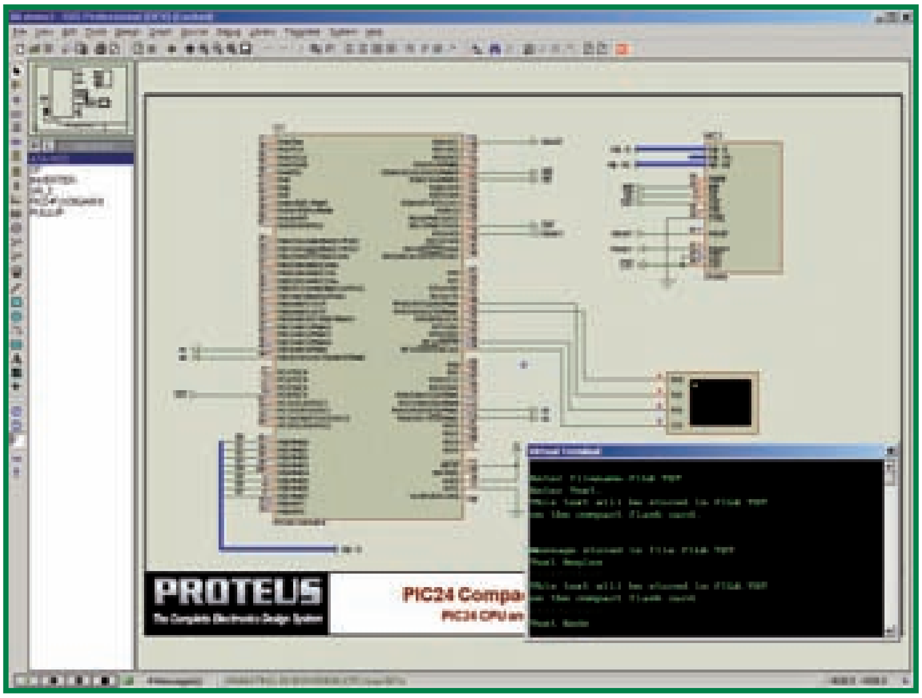


Figure 5. The CF card simulation again proves the sheer power and versatility of VSM combined with MPLAB.

fer you this exclusive first, you must be aware that the firmware is by no means a finished product.

This month's simulation

As before, the archive file you'll need to run this month's free simulation can be found on the Explorer-16 project page. Look for **Demo3.zip** in the Free Downloads Area. Download, store and open it as the previous two simulations in this series.

The code in the main file DEMO3.C allows you to choose a filename and then type some text to be stored in it. Filenames must be 8.3 format because it is a FAT16 storage system. The text entry mode can be ended by pressing Ctrl-Z. Once the file has been closed and 'written' to the CF card, the program re-opens the file and displays it on the terminal. The program uses some simple buffering so that data is written to and read from the storage device 512 bytes at a time. The simulation is shown running in **Figure 5**.

Next month

We will close off the series by turning the Speaking Thermometer into a multi-lingual device. This will nicely combine the methods of creating your own voice files from scratch and file storage on CF cards — with different cards used for each language.

(060280-III)

References

[1] Compact Flash Interface for Microcontroller Systems, Elektor Electronics December 2002.

[2] Data Storage on CompactFlash (CF) Cards, Elektor Electronics March 2004.

[3] CompactFlash (CF) Interface, Elektor Electronics June 2003.

Project news, free downloads & updates for this are available from the Explorer-16 project page at
www.elektor-electronics.co.uk/explorer-16

and the 'Explorer-16' topic on the Forum at
www.elektor-electronics.co.uk/default.aspx?tabid=29&view=topics&forumid=22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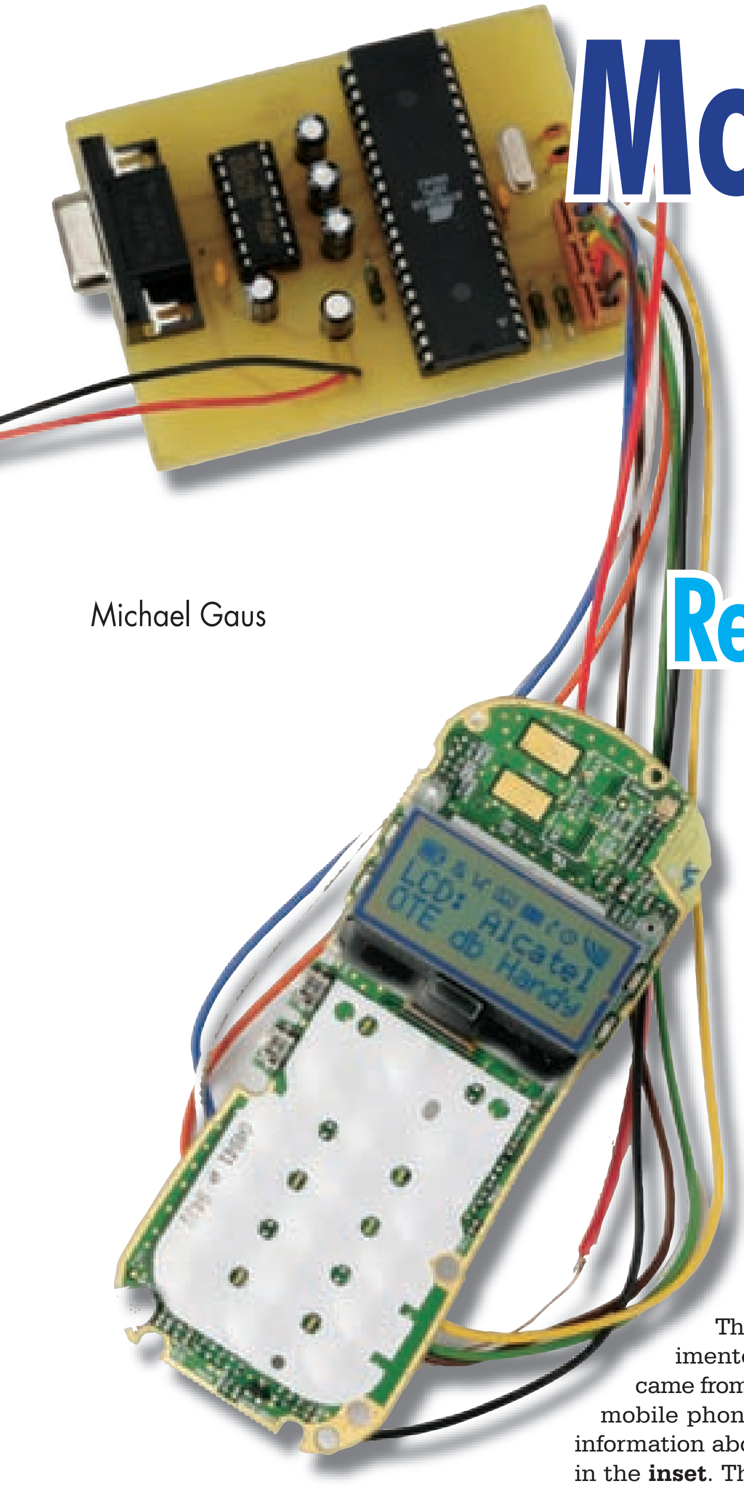

Recycling Alcatel LCDs

Michael Gaus

The biggest obstacle to reusing old mobile phone parts is usually the lack of datasheets. Undeterred, the author has managed to work out how to use the display from an Alcatel phone purely by analysing the printed circuit board and data protocol. As a result he has made it possible to drive the display from an ATmega16 microcontroller.

The display that we experimented with for this project came from an old 'Alcatel OTE db' mobile phone. The most important information about the display is given in the **inset**. The display is controlled serially using the SPI protocol and so only a few wires are required to drive it from a microcontroller. The pinout and protocol were deduced by 'reverse engineering' a (still working) phone with the aid of an oscilloscope to spy on the signal lines. This research enabled us to determine how to drive the display and its character set. The tangible result of all this is the ATmega16 board described here and the firmware residing in it, which together provide an LCD interface that can be connected to the serial port of a PC and controlled using a terminal program. The freeware program LCDHype lets the display be coupled to the Winamp MP3 player to display track title information. A plug-in is available for LCDHype that allows you to track the progress of Ebay auctions on the salvaged LCD, and you will no doubt think of other applications (and post them on the *Elektor Electronics* forums!).

Display characteristics

Display type:	Alphanumeric plus 8 annunciators
Rows:	Two plus annunciator row
Characters per row:	12
Annunciators:	8
Interface:	SPI
Operating voltage:	approximately 3 V (in the mobile phone, 2.9 V)

Mobileware

In the mobile phone the LCD, keypad and LED backlight are all mounted on the same printed circuit board (see photograph). The simplest approach is not to try to desolder the LCD but to use the circuit board as it stands. The control signals can easily be attached to using the solder pads labelled J800 (**Figure 1**). It may even be possible to find a use for the keypad, which is wired in a matrix organisation. It is also possible to detach the LCD from the circuit board without damaging it

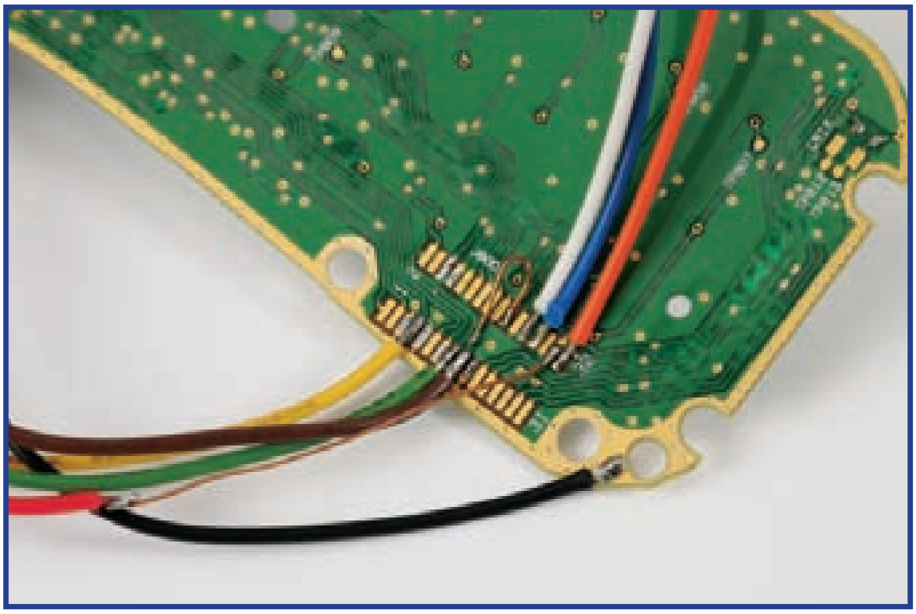

Figure 1. Signal connections on the Alcatel printed circuit board.

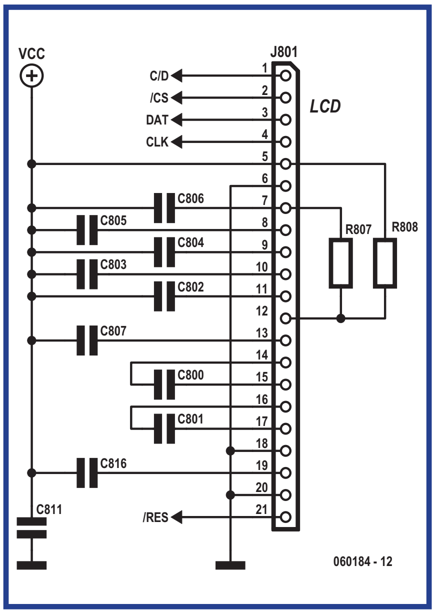

Figure 2. Wiring of the LCD on the original board.

Table 1. LCD pinout on LCD connector J801 and on circuit board connector J800:

Pin (J801)	Pin (J800)	Name	Description
1	7	C/D	Select command or data byte: 0 = command, 1 = data
2	15	$\overline{\text{CS}}$	Chip select, active low
3	26	DAT	SPI data, MSB first
4	24	CLK	SPI clock, maximum 1.8 MHz; data are transferred on the rising edge of the clock
5	17	VCC	Supply voltage, 2.9 V
6, 18, 20	5, 9, 18, 19, 22	GND	Ground
21	32	$\overline{\text{RES}}$	Reset, active low, minimum pulse length 100 µs
-	20	LED_V+	Supply voltage for LED backlight, approximately 3 V
-	30	LED_CTRL	Control input for LED backlight: 10 kΩ series resistor required!

For the wiring of the remaining LCD pins, see Figure 2.

Table 2. One-off initialisation sequence after reset:

Command (hex)	Data (hex)	Notes
A8	E5	
61		
31		
42		
80	00 … (32 times)	
B0	24 … (12 times)	Fill row 1 with space characters
C0	24 … (12 times)	Fill row 2 with space characters
D0	24 … (12 times)	
E0	00 … (12 times)	Blank out annunciator row
A8	1F	
30		
41		
50		
80	07 08 1E 08 1C 08 07	
31		
42		
57		
A8	12	

Note: when sending commands and data the $\overline{\text{CS}}$ signal must be held low.

by desoldering the flexible cable connections. The naked display requires a few external components to operate correctly, such as capacitors for the charge pumps that generate the various required bias voltages: see the LCD wiring in **Figure 2**. The components needed can be desoldered from the original circuit board. **Table 1**, in combination with Figure 2, gives the complete pinout of the LCD.

Control

All the driver functions are implemented in the firmware in the ATmega16. If you simply download the firmware (from the *Elektor Electronics* website, file no. **060184-11.zip**) and program it into the microcontroller, and use the interface board (circuit diagram shown in **Figure 3**, printed circuit board in **Figure 4**) you need not concern yourself

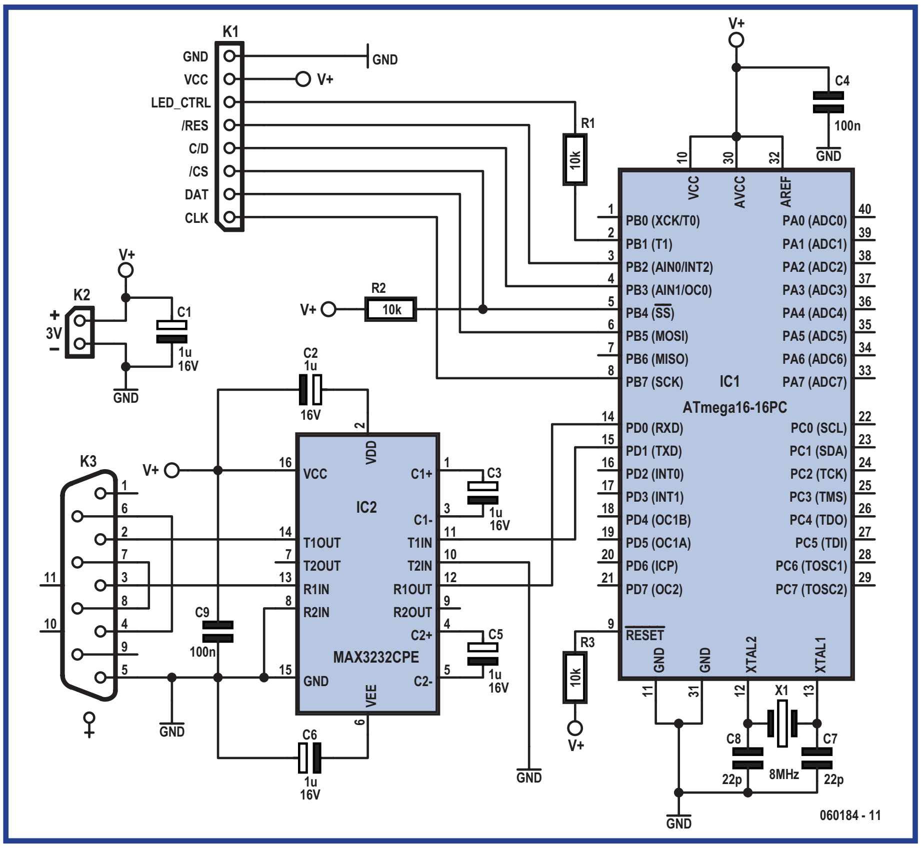

Figure 3. Circuit diagram of the LCD interface board, using an ATmega16.

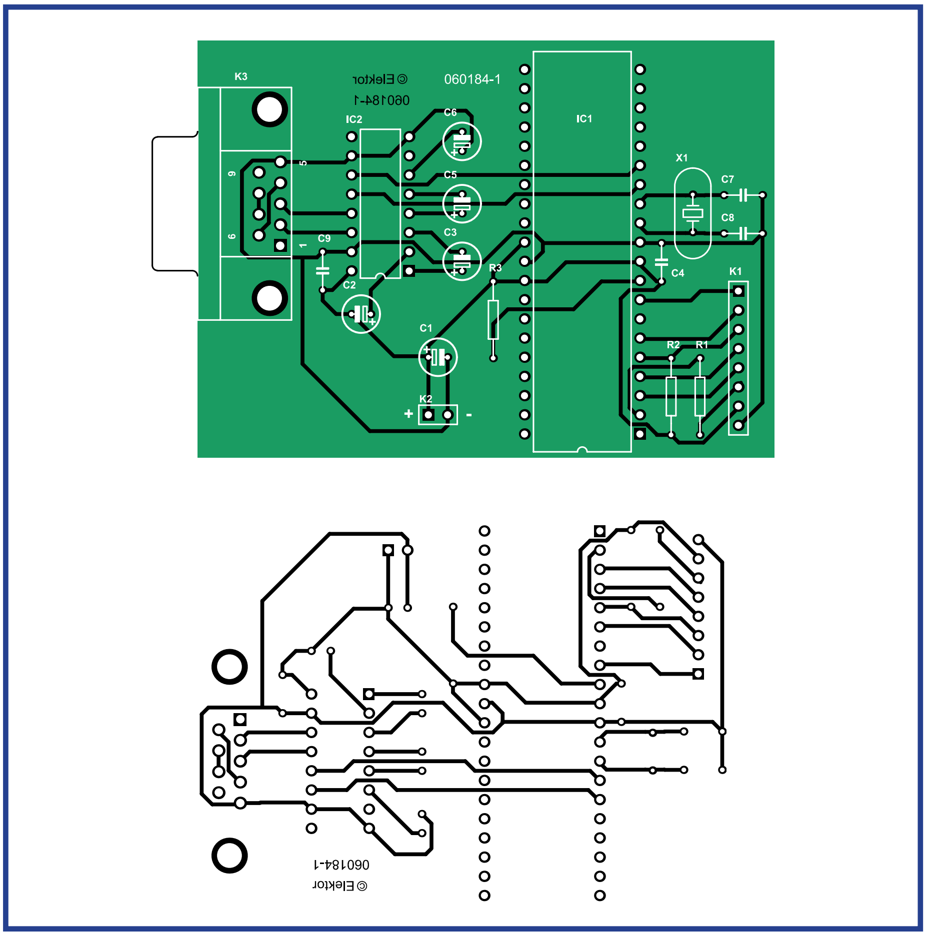

Figure 4. Layout and component mounting plan for the printed circuit board.

with the minutiae of how the display is controlled. However, the details are interesting, and essential if you are considering more advanced applications, and so we shall take a brief look.

Initialisation: the LCD requires a hardware reset on power-up (using the signal $\overline{\text{RES}}$). The following sequence can be used: wait 250 ms; set $\overline{\text{RES}}$ to be an output and set it high; wait 1 ms; set $\overline{\text{RES}}$ low; wait 1 ms; set $\overline{\text{RES}}$ high. After reset a one-off initialisation sequence must be carried out. The necessary commands and data are given in **Table 2**. The /CS signal must be taken low during the transmission of commands and data.

Text output: alphanumeric characters can be produced on the display one row at a time by sending a command byte, which selects the row to be written, followed by 12 data bytes giving the codes for the wanted characters:

Row 1:
command byte 0xB0 followed by 12 character code bytes;

Row 2:
command byte 0xC0 followed by 12 character code bytes.

The character set table is given as a PDF file available for free download from the *Elektor Electronics* website, see **Extra Info** on the web page for this article. The standard ASCII code

COMPONENTS LIST

Resistors
R1,R2,R3 = 10kΩ

Capacitors
C1,C2,C3,C5,C6 = 1µF 16V radial
C4, C9 = 100nF
C7, C8 = 22pF

Semiconductors
IC1 = ATmega16-16PC, programmed, order code **060184-41**
IC2 = MAX3232CPE

Miscellaneous
K1 = 8-way pinheader
K2 = 2-way pinheader
K3 = 9-way sub-D socket (female), angled pins, PCB mount
X1 = 8MHz quartz crystal
PCB, ref. 060184-1, from The PCBshop (see www.elektor-electronics.co.uk)

for digits, letters and so on are offset in the LCD controller's character set by four places. For example, the letter 'A' (ASCII code 0x41) has code 0x45.

Annunciators: the annunciators effectively form their own row of 12 characters, where a total of eight positions (1, 3, 5, 6, 8, 9 and 12) are occupied. The other characters are not visible. Within each character the annunciator is activated by setting the appropriate bit. Annunciator row: command byte 0xE0 followed by 12 data bytes to control the annunciators. The required codes are also given in the PDF download.

Firmware and PC software

If the ATmega16 printed circuit board is not connected to a PC, the firmware (written for the Codevision C compiler) will activate all the annunciators and display the text 'LCD: Alcatel OTE db Handy' ('Handy' being the German word for 'mobile phone'): see **Figure 5**. If the board is connected to the serial port of a PC (straight-through cable, 9600 baud, no parity, one stop bit) it is possible to write text directly to the display using a terminal program. Sending binary codes (for example to switch the backlight on and off) using Hyperterminal under Windows is somewhat awkward: more suitable freeware alternatives are available. The firmware supports cursor movement commands, switching the backlight on and off, and text output. The cursor movement command is:

```
<Esc> [ <row> ; <col> H
```

where <row> is the row number as an ASCII value (0 = annunciator row, 1 = text row 1, 2 = text row 2), and <col> is the column number as an ASCII value (from 1 to 12).

Figure 6 shows an example screenshot from a terminal program. In the lower window we can see the codes that need to be sent to the display to move the cursor to column 3 in the second row: <Esc> is the first code (hex 0x1B, decimal 27), followed by the ASCII codes for '[' (0x5B), '2' (0x32, representing the second row), ';' (0x3B), '3' (0x33, representing the third column) and finally the letter 'H' (0x48).

The backlight is switched on using <Esc> 1 and switched off using <Esc> 0, where 0 and 1 are binary values (not ASCII!). **Figure 7** shows the relevant part of the terminal window when the backlight is being turned on: other settings are as in Figure 6.

The freeware program LCDHype [1] mentioned earlier provides a scripting language to allow arbitrary text to be displayed on the LCD connected to the PC. For example, this might include track title and artist information or spectrum analyser output from the Winamp MP3 player program. In principle any LCD could be used, as long as a suitable driver is available.

A driver has been developed for the Alcatel display, and is available for free download from the *Elektor Electronics* website. If you follow the instructions in the accompanying readme.txt file, the display will show the title information and the spectrum readout in the lower row (see **Figure 8**). The LCDHype website describes further application, including the 'Ebay display' mentioned above.

(060184-I)

Figure 5. Display when the interface board is switched on.

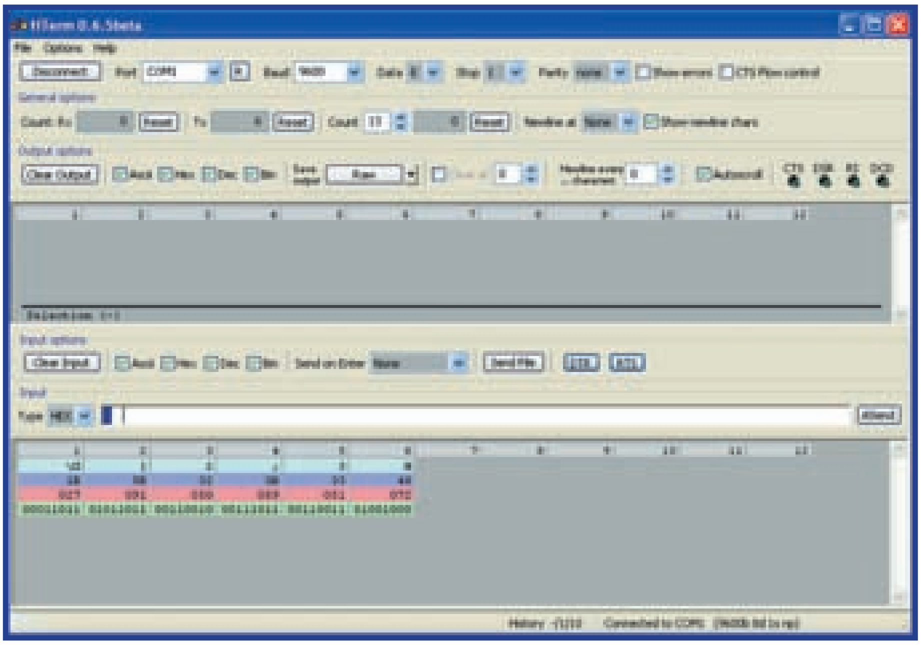

Figure 6. Terminal window showing cursor positioning command.

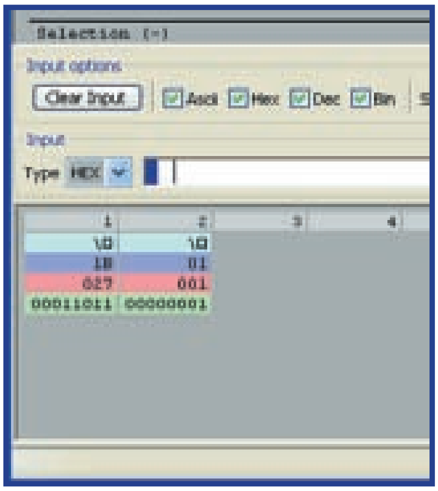

Figure 7. Part of terminal window showing the command to switch on the backlight.

Reference:

[1] www.lcdhype.de

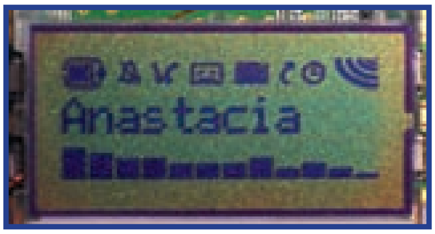

Figure 8. Display of artist name and spectrum analyser output from Winamp on the Alcatel LCD.

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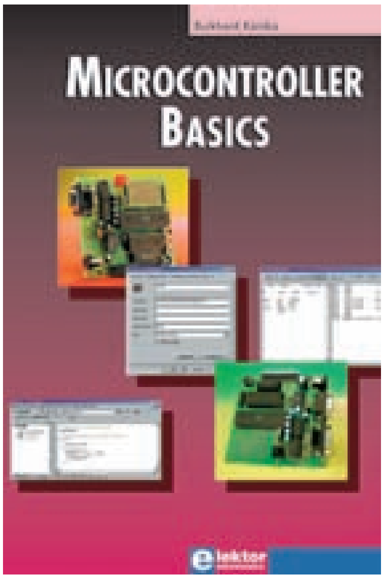

Microcontroller Basics

Burkhard Kainka

Microcontrollers have become an indispensable part of modern electronics. They make things possible that vastly exceed what could be done previously. Innumerable applications show that almost nothing is impossible. There's thus every reason to learn more about them, but that raises the question of where to find a good introduction to this fascinating technology. The answer is easy: this Microcontroller Basics book, combined with the 89S8252 Flash Board project published by Elektor Electronics. This book clearly explains the technology using various microcontroller circuits and programs written in several different programming languages. In the course of the book, the reader gradually develops increased competence in converting his or her ideas into microcontroller circuitry.

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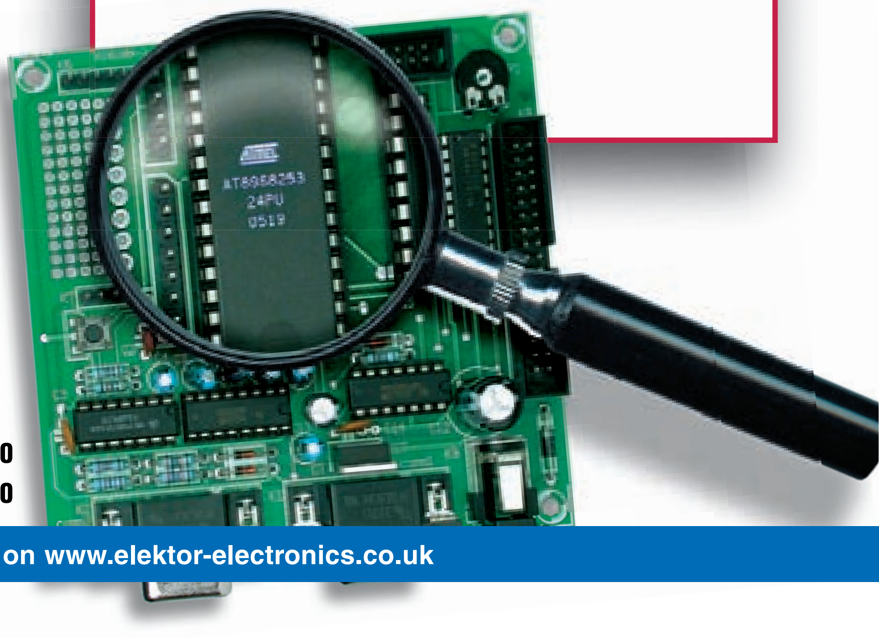

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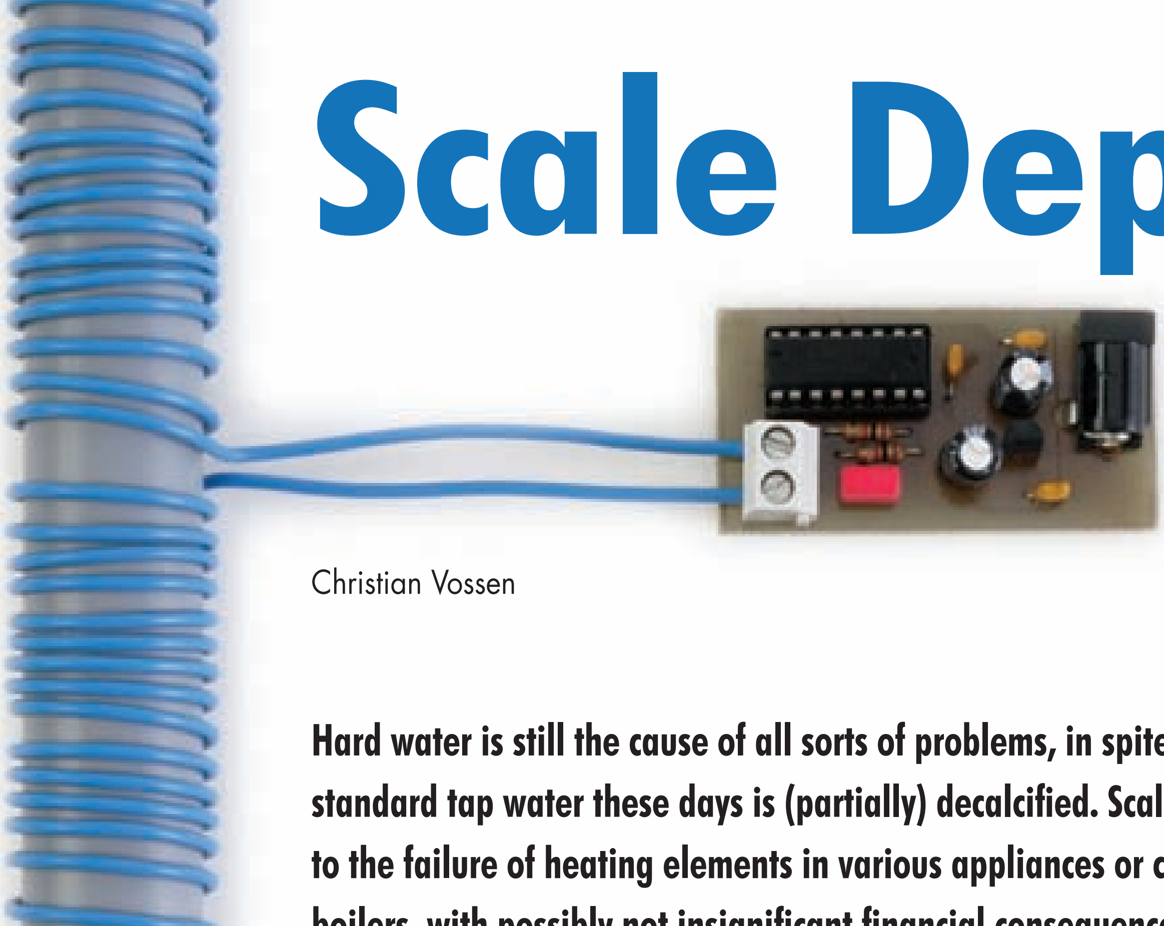
Scale Deposit



Christian Vossen

Hard water is still the cause of all sorts of problems, in spite of the fact that standard tap water these days is (partially) decalcified. Scale deposits can lead to the failure of heating elements in various appliances or cause blockages in boilers, with possibly not insignificant financial consequences. Fortunately it is quite easy to do something about it!

Although the water supplied by nearly all utilities these days is (partially) decalcified, it can still be worthwhile to soften the water a little more. Assuming a hardness of 8 German degrees (°D) — not uncommon in the UK — there is still a moderate amount of calcium hydrogen carbonate dissolved in the water. If the water is heated, then insoluble calcium carbonate is formed (this is popularly referred to as calcium or scale deposits). The very fine calcium carbonate particles deposit mainly on the hot parts of appliances that heat water and form the notorious scale (for example on the heating element of a washing machine or the bottom of a cooking pot).

There exist a number of methods to make hard water soft which make clever use of chemical processes. One method that does not involve chemistry requires the application of a very strong magnetic field. When the water flows through such a field, larger calcium particles are formed by coagulation which do not deposit quite so easily onto a surface. The result: no calcium stains on sanitary fittings and no scale deposits on heating elements.

The water has not really been made any softer after this treatment because all the calcium is still there, it is just that it is not causing us any trouble any more. In addition, we don't really need to get rid of this calcium anyway because this mineral is only harmful to appliances but not to humans (quite the contrary).

Whether such an (electro)magnetic water-'softener' actually works is a topic of fierce debate with widely ranging opinions. Feel free to Google the Internet for more information on this subject.

Whatever can be done with a magnetic field can also be done (or at least it appears that way) with electromagnetic fields. With a handful of parts for just a few pounds we can make such an electronic water softener ourselves.
The circuit drives a couple of coils that function as transmitting antennas. They are wrapped around the water pipe, so that an electromagnetic field (the radio waves) is induced in the water. In order that both the magnetic as well as the electric field components of the radio waves can penetrate into the water it is best that the coil antennas are wound around a (section of) plastic water pipe.

Schematic

The operation of the circuit is as follows (refer to **Figure 1**). An oscillator is built around two of the inverters in IC1 with R2 and C1. This oscillator is tuned to about 2 kHz (t = 2.2 R2C1). This signal is subsequently buffered by two inverters connected in parallel and sent to coil L1. This signal is inverted again and connected to coil L2, so that between the two coils there is a square-wave voltage with a peak-to-peak value that is double that of the power supply voltage. The supply voltage is regulated with a 78L09.
You can easily make the coils yourself from copper wire with a diameter of about 1 mm. Take two pieces of about a meter long (depending on the diameter of the water pipe and the desired number of turns) and make with each wire about 15 turns around the water pipe. It is best if the windings are separated from each other a little. Make sure that the winding direction is the same for both coils. Refer also to **Figure 2**.
For the power supply you can use any

Fighter a simple water softener

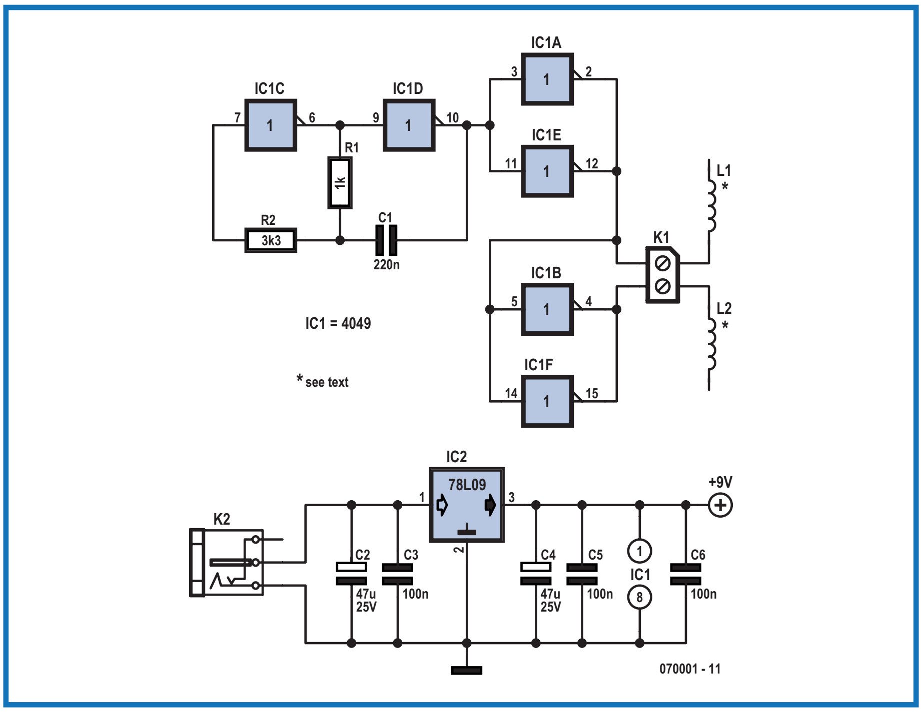


Figure 1. The schematic comprises only 10 components and 2 connectors.

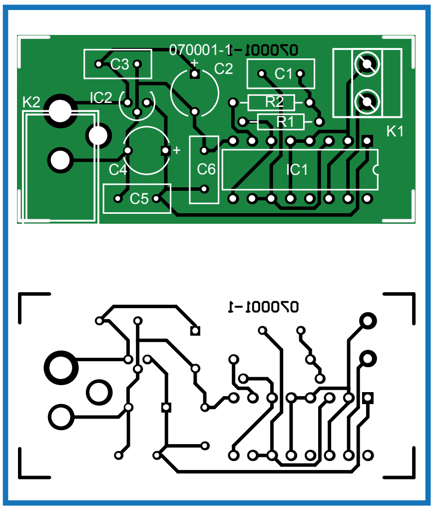


Figure 3. The PCB layout is not very difficult at all with so few components.

spare mains wall adapter that supplies a DC voltage in the range from 12 to 15 V.

Experimenting

There is of course plenty of scope to experiment with this circuit: you can put the windings closer together, increase the frequency, reverse the winding direction of the coils, change the location of the coils on the water pipe, try whether the coils work better around a copper pipe or a plastic one (the latter has our preference), and many more. How much effect this circuit ultimately has can only be established over the long term. Some users of such electronic water softeners (which includes a few colleagues) are wildly enthusiastic about them, while others assert that they notice absolutely no difference. So just try it for yourself, you can build this circuit for a mere few pounds and that is considerably cheaper than similar read-made devices that can be bought in the shops for this purpose.

(070001-I)

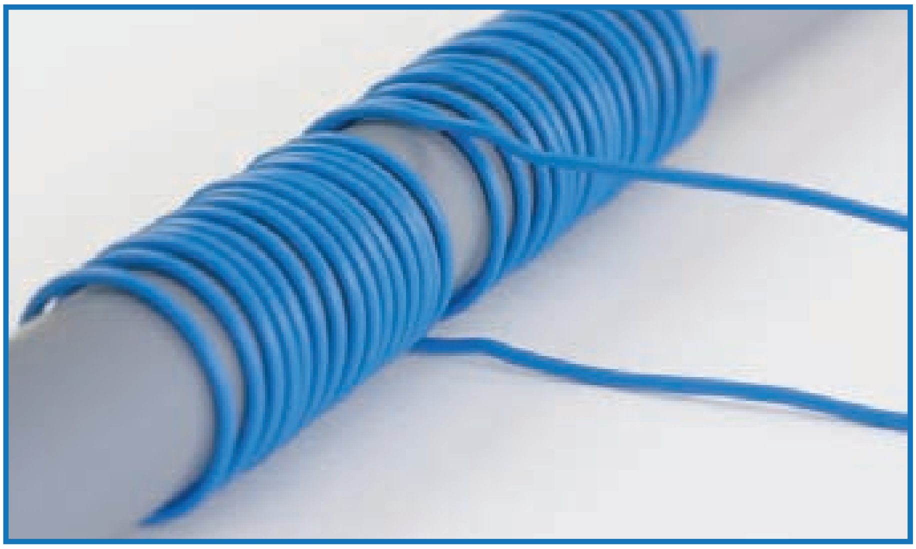


Figure 2. The coils L1 and L2 consist of about 15 turns which are placed next to each other.

COMPONENTS LIST

Resistors
R1,R2 = 1kΩ

Capacitors
C1 = 220nF
C2,C4 = 47µF 25V
C3,C5,C6 = 100nF

Semiconductors
IC1 = 4049
IC2 = 78L09

Miscellaneous
K1 = 2-way PCB terminal block, lead pitch 5mm
K2 = DC adapter socket
PCB, ref. 070001-1, from ThePCBShop (see www.elektor-electronics.co.uk)

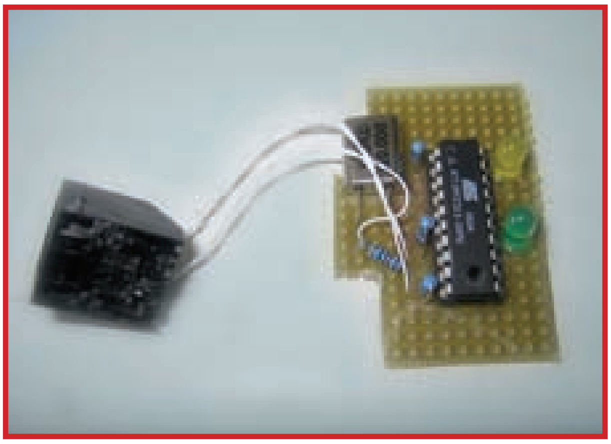
Ethermeter

An alternative network cable tester

Jeroen Domburg & Thijs Beckers

Although wireless networks are becoming more popular these days, cabled networks are still in widespread use. They are usually faster, cheaper (equipment-wise), more secure and easier to configure. One disadvantage of such a hard-wired connection is that the information carrier (the cable) can sometimes give up the ghost. We have designed this circuit to provide a simple test of the connections.

In larger networks it sometimes happens that a cable no longer makes a good connection or has simply been plugged into the wrong socket on the switch. This makes it more difficult to configure the network or to find out where the problem is when things go wrong.



The number of components in this circuit is so small that it can easily be built on a left over piece of experimenter's board.

An empty breath refreshers tin was used for the enclosure. It's just big enough to take three AAA batteries, the circuit board and the connector.

Network problems

For the first type of problem the average network technician will have a useful tool in his toolbox: a cable tester. This usually consists of two boxes, which are connected to the ends of the cable to be tested. One of the boxes will then put a voltage on each of the eight cores of the cable, one at a time. The box at the other end will indicate with LEDs if this voltage has been detected and if it came through the right signal line.

In practice there can be many other causes of failure than just the cable. The connector on the switch may have oxidised or a spike induced in the cable by a nearby lightning strike may have damaged the switch input.
In places where several switches are used or where there are long cable runs it can be difficult to find the other end of the cable. In a perfect world all patch leads should be clearly numbered and for each number it should be documented where the connection ends up. In practice you'll find that several undocumented mutations have occurred in the cabling. In those circumstances it is very difficult to find the other end of the cable and plug it into the second half of the cable tester.

Analysis and implementation

The circuit presented here has been designed to overcome these problems. It works as follows: The suspect cable is connected to the tester. If no problems are found with the cable the corresponding LED on the switch where the other end of the cable is plugged into will start flashing. This makes it easy to spot which connection belongs to the cable. You should be able to tell quickly if the cable (or at least the two cable pairs required for 10/100 Mbit communications) is faulty.

Although the idea itself may appear simple, it doesn't mean that the implementation will also be easy. To make an LED flash on the switch you need more than just a certain voltage on the cable or a continuity between cables. To understand how to do this we need to find out more about how an Ethernet link works at the physical level.
An Ethernet cable consists of four pairs of conductors, of

About the author

Jeroen Domburg is a student at the Saxion Technical University in Enschede, the Netherlands. Jeroen is an enthusiastic hobbyist, with interests in microcontrollers, electronics and computers.

In this column he displays his personal handiwork, modifications and other interesting circuits, which do not necessarily have to be useful. In most cases they are not likely to win a beauty contest and safety is generally taken with a grain of salt. But that doesn't concern the author at all. As long as the circuit does what it was intended for then all is well. You have been warned!

which only two are used for 10 Mbit and the most commonly used type of 100 Mbit. The method of communications over these wires differs between 10 Mbit, the various versions of 100 Mbit and 1000 Mbit Ethernet. But since we only want to test the cables and light up an LED on the switch, it is sufficient to look at just the 10 Mbit specification.

The specification for the Ethernet protocol is known as the 'IEEE 802.3 LAN/MAN CSMA/CD Access Method'. This can be freely downloaded from the IEEE website [1]. Amongst other things, it describes the different transport layers for 10 Mbit Ethernet, such as coaxial cable, thicknet, glass fibre and UTP. From this document we've extracted a few specifications that are relevant to our UTP based tester.

The four signal lines used are called Tx+, Tx–, Rx+ and Rx–. The transmission of data over UTP is differential. This means that when Tx+ becomes positive, Tx– becomes negative and vice versa. This is a standard method used to prevent electromagnetic interference (the same method is used for RS422/RS485).

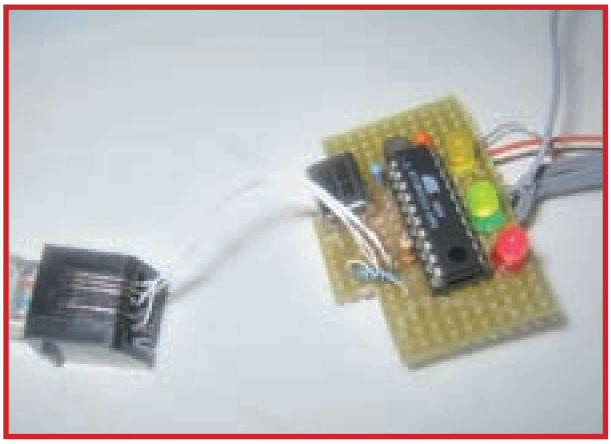
10 Mbit makes uses of Manchester encoding to put 'ones' and 'zeroes' onto the signal line. This means that a '0' is represented by a low-high transition, while a '1' is represented by a high-low transition. This results in there always being enough transitions during a transmission to extract the clock signal. The average voltage on the signal lines stays at 0 V.

The voltage of the signals should be between 2.2 V and 2.8 V. To show when a link is active, use is made of so-called Link Integrity Test pulses (LIT, also known as Normal Link Pulse or NLP). These are pulses with a pulse-width of 1 bit period (1/10,000,000=100 ns). These pulses are sent every 16 ms, as long as there is no other network traffic. To send a link signal it is sufficient to put a 100 ns pulse onto the line every 16 ms.

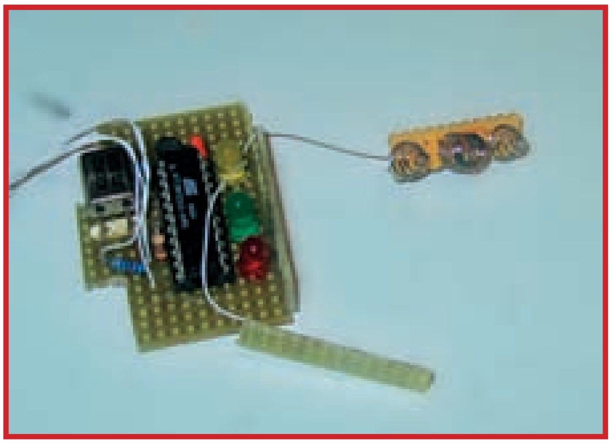
To check that there is a connection from the switch we have to detect signals with a voltage from 2.2 V to 2.8 V. If these are present we can assume that there is a switch at the other end of the cable that is sending either LIT pulses or network traffic.

Another ATtiny2313

Although it is possible to build a circuit that can create and detect the required signals using only discrete TTL ICs, to make life easy we decided to make use again of the Atmel ATtiny2313 AVR (see **Figure 1**). This has a clock that runs at 20 MHz, so the sending and detecting of LIT signals shouldn't be a problem.
Ethernet signals should normally be galvanically isolated,



The circuit is at a working stage. Now we just add the supply (batteries) and mount it into a box.



Using two cut-offs and a pair of battery springs from some old equipment you can make a passable battery holder.

It fits exactly.
The black cube on the left is the UTP connector.

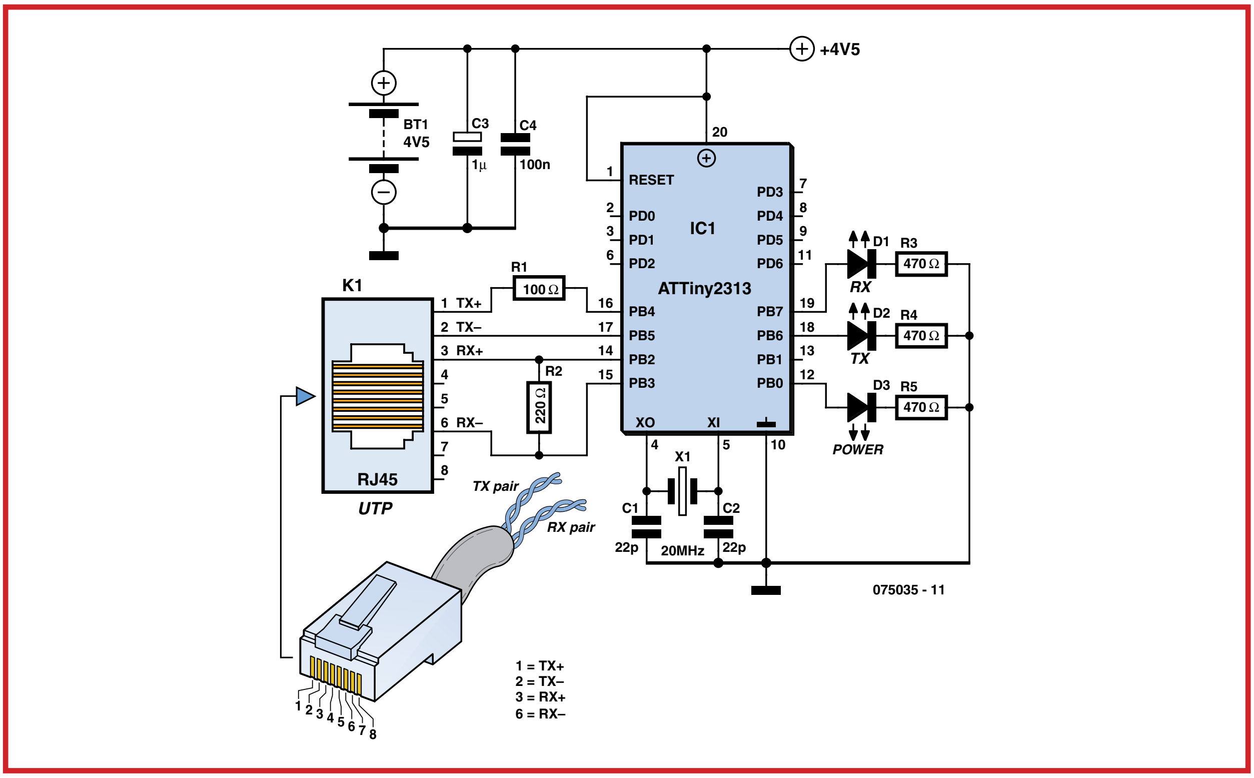


Figure 1. The circuit for the Ethernet tester is fairly small due to the use of an ATtiny2313.

but because the circuit is battery-powered we can connect the UTP lines directly to the microcontroller. The TX lines are terminated with a resistor of 100 Ω (as they should be), but for the RX lines this resistor has a value of 220 Ω. The reason for this is as follows: With a 4.5 V supply voltage the microcontroller can only be guaranteed to interpret a signal of 3.1 V as 'high'. Since Ethernet signals are normally in the range of 2.2 V to 2.8 V, this will not always work. But by increasing the terminating resistor we increase the voltage level and the detection works well. An increase of this resistor would normally mean that the signal will become distorted, making reliable data transmission difficult, but in this application that doesn't matter.

Something that is noticeable from its absence in the circuit diagram is an on/off switch. This has intentionally been left out. The microcontroller itself can determine when the tester should be turned on and off. When the circuit is not in use, the microcontroller is woken up once a second, when it checks if there is an electrical connection between the TX pins of the RJ45 plug. If this isn't the case, the microcontroller goes back into sleep-mode. In this mode the circuit only uses a few tens of microamps, which means that a set of AAA batteries should last a couple of years. When the cable is connected to a switch the circuit jumps into action. A switch terminates the TX lines with a 100 Ω resistor, which produces an electrical connection between the TX lines.

The user interface has been kept simple and consists of three LEDs. The bottom one shows that the circuit is turned on (meaning that the TX pair and terminating resistor in the switch appear to be in order). The top one shows that a signal is detected from the switch (meaning that the RX pair and the associated logic in the switch are in order). The middle LED indicates when the tester is sending LIT pulses. This LED goes on and off every 4 seconds. And because the presence of these LIT pulses is a sign for the switch that there is a network connection, the indicator on the switch will follow at about the same rate.

The microcontroller obviously requires some firmware to function. This has been written in assembly language and both the source code and hex files are available from the author's [2] and Elektor Electronics' [3] websites, as long as the network cables hold out...

(075035)

Web links

[1] http://standards.ieee.org/getieee802/802.3.html

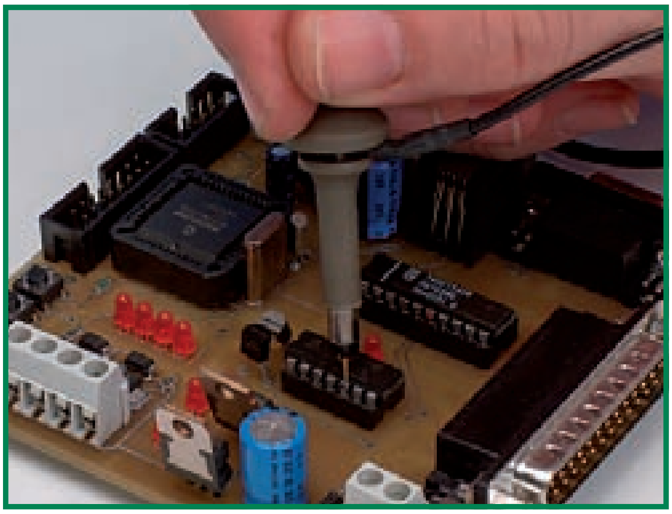
[2] http://sprite.student.utwente.nl/~jeroen/projects/ethermeter/

[3] www.elektor-electronics.co.uk/ (March 2007)

Open CMOS inputs

Luc Lemmens

As a consequence of poor soldering or an etching fault when making the PCB it can happen that there is no connection between two points. Etching faults in particular can take an enormous amount of time when fault finding the PCB. Poor solder joints with through-hole PCBs are still reasonably easy to find by careful inspection of the solder job. With small SMD components this is already a lot more difficult, often requiring the use of a magnifying glass. Since the arrival of lead-free solder, this visual inspection has become much more difficult anyway. Solder with lead gives a nice shiny finish to the connection to indicate that the solder flowed well, a dull surface indicates too much heat or too much time making the connection which is then likely to be of poor quality. Lead-free solder is always dull in appearance and we therefore have lost a good indicator regarding the quality of the solder joint.



CMOS inputs may never be left open circuit. There is a chance that the input ends up at half the supply voltage and the current consumption of the IC will increase enormously. Besides, it can cause noisy interference that can be detected throughout the entire IC or surrounding circuit. Whenever the input is open, perhaps because of a design error, poor soldering or a broken PCB track, it is important that this problem is fixed as soon as possible since it is quite possible that the IC will fail. The most thorough method is to test all connections on the PCB with a multimeter, but this is very time consuming and almost impracticable with all but the simplest of circuit boards.

With a little trick, it is very simple to check with an oscilloscope whether a CMOS-input is dangling free:

Take the probe clip from the probe, measure at an input and at the same time touch the input with a finger. If the input is open we will see the 50-Hz (60-Hz) mains hum on the scope that we are picking up ourselves and applying with our finger to the high-impedance input.

Beware: the input has such a high impedance that it is also susceptible to static discharges. So make sure that you first discharge your hands and just to be sure touch the ground of the circuit with your other 'free' hand. In this way the risk of damaging the circuit with this measurement is very low.

(070054-I)

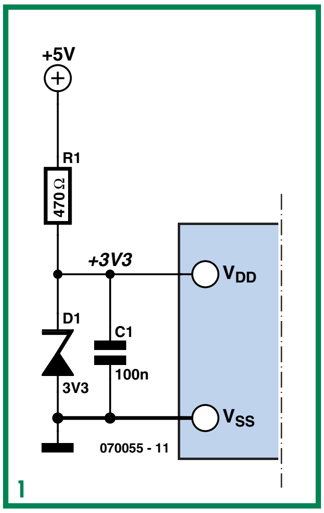
From 5 to 3.3 V

Luc Lemmens

Many microcontrollers these days are powered from 3.3 V (or oven lower voltages) instead of the old, familiar 5 V. Lowering the dissipation and increasing the switching speed are the main considerations for reducing the power supply voltage. In addition, the ever continuing miniaturisation results in transistors inside the ICs that are so small that the breakdown-voltage has become much lower and a 5-V power supply would cause problems.

But many of the peripheral ICs have not (yet) followed this lowering of the supply voltage, with the result that many circuits need two or more different power supply voltages. Assuming that a 5-V power supply is already present, there are several simple methods that can be thought of to derive 3.3 V from that.

The most obvious solution is to use a Low Drop Out (LDO) voltage regulator with a 3.3 V output. This regulator must be an LDO type, because a 'normal' regulator has a drop-out voltage of 2 to 3 V and we don't have that much to play with.



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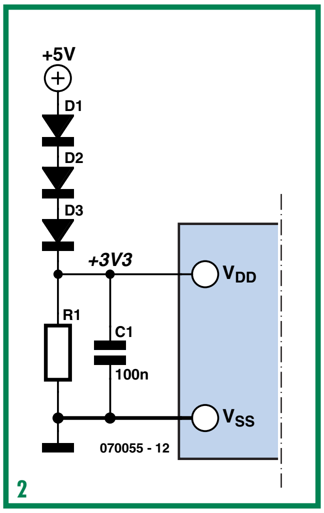


2

A second method (see **Figure 2**) is very cheap: a resistor and a 3.3-V zener diode. But since the zener voltage depends on the current through the zener, it is very important that the correct value is chosen for R1. R1 has to be low enough so that the power supply voltage of the microcontroller is still high enough when the controller draws the maximum amount of current. Additionally, the value of R1 has to be such that the power supply voltage does not rise too much when the controller current is almost zero (for example during reset).

We can see another simple solution in **Figure 2**, where we use the voltage drop across a diode in conduction. This voltage drop is also dependant on the current through the diodes and R1 has to ensure that the voltage across the microcontroller does not become too high when its current consumption is negligible. The diodes have to be selected in such a way that the voltage drop across them is not too high when the microcontroller draws the maximum amount of current.

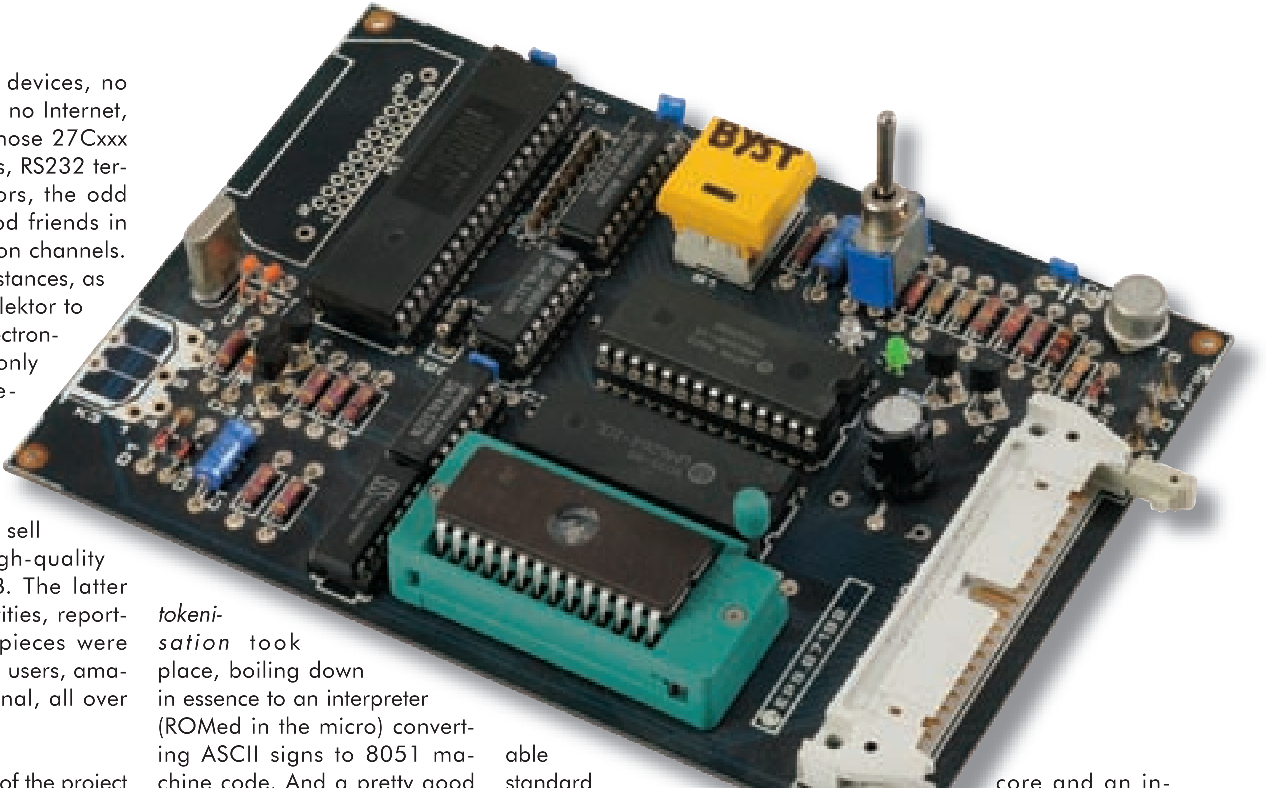
And finally there is always the switching power supply (step-down converter) to make 3.3 V. There are also special ICs available that can generate multiple output voltages at the same time.

Which method you end up using will depend on a number of considerations such as cost, available space on the PCB and the required regulation of the 3.3-V power supply voltage. In particular with regard to the latter consideration, the solutions with diodes are inferior, but they are certainly very small and cheap!

(070055-I)

8052-AH BASIC Single-Board Computer (1987)

Jan Buiting



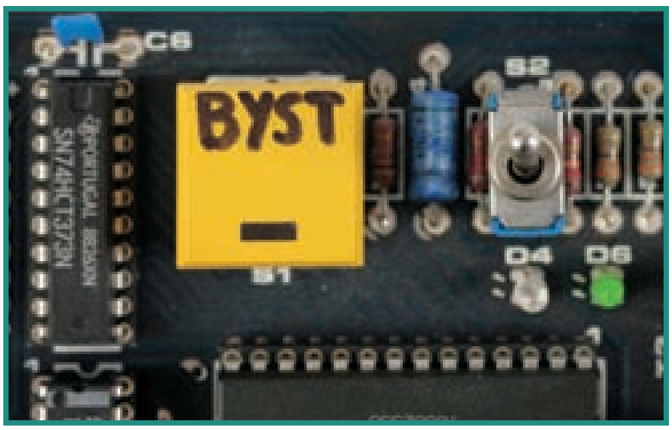
No flash memory devices, no USB, no JTAG and no Internet, but we did have those 27Cxxx windowed EPROMs, RS232 terminals or emulators, the odd PC and a few good friends in Intel's IC distribution channels. The perfect circumstances, as it turned out, for Elektor to become the first electronics journal to not only publish a single-board computer based on Intel's 8052-AH-BASIC microcontroller, but also to sell the associated high-quality double-sided PCB. The latter went in vast quantities, reportedly over 5,000 pieces were sold to enthusiastic users, amateur and professional, all over the globe.

The instant success of the project proved that there was lots of interest in programming a microcontroller in BASIC rather than assembly language. Sceptics, aplenty immediately after the publication of the November 1987 issue, soon fell silent when the actual code executed by the 8052AH micro was valued in terms of speed. The general verdict: "not bad at all, that interpreter is worth its salt".

The BASIC programs for this SBC were written using an ordinary ASCII savvy word processor on a PC — in compliance, of course, with the relevant syntax described by Intel in their *MCS BASIC-52 Users Manual*, which was much sought after. Nor surprisingly, photocopies (138 pages thick) soon surfaced in the electronics retail trade.

Next, the text file containing the BASIC program had to be transferred to the 8052AH micro by means of a communications program (a.k.a. terminal emulator) like Procomm or Telix. During handshake-driven downloading to the 8052AH, a process called *tokenisation* took place, boiling down in essence to an interpreter (ROMed in the micro) converting ASCII signs to 8051 machine code. And a pretty good job it did, albeit that small bugs and imperfections were soon noticed by experts in 8051 family programming. One particularly well liked feature of MCS52 BASIC was the ability for programmers to insert a chunk of assembly code straight into the BASIC program.

The Elektor 8052AH-BASIC computer is likely to have helped an odd-looking frequency like 11.0592 MHz become a standard value for quartz crystals. The reason: the 8051 core divides the clock frequency down to enable standard baud rates like 1200 or 2400 bits/s to be used on the serial line connected to the PC's RS232 port.



The SBC design included an on-board EPROM programmer which was cheerfully supported by MCS-52 BASIC. Its orderly use comprised no more than the 8052AH faithfully programming 2764s and 27128s. However a not so orderly application of the programmer came from simple combination of two facts: (1) the 8052AH-BASIC micro is a combination of a regular 8051 core and an interpreter in on-chip ROM, and (2) the device was frightfully expensive compared to, say, a 80C32. Although the method was never described in detail in Elektor for fear of repercussions from Intel, keen users of the SBC were soon successful in making the 8052AH micro extract and transfer its own interpreter into a file! Next, everybody started using 80C32 micros running BASIC from external EPROM. The alternative was not only much cheaper, but could also be tweaked for speed and performance. At a much later date, I think it was around 1992, Intel released MCS BASIC-52 into the public domain. A flurry of 80C32 SBCs was the result, including our own.

Some IBM PC user on our staff must have learned the hard way that BRST at that time stood for Big Red Switch Time and he or she pencilled the equivalent on the reset pushbutton of the 8052-AH BASIC prototype in our lab, with due correction for colour.

(075025-I)

Retronics is a monthly column covering vintage electronics including legendary Elektor designs. Contributions, suggestions and requests are welcomed; please send an email to editor@elektor-electronics.co.uk, subject: Retronics EE.

Hexadoku

Puzzle with an electronic touch

Hexadoku is drawing not just hundreds of correct answers every month but also encouraging feedback and other kind words from you all. Needless to say we're very pleased to see that Hexadoku has become an established part of the magazine.

The instructions for this puzzle are straightforward. In the diagram composed of 16 x 16 boxes, enter numbers such that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once in each column and in each of the 4x4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation. All correct entries received for each month's puzzle go into a draw for a main prize and three lesser prizes. All you need to do is send us the numbers in the grey boxes.

The puzzle is also available as a **free download** from our website (Magazine → 2007 → March).

Participate!

Please send your solution (the numbers in the grey boxes) by email to:

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Subject: hexadoku 03-2007.

Alternatively, by fax or post to:

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The closing date is
1 April 2007.

The competition is not open to employees of Segment b.v., its business partners and/or associated publishing houses.

Prize winners

The solution of the January 2007 Hexadoku is: **038FA**.

The **E-blocks Starter Kit Professional** goes to:

Peter Hinchcliffe, Fleet (UK).

An **Elektor SHOP voucher worth £35.00** goes to:

Bjarne Lassen (DK);
Harald Paulsen (N);
Andrew Collister (UK)

Congratulations everybody!

		D	6					8	A	2			B	9	F
2	1		3				6				7		8		
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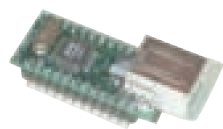

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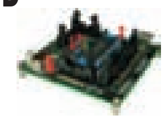

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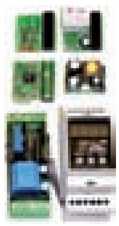

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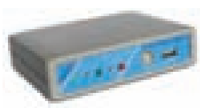

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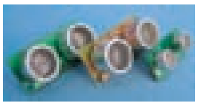

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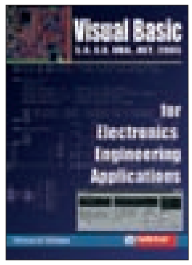

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The April 2007 issue will have our first, educationally aimed, application for the SpYder kit — an accelerometer with an LED readout for direction or and amount (up to 2 g) acceleration (+g) or deceleration (–g). Install the circuit in your car, on your bike, motorbike or scooter and discover if your driving habits cause any of the red LEDs to light!
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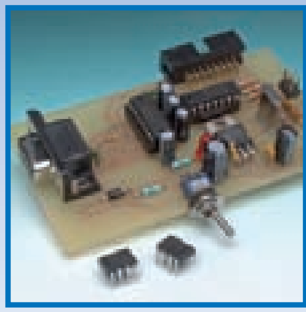
It goes to show the ease of getting a Freescale MC9S08 microcontroller to work using the low-cost SpYder & CodeWarrior environment for programming and debugging. The two PCBs come with a **free accelerometer** device ready-mounted on a small carrier board.

Freescale 68HC08 Programmer

Apart from the microcontrollers described in this month's SpYder article, Freescale also produces devices from a heritage family known as 68HC08. We describe a small but useful programmer/debugger for connection between the serial port on the PC and the MON08 connector on the HC08 target board.



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More and more battery-powered electronics devices appear on the market. Although portability is great in itself, manufacturers have a habit of using batteries with many different sizes and technologies, resulting in lots of different chargers being required at the customer end. In the April 2007 issue we describe a compact unit combining the functions of charger, discharger and capacity tester for NiMH, NiCd, LiPo and LiIon batteries. The unit supplies 0.2 A to 4.5 A in charger mode, and sinks 0.2 A to 5 A in discharger mode.
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Also... Explorer-16 (4); Free Energy?; Solar Cell Technology; Simple Solar Charger; Power Inverter; Mini Project; Hexadoku.

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