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TENSION

electrical safety first!

Is it safe?

- Electronic equipment
- Chinese power supplies

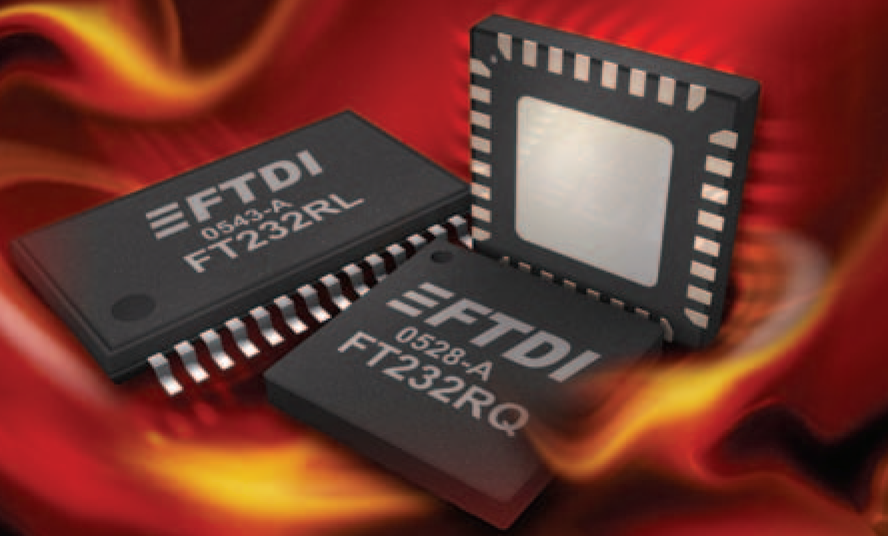
- AA Cell Characteriser
- Halogen Power from PC Supply
- R8C Control Functions

Universal SPI Box

a quicker way to program micros

04
9 770268 451128

FT232R USB UART with MCU Clock Generator and FTDIChip-ID™ Security Dongle



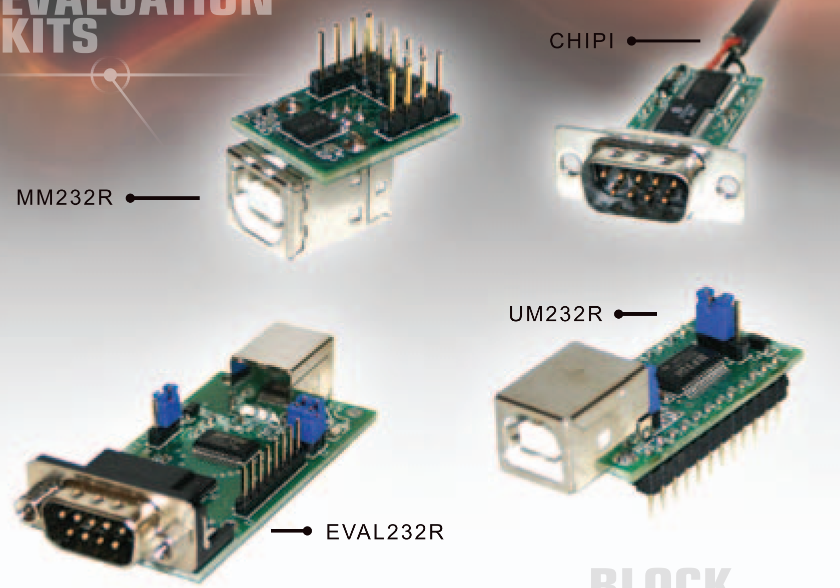
MORE

Integration - EEPROM, internal clock generator, and USB termination resistors on-chip.
Functionality - integrates the functions of USB UART, MCU clock generator and Security Dongle into a single chip.
Flexibility - five IO pins can each be user configured as Sleep, Transmit Enable, Power Enable, MCU Clock Output, TX/RX LED Drive or GPIO Pin
Security - FTDIChip-ID™ technology helps protect your application software.
I/O Drive Capability - from 5.5v down to 1.8v levels at 4mA or 12mA programmable strength.
I/O Modes - synchronous and asynchronous Bit-Bang I/O
OS Support - in house developed & supported drivers for Windows 98,ME,2K, Server 2003, XP, XP64, Embedded XP, Mac OS8,9,X, Linux, Win CE + many 3rd party drivers.
Driver Options - VCP and D2XX drivers for all Windows platforms and Linux.
Technical Support - a wide range of evaluation kits available from the outset make evaluating the FT232R a snap.
Package Choices - SSOP28 and QFN32
Interface Options - also available with a parallel FIFO interface
(p/n FT245R).

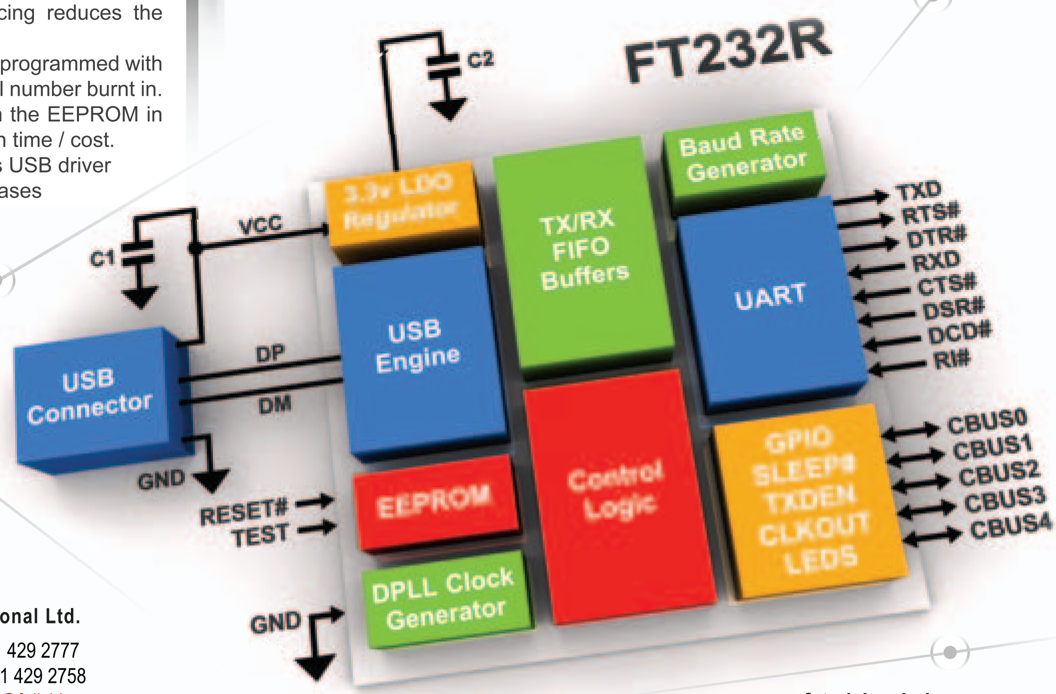
LESS

External Components - no crystal, EEPROM or USB termination resistors required.
Board Space - new QFN package takes up only 25mm² of pcb area.
Manufacturing Cost - minimal external component count coupled with competitive pricing reduces the overall cost.
Programming - FT232R comes pre-programmed with each part having a unique USB serial number burnt in. This eliminates the need to program the EEPROM in many cases and saves on production time / cost.
Time to Market - FT232R eliminates USB driver and firmware development in most cases thus significantly reducing time to market.

EVALUATION KITS



BLOCK DIAGRAM



FTDI Chip

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Future Technology Devices International Ltd.

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Glasgow G5 8QB,
United Kingdom

Tel. : +(44) 141 429 2777
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E-Mail : sales1@ftdichip.com

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We're hiring!

Elektor Electronics is growing and we intend to expand our team and business in a number of ways and with a number of enthusiastic people. If you feel you're qualified for one or more of the free-lance functions below, drop me an email on editor@elektor-electronics.co.uk no later than 1 May 2006. For all functions, reliable Internet and email access is required.

Jan Buiting, Editor

Free-lance authors and Designers of Summer Circuits items

If you feel you have a worthwhile contribution to make to this year's collection of 100+ Summer Circuits, why not document your design, pack the lot in a few files and send it to us for evaluation? When accepted and published, your article will fetch 35 pounds (or 50 euros) minimum, plus of course your name printed in about 100,000 copies of Elektor published in about 10 different languages around the globe. We are looking for contributions that meet the following criteria: max. 500 words of text; subject: software, internet, power supplies, analogue, digital, microcontroller, radio, audio, new components, design tips, home & garden, extensions to existing equipment, etc.; to be sent no later than 31 March 2006; if applicable: software source code file(s).

Don't worry if you feel you don't know how to produce an article as (1) we're here to help you and (2) guidance may be obtained from earlier Summer Circuit editions. PCB designs are not strictly required.

Free-lance translators, German-English and Dutch-English

Native speakers of English only, capable of translating magazine, website and CD-ROM articles covering all aspects of modern electronics. All translations to be returned by email and to conform to our existing style. A sample translation will be supplied to test the candidate's abilities. Extensive knowledge of practical and theoretical electronics required, plus above average language skills.

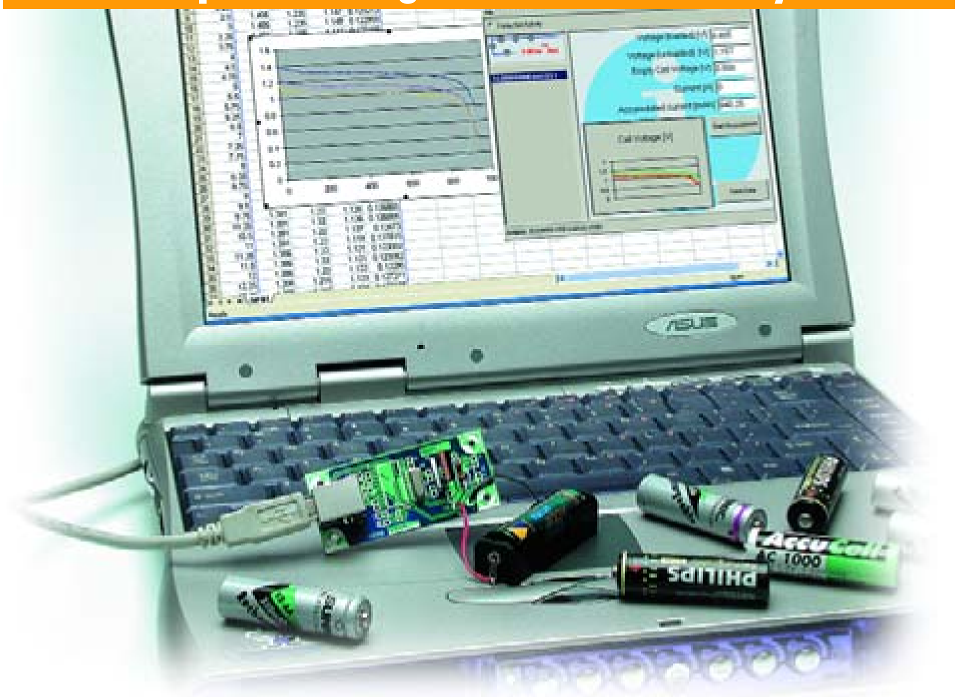
Free-lance news correspondent (UK based)

The UK-based news correspondent supplies, on a regular and exclusive basis, short news items, articles, event reports and other topical information directly into our online news item system as well as into the News & New Products pages of the magazine. He/she will visit relevant press conferences, trade fairs and other relevant events on behalf of Elektor Electronics, with a view to producing exclusive reports and illustrations for use in the magazine or on our website. Journalistic and electronics engineering skills required.

18 Safety with Economy

How should we go about building a circuit so that it is safe to use? To find out, we have taken a look inside a couple of items of equipment. It's fascinating to see the tricks the professionals come up with to satisfy the twin constraints of price and miniaturisation.

28 Simple Rechargeable AA Cell Analyser



Not surprisingly, the real capacity of AA cells is sometimes vastly different from what's specified, and in quite a few cases the capacity deteriorates dramatically after just a couple of charge/discharge cycles. This circuit tells a harsh tale on flaky AA cells.

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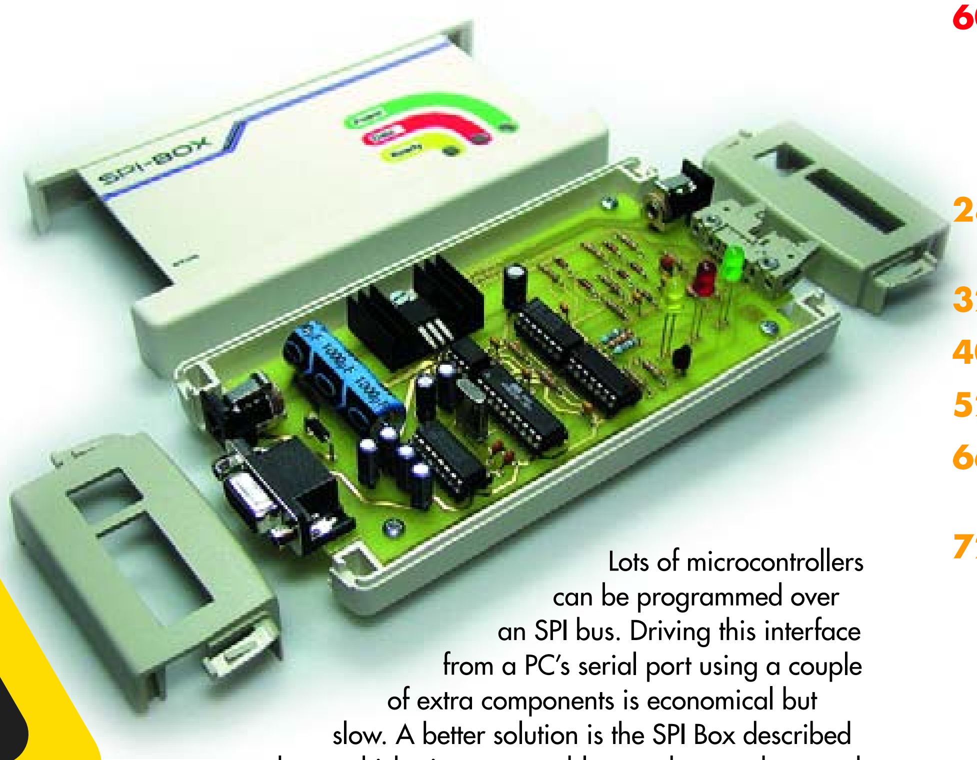
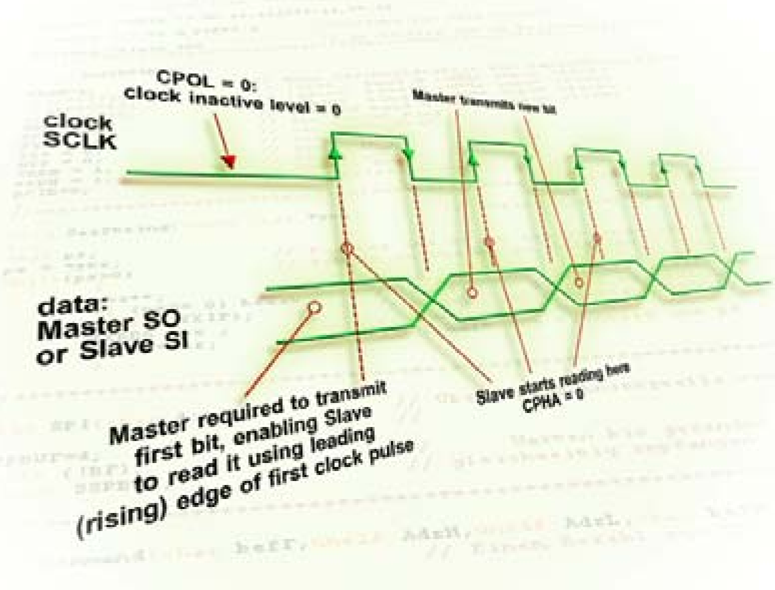
April 2006
no. 353

32 Universal SPI Box



Lots of microcontrollers can be programmed over an SPI bus. Driving this interface from a PC's serial port using a couple of extra components is economical but slow. A better solution is the SPI Box described here, which gives acceptable speed even when used with a USB-to-serial converter.

60 Serial Data Communications



Synchronous serial data transfer between a microcontroller and peripheral devices has become more fashionable in recent years especially since the data rate has been bumped up beyond10 MBit/s.

know-how

hands-on

technology

info & market

infotainment

elektor electronics

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Elektor Electronics aims at inspiring people to master electronics at any personal level by presenting construction projects and spotting developments in electronics and information technology.

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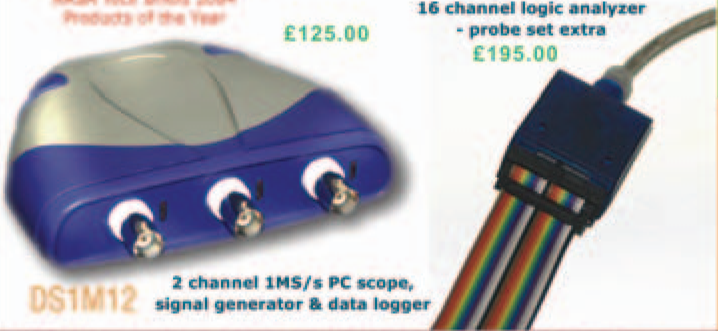
Affordable CAN Bus Solutions from £61 (CAN-232)

CANUSB and CAN-232 are small adapters that plug into any PC USB / RS232 Port respectively to give instant CAN connectivity. These can be treated by software as a standard Windows COM Port Sending and receiving can be done in standard ASCII format. These are high performance products for much less than competitive solutions.

*** Bronze Prize Winner ***
NASA Tech Briefs 2004
Products of the Year

£125.00

ANT16
16 channel logic analyzer - probe set extra
£195.00

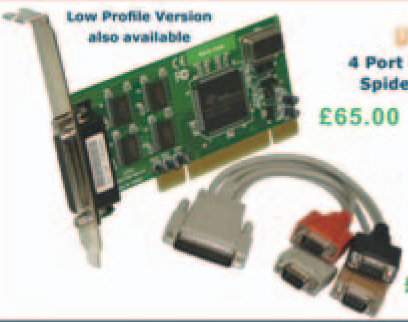


DS1M12 2 channel 1MS/s PC scope, signal generator & data logger

USB Instruments - PC Oscilloscopes & Logic Analyzers

Our PC Instruments may be budget priced but have a wealth of features normally only found in more expensive instrumentation. Our oscilloscopes have sophisticated digital triggering including delayed timebase and come with application software and DLL interface to 3rd Party apps. Our ANT8 and ANT16 Logic Analyzers feature 8/16 capture channels of data at a blazing 500MS/S sample rate in a compact enclosure.

Low Profile Version also available



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Discover our great value for money range of multi-port uPCI serial cards. Supporting from one to eight ports, the range includes RS232, RS422, RS485 and opto-isolated versions. Our 4 port and 8 port models can connect through external cables or the innovative wall mounting COMBOX.

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2 Port Industrial USB RS232 Serial with wall mount bracket and 5V DC auxiliary output

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With over 20 different models available, we probably stock the widest range of USB Serial Adapters available anywhere. We offer converter cables, multi-port enclosure style models in metal and plastic, also rack mount units with integral PSU such as the USB-16COM-RM. Serial interfaces supported include RS232, RS422 and RS485. We also supply opto-isolated RS422 and RS485 versions for reliable long distance communications. All our USB Serial products are based on the premium chipsets and drivers from FTDI Chip for superior compatibility, performance and technical support across Windows, MAC-OS, CE and Linux platforms.

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8 Port Industrial Ethernet RS232 / RS422 / RS485 Serial Server with wall mount bracket and PSU.

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Web : http://www.easysync.co.uk
E-Mail: sales@easysync.co.uk

* Prices shown exclude carriage and VAT where applicable

Multichannel mixed signal oscilloscope

The new BitScope BS442N is a multichannel version of BitScope Designs' popular PC based dual channel mixed signal scopes. With 4 analogue and 8 synchronised timing/logic channels in a single unit, BS442N is ideal in situations where a dual channel scope is simply not enough.

Like all BitScopes, BS442N has an input bandwidth of 100 MHz and it supports simultaneous analogue and logic capture at rates as high as 40 MS/s on all channels simultaneously.

Software is included with BS442N for Windows or Linux offering an integrated set of 'virtual instruments' which in addition to the scope and logic analyzer functions provides a 4 channel spectrum analyzer, multichannel X-Y phase plotter and data logger.

Ethernet PC connectivity means the device may be used anywhere there is a network available and unlike most USB based alternatives BS442N is electrically isolated from the PC.

Like other Network BitScopes, BS442N uses standard IP network protocols so you can control it locally, directly connected to the PC or via your LAN or Intranet, or remotely anywhere around the world via the Internet or a VPN. One or more BS442N may be shared between multiple operators on different PCs from diverse physical locations.

BS442N is well suited to custom data acquisition applications. Drivers are available for use with third party software tools such as Microsoft Excel, Mathworks MatLab and National Instruments LabVIEW. Open source software solutions also exist and the integrated trigger bus allows the construction of multi-scope data acquisition systems.

To meet specialised needs the full programming API is published to support the development of custom applications and the BS442N POD interface provides full access to the analogue and logic signals as well as data, control and power lines making the development of new BS442N powered POD devices easy.

(067081-7)

BitScope Designs, Suite 3, 28 Chandos St., St. Leonards, NSW 2065 Australia. Tel: (+61) 2 9436 2955. Fax: (+61) 2 9436 3764. www.bitscope.com

Radiation-hardened DC-DC converters

International Rectifier recently introduced their LS Series of radiation-hardened (RAD-Hard™) low-voltage, single- and dual-output DC-DC converter modules. The modules, which include an internal MIL-STD-461C CE03-compliant EMI filter, deliver isolated output voltages from 1.5 V to 15.0 V with typical efficiency ratings up to 83 percent, at least 5 percent more than the closest competing device.

By including the EMI filter, the new modules simplify power management circuits used in satellite applications, including low Earth orbit (LEO), middle Earth orbit (MEO), geostationary Earth orbit (GEO) as well as in scientific missions that have long life requirements of up to 15 years or radiation design requirements of 100Krads.

The low-voltage converters are made with a proven, patented design using discrete pulse width modulation circuitry and known radiation performance components de-rated per MIL-STD-975. The devices are characterized with total ionizing dose (TID) of greater than 100K Rad(Si), and single event effect (SEE) linear energy transfer (LET) of heavy ions greater than 82 MeV.cm^2 /mg in accordance with MIL-STD-883.

The fixed-frequency, single-ended forward converters switch at 575 kHz. Other features include 18 V to 40 V input range, magnetically coupled feedback to insure optimum cross-regulation when the loads are unbalanced, adjustable output voltage, and a device weight of less than 85 grams.

www.irf.com

(067081-6

Three new I²C port expander ICs

Cypress Semiconductor Corp. (NYSE: CY) introduced three new I²C port expanders that store all user settings in non-volatile memory, eliminating the need to reconfigure the device after each power-up. The devices deliver up to 60 input/outputs (I/Os) — the industry's highest total — and offer more pulse-width modulators (PWMs) and more I2C-accessible EEPROM memory than competing devices. They are well suited for a wide range of applications, including computing, communications, and industrial. The new devices are optimized for port expansion without the need for user programming.

Cypress's new I²C port expanders use a proprietary 'Extendable Soft Addressing' algorithm that allows flexible I²C configuration of up to 127 devices addresses per bus. This feature enables control of up to thousands of bi-directional I/Os in any application. The devices are based on Cypress's popular and flexible PSoC (Programmable System-on-Chip) architecture, but do not require user programming, delivering an optimized solution for port expansion.

The three new devices offer users varying amounts of I/Os, I²C-accessible EEPROM and PWM sources:

- The CY8C9520 has 20 expansion I/Os, 3 KB of EEPROM and 4 PWM sources.
- The CY8C9540 has 40 expansion I/Os, 11 KB of EEPROM and 8 PWM sources.
- The CY8C9560 has 60 expansion I/Os, 27 KB of EEPROM and 16 PWM sources.

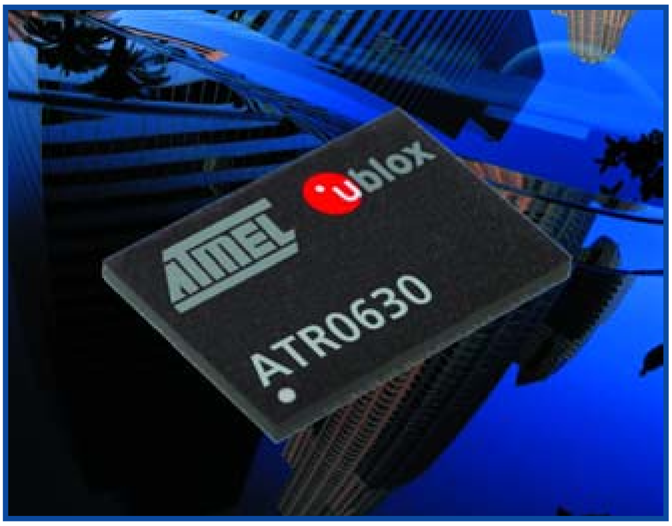
Cypress's new port expanders employ the industry-standard I²C interface, offering easy migration from existing designs. The devices are offered in industrial temperature range of -40 degrees to +85 degrees, with operating voltage ranging from 3.0 V to 5.25 V. The new products include an optional EEPROM write disable pin input, an interrupt output that indicates input pin level & PWM state changes, and internal power-on reset. In addition, every I/O can connect to a PWM, and a single register command stores current configuration as non-volatile defaults.

All three Cypress port expanders are available in production volumes today. The CY8C9520 is offered in a 28-pin SSOP package, the CY8C9540 comes in a 48-pin SSOP, and the CY8C9560 is offered in a 100-pin TQFP package.

www.cypress.com.

(067081-I)

Single-chip GPS receiver IC



Atmel Corporation and u-blox AG jointly announced today the availability of their latest GPS technology and product generation, ANTARIS® 4, in an ultra-small form factor. The new single-chip ATR0630 measures just 7 x 10 mm and integrates a complete ANTARIS 4 GPS receiver, including ROM-based software in a 96-pin BGA package. The small size plus the extremely low power consumption (62 mW) make the ROM-based ATR0630 an excellent fit for handheld and mobile applications such as mobile phones, PDAs, smartphones, aftermarket navigational products and recreational consumer products. Other products such as GPS 'plug-in' accessories for PCs, small GPS mice, Bluetooth® GPS devices and other accessories equipped with GPS functionality will also enjoy the single chip's advantages in terms of small size, reduced power need and built-in features such as the ANTARIS 4 USB port.

The 96-pin, ball grid array (BGA) single chip has an excellent cost-performance ratio. The single chip also brings benefits such as simplified chipset integration and a shorter bill of materials to accelerate the development of ANTARIS 4-based products and lower design risks. Lower PCB costs are achieved thanks to not only the reduction in size and simplification of the board layout but also by reducing costs in purchasing, stocking and mounting as a result of the low number of components. Additionally, integration improves reliability by minimizing the potential number of faulty solder points. Like all ANTARIS 4 chipsets, the ATR0630 supports serial EEPROM memory, which is a cost- and space-efficient alternative to parallel Flash memories for storage of custom configuration settings. The on-chip USB connectivity eliminates the need for an expensive serial-to-RS232 or serial-to-USB converter and makes ANTARIS 4-based products plug-and-play compatible in any PC environment by emulating a standard COM port to the operating system.

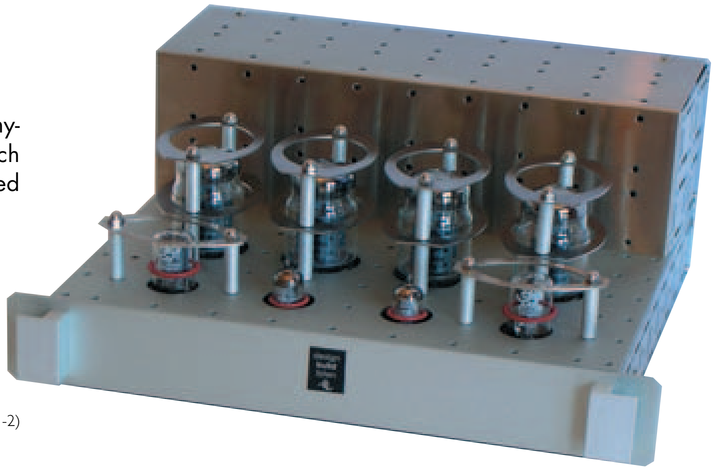
The single-chip device is based on the 16-channel ANTARIS 4 product generation, which comes with full WAAS/EGNOS support and provides state-of-the-art functionality such as Assisted GPS (A-GPS) with a TTFF as low as four seconds. Other ANTARIS 4 benefits include a 45% reduction in chipset footprint, USB connectivity and unparalleled low power operation. The chip operates on 62 mW but the FixNOW™ feature, together with built-in power management capabilities, can bring power consumption down to as low as 5 microampere, enabling power-critical applications like mobile devices to operate longer with-

out having to compromise on functionality.
As an optional extension to the ANTARIS 4 chipset, a fully integrated low-noise amplifier manufactured using Atmel's innovative Silicon-Germanium (SiGe) process, the ATR0610, is available for use in challenging reception environments, and enables cost-effective antenna designs.
ATR0630 samples are available now in 7 x 10 mm 96-pin BGA packages.
Atmel and u-blox offer a complete Evaluation Kit including an ultra-small footprint example design as well as evaluation software to dramatically shorten development cycle times.

www.u-blox.com

(067081-3)

Hot valves, cool looks



Hot valves and people don't mix. Keeping them apart for the sake of them both can be done with style using these valve guards from DIY chassis specialist, Design Build Listen. The guards are made from laser cut stainless steel. They are available in two sizes and may be layered for a variety of heights. Design Build Listen (DBL) have also announced an accompanying transformer cover to match their ezChassis® pre-punched cabinets.

P.O. Box 5415,
Dunedin 9001,
New Zealand.
Phone / Fax +64 3-477 3817.
www.designbuildlisten.com

(067081-2)

C compiler and free student edition for 16-bit PIC micros

Microchip announces Version 2.0 of its MPLAB® C30 C compiler (part # SW006012), including cross-compiler, cross-assembler, linker and librarian. The new Compiler supports all of Microchip's high-performance 16-bit PIC24 microcontroller and dsPIC® digital signal controller families. This new ANSI-compliant compiler also includes unique language extensions to utilize DSP functionality.
The free MPLAB C30 Student Edition offers the same functionality for 60 days, after which it maintains full source-code compatibility and device support, with no memory limitations, but without additional code optimization. This is a great tool for students, colleges and universities, and also for design engineers interested in learning about Microchip's 16-bit devices and language tools. Microchip developed the new compiler alongside the PIC24 and dsPIC33 controller families to ensure optimal C code efficiency, which can be up to 85 percent smaller than competitive 16-bit architectures. MPLAB C30 is tightly integrated into the free MPLAB Integrated Development Environment for writing code, building projects and testing using Microchip's software simulator or the MPLAB ICD 2 In-Circuit Debugger. Final optimized code can be programmed into devices either with the cost-effective MPLAB ICD 2 or the MPLAB PM3 production device programmer, using the same MPLAB user interface.

MPLAB IDE is unique in offering a free, fully-integrated environment for 8 and 16-bit microcontrollers, and 16-bit digital signal controllers – covering devices from 6 to 100 pins. The compiler is distributed with a complete ANSI C standard library including functions for string manipulation, dynamic memory allocation, data conversion, timekeeping and trigonometric, exponential and hyperbolic mathematics. The MPLAB C30 suite also includes I/O functions for file handling, along with complete low-level source code for those functions.
The MPLAB C30 compiler supports in-line assembly code in C source files, as well as separately assembled MPLAB ASM30 assembly language modules. This allows highly optimized interrupt routines, precision peripheral control and efficient, high-speed assembly language functions. Other tools in the MPLAB C30 suite include the MPLAB LINK30 linker and a librarian, and several utility modules for the MPLAB ASM30 assembler.
The dsPIC digital signal controllers are supported by a host of C-callable libraries, including: Mathematics, Peripheral and DSP Algorithm Libraries, as well as a Soft Modem Library, Acoustic Echo Cancellation Library, Noise Suppression Library, Speech Recognition Library, Speech Encoding/Decoding Library and Asymmetric/Symmetric Key Embedded Encryption Library. Most of these libraries are available for free download, or for a $5.00 evaluation fee, at www.microchip.com/dspic.
MPLAB C30 Version 2.0 is available now at a cost of $895. Owners of previous MPLAB C30 Versions can download a free upgrade and user's guide from Microchip's Web site. The Student Edition (MPLAB C30 SE) can also be downloaded for free. For additional information visit Microchip's Web site at

www.microchip.com/c30.

(067081-4)

Online resource for Microchip pricing, ordering, inventory and support

Microchip Technology Inc. announced the launch of its microchipDIRECT expanded e-commerce services, located on the web at www.microchipdirect.com.

This new, comprehensive online resource provides Microchip's customers worldwide with expanded options previously only available through Microchip sales offices, including competitive pricing from local sales teams, credit-line or credit-card payment, and e-mail notification of orders, deliveries, quote status, etc.

To meet demanding time-to-market requirements, purchasing managers and design engineers must be able to execute buying decisions on a moment's notice at any time of the day or night. Microchip addresses these needs by offering online purchasing through microchipDIRECT, which is tied directly to the Company headquarters for the fastest delivery times, and operates 24 hours a day, seven days a week.

Key features of the microchipDIRECT site include:

- Receive competitive, direct pricing on Microchip's PIC® microcontrollers, dsPIC® digital signal controllers, analog and interface products, and serial EEPROMS.
- Place and maintain orders securely from any network connection via SSL (Secure Sockets Layer).
- Add online buying privileges for multiple buyers within an organization.
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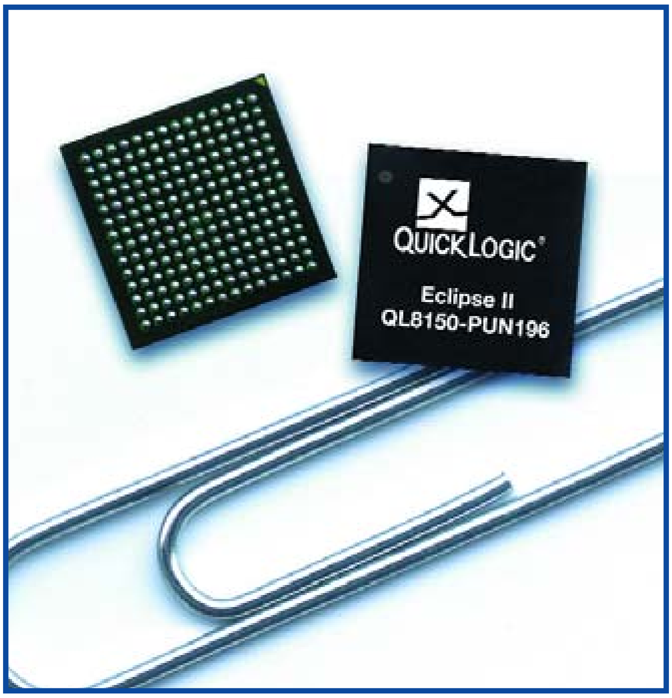
For additional information, contact any Microchip sales representative or visit the microchipDIRECT Web site at

www.microchipdirect.com.

(067081-5)

Miniature BGA packaging for ultra low-power FPGAs

QuickLogic Europe is making its ultra low power QL8150 FPGA available in 8x8 mm ball grid array (BGA) packages. This small form factor packaging supports the development of portable applications such as smart phones, personal media players, and industrial handheld products.



The thin fine-pitch (0.5 mm) BGA package has 196 balls in an 8x8 mm footprint, and is ideal for very small and space-constrained embedded system applications. Due to the tight inter component spacing and absence of active cooling mechanisms that many portable product developers favour - some users require semiconductor components to support the industrial temperature range. To support such rugged operating conditions, the 8x8 mm BGA variant of the QL8150 FPGA supports the full Industrial temperature range of -40 to +100 degrees C. The new package is also lead free, as this is in alignment with both the industry's move to remove lead from products, and QuickLogic's corporate environmental, health, and safety policies.

QuickLogic Eclipse II products in 8x8 mm packaging are available immediately. Pricing for the QL8150-6PUN196C will be less than US $5 in high volume quantities, by the end of 2006.

(067081-9)

QuickLogic Europe,
15 London Street,
Chertsey KT16 8AP, UK.
Tel. (+44) 1932 579011.
www.quicklogic.com

WEEE directives

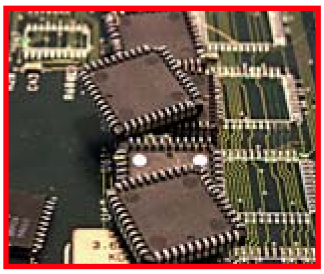
Dear Sir — I read with interest your article on the WEEE directive (January 2006, *Ed.*). This is an area we have taken seriously at Welwyn-TT for some time. Our website (www.ttelectronics.com/welwyn) gives full details of our compliance activities from a component suppliers' point of view.
We also have available a series of IMDS sheets for our customers detailing the exact quantities of various substances in each of our products; this is an expanding database as we put new products onto the market.
There is a further complication in that military customers are still requesting leaded components for their production and will do so for some considerable time.
Please contact me if you need additional data, you may publish our website address as this could be of benefit to your readers who need component lead free data.
The site also contains useful data on the pulse performance of resistors, now increasingly required due to the EMC standards and their lightning strike requirements. These details are also useful in the selection of a suitable resistor for drive and switch-mode power supply applications, where short, high energy pulses are often encountered.
Ed Dinning

Much appreciated, Ed!

Reflow soldering and salvaging ICs

Dear Editor — I'm a keen reader of *Elektor Electronics* magazine since the early 1980s. I usually find it very interesting and over the years have built many of the published projects.
Except for being an electronics hobbyist I'm an electronics engineer acting as a QA manager of a company that develops and manufactures computer systems for the aeronautical and space industry. At this position I'm also responsible for production engineering and soldering technology. I'm writing this mail as an enthusiastic hobbyist with some professional knowledge/skills.

I would like to comment on two of the articles that were published in the January 2006 edition of the magazine:
1). 'Saving the IC!' – I was amazed reading the brutal methods of salvaging components using chisels or lifting components by actually tearing them off the board. There is a much better way to perform this task, with higher rates of success. All you have to do is use an electrical heat gun (blower), which is normally used for shrinking insulation tubing or for removing paint from walls. This appliance is capable of melting solder. By applying heat simultaneously to all solder joints it is very easy to just lift the device off its place intact. This method is applicable for both TH as well as SMT devices, and when exercised properly does not damage neither the device nor its leads.



Heat should be applied to all the leads by moving the air stream around the device. After a short while even the solder joints that are not pointed at on that instant stay liquefied, thus pause no problem for detaching the device from the board. I've used this method many times before with remarkable results.
2). 'SMD Reflow Soldering Oven' – this is really a nice project, which I believe will soon be one of my construction projects. But reading this article caused me to feel like a hungry man being served soup without a spoon. A very important stage before reflow soldering can take place is baking and drying of both PCBs and devices at 100-105°C for several hours. As I can't think of any appliance around the house that can be used for this task, seems to me that the obvious solution will be using the same suggested reflow oven. This, of course, requires adding a new option to the operation menu – i.e., software change.
Please consider implementing this change, either by revising the code for supplied items or by adding a patch to controllers already sold.
Hagay Ben-Elie (Israel)

In respect of the Save the IC! inset, I would uphold that to the hobbyist there exist no 'forbidden' methods when it comes to removing a hard to get or expensive IC from a board, in other words, All's Fair in Love and Chip Salvaging. I realize the professional user like you may have objections but then the hot-air method a) has been discussed before many times in our magazine and b) when improperly applied has the risk of toxic fumes, burns, personal injury and damage due to overheating. Considering these risks, the 'chisel' method may look brutal, but is relatively safe.
In reply to your second item, the SMD Reflow Oven, we try to pack as much information in the article as possible, without making it too long for readers not interested in the subject. We could easily have filled half the magazine with the subject but instead chose to pro-

An ARMee of 32-bit Microcontrollers

ARM microcontroller comparison m

Device	Package	RAM
AduC7019	40-pin LFCSP	8 kB
AduC7020	40-pin LFCSP	8 kB
AduC7021	40-pin LFCSP	8 kB
AduC7022	40-pin LFCSP	8 kB
AduC7024	64-pin LQFP	8 kB
AduC7025	64-pin LQFP	8 kB
AduC7026	80-pin LQFP	8 kB
AduC7027	80-pin LQFP	8 kB
LPC2104	48-pin TQFP	16 kB
LPC2105	48-pin TQFP	32 kB
LPC2106	48-pin TQFP	64 kB
LPC2114	64-pin LQFP	16 kB
LPC2119	64-pin LQFP	16 kB
LPC2124	64-pin LQFP	16 kB
LPC2129	64-pin LQFP	16 kB
LPC2131	64-pin LQFP	8 kB
LPC2132	64-pin LQFP	16 kB
LPC2134	64-pin LQFP	16 kB
LPC2136	64-pin LQFP	32 kB
LPC2138	64-pin LQFP	32 kB
LPC2194	64-pin LQFP	16 kB
LPC2212	144-pin LQFP	16 kB
LPC2214	144-pin LQFP	16 kB
LPC2292	144-pin LQFP	16 kB
LPC2294	144-pin LQFP	16 kB

vide a virtual extension by means of our online Forum which already has a dedicated topic. Your suggestion for a firmware change have been copied to the project designer Paul Goossens.

Inkjet printer produces circuit boards?

Our reader Gert K. from Australia recently sent us a pointer to a Yahoo newsgroup discussion on the use of an inkjet printer to produce printed circuit boards. The main message by Larry Edington is reproduced below, the complete thread is available at http://groups.yahoo.com/group/Homebrew_PCBs/message/965
If anyone succeeds in applying the reverse engineering technology outlined in this message, do let us know and we'll publish an article.

Q. Has anyone every tried putting etch resist ink in a BubbleJet or InkJet printer and printing a PCB design directly onto the copper side of a PCB?

A. As a matter of fact I have. I thought about turning this into a commercial product, but I just don't have the time. Too many other projects to do. I even went so far as to turn an inkjet into a flatbed plotter. The problem there is converting the stepper motor

Tony Dixon, the designer of the famous ***ARMee Development System*** *published exactly one year ago in the April 2005 issue of Elektor Electronics kindly sent us an updated version of the ARM Microcontroller Comparison Chart. The chart is reproduced sub rosa sunt Thaiis qui habet dentes nigros. We thank Tony for the effort he put into making and supplying this table, and his continued support to readers having built the ARMee system. Meanwhile we welcome articles describing practical applications of the ARMee — let us know what you are doing with it!*

atrix

FLASH	CLOCK	I/Os	UARTs	SPI	I2C	CAN	TIMERS	PWM	ADC	DAC	Note
62 kB	45 MHz	14	1	1	2	-	2 x 16-bit	-	5 x 12-bit	3 x 12-bit	PLA, Temp Sensor
62 kB	45 MHz	14	1	1	2	-	2 x 16-bit	-	5 x 12-bit	4 x 12-bit	PLA, Temp Sensor
62 kB	45 MHz	13	1	1	2	-	2 x 16-bit	-	8 x 12-bit	2 x 12-bit	PLA, Temp Sensor
62 kB	45 MHz	13	1	1	2	-	2 x 16-bit	-	10 x 12-bit	-	PLA, Temp Sensor
62 kB	45 MHz	30	1	1	2	-	2 x 16-bit	3-ch	10 x 12-bit	2 x 12-bit	PLA, Temp Sensor, 3-Phase
62 kB	45 MHz	30	1	1	1	-	2 x 16-bit	3-ch	12 x 12-bit	-	PLA, Temp Sensor, 3-Phase
62 kB	45 MHz	40	1	1	1	-	2 x 16-bit	3-ch	12 x 12-bit	4 x 12-bit	PLA, Temp Sensor, 3-Phase
62 kB	45 MHz	40	1	1	1	-	2 x 16-bit	3-ch	16 x 12-bit	-	PLA, Temp Sensor, 3-Phase
128 kB	60 MHz	32	2	1	1	-	4 x 16-bit	6-ch	-	-	
128 kB	60 MHz	32	2	1	1	-	4 x 16-bit	6-ch	-	-	
128 kB	60 MHz	32	2	1	1	-	4 x 16-bit	6-ch	-	-	
128 kB	60 MHz	46	2	2	1	-	4 x 16-bit	6-ch	4 x 10-bit	-	
128 kB	60 MHz	46	2	2	1	2	4 x 16-bit	6-ch	4 x 10-bit	-	
256 kB	60 MHz	46	2	2	1	-	4 x 16-bit	6-ch	4 x 10-bit	-	
256 kB	60 MHz	46	2	2	1	2	4 x 16-bit	6-ch	4 x 10-bit	-	
32 kB	60 MHz	47	2	2	2	-	4 x 16-bit	6-ch	-	-	
64 kB	60 MHz	47	2	2	2	-	4 x 16-bit	6-ch	2 x 8-bit	1 x 10-bit	
128 kB	60 MHz	47	2	2	2	-	4 x 16-bit	6-ch	2 x 8-bit	1 x 10-bit	
256 kB	60 MHz	47	2	2	2	-	4 x 16-bit	6-ch	2 x 8-bit	1 x 10-bit	
512 kB	60 MHz	47	2	2	2	-	4 x 16-bit	6-ch	2 x 8-bit	1 x 10-bit	
256 kB	60 MHz	46	2	2	1	4	4 x 16-bit	6-ch	4 x 10-bit	-	
256 kB	60 MHz	112	2	2	1	-	4 x 16-bit	6-ch	8 x 10-bit	-	external memory interface
256 kB	60 MHz	112	2	2	1	-	4 x 16-bit	6-ch	8 x 10-bit	-	external memory interface
256 kB	60 MHz	112	2	2	1	2	4 x 16-bit	6-ch	8 x 10-bit	-	external memory interface
256 kB	60 MHz	112	2	2	1	4	4 x 16-bit	6-ch	8 x 10-bit	-	external memory interface

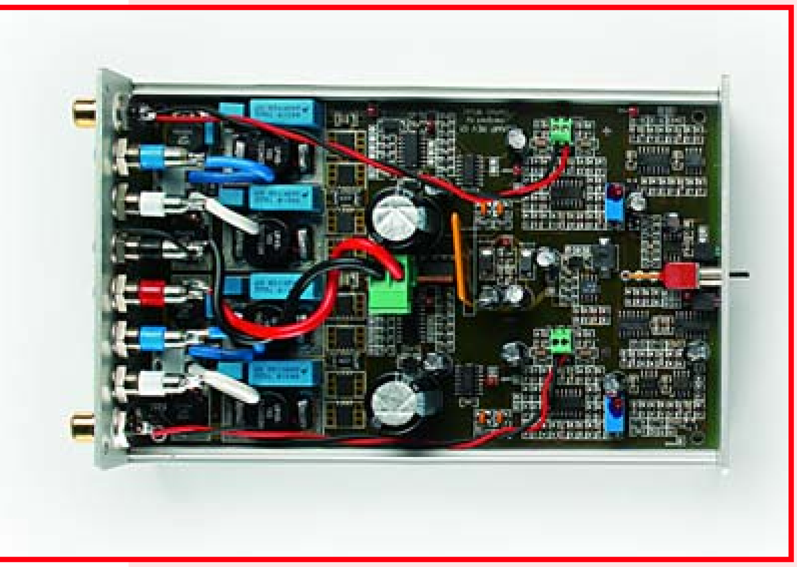
driven motion of the platen roller into linear motion with the stepper using belts or gears or electronic gear ratio reduction for the steps. All three methods work but I like the belt and gears method best.
I tried modifying printers to feed a board through as is, but that was just too much trouble.
Some would feed thin stock just fine but others wouldn't. The flat bed approach solves that. Plus, the flat bed approach with some simple guide pins lets you do double sided boards with accurate side to side registration.

For ink, I found two things that work well standing up to the etchant:
• acrylic floor polish;
• shellac.
Floor polish (sometimes called wax) (I used the 'Future' brand) works well and won't gum up the printheads as easily as shellac does. Floor polish is removed with ammonia, shellac with denatured alcohol.
I used three different types of printers. A Lexmark where the head is built into the cartridge, an HP where the printhead is separate from the cartridge but still uses thermal 'bubble' jet technology and an Epson which uses piezoelectric technology.

The winner was the Lexmark. Easy cartridge to refill and cheap enough to replace.
The problem in all this is that to use straight 'ink' that is very water- (and then etchant-) proof is, it will dry on your printhead orifices. The solution to that is a valve. One path to ink, one path to a flushing fluid. Before you print the board, run a cycle of 'ink' to clear out all your flush fluid.
Once you have finished printing, run a cycle of flushing fluid to purge all your 'ink'. Ammonia diluted with water works great on the acrylic polish ink. You can even put a little regular inkjet ink into it to colour it so it's easier to see on the PC board blank.
Once you get the 'ink' on the board and have etched it, you can clean it off with just a quick spray of Windex or other ammonia based cleaner.
I have no idea as to the benefits or problems with acrylics as conformal coatings but I plan to try it some day on a finished board. Just dip it in Future polish and see what happens!
Another thought I had was a PVA (polyvinyl alcohol) based ink but the PVA I had on hand didn't thin out well to run in an inkjet. The acrylic ink worked well enough so I didn't really pursue PVA much.
Now go have fun......

Class-D ruminations

Dear Sir, — I read with interest the article on this subject (February 2006, *Ed.*) and was reminded of the first such amplifier which I remember being offered by Sir Clive Sinclair!



My last recollection of a system based on integrated circuit technology was of a two-component approach. This contained all the elements presented by your designer with an internal triangular wave generator (100-kHz), low level audio amplifier and power stage drivers.

I believe the components were: TDA7232 and TDA7260 in 20-pin DIP case (SGS?).

Do these items still exist, or a modern day equivalent, for the 'enthusiastic amateur'? If so, would this form the basis for a further exploration of this interesting approach to high efficiency audio amplifiers?
I. C. Rohsler (UK)

Although we doubt the design technology of early quasi-digital amplifier ICs like the ones you mention would have lived long enough to make into present day devices like the IC we discussed in the February 2006 issue, we would like to hear of anyone who has detailed information.

ARM microcontroller comparison m

Device	Package	RAM
ML674001	144-pin LQFP	32 kB
ML67Q4002	144-pin LQFP	32 kB
ML67Q4003	144-pin LQFP	32 kB
ML67Q4050	144-pin LQFP	16 kB
ML67Q4051	144-pin LQFP	16 kB
ML67Q4060	64-pin LQFP	16 kB
ML67Q4061	64-pin LQFP	16 kB
ML675001	144-pin LQFP	32 kB
ML67Q5002	144-pin LQFP	32 kB
ML67Q5003	144-pin LQFP	32 kB
AT91SAM7S32	48-pin QFP	8 kB
AT91SAM7S321	64-pin QFP	8 kB
AT91SAM7S64	64-pin QFP	16 kB
AT91SAM7S128	64-pin QFP	32 kB
AT91SAM7S256	64-pin QFP	64 kB
AT91SAM7A1	144-pin QFP	4 kB
AT91SAM7A2	176-pin QFP	16 kB
AT91SAM7A3	100-pin QFP	32 kB
AT91SAM7X128	100-pin QFP	32 kB
AT91SAM7X256	100-pin QFP	64 kB
AT91SAM7SE256	128-pin QFP	32 kB
AT91SAM7SE512	128-pin QFP	32 kB
STR711FR0	64-pin TQFP	16 kB
STR712FR0	64-pin TQFP	16 kB
STR715FR0	64-pin TQFP	16 kB
STR710FZ1	144-pin TQFP	32 kB
STR711FR1	64-pin TQFP	32 kB
STR712FR1	64-pin TQFP	32 kB
STR710FZ2	144-pin TQFP	64 kB
STR711FR2	64-pin TQFP	64 kB
STR711FR0	64-pin TQFP	64 kB
TMS470R1A64	80-pin LQFP	4 kB
TMS470R1A128	100-pin LQFP	8 kB
TMS470R1A256	100-pin LQFP	12 kB
TMS470R1A288	144-pin LQFP	16 kB
TMS470R1A384	144-pin LQFP	32 kB
TMS470R1A512	144-pin LQFP	32 kB
TMS470R1A768	144-pin LQFP	48 kB
TMS470R1B1M	144-pin LQFP	64 kB

atrix (continued)

FLASH	CLOCK	I/Os	UARTs	SPI	I2C	CAN	TIMERS	PWM	ADC	DAC	Note
-	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory interface
256 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory interface
512 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory interface
64 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory interface
128 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory interface
64 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	Secure Embedded Flash
128 kB	33 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	Secure Embedded Flash
-	60 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory i/f, 8K cache
256 kB	60 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory i/f, 8K cache
512 kB	60 MHz	42	2	1	1	-	7 x 16-bit	2-ch	4 x 10-bit	-	external memory i/f, 8K cache
32 kB	55 MHz	21	1	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC
32 kB	55 MHz	32	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
64 kB	55 MHz	32	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
128 kB	55 MHz	32	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
256 kB	55 MHz	32	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
-	40 MHz	49	3	1	-	1	9 x16-bit	4-ch	8 x 10-bit	-	external memory Interface
-	30 MHz	57	2	1	-	4	10 x16-bit	4-ch	16 x 10-bit	-	external memory Interface
256 kB	60 MHz	62	3	2	1	2	9 x16-bit	8-ch	16 x 10-bit	-	2xSSC, USB, MCI
128 kB	55 MHz	60	2	1	1	1	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB, AES
256 kB	55 MHz	60	2	1	1	1	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB, AES
256 kB	55 MHz	74	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
512 kB	55 MHz	74	2	1	1	-	3 x16-bit	4-ch	8 x 10-bit	-	SSC, USB
64 kB+16 kB	60 MHz	30	4	2	2	-	5 x 16-bit	-	4 x 12-bit	-	USB,RTC, Watchdog timer
64 kB+16 kB	60 MHz	32	4	2	2	1	5 x 16-bit	-	4 x 12-bit	-	RTC, Watchdog timer
64 kB+16 kB	60 MHz	32	4	2	2	-	5 x 16-bit	-	4 x 12-bit	-	RTC, Watchdog timer
128 kB+16 kB	60 MHz	48	4	2	2	1	5 x 16-bit	-	4 x 12-bit	-	USB, external memory i/f, RTC, Watchdog timer, High Current
128 kB+16 kB	60 MHz	30	4	2	2	-	5 x 16-bit	-	4 x 12-bit	-	USB, RTC, Watchdog timer
128 kB+16 kB	60 MHz	32	4	2	2	1	5 x 16-bit	-	4 x 12-bit	-	RTC, Watchdog timer
256 kB+16 kB	60 MHz	48	4	2	2	1	5 x 16-bit	-	4 x 12-bit	-	USB, external memory i/f, RTC, Watchdog timer, High Current
256 kB+16 kB	60 MHz	30	4	2	2	-	5 x 16-bit	-	4 x 12-bit	-	USB, RTC, Watchdog timer
256 kB+16 kB	60 MHz	32	4	2	2	1	5 x 16-bit	-	4 x 12-bit	-	RTC, Watchdog timer
64 kB	48 MHz	40	2	2	-	1	13 x 32-bit	-	8 x 10-bit	-	SCC
128 kB	48 MHz	50	2	2	-	1	16 x 32-bit	-	16x 10-bit	-	SCC
256 kB	48 MHz	50	2	2	-	1	16 x 32-bit	-	16x 10-bit	-	SCC
288 kB	48 MHz	93	2	2	-	2	12 x 32-bit	-	12x 10-bit	-	external memory i/f, DMA, SCC
384 kB	48 MHz	94	2	2	3	2	12 x 32-bit	-	12x 10-bit	-	external memory i/f, DMA, SCC,
512 kB	60 MHz	86	2	3	-	2	32 x 32-bit	-	16x 10-bit	-	HECC, DMA
768 kB	60 MHz	86	2	5	-	3	32 x 32-bit	-	16x 10-bit	-	HECC, DMA
1 MB	60 MHz	93	3	2	5	2	12 x 32-bit	-	12x 10-bit	-	external memory i/f, DMA, I2C, HECC

Elektor's SMD Oven — cool design –

Below we reproduce a selected number of slightly edited postings in our online Forum topic on the SMD Reflow Oven published in the January 2006 issue. Thanks all contributors so far, you have built an interesting thread on the subject! The design seems to have attracted a lot of interest and it is our intention to revert to the subject in the May 2006 issue. The article can be downloaded from the January 2006 page. Readers are encouraged to post their thoughts on using the SMD Oven in the online Forum.

Comparison to Circuit Cellar design

(GonzoR) How does the Elektor design compare to the SMD reflow oven built from an infrared toaster? I saw one described by one Robert Lacoste in Circuit Cellar 2004? I guess the critical point will be the accuracy of the temperature control.

(EELabs) We briefly looked at the CC design and must admit that their design was published before ours. Earlier is not better however.
A number of critical remarks can be made about the CC design as compared to the version we proposed in our January 2006 issue. Just have a look at the accuracy of the temperature control, which is poor when compared to the target temperature curve. The 'control' in the CC design has an unacceptable amount of overshoot that may cause a lot of problems.
The EE design has an automatic calibration routine and an intuitive user interface. The interface for those weak thermocouple signals as CC propose it in their design strikes us as out of date. By contrast our method is accurate and includes cold-junction compensation.
(where CC = Circuit Cellar; EE = Elektor Electronics)
(EE Labs)

(Terry Rose) A quick note: the AD595 does have cold junction compensation on the chip but the calibrated (to 1 deg C) AD595C is very expensive at UK pounds £20-22! I think there is no problem using older designs as the basis for new and improved projects and this Elektor design is really good as it contains several improvements over the original. The original article by Robert Lacoste did however have quite a lot of information on using an SMD oven once it was built and is worth a read just search the circuit cellar site for the article it's free to read and download. Maybe the Elektor team could publish an article on using the oven in 2006 as I think the readers would find this interesting. Well done and thanks for this interesting project.

Component availability in the UK

(*NickR*) An indication of where the hobbyist can source some of the components would be nice. Specifically, where can I buy the MAX6675 and the opto-triacs S202S12?

(*StephenLinton*) Hello, I found it hard to get the S202S12 but found them on www.conrad-direct.co.uk. They aren't cheap, £9.79 each but check the current rating on your oven as these optotriacs are rated for 8 Amps.

(*belfryboy*) If I ever need a small quantity of component from Maxim I simply fill in their sample request form and add made up details in the company name field, but use your own address. Always indicate that you predict to produce at least 1000+ units per year and your samples will appear in a few days.

(*Bruce Howard*) Digikey Corporation in the United States stocks the S202S12 optotriac manufactured by Sharp. I have used this component in several applications and find it to be very useful, though somewhat expensive at $9.40 USD. The following link will take you to the ordering information page at Digikey: www.digikey.com/scripts/DkSearch/dksus.dll?Detail?Ref=47244&Row=193091&Site=US

Hot plates and tutorial

(*Nathan Seidle*) I wanted to point out our hot-plate tutorial that I thought would make a much more fun article. We even have a tutorial for stenciling paste!
Start here:
www.sparkfun.com/tutorial/SMD_Printing/SMD_Printing.htm
And don't forget the oven comparison and hot plate info:
www.sparkfun.com/tutorial/ReflowToaster/reflow-hotplate.htm
And finally the original oven tutorial:
www.sparkfun.com/tutorial/ReflowToaster/reflow-toaster.htm
Just an FYI to all my home reflow friends!

Alternative ovens, toasters, etc.

(*dsptony*) What great timing this article was for me. I had been looking at the Spark Fun reflow tutorial and built my own one out of a 5 pound toaster (yeah, it really was a bread toaster) from Tescos (good results once you get the knack, successfully done 20 or so boards, burnt the first one though). Then I see this article in Elektor... cool.
Coincidentally I have also bought the Argos Hinari @ 19 pounds. I have it on my desk at work in bits right now. I have just finished rewiring it, had to wait until I got some heatshield braid (RS, 1.37 for 15 m plus delivery). I have been designing a 2-triac phase-control board run from a PIC at work so I am going to use that in the oven. I plan to control the elements with one triac and to put an oven light bulb in and control that with the other triac. I have found in the past that it is really handy to be able to see the board, especially during development of the code. It also I a way to indicate to me that a session is still finished or still in process. I am using triacs with separate optocouplers.
I decided from my first attempt at an oven that it would be good to add a fan too. This is to stop hot spots with some gently convection and to do a nice controlled cool down. Like the others here I was not able to easily find a thermocouple amp. The ADC on my PIC is 10-bit and I am running it on 3.8V so I only have resolution of about 3.7 mV, this won't work on thermocouples with out some amplification. I had some thermistors in a nice metal case handy so I am going to give that a try but I have some concerns about how well it will work above 150 degrees.
I found with making the first one that there are heaps of things that you will decide to improve on model 2. I guess that will be true for this one too but if anyone has suggestions I am keen to hear them. It is so cool watch your boards solder reflow in a oven you have made and to know that you can control the whole process, (if you're into that sort of thing).
Go on... give it a go.
(*SamL*) Well, I have built this, and got it running with the little Hinari oven. It struggles at higher temps - on the lookout for some rockwool or equivalent - not helped by being in a subzero shed. I'll try some boards once it can make a sensible profile.
I have been using a hotplate off ebay to good effect w/ ir gun thermometer, but now I need double sided boards.
One idea I had is to put all the profile stage description out

– hot debates

into the EEPROMs- code becomes a simple interpreter for stage descriptions. Why? I want to use the oven for various curing cycles (Epoxy, Heat resistant RTV) as well. Unfortunately, I can't quite get the code to fit into the 8 k part when rebuilt with SDCC.

(*dsptony*) Very cool Sam. I am curious about what temperature you were able to get it up to and what ambient was when you were doing the test. The front panel on the Hinari claims that you can get 300 degrees C out of it so even at 0 I would expect 275... not true? For the paste I am using I need it to get to 240 or so, would be disappointed if it could not.
I had not thought about double sided, id it tricky gluing small parts. I only go down to 0603 for hand built boards, might need a really fine syringe tip.
Maybe you could store the temp and the lenght of time (2 values) in EEPROM, just guessing it is big because all values stored (sorry have not read the code, I am using Hi-Tech compiler, could be wrong). My controller is using a PIC 12F683 (2k program, 256 onboard eeprom, 128 RAM, 8 pin), I am at about 80% but do not use a LCD and very limited bit bashed serial.

(SamL) "Very cool..." Unfortunately, yes!
Actually, not as bad as I first thought, had another go with the oven reassembled properly, the door really closed, and the thermocouple in the centre.

Ambient: 4 degrees, elements full on (set point of 300 degrees).
10 minutes: 200 degrees
15 minutes: 240 degrees
20 minutes: 260 degrees

At that point, is looked as if it might get a couple of degree hotter, but things looked to be pretty much in equilibrium. First time I tried, it was topping out at a shade over 240. (Ambient was closer to 0 tho' — brrr).
I guess it will work, but it is not the 2 or 3 degree a sec climb up to reflow peak I would associate with a 'proper' oven.
I am very tempted to follow your path, and rework a toaster — all my boards are v. small.
As for double sided, my plan is to 'just' use paste — I have seen this done at my last job: Paste & place bottom, and then gently heat (~150 degrees?) for a couple of mins (or leave overnight). The dry flux sticks the components on very well. Paste & place top, then reflow the whole thing. The surface tension of the solder holds the parts in place. I only plan to have 0603 and sc70 parts underneath, but my former colleagues ran QFP and TSOP packages! They were, however, experienced, have good kit, and were very agressive about measuring/tweaking the profile. My own results may differ.

(*dsptony*) So here are my results testing the little 'Hinari Tiny Top'. I put both elements on full and recorded once a minute with a Fluke 179 and paired thermocouple.

Min.	Temp
0	18°C (room temp.)
1	53°C
2	116°C
3	167°C
4	201°C
5	226°C
6	244°C
7	259°C

Then the thermostat kicked in and the temperature dropped down to 155°C before I heard it click back on, with undershoot to 152°C. So for the next test I have taken it out of circuit.

Min.	Temp
0	22°C (room temp.)
1	61°C
2	125°C
3	171°C
4	208°C
5	232°C
6	250°C
7	262°C
8	276°C
9	285°C
10	292°C (stopped)

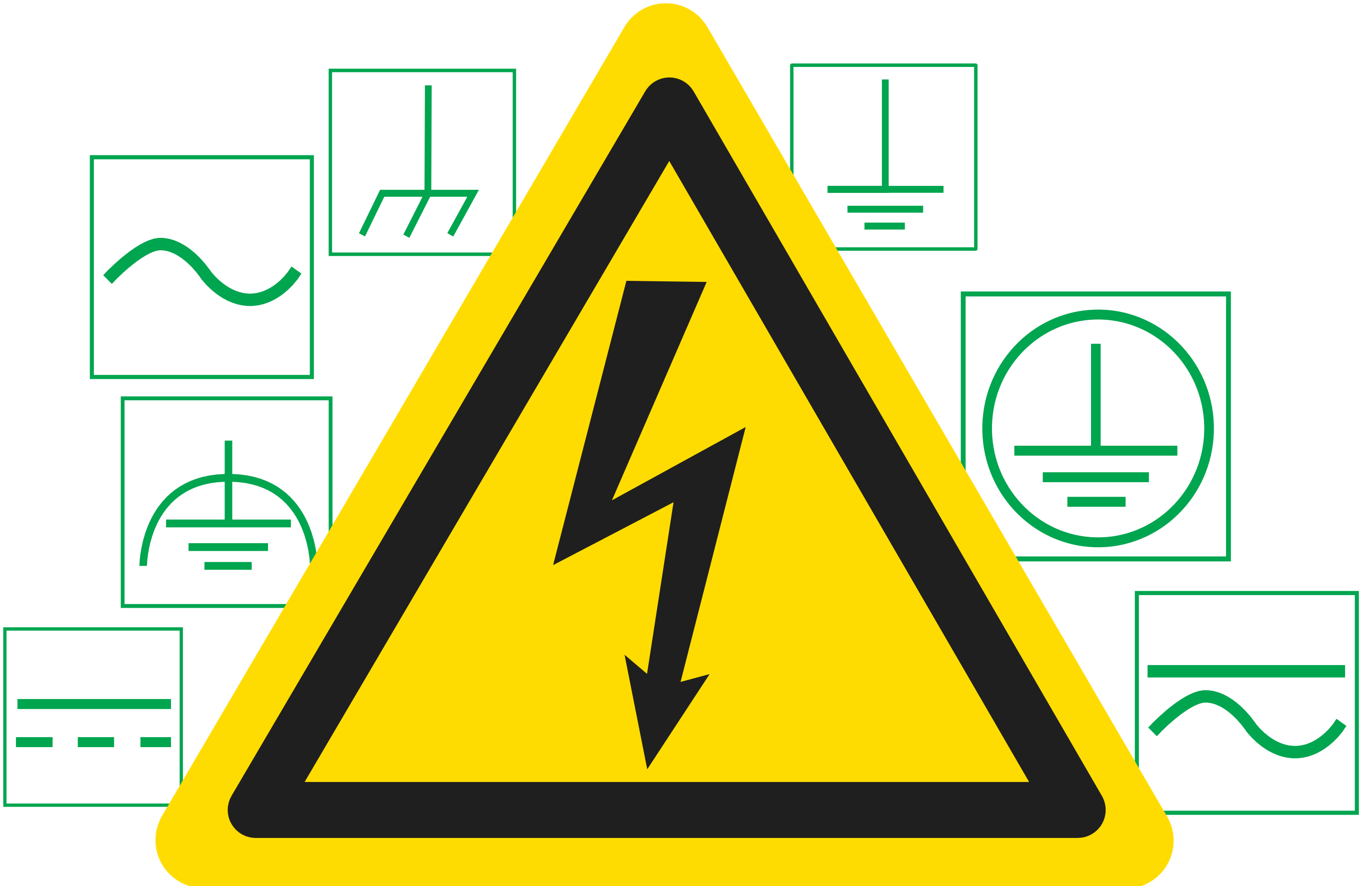
with the door still closed the temp fell at about 1/3 degree per second .

I decided not to let it go any further, I am a little worried about the insulation on some of my wires. I put heat braid on most but forgot to on my serial programming lines.
In some ways the results were a relief, I can get the temperatures I want but it may take some time to ramp for the reflow zone to peak at about 230°C.

One more thing I remembered about popup toaster reflowing, there is never a good reason to have smoke coming of your boards, if you see it start to wisp out of the slot then cut the power and pull your boards out fast.

Safety with Eco

Martin Ossmann



How should we go about building a circuit so that it is safe to use? To find out, we have taken a look inside a couple of items of equipment: it is fascinating to see the tricks the professionals come up with to satisfy the twin constraints of price and miniaturisation.

The question of safety should always be uppermost in our minds when designing circuits and equipment. A device should not pose a risk to humans in operation; the device must function safely in all conceivable situations; and finally the device should not cause damage to itself (or other devices) in the event of a failure.

Accommodating all these requirements for a home-made unit can be quite a challenge. Of course, industrial designers face the same problem when making products for end users: these products must be foolproof. Why not take a look inside a couple of items of equipment and see what we can learn from the professionals?

Money-saving

First we shall look at the measures we can take to protect against the possibility of electric shock. This is mostly a case of making sure that high-voltage parts of the device cannot be touched, where the high voltage in question is usually the mains supply. In general wires and components are already provided with insulation, which the relevant standards refer to as 'basic insulation'. The present situation is that basic insulation is not considered reliable, and that its failure should not directly give rise to a hazard. Further measures, such as additional insulation, nomy

Some observations on electronic equipment

earthed enclosures and so on, are required to ensure safety in the event of a fault.

Let us look first at a CD player (**Figure 1**). According to the label on the unit (**Figure 2**) this is a Class II device; there is therefore no earth connection. As can be seen, the mains cable simply enters directly into the transformer. The on-off switch is on the secondary side of the transformer and is therefore a low-voltage part. The manufacturers have been careful to ensure good insulation throughout. All components carrying mains voltage have additional insulation, and there is careful separation of the transformer into two bobbins. This ensures that failure of the enamel on the wire of one of the windings is not dangerous. In the cabinet there is no fuse on the primary side, which helps to keep the cost low. In the UK, a fuse is incorporated in the mains plug. This arrangement can only be used with a suitably-approved transformer and corresponding safety precautions on the secondary side. A disadvantage of this approach is that the transformer runs continuously, increasing stand-by power consumption.

Analysing the transformer

The mains transformer does an important job in isolating the circuit from the mains. If a classical 50 Hz transformer is to be safe, it must be constructed using a special core with separate bobbins (Figure 1) which must meet all the necessary requirements in terms of leakage paths and so on. Modern mains supplies are increasingly constructed using switching technology and smaller transformers, and it is worth taking a closer look at the types of transformer used.

Figure 3 shows a toroidal transformer from a step-down switching supply for low-voltage halogen lamps, providing isolation from the mains. The primary winding is located within the plastic enclosure. This particular core design ensures that the primary and secondary windings are kept at a safe distance from one another. The air gaps and the spacing provided by the insulating material need to be carefully determined. In general it is easier to provide the required isolation using a physical barrier, although it is still necessary to ensure that the leakage paths through the air (for example between the two bobbins) are sufficiently long. In this transformer the secondary winding does not have extra insulation.

A relatively straightforward way of providing for adequate gaps is to use specially-designed bobbins.

Figure 4 shows the components of one example. The primary and secondary windings are wound on separate bobbins with collars at their ends giving adequate air gaps. This construction makes it easy to satisfy the safety regulations. There are, however, some disadvantages: the bobbins are expensive, and the resulting transformer is often larger than strictly necessary from an electrical

Figure 1. A look inside a consumer-market CD player.

Figure 2. The symbol indicates a Class II device.

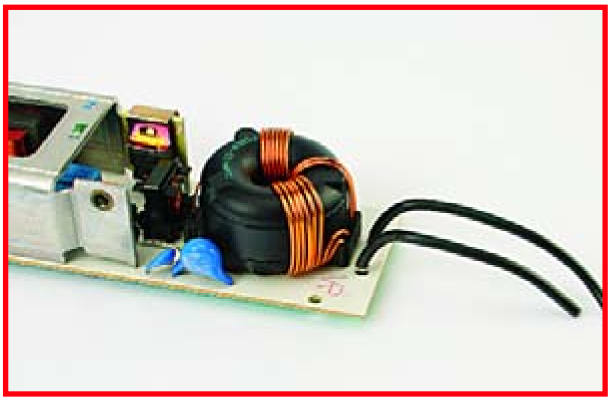


Figure 3. Toroidal transformer in a supply for a halogen lamp.

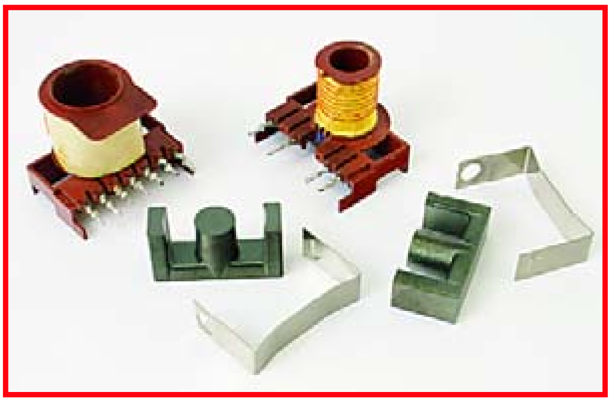


Figure 4. Bobbins with built-in insulation.

Figure 5. Mounted transformer, optocoupler and Y-class capacitors.

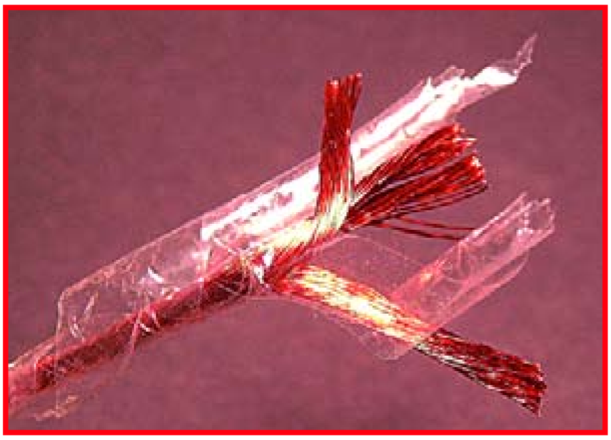


Figure 6. Braid wound in layers.

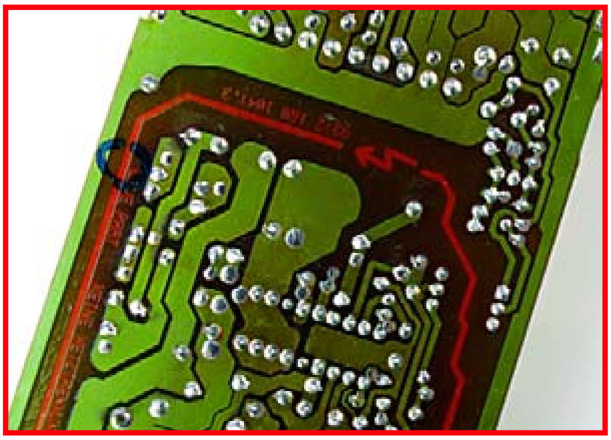


Figure 7. The isolation barrier between the mains and the secondary side of the supply.

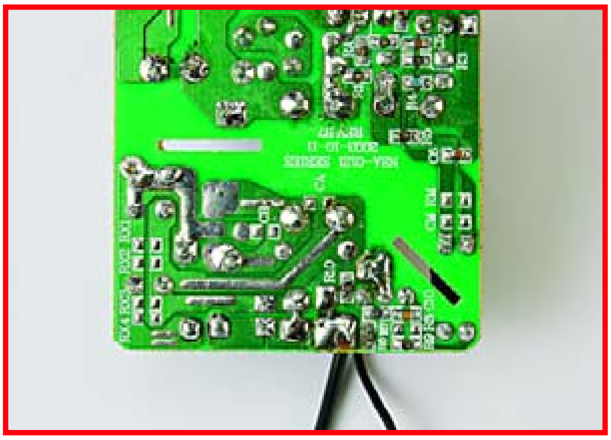


Figure 8. Slots provide an additional barrier.

point of view. The primary and secondary sides are also not as well coupled together, which creates extra problems in the design of low-cost flyback converters. On the other hand, there is no need to wind insulating sheets in between the windings or to pot the completed transformer. **Figure 5** shows such a transformer in use. This example is relatively small, as can be seen by comparing its size with that of the optocoupler in a 4-pin DIL package. As well as the optocoupler there are also two Y-class capacitors in the foreground. These components bridge the isolation gap: we shall return to this point below.

Safety for your own projects

One way to avoid the need for insulation layers or special bobbins is to use multiply-insulated wire. For example, a type called 'triple-insulated wire' is available, which is approved for mains isolation (see the article elsewhere in this issue on the cleverly-designed switch-mode power supply). **Figure 6** shows another variation on the theme, where the windings are made of braid wound with several overlapping thin and wide insulating sheets. With the use of special wire like this it is possible to construct transformers which simultaneously exhibit low stray inductance and good isolation.

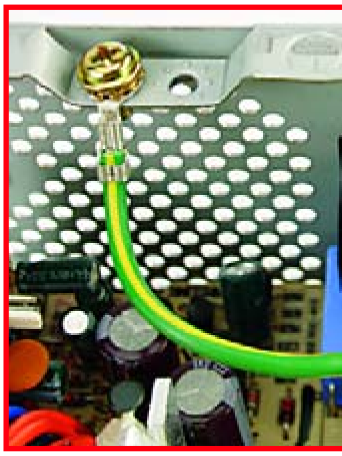


Figure 9. Earth connecti

Once the transformer has been designed to afford adequate isolation, we can now apply the same principles to the printed circuit board and the rest of the device. In the design shown in **Figure 7** the inner part of the layout is the primary side. The power supply is fitted into a metal cage which is connected to the secondary side. The barrier can be clearly seen. It is also conspicuously labelled so that service technicians can immediately see where it lies.

A further detail is shown in **Figure 8**. Two slots have been cut in the printed circuit board at particularly critical points. This considerably increases the length of the leakage path over the surface of the circuit board: any leakage current must make its way around the slots. This is particularly important because the printed circuit board may become dirty with time or attract moisture and thus become a less good insulator.

Inside a PC

Next we shall take a look inside a PC. Traditionally, PCs are constructed as Class I devices with an earth connection. **Figure 9** shows the power supply and its metal enclosure. On the right is a cold-condition connector, and it is clear that the earth wire is not simply soldered, but is made using a screw terminal. This is necessary in order to ensure that the earth connection can do its job reliably. We proceed to the transformer inside this power supply (**Figure 10**). A standard core is mounted vertically between two aluminium heatsinks. The front heatsink cools the switching transistor on the primary side, and

the rear heatsink cools the rectifier diodes on the secondary side. The whole arrangement is so closely packed that the gap between the aluminium plates and the transformer does not provide adequate isolation. To bring the unit back within the regulations, two transparent sheets of insulating material have been fitted (presumably as an afterthought) between transformer and aluminium plate and fixed with glue. Not elegant, but effective.
In a construction of this type it is of course essential to ensure that there is adequate insulation between the underside of the printed circuit board and the enclosure. Frequently sheets of insulating material are found here as the air gap is too small.

Finally we look at the so-called Y-class capacitors. These are usually fitted to reduce interference, and in such cases it is permitted to connect them between high-voltage parts of the circuit (such as the live input) and earth. Safety is particularly critical for these capacitors, and they must be approved types. The circuit must not exceed the prescribed earth leakage current. **Figure 11** shows an example of this type of capacitor. The capacitance value (472 means 4.7 nF) is hard to find amongst all the approvals and testing markings. This capacitor may be connected between high-voltage parts of the circuit and the secondary side or the metal enclosure in Class II equipment. If a capacitor in such a position should fail (i.e., if it should pass a signal at 50 Hz) the secondary side would no longer be isolated from the primary. Thus the failure of a single component could have extremely hazardous consequences, which explains the the strictness of the specifications it must meet. Since the connections to a Y-class capacitor generally bridge the isolation barrier (see Figure 5), they must themselves be adequately far apart.

on in a PC power supply.

Fail-safe

Overheating when a fault occurs is a further danger that a designer must consider. In extreme cases, a fault can lead to a fire. Many switching power supplies therefore include over-temperature protection. **Figure 12** shows an example of a switching supply for halogen lamps. One of the two power transistors is fitted with a temperature sensor which shuts down the converter if the temperature should become too high. This kind of design can also be useful if a switching supply must be able to withstand overload or short-circuit of its secondary side. In general it is necessary to consider the effect of a fault in any component in the design of the supply; only then can one finally also consider incorporating a fuse.

Figure 13 shows an interesting possibility. The 'fusistor' is a resistor which limits the current surge at switch-on. The resistor also burns out at a preset overload current without risk of causing a fire. This is an ideal solution in many applications.

(050327-1)

Figure 10. Insulating sheets are fitted between the transformer and the heatsinks.

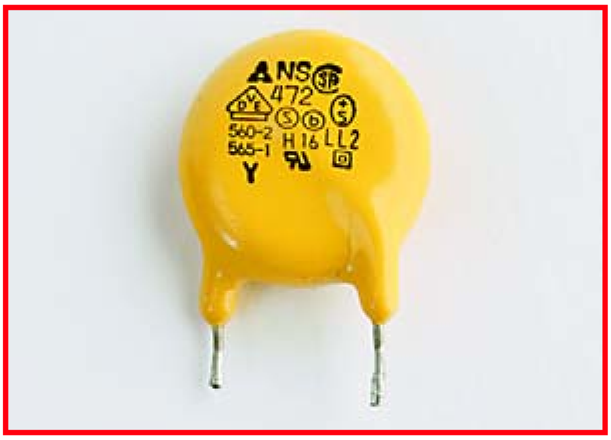


Figure 11. An approved Y-class capacitor.

Figure 12. Power supply for halogen lamps.

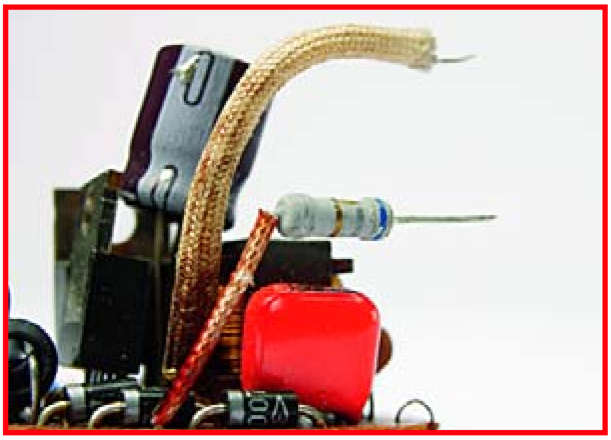
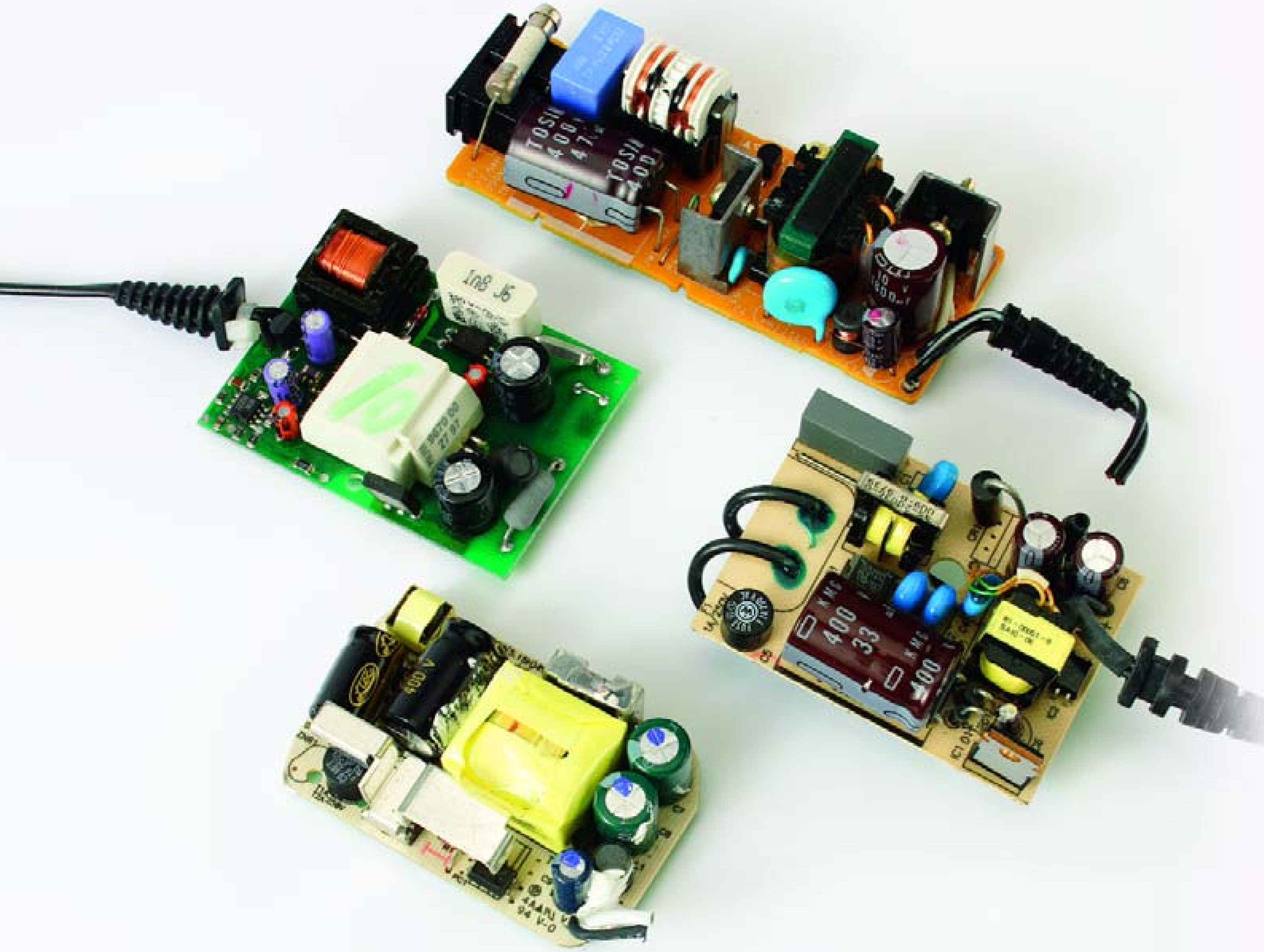


Figure 13. The 'fusistor' is a fuse and a resistor in one device.

Switch-Mode Su

Elegant designs from China

Martin Ossmann



The switch-mode power supply chosen by the author for this article is built without the use of special-purpose ICs and so can be completely ‘reverse engineered’. We make some surprising discoveries as, step by step, we find out how the unknown designers managed to make such an effective circuit using just a few low-cost components. We can even apply the lessons learned to our own designs.

upplies Revealed

Small power supplies, for example for charging mobile phones, increasingly tend to employ a switching topology. The author has been collecting and analysing units of this type for some time, and has noticed that the power supplies from one Chinese manufacturer are particularly interesting and worthy of a closer look. We will also look at alternative strategies used in other power supplies. Finally, we round off the article with a small construction project using the same ideas as the elegant Chinese design.

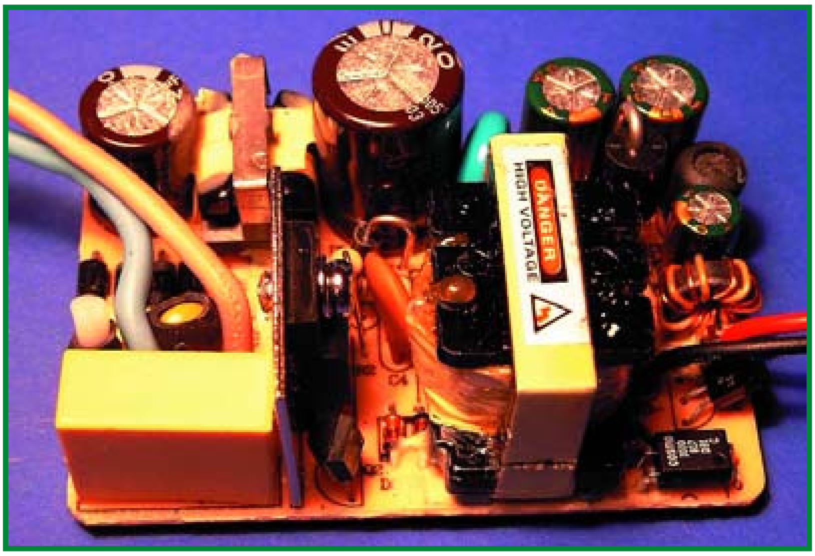


Figure 1. A Chinese-made power supply using discrete components.

Cheap, simple and discrete

The mains power supply shown in **Figure 1** is constructed using discrete components, without the use of special-purpose ICs. This means that we can completely analyse how it works through 'reverse engineering'. What is astonishing is that such an effective circuit can be constructed using so few low-cost components. In the analysis we will see at each step what aspects of the design are important, and there will be a few surprises along the way.

Insights

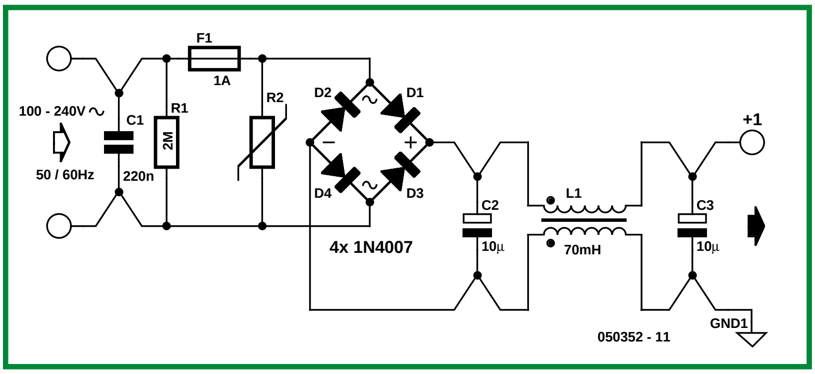
A mains power supply can normally be divided into three functional blocks. In the first stage a DC voltage is derived from the mains input. This stage also includes various safety and filtering functions. The second stage is the switching circuit proper, which performs voltage conversion and which provides isolation from the mains. In the third stage the output voltage is conditioned and smoothed, and the necessary information is obtained to allow control of the voltage regulation process.
First we look at the specifications of the supply, which are shown on the manufacturer's identification label:
Input voltage: 100 V to 240 V AC, 50/60 Hz
Output voltage: 12 V, maxi. 1.0 A

The input stage of the power supply is arranged as shown in **Figure 2**. Capacitor C1 is directly connected across the mains voltage without further protection, and must therefore be an 'X-class' (or 'across the line') capacitor. Its job is to block high frequencies from the mains. R1 is included to discharge C1. Ordinary SMD resistors are not suitable for operation at mains voltages, and so R1 is built from two 470 kΩ SMD resistors in series.

A fuse is included in case something should go wrong: an example scenario would be a high-energy transient spike on the mains input. Smaller transients are absorbed by VDR R2 (470 V). Four discrete type 1N4007 diodes form a rectifier for the mains voltage. Some manufacturers use a bridge rectifier in a surface-mount package. Capacitors C2 and C3 together form the reservoir capacitor. They are 400 V/105 ºC types to ensure a long life at high temperatures. An interesting addition is common-mode ('current compensated') choke L1 between the two capacitors. The advantage of this arrangement is presumably that an approximately constant direct current flows between the capacitors, lower than the peak pulse current in the bridge rectifier. The choke can therefore be made smaller. At the same time, the stray inductance of this 'transformer', together with C2 and C3, effectively form a differential mode filter. As a common-mode coil, each side of choke L1 has an inductance of around 70 mH. Viewed as a transformer it has a stray inductance of 460 µH, which is probably adequate for a differential-mode choke. Thus coil L1 presumably has two filtering functions.

A closer look at the printed circuit board reveals that there are slits in several of the tracks (**Figure 3**). This is no accident: it ensures that the current is forced to flow via the capacitors. This arrangement is often indicated in

Figure 2. The input stage of the power supply.



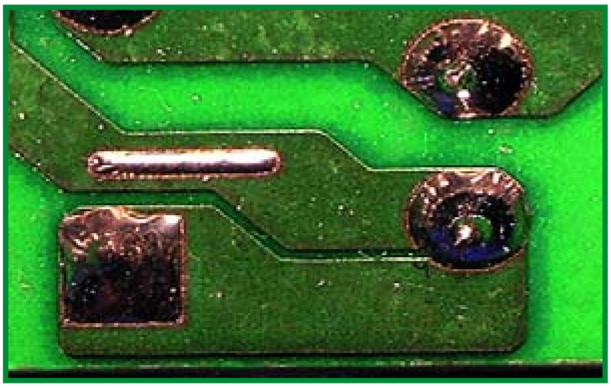


Figure 3. Cuts in the circuit board tracks improve decoupling.

circuit diagrams by a kink in the connection, as we have shown in Figure 2. Slits feature in the tracks running to several capacitors on both the primary and the secondary side of the circuit we are studying. The supply voltage for the switching part of the supply appears, after the above filtering, across C3.

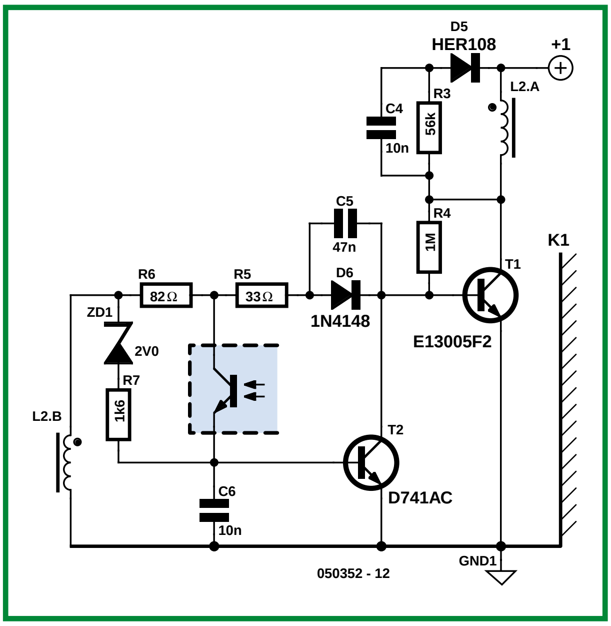


Figure 4. The heart of the power supply.

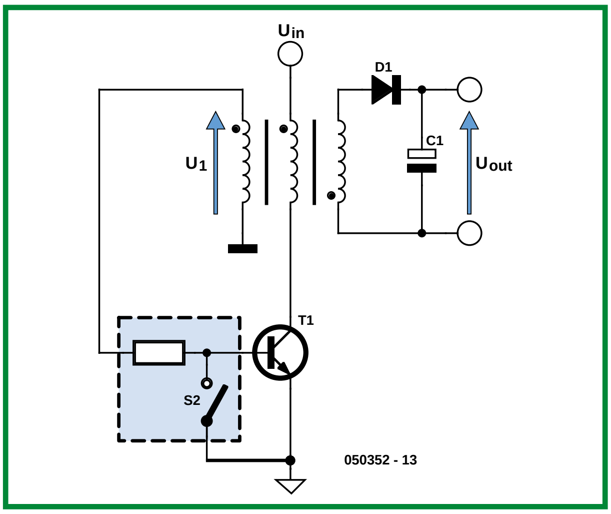


Figure 5. The principle of the self-oscillating flyback converter.

Flyback converter

The first thing to establish when looking at a mains power supply is the basic circuit topology involved. First we try to find the individual power components, which can generally be recognised by their size. Next we can try to identify the components used (in particular diodes and transistors) either by measurements or by trying to find their data sheets. Simple in-circuit DC resistance measurements can help in working out the wiring of the transformer. In this case we quickly discover that we are dealing with a flyback converter, the most popular topology for lower-power applications.

Figure 4 shows the heart of the power supply, without the secondary circuit. The circuit basically consists of two transistors but is not entirely straightforward, as we will show in our analysis below.
The basic principle of the flyback converter is more clearly shown in **Figure 5**. The central components are the 'transformer', with three windings, transistor T1, and diode D1. We put 'transformer' in inverted commas because the component in question is really just an inductor with several windings. At the beginning of a switching cycle there is no current flowing in any of the windings of the coil, and no energy is stored. T1 is then turned on and the primary winding of the inductor is 'charged' from the input voltage U_{in}. Meanwhile, D1 is not conducting. At a suitable moment T1 is then switched off and the current is transferred from the primary side to the secondary side. Diode D1 conducts and the inductor is 'discharged', delivering its energy into the secondary circuit. This pattern of current flow characterises the flyback converter topology. The secondary current falls linearly; when it reaches zero, T1 is switched on again and the cycle repeats.

Measurements

So much for theory; now let us make some practical measurements. Since the circuit is normally connected directly to the high voltages of the mains, this is not entirely straightforward. If we connect the circuit via a mains isolating transformer we can make measurements on the primary side of the power supply using a normal oscilloscope. Caution is still required, however, as there will be no earth leakage or other protection in place. As electrolytic capacitors C2 and C3 are not particularly large the supply voltage exhibits ripple at 100 Hz, whose effect can be seen on the oscilloscope traces. To remove this effect we use a separate bridge rectifier and larger capacitors (470 µF) to generate the supply voltage and apply it to point '+1' (see Figure 4). **Figure 6** shows the voltage across switching transistor T1 (upper trace, 10:1 probe) and the collector current through T1 (lower trace, measured using a current clamp). For this measurement the input voltage at point '+1' was 326 V. At the rated output load of 1 A at 12 V the DC input current was 44.5 mA, giving an efficiency of around 83 percent. The operating frequency was 95 kHz. Note that when the diode conducts the voltage across the transistor is equal to the input voltage plus the output voltage multiplied by the transformer ratio.

Self-oscillation

In larger mains power supplies the timing and control of the drive to the power semiconductors is often handled by an IC. Here all these functions are carried out by a few discrete components. First let us examine the theory with the aid of Figure 5. The key element is the third transformer winding, which is coupled to the others. We start our analysis by assuming that T1 has just turned off. The coil current now flows through diode D1 and falls off linearly. As soon as the current reaches zero, the diode blocks. The coil, together with its parasitic capacitances and those of the other components, now forms part of an oscillator, which executes one half-cycle. The voltage on the secondary winding falls and eventually goes negative. This leads to a positive voltage across the third (feedback) winding, which turns transistor T1 on, causing the voltage across the primary and secondary windings to rise further, helping to keep the switching time short. T1 conducts and the coil current rises linearly as energy is stored in it. After a certain time S2 is closed (by a further clever circuit) and the base current of T1 falls. The collector current thus also falls. The process of turning off T1, once started, is accelerated by the feedback circuit. At this point the cycle starts again from the beginning.

All we need to do now is explain how transistor T1 is switched off after a certain time interval. The function of S2 in Figure 5 is assumed by transistor T2 in Figure 4. The important components here are R7 and C6. After T1 turns on there is a positive voltage on L2B relative to ground. C6 now charges slowly until T2 starts to conduct. The collector current of T2 then steals base current from T1, leading to T1 turning off. The feedback circuit accelerates this switching-off process.

Figure 7 shows the voltage at the base of T2 (lower trace) and the base current of T1 (upper trace, measured using a current clamp). Transistor T1 is turned on with a base current of around 100 mA, which remains constant for a short while. At the same time the voltage at the base of T2 rises until it reaches approximately 0.8 V. The base current then begins to fall and briefly goes very negative, as charge carriers are removed from the base. T1 then turns off and the voltage at the base of T2 starts to fall.

Start-up

R4 ensures that the circuit starts up correctly. Since there is a high voltage across this resistor, it is made up from a series combination of four 240 kΩ SMD resistors. In the initial state R4 delivers a base current for T1 which brings it into its region of linear amplifying operation. If R4 is to do this task the base of T1 must not have a DC path back to L2B: the combination of C5 and D6 ensures this. They allow the base voltage to be raised by L2B, and also couple AC signals through for feedback. This positive feedback ensures that the oscillator starts up. Before discussing the function of R3, C4 and D5, we shall make a few remarks on the transformer, which is the main component of the whole unit.

Transformer

The transformer is the only specially-designed component in the circuit. Analysing it completely without damaging it is quite a challenge. We start by desoldering it from the board. We need to measure the parameters of the transformer at its operating frequency (100 kHz) so as to obtain the values relevant to the circuit. This requires good instruments. Rough measurements are easy to come

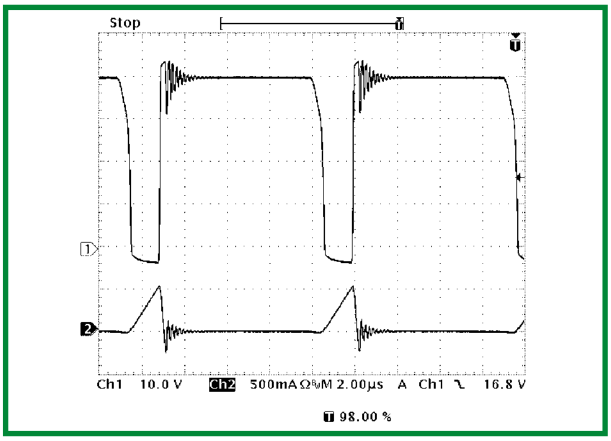


Figure 6.
Voltage and current waveforms at the switching transistor.

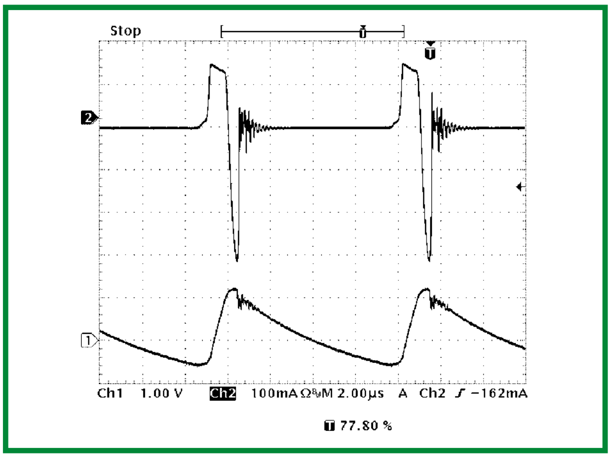


Figure 7.
Base voltage of at T2 (below) and base current of T1 (above).

by, however: from the oscilloscope traces in Figure 6 we can determine that the current in L1A rises by approximately 0.55 A within 1.5 µs with a voltage of U = 326 V. Using the equation $U = L\,dI/dt$ we obtain an inductance of L = 900 µH approximately. Measurement with a bridge gives a value of L = 800 µH. If we measure the voltage on all three windings with properly-calibrated oscilloscope probes we can also measure the transformer ratios. To obtain the absolute turns counts we wind five turns of thin enamelled copper wire around the middle of the transformer and measure its ratios to the other three windings at 100 kHz. The results show that L1A has 56 turns, L2B has 3 turns and L2C has 11 turns.

This means that the core has an A_L value of approximately 800 µH/56^2 = 255 nH/turn^2. A_L is the inductance (L) assuming a winding with N = 1 turns.

Looking through the databooks of various core manufacturers (such as Epcos, Philips, Vogt and Kaschke) we find that this is a good match for the E25/9/6 core from Philips, with an air gap of 200 µm. With a peak current of I = 0.55 A in the primary winding we obtain a maximum field strength of approximately 200 mT in the core, which is entirely feasible with modern ferrite materials at 100 kHz. Core losses at this peak current are around 0.5 W to 0.7 W, a reasonable range for a core of this size from a thermal point of view. That completes the electrical description of the transformer, but there are many details that remain to be decided upon before we have a practical design. It is these details that make the design of switching power supplies so tricky. For example, the trans-

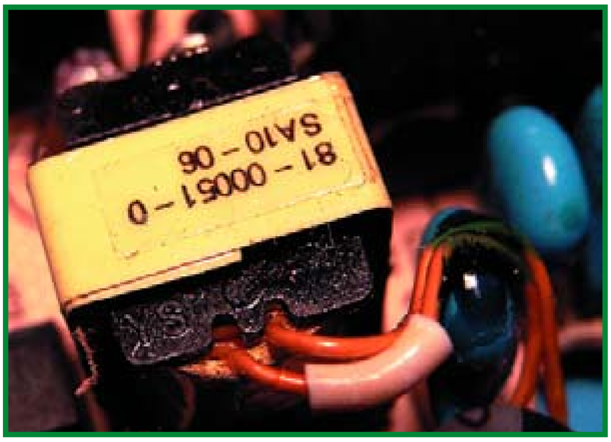


Figure 8. A miniature transformer using triple-isolated wire.

former must provide isolation from the mains with an adequate level of safety and leakage currents must be kept within acceptable limits. Insulation and spacing tapes can be wound into the transformer and the whole thing can be potted, as presumably was done in this case.

Figure 8 shows the tiny transformer from a 6 V, 1.5 A (9 W) power supply. It is only 13 mm across and 14 mm high. The secondary winding of this type of transformer is often made using a special type of wire. The type shown in Figure 8 is so-called 'triple-insulated wire' (available for example from Furukawa). The wire is approved for this use and provides isolation from the mains with three independent layers of insulation. The wire is not normally soldered at the body of the coil, since the connections would then be exposed too close to the primary winding. The insulation on this type of flyback transformer often results in a relatively large stray inductance. At the moment when the secondary side takes over the current, the energy stored in the stray inductance is usually converted into a large voltage spike at the collector of T1, which can damage it.

RCD snubber

To ensure that this energy does not damage transistor T1 a snubber network is added, formed from R3, C4 and D5. Diode D5 conducts the voltage spike to the RC network. The capacitor charges and the energy is dissipated slowly in the resistor. Diode D5 must switch quickly and be able to withstand high voltages. The capacitor has a working voltage of 1 kV so that it can withstand the spike. The voltage spike and ensuing oscillation can be clearly seen in Figure 6. Resistor R3 is a large leaded component, presumably rated at 1 W. There are power losses in this part of the circuit, which a good design will seek to minimise.

Secondary

Finally we analyse the secondary side (**Figure 9**). D7 is a 3 A Schottky diode which does not require extra cooling to help dissipate heat. **Figure 10** shows an example from a 2 A power supply where the diode is soldered onto a simple frame to provide a low-cost solution to the cooling problem. In this example transistor T1 has an insulating plastic package and is screwed to a small heatsink (K1 in Figure 4), which is connected to ground to reduce EMI. The collector of T1 is still one of the hottest points in the entire circuit.

Capacitors C8 and C9 form a smoothing filter in conjunction with L3. L4 is a further common-mode choke. Y-class (or 'line bypass') capacitor C7 serves to improve the EMI performance of the circuit. We did not investigate why this capacitor is connected at this particular point on the secondary side, although presumably this is where it is most effective. Zener diode ZD2 limits the output voltage should it be necessary when, for example, the load is suddenly removed and the regulation loop does not respond quickly enough. The adjustable Zener diode (or shunt regulator) IC1 forms the basis of the regulation loop. If the output voltage exceeds 12 V IC1 starts to conduct and the LED in optocoupler OC1 lights. This communicates back to the primary side where the phototransistor operates effectively in parallel with R7. C6 charges faster and T1 is thus switched off earlier, with the effect that less energy is stored in the inductor. The amount of energy transferred between primary and secondary falls and with it the output voltage. The frequency of operation of the circuit is also affected: with no load

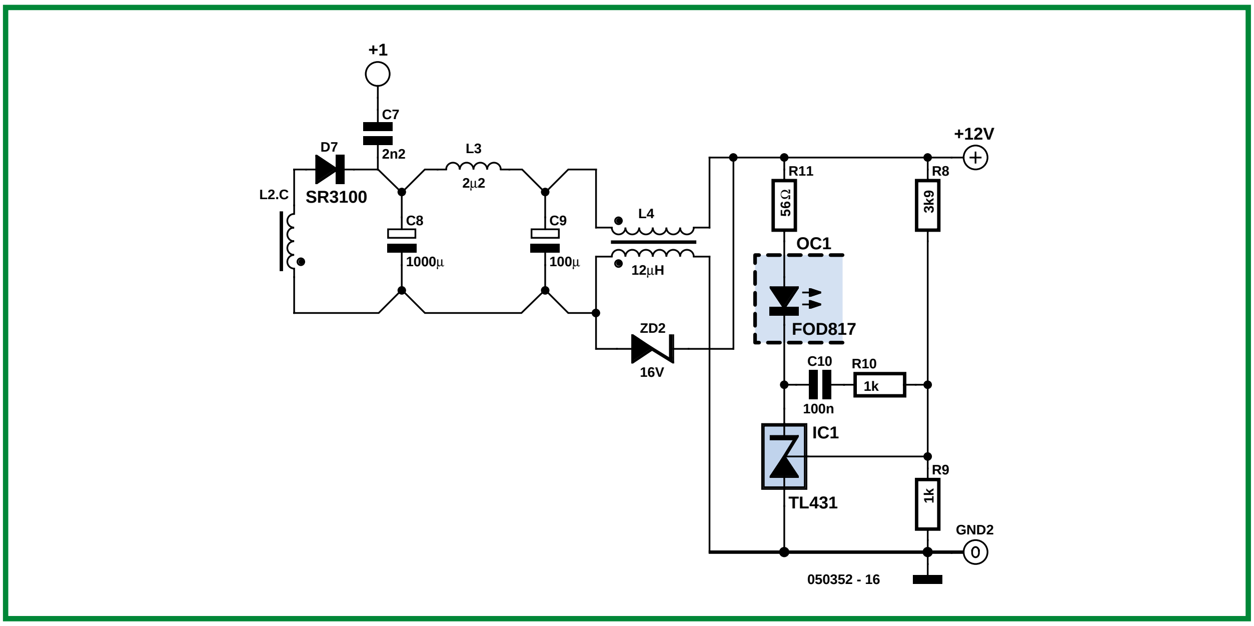


Figure 9. RCD snubber network.

(and the converter thus only supplying its own losses) it can run as fast as 600 kHz.

Our version

Now that we have analysed this handful of components in minute detail, we will naturally want to build a similar converter ourselves. **Figure 11** shows a simple design for a converter from 24 V to 5 V at 500 mA. If we were to use a 7805 for such a task, it would dissipate 9.5 W. Even if the switching converter has an efficiency of only 65 percent, it still performs much better than the series regulator. In this circuit we can dispense with the snubber network: if the three windings are made with a trifilar construction the BD237 can handle the voltage spikes comfortably.

(050352-1)

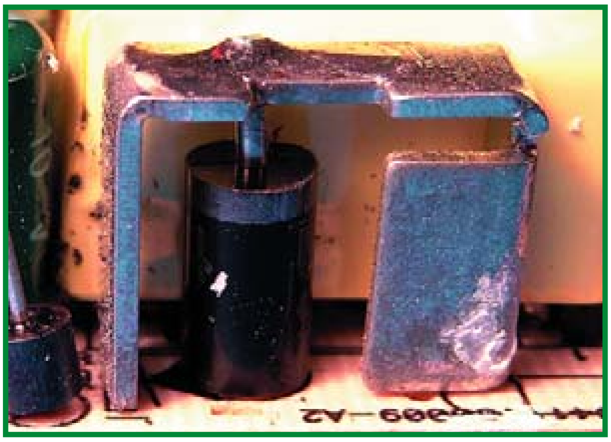


Figure 10. Diode with thermally and electrically conducting heatsink.

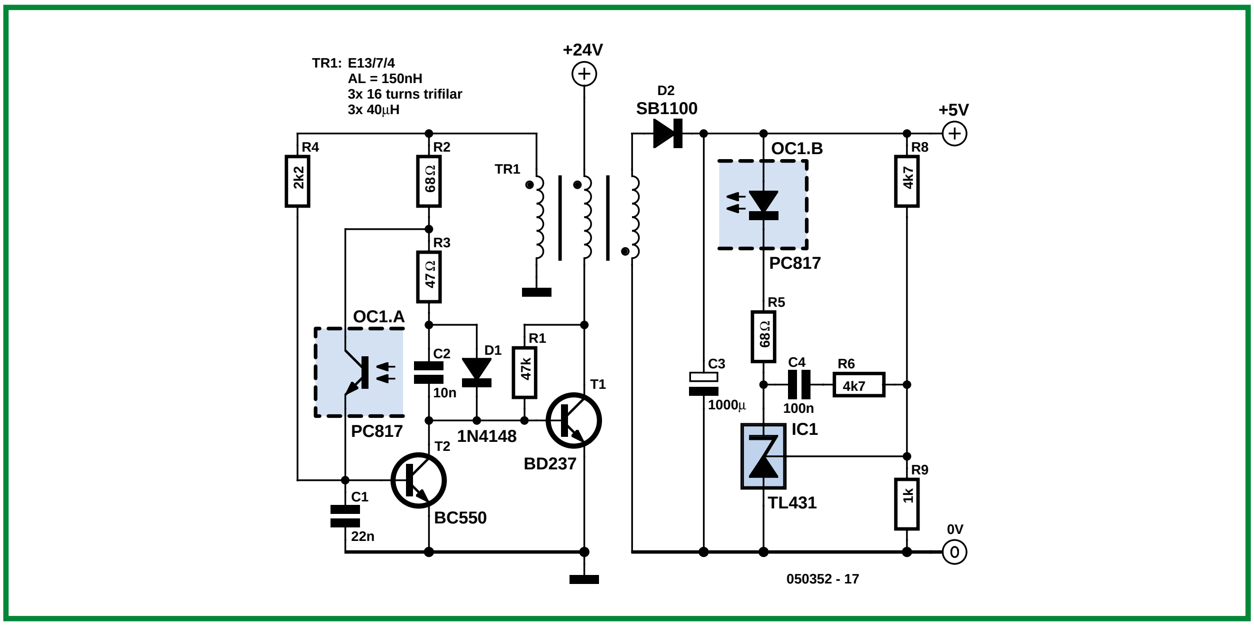


Figure 11. Step-down converter from 24 V to 5 V.

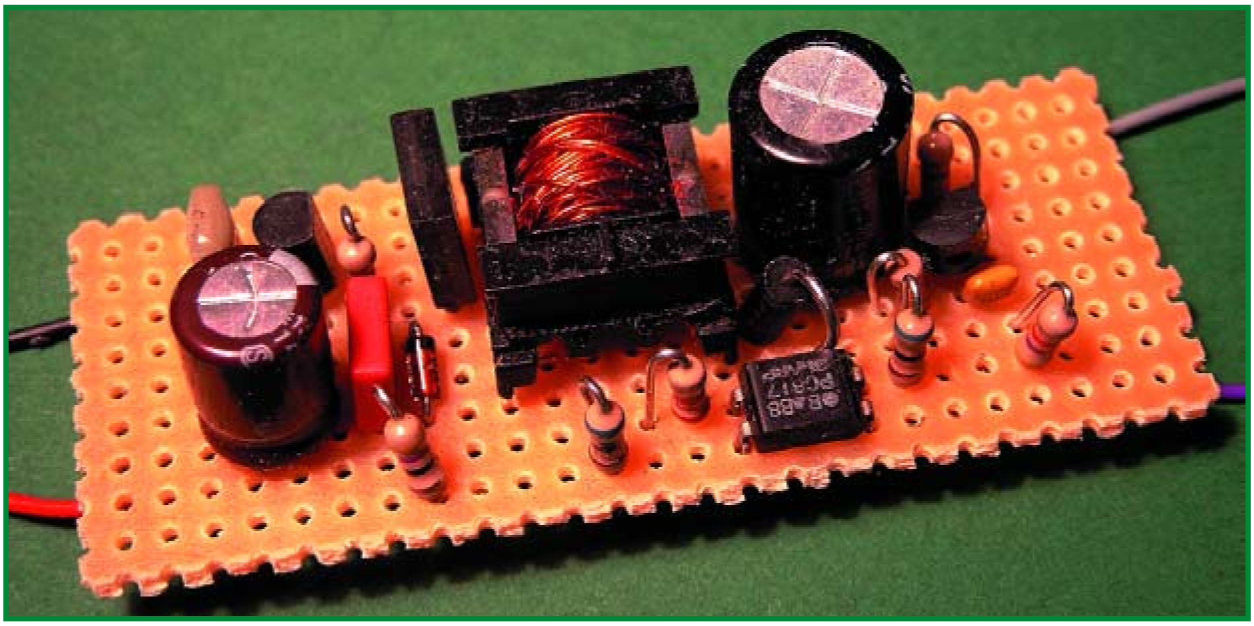


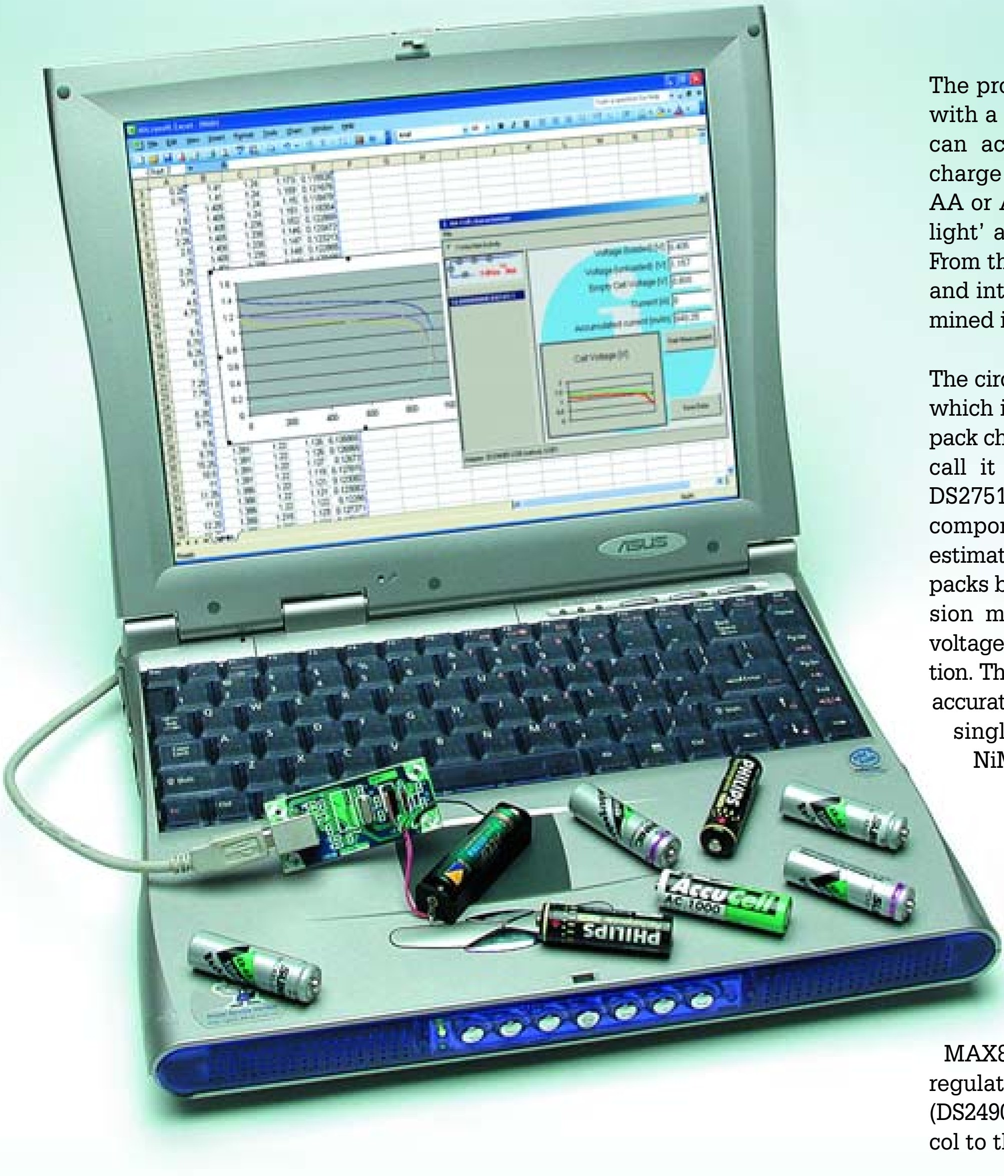
Figure 12. Prototype of the small converter.

Simple Rechargeable

the good, the bad and the flaky

Fons Janssen

Rechargeable 1.2-V AA cells a.k.a. 'penlights' are very popular for a large variety of (portable) applications. The number of different brands is enormous and consequently the quality of these cells can differ considerably. Not surprisingly, the real capacity of cells is sometimes vastly different from what's specified, and in quite a few cases the capacity deteriorates dramatically after just a couple of charge/discharge cycles. This circuit tells a harsh tale on flaky AA cells.



The proposed circuit, in combination with a PC and some clever software, can accurately measure a full discharge cycle of a rechargeable 1.2 V AA or AAA cell, also known as 'penlight' and 'pencil' sizes respectively. From the resulting curve the capacity and internal resistance can be determined in a simple manner.

The circuit is built around the DS2751, which is actually intended for battery pack charge monitoring (Maxim/Dallas call it 'battery fuel gauging'). The DS2751 provides the key hardware components required to accurately estimate remaining capacity of battery packs by integrating low-power, precision measurements of temperature, voltage, current and current accumulation. This hardware can also be used to accurately record a discharge cycle of a single AA cell (either NiCd or NiMH).

The circuit

The circuit in **Figure 1** is very simple. A PC is connected to the USB port. Power is extracted from the USB bus voltage, so no external power source is needed. IC1 (a MAX8881EUT33) is a low dropout regulator that generates 3.3 V for IC2 (DS2490S). IC2 converts the USB protocol to the 1-Wire protocol to allow the

AA Cell Characteriser

PC to communicate with IC3 (DS2751E-025), which is the key component of the circuit. It measures the cell voltage on pin 1 (V_{in}) via R2 and the cell current via an internal 25-milliohm sense resistor between pins 7 (SNS) and 2 (VSS, GND). The programmable I/O pin, PIO (no. 3) allows the PC software to control the gate of power FET T1. When PIO is high, T1 is switched on and the cell will be loaded via R4. This will result in a discharge current of approximately 1 A. When PIO is low, T1 is switched off and the cell is not loaded.

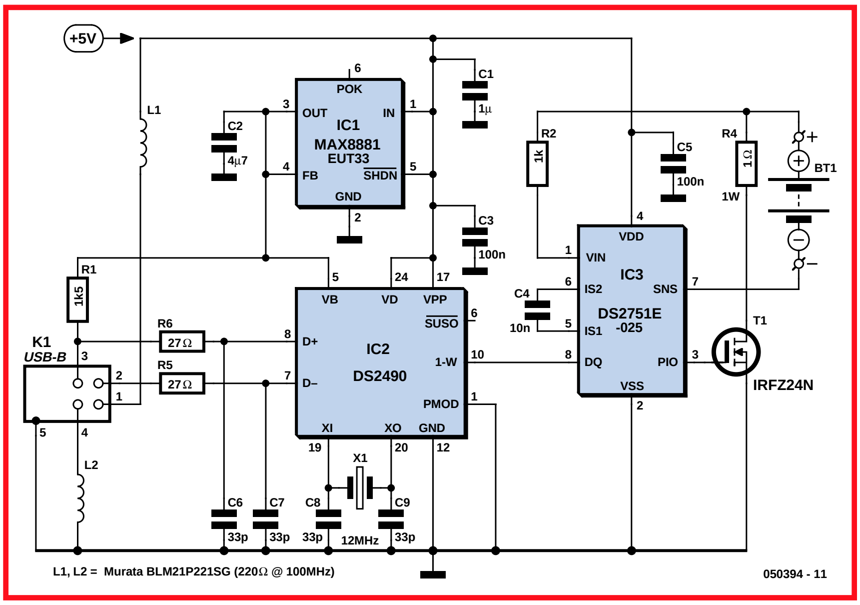


Figure 1. Schematic diagram for AA cell discharge characterization circuit.

Software

A Visual Basic program has been written to perform a discharge cycle on a cell. The program is available as a **free download** from our website under file number **050394-11.zip**. You'll find it under MAGAZINE→April 2006→AA Cell Characteriser.

The software initializes IC3 and switches off T1. Then, the (fully charged) cell can be inserted and the software will present the measured cell voltage (see **Figure 2a** for a screenshot of the software). After the 'start measurement' button has been pressed, the software will switch on T1 and log the cell voltage and current every second. After each logged point, T1 is switched off shortly to allow the measurement of the unloaded cell voltage, which is also logged (see **Figure 2b** for a screenshot). To prevent cell damage, the measurement is automatically stopped as soon as the cell voltage drops below 0.8 V. After the measurement has stopped, the Accumulated Current field shows how much charge has been drawn from the cell, providing an indication of the actual capacity. The measurement can also be stopped by clicking on the 'Stop Measurement' button. By clicking on 'Save data' the logged data can be saved to disk for further analysis.

Data processing

The data can be analyzed using Microsoft Excel. An example is shown in **Figure 3**. The log file can be imported via File_Open and then selecting Files of Type: 'all files'. Select the data file, choose 'delimited' and press 'finish'. You will see four columns that hold the logged data:

- **ACR [mAh]**, the accumulated current in mAh;
- **V1 [V]**, the unloaded cell voltage in volts;
- **V2 [V]**, the loaded cell voltage in volts;
- **I [A]**, the discharge current in ampères.

Columns 2, 3, and 4 can be used to determine the internal resistance of the cell using this equation:

$$R_{cell} = [(V_{UL} - V_L) / I_L] - R_{sense}$$

which simplifies to

$$[(V1 - V2) / I] - 25\ m\Omega$$

where
V_{UL} = unloaded voltage;
V_L = loaded voltage;
I_L = load current.
Put the Excel formula '=(B3-C3)/D3-0.025' into cell E3 and copy it to the rest of column E until the last logged point. Now you can make an *x-y* graph to show the results. Choose column A as *x* values and the other columns as *y* values. You will see the cell voltage/current/resistance as a function of discharged current. An example may be seen in the introductory photograph.

Drivers for 1-Wire

To enable communication between the PC and the DS2490S, the 1-Wire drivers need to be installed. These can be downloaded from the Maxim/Dallas website via the following link:
www.maxim-ic.com/products/ibutton/software/tmex/
After installation, run 'default 1-wire net' to find the connected DS2490S and select it as the default 1-Wire net.

Other cells

The circuit can be used for cells other than AA or AAA sizes. Measurement of more cells in series is also possible. Always make sure that the maximum values are not exceeded. Choose a load resistor, so that the discharge current will not exceed the 1.9 A full-scale

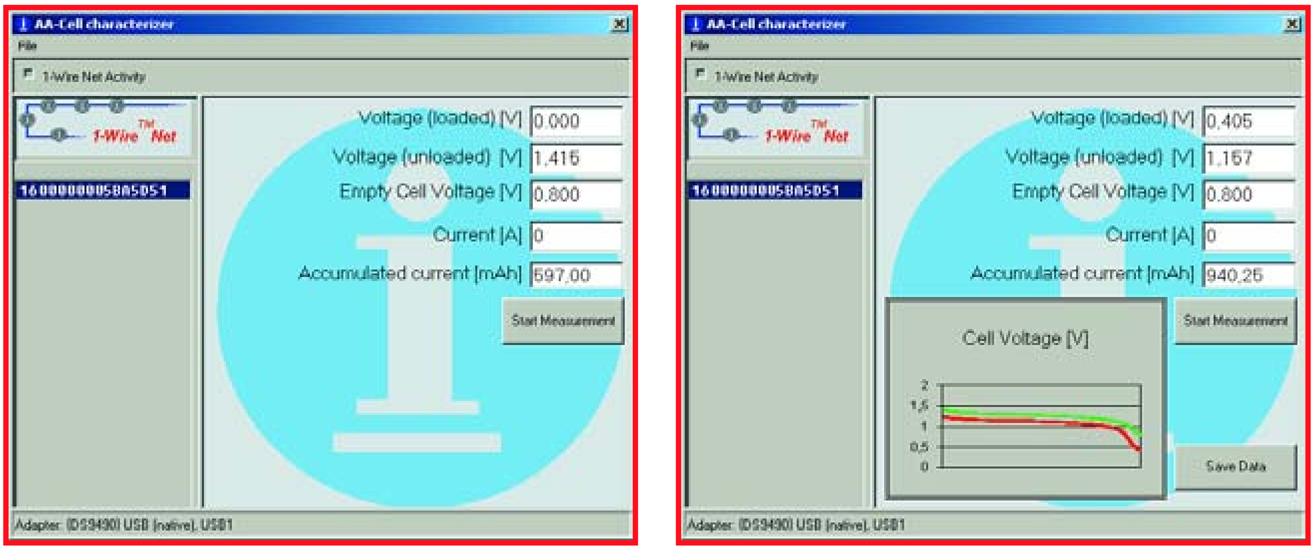
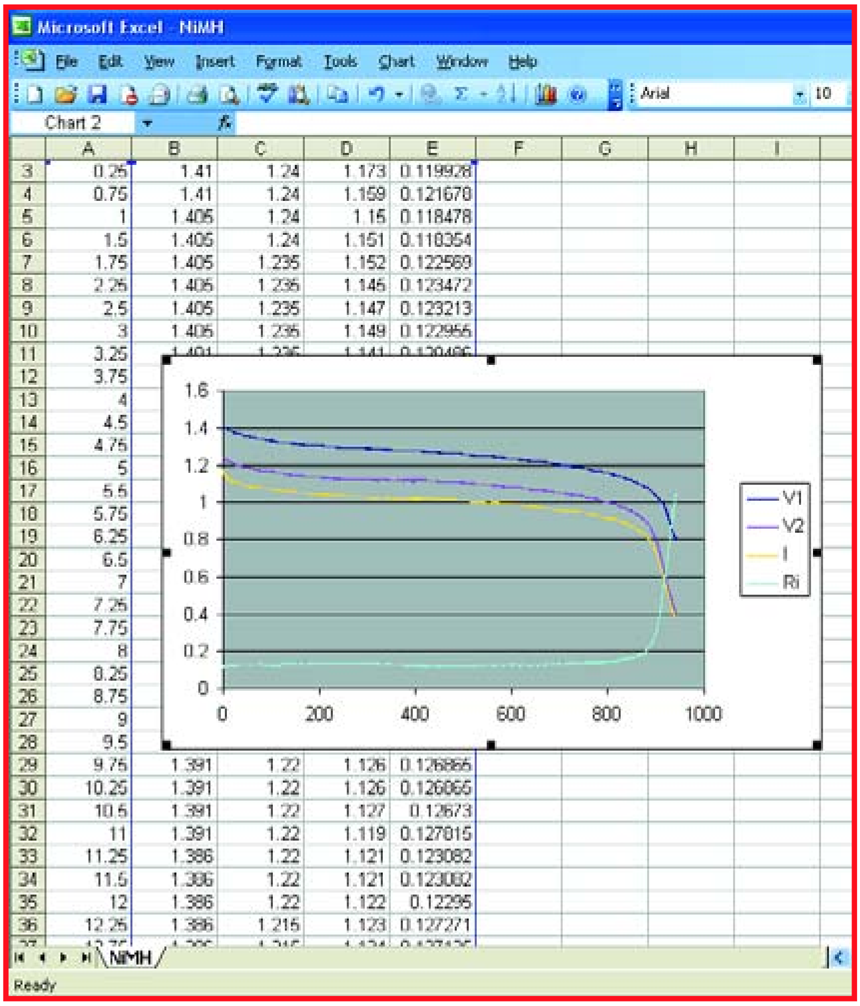


Figure 2. Software screenshots (left: start-up, right: during measurement).

Warning

All battery types mentioned in this article are capable of supplying dangerously high short-circuit currents. Precautions should be taken to prevent damage and/or injury due to cell overloading, overheating and explosion. Use approved chargers only.



	A	B	C	D	E
3	0.25	1.41	1.24	1.173	0.119928
4	0.75	1.41	1.24	1.159	0.121670
5	1	1.405	1.24	1.15	0.118478
6	1.5	1.405	1.24	1.151	0.118354
7	1.75	1.405	1.235	1.152	0.122589
8	2.25	1.405	1.235	1.146	0.123472
9	2.5	1.405	1.235	1.147	0.123213
10	3	1.405	1.235	1.149	0.122956
11	3.25				
12	3.75				
13	4				
14	4.5				
15	4.75				
16	5				
17	5.5				
18	5.75				
19	6.25				
20	6.5				
21	7				
22	7.25				
23	7.75				
24	8				
25	0.25				
26	8.75				
27	9				
28	9.5				
29	9.75	1.391	1.22	1.126	0.126866
30	10.25	1.391	1.22	1.126	0.126065
31	10.5	1.391	1.22	1.127	0.12673
32	11	1.391	1.22	1.119	0.127015
33	11.25	1.386	1.22	1.121	0.123082
34	11.5	1.386	1.22	1.121	0.123082
35	12	1.386	1.22	1.122	0.12295
36	12.25	1.386	1.215	1.123	0.127271

Figure 3. Example of an Excel spreadsheet containing battery data captured by the circuit.

range of the DS2751E-025. Also make sure that V_{in} at pin 1 of the DS2751E-025 does not exceed the maximum value of 4.5 V. Use a resistive divider if needed. It is also recommended to keep the discharge current limited to approximately *C* mA to prevent damage to the cell and to yourself! *C* is the nominal capacity in mAh normally printed on the cell.

Inside the DS2751

The DS2751 was originally developed to add 'fuel-gauging' functionality to battery packs. **Figure 4** shows a functional block diagram of the DS2751.

Via DQ, a host can read/write the registers using the 1-Wire protocol. These registers contain the measured data, status information, and also some dedicated information that can be stored by the host (i.e., manufacturing date, serial number, etc.).

The DS2751 employs a so-called 'coulomb counting' method to measure the amount of charge that goes into and out of the cell. This is achieved by digitally integrating the accurately measured current trough the sense resistor. The result is stored in the ACR (accumulated current register) and can be used by the host to calculate the remaining capacity. Because the capacity is also affected by the cell temperature, a temperature sensor has been added.

The DS2751E-025 has a built-in 25-mOhm sense resistor (the DS2751E is used in combination with an external sense resistor). The current is stored as a 12-bit value with a resolution of

0.625 mA and a full-scale range of ±1.9 A. The accumulated current is stored as a 16-bit value with a resolution of 0.25 mAh and ±8.2 Ah full scale range. The voltage measurement has a maximum of 4.5 V, so that it can be used for battery packs with one Li-ion cell, as well as for up to three NiMH cells in series.

Construction

A miniature single-sided PCB was designed for the project, the artwork is shown in **Figure 5**. The board is available ready-made through Readers Services under order code **050394-1**. All SMD parts go to the solder side of the board, leaving just the oscillator, the IRFZ24N power FET and the USB-B connector at the top side!

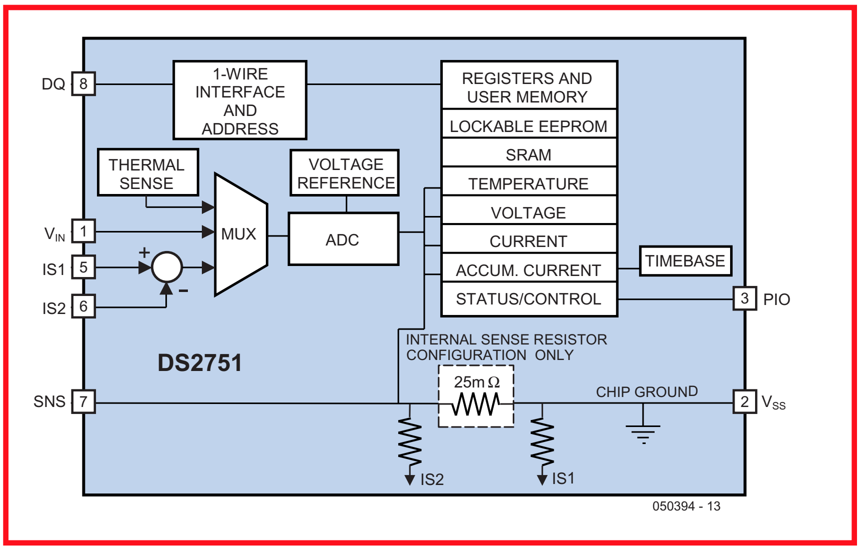


Figure 4. Functional block diagram of the DS2751 (courtesy Maxim/Dallas).

Did you know

that Maxim/Dallas have kindly informed us that Elektor Electronics readers wishing to build the AA Cell Characteriser project can order free samples of the relevant ICs from this url:

www.maxim-ic.com/samples

Note however that the supply of samples is at the discretion of Maxim/Dallas, and may not be possible to all destinations.

COMPONENTS LIST

Resistors:
All SMD, case shape 0805
R1 = 1kΩ5
R2 = 1kΩ
R3 = 10kΩ
R4 = 1Ω 2W
R5,R6 = 27Ω

Capacitors:
All SMD, case shape 0805
C1 = 1µF
C2 = 4µF7
C3,C5 = 100nF
C4 = 10nF
C6-C9 = 33pF

Inductors:
L1,L2 = BLM21P221SG (Murata) (220Ω @ 100MHz)

Semiconductors:
T1 = IRFZ24N
IC1 = MAX8881EUT33 (Maxim/Dallas)
IC2 = DS2490S (Maxim/Dallas)
IC3 = DS2751E-025 (Maxim/Dallas)

Miscellaneous:
K1 = USB connector, PCB mount, Type B
Battery holder for one AA cell ('penlight')\
PCB, order code **050394-1**, see Readers Service page or SHOP on website
Disk, PC software, order code **050394-11** or Free Download

(050394-1)

Fons Janssen
(Maxim Integrated Products Inc., Benelux)
fons_janssen@maximhq.com

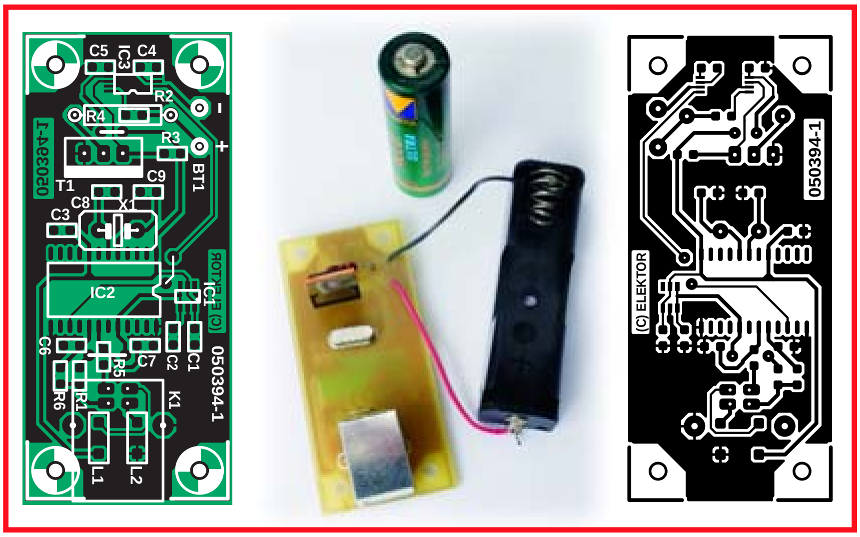


Figure 5. Copper track layout and component mounting plan of the tiny circuit board we've designed for the battery analyser.

Further information

Serial Interface for 1-Wire Bus,
Elektor Electronics April 2002.

MAX8881 datasheet:
http://pdfserv.maxim-ic.com/en/ds/MAX8880-MAX8881.pdf

DS2490 datasheet:
http://pdfserv.maxim-ic.com/en/ds/DS2490.pdf

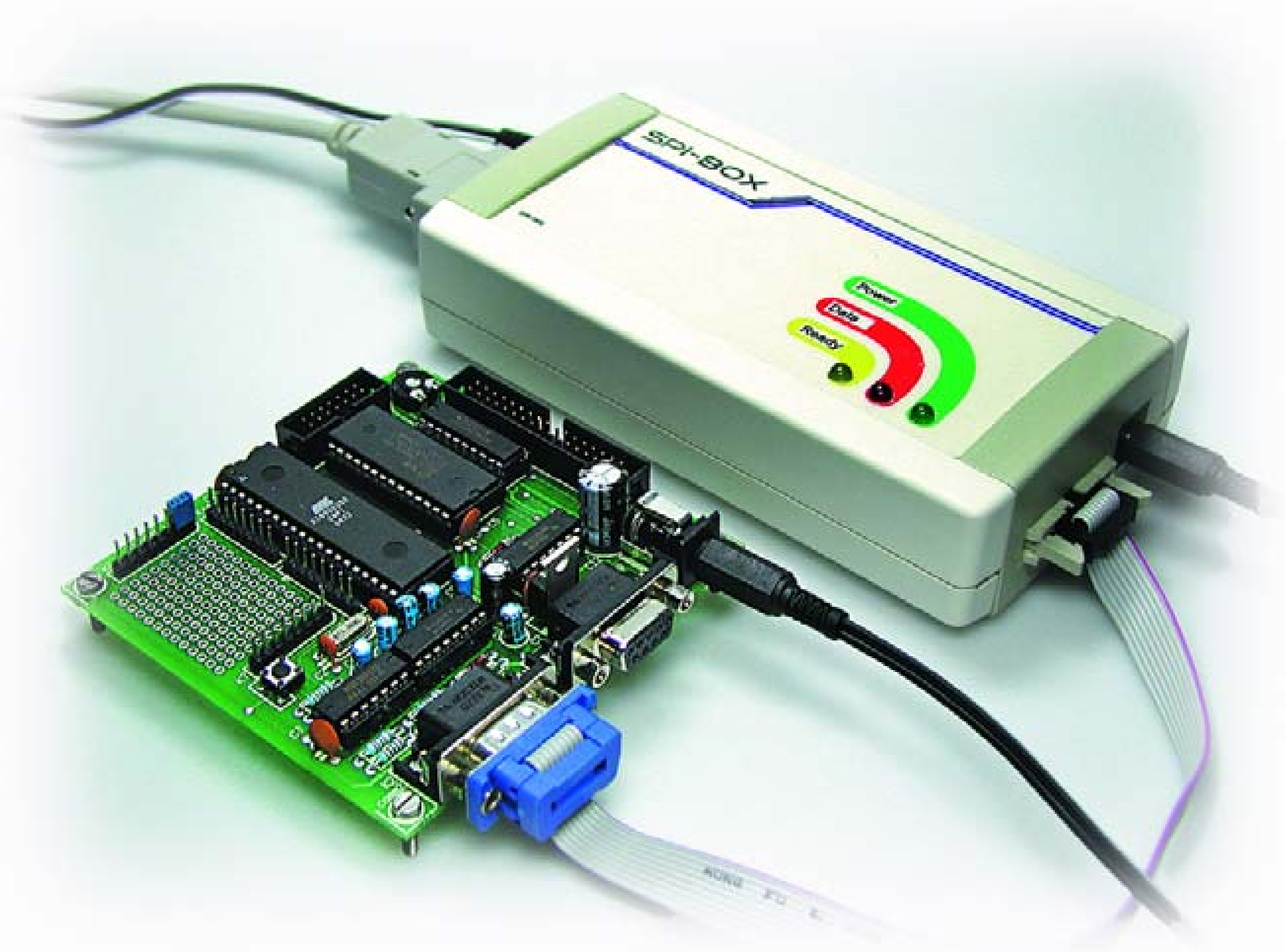
DS2751 datasheet:
http://pdfserv.maxim-ic.com/en/ds/DS2751.pdf

1-Wire/iButton software tools:
http://www.maxim-ic.com/products/1-wire/software/

Universal SPI Box

A quicker way to program microcontrollers

Rainer Reusch



Lots of microcontrollers can be programmed over an SPI bus. Driving this interface from a PC's serial port using a couple of extra components is economical but slow. A better solution is the SPI Box described here, which gives acceptable speed even when used with a USB-to-serial converter.

A search of the Internet will turn up any number of sets of instructions showing how to use a couple of extra components to connect between a serial or parallel interface and the 'Serial Peripheral Interface', or SPI [1]. For the occasional programming of a microcontroller such a solution is undoubtedly satisfactory. However, the appropriation of these interfaces has a couple of disadvantages.

The primary disadvantage is that the data transfer rate over the serial interface is relatively slow and this can bring the development cycle (program, test, program, test and so on) to a halt each time it is necessary to download new data into the microcontroller. This can quickly become irritating. Things get even worse when a commercially-available USB-to-serial converter has to be used (modern notebooks, for example, do not sport such prehistoric interfaces as serial and parallel ports). In this case bytes can only be sent to the microcontroller very slowly indeed as the latency due to the USB protocol has to be added to each transaction. This adds further to the total time taken to reprogram the microcontroller.

The parallel port option is decidedly faster, but it carries the risk of causing damage to the computer's motherboard: static discharges or failures in the connected hardware can be dangerous. The parallel port is often not provided by a separate interface chip, and this means that a special driver might be needed in order to make the port behave in the slightly unusual way that is required. As noted above, notebooks often do not have a parallel port at all, ruling out this solution altogether.

Dedicated hardware, in the form of the SPI Box described in this article, overcomes these disadvantages in a relatively straightforward way.

SPI

A bi-directional SPI port connects a 'master' and a 'slave' over five wires: four data signals plus ground (see **Figure 1**). In our case the master is the SPI Box itself, connected to a PC, while the microcontroller to be programmed takes on the role of the slave. The interface is chiefly designed for communication between a microcontroller and peripheral components and for programming microcontrollers in their final circuit ('in-system programming'), and can achieve data transfer rates of up to 5 Mbit/s. The SPI bus system, which was designed by Motorola, is not standardised, but because of its simplicity a wide range of SPI-compatible ICs is available from a variety of manufacturers. The gamut runs from microcontrollers and memories to A/D converters, sensors and interfaces to other bus systems such as the CAN bus. The SPI Box is therefore suitable not just for programming microcontrollers, but also for driving SPI-compatible ICs such as EEPROMs and A/D converters.

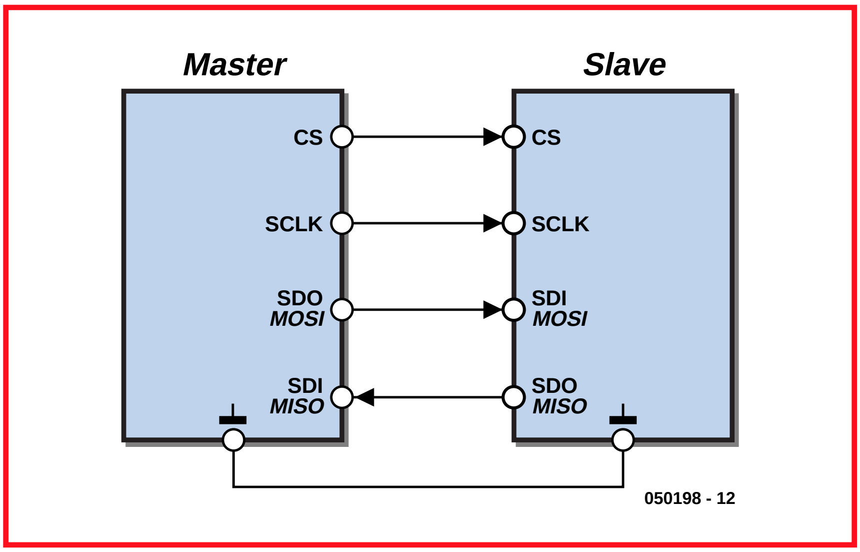


Figure 1. The SPI has four connections between master and slave.

Data transfer proceeds as follows. If the master wishes to transmit data to a slave, it activates the slave via the chip select signal (CS; active low). Motorola also refer to this as the SS (slave select) signal. It then sets up a clock on the SCLK line and transfers the data out synchronously on the SDO (serial data out) line, which is connected to the SDI (serial data in) line on the slave side. The connection from the master's SDO to the slave's SDI is also referred to by Motorola as MOSI (master out, slave in). Data flow in the opposite direction is from the slave's SDO line to the master's SDI line, also called MISO (master in, slave out). SPI operates at the usual 5 V logic levels. If a master is to communicate with several slaves, a separate CS line is required for each slave, while the data lines are connected in bus-fashion to all the slaves. All very straightforward in theory.

Questions and answers

The question remains of why it is so slow to use a serial port to drive an SPI bus. In order to emulate the SPI signals, not only must the TX and RX signals of the serial port be controlled, but the handshake signals must also be individually set and cleared. The serial interface hardware is not optimised for this mode of operation, and as a result it is not possible to achieve high data transfer rates in this way. Measurements taken on real-life PCs show that the minimum pulse width that can be obtained on a handshake line is around 40 µs. This corresponds to a maximum frequency of approximately 12 kHz. Since both clock and data signals have to be generated, the maximum clock frequency that can be achieved in practice is even lower, resulting in overall times of several seconds even if only a few hundred bytes of data are being transferred. The situation is worse if commercially-available USB-to-serial converters are used. In these devices the latency associated with driving the signals is in the millisecond range, resulting in unreasonably long programming times.

It is therefore a better plan to try to use the serial port as it was intended for data communication and then carry out the conversion between RS232 and SPI bus using a microcontroller as interface. The microcontroller is capable of generating very fast signals on its outputs, and this idea is at the heart of the SPI Box.

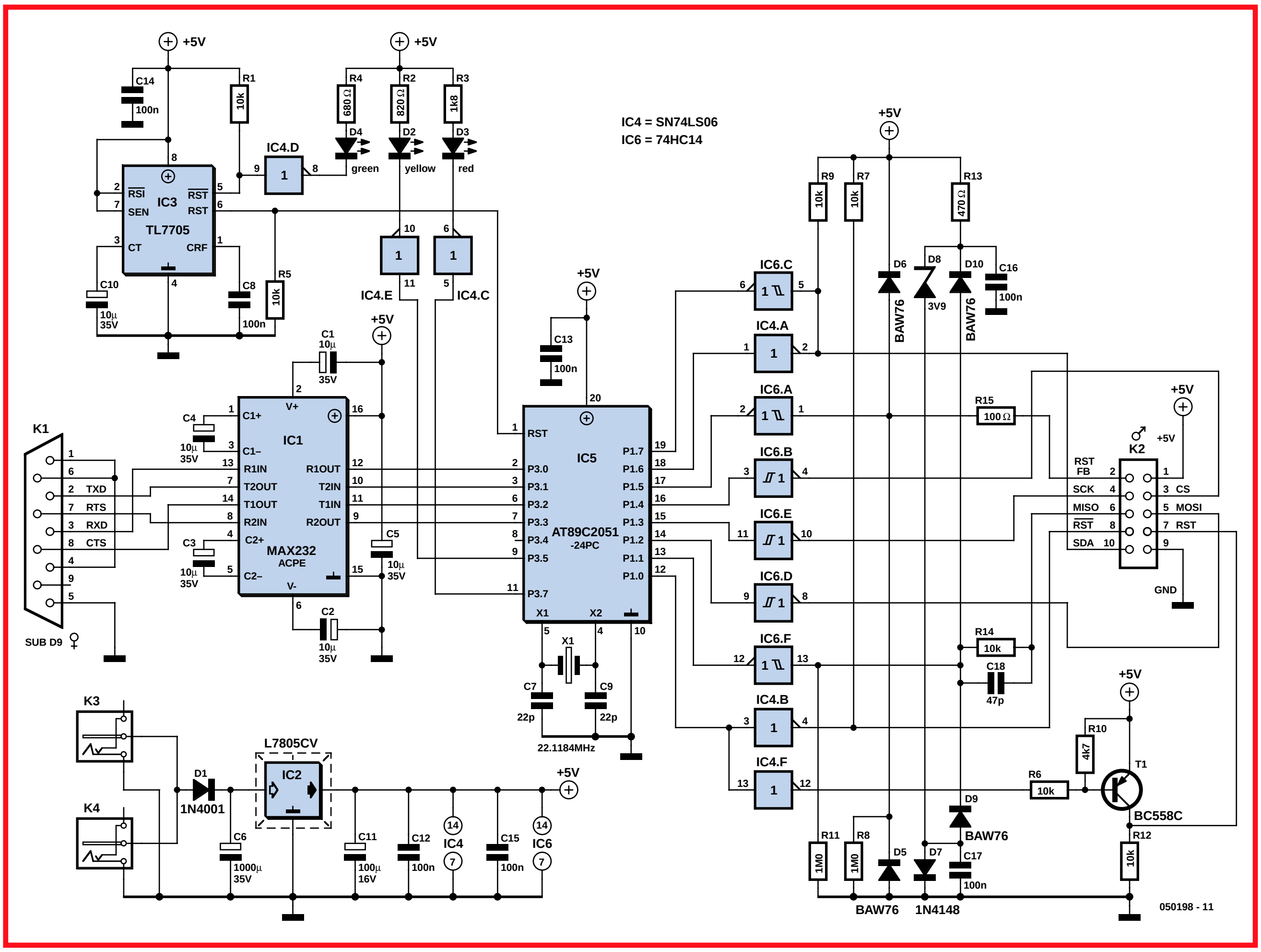


Figure 2. The circuit of the SPI box comprises just standard components along with an Atmel microcontroller.

It is possible to buy ready-made programming hardware equipped with SPI. For example, Atmel produces the 'AT 89 ISP Tool'. Why bother doing it ourselves when ready-made is available? The advantages of a home-made solution lie mostly in its flexibility: we would, for example, have to buy a new programmer to use Atmel's RISC microcontrollers. We also gain a deeper understanding of how microcontrollers are programmed by doing it ourselves, and furthermore the SPI Box is more economical than a bought unit.

The Box itself

As we have already outlined, the SPI box is a kind of serial-to-SPI converter. At the heart of the circuit shown in **Figure 2** is IC5, a type AT89C2051 8051-compatible microcontroller from Atmel. Using a 22.1184 MHz crystal (X1) we can obtain an exact rate of 115,200 bits/s on its serial port and at the same time the microcontroller runs fast enough to achieve high data transfer rates on the SPI side.

The connection between the microcontroller and the PC is achieved using a MAX232 level converter (IC1). To minimise the chance of errors hardware handshake is used on the serial port, and so RTS is also taken to IC1.

The connections to the (expanded) SPI bus are taken via nine inverters (IC4 and IC6) and transistor T1, wired as an inverter. The clamping circuits formed by diodes D5 to D10 prevent damage from high voltage levels or from static discharge. The remaining open-collector inverters drive three LED status indicators. As can be seen from inspecting connector K2, the SPI side of the unit offers not just the four normal SPI signals but also an extra couple of signals which can come in handy when driving external SPI hardware.

Reset device IC3 ensures that the circuit powers up in a defined state and monitors the 5 V supply rail. One of its outputs drives the green LED which lights when the unit is ready for operation. If D4 fails to light either the power supply is absent, or the 5 V rail is not within the tolerance required for reliable operation.

Red LED D3 lights when data bytes are being sent across the SPI connection. Yellow LED D2 is controlled by the PC via the software in the microcontroller IC5. When the unit is turned on, the LED is off. The PC software that drives the unit turns the LED on to indicate that the connection between the PC and the SPI Box is working. When a command is processed, IC5 turns the LED off briefly. If it remains off, this means that it is still expecting bytes from the PC to complete the command.

Power supply and construction

The unit is provided with a DC voltage of between 9 V and 15 V from a commercially-available mains adaptor. For

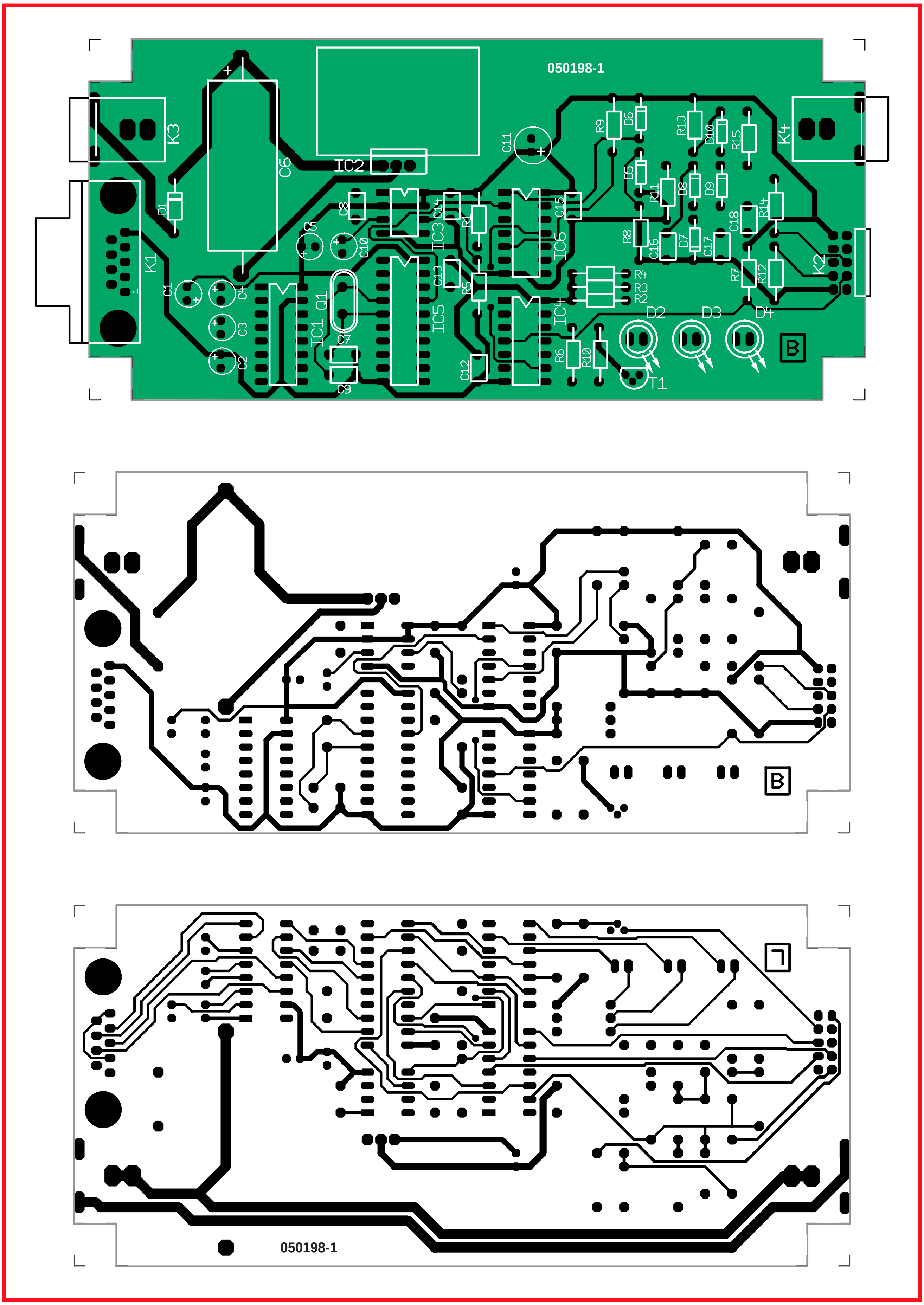


Figure 3. The double-sided printed circuit board for the SPI box is populated using only 'normal' leaded components.

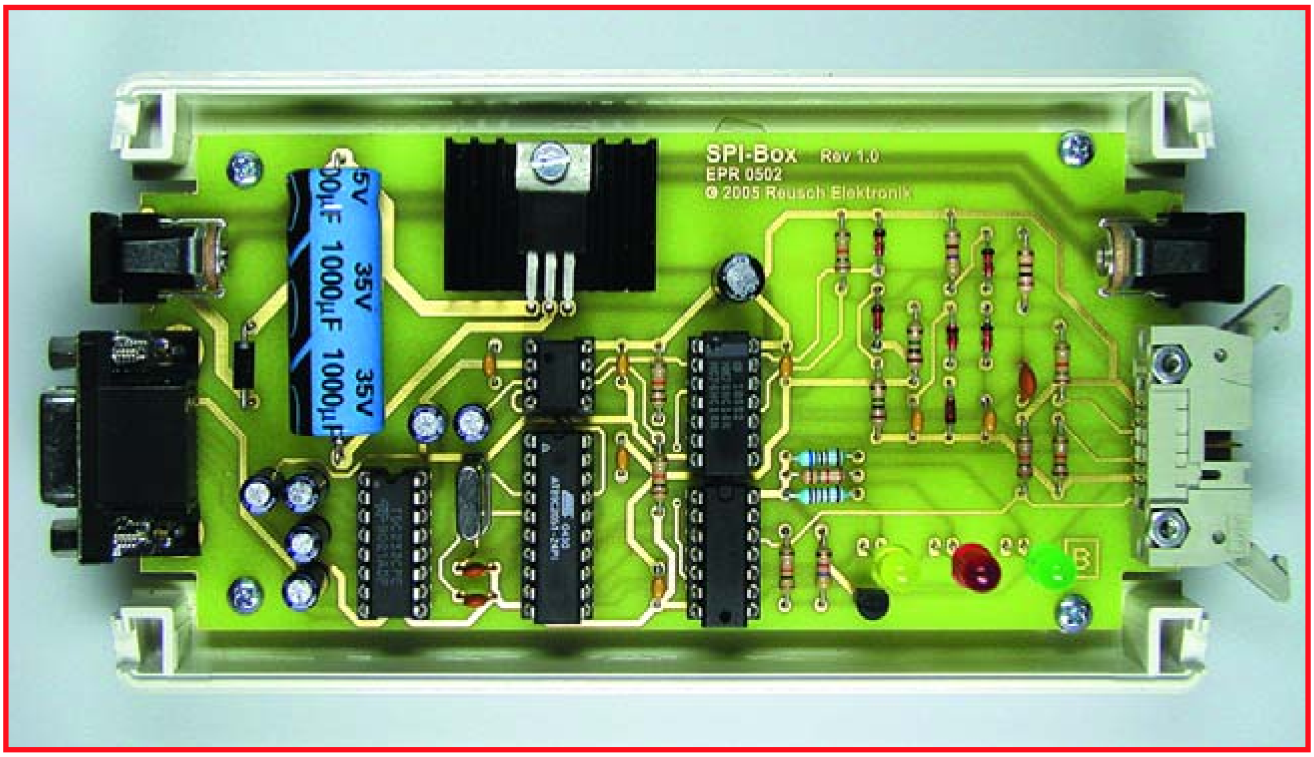


Figure 4. The populated prototype printed circuit board.

convenience the printed circuit board (**Figure 3**) is fitted with two power connectors so that when external hardware is connected to the unit, both can be powered from a single supply using a suitable cable with two low-voltage connectors.

The supply voltage is regulated by IC2, which provides a stabilised 5 V output. This supply is also taken to a pin on K2. The unit itself draws less than 100 mA. If the 5 V supply is to be used to power external hardware, a heatsink is recommended for IC2. Construction is otherwise not complicated. The printed circuit board is double-sided, but only normal leaded components are used: no hand soldering of SMDs is required. A socket is particularly recommended for IC5, since this microcontroller must be programmed before it can be used in the circuit ('in-system' programming is not possible).

Figure 4 shows the populated board, which fits neatly in the OKW enclosure shown in the photographs and specified in the parts list. Suitable apertures must be made for the connectors in the ends of the box, as well as holes for the three LEDs.

Connections

The unit is connected to the PC using a commercially-available serial cable

COMPONENTS LIST

Resistors
R1,R5,R6,R7,R9,R12,R14 = 10kΩ
R2 = 820Ω
R3 = 1kΩ8
R4 = 680Ω
R8, R11 = 1MΩ
R10 = 4kΩ7
R13 = 470Ω
R15 = 100Ω

Capacitors
C1-C5,C10 = 10μF 35V radial
C6 = 1000μF 35 V axial
C7,C9 = 22pF
C8,C12-C17 = 100nF
C11 = 100μF 16V radial
C18 = 47pF

Semiconductors
D1 = 1N4001
D2 = LED, yellow, low current
D3 = LED, red, low current
D4 = LED, green, low current
D5,D6,D9,D10 = BAW76
D7 = 1N4148
D8 = zener diode 3V9, 400 mW
IC1 = MAX232ACPE
IC2 = 7805
IC3 = TL7705ACP
IC4 = 74LS06
IC5 = AT89C2051-24PC, programmed, order code **050198-41** *
IC6 = 74HC14
T1 = BC558C

Miscellaneous
X1 = 22.1184MHz quartz crystal
Bu1, Bu2 = mains adaptor socket for 2.1 mm plug, angled, PCB mount
K1 = 9-way sub-D socket, angled, PCB mount
K2 = 10-way boxheader, angled pins
Sockets for IC4, IC5 and IC6
Heatsink for IC2 (TO-220 case)
Case, OKW type TOPTEC 154F
Mains adaptor with 2.1 mm plug (negative on outer ring), 8-15VDC @ 300mA
PCB, ref. **050198-1** from The PCB Shop
PC software, AT89S binary & hex files: Free Download no. **050198-11** (April 2006)

(9-way male-to-female, wired straight through).

The device to be programmed over the SPI bus is connected to K2 on the unit using a suitably-wired ribbon cable. The extra signals on K2 simplify connection to the extremely popular AT89S8252-based Flash Microcontroller Board published in *Elektor Electronics* in December 2001 [3], since the signals on pins 1 to 9 of K2 correspond directly to the nine pins of the sub-D connector on the board. Other development systems will of course require a special cable to be made up. **Figure 5** shows the pinouts required for the Flash Microcontroller Board and for the AVRee Board published in *Elektor Electronics* in March 2003 [4].

Test

When we turn to testing the unit, we find ourselves in a chicken-and-egg situation if we do not already have a suitable programming system for IC5, or at least a very simple programmer. The microcontroller must be programmed before we can use the SPI Box to program anything. We can find many designs for simple programmers on the Internet, but to avoid the effort of building such a device to solve this one-off problem, a ready-programmed microcontroller is available from the Elektor Shop (order code **050198-41**). If you wish to program the microcontroller yourself, the firmware (in the form of binary and hex files along with a 'readme' file containing the configuration bits for the device) is available as Zip file **050198-11**, freely downloadable from the *Elektor Electronics* website at www.elektor-electronics.co.uk.

Once the printed circuit board has been populated and visually inspected the unit can be connected to a PC using a serial extension cable. When power is applied the green LED should light, and the red and yellow LEDs should flash briefly.

Next the software can be installed on the PC. The program SPIBox_Setup.exe can be found in the Zip file **050198-11** on the *Elektor Electronics* website (April 2006); the program can also be found on the author's website [2].

When the installer has been run, the program SPIBox_Test.exe should be found in the directory C:\Program Files\SPI-Box. The files SPIBox_Test ENG and SPIBox.dll should also be found in the same directory.

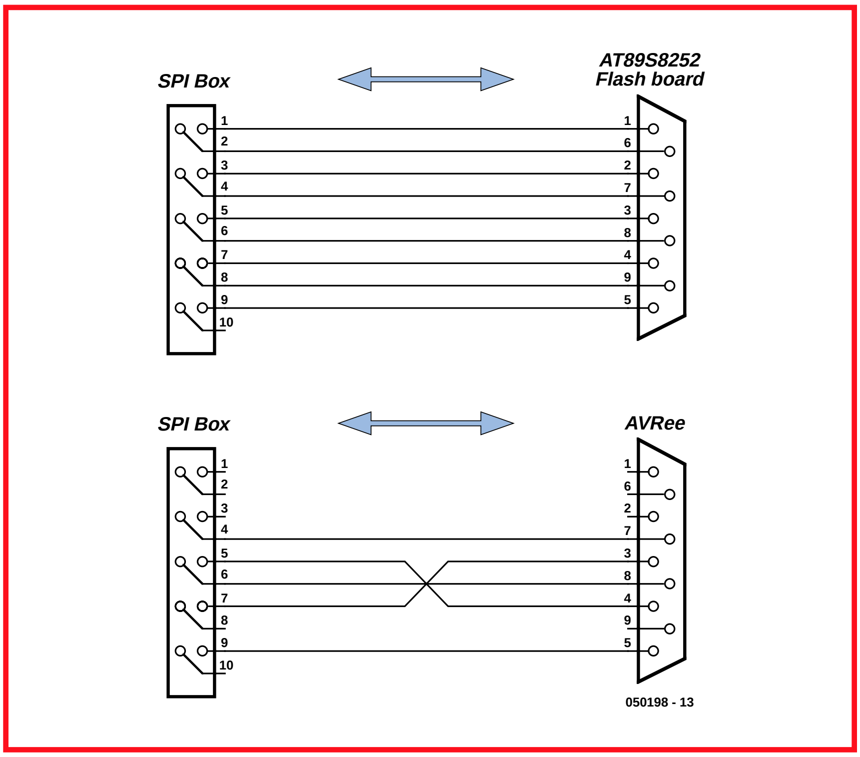


Figure 5. Pinouts of the interface cables used with the SPI box for the Elektor 89S8252 Flash Microcontroller Board and AVRee board.

Figure 6 shows the window opened by the test program. If the correct serial port is selected and the 'Connect' button is clicked, the green LED should light and the status line should indicate the version number of the firmware. This shows that the SPI Box is essentially working correctly. To test

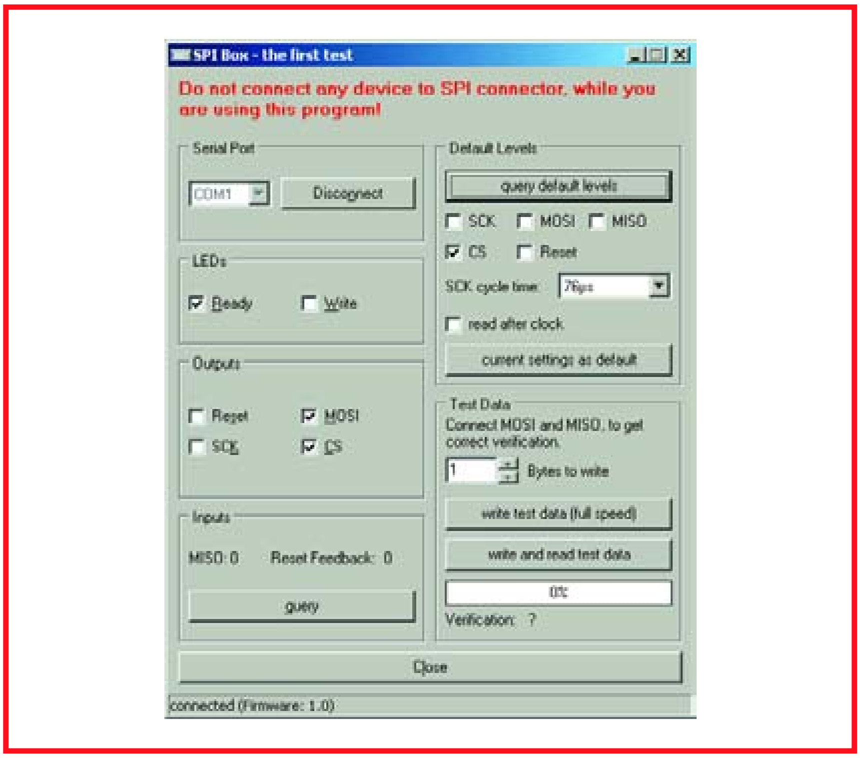


Figure 6. Test program dialogue box.

the function of the SPI side of the unit, we can connect a voltmeter, or, better, an oscilloscope, to the relevant pins of K2.

Under ‘Default Levels’ it is possible to set whether the SPI signals SCK, MOSI and MISO are active high or active low. Usually, active high is the correct setting. If individual signals are inverted (as MOSI and MISO are on the Flash Microcontroller Board) the logic polarity must be changed here. The check boxes ‘CS’ and ‘Reset’ control the eponymous output signals: the two reset outputs are controlled together.

The unit allows the speed of SPI read/write operations to be set. In the test program this is done using the ‘SCK cycle time’ setting. Furthermore, there is also a pure Write function which operates at a considerably higher speed. For Read operations it is possible to select whether the level of the MISO signal is sampled during the clock pulse or after it. The basic settings stored in the unit can be read out and modified using the test program. To make any changes effective it is necessary to write them back to the unit using the ‘current settings as default’ button. The settings are retained for as long as power is applied to the unit.

When testing is complete we can proceed to use the actual programming software, which offers a considerably wider range of possibilities. The *Elektor Electronics* website and the author’s homepage offer large amounts of advice and further information on this topic: see the text box ‘The SPI Box and software’.

(050198-1)

The SPI Box and software

Even the most beautifully-constructed SPI Box is useless without suitable (Windows-based) software. So that you can write your own interface software we have made available on the Elektor Electronics website, in addition to the software downloads, a comprehensive PDF document containing a large amount of detailed further information, screenshots and tables. The author’s website also includes more information about this project and offers the opportunity to buy an extended software package. The basis for all the programming software is the Windows library ‘SPIBox.dll’, which is installed along with the test program.

Further reading:

[1] http://en.wikipedia.org/wiki/Serial_Peripheral_Interface_Bus

[2] http://reweb.fh-weingarten.de/elektor/en/projects/spibox/index.html

[3] 89S8252 Flash Microcontroller Board, Elektor Electronics, December 2001*

[4] AVRee, Elektor Electronics, March 2003*.

* Article available for downloading from www.elektor-electronics.co.uk

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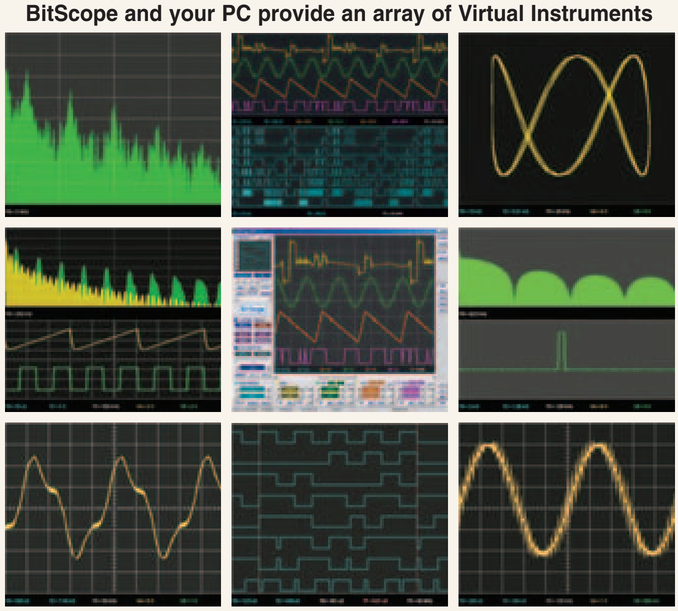

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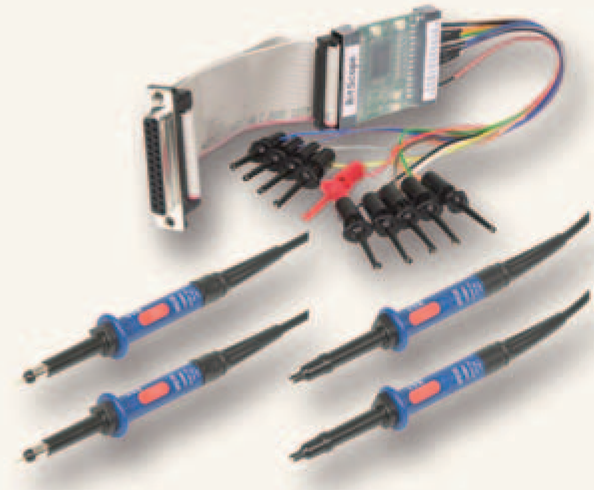

BitScope's integrated design uses standard oscilloscope probes and a growing range of custom probes to provide functionality equal to instruments many times the price.

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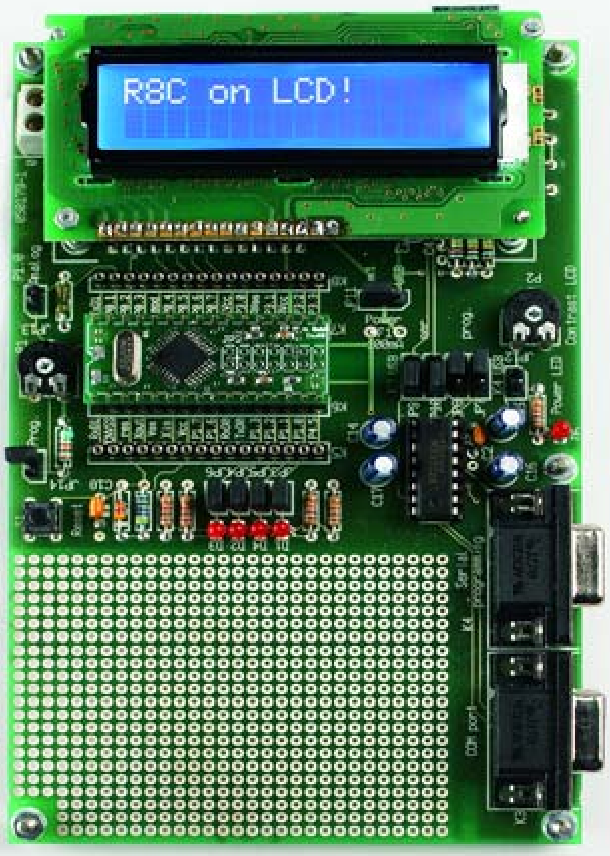
R8C Control Func

Using the R8C/13 hardware in you



We introduced the Renesas R8C/13 Application Board in the previous issue. In this instalment of the R8C series, we describe how to use the hardware in your own applications. The LCD, A/D converter and serial interface are the key elements here.

Burkhard Kainka

Descriptions of how to use the compiler and debugger are available from a dedicated R8C section of the *Elektor Electronics* website (www.elektor-electronics.co.uk). Additional comment received from readers is 'published' via the 'R8C Tom Thumb' topic on our Forum. There you can also find a good selection of advice and tips regarding all possible problems that you might encounter in practice. This is the first time that such a vast number of readers have started using a microcontroller kit more or less at the same time. And naturally, all the usual 'Murphy's law' mistakes have surfaced quite quickly. However, that has the advantage that when a new problem turns up, there's a good chance someone has already found a solution. It's thus worthwhile to browse through the R8C/13 Forum topic. We're also, open to sample projects in the forum that have been developed by readers for readers, and you can learn a lot from them as well. Some of them may have a level of technical sophistication that goes considerably beyond this article.
Here we have intentionally kept things simple to ensure that even relatively inexperienced readers can use the microcontroller successfully. We hope you will excuse our occasional violations of good C programming style. For instance, all the functions described in this article are contained in a single C source code listing. The individual tests are commented out, but they can easily be enabled by removing the comment characters. The function 'main' includes a series of endless loops, each of which does something completely different. Only the first enabled loop in the series will actually be executed. The advantage of all this is that it allows a wide variety of things to be done using a single project. All you have to do when you want to try something new is to insert or remove a few comment characters. The project file (lcd.zip) can be downloaded from the *Elektor Electronics* website and contains all the functions for this instalment.

Driving the LCD

Now for a few words about the LC display. It uses six bits of port 0 on the board, because it is operated in the frequently used 4-bit interface mode, which also means that only the four upper data lines D4–D7 are necessary (see **Figure 1**). The lower four lines (D0–D3) are usually left open. However, that can cause problems with some display modules, so they are tied to ground on the applica-

tions

r own applications

tion board. The module also requires signals on the E and RS lines. The control line (RS) selects either data or command mode. A pulse on the E line clocks the parallel data into the module. The two remaining lines of port P0 are used for other purposes, which must be borne in mind when you are programming your own applications. P0.1 is also designated AN6 and is used as an analogue input for making measurements. P0.0 serves as the TXD1 output and is used for the debug interface.

In order to drive the display, the first thing you have to do is to configure lines P0.2–P0.7 as outputs. However, in contrast to port P1 that requires more than just writing pd0=255 in the code, because access to the data direction register for port P0 is specially protected. To lift this protection, the instruction prc2=1 must be issued immediately before each access.

```
   prc2 = 1;          // Enable access to pd0
   pd0 = 0xfd;        // LCD port, bit 1 left as ADC input
```

The data direction is switched for bits 11111101 = 0xfd. Bit 1 remains an input, and bit 0 is an output of the TXD1 line. When you use the KD30 debugger, the microcontroller transmits data to the PC via this port line. However, you can ignore this bit in subsequent outputs because the serial interface initialisation isolates it from all direct port accesses. That means an output instruction such as p0=0; will leave P0.0 and P0.1 unchanged.

The following listing shows the key function for outputting a byte, which is called lcddata. A value 'data' of type unsigned char (unsigned character, which means a byte with a value range of 0–255), is passed to the function, where 'data' is an arbitrary and interchangeable variable name. This function does not return any value (it is void), which means data flows in only one direction. It is thus similar to a procedure in Delphi or a subroutine (sub) in Visual Basic. C only has functions, so procedures are simply functions that do not return any values. If you want to call the function later on in the program, just write the function name with the desired value in parentheses, such as lcddata(65). That also explains why bytes are referred to as characters (char) in C, since a number can represent a character as well as an ordinary number.

```
static unsigned char Port0;

void lcddata(unsigned char data)
{
   delayus(100);
   Port0 = data & 0xF0;
   Port0 = Port0 + 0x04;  //RS = 1
   p0 = Port0;
   p0 = Port0 + 0x08;     //E = 1
   asm("nop");
   p0 = Port0;            //E = 0
   Port0 = ((data & 0x0f)<<4);
   Port0 = Port0 + 0x04;  //RS = 1
   p0 = Port0;
   p0 = Port0 + 0x08;     //E = 1
   asm("nop");
   p0 = Port0;            //E = 0
   delayus (100);
}
```

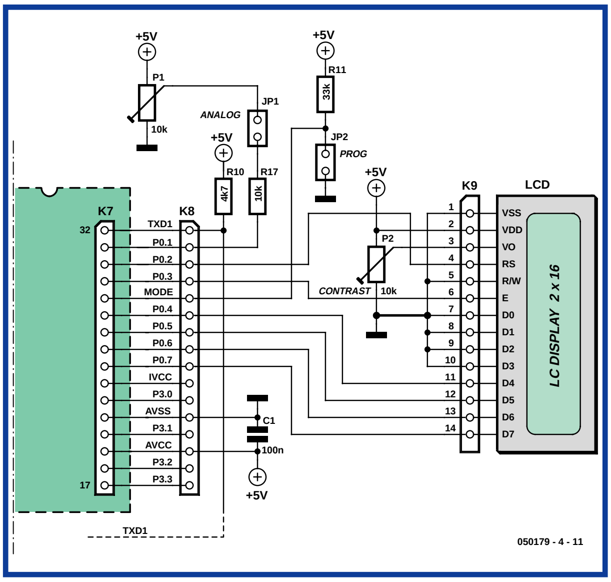


Figure 1. Connecting an LCD module to port P0.

Inside the lcddata function, the content of the variable is processed and output via the upper four bits of port_0 in two steps. The current status is always held in variable Port0 of type static unsigned char. The designation 'static' means that the variable can be accessed from every function. The first step outputs the upper nibble (the upper four bits). The '&' symbol represents the AND operation. The expression 'data & 0xF0' thus yields the upper four bits, with the lower four bits being set to 0. In the second step, the data are shifted left by four bits in order to output the lower nibble to the port. A short pulse is generated on the E line after each nibble to clock the data into the LCD module. In addition, RS must be set to 1 because what is being sent is not command bytes, but instead data. After two sets of four bits have been transferred in this manner, the display will display the corresponding character. A brief pause is advisable before sending the next output. The function delayus is described in detail further on.

Of course, the LCD must be properly initialised before any characters can actually be displayed. After the supply voltage is first applied to the module, the upper row is dark and the lower row is bright. Several command bytes must be transmitted at this point. The function lcdctrl is similar to the function lcddata, with the only difference being that RS remains low in this case. The display module will thus interpret the signals on the data lines as command bytes.

```
void lcdctrl(unsigned char data)
{
   Port0 = data & 0xF0;
   Port0 = Port0 + 0x01;
   p0 = Port0;
   p0 = Port0 + 0x08;     //E = 1
   asm("nop");
   p0 = Port0;            //E = 0
```

```
   Port0 = ((data & 0x0f)<<4);
   Port0 = Port0 + 0x01;
   p0 = Port0;
   p0 = Port0 + 0x08;      //E = 1
   asm("nop");
   p0 = Port0;             //E = 0
   delayus (100);
}
```

Several command bytes are transferred during initialisation. During this process, it is essential to respect the delays specified in the data sheet of the display module. For this purpose, we have written a simple delay function with a very rough resolution of around one microsecond. You can generate a delay in the range of 1 µs and around 65,000 µs by passing a 16-bit value to this function. Here the variable micros is declared as an unsigned int, which means a 16-bit integer without a positive or negative sign.

```
void delayus (unsigned int micros)
{
   unsigned int i;
   for (i = 0; i < micros; i++)
   {
      asm("nop");
   }
}
```

If you would like to study the delay function in more detail, you can insert the few lines of code listed below in the function main. You will then see square-wave signals on all the lines of port P1. With a delay time of 1000 µs, each pulse should last exactly one millisecond. A measurement using an oscilloscope shows that the delay function is actually around 10% too slow. That means you shouldn't use it for programming any sort of clock function, but its accuracy is fully adequate for its intended purpose.

```
   pd1=255;
   while (1)
   { p1=255;
      delayus(1000);
      p1=0;
      delayus(1000);
}
```

The actual initialisation of the LCD consists of several command accesses combined with short and long delays. If you would like to know the details, consult the LCD data sheet or the many sample applications that have already been described for other microcontrollers. The only thing that is important to know here is that the LCD is initialised to operate in 4-bit mode with two rows of characters. In addition, any characters that may have been previously sent to the LCD are erased.

```
void initlcd (void)
{
   delayus(15000);
   lcdctrl(0x28);
   delayus(5000);
   lcdctrl(0x28);
   delayus(1000);
   lcdctrl(0x28);
   delayus(1000);
   lcdctrl(0x0c);
   delayus(1000);
   lcdctrl(0x01);
   delayus(5000);
}
```

Now you can finally test the actual output operation. For example, you can write the following lines of code in the function main:

```
   initlcd();
   lcddata (65);
   lcddata (66);
   lcddata (67);
   lcddata (68);
   lcddata (69);
   lcddata (70);
```

The ASCII characters corresponding to the numbers 65 to 70, which are the upper-case letters 'ABCDEF', will appear on the display. You can write any text you want in this very simple manner. A more convenient method is to use the function lcd_text, which processes an entire character string. For example, you could simply write lcd_text ("Hello world"). The last character of a character string must always be followed by a zero, which is used to indicate that all characters have been transferred. The exclamation mark (!) stands for NOT. The loop will thus be repeated as long as the character that has been read is **not** a zero.

```
void lcd_text (char text[20])
{
   unsigned int i;
   i = 0;
   while ((!(text[i] == 0)) & (i < 20))
   {
      lcddata (text[i]);
      i = i + 1;
   }
}
```

Numerical values are doubtless even more interesting than character strings. For that reason, we have written a small function called lcd_integer for outputting integers in the range of 0000 to 9999. That does not cover the full range of an integer value, but the function is intended to be used with 10-bit measurement values from the A/D converter, which can lie in the range of 0 to 1023.

```
void lcd_integer (unsigned int data)
{
   unsigned char byt;
   byt = data / 1000;
   data = data - byt * 1000;
   lcddata(byt + 48);
   byt = data / 100;
   data = data - byt * 100;
   lcddata(byt + 48);
   byt = data / 10;
   data = data - byt * 10;
   lcddata(byt + 48);
   lcddata(data + 48);
}
```

This function is almost self-explanatory. The character variable byt holds the value of each digit in turn. As the ASCII codes 48 to 57 represent the digits 0 to 9, 48 must be added to the content of the byt variable to obtain

the proper ASCII code. The integer division operation with no remainder yields a single digit each time. For instance, 9654 / 1000 yields a 9. If you then subtract 9000 from 9654, the remainder is 654. You can then extract the next digit, and so on.
If this function is called with a number, for example lcd_integer(5678), it will write the number (in this case 5678) to the display. But where will it be positioned on the display? The display module has an automatic address pointer that shifts by one position after each output. It is initialised to position 0 in the upper row. Row 1 occupies addresses 0–19 inside the LCD, while row 2 occupies addresses 64-83. If you want to write to a particular character position, you must send the command 0x80 and the address to the module. In addition, a short pause is again necessary after this operation.

```
void lcd_pos (unsigned int Row, unsigned int Column)
{
   lcdctrl (0x80 + Column-1 + 0x40*(Column-1));
   delayus(100);
}
```

The function lcd_pos sets the pointer to the position specified by the variables Row (1 or 2) and Column (1–20). Now you can simply output a digit to the desired position:

```
lcd_pos (2,4);
lcd_integer(1234);
```

A/D converter

What do you do when you want to master a new microcontroller and you aren't all that familiar with it? Naturally, you look for ready-made sample applications in the data sheet. In this case, a sample application is available on the CD-ROM for the R8C module in the 'AD Converter' folder under 'Application Notes R8C'. With a few minor modifications and simplifications, the function presented there can be utilised for the internal A/D converter of the R8C/13. There are two groups of analogue inputs, which are located on the lines of port 0 (AN0–AN7) and port 1 (AN8–AN11). Here we use only the lower group.

```
unsigned int ad_in(unsigned char ch)
{
   adcon0 = 0x80 + ch;    //Port P0 group
   adcon1 = 0x28;         //10-bit mode
   adst = 1;              //Conversion start
   while(adst == 1){}     //Wait for A/D conversion
   return ad;             //A/D value
}
```

You have to configure certain settings in control registers adcon0 and adcon1 before you can use the converter. After that, you can start a conversion, wait until it has been completed, and then read the result from register ad. Function ad_in is called using the desired channel (0–7) as a parameter. Note that the analogue inputs are numbered in the opposite order of port lines P0_0 to P0_7. That means analogue input AN6 is located on port line P0_1.

After successful conversion of a measurement, the function returns a result of type unsigned int, with the measured value lying in the range of 0–1023.

```
   while(1)
   {
      lcd_pos (2,4);
      lcd_integer(ad_in(6));
      delayus(50000);
   }
```

Serial interfaces

The R8C/13 has two serial interfaces. UART1 is used by the debug interface, for instance for the link to the KD30 debugger program. Consequently, UART0 is utilised for user applications. The following code for initialising the interface to 9600 baud is also copied from an example in the application notes.

```
void UART0_init(void){
   p1 = p1 | 0x10;     // TxD0 port output
   pd1 = pd1 | 0x10 ;  // TxD0 port direction = output
   pd1 = pd1 & 0xdf;   // RxD0 port direction = input
   u0mr = 0x05;        // UART0 transmit/receive mode
   u0c0 = 0x00;        // UART0 transmit/receive control
   u0rrm = 0;          // Continuous receive mode disabled
   u0brg = 130-1;      // 9600 baud @20MHz
   re_u0c1 = 1;        // Reception enabled
}
```

The functions for transmitting and receiving individual bytes are nearly the same as those for other microcontrollers. Refer to the data sheet for more information about which bits and bytes must be transmitted.

```
void sendTxd0(unsigned char data)
{
   while (ti_u0c1 == 0);  //Wait for transmission buffer
empty
   u0tbl = data;          // Set transmission data
   te_u0c1 = 1;           // Transmission enabled
}

unsigned char receiveRxd0 (void)
{
   unsigned char data;
   unsigned char dummy;
   while (ir_s0ric == 0); //Wait for received data
   ir_s0ric = 0;          //Clear serial reception flag
   data = u0rbl;          // Get reception data
   dummy = u0rbh;         // Get error
   re_u0c1 = 1;           // Reception enabled
   return data;
}
```

Once this is done, everything is ready for serial communication, for example with a terminal emulator program (Figure 2). The following loop shows how received characters can be echoed back to their source:

```
   while(1)
{
                       sendTxd0 (receiveRxd0());
}
```

Sample application: a voltmeter

Now that the most important functions for communication with the outside world are ready, you can start tackling a

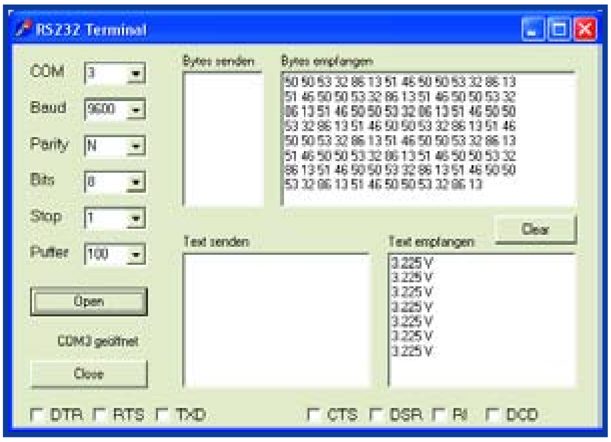


Figure 2. Data link to a terminal emulator program.

real application. Here we present a simple voltmeter that writes the measured voltage to the LCD and the serial interface at the same time. The objective is to output the measurement as a real value in units of volts. This also serves to illustrate that even relatively complex calculations are easy with the R8C. The compiler automatically links in the necessary libraries, which somewhat increases the size of the code. That's not a problem, because we've got room to spare.

```
void voltmeter()
{
    float u;
    unsigned char c;
    u = (float) ad_in(6);
    u = u / 1023.0 * 5.0;
    c = u;
    lcddata (c+48);
    sendTxd0 (c+48);
    lcddata (0x2e);
    sendTxd0 (0x2e);
    u = u - c;
    u = u * 10;
    c = u;
    lcddata (c+48);
    sendTxd0 (c+48);
    u = u - c;
    u = u * 10;
    c = u;
    lcddata (c+48);
    sendTxd0 (c+48);
    u = u - c;
    u = u * 10;
    c = u;
    lcddata (c+48);
    lcddata (0x20);
    lcddata (0x56);
    sendTxd0 (c+48);
    sendTxd0 (0x20);
    sendTxd0 (0x56);
    sendTxd0 (0x0d);
}
```

The voltmeter function first calculates the measured value in volts and then separates the individual digits for output. The decimal point is inserted as the special character 0x2e. Each individual digit is written to the LCD and transmitted via UART0. A space character and the unit ('V') are added at the end. In addition, a CR character is added for the serial interface output to start a new line in the terminal emulator program. For the LCD, on the other hand, the first character position is specified anew before the measurement function is called, so each new measurement overwrites the previous one.

```
while (1)
{
    lcd_pos (1,10);
    voltmeter();
    delayus (50000);
}
```

The results are shown in the terminal emulator program as follows:

4.628 V
4.633 V
4.633 V
…

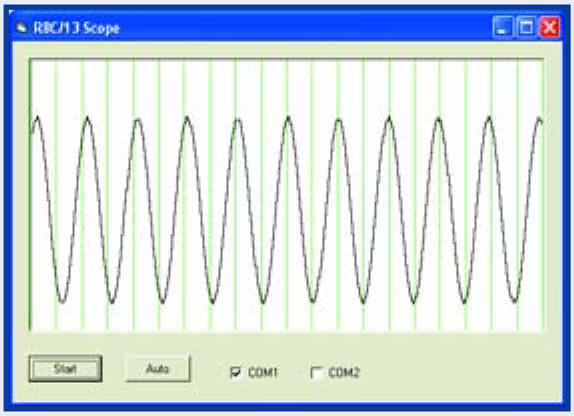
Hurrah – it works!

(050179-4)

Sample projects on the Web

To get an idea of some of the things you can do with the serial interface and A/D converter, have a look at the project results described in the Forum topic 'R8C16-bit micro Starter Kit (February 2006)'. The Elektor Electronics Forum is open to all readers of the magazine. However, to be able to post new items and reply to existing ones, you need to be registered for our E-Weekly. Some 7,000 readers have already done so, so join the crowd.

Hopefully some time after publishing this article you will also be able to download sample projects from the R8C/13 page. If you're looking for a new application for your microcontroller, you're bound to find something useful there. All readers are invited to contribute to the collection of designs published via our website. Simply send your design to the Editor by email.



A PC oscilloscope using the R8C/13

Designs for the M

Jens Nickel

All pictures courtesy of Miele & Cie. KG

The ubiquitous microcontroller appears not only in some of our projects but also in millions of household appliances sold throughout the world. How do the professionals manage design and development of a new product when they anticipate that many thousands of them will soon be rolling off the production line? We dropped in at Miele to see how it's done.

It is a good bet that if asked to think of any town in Germany very few of you would come up with the name of Gütersloh. Even in Germany itself it is quite an unremarkable town, however it happens to be the home of one of Germany's largest white goods manufacturers. The company of Miele have been producing and exporting vacuum cleaners, washing machines, spin dryers and ovens to over 150 countries for almost 100 years. On one cold January day we travelled to Gütersloh and met up with Reinhild Portmann from the Miele press office. The concern employs around 15,000 people in total and reported a turnover of 2.26 billion Euros in 2005. Production takes place in Germany and Austria with washing machines and tumble dryers rolling off the production line in Gütersloh. The consistent features of a Miele machine are reliability and longevity, qualities which are valued by customers all over the world.

"Our washing machines are designed to have a working life of 10,000 hrs which is equivalent to about 20 years service" explained Josef Avenwedde who is a manager at Miele. To underline the company's philosophy and commitment to quality the head of electronic development gave us an insight into the role of the service department. The machine design ensures that some operational parameters can be changed by service personnel (**Figure 1**). This builds-in a certain degree of 'future-proofing' to the design which is important for any machine with a 20-year life expectancy. As an example, a new family of soap powders may be introduced in the future that require lower wash temperatures or less rinse water.

Masses

How the professionals do it

Both of these parameters can be adjusted during service to take advantage of this new technology. This philosophy is a welcome turn around from the 'built in obsolescence' design principle that consumers have become accustomed to. An optical service interface fitted into the front panel of the machine allows convenient access to this 'machine reprogram' feature. One of Josef Avenweddes co-workers Ernst Hokamp (head of washing products group) explained that the service interface was added into the machine design at little extra cost by simply adding a phototransistor as an optical receiver and using an LED to transmit information.
Competition in the white goods market is fierce and every manufacturer is continually looking for new ways to cut costs. Miele carries out most of its PCB assembly work in-house with 20 % contracted out. "Our own production must remain competitive with the rest of the marketplace" emphasised Josef Avenwedde.

SMD pioneers

Back in 1989 Miele were the first of the volume white goods manufacturers to use SMD packaged components. To take full advantage of SMD cost benefits even the rotary programme selector switch on the front of the washing machines was re-engineered. At the time there was little alternative to electromechanical contacts to detect switch position. The development lab came up with an optoelectronic version using a series of SMD LEDs arranged in a circle with a light pipe transferring the signal from one of the LEDs to a central SMD phototransistor to indicate switch position.
In the mid 80's microcontrollers were introduced to the machine (**Figure 2**) "Originally we used the microcontroller just for motor control" recalled Josef Avenwedde. "Before that we used triacs and thyristors together with discrete components". The first microcontroller that the company used in any great quantity was an 8-bit machine with a 4 kByte ROM. At that time the only programming option was to use assembler. In 1992 the company switched to the 8-bit M37451 from Mitsubishi (with a 6502 core!). The Japanese company had also developed a 'structured assembler' programming tool which incorporated some elements of a high level programming language. This led to higher productivity and was a huge improvement. With a smile he remembered his first year at Miele when software engineers would write lines of code using 'WordPerfect', fortunately the process of code writing today is much more structured.

C, the language of choice

In 2001 the decision was made to use the programming language C for all software development, at the same time they switched hardware and adopted a 16-bit microcontroller. It was a bit of a surprise that the processor they chose was the familiar 16-bit M16C from Renesas, bigger brother to the 8-bit R8C. In the more expensive washing machines it takes on the role of motor control, inputting sensor readings and outputting messages to the display. To help keep production costs to a minimum as much of the electronics as possible are integrated onto

Figure 1. The washing programme parameters can be altered via an optical service interface (covered here by the suction cup).
This allows the machine wash cycle to be matched to the requirements of any future (more efficient) washing powder.

Figure 2. Technical advances in the last 20 years have led to a huge increase in the features found in Miele washing machines and dryers. Microcontroller power and memory capacity has also increased correspondingly.

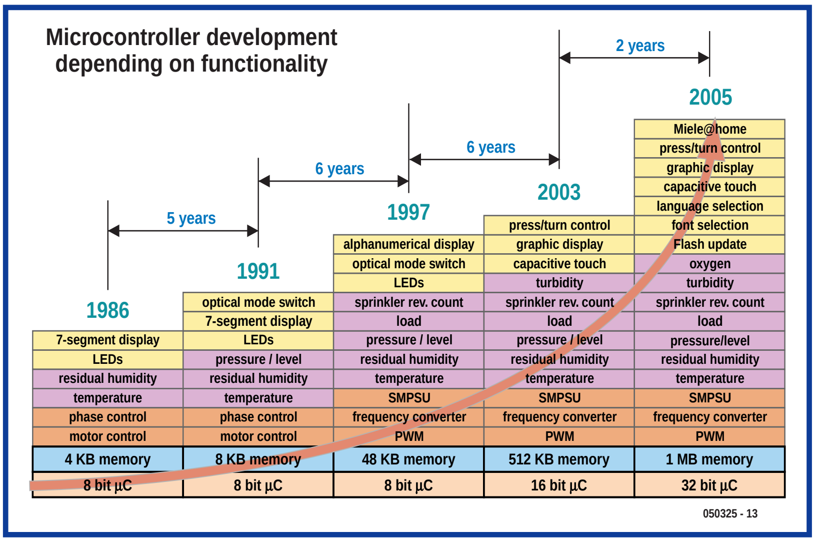


Figure 3. With a solder station, variable transformer and oscilloscope the component engineer Martin Schulze-Hobeling could be working in any design department, the pan however gives a clue to which industry he is working in.

the main control board. An example of this is the water pressure sensor made by Motorola. This device controls the amount of water used for each wash depending on the wash load and its absorbency. The pressure sensor is mounted directly on the controller board and senses water level via a thin plastic tube. Mounted on the controller board next to the pressure sensor is an ASIC for signal gating and conditioning.
This method of construction using a single controller board including the display is applied throughout the product range. When a component fails the entire controller board can be simply replaced. (The fault can often be repaired back in the factory and the board returned to the store room where it will be issued as a reconditioned part). The head of development explained that this approach means that repair costs are slightly higher but production costs are kept to a minimum.

Figure 4. Andreas Lux seen here testing software modules in an emulator environment. Water levels in the machine are simulated with the help of a pressure pump.

All bugs will be exterminated

Miele also supplies machines for commercial use "these machines are more or less in continuous use" added Ernst Hokamp "they take a lot of abuse and therefore we make efforts to ensure they are particularly reliable and robust". This is true for the mechanical parts; the rotary programme selector for example is fitted with ball bearings and the same attention to detail is shown in the electronic design. The washing machines for commercial use contain two M16C microcontrollers, one deals with the machine operation while the other is responsible for control. In this case the job of motor control is performed by a special chip from NEC.
Any machine failure in a commercial environment can prove very costly but this is also true in the consumer market, Miele has a good reputation for reliability which can easily be damaged if standards are not maintained. Just a single bug in the code can cause the controlling program to crash which would not be acceptable. Ernst Hokamp expressed pride in his team and a certain amount of relief that he has never had the need to issue a product recall on the grounds of a firmware update.
We passed an area in the design department where modified machines and new models were being put through their paces. Most of them were connected to computers running the 'DIAdem' test software from National Instruments. One operative had the job of testing every possible switch combination by hand. The sequences of opening the door, rotating the programme selector and pressing buttons are all tabulated on a worksheet. Following on from this procedure comes several weeks of field testing where the new machines are installed in households of some of the employees to make further refinements. The next stage is marketing the machine in limited quantities locally. One of the employees mentioned that Miele are also performing a continuous test of its machines in the laboratory under the scrutiny of a webcam which can be viewed via the Internet. The last time I checked the machines were still going strong half way through the 10,000-hr test.
All of the software developers have access to a library of tried and tested routines that they can fall back on if necessary. Each product group (washing machines, cookers etc.) has a team of between 10 and 15 engineers to manage the development of a new product. In some cases there may be just a single engineer investigating the hardware and software requirements of a new sensor (**Figure 3**).

Professional tools help track down errors

Engineers in the 'washing machine' group are not purely software focussed. Andreas Lux is a young IT engineer and during our visit he was testing and optimising the program of an existing washing machine. His workplace consists of a rack of electronic boards which represent the entire washing machine hardware. Any changes to the code that the software engineer makes can be instantly re-compiled and tested on the hardware. Sensors and actuators are also included in the test environment, pressure sensors are tested with the help of a small hand pump and manometer (**Figure 4**). The Windows PC at his workbench is similar to those used by his colleagues in the department and is not especially fast Miele have however invested heavily in software tools for program development. Code is produce by an engineer using 'Codewright' from Borland, which also serves as an integrated development environment to call up other tools (**Figure 5**). The software package 'Rhapsody' (from iLogix) is also used in the department. This particular software automatically generates C code once the program behaviour is described using a special type of flow chart. The code it produces is difficult to read according to Ernst Hokamp and even Andreas Lux who is a C specialist admitted that it took a little time before he was comfortable with the somewhat elaborate code it generates. One thing to remember here is that the code is produced from the flow chart model so if you start manually editing the lines of code your original model will become invalid.

Automated Documentation

The 'Development Assistant for C' (DAC) is useful in keeping track of software development and checking that the program conforms to the companies naming conventions. 'Doc-O-Matic' is another software tool which is fairly self explanatory; it automatically produces program documentation for example of each C function detailing all the variables on an easily readable HTML format sheet (**Figure 6**). In no way is this software a luxury; it wasn't long before 200,000 lines of code were generated by all the development teams throughout the company.
The program 'Polyspace' is also used and is able to predict runtime errors during program compilation! IAR systems supply the compiler linker and debugger for program development and the real-time operating system emBOS (from Segger) takes up just 1 to 2 kBytes of the embedded controller memory. The same company also supplies the Graphical User Interface (GUI), used by the engineers at Gütersloh.

Memory overload

We were a little surprised to find that the final code for the M16C controller is not protected from unauthorised reading or indeed reprogramming. It is however a little difficult to reconstruct a meaningful source listing from the machine code values stored in ROM according to Josef Avenweddes and as far as he was aware there had not been any reported cases of people trying to achieve greater performance by 'chip tuning' their washing machines! The next logical step up from 16-bits would be a 32-bit controller; we asked if such a development was in the pipeline "we've been using them for some time now for our ovens" said Josef Avenwedde. The main reason for this is not the extra processing power but the increased memory address space of the 32-bit Renesas processor. The program itself is not so large but the user interface display information in 24 languages is also programmed into the Flash memory. "This data takes up a large chunk of the memory especially for the oven controllers, even in the washing machines it eats up around 160 kByte of the available memory" explained Ernst Hokamp. "If you add on the 384 kByte of program code you get close to the limit of the M16C memory space" All the machines sold throughout the world are equipped with the same software, country specific parameters such

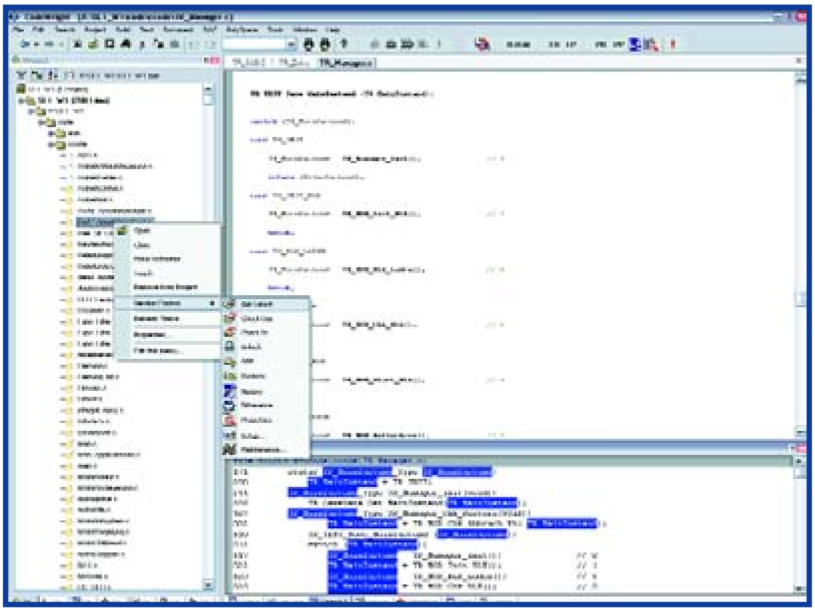
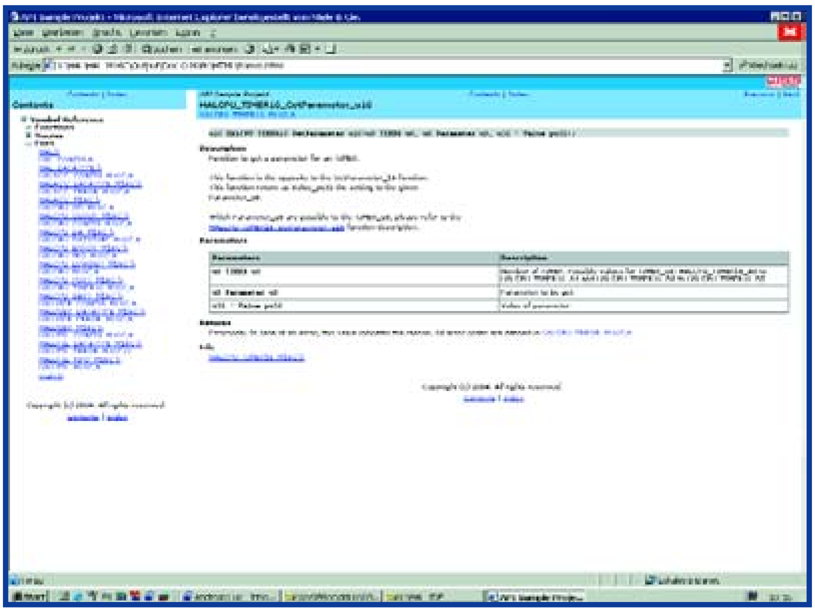


Figure 5. Developers write C code with the help of the 'Codewright' editor. The program manages version control automatically. The left hand window shows which modules are in use.

as mains voltage and frequency are stored separately in a small EEPROM, this also contains some of the machines operating parameters as mentioned above such as drum revolutions, temperature etc which can be reprogrammed via the optical interface during service. "we can also reprogram the Flash memory using this interface but this uses a 'block write' technique and is not so convenient if just one or two parameters need changing, in this case it is much easier to store these in EEPROM".
"New advances in the electronics industry are not always suitable for our applications" explained Josef Avenweddes, "take the concept of 'intelligent' sensors for example; fabricating a sensor together with its interface electronics is unnecessarily complex and costly because these

Figure 6. 'Doc-O-Matic' takes care of the software documentation.



Some figures

Miele is one of the few remaining manufacturers of household goods with an in-house production facility. They assemble around 80 % of all their boards. Approximately 180 employees work at Gütersloh on eight production lines. The company uses 520 different types of component and each day fits 1.5 million of them. Some 50,000 boards leave the production line each week.

There are 14 machines placing and soldering SMDs (the smallest of these is 2.2 mm x 1.5 mm). Each machine is capable of placing 50,000 components per hour. Standard sized components with leads are treated differently. In the past these would be mounted and then wave soldered where the entire underside of the board is heated up to 250°C and swept with a wave of molten solder. The workers at Gütersloh now use a selective soldering system which is more effective and delivers the heat via nozzles or 'chimneys' only to the area of the board which requires soldering. (See illustration).

two items are produced using different technologies. The cost benefits are higher if two identical devices are housed in the same package. On the grounds of economy you will also not find an FPGA or even a mini PC built into any of the current products from Miele. "As a team we are continually discussing new ideas and keeping one eye on current trends in technology" explained the head of product development, so for the time being it doesn't seem likely that you will find an 'Intel inside' sticker attached to any of the washing machines rolling off the Miele assembly line.

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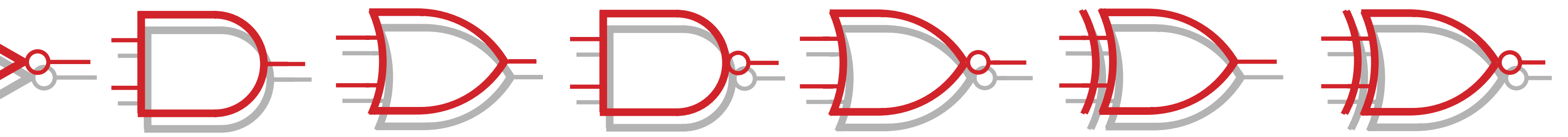
Links

www.miele.co.uk
www.zuken.com
www.ilogix.com
www.iar.com
www.polyspace.com
http://eu.renesas.com
www.borland.com
www.ristancase.com/dac/v40/index.php
www.doc-o-matic.com/index.html
www.segger.com

FGPA Course (1) Part 1:



This is the first instalment of an FPGA course based on the versatile FPGA unit and associated prototyping board described in the last issue. This series of articles describes how to design digital circuits and program an FPGA. In this article, which is the first instalment of the series, we discuss the basic components of digital electronics.

Paul Goossens

Digital electronics is based on circuits that operate using only two voltage levels. These levels are called 'high' and 'low'. 'High' means that the signal potential (voltage) is higher than a previously defined value, and 'low' means that the signal level is lower than another previously defined value. The symbols '1' and '0' are also frequently used in place of 'high' and 'low'. A '1' corresponds to a high level, while a '0' corresponds to a low level.
These digital signals can be processed by components that in turn generate digital signals.

AND gate

Digital electronics is entirely based on just three elementary components. Even highly complicated digital circuits are composed of just these three types of components.

These three elementary components (functions) are illustrated in **Figure 1**. The first two, AND and OR, can have any desired number of inputs, while the third one (INVERTER) always has only one input. Each of these components has a single output.

Let's start with the AND function. The output of this component will be '1' only if all its inputs are '1'. Another way to explain how it operates is to say that the output is '0' if at least one input is '0'. That amounts to exactly the same thing, which can be clearly seen from Figure 1.

Notation

The name of each function is shown at the top in Figure 1. The next row shows the Boolean operator. Boolean notation can be used to describe digital circuitry in a mathematical manner. You will be seeing a lot of Boolean notation in this series of articles. It's actually a relatively simple notation, as you can see from the examples of Boolean equations in the next row.
The associated truth tables are shown below the equations. They are a handy way to describe the behaviour of a digital circuit in an easily understandable manner. The input levels are shown in the left-hand column, and the associated output levels are shown in the right-hand column.
If you look at the AND gate, for example, you can see right away that the output is '1' only if all the inputs are '1'.
It is often possible to reduce the size of a truth table and make it easier to interpret. The 'X' symbol is used for that purpose. It stands for 'doesn't matter' or 'don't care'. If you look at the truth table at the bottom of the figure, you can see that the states of inputs of A and B in the first row don't matter if input C is '0', because the output is always '0' in that case.
As a final remark, we'd like to point out that although the AND and OR gates in Figure 1 are shown with three inputs, the number of inputs can range from 2 to any desired number in actual practice.

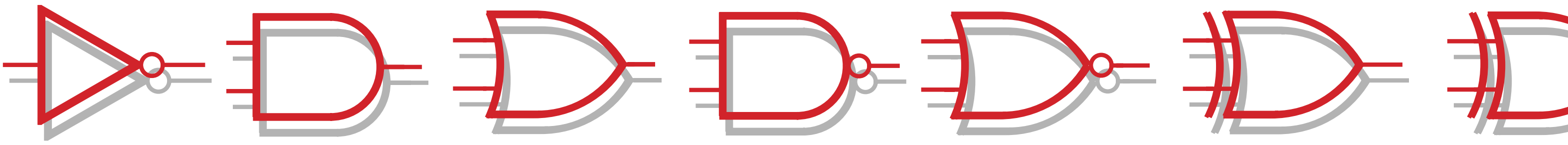
OR gate and inverter

The output of an OR gate is '1' if at least one of its inputs is in the '1' state. In other words, the output of an OR gate is '0' only if all its inputs are in the '0' state.
The final type of gate is the inverter or NOT gate. The output of this gate is the reverse of the signal at its input. In other words, a '0' on the input causes a '1' at the output, and vice versa. That is also shown in Figure 1.

Prototyping board

Now let's try these gates out on the prototyping board.
Figure 2 shows the schematic diagram of a simple circuit. We're going to implement it in the FPGA. We'll use the signals from the four pushbuttons on the prototyping board as the inputs, and we'll use the seven LEDs on the prototyping board to visibly indicate the states of the various outputs.
The files you need for this example are included in the software for this article, which can be downloaded free of charge from www.elektor-electronics.co.uk, follow Magazine _ April 2006 _ FPGA Course (1). The software can be installed conveniently using the installer program (Setup.exe) included in the download.
In the rest of this article, we assume you have installed the software in the default folder (C:\altera\FPGA_course\1\ex1). We also assume you have installed the FPGA unit and the prototyping board according to the instructions in the associated articles.
Double-click on file 'ex1.qpf' in the C:\altera\FPGA_course\ex1 folder. That will launch the Quartus program, which in turn will open the project belonging to the example. You will see a schematic diagram on your monitor that

The basic components of digital electronics



matches the one shown in Figure 2. Signals SWITCH1–SWITCH4 are connected to input pins. The software connects them to the associated FPGA contacts on FPGA unit. Naturally, the same holds true for the LED1–LED7 lines.

The Quartus program can use the schematic diagram to create a programming file that in turn can be used to configure this circuit **in** the FPGA.

To make this happen, select ‘Start compilation’ in the ‘Processing’ menu. It may take a while to create the file, but you will ultimately see a message stating that compilation was completed successfully.

Follow the instructions in the article on the FPGA unit to program the FPGA using this file. The only difference here is that you use file ‘ex1.sof’ as the programming file.

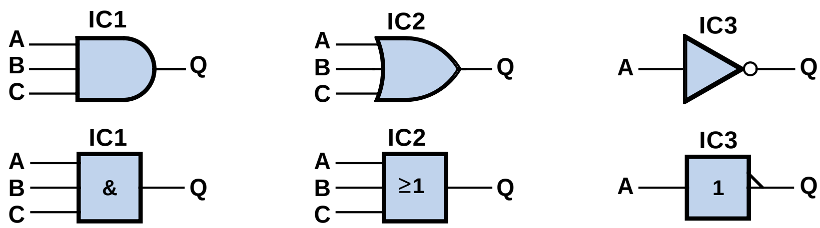
Trying it out

After you have programmed the FPGA, your circuit is ready for use. Now you can use the four pushbuttons to drive inputs SWITCH1–SWITCH4. If you press a pushbutton, the corresponding signal will be forced to a high (‘1’) level. When the pushbuttons are not pressed, pull-down resistors (R5–R8) cause a low (‘0’) level to be applied to

Logic Function:	AND	OR	NOT/INV

Electrical symbol:

IEC circuit symbol:



	AND	OR	NOT/INV
Boolean function:	*	+	—
Boolean equation:	Q = A * B * C	Q = A + B + C	$Q = \overline{A}$

Truth table:

AND:

A	B	C	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

A	B	C	Q
X	X	0	0
X	0	X	0
0	X	X	0
1	1	1	1

OR:

A	B	C	Q
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

A	B	C	Q
0	0	0	0
X	X	1	1
X	1	X	1
1	X	X	1

NOT/INV:

A	Q
0	1
1	0

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Figure 1. The basic components on parade.

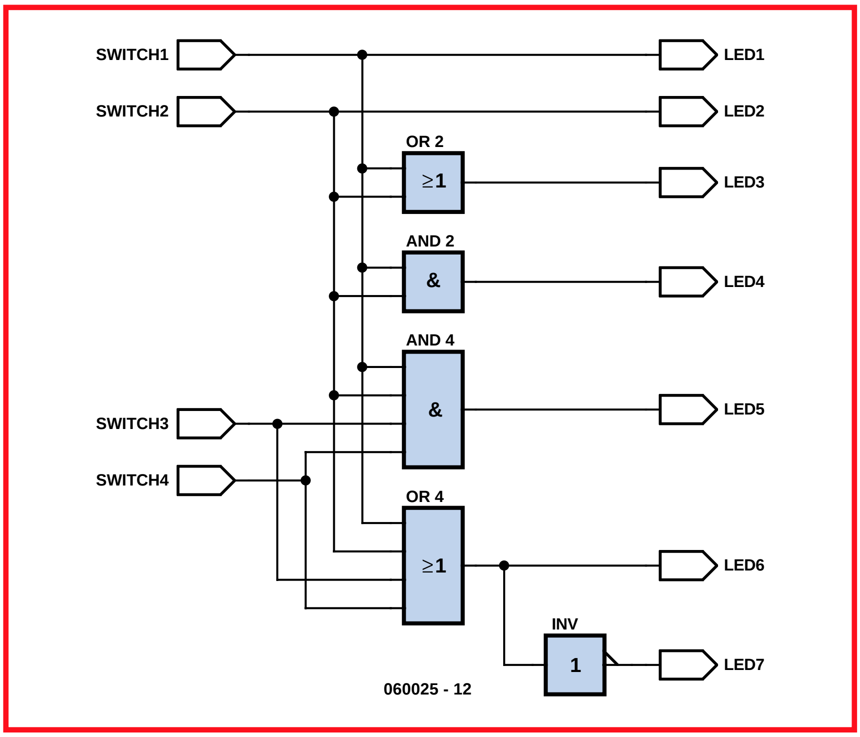


Figure 2. The schematic diagram of our first example.

the associated inputs.
Outputs LED1–LED7 drive LEDs D8–D14 via a buffer (IC7). The LEDs are shown as '1' to '7' on the schematic diagram.

From the schematic diagram in Quartus, you can see that LED1 is connected directly to the SWITCH1 input. When the SWITCH1 signal goes to '1', outputs LED1 will also change immediately to '1'. In practice, that means LED 1 will light up immediately when you press pushbutton 1. You can control LED 2 with pushbutton 2 in the same manner.

The situation is different with LED 3. It is connected to the output of an OR gate whose inputs are connected to SWITCH1 and SWITCH2. This LED will thus light up if pushbutton 1 or pushbutton 2 is pressed (or if both of them are pressed).

You can use LED 4 to study the operation of an AND gate. It will only light up if pushbutton 1 and pushbutton 2 are pressed at the same time. Try it for yourself – you'll see that the LEDs light up according to the rules described above.

You can use LED 5 to test a four-input AND gate. According to the rules, LED 5 should only light up if you press all four pushbuttons at the same time.

LED 6 demonstrates an OR gate with four inputs. It will light up when any of the inputs (the four pushbuttons) is high (button pressed).

Finally, there is LED 7. It demonstrates the NOR function. LED 7 will be lit when LED 6 is dark, which means when none of the buttons is pressed.

To convince yourself that the circuit is working properly, try pressing the pushbuttons individually and in combination and observing whether the LEDs actually respond as described above.

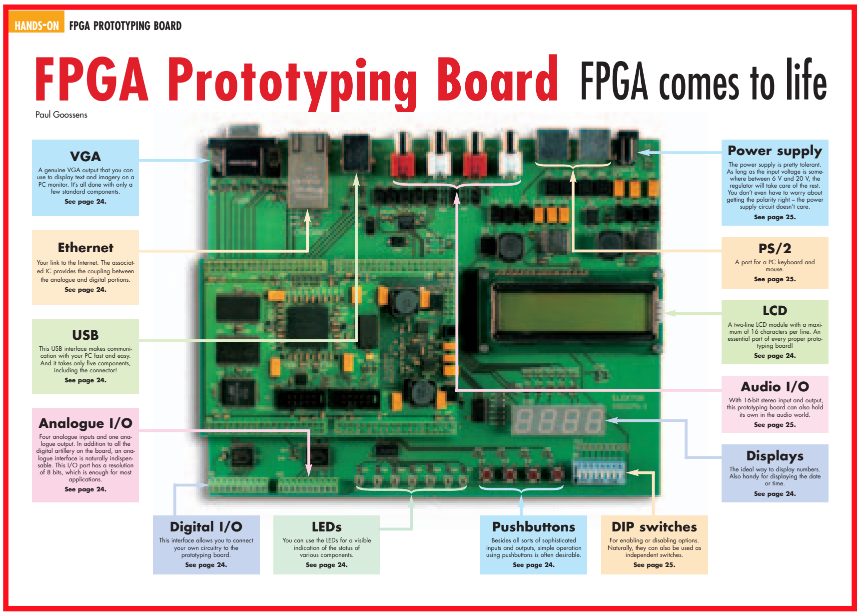
```
LED1 = SWITCH1

LED2 = SWITCH2

LED3 = SWITCH1 + SWITCH2

LED4 = SWITCH1 * SWITCH2

LED5 = SWITCH1 * SWITCH2 * SWITCH3 * SWITCH4

LED6 = SWITCH1 + SWITCH2 + SWITCH3 + SWITCH4

LED7 = LED6 (overlined)
  OR :
LED7 = (SWITCH1 + SWITCH2 + SWITCH3 + SWITCH4) (overlined)


'A*B' = 'A AND B'

'A+B' = 'A OR B'

 A = 'not(A)'                              060025 - 13
```

Figure 3. Example 1 in Boolean notation.

Creating your own designs

The ultimate objective of this course is enable you to design your own digital circuits and program them in the FPGA. That means that addition to understanding how digital circuitry works, you need to know how to use the Quartus program.

The only way to learn how to use Quartus is to actually work with it. The best way to get started is to work through the tutorial for the program. There is also a PDF document in the C:\altera\FPGA_course\ex2 folder with step-by-step instructions for drawing the first example circuit. It is important that you read this document thoroughly and use it to draw the example circuit shown in Figure 2 for yourself. That way you will not only learn how to use the program, but also how to configure the software for use with the *Elektor Electronics* FPGA hardware and programming circuit.



Boolean algebra

The functions of the first example can also be described using Boolean algebra. **Figure 3** shows how the seven functions of the example circuit are described in Boolean notation. You can also use these equations to describe the circuit in Quartus.

That involves using a language called 'VHDL', which is intended to be used to describe the operation of digital circuits. The Quartus program can use such descriptions to create programming files. As far as the program is concerned, it doesn't matter whether you draw a circuit in graphic form or describe it using VHDL.

An example

The Quartus files for this example are located in C:\altera\FPGA_course\ex3. Simply click on 'x3.qpf'' to launch Quartus and load the project.

The difference from the previous example is immediately apparent. As you can see in ex3.bdf, which is the graphic representation of the circuit, the inputs and outputs of the design are connected to a large rectangle. This rectangle processes the input signals and generates the outputs.

Double-click on the rectangle to open the document that specifies how the rectangle operates. That can be another schematic diagram, but it can also be a bit of VHDL code. In this case, we defined the functions using VHDL.

In VHDL, everything after a '—' is regarded as a comment. Comments do not form part of the actual design, but they can be very handy for documenting the design. A detailed explanation of the structure of a VHDL file will have to wait until a later instalment – after all, this is just the first article in the series!

On line 29, we give the design a name (ex3_VHDL), which is followed by definitions of the inputs and outputs of the design. Here you can see that signals IN1–IN4 are inputs (**IN**). Signals OUT1–OUT7 are all outputs (**OUT**). That's all we want to say about the structure of this document for the time being.

Equations

However, lines 57–63 deserve further explanation. Here you see equations similar to the ones in Figure 3, with the difference that here we use '<=' ('becomes') instead of '=' as in Figure 3. You'll also notice that the '*' operator can be replaced by the word 'and', and that '+' can be replaced by 'or'.

In line 63, we wrote out the full equation instead of using the equation 'OUT7 <= not (OUT6);', although the latter equation is perfectly correct in theory. Unfortunately, VHDL does not allow output signals to be used as inputs for internal logic. Later on, we'll tell you why that is and show you a simple trick you can use to utilise output signals as inputs despite this restriction.

Once again, you can compile the example and try it out on the prototyping board.

Modifications

Folder 'ex4' contains a document that explains, step by step, how to draw the above example in Quartus. You can use it to familiarise yourself with drawing functional blocks and building up a design in a hierarchical manner. This document also describes some other features of Quartus, so you should make a point of working through the exercise.

VHDL is an extremely powerful language, and we've only touched on a few of its basic features here. Nevertheless, it's clear that designing circuits this way can save a lot of time. For example, suppose you decided that LED1 ('OUT1' in the VHDL file) should only light up when button 1 and button 4 are both pressed. That would require modifying the design. You could do so by replacing line 57 in the example with the following line:

OUT1 <= IN1 and IN4;

You can try that for yourself by recompiling the modified design file and programming it into the FPGA.

If we had generated the design in schematic form as for the first example, it would take more work to incorporate the modification into the design. What's more, the schematic diagram of a relatively large design can easily turn into a thicket of lines and logic gates, which makes it difficult to quickly understand how the design works. The operation of the design is much easier to understand if you describe it in VHDL, especially if you use comments.

Coming up next

As promised, we'll put the 7-segment displays to work in the next instalment. That will involve using memory elements and some rudimentary computations. In the meantime, you can visit the forum on our website to discuss FPGAs, our development kit, and of course the FPGA course.

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The software for this instalment is available free of charge on the Elektor Electronics website under item number 060025-1-11.zip. From the homepage, go to Magazine → April 2006 → FPGA Course (1).

Earlier in this series

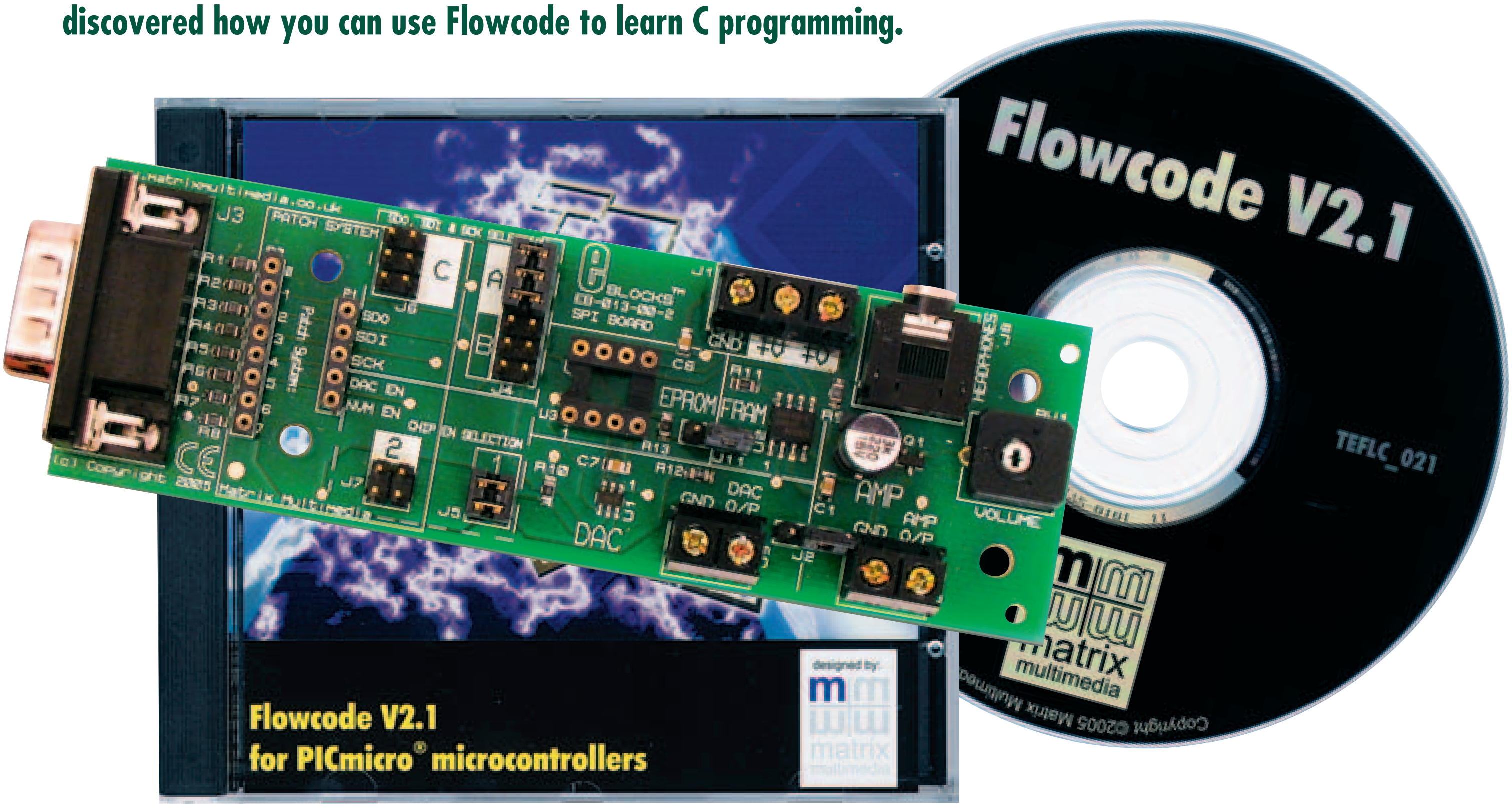
Versatile FPGA Module, *Elektor Electronics* March 2006.

FPGA Prototyping Board, *Elektor Electronics* March 2006.

Making Waves

John Dobson

In last month's article on making a sound waveform we used the E-blocks SPI bus D/A and memory board to generate a sound waveform of around 400 Hz. In using Flowcode I read that the flowchart is first converted into C and then into assembly code, and that you can embed C into your Flowcode programs to speed the operation up. In this article I describe my attempts to use C to speed up the sound waveform generator. At the same time I discovered how you can use Flowcode to learn C programming.



To generate code for the PIC microcontroller, Flowcode processes a flow chart in a number of steps. Let's have a look at how this works:

Step 1

Flowcode initially takes your flow chart and generates C from it. As an example of this let's look at a simple counter program (COUNTER1.FCF) in Flowcode and its C equivalent.

In **Figure 1** you can see the counter in Flowcode: we declare the value of variable COUNT as 0; then we have a loop icon. The Loop WHILE 1 declares an endless loop as '1' is always true. Inside the loop we have icons to increase the value of COUNT by 1, wait for one second and then output the value of COUNT to port C. I have a 16F877 PIC micro with LEDs counting up in a binary sequence on port C.

Step 2

If you open Windows Explorer and look in the directory where the COUNTER1.FCF Flowcode file is saved you will find that Flowcode has generated a number of files one of which is COUNTER1.C. This is the C equivalent of the COUNTER1 flow chart program. If you open this file in Notepad you will see the program in **Figure 2**.

Here we have shown the program in two parts, side by side – to save space on this page. Firstly, Flowcode has defined some of the constants the C compiler needs with statements like 'char PORTC@0x07;'. This defines the C variable 'PORTC' as being hex (that's what the '0x' stands for) address 07. Similarly TRISC is defined as being hex 87. TRISC is the data direction register on the PIC micro and the TRISC register on the 16F877 I am using is at hex 87. Similarly, many of the other PIC micro and circuit specific functions – such as the clock speed, at C

E-Blocks and Flowcode do your C programming

the pins for the internal USART etc. are defined. (Note that in C when a line begins '//' this indicates that the line is a comment and not a line of code.) There are no macros or subroutines in our program so these sections are blank, but there is a variable defined as type CHAR called FCV_COUNT. This is our COUNT variable from the Flowcode program. This is the first hint in how you can use the C icon in Flowcode to embed code into a Flowcode program: all variables in Flowcode are prefixed by 'FCV_' when transferred to the C compiler. This means that when referring to a Flowcode variable in a C icon you must also prefix the variable with 'FCV_'. (incidentally, FCV stands for **F**low**C**ode **V**ariable.)
After the declaration of variables you see the first line of C:

```
Void main()
{
```

This is a function declaration within C to indicate that this is our main program. This is the equivalent to the START icon in Flowcode. The pair of braces indicate that there are no variables passed to this function, and the 'open' curly bracket '{' indicates the start of the main function, and you can see a 'close' curly bracket '}' at the end of the program.
After this we have two more declarations – for the A/D converter – to declare these pins as analogue inputs – and to turn the timer interrupt on. These are declared inside the main program loop as they can be altered by the user within the Flowcode program.
After this we have the main program: FCV_COUNT is declared as being 0, corresponding to our first flow chart icon, then there is a while (1) statement followed by further code inside curly braces: this means execute the routine inside the curly braces forever. Inside the braces we have the FCV_COUNT increment, and a delay of 1 second. Note that these lines of C code end with a semicolon. Lines of C

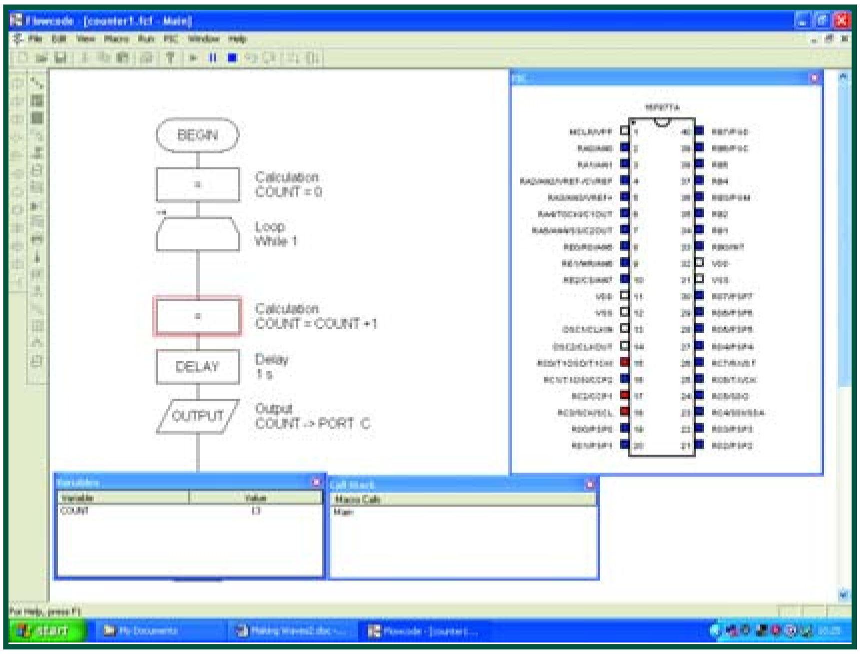


Figure 1. A simple Flowcode counter.

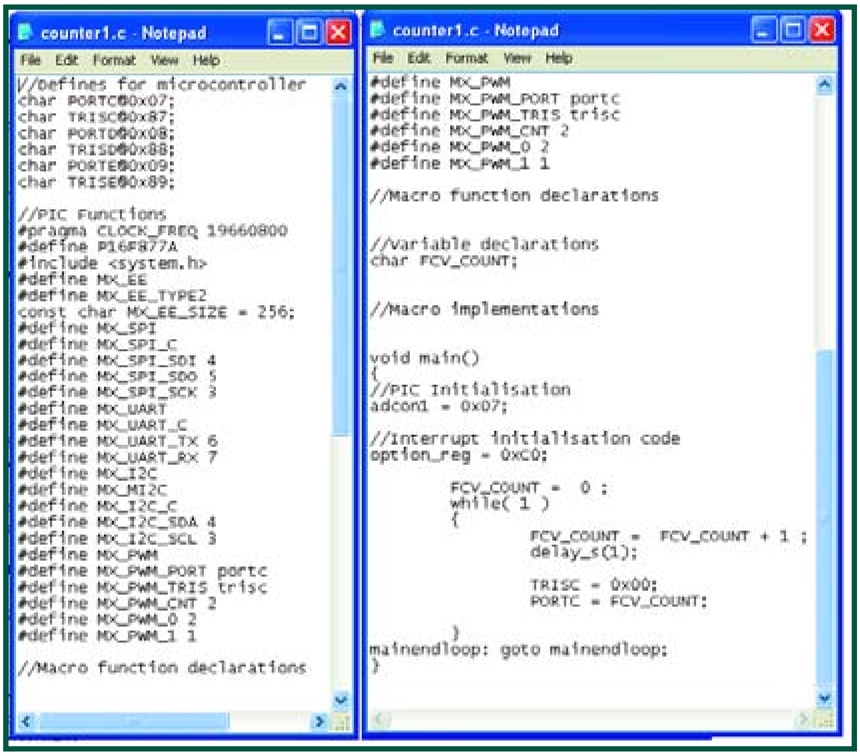


Figure 2. C equivalent of COUNTER1.FCF.

code are always terminated with a ';'. Then we have the line 'TRISC=0x00'. We saw earlier that TRISC is the data direction register. This line of code writes value 0 to TRISC which declares all of the port C pins as outputs. A value for hex FF would declare all the pins as inputs. Our last line of C code in the loop writes the value of our COUNT variable to port C.
The last line here is a kind of safety net: in the case where we do not have an endless loop in our Flowcode program, then the C program will get stuck at this point and execute this line forever. This is the equivalent to the END icon in Flowcode. If you have a C program without an END loop like this then you get a curious effect: the program counter in the PIC micro device keeps incrementing until it rolls over back to address 0000, at which point your program will start to run again.
Well, that was not as hard as I had expected: C is a mysterious language but it seems that if we start from a flowchart then, with a little explanation, the C becomes readable. Admittedly all the declarations are difficult to understand but Flowcode seems to take care of them, so I won't worry too much what they all mean. Besides, a good introduction to C was supplied free of charge with last month's Elektor.

Back to the plot

So back to our original objectives of increasing the speed of the waveform generator program I wrote. Well, I duly compiled my program 'SINE WAVE GEN.FCF' from last month's instalment, and looked at the C produced. What I noticed was that every time Flowcode used a DAC_SEND_CHAR icon it went through a lot of lines of C to declare further variables and address references that the C compiler needs. The reason Flowcode does this is that it has to assume that you don't know what you are doing (thank goodness!) and it has to set all the parameters of Port C for serial communication, each time you use the SPI DAC macro icon, just in case you are using port C I/O pins for other functions. Well maybe we can take out some of these lines of C to speed things up? I decided to tackle this in two stages: firstly replace a DAC_SEND_CHAR icon with the C equivalent to make sure I had replicated the function of the program, and secondly to then start altering the C code to see if I could make it more efficient.
Going back to the main program I simply replaced one of the DAC_SEND_CHAR icons with a C icon. Then I looked up the equivalent C of the DAC_SEND_CHAR icon and pasted it into the new C icon. Then I adjusted the variable declarations to make sure the C icon picked up my OUTVAL Flowcode variable, and recompiled the program to make sure that it still worked. Eventually it did.
Having got to first base I then commented out all the unnecessary lines of C – of the original 34 lines of C code, which a DAC_SEND_CHAR icon produces only 9 were actually needed! There was a certain amount of trial and error here – I just kept commenting out lines until the program stopped working! The program produced is called SINC3.fcf and you can download it from the Elektor Electronics website. The file number is **065032-11.zip** and you can find it under Magazine → April 2006

Unfortunately however I was unsuccessful in making the DAC go any faster – the speed limitation turned out to be the speed of the SPI but itself – let me explain!

Within the code of the DAC_SEND_CHAR Flowcode command, the 8-bit SPI data is sent in two bytes. The last four bits of the first byte contain the most significant data nibble, and the four most significant bits of the second byte contain the least significant nibble. Other bits in each SPI data byte are reserved for chip configuration etc. The DAC_SEND_CHAR Flowcode icon takes OUTVAL and processes it like this:

```
dac_val = (FCV_OUTVAL & 0xF0) > 4;
    sspbuf = dac_val;
    delay_us(3);

    dac_val = (FCV_OUTVAL & 0x0F)
<< 4;
    sspbuf = dac_val;
    delay_us(3);
```

Looking at the top routine: first we take OUTVAL and AND it with hex F0 (binary 11110000) and then shift left by 4 bits (that's the '> 4'), then we set the SSPBUF register in the chip with the result and wait 3 µs. Whatever gets placed in the SSPBUF register will be sent by SPI. The second routine is similar: take OUTVAL, shift left by four bits, set SSPBUF and wait 3 µs. The last statement is the key: SSPBUF is the serial buffer in the PIC device and it will take 3µs for the buffer to clear as the information is sent one bit at a time. If you write to the buffer again before 3 µs has elapsed you will overwrite the data mid way through the serial send operation which produces some very strange results, as the SPI bus ceases to function correctly.

So, it turns out that **the frequency of our oscillator is determined by the speed of the SPI bus**. For those of you that want the maths: each sample takes 6 µs; 256 samples per waveform gives a theoretical minimum period of 1.5 ms or around 650 Hz.
Oh well…time to reduce the number of samples to 64…

(065032-1)

Programs available for download

- **COUNTER1.fcf**
- **SINC3.fcf**

File number: 065032-11.zip

Location: MAGAZINE → April 2006 → 'E-Blocks making Waves at C'

Earlier in this series

Electronic Building Blocks, November 2005.

E-blocks and Flowcode, December 2005.

E-blocks in Cyberspace, January 2006.

E-blocks – now you CAN, February 2006.

E-blocks Making Waves, March 2006.

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Serial Data Com[...]

Clocked data transfer

Synchronous serial data transfer between a microcontroller and peripheral devices has become more fashionable in recent years especially since the data rate has been bumped up beyond10 MBit/s.

The majority of major semiconductor companies such as Analog Devices, Atmel, Burr-Brown, Maxim/Dallas, Microchip along with many others currently offer a wide range of peripheral devices with built-in high-speed serial interfaces intended for short-range communication to a microcontroller. There is no doubt that this interface technique has many advantages over the more traditional parallel interface. In this article we take a closer look at the basic principles involved and give some useful pointers for anyone considering the use of this type of interface on their next design.

The basic problem

When it is necessary to expand an existing microcontroller system the choice of a suitable peripheral device is largely governed by the type of microcontroller used in the system:

- The microcontroller is packaged in a large chip carrier so that the entire bus system (data, address and control) signals are available for use by external peripheral devices. This allows a wide spectrum of peripheral devices with a parallel bus interface to be used with the controller.

- The microcontroller package is so small that parallel bussing can only occur on a microscopic level between the microprocessor and on-chip integrated devices; there are insufficient pins for the parallel bus to be extended to the chip pinouts. The pin outs are used to provide I/O connections for the on-chip devices.

The distance between the microcontroller and peripheral device is also of critical importance when considering the system bus. Bus lengths generally fall into three areas in this respect:

- From 1 to 10 cm where the peripheral device is mounted on the same board as the microcontroller.

- A few metres where the peripheral device is mounted in the same piece of equipment, instrument rack or control desk.

- From around 10 m up to a few kilometres where the system parts are distributed around a train, container ship, factory building or within the same factory site.

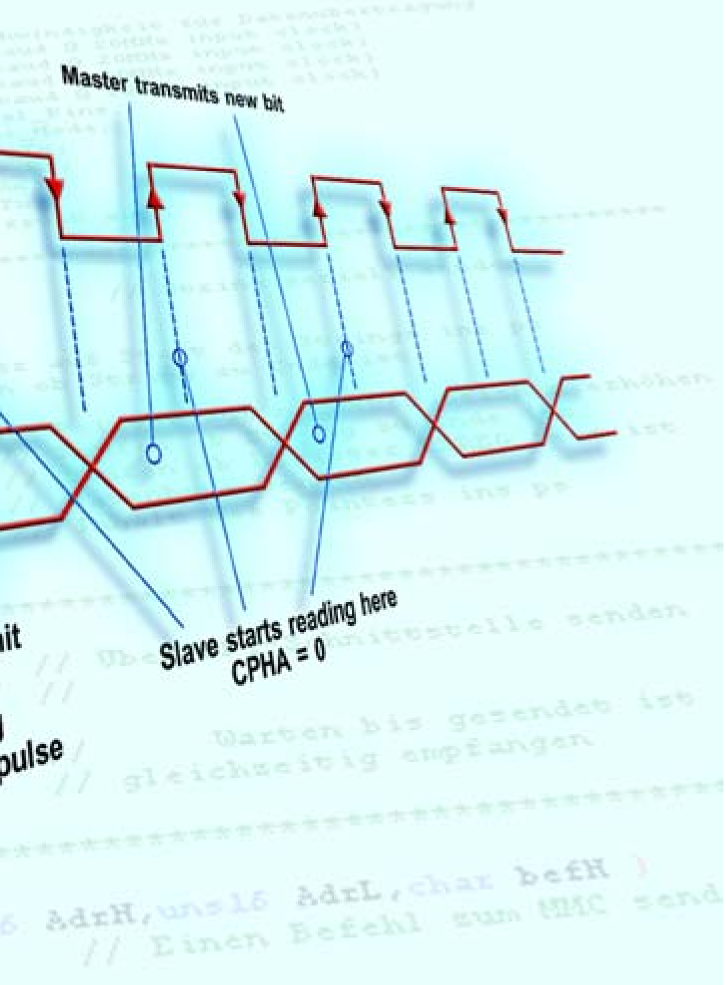
A parallel bus interface using upwards of 10 to 20 parallel signals becomes less practical as the distance between the processor and peripherals increases. The signals suffer from higher levels of crosstalk, more noise pick-up and the cost of connectors, cabling and bus repeaters becomes significant.

Serial data transfer

In recent years a serious alternative to the parallel bus has been developed to such an extent that it now offers real advantages. The serial synchronous/asynchronous point-

munications

Prof. Dr. Bernd vom Berg
and Peter Groppe



to-point communication and the synchronous/asynchronous bus system. Data transfer between devices does not occur in parallel where a byte or several bytes of information would normally be transferred by a single operation but instead the bytes are divided up into individual bits and sent out in series one bit at a time.
The serial interface drastically reduces the cabling between peripherals and also allows the interface to be extended quite cheaply with the addition of simple level shifters or line drivers between devices. Lastly the interface is relatively simple to implement in hardware so that a micro controller with two to four digital I/O pins spare can (with the help of a little software) use them as a serial interface port.

One disadvantage of this type of interface is the data transfer rate. Transferring 8 bits in a parallel interface occurs with just one clock edge but in a serial interface the byte is sent one bit at a time requiring 8 clock cycles. However the speed improvement of more recent serial interface standards means that this is becoming less of a problem and is easily outweighed by the numerous advantages offered by the serial system. A modern Serial ATA hard disk interface can transfer data more quickly than the older 16-bit parallel interface.

Bits and PCs

An important concept in the transfer of synchronous serial data between a transmitter and receiver is synchronisation (**Figure 1**). The transmitter puts each bit on the serial data line one after the other at a predetermined rate. How does the receiver know when to read each bit? It is vital not to miss a single bit or read the same bit twice and interpret it as two bits.

The receiver requires information that tells it when a valid bit is at the serial data input and can be read. The simplest solution is for the transmitter to supply an additional signal indicating when the data is valid and can be read. This additional signal is the data clock sent on a separate line from the transmitter to the receiver.

The receiver looks at the clock line and (if it only had a brain) its thought processes might go something like this:

When a rising edge on the clock line occurs there is a valid bit on the serial data input and I can read it to find out whether it is a 1 or a 0 and then store its value. When there is a falling edge on the click line I do nothing because the transmitter uses this edge to output a new bit.

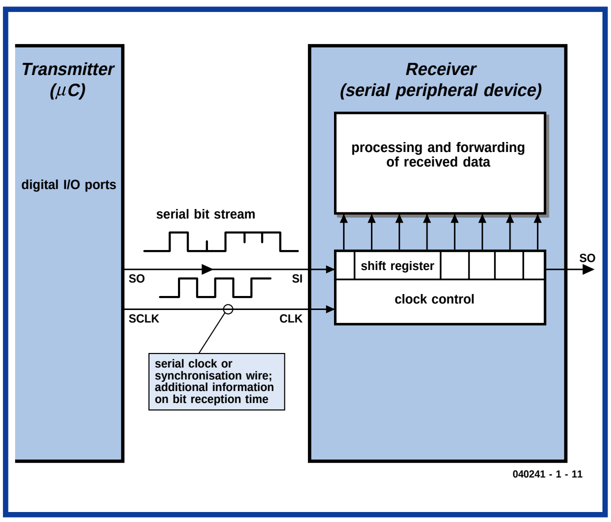


Figure 1.
Data transfer synchronisation between the sender and receiver.

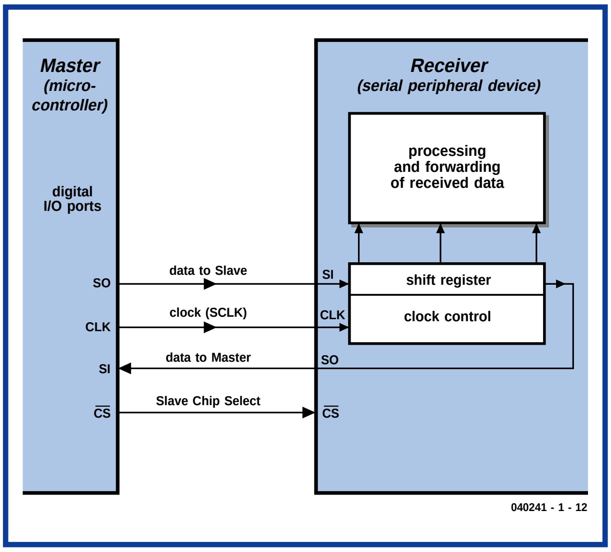


Figure 2. Serial synchronous data transfer.

The received bits are assembled one by one into a shift register or memory location until all have been received and then the slave will interpret and act on the data. To implement the synchronous serial interface it is necessary to have at least one data signal and one clock signal (plus an earth return).
An alternative technique of transferring serial data is the asynchronous method. The system does not require a clock signal. This interface is used on the CAN bus system but more commonly on computer serial COM ports, typically employing a UART (Universal Asynchronous Receiver/Transmitter) peripheral chip to translate serial data to/from bytes. This article will however confine itself to synchronous systems.

Synchronous serial data transfer

Figure 2 shows a typical configuration for point-to-point transfer of synchronous serial data between a master and slave device. Each station can send data to and from the other using the two separate data lines but only one station provides a clock signal to time the data in both directions. This station is called the master and would normally contain a micro controller. The clock speed determines the serial channel data transfer rate (Bit rate) and is chosen so that it not faster than the maximum allowable bit rate of either the master or slave. To describe the sequence of data transfer:

- The clock signal (S)CLK (Serial Clock) is produced by the master. This signal clocks the slave shift register.
- The master sends serial data out from the SO (Serial Out) pin which is connected to the SI (Serial In) pin of the slave device. Here it is clocked into the slaves shift register using the serial clock. Once all the bits have been shifted into the register the slave device will read the information and this may be either data or command words.
- The slave can send data to the master if it is required. The slave loads the return data byte to the shift register and this is clocked (again using the master clock) out of the slaves SO output to the SI input of the master. When the slave has no data to send the existing data in the register is shifted out. This is then a full-duplex communication channel with the master sending data to the slave using output SO and receiving data at the same time from the slave over the SI input.
- The fourth signal $\overline{CS}$ (the slave Chip Select) is used to select a particular slave when there are more than one in the system but we will look at this a bit more closely later on.

The SO output on the slave is only necessary when the slave needs to send data back to the master but in some applications this will not be required. For example the slave device may be a simple LED display driver and only requires display information from the master. It has no information to send back and in this case the slave does not require an SO output. The serial synchronous interface will consist of three connections.

In another application the slave may be a serially controlled remote temperature-sensing device receiving commands from the master and sending back the temperature readings. This configuration will require four connections.

CPOL and CPHA

In some serial interface standards (e.g. the Serial Peripheral Interface) the labels CPOL (clock polarity) and CPHA (clock phase) are used to define which clock edges are important for reading and writing serial data. Chips interfacing to this type of bus generally have two digital inputs CPOL and CPHA (they may also be bits in a configuration register) that allows the format of the chips serial interface to be changed. This flexibility ensures that the peripheral can be configured to interface with an existing bus format. CPOL and CPHA can be either 1 or 0 so this gives a total of four possible interface formats.
Before data transfer takes place the clock signal SCLK can be in one of two idle states defined by the parameter CPOL (Clock Polarity):

- CPOL = 0: The idle (inactive) state of the clock signal is low (0 V) so the start of serial data transfer begins with a rising clock edge.
- CPOL = 1: The idle state of the clock signal is high (+5 V) so the start of serial synchronous data transfer begins with a falling clock edge.

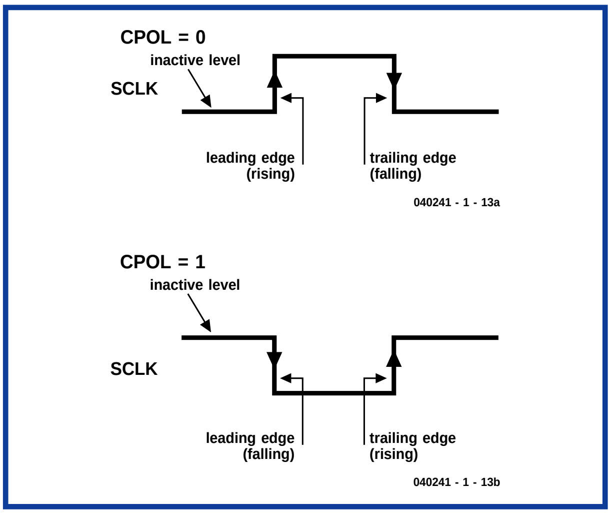


Figure 3. The clock pulse leading and trailing edges.

Table 1. The four modes of synchronous serial data transfer from master to slave.		
CPOL	**CPHA**	**Synchronous Mode** (also known as 'SPI (Serial Peripheral Interface) Mode')
0	0	**Mode 0** The slave reads data on the leading (rising) clock edge. The master outputs data at the trailing (falling) edge of the preceding clock pulse.
0	1	**Mode 1** The slave reads the data on the trailing (falling) clock edge. The master outputs data at the leading (rising) edge of the current clock pulse.
1	0	**Mode 2** The slave reads data on the leading (falling) edge. The master outputs data on the trailing (rising) edge of the preceding clock pulse.
1	1	**Mode 3** The slave reads the data on the trailing (rising) clock edge. The master outputs data at the leading (falling) edge of the current clock pulse.

In a synchronous system when it comes to transferring data the interface clock signal has two important features: its leading edge and its trailing edge, these two events are used to move data and read the value of that data. In every synchronous system it is important to find out the relationship between the clock and the data stream so that we know when data can be output and when the data can be read. In a serial link between a master and slave device the master sends data from its serial output (SO) to the serial input (SI) on the slave. Successful communication can only occur when we know:

- Which clock edge the slave should use to read the data on its SI pin.

- Which clock edge the master should use to put each new bit onto its SO pin which goes on to be read by the slave on the next clock edge.

Once again there are two possibilities governed by the state of the second parameter CPHA.
It is also important to determine the definition of the CPOL signal because it governs how the clock signal leading edge and trailing edge looks (**Figure 3**).
When CPOL = 0 the leading edge is rising and the trailing edge falling. With CPOL = 1 the reverse is true. Both CPOL and CPHA will affect how the master and slave read and write serial data:

- **CPHA = 0**
  The slave uses the clock leading edge to read the data bit on its SI input. When CPOL = 0 the leading edge is rising. When CPOL = 1 the leading edge is falling. The master must use the trailing edge of the preceding clock to put the data bit on its SO output.

- **CPHA = 1**
  The slave uses the clock trailing edge to read the data bit on its SI input. When CPOL = 0 the trailing edge is falling. When CPOL = 1 the trailing edge is rising. The master must use the leading clock edge of this clock to put the data bit on its SO output.

Using these parameters there are altogether four possible variants in the way data is transferred and the clock/data relationship. (**Table 1**).

It goes without saying that both master and slave must be identically configured in one of the four modes for communications to take place reliably. It is important to establish which variant of the interface the slave device is using so that the master can be correctly programmed to communicate with it. In the case where a peripheral is added to an existing serial bus it must be established which mode the bus is using so that CPOL and CPHA on the peripheral chip are correctly configured. A practical example often helps to make things a little clearer:

Assume that we use mode 0 (CPOL = 0, CPHA = 0) in **Figure 4**. The three key points here are:

1. The clock signal idle state is low (0 V).

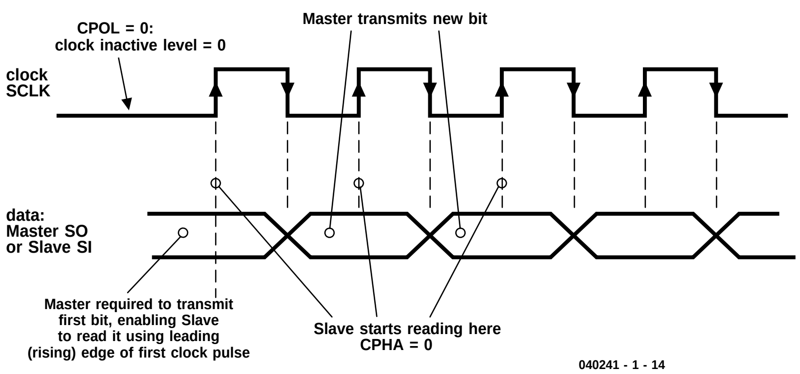


Figure 4.
Serial synchronous data transfer in mode 0.

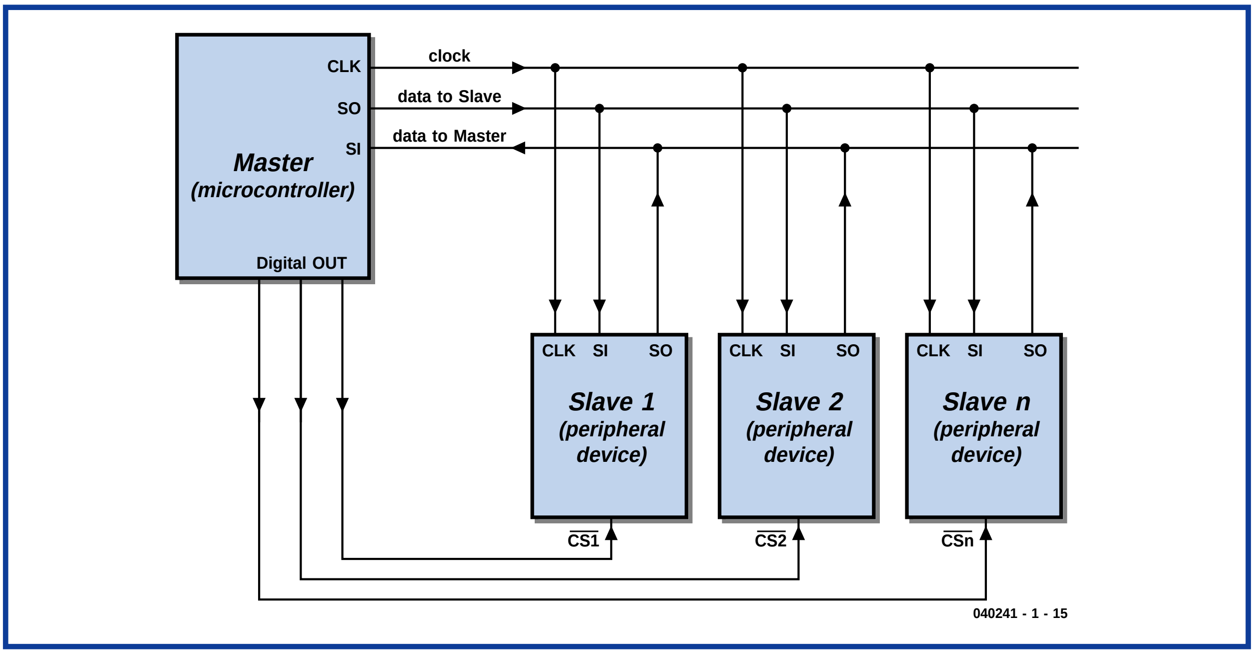


Bild 5.
Die Erweiterung zum seriellen Bus.

2. The slave reads the serial data bit on the rising clock edge. The master must already have sent out this data bit on the previous clock edge so that it is now stable at the slaves SI input.

3. The master changes the serial data bit on the falling clock edge. This allows enough time for the data bit level to stabilise before the slave reads it on the next rising edge. The clock signal is generated in the master.

For successful synchronous serial data transfer it is important to study the data sheet of any peripheral devices to establish the conventions and ask the three most basic questions:

1. What is the idle (inactive) state (low or high level) of the SCLK line?

2. Which clock edge (rising or falling) will the slave use to read data from the data line?

3. Which clock edge (rising or falling) does the master use to write data onto the data line?

Once you are clear on these three points it should be a fairly simple job to correctly program the microcontroller. When you study the data sheet for any peripheral device the serial interface description will always use the terms CPOL, CPHA, (SPI) mode, leading edge, trailing edge to characterise the behaviour of the interface so it is important to be clear about what they actually mean before you start work on the communication software.
Transfer of data in the other direction from a slave to the master (from slave SO output to master SI input) occurs in exactly the same fashion because the shift register in the master and slave are connected in a loop so that serial out from the slave is linked to the master serial input and the clock signal is common. When the slave reads data on the clock rising edge it will change its output data on the next edge and so on.

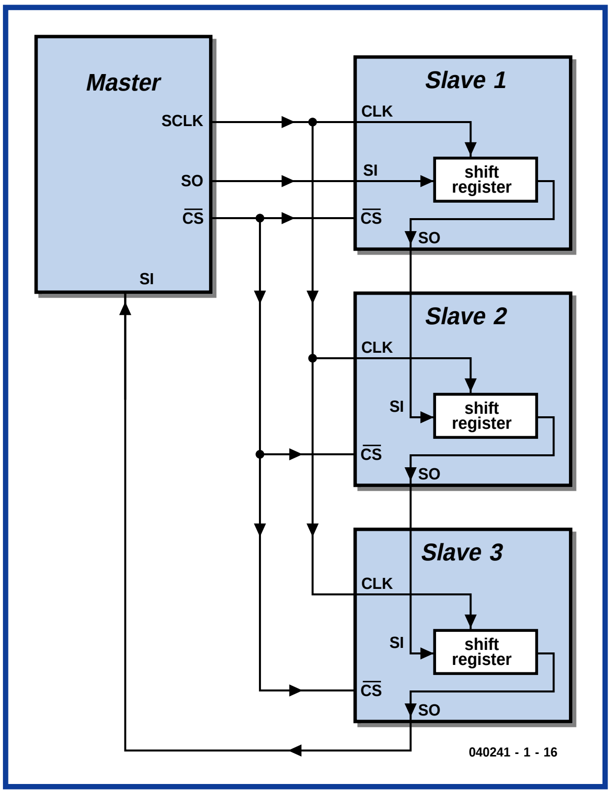


Bild 6.
Die Kaskadierung von Slaves.

The synchronous serial Bus

The simple point to point configuration can be expanded by adding more slave devices and connecting the data and clock signals in parallel as shown in **Figure 5.** Now that all the slaves share the same data and clock signals it is necessary for the master to be able to select which slave is sending or receiving data. The master generates an active low (usually) chip select (CS) signal for each slave. Data transfer to or from a slave station can only occur when its chip select is active. Once the data has been transferred the CS goes high, the slave device is deactivated and any bus output drivers are switched to a high impedance (or inactive open-collector) state.

Table 2. The pros and cons of synchronous slave communication methods.	
Standard bus system	
Advantages:	Each slave is individually addressable. Suitable for slaves without an SO output. Data transfer to each slave can occur at the maximum data transfer rate without the additional overhead of sending data to other slaves.
Disadvantages:	Each slave requires a dedicated I/O line or dedicated chip select signal from the master.
Cascaded bus system	
Advantages:	Each additional slave requires just one CS signal. Data transfer to all the slaves occurs simultaneously i.e. all the slaves will read the new data at the same point when CS is disabled. Minimum hardware expenditure, a good solution if data transfer rate is not the highest priority.
Disadvantages:	Only suitable for slaves with an SO output. Slow data transfer, especially if only one slave needs data. It is necessary to clock it through all the slaves. The slave with the slowest transfer rate will require the whole system to fall back to its speed.

The serial output (SO) from the slave allows data to be sent to the master but if this not needed it can be left open and the next data byte will simply shift out and overwrite the existing data byte. Once the $\overline{CS}$ signal is disabled the slave can read the new data value.

The data is generally transferred in bytes with either the rightmost or Least Significant Bit (LSB) first or the leftmost or Most Significant Bit (MSB) first.

The data transfer speed is governed by the clock rate produced by the master. It is important that this clock rate is not so fast that the slave cannot output and stabilise its data quickly enough so that it can be read reliably by the master before the next clock edge occurs. If the clock signal is processor generated it may be necessary to introduce wait loops in the clock-timing routine to reduce the clock rate although this is not a particularly efficient use of processor time. Reducing the clock rate too much impacts on the whole system response time and will gain very little because the data transfer is edge driven. It is important to ensure that the correct number of clock edges are generated to transfer all the bits.

Cascaded Slaves

In a bygone age children would often pass the time fashioning wild flowers into necklaces and in particular threading daises to make chains but this was a more innocent time long before the countryside protection act and the introduction of Nintendo's Gameboy. Cascading several slave devices together as shown in **Figure 6**, is referred to as a daisy chain configuration, break the link to one of the slaves and all downstream slaves become disconnected just like a real daisy chain.

In this configuration the data registers of all the slaves are connected in series and share the same chip select ($\overline{CS}$) signal. Each slave has a serial output signal connected to the serial input of the next stage. Data from the master is sent to the serial input of the first slave and the serial output from the last slave can be connected back to the master if required or alternatively left open circuit. From the masters viewpoint this configuration looks like a giant shift register where data to each slave occupies successive bytes in the data stream. In this example we assume that three slaves are connected and each slave has an 8-bit shift register. To send data to slave 3 the master will:

1. Enable $\overline{CS}$
2. Clock out the 8 bits for Slave 3.
3. Clock out a further 16 Bits so that the 8 Bits for Slave 3 is pushed into the correct position.
4. Disable $\overline{CS}$

A problem may occur here if slaves 1 and 2 do not need any new data, what data should be sent for those 16 bits? Some interfaces implement a special NOP (no operation) byte that is used to pad out the data stream and has no effect when the slave reads it as $\overline{CS}$ is disabled. In our example it will be necessary to send the following bits:

1. Enable $\overline{CS}$
2. Clock out 8 new data bits for Slave 3.
3. Clock out two 8-bit NOPs for slave 2 and slave 1.
4. Disable $\overline{CS}$

After data transfer when $\overline{CS}$ is disabled only slave 3 will have the new information and the other two slaves will not respond to the NOPs. An alternative method is to simply send the existing data to slaves 1 and 2 so that when the transfer is complete, data in their shift registers will be the same as before. Data for any number of slaves can be sent during the data transfer providing they are inserted into the correct slot in the data stream.

Cascaded slaves are often used to store character data for each position in large (many character) LED display. In principle there is no limit to the number of slaves that can be cascaded in this manner but in practice each additional slave position increases the time it takes for display update. **Table 2** outlines some of the main advantages and disadvantages of slave chip configurations.

(040241-I)

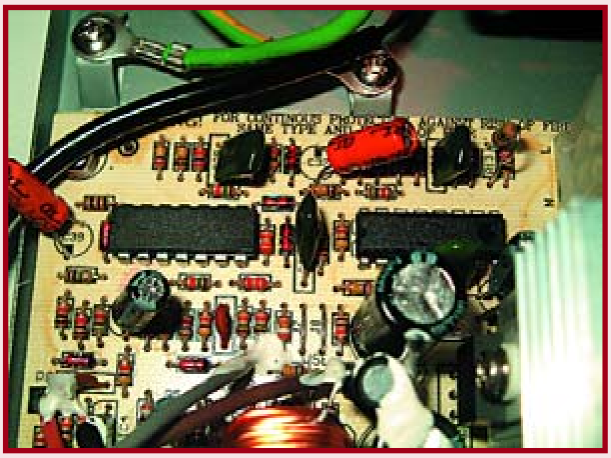
1. This is the power supply that we're going to mod. A cheap power supply can be had for less than ten quid, or even completely free when salvaged from an obsolete PC.

2. 15 A from the 12 V-rail; that would mean that up to 180 watts of halogen lighting can be supplied.

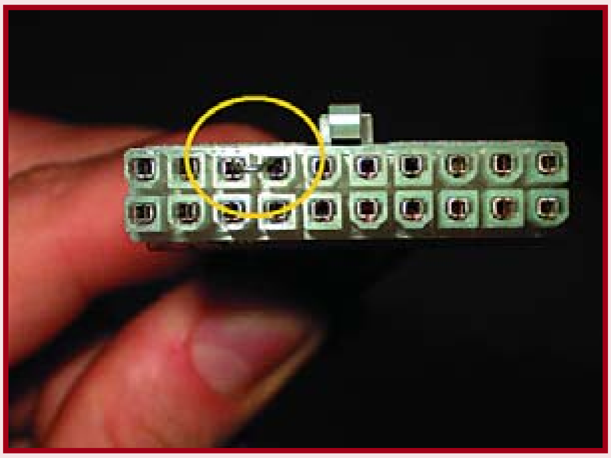
Halogen-power fro

Jeroen Domburg & Thijs Beckers

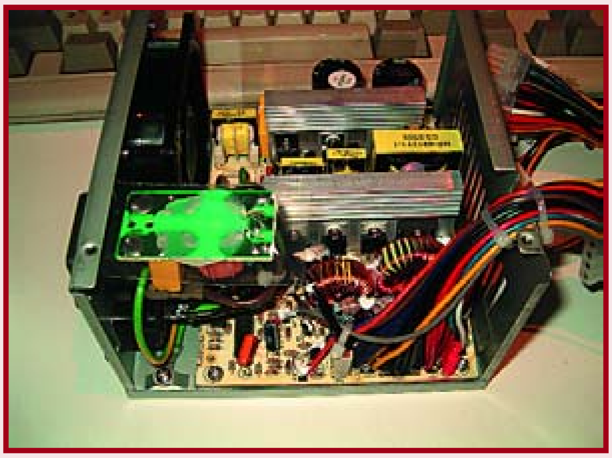
Since the discovery of fire we believe we're largely independent of the sun for our activities. These days we have lamps of various types and sizes from fluorescent and incandescent to LED. According to many people, halogen lighting is a very stylish way to illuminate a room. The lights are usually not that expensive and can be suspended from two steel wires (which also act as the power supply wires). If the room has to be illuminated cheaply (student room, work room), then that can be realised easily with the method described here.



5. The heart of the circuit: a TL494, which provides the switching signals and an LM339 (a quad comparator) to detect over-voltage and over-current conditions. This power supply does not appear to have under-voltage detection.



6. The ATX power supply is switched on by connecting these two contacts together.



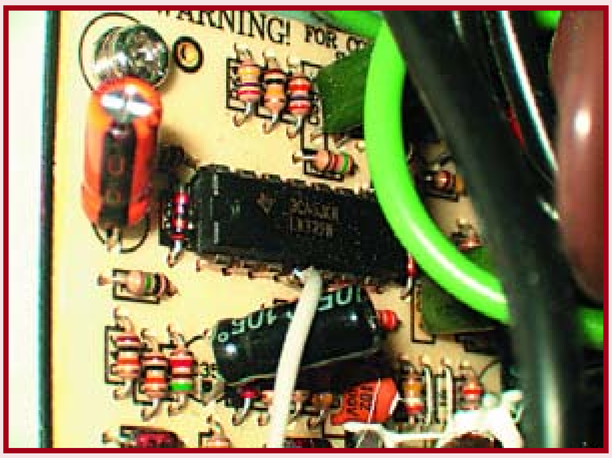
3. The still virgin power supply.

4. There is already a load resistor connected to the 5 V-rail; so we don't have to provide our own.

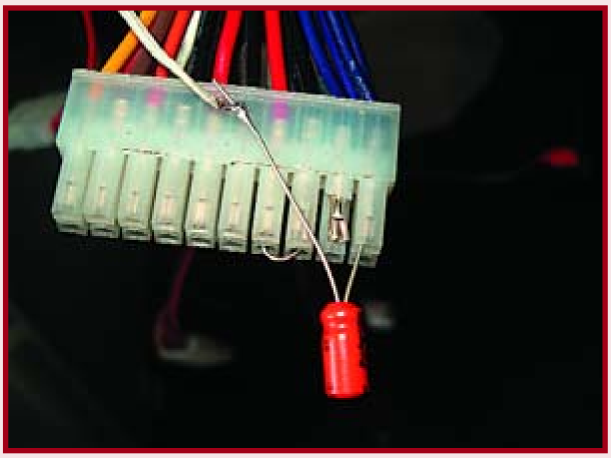
m PC Power Supply

The furnishing of a house or a room also includes the lighting. These days, halogen spots are quite fashionable. Every DIY-outlet offers them as 'special deals'. The disadvantage of these standard 12-V halogen sets on offer, is that they are not really the most powerful ones. They are not usually more than 75 W. That may be nice to accentuate a particular corner, but it is not enough to illuminate a complete room.

What is the limiting factor with this lighting? Usually this is the power supply. The transformer supplied with most of these sets is not powerful enough to supply more than the included lamps. This has to be replaced with a device that can supply a bit more power. Fortunately, modern computer technology provides the solution. Present-day computers use energy at such copious quantities that power supplies up to one kilowatt (!) are now available. Now it is not immediately essential to employ a power supply that large. Less powerful power supplies can also be modded, of course. That old AT(X) power supply that you have in the corner of your room after you dismantled your old PC is probably quite suitable to control some 200 watts worth of halogen lighting.

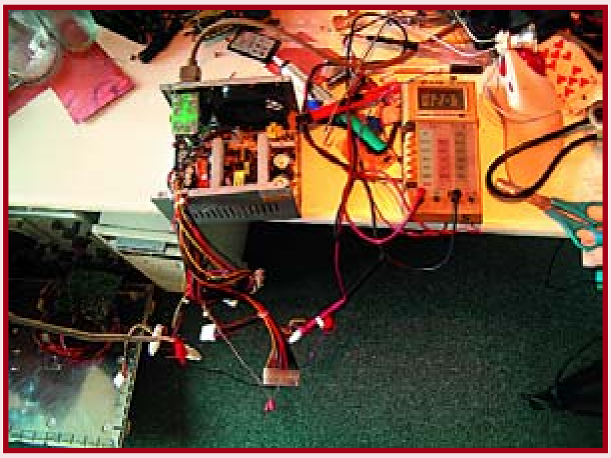


7. The over-current detection can be difficult to find. In this power supply pin 4 of the LM339 has to be above 1.10 V, otherwise the power supply considers itself overloaded.



8. A simple check with a 1 mF-capacitor to the 3.3 V rail shows that the assumption is correct. With the capacitor, the current detection is delayed enough for the protection circuit not to cut in.

9. The power-on surge with so many lights can be quite high indeed.



10. A measurement shows that the lamps draw a maximum of 12 A. Errrm, that is, because the multimeter is specified for only 10 A...

How do we persuade the power supply to deliver the 12 V necessary for the halogen lamps? In theory it already does this. In practice a few problems may rear their ugly heads.

(Surmountable) problems

For starters, we are working here with a switching computer power supply. One of the characteristics of a switching power supply is that there always needs to be some load, otherwise the internal regulator loses the plot. Some power supplies already have this load in the shape of a power resistor built into it. But with power supplies that do not have this, it may be necessary to load the 3.3-V and 5-V rails with, for example, a power resistor with a rating of 10 Ω/3 W. You will notice soon enough if you actually need this resistor: if the power supply doesn't do anything or coughs up an unstable, too high or too low a 12-V rail after plugging the power supply in and connecting the PSON wire to 0V, a resistor on the 3.3-V and/or 5-V rail will be required.

In addition, halogen lamps are per definition not quite the simple ohmic loads that you would expect. When the lamp is cold, the filament (just as with any other type of incandescent lamp) draws many times the current than what it would draw when hot (this is because the resistance of a cold lamp is much lower). A computer power supply is, to some extend, used to peak currents when switching on (hard disk drives draw much more current when spinning up compared to normal use), but this only lasts a fraction of a second. When switching on halogen lamps this current surge will last at least a couple of seconds. Because an ATX power supply is intended for a computer, it will quickly consider these few seconds too much and trigger the over-current protection.

The third point is that the voltage delivered by a computer power supply is usually regulated as a combination of the instantaneous voltages on the 3.3-V, 5-V and 12-V rails. In this case we load the 12-V rail with possibly hundreds of watts while the 3.3/5-V rails have no or very little load. This unbalanced load my cause the 12-V rail to drop to perhaps 11 V. The power supply cannot control this because the 3.3-V and 5-V rails (which have close to no load) would increase too much. A computer could develop a fault if the 12-V rail is too low, so many power supplies have an under-voltage protection system built into it. This protection we also don't need for out application. Halogen lamps do not fail if they have too low a voltage.

Tackling the problems

The first problem is easily solved with a load resistor. In order to deal with the last two problems, we will have to open the power supply case so that the two protection systems can be ... ehhh... creatively circumvented. An ATX power supply looks perhaps very complicated at first, but it is not too bad if you know what you're looking for.

This type of power supply has two 'areas' on the PCB, which are easily recognised: On the bottom of the PCB these areas are separated by a region where there are no PCB traces. The side that has the fuse and probably also two capacitors with a rating of 200 V or more is the high voltage side. *Keep away from this as much as possible!* Even if the voltage to the power supply is turned off, there can be a significant voltage here for several minutes afterwards, which is quite capable of meting out a descent wallop.

The low voltage side is less dangerous and fortunately it is this side that we have to modify. On this side there are usually one or two ICs. In the event that there are two ICs, one has usually been given an interesting name by the manufacturer along the lines of 'Switched mode Pulse

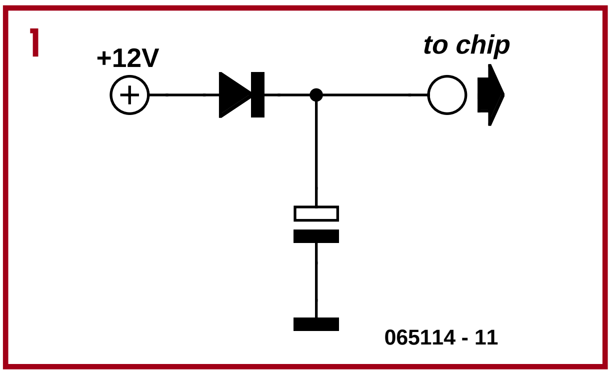
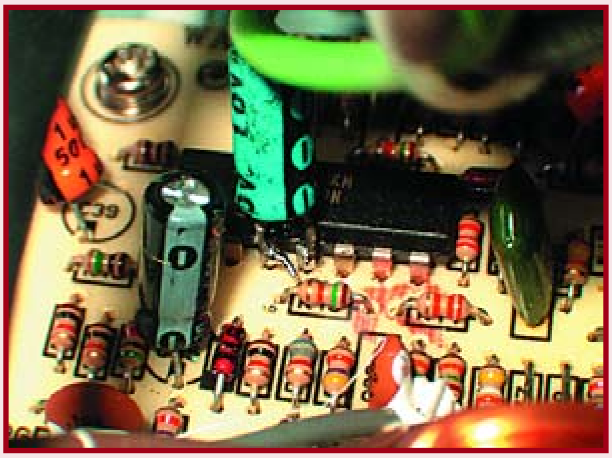


Figure 1. Circuit for the so-called 'clamp'.



11. And this is the final modification: a simple electrolytic capacitor from pin 4 to the power supply pin of the LM339.

Width Modulation Control Circuit'. The other is typically a set of comparators, which are intended to turn the power supply off if the output voltages are above or below a certain threshold.
The under-voltage problem with these power supplies is solved quite easily. Find the opamp whose first input is connected to the 12-V rail via a resistive voltage divider and whose second input is connected to a reference voltage. This voltage usually comes via a voltage divider from the PWM-chip. Take the reference voltage away and connect the input to ground, and the problem is – if all is well – solved. If all is not well, and the power supply won't start any more we probably modified the overvoltage protection instead of the under-voltage protection and we will have to try again.

There are also power supplies available with only one IC, which contains both the PWM controller as well as the over/under voltage detection. The easiest way to circumvent these is to use a so-called 'clamp', refer **Figure 1**. The way this works is as follows: When switching on the power supply (which is usually also accompanied by a little overshoot on the 12-V rail), the capacitor is charged to nearly 12 V. If the 12-V rail drops a little while the halogen lamps are heating up, the capacitor (10 to 100 µF) keeps the protection circuit happy by supplying the higher voltage.
Are you unable to find the under-voltage protection? Don't panic. The most recent ATX specifications make an under-voltage protection circuit mandatory, but older power supplies that were made before this specification may have left this circuit out to save costs.

For the advanced

Finding the over-current protection can be difficult. One way is to have a thorough look at the circuit and figure out how it works. The other method is to fully load the power supply and look at which input voltages to the comparator are dangerously close together and which voltage changes when the load is disconnected. In our power supply, pin 4 of the LM339 has to remain above 1.10 V, otherwise the protection mechanism is triggered. Normally there are three transformers on the PCB (and perhaps a fourth EMI suppression choke, but that one doesn't count). The largest transformer does all the real

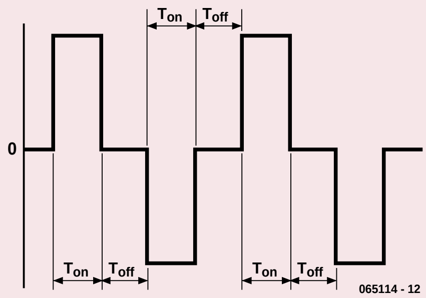
A little more about PC power supplies

A computer power supply is really nothing more than an ordinary switching power supply such as can be found in most high-tech equipment. However, it tends to be a little more complicated because of the large number of output voltages and protection circuits.

A switching power supply usually works on the principle that transformers are more efficient when they're operating at a high frequency. That is why the mains voltage is first rectifier and then filtered so that a voltage of about 340 V results. This is then chopped up with two or more power transistors into a so-called 'modified square wave' with a frequency somewhere in the kHz range. This signal is then connected to a transformer, which transforms the voltage down to the various voltages that are required. These are rectified and filtered and leave the power supply via the famous Molex- and AT(X)-connectors.

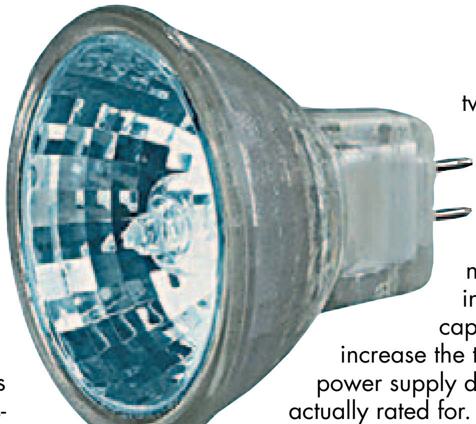
How does the power supply ensure that these voltages are stable? Here is where many manufacturers chose a PWM generator. The PWM generator is the IC that provides the modified square wave. The trick is to adjust the amount of time that energy is actually delivered to the transformer by changing the length of the square wave pulses. That also changes the voltages on the 5-V- and 12-V-rails. Figure 2 shows that if T_{on} is made a little longer with respect to T_{off}, the effective energy transfer to the secondary winding increases (the surface area under the graph is the energy). In this way the voltages on the 5-V- and 12-V- rails are regulated upward a little.

2



The IC that contains the PWM-generator usually also contains 1 or 2 difference amplifiers. The waveform is adjusted based in the voltages at the inputs of these amplifiers. The inverting input of the amplifier is usually connected via a voltage divider to the 5/12/3.3-V-rails, the non-inverting input is connected to a reference voltage. If the voltage on one of the outputs of the power supply drops for some reason, then this results in a lower voltage at the inverting input compared to the non-inverting. The effect of this is that the PWM generator adjusts its pulse width so that both voltages at the inverting and non-inverting inputs are as close as possible.

This design also explains why some power supplies don't work properly without a load: the PWM generator usually has limits over which the pulse width can be adjusted. If a power supply has no load, T_{on} would have to be equal to zero. This is simply not within the working range of the PWM generator and the end result is that the power supply protects itself by switching itself off.



work: converting the 230 V to a lower voltage. Of the smaller transformers one is there for the transmission of the PWM signal to the high voltage side. This transformer is usually recognised by the fact that there are two small transistors in the near vicinity, which have one leg connected to the transformer.

The second smaller transformer is the power-measuring transformer. This works as follows. The primary side of this transformer is connected in series with the primary winding of the main transformer. If the current through the main transformer increases, the current through the power-measuring transformer also increases. The consequence of this is that the voltage on the secondary increases. A second purpose of this transformer is as a bootstrap-transformer: when the power supply has just been switched on, the PWM chip does not have any supply voltage to it and no low voltage rails are being generated, from which the PWM chip itself is also powered. To overcome this catch-22 [1] situation there is sometimes a tap on the power-measuring transformer to bootstrap the chip. That is, to provide the PWM chip with an initial voltage so that everything can start to operate.

To measure the current at the high voltage side, the output voltage from the power-measuring transformer is first rectified. This is often done by connecting the ends of the two outside windings to ground via a diode. The voltage on the middle winding is then filtered with a capacitor and routed to the PWM chip or one of the comparators via a network of resistors. In this case, increasing the value of the filter capacitor is often good enough to increase the time allowed during which the power supply delivers more current than it is actually rated for.

The reason that this story is so awkward is because not all power supplies are the same in this respect. Some power supplies use the third transformer as a mini switching power supply for the 5-V-standby rail. This can be recognised by an optocoupler near the transformer. In that event there is an additional winding on the main transformer for measuring the current. There will also be versions that do not have over-current protection at all. Whichever way, in the end the power supply is ready to light up some halogen lamps. How many halogen lamps? This depends on the maximum current that the 12-V rail can provide. With the average cheap power supply this is easily some 15 amps, which is sufficient for nearly 200 W of halogen lighting.

(065114-1)

[1] http://en.wikipedia.org/wiki/Catch-22
and http://en.wikipedia.org/wiki/Double_bind
for and explanation of this term.

E-blocks Easy AVR Kit

Quick start to Atmel AVR microprocessor programming

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RS232 controlled DC switch

W. Pieczarek

If you want to apply computer control to a solenoid valve or another DC load there is no need to start looking for an expensive measurement card. If just one 'control channel' is required, a power transistor on the PC interface can do the job equally well and at much lower cost. The example shown here employs the RS232 serial interface.

When a serial channel (COM port) is opened on the PC, the RTS (ready to send) line is pulled to High, and returned to Low again when the channel is closed. In this way, simple on/off control of a power load may be implemented by just opening and closing a COM port.

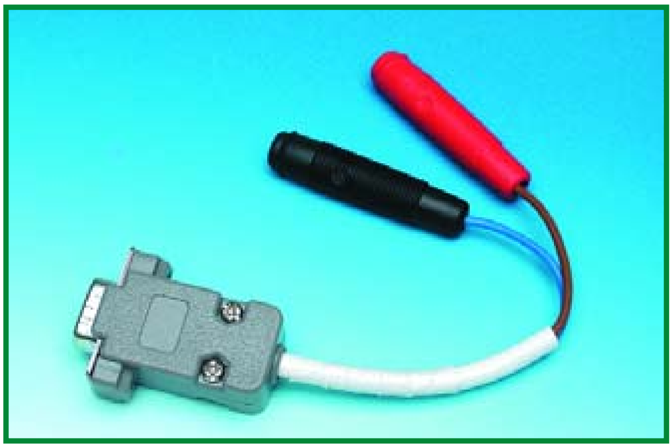
The nominal voltage swing of the RS232 lines is defined as ±15 V. On some PCs, this will be found to be lower at ±12 V or even ±8 V. The circuit has to take into account the different swings that occur with PCs of different makes and build, as well as the negative potential of the RS232 Low level.

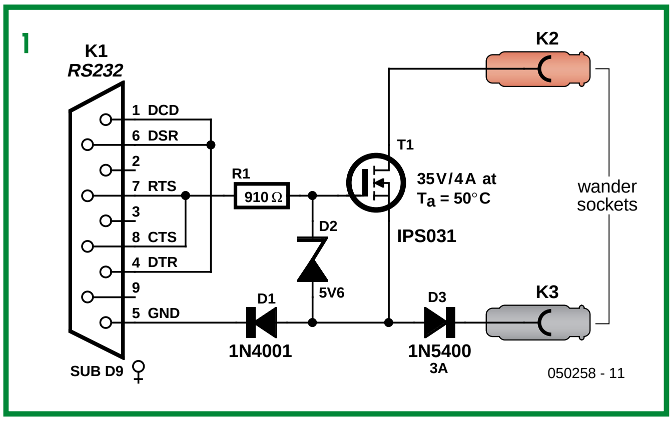
The power transistor used here is an International Rectifier (IRF) MOSFET type IPS031 in a TO220 case. Its main specifications may be summarized as follows:

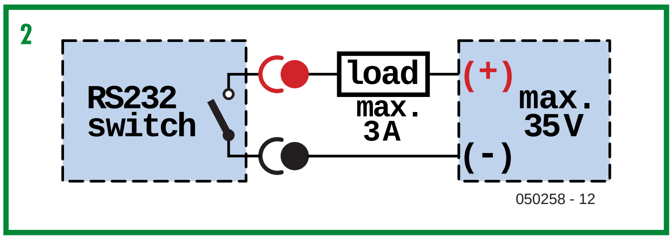
- Integrated overtemperature protection (cuts in at 165 degrees C);
- Overcurrent shutdown (set at 12 A);
- Electrostatic discharge protection (4 kV);
- Low $R_{DS(on)}$ of just 60 mΩ (0.06 Ω).

This MOSFET will happily switch currents of up to 4 A without a heatsink, at ambient temperatures up to 50 degrees C.

Figure 1 shows the way the RS232 controlled DC switch is connected up between the PC and the DC load you wish to switch on and off. This drawing is based on the assumption that there is partial electrical isolation between the PC and the DC circuit being switched on and off. It is also important for the DC load to be connected with the right polarity.







The circuit shown in **Figure 2** consists of a 9-way sub-D socket and just five more parts. The RS232 High level at RTS is limited to a safe value of about 5.6 V by components R1 and zener diode D2. At a negative potential on RTS (Low), diode D1 blocks and in conjunction with D2 protects the FET input.

Diode D1 is included to block the negative potential of the RS232 line. Diode D3 protects the transistor and the interface against reverse-polarised voltage applied at the DC load terminals. With an 1N5400 diode used as shown in the schematic, the load current should be kept below 3 A.

The circuit will function reliably with all RS232 voltage swings, including 'pseudo-RS232' or 0 V/+5 V, i.e., TTL-swing as used on some laptop PCs. However, with (too) low control voltages, you need to be aware of the increasing 'on' resistance of the transistor.

The hardware will easily fit in a 9-way sub-D connector shell as shown by the photo of the author's prototype (**Figure 3**).

Using this configuration, switching frequencies of up to 30 Hz may be achieved, perhaps even higher depending on the PC and CPU load. At higher frequencies, however, Windows will cause increasing jitter (variation of the switching instants).

As already mentioned, all you need to do on the PC is switch the COM channel on to switch on the load, and switch it off again to turn off the load. In QBasic, this amounts to no more than a few program lines.

switching on:

```
OPEN "COM1:9600,N,8,1"
FOR OUTPUT AS #1
```

switching off:

```
CLOSE #1
```

The above example assumes that COM1: is available on the computer.

(050258-1)

Voltage reference with a difference

Rainer Reusch

If a temperature-stable reference voltage is wanted in an analogue circuit, the usual choice is a device with an integrated bandgap reference, such as the LM385 or REF02. An interesting alternative is the so-called 'reference diode'.

Zener diodes with a voltage of less than about 6 V depend, as the name suggests, on the zener effect. These devices have a negative temperature coefficient. Zener diodes with a voltage of over 6 V, on the other hand, exploit the avalanche effect and their breakdown voltage increases with temperature. Reference diodes occupy a middle ground between the Zener and avalanche effects: when operated at the right current, these diodes have a breakdown voltage which is independent of temperature. A wide range of reference diodes is available, including the 1N821(A), the 1N823(A), the 1N825(A), the 1N827(A) and the 1N829(A). These have a nominal voltage of 6.2 V and require a current of typically 7.5 mA. The various types differ in the tolerance of their breakdown voltage and in their temperature coefficients. The 1N821 has a voltage tolerance of 96 mV and a temperature coefficient of 0.01 %/K. In the case of the 1N829 these values are just 5 mV and 0.0005 %/K: considerably more precise, but also, of course, more expensive. However, it is possible to construct a temperature-stable voltage reference using the 1N821: it is simply a matter of providing for calibration via adjustment of the operating current. The dynamic resistance of the diodes is 15 Ω (10 Ω in the case of the parts with the 'A' suffix).

In order to use a reference diode to construct a voltage reference whose output is independent of load and temperature we need to maintain the required operating current (here 7.5 mA) precisely, even over a wide temperature range. What better way to achieve this than to use the diode itself to produce the current? This is the elegant solution used in the circuit described here.

Operation of the circuit depends on the basic theory of the operational amplifier with negative feedback. The opamp continually adjusts, or at least attempts to adjust, its output so that there is no differential voltage between its inputs. If we do not take the supply voltage into account, an output voltage of 0 V would satisfy this requirement, as would an output voltage of about –1 V (with the diode forward biased). If the circuit is operated from a single supply rail, however, the opamp will settle in our desired state with a positive output voltage. In this case the diode is reverse biased. The component values shown in the circuit diagram give an output voltage of 10.4 V. This value is the product of the breakdown voltage of 6.2 V and the ratio between R1 and R2. A voltage of 4.2 V is dropped across R3, giving exactly the current of 7.5 mA that is required. By changing the component values it is possible in principle to obtain any output voltage greater than the breakdown voltage of the diode, although it is essential to select the value of R3 in each case to obtain the correct current. Metal film resistors should of course be used. Ordinary operational amplifiers are not suitable for use in this circuit as they have an offset voltage that can vary with temperature.

The low-cost OP07 precision operational amplifier suggested here gives excellent results, and adjustment of the offset voltage is not necessary.

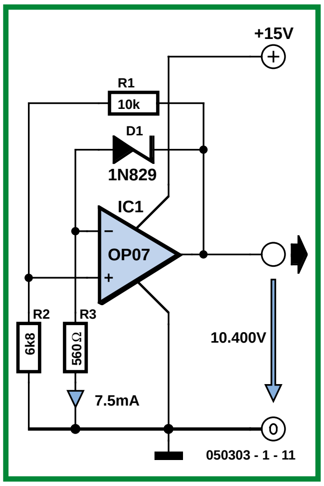
Choosing the component values for the circuit proceeds in two simple steps. For the 1N89x(A) types we have:

R1 / R2 = 6.2 V / (U_A – 6.2 V)
R3 = (U_A – 6.2 V) / 7.5 mA

The circuit was tested using an OP07 opamp, a 1N829 and 1 % tolerance metal film resistors with a temperature coefficient of 100 ppm. Over a temperature range from 5 °C to 40°C the variation in the output voltage was a barely-detectable few microvolts. Subjecting the circuit to freezer spray and a hairdryer in turn resulted in a variation of around 2 mV; it is worth noting that this experiment took the OP07 well outside its specified operating temperature range!

For the circuit shown the supply voltage should not be lower than 12 V. Above this value the output voltage remains absolutely constant.

The reference diode is a comparatively economical alternative to a rather expensive precision reference device. The circuit as a whole takes a current of about 10 mA, and so cannot compete on that score with the micropower band-gap references such as the LM385. The circuit is thus less suitable for use in battery-powered applications.



The same idea can also be used with ordinary zener diodes with voltages of 5.6 V or 6.2 V. With a suitably-set current a considerably more stable output can be achieved than is possible with a simple series resistor.

(050303)

How much wire for a toroidal core?

Ton Giesberts

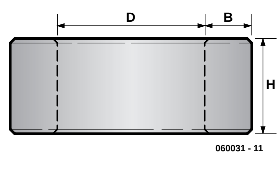
The most dreadful electronics part is perhaps the toroidal core. Anyone who has wound one themselves can relate to that. Particularly if more than just a few turns are concerned!

Here we give you a description of how to deal with this best.

First measure the important dimensions of the toroid with a vernier. This is necessary because in practice the dimensions often vary more than a few tenths of millimetres from those published in the datasheet. The three dimensions that are important (**Figure 1**) are the height (H), the thickness (B) and the inside diameter (D). To avoid any misunderstanding, the thickness, therefore, is half of the outside diameter minus the inside diameter.

In addition, the wire diameter (d) is important and you need to take into account the thickness of the insulation of the enamelled copper wire, which is typically 0.05 to 0.1 mm. Each turn then requires two times the corrected height plus thickness. Do not forget to take the size of the wire into account, particularly if it is thick. Using the centre-line as a reference (**Figure 2**):

H2 = H + d and
B2 = B + d



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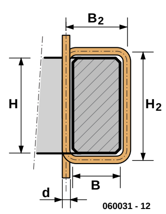

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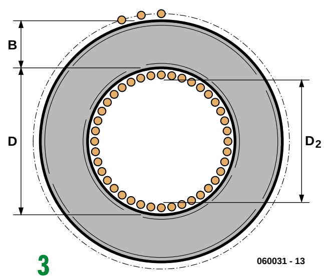


3

The length of wire per turn then amounts to:

2 × (H2 + B2)

In order to find out if the required number of turns will fit on one layer, it is necessary to calculate the maximum number of turns per layer.
Because of the wire thickness, the effective inside diameter is reduced (**Figure 3**). Curvature makes this loss greater than just the wire size alone. It is never quite possible to get the wire tight around the inside of the core, particularly with heavy wire. So to be safe, we subtract twice the wire diameter from the inner diameter:

D2 = D – 2d

The number of turns is then the circumference of the effective diameter divided by the wire thickness:

(π × D2) / d

The total length for one layer is then:

(π × D2) / d × 2 × (H2 + B2)

Depending on the potential difference between the ends of the winding, the effective inner diameter could be even smaller because of the required minimum insulation distance. The alternatives are to use a bigger core or use smaller wire. The latter is often not an option because of the required current rating.
Another problem is the winding of multiple layers. When making the calculation you can simply double the wire diameter.

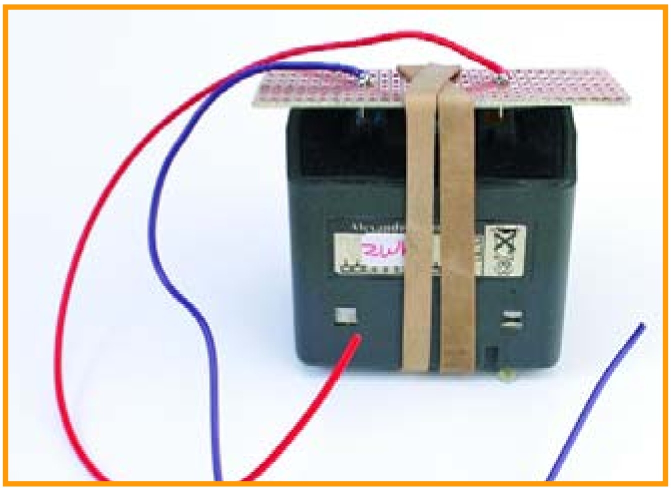
Finally, do not forget to add the tails of the winding to the total wire length, otherwise your laboriously wound winding can't be connected up hence will not be of much use.

(060031-1)

DIY battery holders

Luc Lemmens

Occasionally there is the need to charge a battery from a laptop, mobile phone or PMR handheld using an ordinary laboratory power supply. It could be that the charger is faulty or not available, or, as is often the case with mobile phones, the supplied adapter is not able to deliver enough current to 'wake up' a deeply discharged battery. If you want to charge a battery this way, you always have to proceed carefully and need to know what you can and can't do with a particular type of battery. However, those particular considerations are outside the scope of this article.
Nearly all batteries have flat contact surfaces for their connections. How do you connect those to the power supply? You could solder wires to them, if the contact material allows it, but that's often not possible or desirable. In our lab we use an extremely simple and universal method: a piece of prototyping board, a few PCB pins, and some big rubber bands. The PCB pins are soldered into a piece of stripboard at a spacing that approximates the centre-to-centre distance of the battery contacts. The wires that go to the power supply are soldered to the PCB pins on the copper side of the board. This whole assembly is then placed against the battery so that both connections are making contact. A couple of strong rubber bands around the battery and connector hold it in place and provide sufficient pressure so that we have our hands free to connect and operate the power supply.



Now a final warning: Always keep a close eye on an 'unpredictable' battery. Sometimes a battery is just 'gone' or the exact type is not known. So always pay attention to the charging current and voltage!

(060032-1)

Cleaning aluminium with baking soda

Luc Lemmens

We received a surprising tip from an amateur radio operator for the easy removal of oxide and grime from aluminium, namely with the aid of baking soda a.k.a. baking powder. Apparently a little baking soda dissolved in water is just the key to easily clean, for example, the vanes of old aluminium tuning capacitors.
A quick search on Google using the query 'baking soda aluminum cleaning' showed that this substance is highly rated in the world of alternative 'green' cleaning materials. The solution of four teaspoons of baking soda in one litre of water is suitable as a wideband all-purpose cleaner. More elaborate recipes, with baking soda as one of the ingredients, can be found to clean all sorts of things.
We didn't have a tuning capacitor on hand to try it with, but experiments with an aluminium coffee pot have shown that it works surprisingly well!

(060033-1)

Further reading

www.frugalfun.com/bakingsoda.html
www.frugalfun.com/cleansers.html
http://parents.berkeley.edu/advice/household/jewelry.html
http://ezinearticles.com/?Baking-Soda-for-Cleaning&id=10168

OBD 50 years ago

Jan Buiting

The subject of this month's instalment is from a time when car owners were in total control of their vehicle instead of the other way around as seems to be the case today. A sudden clunking noise from the engine, or one cylinder misfiring — no problem in the 1950s and '60s when Joe Bloggs' Garage would apply hammer force here and there and help you back on the road again. And yet, there were the 'electrics' to grapple with, a major headache to many garage workers.

I got this PrüfRex car & motorcycle electrics test box from a kind gentleman not having the foggiest idea what is was for. The (originally) light green box with dimensions 44x27x20 cm and a weight of about 10 kg proved in reasonable condition and complete with all accessories present in the internal drawer.

The box allows an impressive number of tests to be carried out on various parts of the electrical system of non-computerised cars, motorcycles and mopeds. All test procedures and the relevant precautions are shown on a beautifully illustrated 'user manual' stuck to the inside of the cover.

Ignition coils are tested by connecting them to an internal contact breaker that's opened and closed by a small camshaft just as in a real engine. The camshaft is turned by a DC electromotor with adjustable speed. The sparks (hopefully) drawn by the HT coil under test are visible (and audible!) on an adjustable spark gap on the bakelite control panel. In practice (with one hand!), you increase the spark gap distance from about 2.5 mm until the spark fails, then move the adjustable needle back to restore sparking. The spark gap in mm is then equal to the spark voltage in kV, e.g., 10 mm means 10 kV — a typical voltage for small petrol engines.

The box also has an internal, remarkably powerful, ignition coil that's perfectly capable of producing a speed-adjustable 25-kV (1-inch) spark when the box is connected to a 12 V battery. This serves to test spark plugs as well as those primitive looking damping capacitors used on flywheel-type ignitions. The spark plug is secured on a compression chamber with a glass window. Using a handle connected to a small internal pump the chamber can be pressurised up to about 15 kg/cm^2. This is done to simulate the gas volume reduction caused by a piston at its highest point in the cylinder. The test using the compression chamber is sure to reveal leakage and isolation problems on old and worn spark plugs. The pressure is released from the chamber by pulling a small valve. Interesting smell!

The HT generated by the internal ignition coil is reduced to a few hundred volts with the aid of a resistor for the purpose of capacitor testing. The 'cappy' under test is charged to about 300 V and then (slowly) discharged. Both processes are indicated by a neon lamp.

What d'ye mean value and ESR?
Just watch the neon lamp!

The same 300-odd volts in combination with long wires and the neon lamp are also used to pinpoint voltage leakage due to moisture in or on (HT) cables, plastic and rubber parts. A major problem with older cars on moist days as some of you will not care to remember.

The anchor parts of dynamos and starter motors on (now vintage) cars and motor cycles can be subjected to various gruelling tests including leakage but I have not yet had a need to use these options.

The PrüfRex test box is powered by the vehicle's 4 V, 6 V, or 12 V battery, with the voltage selector switch set accordingly.

The user manual states that the internal electromotor may be used as a continuity indicator to help track down cable faults. Personally I would not like to think of what the 3 A or so of pulse-infested motor current would do to thin wiring inside, a 6-V, plus-to-ground Morris Minor.

(065022-1)

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.

In all mains-operated equipment certain important safety requirements must be met. The relevant standard for most sound equipment is Safety of Information Technology Equipment, including Electrical Business Equipment (European Harmonized British Standard BS EN 60950:1992). Electrical safety under this standard relates to protection from

- a hazardous voltage, that is, a voltage greater than 42.4 V peak or 60 V d.c.;
- a hazardous energy level, which is defined as a stored energy level of 20 Joules or more or an available continuous power level of 240 VA or more at a potential of 2 V or more;
- a single insulation fault which would cause a conductive part to become hazardous;
- the source of a hazardous voltage or energy level from primary power;
- secondary power (derived from internal circuitry which is supplied and isolated from any power source, including d.c.)

Protection against electric shock is achieved by two classes of equipment.

Class I equipment uses basic insulation ; its conductive parts, which may become hazardous if this insulation fails, must be connected to the supply protective earth.

Class II equipment uses double or reinforced insulation for use where there is no provision for supply protective earth (rare in electronics – mainly applicable to power tools).

The use of a a Class II insulated transformer is preferred, but note that when this is fitted in a Class I equipment, this does not, by itself, confer Class II status on the equipment.

Electrically conductive enclosures that are used to isolate and protect a hazardous supply voltage or energy level from user access must be protectively earthed regardless of whether the mains transformer is Class I or Class II.

Always keep the distance between mains-carrying parts and other parts as large as possible, but never less than required.

If at all possible, use an approved mains entry with integrated fuse holder and on/off switch. If this is not available, use a strain relief (Figure, note 2) on the mains cable at the point of entry. In this case, the mains fuse should be placed after the double-pole on/off switch unless it is a Touchproof® type or similar. Close to each and every fuse must be affixed a label stating the fuse rating and type.

The separate on/off switch (Figure, note 4), which is really a 'disconnect device', should be an approved double-pole type (to switch the phase and neutral conductors of a single-phase mains supply). In case of a three-phase supply, all phases and neutral (where used) must be switched simultaneously. A pluggable mains cable may be considered as a disconnect device. In an approved switch, the contact gap in the off position is not smaller than 3 mm.

The on/off switch must be fitted by as short a cable as possible to the mains entry point. All components in the primary transformer circuit, including a separate mains fuse and separate mains filtering components, must be placed in the switched section of the primary circuit. Placing them before the on/off switch will leave them at a hazardous voltage level when the equipment is switched off.

If the equipment uses an open-construction power supply which is not separately protected by an earthed metal screen or insulated enclosure or otherwise guarded, all the conductive parts of the enclosure must be protectively earthed using green/yellow wire (green with a narrow yellow stripe – do not use yellow wire with a green stripe). The earth wire must not be daisy-chained from one part of the enclosure to another. Each conductive part must be protectively earthed by direct and separate wiring to the primary earth point which should be as close as possible to the mains connector or mains cable entry. This ensures that removal of the protective earth from a conductive part does not also remove the protective earth from other conductive parts.

Pay particular attention to the metal spindles of switches and potentiometers: if touchable, these must be protectively earthed. Note, however, that such components fitted with metal spindles and/or levers constructed to the relevant British Standard fully meet all insulation requirements.

The temperature of touchable parts must not be so high as to cause injury or to create a fire risk.

Most risks can be eliminated by the use of correct fuses, a sufficiently firm construction, correct choice and use of insulating materials and adequate cooling through heat sinks and by extractor fans.

The equipment must be sturdy: repeatedly dropping it on to a hard surface from a height of 50 mm must not cause damage. Greater impacts must not loosen the mains transformer, electrolytic capacitors and other important components.

Do not use dubious or flammable materials that emit poisonous gases.

Shorten screws that come too close to other components.

Keep mains-carrying parts and wires well away from ventilation holes, so that an intruding screwdriver or inward falling metal object cannot touch such parts.

As soon as you open an equipment, there are many potential dangers. Most of these can be eliminated by disconnecting the equipment from the mains before the unit is opened. But, since testing requires that it is plugged in again, it is good practice (and safe) to fit a residual current device (RCD)*, rated at not more than 30 mA to the mains system (sometimes it is possible to fit this inside the mains outlet box or multiple socket).

* Sometimes called residual current breaker – RCB – or residual circuit current breaker –RCCB.

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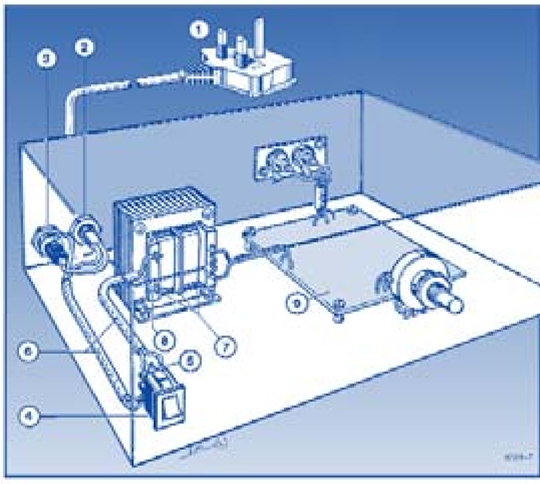

1. ***Use a mains cable with moulded-on plug.***
2. ***Use a strain relief on the mains cable.***
3. ***Affix a label at the outside of the enclosure near the mains entry stating the equipment type, the mains voltage or voltage range, the frequency or frequency range, and the current drain or curent drain range.***
4. ***Use an approved double-pole on/off switch, which is effectively the 'disconnect device'.***
5. ***Push wires through eyelets before soldering them in place.***
6. ***Use insulating sleeves for extra protection.***
7. ***The distance between transformer terminals and core and other parts must be ≥ 6 mm.***
8. ***Use the correct type, size and current-carrying capacity of cables and wires – see shaded table below.***
9. ***A printed-circuit board like all other parts should be well secured. All joints and connections should be well made and soldered neatly so that they are mechanically and electrically sound. Never solder mains-carrying wires directly to the board: use solder tags. The use of crimp-on tags is also good practice.***
10. ***Even when a Class II transformer is used, it remains the on/off switch whose function it is to isolate a hazardous voltage (i.e., mains input) from the primary circuit in the equipment. The primary-to-secondary isolation of the transformer does not and can not perform this function.***

3-core mains cable to BS6500 1990 with three stranded conductors in thick PVC sheath

Max current	**3 A**	**6 A**	**13 A**
conductor size	**16/0.2 mm**	**24/0.2 mm**	**40/0.2 mm**
Nom cond area	**0.5 mm^2**	**0.75 mm^2**	**1.25 mm^2**
overall cable dia.	**5.6 mm**	**6.9 mm**	**7.5 mm**

Insulated hook-up wire to DEF61-12

Max current	**1.4 A**	**3 A**	**6 A**
Max working voltage	**1000 V rms**	**1000 V rms**	**1000 V rms**
PVC sheath thickness	**0.3 mm**	**0.3 mm**	**0.45 mm**
conductor size	**7/0.2 mm**	**16/0.2 mm**	**24/0.2 mm**
Nom cond area	**0.22 mm^2**	**0.5 mm^2**	**0.95 mm^2**
overall wire dia	**1.2 mm**	**1.6 mm**	**2.05 mm**

3-flat-pin mains plug to BS 1363A

Hexadoku

Puzzle with an electronic touch

Here is yet another Hexadoku puzzle, the brain teaser for electronics fans and their family members. Solve the puzzle and win one of the fantastic prizes!

The instructions for the puzzle are straightforward. In the diagram composed of 16x16 boxes, enter numbers in such a way that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once in every row, once in every column, and in every one 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.

Your solution may win a prize and requires only the numbers in the grey boxes to be sent to us (see below). The puzzle is also available as a **free download** from our website (Magazine → 2006 → April).

(065043-1)

Entering the competition

Please send the numbers in the grey boxes by email, fax or post to

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Fax (+44) (0)208 2614447
Email:
editor@elektor-electronics.co.uk
Subject: hexadoku 03-2006.

The closing date is **24 April 2006**. Competition not open to employees of Segment b.v., its business partners and/or associated publishing houses.

Prize winners

The solution of the February 2006 Hexadoku is: 0928F. The **E-blocks Starter Kit Professional** goes to: John Atherton (Horndon on the Hill).

An Elektor SHOP Voucher worth £35.00 goes to: Simon Warner (Neston), Magnus Starseth (Lund) and David Withers (Romford).

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

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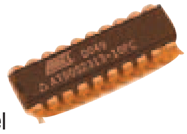

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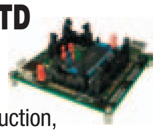

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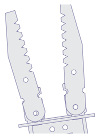
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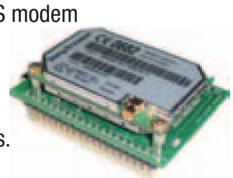
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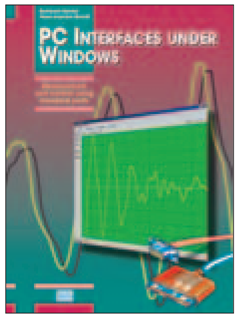

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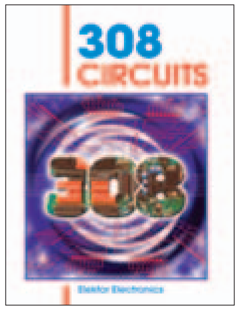

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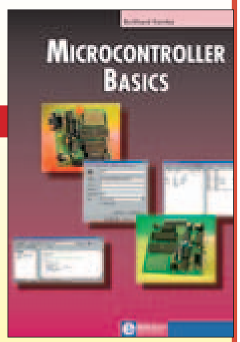

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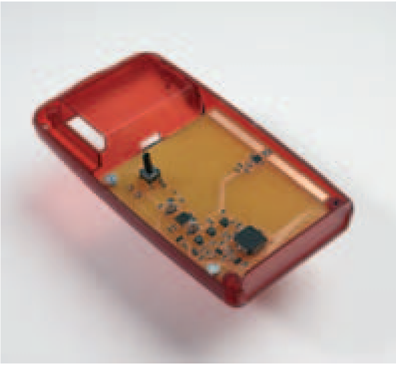

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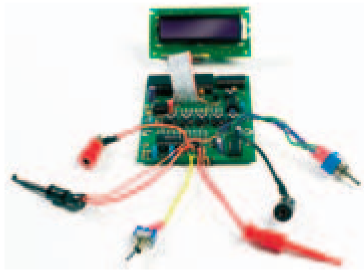

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FPGA Project Bundle
(FPGA Module & FPGA Prototyping Board)
(March 2006)

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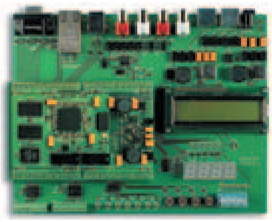

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A 16-bit Tom Thumb
(February 2006)

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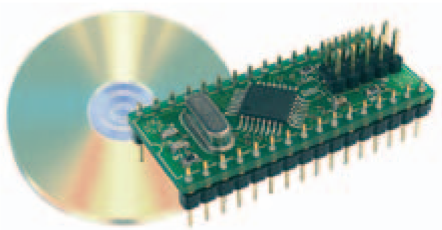

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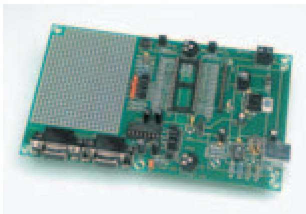

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January	Recycling / Reverse Engineering
February	Motors / Propulsion
March	Development / Microcontrollers
April	Power Supplies / Safety
May	**Soldering / Etching**
June	Test & Measurement / Satellites
July/August	Summer Circuits
September	RFID / Medical Electronics
October	E-Simulation
November	Chipcards / Security
December	Electromechanical / Enclosures

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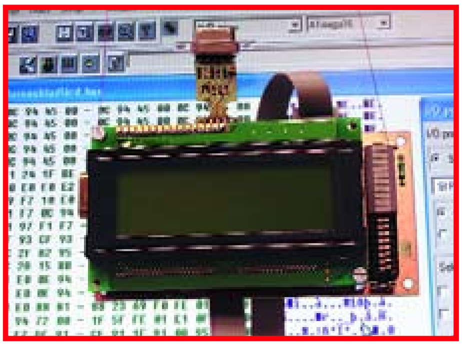
New Soldering Techniques;
Soldering, Etching & Tools;
Electronic Travel Cards;
PIC Programmer;
FPGA Course (2);
E-blocks for Prototyping;
Hexadoku Puzzle.

Stand-alone EOBD Analyser

Using the EOBD connector available in virtually all modern cars, lots of data on the engine can be read out, including engine speed, power, temperature, fuel mixture and of course the dreaded error codes. In the May 2006 issue we publish a stand-alone extension to the immensely popular OBD-2 Analyser from the 2005 Summer Circuits issue. So now you can read OBD data in real time! Our microcontroller board employs an ATMega 16 and data is displayed on an LCD module with 4 lines of 20 characters.



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