elektor
electronics
lead

MOTORS

Theoretical:
- **DC including Brushless**
- **Piezo**
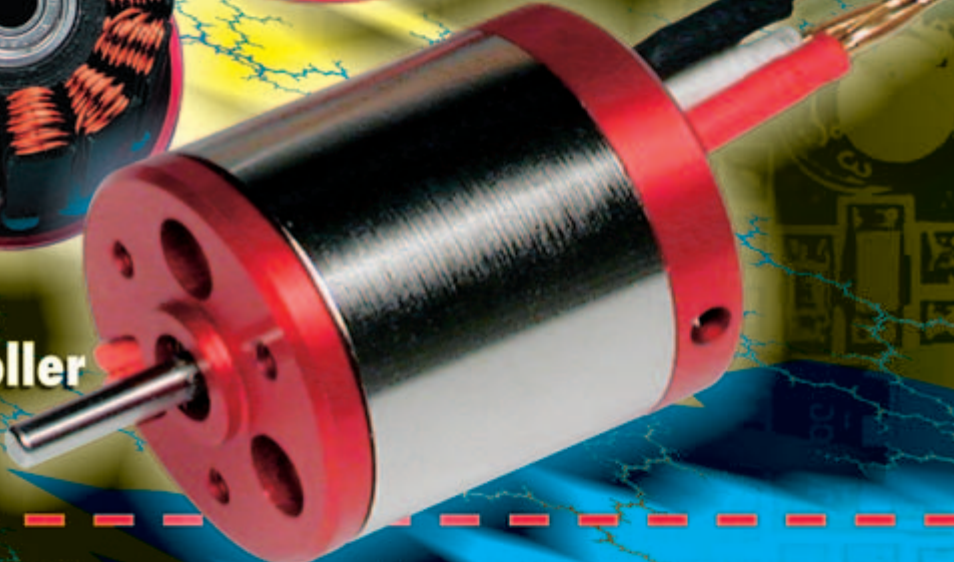
Practical:
- **Brushless Motor Controller (for R/C models)**

- **Turn a router into a webserver for less than £20**
- **Renesas R8C 16-bit micro starter kit for less than £15**

Design problems:

The class-D amplifier that failed to perform
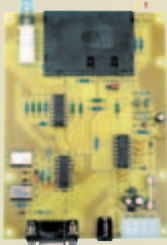
02

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
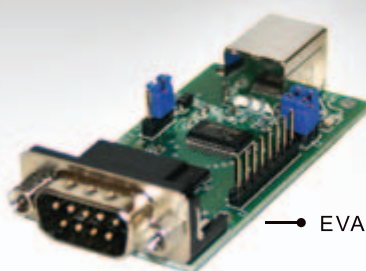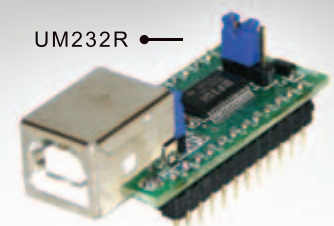
CHIPI

MM232R

UM232R

EVAL232R

BLOCK DIAGRAM
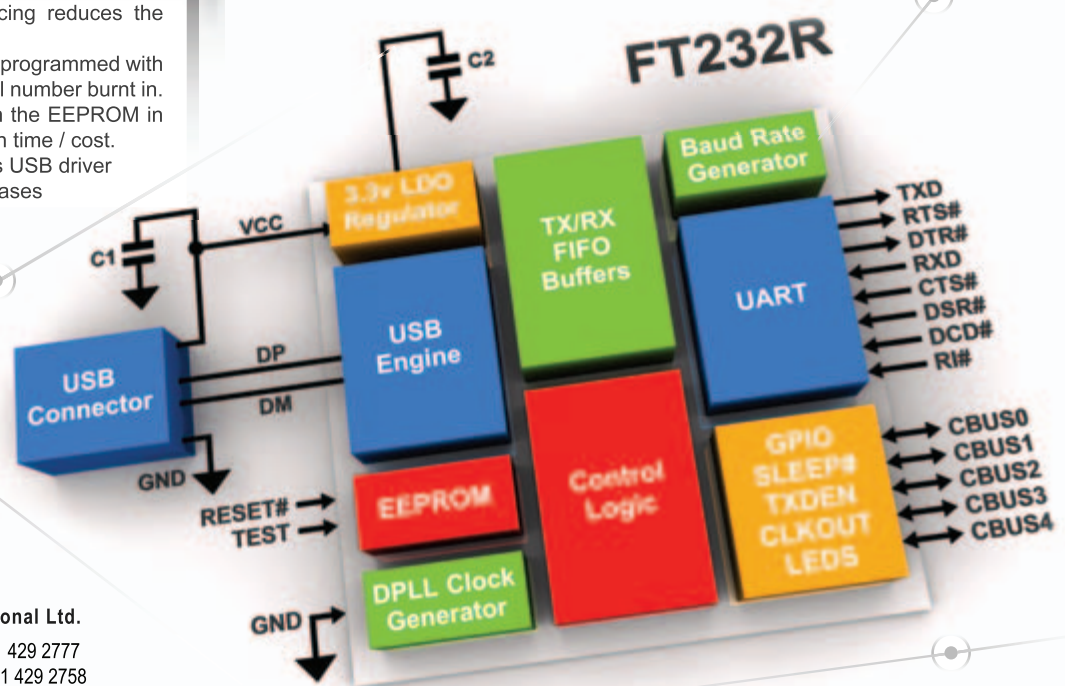
FT232R block diagram

w w w . f t d i c h i p . c o m

A 16-bit Microcontroller Starter Kit for under 10 pounds

With this issue we start selling our R8C/13 Starter Kit at a price you can't refuse: just £8.30 plus P&P. If ever you wanted to get your hands on a ready-made 16-bit microcontroller board with associated software tools on a CD-ROM now's the time to grab yourself a bargain. For the benefit of our readers we've been able to strike an exclusive deal with Renesas and their distributor Glyn for the distribution, at very low cost, of their R8C 16-bit microcontroller module. That's right, a module, so there's no SMDs to solder or parts lost to mum's vacuum cleaner. All you need to do is solder a normal size pinheader supplied with the kit. This, we're pretty confident, most of you will be able to pull off. Although supposedly we're testing your solder skills, the real reason the pinheader isn't on the modules is that it allows low-cost packaging to be used. You can start using your R8C microcontroller module straight away using the 'get-u-going' examples in this issue. Next month, we will take the project one step further by mounting the tiny R8C module on a motherboard that not only unleashes the full connectivity in terms of port lines etc, but also adds five or so add-on functions like USB and a power supply!

The module being available at low cost through our Readers Services and with several follow-up articles (including a 'C Programming' mini course) in the pipeline, our R8C project is expected to generate quite a bit of interest. As you read this, my colleagues Denis and Patrick in the website department will have created easy links on the home page to a special R8C section that takes you to the ordering system or to dedicated topics in our online Forum. There, we hope, users will start exchanging ideas and help each other in case of problems. With apologies to those already aware of it, our online Forum is open to anyone — 'write' access to Forum topics however is a privilege of those of you having subscribed (free of charge) to the E-weekly newsletter. My current estimate is that about 35 percent of buyers or subscribers to the magazine have already done so, which is encouraging to say the least.

Jan Buiting, Editor

22 Brushless Motor Controller

This article should appeal to enthusiasts using radio controlled scale models that include an electrical motor without permanent magnet brushes, usually called 'brushless motors'. These ultra-quiet motors require complex drive electronics and Elektor comes up with the goods.

34 Micro Motors
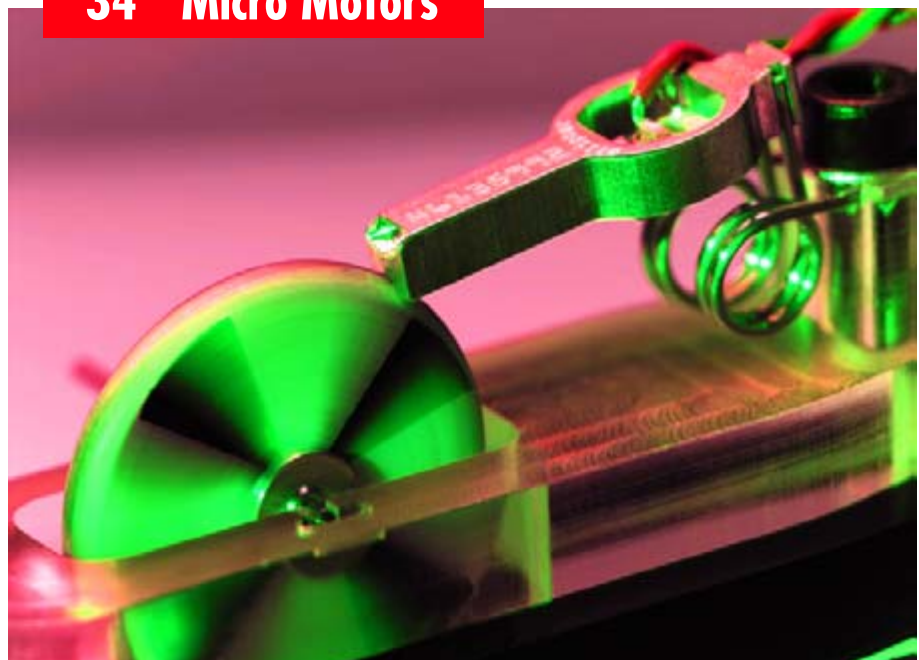
Piezoelectric actuators and motors are finding more and more applications. These drives feature excellent dynamics, accuracy down to nanometres and tiny physical dimensions. Nothing to stop the march of the miniature machines!

CONTENTS

38 A 16-bit Tom Thumb
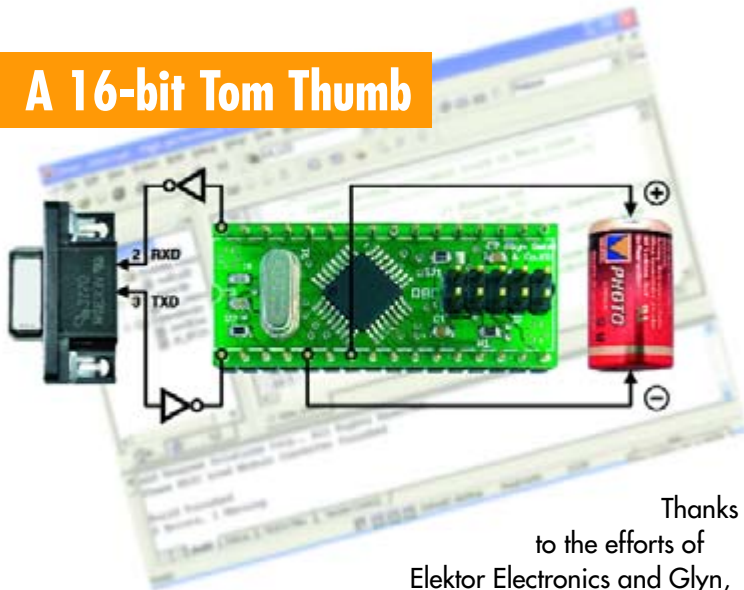
Thanks to the efforts of Elektor Electronics and Glyn, for the first time now a European electronics magazine supplies a complete microcontroller starter board and accompanying software CD-ROM at less than 10 pounds. We already introduced the Renesas R8C in the previous issue. Now it's time to start using it.

46 Inexpensive (Web) Server

Here's how to modify an £20 router into a network or web server. We do need to add some extra storage space and also show you how to add a USB port to an inexpensive router. Apart from providing the required memory expansion it also offers ways to implement many other applications.

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affordable CAN Bus to USB and RS232 interface solutions

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NASA Tech Briefs 2004
Products of the Year

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2 x 1MS/s Input Channels + waveform generator output. EasyScope & EasyLogger s/w included.

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Affordable CAN Bus Solutions

CANUSB is a very small dongle that plugs into any PC USB Port and gives an instant CAN connectivity. This means it can be treated by software as a standard COM Port (serial RS232 port) which eliminates the need for any extra drivers or by installing a direct driver DLL for faster communications and higher CAN bus loads. CAN232 is a very small dongle that plugs into any PC COM Port, or any other RS232 port in an embedded system and gives an instant CAN connectivity. This means it can be treated by software as a standard COM Port (serial RS232 port) which eliminates the need for any extra drivers. Sending and receiving can be done in standard ASCII format.

priced from £61.00 (CAN-232)

USB Instruments - PC Oscilloscopes & Logic Analyzers

Our range of PC Instruments may be budget priced but have a wealth of features normally only found in more expensive instrumentation. Our DS1M12 and PS40M10 oscilloscopes have sophisticated digital triggering including delayed timebase and come with our EasyScope oscilloscope / spectrum analyzer / voltage and frequency display application software and our EasyLogger data logging software. We also provide Windows DLLs and code examples for 3rd party software interfacing to our scopes.
Our ANT8 and ANT16 Logic Analyzers feature 8/16 capture channels of data at a blazing 500MS/S sample rate in a compact enclosure.

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1 to 16 port USB to Serial Adapters

With over 16 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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Web : http://www.easysync.co.uk
E-Mail: sales@easysync.co.uk

* Prices shown exclude carriage and VAT where applicable

2005 Cumulative Index

The Cumulative Index for Elektor Electronics year Volume 31 (2005) was not printed in the December 2005 issue to save pages for articles. The document has been duly produced however and may be downloaded free of charge from the December 2005 page of our website at www.elektor-electronics.co.uk. Select Magazine, then 2005, then December. Readers wishing to obtain a free copy on paper may contact our sales office at Elektor Electronics (Publishing), 1000 Great West Road, Brentford TW8 9HH, UK. Tel. (+44) (0)208 2614509.
(Editor)

Website news and announcements

A **new, upgraded server** has been installed at www.elektor-electronics.co.uk to handle the increasing amount of traffic generated by our website. We thank our customers for their patience waiting for responses from the old server, particularly between 15 November and 4 December 2005, and hope they have not been inconvenienced too much. The new server has been online since 5 December 2006 with good results.

In our online Forum (freely accessible to all readers!) a new topic folder has been created for the **SMD Reflow Oven** project from our January 2006 issue, which is generating great interest. We would certainly like to hear of your experiences in converting your own oven!

As of the January 2006 issue, 'Mailbox' can be downloaded **free of charge** as a pdf file. This may include material belonging with 'Rejektor' items that could not be fitted in the magazine.

Free Electronics CAD tools DVD (3)

Dear Editor — I purchased last month's issue (November 2004, Ed.) because of the review of PCB software. One package missing from the DVD is Winqcad (www.winq-cad.com) They have a huge user base in Canada and have reasonable transfer from Orcad, Cadstar and Eagle. Surprised it was missed! Great magazine!
Bernard Gill (Canada)

Well Bernard Microcad, the makers of Winqcad were duly contacted but unfortunately did not grant us permission to include their product on the 'Kaleidoscope' DVD. It looks like Winqcad missed an opportunity, not Elektor!

Free Electronics CAD tools DVD (4)

Dear Sir — Having been an ardent fan of your excellent magazine for a good many years now (I think about 28, anyway it was before Junior Computer), I cannot remember ever having been disappointed with any of your articles or features in the magazine, until now!
I have recently developed an interest in CAD and have been trying to get started, so when you advertised last month the free DVD with various E-CAD programs on it, I thought what an good way to evaluate and gain a little bit more knowledge on the subject, So I eagerly awaited the November 2005 issue (as with most issues really).

As your lead article suggested, I took the batteries out of the door bell, unplugged the phone, I had some cans of lager to hand, packed the wife of to the mother-in-law, gave the kids some money to go out with, then got down to some serious evaluation.
I inserted the DVD into the drive, then, with bated breath I waited for the DVD to load, but, as ever, at times like these, the ubiquitous computer fairy waved her magic wand and nothing happened, much to my disappointment.
I have tried the DVD on a friend's machine with exactly the same results, so it appears that the Gods are not with me this time, and I think they are trying to tell me something.
Keep up the excellent work, the E-blocks looks very promising, and I will be definitely looking further into them.
Martin (UK)

Our statistics show that 0.01376% of our readers actually attempted to run the DVD in a CD-ROM drive. Seriously, only five of about 100,000 DVDs produced for Elektor's international print run could be confirmed as defective. These were replaced free of charge by our Customer Services department. Nice try also those of you who claimed to have bought a November 2005 issue without the DVD secured to page 13, but also without proof of purchase of the magazine. Not forgetting those asking where they could download the entire DVD contents. We guess this is natural if you give away something for free.
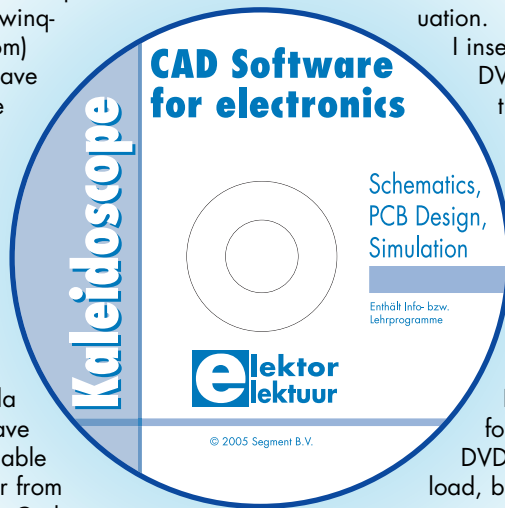
Battery backup for bike — help please (2)

Hi Jan — this is in response to Alan Bradley's call for help with his circuit (Mailbox, December 2005, Ed.). The 100 µF (in series with the diode) and the 10 µF condensers need a path to get rid of the negative potential built up at the junction: negative electrode to anode of diode. A 10-k resistor to common would be a suitable value.
I would also render the 100-µF unpolarized by adding a back to back other 100 µF as now there will be AC on the condenser plates, like the two left ones at the alternator connection (a dynamo supplies DC, I think).
It could have worked if the condenser started leaking. Alternatively it could also be solved by keeping the 100 µF as it is and placing a resistor in parallel on it, once again to create a path to get rid of some negative potential. Making the resistor adjustable could then set the threshold of the sensor.
George Brennet (UK)

Thanks for that George, the explanations look quite plausible but would have to be tested in practice. The full circuit diagram as sent in by Alan Bradley appeared in Mailbox, December 2005 issue. Other readers are invited to add their views on the problem, please.

Retronics on multimeters (1)

Dear Jan — your article on vintage analogue multimeters in the December 2005 issue. One of the explanations of

the popularity of the Simpson 260 multimeter (on Ebay, at least) must be that it's still being used in aircraft maintenance. In fact, a number of Boeing aircraft maintenance documents mention the use of the Simpson Model 260!

Christian Wendt (Germany)

Retronics on multimeters (2)

We thank Mr. Reznor of Solihull for sending us a copy of the Philips PM241 multimeter service documentation and user manual, as well as for confirming that the instrument was first sold in 1971.

The user manual confirmed our assumptions about the use of the strange 'I/0.4' pushbutton on the range switch of the PM241 and its successor model the PM2411.

Improved DECT battery charger

Dear Editor — I'd like to respond to your Summer Circuits item entitled 'Improved DECT Battery Charger'. Basically, your story is correct and it is desirable to reduce the charge current of NiCd batteries on permanent charging to levels even smaller than 0.1 C. So I decided to have a go at my own DECT set.

The charger with the set looks a bit different and consist of a current source built from a diode and a transistor, the latter supplying about 30 mA. The batteries in the phone are 280 mAh types. I reduced the current to about

18 mA (approx. 0.065 C) by increasing the value of the resistor in the current source. The result: flat batteries after about two weeks. It then occurred to me that the phone itself also draws current when placed in the charger pod. So, in my case, the manufacturer did manage to design a proper charger.

Nico de Vries (Netherlands)

A valid point Nico that should be taken into account when dimensioning the charge current. Thanks for letting us know.

Elektor Year Volume CD-ROM problems

Dear Jan — I am unfortunately unable to install the Elektor annual CD-ROM.
After running Setup, I get the error report:
16-bit Windows subsystem C:\winnt\system32\autoexec.nt System file unsuitable for ms dos and Microsoft applications.
Next, when I run EASETUP.EXE, something is being installed and I am informed that the installation is successful. However, when starting the Archive program I once again get the above error report telling me the system file is unsuitable. I am using Windows 2000 Professional. Can you help, please?

K. Johnson (UK)

We not only know the error report, we also have the solution to the problem.
From the directory 'c:\winnt\repair' copy the file 'autoexec.nt' and paste it into the 'winnt\system32' directory (i.e.,

Xmas Special edition (1)

Dear Editor — I have just received the December 2005 edition of *Elektor Electronics* magazine and the articles make, as usual, very interesting reading.
However, I am disappointed. Your previous December issues carried the Xmas Special 30 circuits and design ideas for the Xmas holidays. These are missing this year and I feel you have let us down. I hope to see them again in next year's Xmas edition.

Ken Barry (UK)

Xmas Special edition (2)

Dear Jan — what happened to the circuit supplement in the December issue?
I always looked forward to these idea-provoking small projects. I was disappointed to find the supplement missing from the December issue after 15 years with no explanation or statement that the feature had been suspended.
As a result of this, the magazine seemed a bit 'thin' for articles. I do not expect every issue to be full of articles or projects that are of interest to me, if that were so, I would not have been a subscriber since 1978.
Generally *Elektor* does very well to provide a varied mix of interesting and useful articles and projects, written by some excellent contributors and staff writers. So this letter is not intended as a criticism of the magazine, more as to observe that a feature has disappeared without a word of explanation after being enjoyed for so long. Please bring back our supplement !!

Pat Redway (UK)

Thanks Ken, Pat and other readers who wrote us on the same subject. There are no longer 30+

small circuits in the December issue because all 100+ we produce in a year have been included in the 'Summer Circuits' issue. At 144 pages the 2005 Summer Circuits edition was the thickest issue of Elektor Electronics ever printed. So, we have not let our readers down and in fact have again published more articles in a year volume than any of our competitors on newsstand distribution in the UK.
Starting in 1988 and ending in 2004 (and only in the English-language version of Elektor), 60-70 articles from our annual stock went into the July/August ('Summer Circuits') issue, and the remaining 30-35, into the December issue. Due to centralized production and simultaneous printing of all four-language editions of Elektor, in 2005 we changed this to 100+ articles in the July/August issue, thereby restoring an Elektor tradition in existence between 1975 (the year of our first issue) and 1987. The change was duly announced in the June 2005 magazine as well as in several news items on our website;, sorry if you missed these. I am pleased to say that we had an encouraging amount of positive feedback in response to the return of the 100+ items version of the 'Summer Circuits' issue. The change was rewarded with newsstand sales figures nearly 10% up as compared with the previous year.
Besides articles in good Christmas spirit, the December 2005 issue contains four major construction articles and three design tips which, I hope, have kept many readers busy over the Christmas holidays.

Quizz'Away – Solution to the December 2005 problem (p. 78, 'LEDs detect light')

Very few correct entries were received for this, the last, problem in the series. Einstein received the Nobel Prize for Physics for his research work on the photoelectrical effect, which was actually the subject of the December 2005 problem. For a current to be generated in an LED in response to illumination with visible light, one condition has to be fulfilled: the photon energy must be sufficient to overcome the so-called 'bandgap'. No measurable current is generated if insufficient energy is presented. The number of electrons 'freed' is proportional to the light current generated. The energy W held by the photons is related to the wavelength λ as in

$$W = h\,c\,/\,\lambda$$
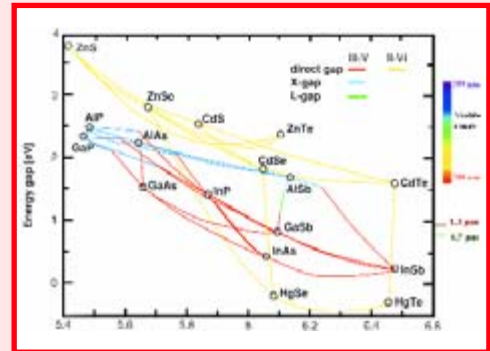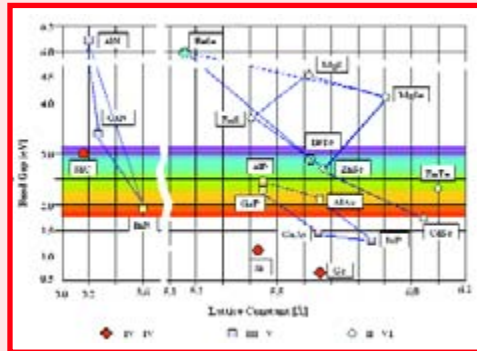
Where h = 6.626·10^{-34} joule second, i.e. Planck's constant and c = 2.997·10^8 m/s, i.e. the light speed in vacuum. The bandgap energy is usually expressed in electronvolts, where 1 eV equals the energy acquired by an electron when passing freely through a potential difference of 1 volt.
As an electron has a charge, e, of e = 1.602·10^{-19} joule second, we get 1 eV =

1.602·10^{-19} joule second. Green LEDs may be produced from, for example, gallium-phosphide (GaP). In that case the bandgap energy equals 2.19 eV, corresponding to a wavelength of λ = 565 nm. Because a laser pointer transmits fairly narrow-band light at 650 nm, its photons have insufficient energy to generate current in a green LED. The same applies to a yellow LED, so

the two missing entries in the table (last question) should read I = 0 nA. The value is confirmed by practical measurements. A useful overview of semiconductor materials and their bandgap energy values may be found at

**www.tf.uni-kiel.de/matwis/
amat/semi_en/kap_5/
backbone/r5_1_4.html**

---

replace the existing file). Next, make the file read-only to prevent it being erased when the PC is switched off and on again.

The problem seems to occur frequently and postings in internet forums seem to indicate that the file is often subject to damage by viruses and Trojans.

E-blocks and the CAN bus
Dear Editor — I happened to read a bit about E-blocks in the latest Elektor issue. I am interested in a CAN bus interface for a different project.

Where do I find a description of the SPI bus and the commands necessary to communicate via the interface? As I understand it, E-blocks can be ordered through your Readers Services department.
Peter Blackburn

The datasheets supplied with the E-blocks CAN bus module include a short description of the basic CAN operation as well as pointers to further information available from the Matrix Multimedia website.
There are also references to datasheets of the CAN controllers used on this board. These include:
• AN713 – Controller Area Network (CAN) Basics
• AN215 – A Simple CAN Node
• MCP2515 datasheets

An article on the E-blocks CAN module is printed in this issue. For background articles on the

CAN bus and several projects published in pasty issues of Elektor, simply type 'Controller Area Network' or 'CAN' in the search box on our website homepage. All articles returned by the search engine can be downloaded individually.

Corrections & Updates

SC Analyser 2005
April 2005, p. 34, 030451-1
The parts list states a wrong enclosure; this should be a Hammond type 1593YBK.

Pocket-sized DVB-T receiver design with USB 2.0

Micronas today announced immediate availability of Mic-StickD, a production-ready reference design which enables watching and controlling live DVB-T broadcasts on any USB 2.0-equipped desktop and notebook PC. The design is built around best-in-class components to achieve the required reception performance: a Micronas DRX 3975D COFDM (coded orthogonal frequency division multiplexing) demodulator, a Microtune® MicroTuner™ MT2060 digital TV tuner and a Cypress EZ-USB FX2LP™ controller. OEMs can put this reference design into production immediately.

DRX 3975D is the first COFDM demodulator to substantially exceed all requirements of the NorDig-Unified v1.0.2 Receiver Specification. This allows a single design for MicStickD to be compatible with all DVB-T reception standards worldwide. Mic-StickD enables you to freely roam across the country or throughout your home.

DRX 3975D uses advanced digital filtering techniques, in combination with a powerful A/D converter and PLL configuration,

to ensure a crisp viewing experience even under challenging adjacent channel conditions. Thus, a simple, non-switchable SAW filter is sufficient. A unique pre-SAW IF sense input enables fully autonomous and stable RF-AGC control of the MT2060 eliminating the need for additional RF-AGC circuitry. DRX 3975D implements a progressive digital algorithm in the channel estimator, leading to exceptional results in multipath and dynamic echo conditions. This is important for Single Frequency Networks and

indoor reception.

The Microtune MT2060 single-chip tuner is engineered to combine low power consumption with excellent radio frequency (RF) performance. Its single 16-MHz crystal is sufficient to provide the clock signal for both the MT2060 and DRX 3975D. The Cypress EZ-USB FX2LP controller easily handles the high data rate of digital television.

All of these features combine to deliver top-quality TV images from a USB device measuring only 2.2 cm by 6.2 cm (0.9" by 2.5").

The MicStickD tuner and capture

driver is compliant with the Microsoft Broadcast Driver Architecture (BDA) standard for Windows. This ensures optimum performance and compatibility with PC software applications, such as CyberLink PowerCinema™. There is no need for an external power supply, because MicStickD fully complies with the USB 2.0 bus-powered specification.

The MicStickD reference design comes complete with schematics, Gerber files, Protel design files, a Bill-of-Materials (BOM) and driver software.

The BOM has been carefully optimized for low manufacturing cost. MicStickD can be built for around 20 USD in quantities of 100K. OEMs can add an enclosure design of their choosing and go straight to production. This royalty-free MicStickD DVB-T USB design kit is available now.

Product information on the DRX 3975D COFDM demodulator may be found at

www.micronas.com/products/ by_function/drx_397yd/ product_information/index.html

www.micronas.com

(067016-1)

Veronex customisation services

The Veronex family of small plastic instrument cases from Vero Electronics, a division of APW, is extremely versatile, suitable for a wide variety of OEM, consumer electronics, electrical and instrumentation applications. Available as standard in three colours, four plan sizes, nine heights, plastic and aluminium front panels and three different configurations. The extensive range of accessories and a short lead-time full customisation service makes it one of the most adaptable small enclosures on the market.

As the original manufacturer, VERO Electronics is fully equipped with the required systems and equipment to be able

to offer a rapid response prototyping service, short run pre-production quantities and volume manufacturing of modified and customised versions. The Quick Customisation Service is simplicity itself: AutoCAD files or engineering drawings are freely available to customers, who simply mark them up with the required modifications and return them to receive a firm quotation.

All sizes can be supplied with an internal copper-silver painted coating to provide EMC capability; typical attenuations are better than 95 dB at 1 MHz, falling to 46dB at 1 GHz. All sizes can be moulded in many different materials and colours; milling, punching, drilling and silk screening of both the enclosure body and end panels is also available. IR-transparent end panels, battery compartments and holders, belt clips, LCD viewing windows can all be supplied.

Vero Electronics, Electron Way, Chandlers Ford, Hants SO53 4ZR. Tel: + 44 (0)23 8026 6300, fax:+ 44 (0)23 8026 5126. www.vero-electronics.com

(067016-2)

USB UART bridge has built-in security dongle

Future Technology Devices International Ltd (FTDI) have unveiled the FT232R – the next generation of their popular USB- UART Bridge family. This highly integrated device includes onboard EEPROM, master clock generator, 3.3 V LDO regulator, reset generator and USB termination resistors. Only two external decoupling capacitors are required for a minimal configuration. In addition to the full set of modem control signals, the device features five IO pins which can be configured in EEPROM to have several functions including providing a output clock which can be used to drive an external MCU or FPGA.

Each device has a unique number (the FTDIChip-ID™) burnt into it at manufacturing time which cannot be altered by the end user. Though an encryption scheme, this feature can be used by product designers to protect their application software from being copied. FT232R features a wide range of royalty-free FTDI developed drivers for 32 and 64 bit operating systems including Windows, CE, Linux and MAC-OS. The FT232R comes in both standard SSOP-28 and miniature QFN-32 5mm x 5mm package options. A version of the device with a parallel FIFO interface (p/n FT245R) is also available.

**Future Technology Devices International Ltd.,
373 Scotland Street,
Glasgow G5 8QB.
Tel. (+44) (0)141 429 2777,
fax (+44) (0)141 429 2758.
sales1@ftdichip.com.
www.ftdichip.com**

(067016-3)

Game console development doesn't have to be a War Of The Worlds

Nurve Networks LLC's new XGameStation Pico Edition educational game console development kit is now shipping worldwide. The Pico Edition is a follow up to the previously released pre-assembled XGameStation Micro Edition. The Pico Edition is for students and hobbyists that actually want to build the system by hand from a kit of parts. The Pico Edition comes as a kit complete with a solderless breadboard and all the components to build an entire working game console in about 1-2 hours.

Video games generate billions of dollars in revenue each year and game programming books occupy rows of bookstore shelf space. Video game development has made its way into college curriculums and entire game programming universities have emerged. But video games run on advanced hardware, the design of which is a black art that few understand.

For more than a decade, books by Computer Scientist and bestselling game development author Andre LaMothe (his latest title "Tricks of the 3D Game Programming Gurus") have taught generations of game developers to create today's cutting-edge video games. Now, his focus is changing from video game software to video game hardware with the unveiling of the XGameStation Micro and Pico Editions, a revolutionary new way to learn about the hardware that goes into building game consoles themselves.
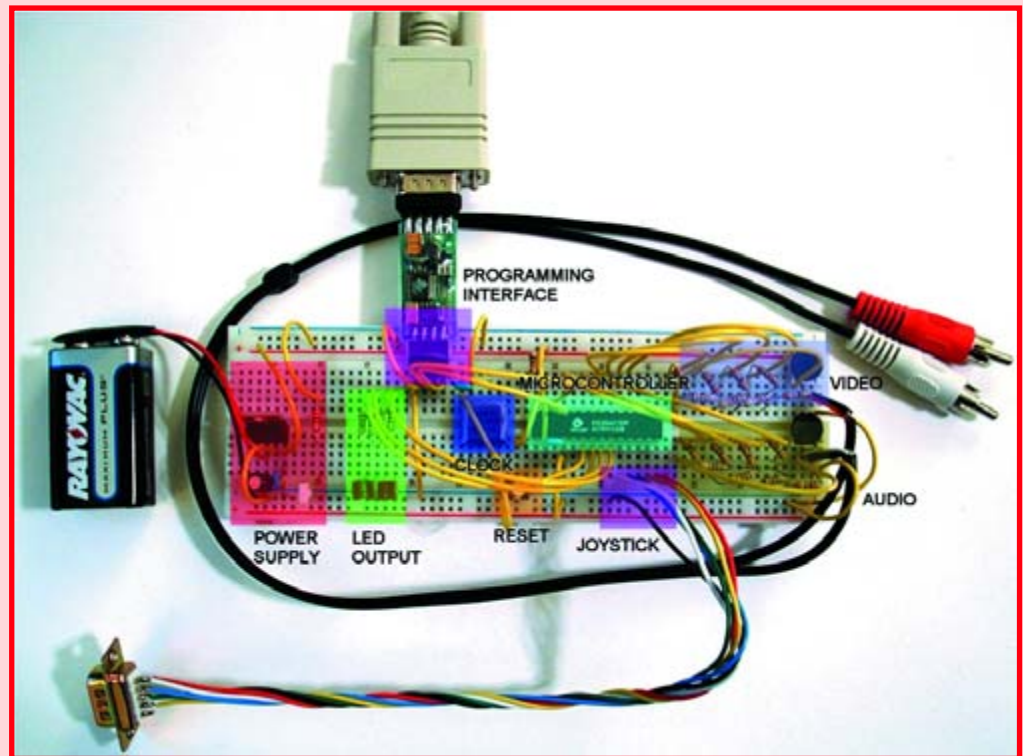
The XGameStation Pico Edition (XGS PE) is a complete game development kit inspired by classic systems such as the Atari 2600, 800, Apple II, C64 and Nintendo Entertainment System. The XGS PE kit includes a kit complete with all the parts, necessary cables, an eBook written by Andre LaMothe on the design and programming of the XGS Pico Edition along with all the software necessary to create your own games, demos, and experiments.

Armed with a complete understanding of how the system was built and operates, users then create their own games or play games made by their peers. The online community at www.xgamestation.com completes the system's appeal, providing a place for XGameStation developers to share ideas, software and even discuss hardware modifications.

The system plugs into any NTSC TV and supports vintage Atari 2600 controllers. XGameStation Pico Edition's games and applications are stored on the internal processor's Flash memory, allowing users to develop and download their games from a PC using the accompanying tools. The official Website for the XGameStation is www.xgamestation.com/?refid=pr, where you will find media, downloads, demos, and more information on purchasing the XGS Pico and Micro Editions.

(067016-4)

New 16-bit XAP4 processor core

Cambridge Consultants has released a new 16-bit RISC microprocessor IP core, which it will feature at the Design & Reuse IP-SoC conference in Grenoble, France on December 7th and 8th 2005.

The all-new 16-bit XAP4 features a modern, high-performance RISC architecture with low gate count, low power consumption and high code density. It is optimized for use in cost and performance sensitive ASIC designs and is available for evaluation now. On a 0.18 micron CMOS fabrication process, XAP4 can deliver up to 63 Dhrystone MIPS at a clock frequency of 117 MHz. This benchmark performance of 0.54 MIPS/MHz is a 50% improvement over Cambridge Consultants' previous 16-bit processor, XAP2, which has been manufactured in hundreds of millions by licensees such as CSR, and in ZigBee radios, automotive devices and low-power industrial and medical sensors.

The XAP4 has both 16-bit data and address buses and is capable of running programs up to 64 kBytes. The first implementation of the processor has a two-stage pipelined Von Neumann architecture. It is delivered to licensees as a soft IP core in Verilog RTL that can be synthesized in as few as 12k gates for ASICs where die size and power consumption must be as small as possible. Cambridge Consultants has already delivered XAP4 to one licensee and is in discussion with other prospective customers at present.

The 16-bit XAP4 is the latest addition to Cambridge Consultants' microprocessor core line-up. There is also the 32-bit XAP3 for more demanding applications, and in development is the XAP5 that also uses 16-bit data but extends the address bus to 24-bits, providing support for larger program sizes up to 16 Mbytes. All these processor cores include Cambridge Consultants' SIF debug logic, which provides full control over the processor and access to its debug registers, together with non-invasive access to any part of the processor's memory map for data acquisition while a system is running.

The architecture and design of the XAP3, XAP4 and XAP5 processors was conceived at Cambridge Consultants to fulfil the requirements of modern ASIC-based systems running code written by different programmers including real-time operating systems. All the processors include hardware support for privileged operating system modes where code running in user mode cannot corrupt supervisor or interrupt code. Code is position independent and there is also support for unaligned data access, making programs easy to port and quick to run. Most programs will be written in C and the processors feature direct support for many of the language constructs, which results in higher code density. There is hardware support for rapid context switching, for example, when interrupts occur, and there are multi-cycle instructions to speed up multiply, divide and block copy operations.
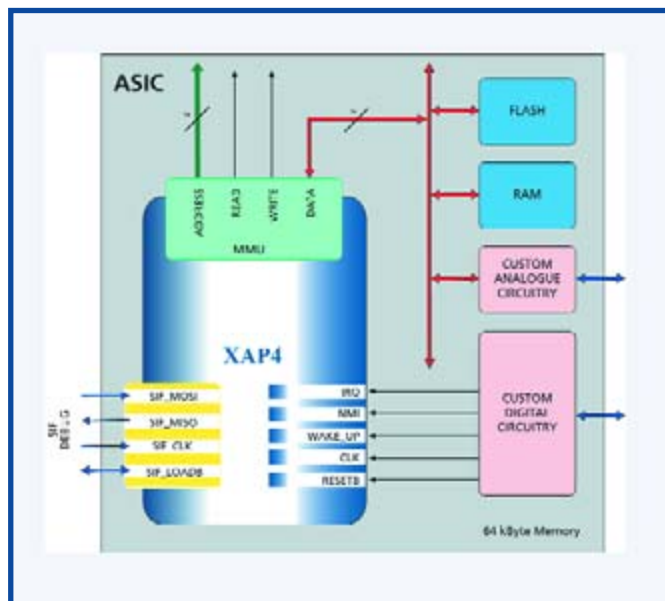
All of Cambridge Consultants' XAP microprocessors are supported by its xIDE integrated software development and debug environment, which includes a programmer's editor, assembler, debug interface, instruction set simulator, project build manager and GCC compiler, which provides the path for programming in C++. xIDE is quick and easy to install and use on Windows PCs, with Linux/Unix and Mac OS versions also available. xIDE can be customized to add features specific to a licensee's ASIC or ASSP, and licensees can brand and deliver xIDE to their developers.

Other advanced technical features of the XAP3, XAP4 and XAP5 include: hardware support for operation as a slave processor when a master processor downloads a code image and bootstraps the XAP, support for multi-processor debug over SIF and architectures for combining XAP with Cambridge Consultants' APE signal processing engine, which offers a dynamic data path routing capability. Details of the cores can be found at www.CambridgeConsultants.com / ASIC, including trial downloads of the xIDE software tools.

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(067016-6)

Advertisement

SOT-23 Li-ion / Li-polymer battery charger

Microchip announces the expansion of its power-management family with the MCP73831 battery charger – a fully-integrated, single-cell, Li-Ion/Li-Polymer charge-management controller. Equipped with a pass transistor, current sensing and reverse-discharge protection, the MCP73831 charger reduces the number of components needed for battery-charger designs. Another key feature of the MCP73831 charger is its simple status output that directly drives single or multi-colour light-emitting diodes (LEDs).

Its highly accurate, pre-set voltage regulation (maximum up to 0.75 percent) results in more fully charged batteries and extended battery life. In addition, the device's charge current is user-programmable, enabling customized charging currents for specific applications. The controller also features on-chip thermal regulation that decreases charge current in over temperature situations, thus preventing damage to the device. The charger also supports multiple regulation voltage outputs, making it an effective charging solution for different types of Lithium battery technology.

The device's 5-pin SOT-23 or 8-pin, 2 mm x 3 mm, thermally efficient DFN package enables smaller, smarter charger designs for a variety of portable devices such as Bluetooth® headsets, MP3 players and digital cameras. The thermal efficiency of the DFN package also allows high charging currents of up to 500 mA for faster charging.

Microchip offers the MCP73831EV Evaluation Board for $45 to support the development of battery charger applications using the new MCP73831 charger. This board is available today at **http://buy.microchip.com/.**

The MCP73831 is available today for sampling and volume production. For additional information on the product see www.microchip.com/MCP73831

(067016-5)

SmartProg2 now with USB

The growing popularity of notebook PCs and the absence of the parallel interface (LPT port) even on desktop PCs is the reason for the gradual extension of the portfolio of Elnec programmers with types connectable to a PC through the USB port.

The first such Elnec programmer with the USB interface was BeeProg. SmartProg2 comes as the second one. Thousands of sold SmartProgs were the argument for a modification of the type, to make it connectable to a PC through the USB port instead of the LPT port. The basis of SmartProg2's hardware is a 40-pin versatile pindriver and freely programmable voltage generators, as well as the limitation of the logical high level, which allow to support low-voltage (as well as true LV) chips, from 2 V up. All supported chips with up to 40 pins are programmed in the base socket. The traditional diagnostic POD (for self-testing) is an ELNEC standard.

The quality hardware is complemented by top software, which, as a standard, supports all MS Windows operating systems (from WIN.95 to WIN.XP). The latest version of the software is available on our website (www.elnec.com), free of charge, of course. SmartProg2 supports more than 10500 programmable circuits (February 2005) and their number is constantly growing.

SmartProg2 is controlled by a status automat, based on a powerful FPGA circuit, and it supports communication with a PC through the full-speed USB 2.0 interface, so the programming of circuits is very fast. Its reliability is enhanced by the classic ELNEC-designed metal casing. The dust cover of the ZIF socket, supplied as a standard, and a rubber pad under the socket's lever, protecting the programmer's surface against damage, speak about the sense of detail. SmartProg2's target segment is the customers who require a versatile programmer as well as those who find BeeProg too powerful and therefore unnecessarily costly. 'In circuit' programming through the ISP connector may therefore be the decisive argument for SmartProg2 becoming your favourite.

More information at:
www.elnec.sk

(067016-7)

The Quiet Revolution
Using electronics to make the (almost) ideal DC motor

Ludwig Retzbach
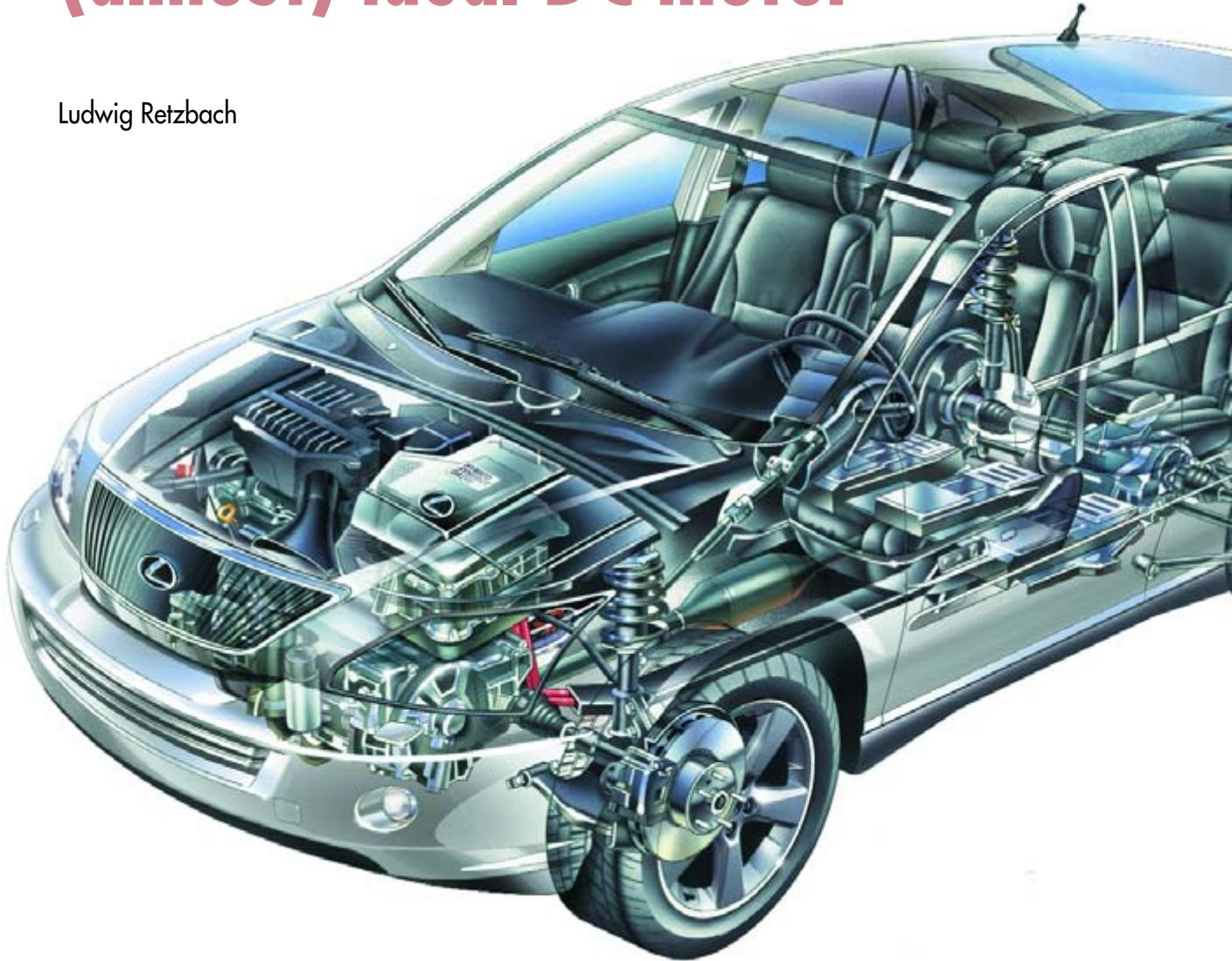
Electric motors are impressively simple and efficient. Whereas even the most modern diesel engine might have an efficiency of no more than 45 %, a modern DC motor can achieve a figure as high as 98 %. This is accompanied by extremely high torque, excellent power-to-weight ratio, good reliability and comparatively low cost. Following extraordinary developments in the field of electric model aircraft, the special qualities of DC motors have also led to their increasing use in hybrid vehicles. Unfortunately, the perfect mobile power source still needs to be invented before the steam-engine-inspired internal combustion engine can finally be consigned to the museum.

When efficiency figures rise to within a few percent of the magical 100 % value, minds will no doubt fill with doubts and thoughts of perpetual motion machines. But there is no need for concern: here physics is on our side. And it will not come as a surprise that the automotive industry is also turning to the electric motor with hybrid technology. Indeed, the electric motor has already made more progress than many realise: already the first race has been won by an electrically-powered vehicle. A modern vehicle, although not usually electrically-powered, will nevertheless have a starter, steering, cooling system, electric windows, electric mirrors, powered seat adjustments, ventilation and suspension control, all driven by electric motors. This list is far from complete: a fully-equipped luxury car will have well over a hundred invisible DC-powered helping hands, driving demand for greater efficiency and lower weight. Although in a comparatively less advanced state of development, the situation has been similar in model aircraft technology for some time. The might of the DC motor is pitted against the force of gravity in electric aircraft under F5B competition rules, where a two kilogram model aircraft can be catapulted vertically into the air at 80 metres per second. The power consumption of these motors, which have a mass of around 300 grams, can be nearly four kilowatts. Although some might dismiss these hobby activities as frivolous, they have in fact acted as a pacemaker for other, more 'down to earth' applications. Any DIY fan will appreciate the increased productivity that comes from having a convenient and light cordless screwdriver: a benefit of powerful and low-weight motor and battery technology.

What it's all about

The electric motor is a transducer which converts electric power (P_{in}), the product of voltage (U) and current (I), into mechanical power (P_{out}), which can be calculated by multiplying angular velocity (ω) by torque (τ). The efficiency (η) is calculated as the ratio between the output power and the input power. Power loss is the difference between the input power and the output power (**Figure 1**); this power is not strictly 'lost', but rather converted into heat. This dissipated heat warms the internals of the motor, which reduces its efficiency further as the resistance of the copper increases. Ultimately this can lead to overload and thermal failure: with temperature sensitive magnetic materials this can occur at between 120 °C and 150 °C. Good efficiency is of fundamental importance to electric motors, not just in the interest of better use of energy, but also in the interest of longer operating life. Two motors of equal size, one with an efficiency of 80 % and one with an efficiency of 90 %, although differing in efficiency by 'only' 10 %, differ in power dissipation by 50 %. The maximum power that can be converted by an electric motor is also chiefly dependent on its efficiency. Forced cooling systems, such as built-in fans, can of course be added, but these make the motor more complicated. They also consume power even when they are not actually needed, such as under
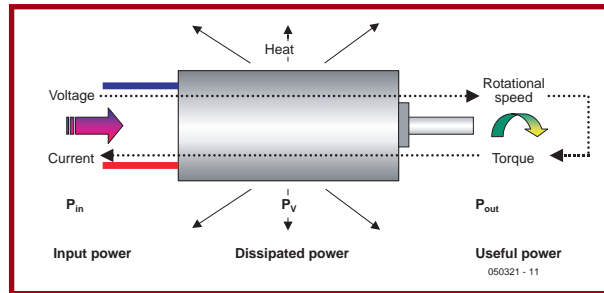
Figure 1.
The electric motor is a very effective converter of power.

low load and correspondingly high rotational speed. Another characteristic of modern motors is that achieving high rotational speeds (greater than 50,000 rpm) no longer presents an obstacle. In the majority of applications electric motors should be able to produce enough torque, reducing the need for gearing even to the point where direct drive using a hub-mounted motor is feasible. Of course, a high current is required to achieve a high power output, which can be expensive, especially when using batteries. To achieve the same torque with lower current, the number of turns in the motor windings can be suitably increased; this has the side-effect of increasing the resistance of the windings. In either case, the power dissipation in the windings must be borne in mind. The power dissipation depends on the current and the resistance: $P = I^2R$. The shape of the windings is also important. The available space must be filled as completely as possible ('high fill factor': see **Figure 2**) and as much of the copper as possible should move within the magnetic flux: the ends of the windings contribute to power losses but not to torque.

It is difficult to achieve high torque and high efficiency simultaneously, but there are a few techniques available to try to get the best of both worlds. An example is the use of a strong magnetic field. If permanent magnets are used, then the main question is one of material cost. Modern DC motors use neodymium (NdFeB) magnets, which have up to ten times the energy product ($B \times H$) of normal ferrite (SrFe) magnets. This increases torque and reduces the specific rotational speed (n_{spec}). Neodymium magnets can achieve remanence values of up to 1300 millitesla (mT). Unfortunately they are more temperature sensitive: for higher thermal robustness cobalt-samarium magnets (for example SmCo5 alloy) can be used, although these offer a remanence of 'only' up to about 1000 mT (**Figure 3**).

Figure 2.
A high fill factor is important: here there is some room for improvement!
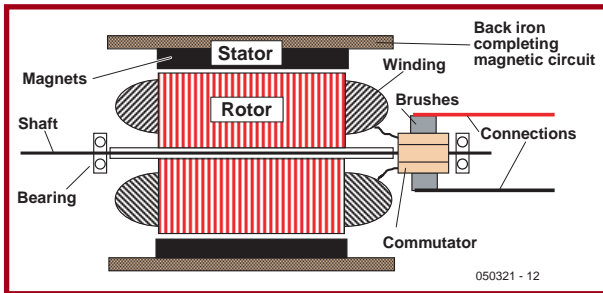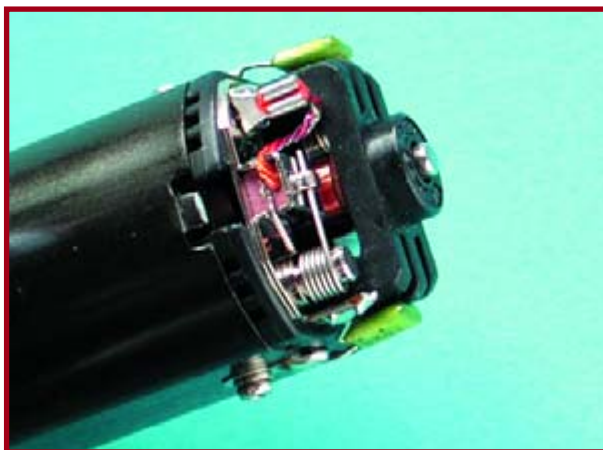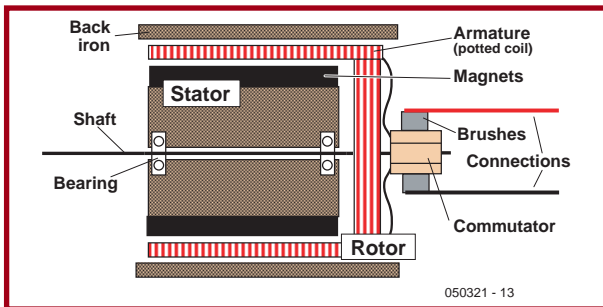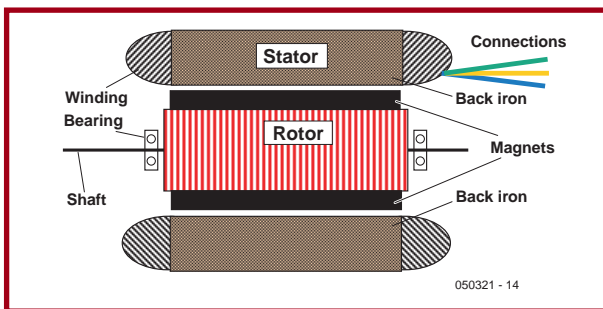
A powerful magnet is only half the battle. Like an electric circuit, the magnetic circuit must be short and of adequately large cross section (low 'magnetic impedance'). This is best achieved using a large amount of iron, which is also, unfortunately, heavy and responsible for further losses. When an iron core (which in conventional motors also carries the windings) rotates in a magnetic field there are iron losses which comprise losses due to hysteresis and losses due to eddy currents, and which are speed dependent. It is not possible to prevent these losses, and so the efficiency of the motor decreases with increasing speed. To reduce the losses as far as possible, motor manufacturers use high-quality iron (a 'soft magnet') and a large number of segments. Iron cores are never solid, but divided lengthwise into as many layers as possible, isolated from one another and thus cutting the path of eddy currents. Eddy currents arise not only in the core but also in all other electrically-conducting parts of the motor, including the magnet and the windings. These are reduced by the rather involved technique of segmenting the magnet and making the windings from a number of fine parallel wires or a braid rather than a single solid conductor. The desire to avoid iron core losses has prompted the invention of iron-free motors, but these do not exactly offer high levels of torque. The ideal motor, then, has yet to be invented: we must be content with selecting a suitable motor depending on the requirements of each application.

Classical designs

In numerical terms the dominant technology is the iron core motor (**Figure 4**). The rotor has at least three coil segments, which suffice for most low-voltage applications. High operating speeds require a balanced epoxy-potted rotor. Around it, separated by an air gap of a few tenths of a millimetre, is the stator comprising a system of permanent magnets. The motor housing completes the magnetic circuit (like a return wire in an electrical circuit). The coil connections run to the individual commutator segments, from where the current flows via sliding brushes (generally made of copper-loaded graphite, also called 'carbon') to the motor connections. The brush arrangement is the part most prone to wear and failure. Its size reflects the power of the
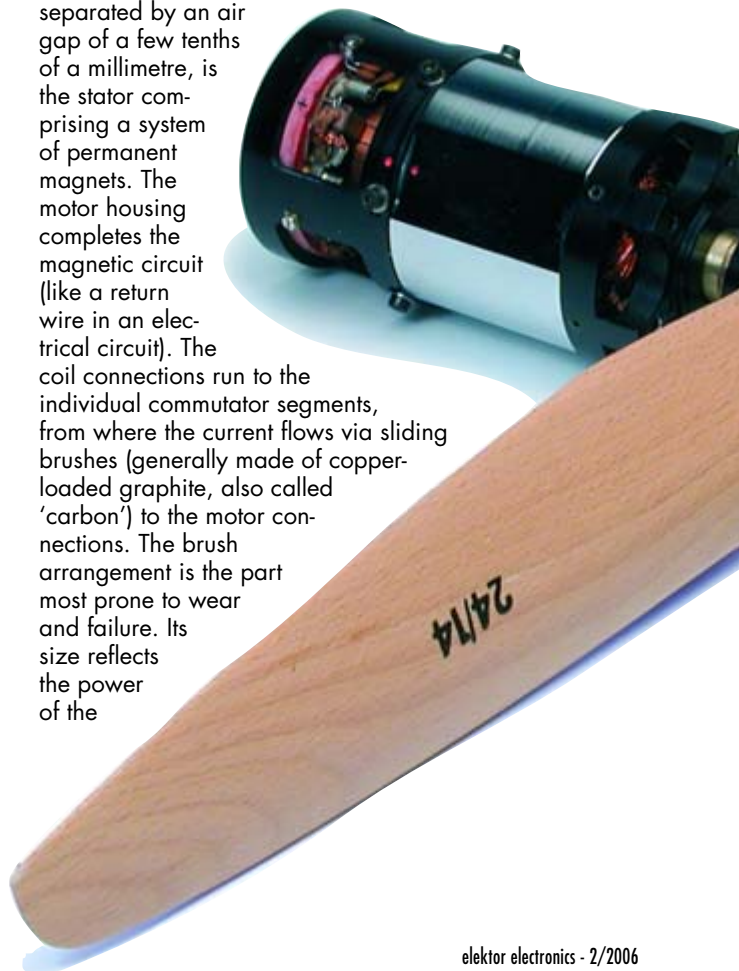
motor: in high-current motors the commutator (also known as the 'collector') is large and the wide brushes exert a high pressure in order to minimise voltage drop. The whole system looks, and behaves, like a shoe brake. Motors of this type require a high no-load current just to overcome the braking torque. The motor operates rather more economically at higher load, when the external torque is several times greater than the internal torque. Conversely, smaller brushes exerting a lesser force can only carry low currents if wear is to be kept within reasonable limits, which considerably restricts the range of possible applications of these motors. A further disadvantage is the radio-frequency interference produced by the commutator, which increases wear and entails the use suppression measures (**Figure 5**).

More sophisticated are the so-called 'ironless core' motors (**Figure 6**). Here an iron-free armature (generally a self-supporting coil potted with fibreglass cloth) rotates around a central magnet. The motor enclosure completes the magnetic circuit. Since there is no iron rotating in the field, iron losses are negligible and efficiencies of over 90 % are possible. These motors also offer relatively low torque since the magnetic flux has to span two air gaps and the thickness of the coil. Ironless core motors are generally powered via fine precious-metal brushes. Their advantage is their high efficiency (albeit at low power) and in particular the low inertia of the rotor. They are therefore suitable where rapid response is required with continuously changing speed and direction of rotation.

Silicon replaces carbon

The wear and losses entailed by the use of a commutator are not the only disadvantages of a conventional motor. Since it is a purely mechanical construction, the manufacturer has rather limited choices regarding current management. Things are rather different when we introduce modern electronics into the picture (see the text box and the brushless motor controller project, elsewhere in this issue). Of the two halves of the magnetic system it is now not necessarily the electrical part, i.e. the coil, that has to turn. In electronically- commutated, and therefore brushless (or sometimes 'BL') motors, it is the magnet that turns (**Figure 7**). This gives a smoother rotation than can be achieved using copper coils and speed stability is also improved, now depending only on the quality of the bearings, which are the only remaining mechanical parts prone to wear. The first brushless motors delivered power at very high speeds, meaning that a planetary gearbox needed to be attached. The motor itself is of simple construction: all that is involved is a cylindrical central magnet with three potted coils around it and a laminated iron enclosure to complete the magnetic circuit (**Figure 8**). Since the ends of the windings are relatively large in this design of motor, the devices are considerably longer
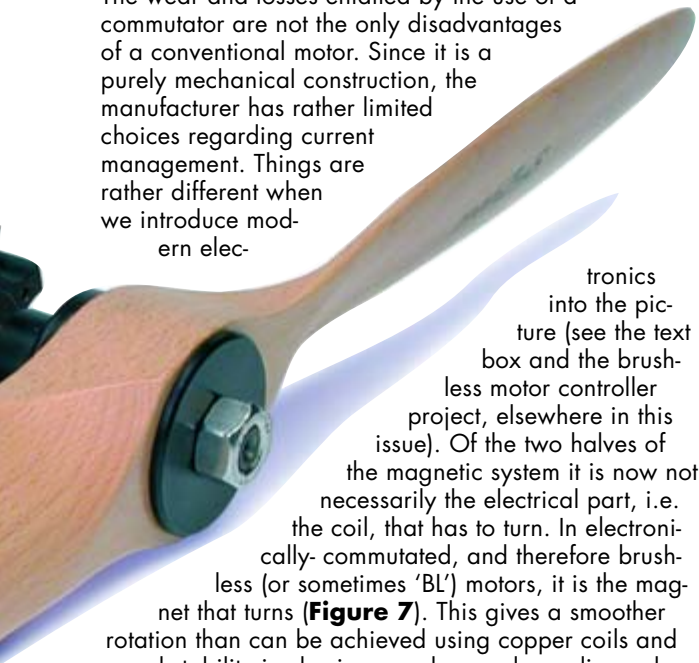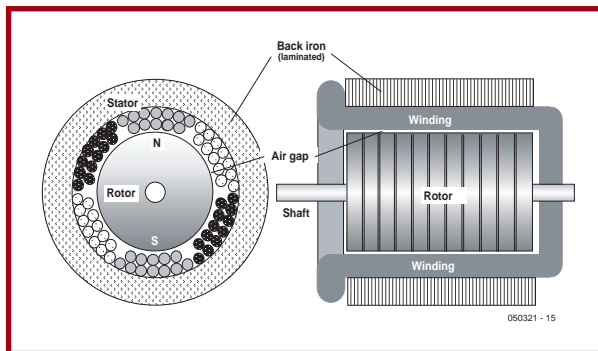
Figure 8.
Construction of a two-pole motor with air-gap winding.
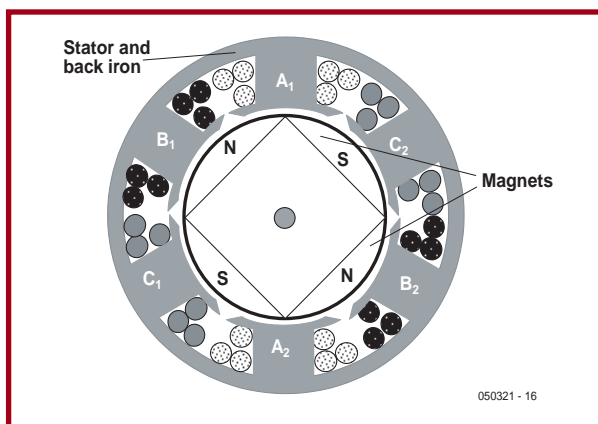
Figure 9.
Diagram of a slot-wound four-pole motor.

Figure 10.
Pseudo-iron-free 'Tango' motor with a six-pole rotor.
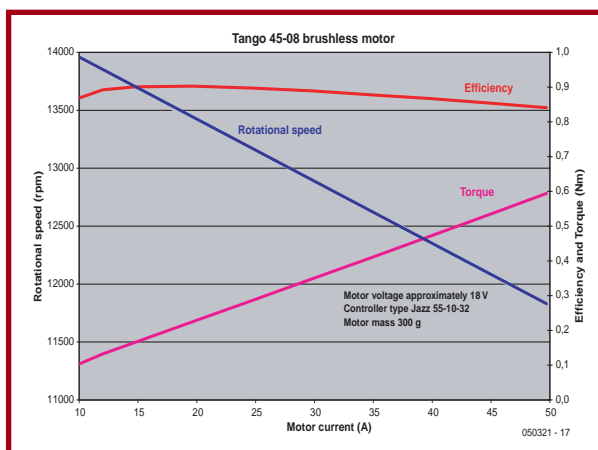
Figure 11.
The speed, torque and efficiency of the motor of Figure 10 depend on the motor current.
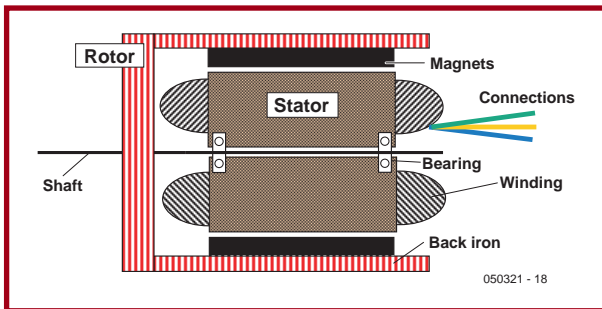
than their diameter. This gives improved efficiency (greater than 90 %) and power-to-weight ratio.

More poles

Greater torque is of course desirable. One tried and tested method is to increase the number of magnet poles: in conventional technology (using brushes) this was simply too complicated to achieve. A four-pole motor (**Figure 9**) has a magnet pole every 90 degrees, alternating north and south. This functions as if there were two motors in one enclosure. This halves the speed of the motor, as one transition from north to south and back corresponds to only half a revolution. The torque, however, is multiplied by four. Sometimes we speak of an 'electrical 2:1 reduction gearing'.

This idea can be taken further: to six, eight or even ten poles distributed around the rotor, with a corresponding gearing-down effect. The paths of the magnetic flux are also shorter, running from a north pole to an adjacent,

rather than an opposite, south pole. The enclosure completing the magnetic circuit can then be made thinner, thus reducing the total weight of the motor.

An interesting development in this direction is the 'Tango' modellers' motor from Kontronik. The 6-pole rotor (**Figure 10**) is surrounded by an iron-free self-supporting coil as stator. This is enclosed in a thin-walled iron cylinder which completes the magnetic circuit. The novel feature is that this cylinder is mechanically linked to the rotor and turns with it. There is thus no relative motion between the magnetic field and the iron, minimising speed-dependent losses. This is a brushless variation on the ironless core motor which, thanks to the use of six poles, offers formidable torque (see **Figure 11**).

External rotors

Of course there are limits to the number of poles that can be used. As the magnets get smaller the windings also have to be split into more and more segments. In itself this does not cause any great problems, but it turns out that as the poles of the magnets are sited closer and closer together efficiency falls off. This is because part of the flux finds its way to a neighbouring pole without passing through the stator. As a result, the gearing relationship between speed and torque does not hold for higher pole counts. Greater spacing is required between the poles, which implies that they need to be arranged in a larger circle (see **Figure 12**). So as not to increase the size of the enclosure, the design is turned inside-out: thin permanent magnets on the outside, thick electromagnets (the coils) on the inside. The result is a so-called 'external rotor' (see **Figure 13**). One useful side-effect of this arrangement is the greater leverage that the force produced between stator and rotor has on the output of the motor, which increases torque still further. The exterior of the motor can no longer be held fixed, but there is the advantage that the magnets, turning along with the exterior part of the enclosure, are better cooled and therefore less likely to overheat when the motor is overloaded. Multi-pole exterior rotor designs, with their exceptional torque, are pre-eminent among electric motors and strike terror into the hearts of gearbox manufacturers. If a gearbox is required, it is essential to ensure that it can withstand the torque the motor is capable of producing. A disadvantage of the exterior rotor design is that it is harder to cool the stator, which now lies in the middle of the motor. Copper and iron losses have to be managed, and there is less space for the windings. The main application area for this type of motor (**Figure 14**) is therefore where brief or intermittent bursts of power are required, such as in hybrid-drive cars and in electric model aircraft. A special place is occupied by LRK motors, which fulfil the requirements of modellers for directly driving as large a propeller as possible. They feature a very simple and therefore economical construction: a free-running rotor with normally 14 magnets (ten magnets is also possible) encloses a 12-part stator. A special winding technique is used called 'separated phase sectors', or SPS: here each phase is assigned to a separate sector. This guarantees a very close magnetic coupling between the two magnetic systems and a high speed reduction ratio and correspondingly high torque.

Drives of the future

Power electronics and modern magnetic materials have brought about radical, but practically unnoticed changes

in electric motor technology: what one might call a 'quiet revolution'. In many applications brushless electric motors deliver better power-to-weight ratio than fuel-powered engines. In automotive drive systems we are only now learning how to take advantage of the enormous torque that electric motors can provide, practically independent of speed, as featured in high-performance hybrid vehicles such as the Lexus RX 400h. The main electric motor in this large car delivers 123 kW (167 bhp) with a torque of 333 Newton-metres. A second electric motor driving only the rear axle provides a further 50 kW (68 bhp) with a torque of 130 Newton-metres. Together the two motors form a permanently engaged three-phase electronically-controlled drive operating from a maximum voltage of 650 V. The battery for the hybrid system is made up from a total of 240 NiMH cells. With a nominal cell voltage of 1.2 V this makes for a total battery voltage of 288 V, from which a central inverter generates appropriate voltages for the motors. Each cell has a capacity of 6.5 Ah, giving a total stored energy at 288 V of 1.87 kWh. The battery can deliver a power of 45 kW. The current trend towards hybrid technology not only has the benefit of saving energy and reducing CO_2 emissions; it also means that electric drives in larger cars can be tested and refined without using revolutionary battery technology. If at some point a suitable power source (such as the fuel cell) becomes available to allow a purely electric drive system to be built, the relevant motor technology will already be mature. The hybrid concept will take another step forward when lithium-based batteries, which are considerably more powerful than their nickel-based counterparts, are used in cars. Here again model aircraft builders are already one step ahead!

(050321-1)

What keeps it turning?

Fundamentally all electric motors consist of two magnetic systems which interact with one another. One is fixed, and is called the **stator**. The other is mounted so that it can rotate, and is called the **rotor**. In modern DC electric motors one of the systems is invariably constructed using permanent magnets with fixed polarity while the other is constructed from electromagnets whose polarity depends on the direction of current flow in them. The interaction between the two systems is governed by the familiar principle that like poles repel and unlike poles attract. To achieve continuous rotation it is necessary to reverse the polarity of the electromagnet system at the moment when the two (previously) unlike poles come to their point of closest approach. In electric motors this polarity reversal is called commutation. In conventional motors the polarity reversal is achieved using purely mechanical means, where copper commutator segments rotate under fixed 'brushes' with which they make electrical contact.

In brushless (BL) motors electronic circuits in the form of bridges constructed from power FETs are used (**Figure 15**). To be able to start the motor up and keep it running, at least three half bridges are required. The three outputs go to the motor windings, which can be arranged in a delta or in a star configuration (**Figure 16**).

The three windings are connected to the DC supply in turn, so creating a rotating magnetic field that drags the rotor with it. Exchanging two of the phase connections will reverse the direction of the motor.

The similarity to three-phase motors is striking. In principle the electronically-commutated DC motor is identical to a synchronous motor, although the field rotation rate is not fixed in relation to the mains frequency and the motor need not lose step with the field under high load. The types of brushless motor described here generally produce their own field frequency in the control electronics, the field turning as the rotor does and the windings only being switched when the rotor is in the correct position.

To determine the position of the rotor poles magnetic field sensors (such as Hall effect sensors) can be used; more recent designs, however, dispense with the sensors and determine the position of the rotor from the back EMF produced by the motor, which is available across any winding that is not at that moment connected to the power supply. Since this voltage can only be measured when the motor is running, start-up must be done in 'open-loop' mode without this feedback: sensorless motors therefore tend not to start up very smoothly.

As you would expect from *Elektor Electronics*, we put theory into practice: elsewhere in this issue you will find a project to build a controller for brushless DC motors.
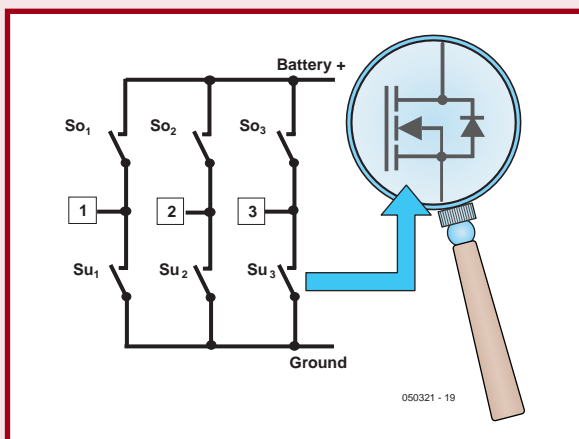
Figure 15. Simplified three-phase bridge drive circuit. The control electronics ensures that two switches in the same column are never on simultaneously.
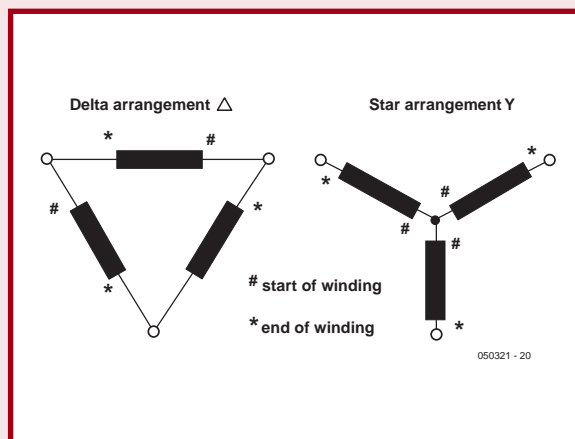
Figure 16. The motor windings can be wired in a star or delta arrangement.

Florent Coste

Brushless Motor Controller

Speed control for radio controlled scale models

This article mainly concerns enthusiasts using radio controlled scale models that include an electrical motor without permanent magnet brushes, usually called 'brushless motors'.

The massive interest in recent years for this type of propulsion system has made it possible to take electric motors to record levels in terms of efficiency and compactness, with the inevitable trade-off of increased complexity in control electronics. This article describes the basic theoretical principles linked to the operation of these motors, and a solution that is dependent on the ST7 microcontroller, recently introduced to the market and completely dedicated to this type of application.

The brushless motor

Not very complicated, a brushless motor is characterised simply by three coiled phases, distributed along a stator and positioned across a rotor composed of permanent magnets. Manufacturers often state the number of pole pairs characterising their motors. Applying current to the coils produces a magnetic field. The 'secret' lies in an appropriate sequence applied to three phases of the motor in order to induce mechanical rotation.

The three coils will allow us to produce a magnetic field in six different directions; the induced (coils) and 'natural' magnetic fields of the magnets tend to be aligned from this point, to finally describe a complete rotation.

To do this, you will need six switches, which are, in our application, none other than MOSFETs, in order to apply the sequence also known under the

name of 'trapezoidal method' (*cf* the shape of the motor current waveform). **Figure 1** shows the current induced in the coils during these six steps, and the resulting mechanics are shown in **Figure 2**.
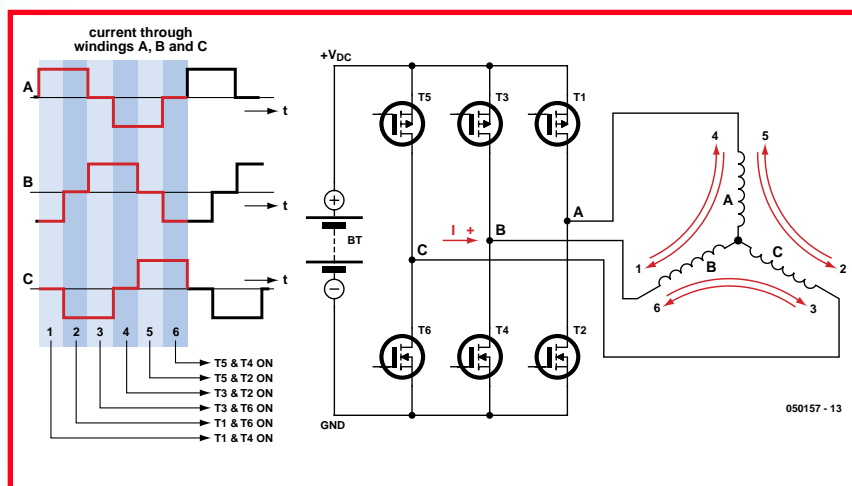
Figure 1. Six successive steps for one complete rotation of the induced magnetic field.
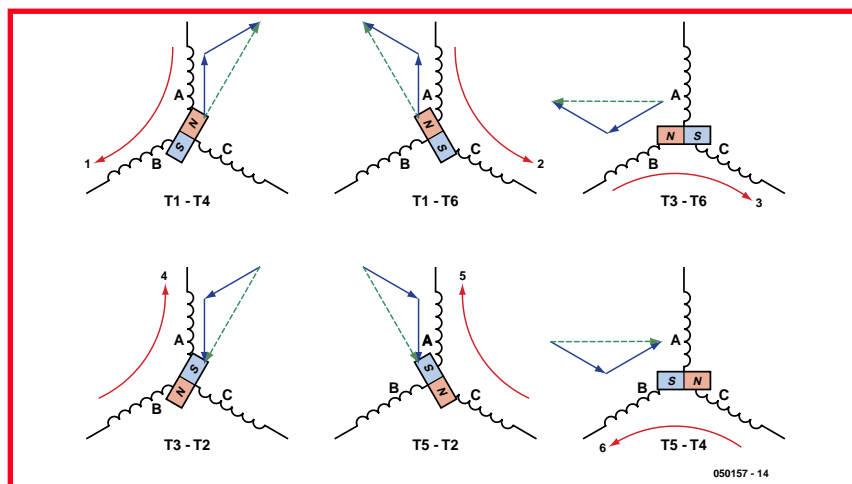
Figure 2. Alignment of the induced magnetic field for each of the six steps.
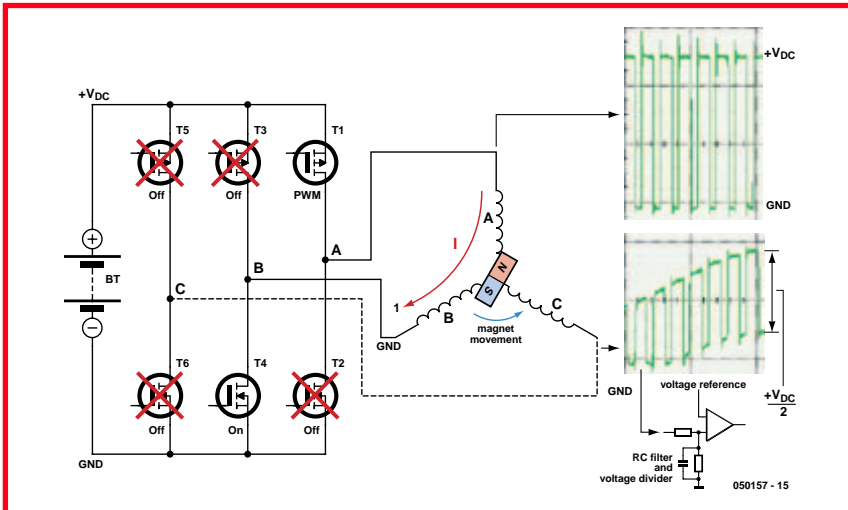
Figure 3. Voltages at the terminals of phases A & C (step 1).

The control principle

We can model the power stage, with six switches operating at fixed-frequency PWM (Pulse Width Modulation), allowing us to describe six distinct steps during which two of the three phases are excited. We'll call

Figure 4. Demagnetisation of the phase being observed.

passing from one step to the following step, 'commutation' (1→2, 2→3, 3→4, 4→5, 5→6, 6→1) The current is adjusted by varying the pulse width (duty cycle) of the control signals applied to the power MOSFET gates, thus allowing the coil and magnet fields to reach alignment more or less quickly. And it follows, at low current, we get low rotation speed, and conversely.

The entire control principle of this type of motor depends on the response to only one question: when should the commutation from step n to step (n+1) occur? For that, we must be able to detect magnets passing in front of the coils, and to remain in perfect synchronisation with this mechanism at each step. In addition, we must verify that the motors are really synchronous motors, because, in the end, stator flux and mechanical rotation speed will be identical with only one pole pair; the number of pole pairs determine the ratio between electrical time (time required for six switches) and mechanical time (time required to complete one complete physical rotation). Therefore, one motor with only one pole pair will need six commutations (step 1 tthrough 6) to perform one 360-degree rotation. For two pole pairs, we must perform two times six commutations, or 12 commutations. Here, we see the ratio enabling the conversion between electrical and mechanical frequency: a motor which has, for example, seven pole pairs, revolving at an RPM of 15,000 (or 250 Hz), will actually operate at an electrical frequency of 7*15000/60 = 1750 Hz, or a commutation frequency of (passing from step n

to (n+1)) from 6 * 1750 = 10.5 kHz. Be careful not to confuse commutation frequency and applied PWM frequency on the motor windings, as they are two very independent things!

The first controllers that came into being some years ago actually came with Hall-effect sensors informing the electronics about the rotor position and causing commutation at the right time. More recently, in response to a wider motor market, sensorless' solutions were introduced, being capable of accommodating connections to three phases. Clearly, our setup falls into this last category.

Detection of the rotor position and synchronisation

At each step, only two or three phases are utilized. Why not use this floating phase to send the signal which will trigger the next commutation? This is an excellent idea relating to the electrical data moved at this specific point. And what happens? When the motor runs, the movement of the magnets induce a voltage (increasing or decreasing) to the unenergised coil terminals (electromotive force), and this happens independently from the energy injected into the other two coils (manual rotation of the axis and a simple voltmeter in AC mode connected between two phases of a unconnected motor enables us, in general, to generate consequential voltages). With the help of this induced voltage, we are then ready to detect a synchronous signal from magnet movement. **Figure 3** shows oscillograms of phases A and C during step 1.

We apply the PWM signal to MOSFET T1, while T4 effectively short-circuits phase B to ground. Phases A and B form a resistor divider (theoretically, the phases have the same resistor), and we receive the PWM signal in A divided by two at point C, to which the voltage induced by magnet movement is added.

All that is left is to choose a precise point on this curve which will give us one piece of synchronisation data — all that is needed is one simple voltage reference and one comparator.

After filtering, we can trigger a signal indicating that the induced voltage has reached the value set by the reference, also called 'zero-crossing'. After this, commutation can intervene after a certain manually adjusted time delay. This delay is used to adjust the phase
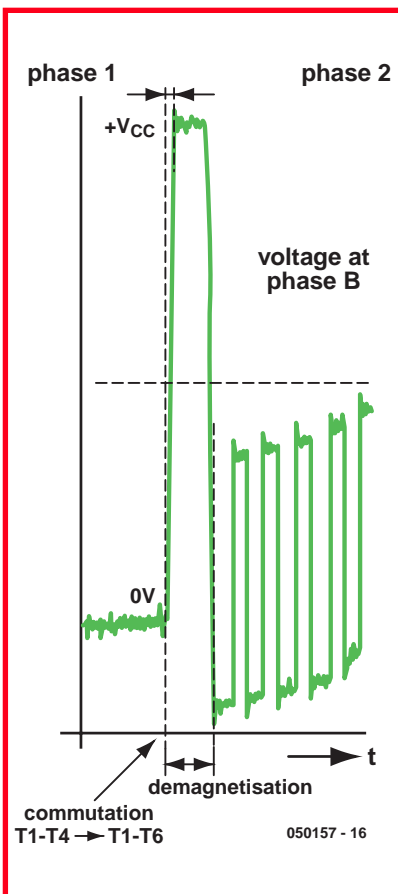
advance and the system efficiency. A very strong advance allows us to obtain more motor revolutions at the cost of more current consumption. Finally, please note that this electromotive force can only be detected after the coil has been completely demagnetised, which means waiting after each commutation. **Figure 4** clearly shows this phenomena when passing from step 1 to step 2.

Brushless controller for R/C

The proposed setup depends on a recently introduced microcontroller put on the market by the STMicroelectronics company, the ST7MC (MC for Motor Control). This unit contains everything you need to drive a 3-phase stage (permanent magnet motors as well as induction motors), in addition to a list of comparators, digital filters, and other reference voltages, in order to operate all types of brushless motors, as in this example. Here, we need to make an 8-bit core with 8 kB of Flash memory and 384 bytes of RAM, just enough to handle the software required for this application! More

standard peripherals are used to bolster the core, like a 10-bit CAN, two 16-bit timers, one supply voltage supervisor, one PLL to double and filter the clock signal, and so on.

Schematics: a modular approach

Considering the nature of this application, we had to find a compromise between compactness, component supply, and performance in comparison with what we can already find on the market. For compactness, a modular approach was selected in order to be able to electronically separate control electronics and the power stage. Some readers could, for example, adapt the control module to a home made power stage. Moreover, two double-sided modules give us four layers of copper for soldering the components, which is far from being a luxury! We opted for a discrete approach and avoided exotic integrated circuits that are practically impossible to find in general retail stores. On the performance side, the microcontroller is really what makes the difference! Its digital filters, easy to configure, give us the freedom to do

without RC filters in order to extract information faster, without added phase delay. Even more interesting, this micro permits four sampling methods (one of which is patented), and two of them are implemented here, guaranteeing us a progressive, secure start-up.

The micro board

The schematics for this board, shown in **Figure 5**, are brilliant by their simplicity. The power supply for the micro, the receiver, and the servos are built with the help of two 5 V/1 A regulators in parallel with a low-drop type. Select the BA05FP model rather than the L4941, which offers standby voltage of more than 20 V (approximately 18 V for the L4941). Obviously, there is no question of powering four standard servos with 20 volts given the power to be dissipated; in this case, we need to opt for a switch mode power supply or simply a separate external battery for the receiver and servos.

It all depends, therefore, on the work load (type of servos) and the power to be dissipated (it only concerns one
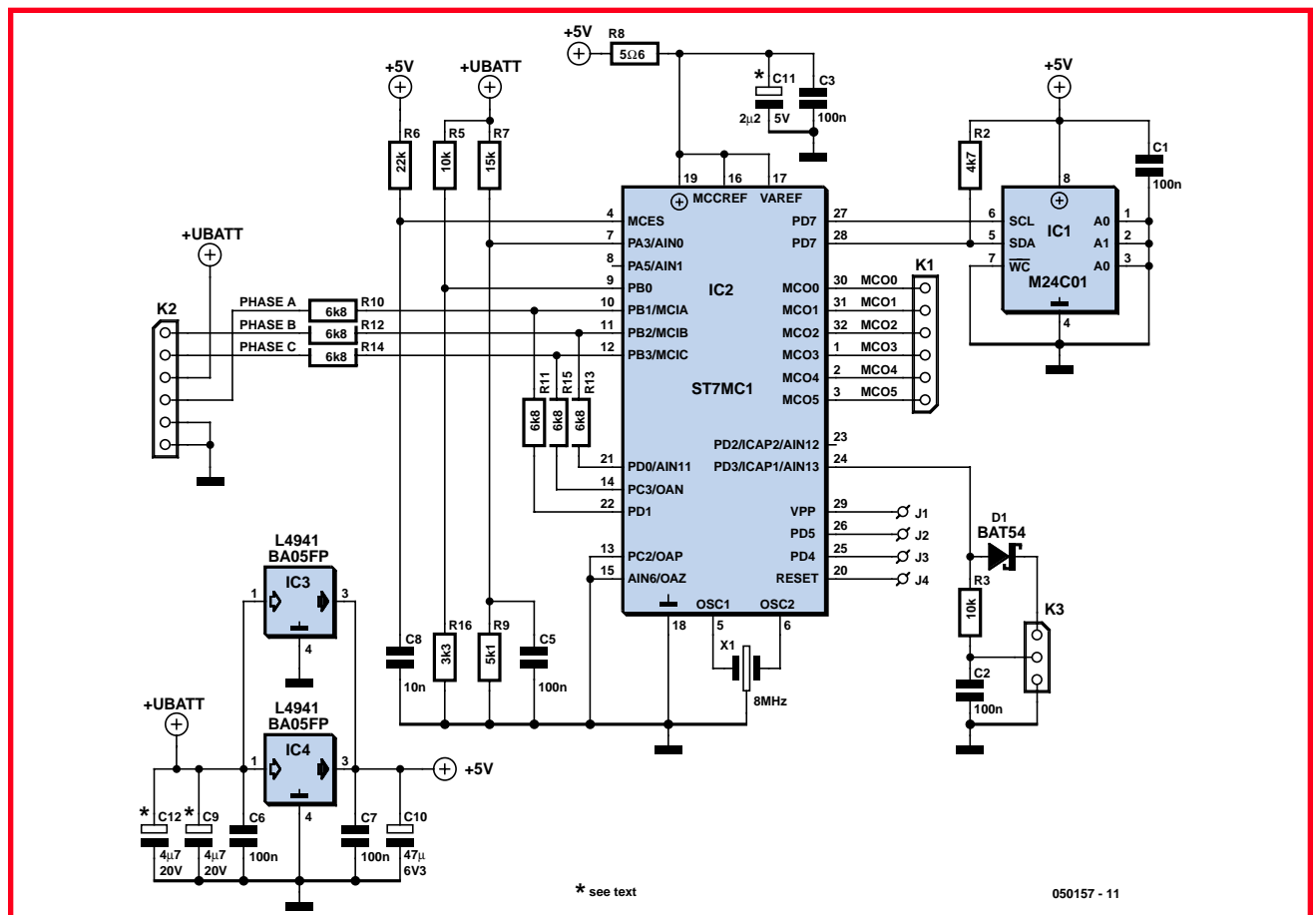
Figure 5. The control module, how could it be any simpler?
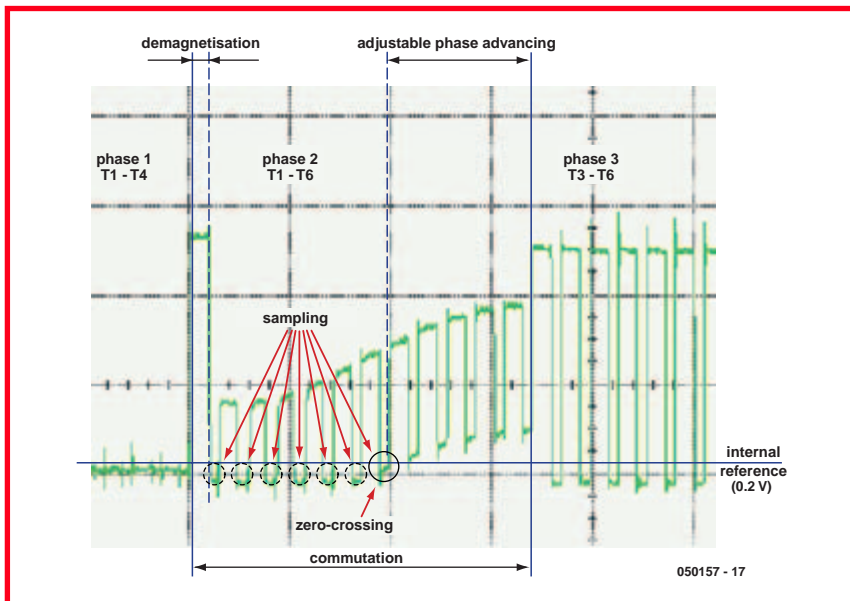
Figure 6. Sampling during OFF time.

Figure 7. Sampling during ON time.

linear regulation). Regulators are used to power one receiver and several servos with no problem with approximately ten volts (be careful that there is no resistance in the controls because consumption can rapidly bring about overheating of the regulators followed by a standby setting). The signal coming from the receiver is applied to pin PD3 and the D1/R3 network is used to somewhat boost the receivers, operating at low voltage (3.3 V). A small I^{2}C EEPROM is used to backup controller programming. PA3 is connected via a resistor divider and is used to monitor battery voltage. The MCES input (pin 4) is used to put the power stage on standby when a low level is applied to it; it is not used in the setup and will be forced into high state. The AVD (Auxiliary Voltage Detector, detector of low voltage on the micro power supply) will generate an interrupt which will immediately cut-off the power stage if the power supply drops below 4.75 V in order to guarantee, at a minimum, the power supply for the servos and receiver. This is only temporary and the power stage will be operational again as soon as the power supply is brought back up to a minimum of 5.3 V or the programmed BEC cut-off voltage (which is necessarily superior, or at least equal to, 6 V for two Li-Po or six NiMH cells). It may be time to think about putting down your model! Also note that sudden power stage cutoffs are either the sign that the batteries are reaching the end of their lifespan and can no longer supply the current required, and that the voltage will drop dramatically, or that defective servos are drawing too much current from the regulators.

For the rest, we have six independent control signals for the MOSFET gate commands (MCO0 to MCO5); pins 10 to 12 are inputs enabling the sampling of signals relative to the detection of 'zero-crossing' events. Two sampling modes are combined here; the first, used to start-up the motor, is a sampling when the PWM gate command signal is OFF (method patented by ST). Pins 10 to 12 are then directly connected to phases via resistors R10, R12 and R14 (outputs PD0, PD1 and PC3 are left in high impedance), and the sampling occurs at each PWM pulse, as is shown in **Figure 6**. This method allows for increased sensitivity because the zero-crossing signal is not attenuated by any resistor divider.

When the motor reaches sufficient rate, the sampling occurs during the ON time of the PWM. Outputs PD0, PD1 and PC3 go to low state and the PWM signal then returns to a level that can be understood by the micro, via dividers R10/R11, R12/R13 and R14/R15. The reference voltage used becomes external, present on PB0. **Figure 7** shows the oscillogram of the unenergised phase.

High-frequency sampling (1 MHz) during the ON time of the PWM makes it possible to achieve a ratio of 100%, and guarantees a maximum rate (no phase delay due to using RC networks as in traditional setups).

The power stage

We opted for an entirely discrete approach, as the diagram in **Figure 8** shows, in order to make the setup accessible. We did not want to use specialised integrated circuits to control the power MOSFET gates. The driver designs were not easy because the specifications call for a variable power supply voltage of between 5.5 and 20 V and require utilising synchronous rectification (see explanation below) to make our setup more attrac-
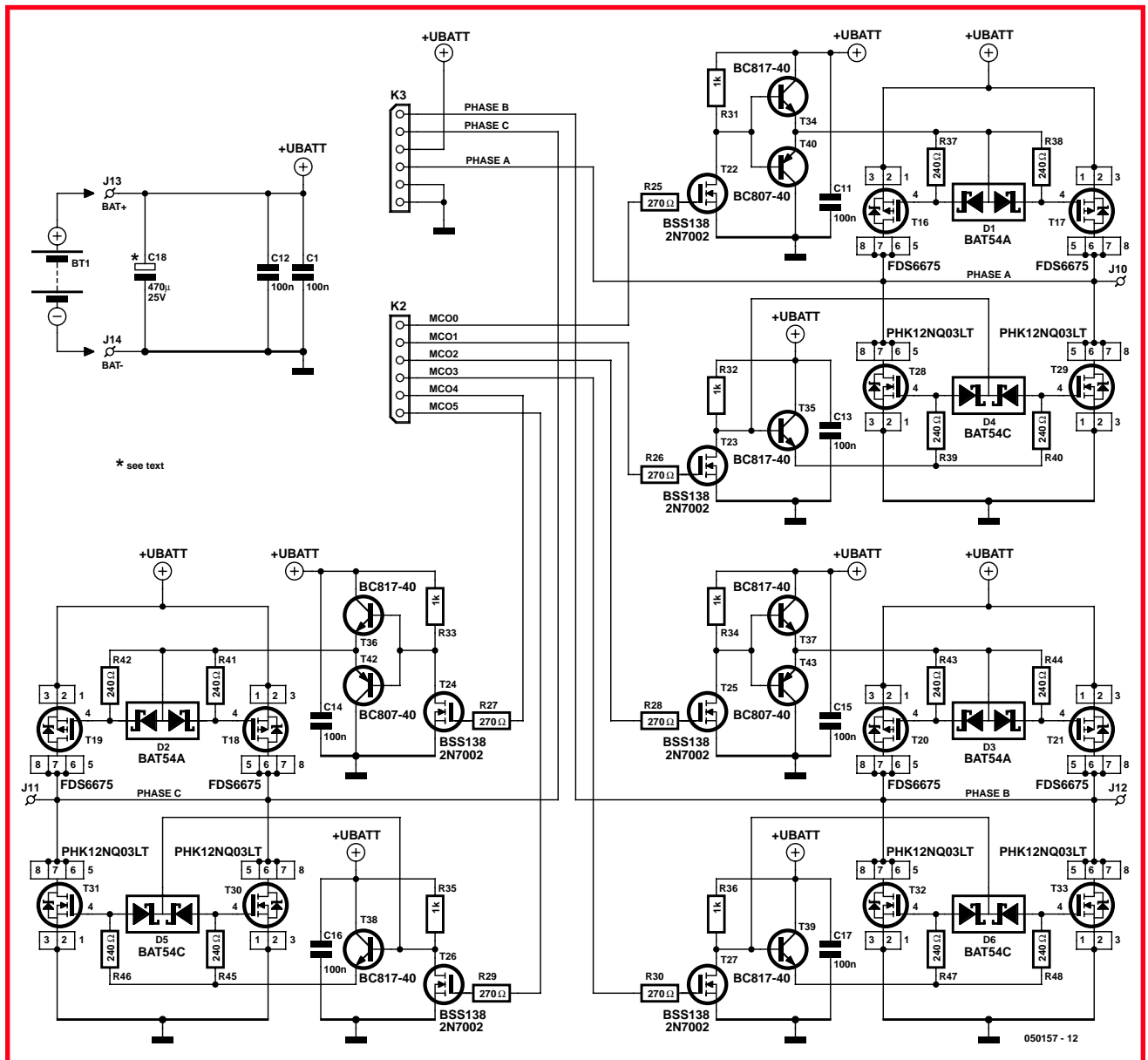
Figure 8. Circuit diagram of the 'power stage' module.

tive and better-performing than the controllers currently available for sale. The final setup could also be accommodated with any other power MOSFET, as long as it is capable of commuting current required. A large choice of transistors in SO8 case can work, the ones used in our setup are just an example.

The three-phase bridge actually has three identical branches; let's focus on one branch only, for example the set T22/T23/…/T17/T29 (top left of the diagram). First, the micro control signal is raised again. With the help of a small MOSFET and a pull-up resistor (R3/T22), we go from a TTL level to an output toggling between 0 volts and

virtually the power supply voltage. The 1-kΩ resistor is sufficient as a good compromise between the slew rate on the drain and low static power consumption (resistor R22 dissipates when MOSFET T22 is ON; small current consumption in that case). This signal is then handled in two different ways. For the P MOSFET, we drive a push-pull composed of transistors BC817/BC807. We based our choice of these transistors on their low V_{beon} characteristic which makes it possible to stay below the $V_{gs\ threshold}$ of the P MOSFET, with a gain and capacity in high current, guaranteeing impeccable OFF and ON positioning of the power transistors, no matter what their tem-

perature. Relating to type N MOSFETS, a simple gate pull-up to the power supply voltage is performed using BC817, and the OFF setting is directly exercised by the small MOSFET at driver input (T22). Therefore, a complete push-pull stage is not necessary in this specific case, and we have more than the $V_{forward}$ of the BAT54C diode which is interposed between the T22 drain and the MOSFET T28/T29 gate. One more thing on the network of resistors and diodes in the power MOSFET gate (D4/R39, for example). In order not to overload the power supply, and to avoid any risk of short-circuiting the branch (cross-conduction, the MOSFETs of the same branch then
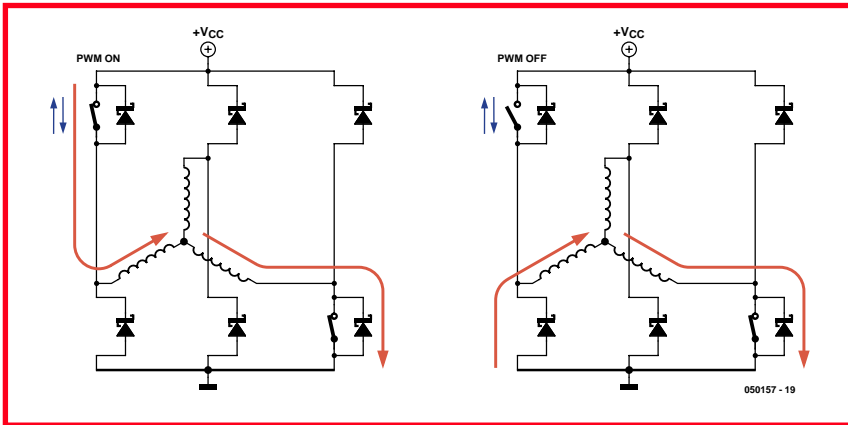
Figure 9. Current during PWM ON and OFF.

conduct at the same time, which can cause a short-circuit and, in general, destroy the transistors), it is imperative to prioritize a very fast OFF setting and a slow ON setting. In this way, the BAT54C diodes allow for a very fast pull-up/down to the power MOSFET gates (to 0 or +Vbattery according to the type N or P of the MOSFET), while the ON setting is at 240 Ω (R37, for

example). We can then operate the motor-control cell of the micro to its utmost and utilise synchronous rectification. How about that?

Synchronous rectification

Figure 9 shows what happens in a bridge branch when the PWM signal is applied to the P MOSFET. When the

PWM is ON (closed switch), the current thus passes through the top MOS-FET to go into one of the motor phases. When the PWM is OFF (open switch), the current (continuous to the coil terminals) must make a path via the bottom transistor in the same bridge branch. If the bottom MOSFET is OFF, this current shall pass this way via the internal freewheeling diode (poor diode quality, in general). A rise in temperature will result, which is, by the way, the main reason a MOSFET stage would overheat in this type of application. In summary, why not utilise the bottom MOSFET N when the top MOSFET P is OFF? That is quite clearly the definition of 'synchronous rectification'.

When the top P MOSFET "is open", the bottom N MOSFET closes after an adjustable time delay called dead time which is required to avoid any short-circuit of the branch; this time delay has been set at 325 ns in this application. Then, the current no longer flows to the freewheeling diode, but rather to the MOSFET. Transistor heating is significantly reduced because then only one resistor, equivalent to a few milliohms, is visible on the current path. A fair number of manufacturers do not take advantage of synchronous rectification because the microcontrollers utilised are simply not capable of generating such signals.

Construction

The boards are both double-sided, and components must be soldered to each side (a necessary evil to keep the size of the circuit within the correct proportions). Despite the fineness of some copper traces, it is very well possible to build these boards with traditional materials. The author has made numerous PCBs with a simple laser printer and a ferric chloride etching solution. If you do not have access to boards with through holes, then it is best to proceed with installing bridges via linking each side of the circuit (using wire wrapping, for example) and to cut them as close as possible to the board. Next comes installing the integrated circuits, such as the micro, 5-V regulators, EEPROM, quartz crystal, as well as the two rows of six MOSFETs: for the latter, be careful to align them properly, avoiding raising some of the devices with respect to others because you will have to add a common heat-sink. If not, a fine file can be used to level the MOSFET modules; however,
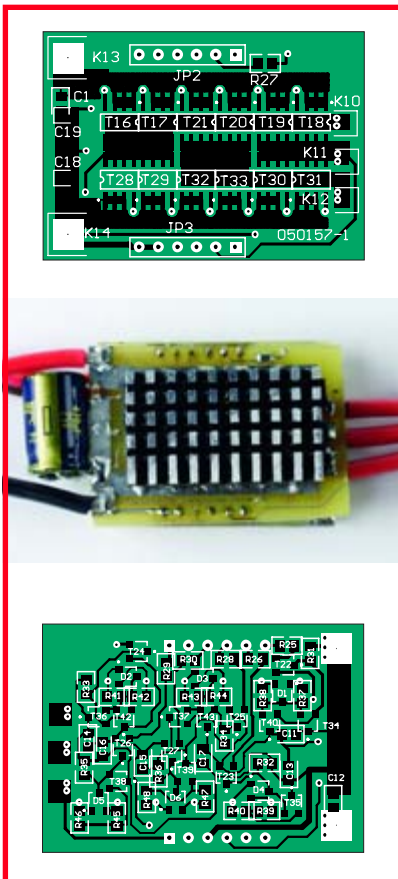
Figure 10. The double-sided board of the power stage.
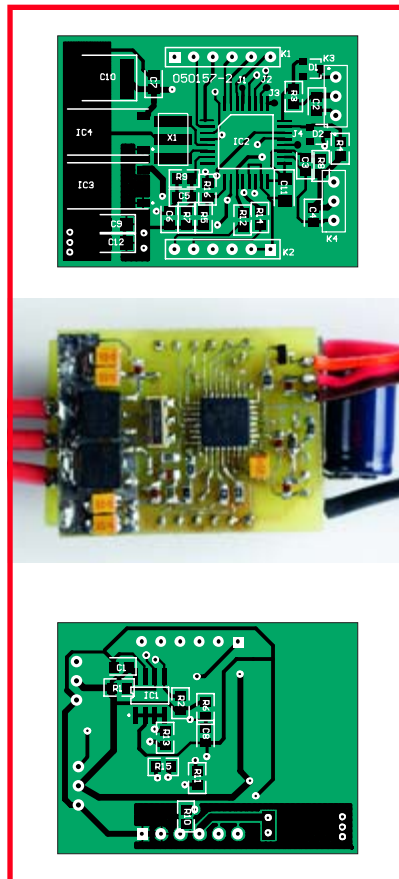
Figure 11. The double-sided board of the control module.
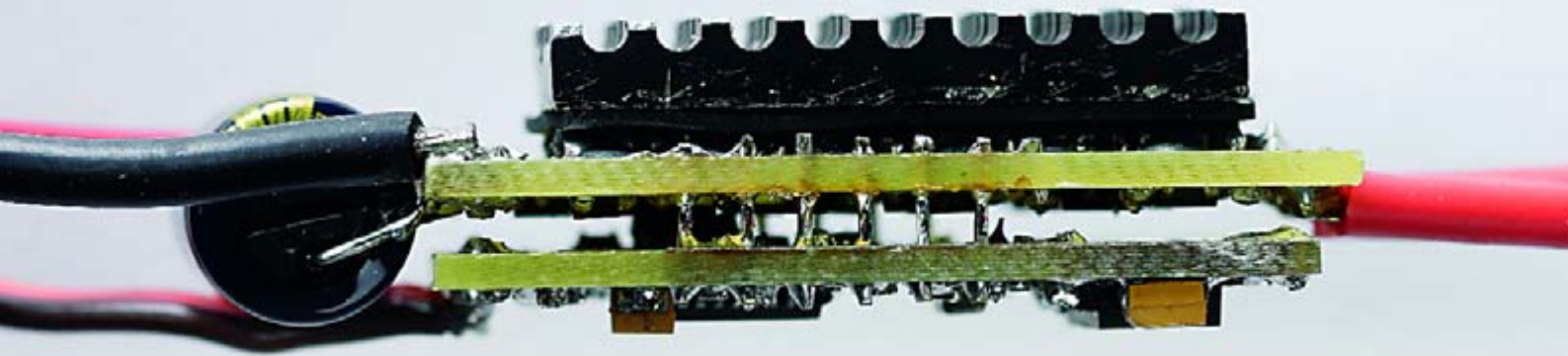
be careful not to damage the silicon! Note: due to very strong currents flowing (peak currents potentially above 25 A), it is absolutely imperative to plate (tin) the MOSFET supply lines as well as the copper lines going toward the three phases, or else risk destroying the copper traces! A good soldering iron and a little coordination make it possible to distribute an even layer of tin (keeping it flat because these traces pass under the MOS-FETs). It is also advised to pull two lines of copper between the two MOSFET rows (1-mm diameter cable, for example) to phases 'a' and 'b' (unnecessary for phase 'c' which is right next to its connector).

Next, we can proceed to installing all of the discrete components, such as resistors, diodes, stage MOSFETs for gate control and push-pull stage MOS-FETs. Finally, we advance to soldering the C18 electrolytic capacitor (low ESR), placed between the two battery supply connectors (there is enough space for a second capacitor for those who would like to add another one, but it's not really necessary for the power level of this setup, but may become necessary if you make a 'heavy-duty' stage, since it's only about adding parallel MOSFETs). We can then solder the two power supply cables to the battery and the cables to the three phases of the motor. Finally, we still have to proceed to the installation of connectors K1 and K2 on the power board section.

It is recommended to do a small operating test before coupling our two boards. To do this, solder three 10 kΩ pull-down resistors between ground and pins 2, 4 and 6 at K2, as well as three other 10 kΩ pull-up resistors between $+V_{cc}$ and pins 1, 3 and 5 in order to switch all MOSFETS to OFF (open switch). With the help of a small power supply from 5 to 15 V, current-limited (500 mA, for example, avoid batteries or rather use a series resistor from 20 to 50 Ω, for example, to power the circuit), first verify the levels present on each power MOSFET gate; each MOSFET P gate must be brought to an approximate voltage $+V_{cc}$ minus the V_{beon} on the BC817 (or approximately

COMPONENT LIST

Microcontroller board

Resistors:
R1,R4 = not fited
R2 = 4kΩ7
R3,R5 = 10kΩ
R6 = 22kΩ
R7 = 15kΩ
R8 = 5Ω6
R9 = 5kΩ1
R10-R15 = 6kΩ8
R16 = 3kΩ3

Capacitors:
C1,C2,C3,C5,C6,C7 = 100nF
C4 = not fitted
C8 = 10nF
C9*,C12* = 4µF7 20V low ESR
C10 = 47µF 6V3
C11* = 2µF2 5V low ESR

Semiconductors :
D1 = BAT54
IC1 = M24C01

IC2 = ST7MC1, programmed, Publishers order code 050157-41)
IC3,IC4 = L4941 BA05FP

Miscellaneous:
X1 = 8MHz quartz crystal
K1,K2 = see text
K3 = 3-way SIL header with 1 jumper
PCB, ref, 050157-1 from The PCBShop

Power driver board

Resistors:
R25-R30 = 270Ω
R31-R36 = 1kΩ
R37-R48 = 240Ω

Capacitors:
C1,C11-C17 = 100nF
C2-C10 = not fitted
C18 = 470µF 6V3

Semiconductors:
D1,D2,D3 = BAT54A
D4,D5,D6 = BAT54C
T16-T21 = FDS6675
T22-T27 = BSS138, 2N7002
T28-T33 = PHK12NQ03LT

T34-T39 = BC817-40
T40,T42,T43 = BC807-40
T41 = not fitted

Miscellaneous:
K2,K3 = see text
PCB, ref. 050157-1 and -2 from The PCBShop

Controller configuration

PWM 24 kHz

Brake OFF

Soft-start ON

Auto LiPO detect (3 cells, 12.6V)

BEC OFF

Phase advance
at min rate: 18 degrees,
at max rate: 30 degrees

The environment

A small budget makes it easier to take risks. Development tools are free, only the debugging/ programming interface needs to be paid for. Softecmicrosystems (http://www.softecmicro.com)

proposes a debugging interface used to emulate and program all of the devices of the whole ST7 flash family. Finally, it is possible to obtain a ST7MC starter kit.(www.softecmicro.com/products.html?type=detail&title=AK-ST7FMC)

includes a micro board, a high-voltage power stage, a brush-less motor and software, operating in Windows, to learn and get practice on this type of application.

300 to 400 mV), while the MOSFET N gates must be at almost zero voltage. Next, we can apply a voltage of +V_{cc} on pins 2, 4 and 6 to put the MOSFET P to ON (closed switch). Verify that we have approx 300 to 400 mV voltage at each gate. Disconnect the +V_{cc} from pins 2, 4 and 6 (MOSFET P OFF), and short-circuit pins 1, 3 and 5 to ground. Then verify that we have an approximate voltage of +V_{cc} less 300 to 400 mV on the gates of each N MOS-FET. Everything is operational? Perfect! You can then unsolder the pull-up/down resistors, and solder the two boards. All that is left to do is add a little bit of heat-conducting paste to the MOSFET metal tabs, add a small heatsink, and wrap it all in a piece of heat shrink tubing; so well done you could mistake it for a commercial product!.

One last important point; for those who would like to make their own PCB layout; it is absolutely necessary to separate wiring for ground lines and +V_{cc} of power MOSFETs from the rest of the circuit, in order to avoid any problem of commutation noise. Star wiring is therefore necessary.

In the current version of the Brushless Controller for R/C Models, some of the components are not required (place has been reserved for future extension, such as a regulation loop, for example). Consequently, it is possible to omit the following components:
- C19 on the power board (which is, in any case, wired on the outside), this additional capacitor may be needed for more 'heavy-duty' power stages (as mentioned above).
– Pull-up resistor R1 on the SCL line from the unused EEPROM, (removed from the diagram but present on the

layout) D2, R4, C4, K4, reserved for a second additional path to adjust a regulation loop, for example (not implemented in this version of the software, perhaps one day soon?).

Implementation and operation

The most appropriate spot for the controller is in a ventilated part of the scale model, if possible. This obviously depends on available space. An instruction manual, that may be downloaded from our website, will help you configure the controller. At the least, you must have calibrated the throttle for the initial tests. Modellers will recognize traditional configurations for this type of circuit, like active braking, soft-start to gentle start, for example, electrical helicopter rotors, choice for PWM

operating frequency, configuration for battery type. We have, however, opted for a 2-point adjustable phase advance (see instruction manual) allowing us to have a linear variation (dependent on the throttle position) between minimum and maximum motor speed; it is actually generally preferable to have soft timing (10-15 degrees, for example) and more aggressive with hard timing (25-30 degrees).

If your motor is operating at a high (electrical) frequency, please note that it is better to have a high PWM frequency (24 or even 48 kHz). For example, for a motor rotating at 20,000 RPM having eight pole pairs, we obtain a commutation frequency of: 6 (commutations per electrical cycle) * 8 (pole pairs) * (20,000 RPM/60) = 16 kHz. In order to guarantee a minimum number
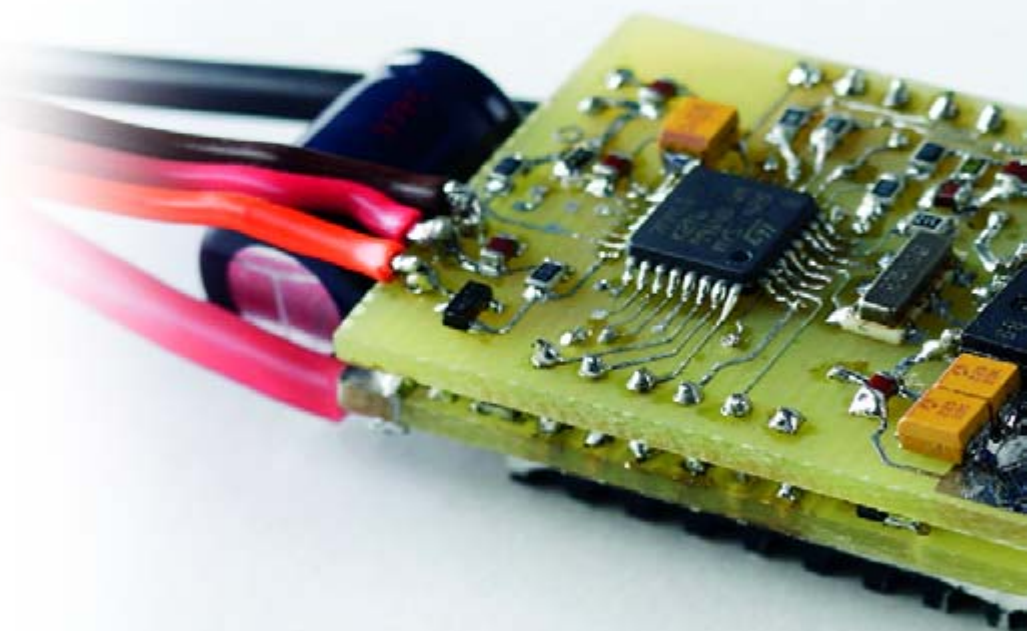
The author

Florent Coste received his engineering degree in microelectronics in 2000 from the Charles Fabry Institute in Marseilles, France. Since that time he has been employed as an application and support engineer by STMicroelectronics and is based in Hong Kong. Having specialised in microcontroller software, he worked for two years in close collaboration with Asian clients to implement the multimedia platform. Later, he specialised in motor control applications, which led him to develop projects based on micros (specifically the ST7MC, to mention only the latest, trendy ST micro) dedicated to driving synchronous (brushless, air conditioned, for example) and asynchronous (induction) motors. A big fan of aeromodelling and electronics, Florent uses his knowledge in those two fields to further his hobby.

of PWM pulse widths between each commutation, it is better to use an operating frequency of 24 of 48 kHz! Relating to overheating of the power MOSFET, despite a higher frequency, that does not change a lot because we are using synchronous rectification. The curious among you can connect a voltmeter/oscilloscope in frequency meter mode to pin PA5 of the microcontroller; the TTL signal is at a frequency identical to the electrical frequency of the motor. Knowing the number of pole pairs allows us to immediately deduce the timing of the motor (reminder: motor timing (RPM) = 60* F_{elec} /number of pole pairs). One last point that we have not yet stressed: when starting with a cold motor, start-up always follows a linear acceleration ramp during which we 'force' the motor to a

sufficient timing level (by manually setting the current and the time between each commutation) to be able to detect the electromotive force on the unenergised windings (from which comes the characteristic clicking noise at start-up with 'sensorless' controllers). In this application, this phase is always at 12 kHz of PWM in sampling mode during OFF time (ST patented method, see F**igure 8**). Once started, the micro will automatically switch into synchronous rectification mode, at the PWM frequency that has been programmed by the user, and sampling during the ON time (see **Figure 7**).

Attempt at conclusion

It is absolutely impossible to make a detailed presentation of control methods related to brushless motors in only a few pages, and there remain many things to say regarding theory, as well as about the ST7MC microcontroller! However, the more inquisitive among you will be able to satisfy their desire for further knowledge by reading the many application notes on the STMicroelectronics website (AN1905 for example: http://www.st.com/stonline/books/pdf/docs/10267.pdf). The software was written in C and required several months to develop. The choice was based on the COSMIC compiler (16 k version, free on the COSMIC website: http://www.cosmicsoftware.com/download_st7_16k.php which is a reference in terms of code optimisation. A downloadable generic library on our Elektor website gives you the option of attempting multiple experiments, and why not, in the end, write your own custom software? It is entirely possi-

ble, for example, to implement a regulation loop like the one described in the application note mentioned above — very useful for R/C helicopters in order to have constant rotor timing. Plenty of room for experiments! If you use our setup as your target board during every debugging (or programming) session, you will have to add pull-up resistors to the ground or $+V_{cc}$ on the K2 connector (as already explained in the "construction" paragraph), in order to ensure that all the MOSFETs are OFF (open switch); actually, outputs MCO0 to MCO5 of the micro, in this specific example, move into high impedance, and no longer ensure that they are OFF.

(050157-1)

Internet links

Softecmicrosystems:
www.softecmicro.com

COSMIC:
www.cosmicsoftware.com/
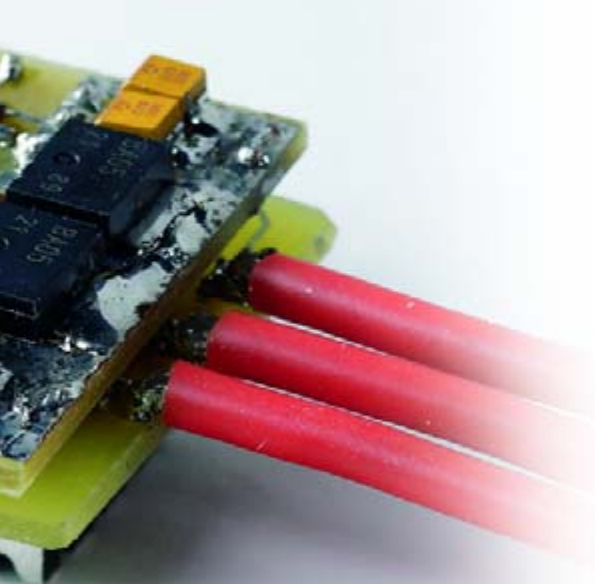   download_st7_16k.php

STMicroelectronics:
www.st.com

Application note:
www.st.com/stonline/books/pdf/docs/
    10267.pdf

Starter-kit ST7MC:
www.softecmicro.com/products.html?type
    =detail&title=AK-ST7FMC

Micro Motors
March of the miniature machines

Jens Nickel
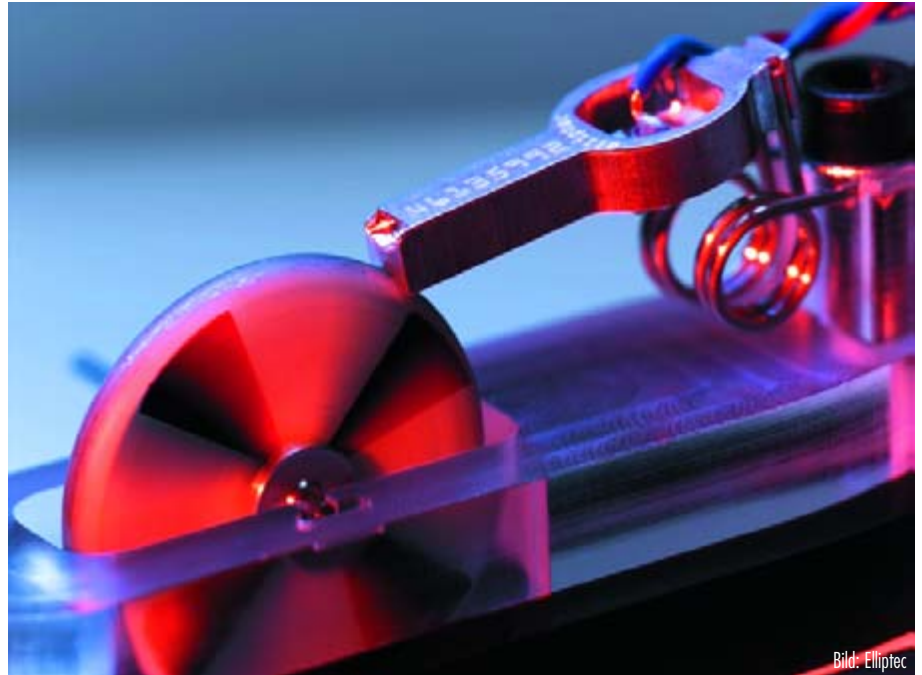
Figure 1.
This piezoelectric motor with a single-channel drive can produce linear and rotational movements [3].
(Source: Elliptec)

Piezoelectric actuators and motors are finding more and more applications. These drives feature excellent dynamics, accuracy down to nanometres and tiny physical dimensions.

In many cases the discovery of a new physical phenomenon has precipitated an immediate technical revolution: examples include X-rays and the transistor. In other cases it has taken several decades before the potential of a discovery is realised, such as in the case of superconductivity (discovered in 1911) and the effect we describe below.

In the year 1880 two French brothers, Jacques and Pierre Curie, discovered that charge is generated on crystals of tourmaline when pressure is applied. This became known as the piezoelectric effect (from the Greek word 'piezein' meaning 'to press'). The reverse phenomenon was also observed: certain materials change shape in characteristic ways when a voltage is applied. Apart from piezoelectric gas lighters and quartz crystals (which exploit both processes), technical applications were of rather a recondite nature. In the last ten or twenty years there has been a resurgence of interest in the piezoelectric effect, with the promise of making electric drives with revolutionary characteristics. That this has become possible is due in no small measure to advances in materials science and (micro)controller technology.

Ceramics in fashion

The piezoelectric effect is observed in many naturally-occurring materials. One example is quartz: if pressure is applied along a particular axis of the crystal (the so-called polar axis), a voltage can be measured across the corresponding opposite sides: for more details see the text box. If a voltage is applied across the crystal, it shrinks or expands. This is known as the inverse piezoelectric effect. There are synthetic materials that exhibit even better characteristics than quartz. Lead zirconate titanate (PZT), a ceramic, can even be polarised, which means that the axis and polarity of the piezoelectric effect can be determined at will [1]. The ceramic is composed of a large number of individual crystals fused together, which gives rise to an interesting effect. Under a strong electric field the orientation of the polar axis shifts by up to 180 °. If the ceramic is cooled from the molten state the individual crystals are randomly oriented and the material as a whole exhibits no piezoelectric effect. Under a strong electric field the polar axes of the individual crystals align, giving rise to expanded domains all polarised in the same direction and a pre-

ferred axis to the material. By analogy with the magneti-sation of iron in a magnetic field such materials are also called 'ferroelectric'. Polarised PZT exhibits an exception-ally strong piezoelectric effect in the direction of this axis. Since ceramics are now relatively easily available in a wide range of forms, they are the materials of choice in several applications, which we shall now look at [2].

Resonators

To construct a drive we will need to use the inverse piezo-electric effect. Depending on the polarity of the voltage applied along the polar axis the material will shrink or expand by up to 0.15 %. Using an alternating or pulsed voltage the material can be made to oscillate. The partic-ular material used, the polar axis and the direction of the electric field, and the shape of the sample all have an effect on the resulting movement. Piezo elements can be made to oscillate in longitudinal length mode, thickness extension mode, transverse bending mode or shear mode as required [1].

Large displacements and corresponding oscillation can be achieved when the applied voltage varies at the reso-nant frequency of the sample, which depends on its elas-ticity and its dimensions. This technique is employed in quartz crystal oscillators, where a block cut from a very pure quartz crystal (in the right direction!) forms an exceptionally precise and stable RF frequency standard.

Actuators

Among applications of the inverse piezoelectric effect we distinguish 'resonators' from 'actuators and motors'. Actua-tors move by a few micrometres when a DC voltage is applied. This movement can be increased using a lever sys-

tem or by arranging a series of actuators in a stack. Com-plex motions can also be realised using cunning physical arrangements and wiring of multiple actuator elements. One example application is the micropump, capable of pumping a few nanolitres to a few microlitres of fluid. Such devices are used in inkjet printers and in chemical analysis applications. The piezoelectric actuators in mod-ern direct injection diesel and petrol engines resemble a valve. A pressure of up to 2000 bar is built up by a stack of piezoelectric elements (**Figure 2**) moving a needle inside a nozzle. When required a tiny drop of fuel (a few microlitres) is injected into the cylinder. Because of its high speed it is immediately whisked into a combustible mixture. Compared to conventional injection nozzles, which use magnetic valves, the piezoelectric actuators are some three times faster and allow multiple injections per stroke of the cylinder. This lets the fuel burning process be further optimised.

A closer look at a quartz crystal

The piezoelectric effect can readily be explained with reference to quartz (SiO_2). The atoms in quartz form a regular grid with each silicon atom being surrounded by a tetrahedral arrangement of oxygen atoms (**Figure A**). The oxygen atoms tend to attract electrons from the silicon atoms, making the silicon atoms positively charged and the oxygen atoms negatively charged. If pressure is applied to the quartz crystal along the axis joining an apex of the tetrahedron to the middle of the opposite base, the opposing charges are pushed relatively closer together, giving rise to an electric field (**Figure B**), and a potential dif-ference can be measured. This distin-guished axis of the quartz crystal is called a polar axis. If pressure is applied perpendicular to this axis the quartz crystal expands along its polar axis because of its elasticity. The charges move in the opposite direc-tion, resulting in an oppositely-polarised electric field (**Figure C**).

The piezoelectric effect is not present in all crystal structures: if the positive and negative charges are arranged in a cubic lattice as in cooking salt, the charge movements on average cancel out over the entire crystal and the sub-stance consequently exhibits no piezo-electric effect.

The piezoelectric effect is (almost exclusively) linear, which means that a doubling in pressure corresponds to a doubling of the electric field. In other words, the ratio between the mechanical pressure and the electric field is a constant. The constant depends on the direction of the pressure and the direction of the field: since there are three spatial dimensions for each quantity there is a total of nine constants in all. Also, shearing motions can produce an electric field, so that for a full description of the piezoelectric effect for a given substance a total of 18 constants must be specified!
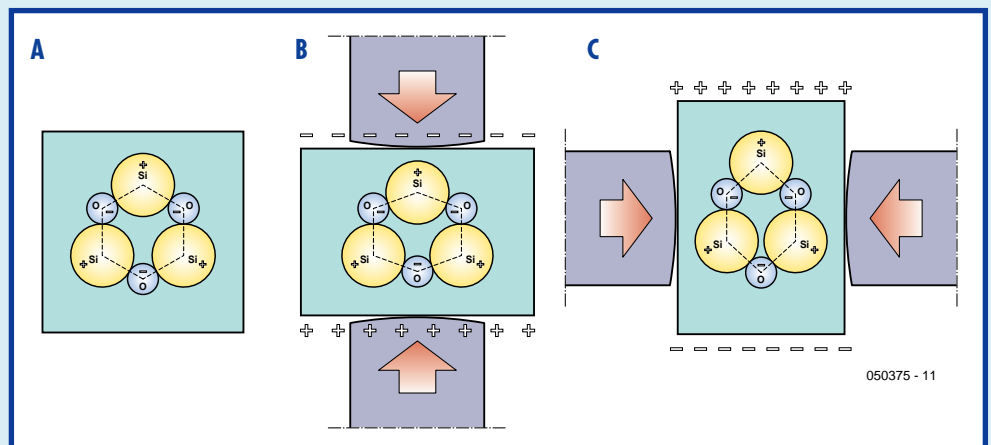
050375 - 11
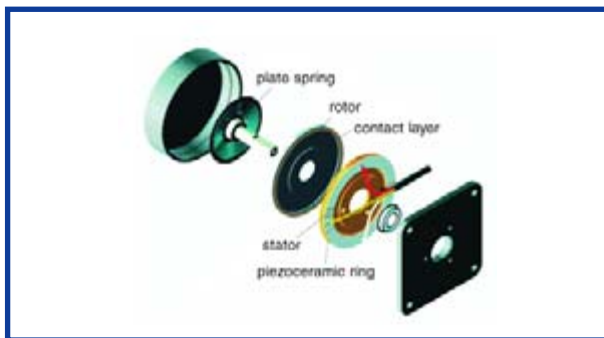
Another application is in the field of consumer electronics. Thomson make a rear-projection television where a piezoelectric actuator moves a mirror in the light path rapidly to and fro to move the picture up or down by up to one line. With the aid of a cunning control circuit the effective resolution is thus increased [3].

Piezoelectric motors

In a piezoelectric motor the oscillation of the fixed piezo element (the stator) must be transferred to the moving part

(the rotor). In principle the rotor can be periodically pushed by a linearly moving stator and be held fixed in between pushes (the 'inchworm' principle), or it can continue to move in the same direction because of its inertia. More advanced are the so-called ultrasound motors. Here the piezo element has a voltage applied to one side and is set oscillating using, for example, a squarewave signal. Strong resonance is achieved at a frequency between 30 kHz and 1000 kHz: hence the name 'ultrasound motor'. The material is shaped so that two oscillations (a bending oscillation and an extension oscillation) are superimposed, making the end of the stator move in an elliptical path. At one point on this elliptical path the stator touches the rotor, advancing it by a few micrometres. At a different frequency the two component oscillations are superimposed in such a way that the elliptical motion occurs in the reverse direction and the motor turns backwards.

This principle is used in a motor made by the company Elliptec. The compact unit comprises a 2 cm long distinctively-shaped aluminium piece incorporating a pioze element (see **Figure 1**) with a spring at one end. The spring presses on the element and its free end pushes on a small wheel or on a small plastic rod. A microcontroller is used to control the motor, generating a 5 V to 8 V square or sine wave. According to the manufacturer, the controller should have a resolution of at most 1 kHz (preferably 300 Hz): a single-pin output is sufficient. The best choice is to use a microcontroller with built-in PWM function. The squarewave signal must be amplified using two transistors and filtered using a coil to remove harmonics from the signal sent to the device [3].
At a frequency of around 79 kHz the Elliptec motor runs forwards, and at a frequency of around 97 kHz it turns backwards. The two partial movements are superimposed in a way that causes the elliptic movement to be backwards. The optimum frequency can be determined by the control electronics, for example by measuring the current consumption of the unit. The speed of the motor can be controlled by adjusting the mark-space ratio of the signal. The motor delivers a force of between about 0.2 N and 0.4 N; the step size is given by the manufacturer as 10 µm. One application for this tiny motor is in models: Märklin have used the motor to slowly (and hence realistically) raise the pantograph in a model electric locomotive [4].

Advantages

A piezoelectric motor produces no magnetic field, and can therefore be used in sensitive nuclear magnetic resonance tomography machines. Also, piezoelectric motors move in very tiny steps. The speed and power output of these motors is therefore limited, but the micrometre-scale steps allow an exceptionally high positioning precision. Once the desired position is reached a DC voltage can be applied, which allows partial forward or reverse steps with accuracy in the nanometre range. This makes the piezoelectric motor ideal for sliding stages in nanotechnology applications and microscopes and for micromanipulators in analysis and medicine (**Figure 3**) [5]. Machine tools where only a small holding force is required can also make use of piezo motors. In contrast to the motor described above, which only requires a single channel to control it, this type requires two, four or even more signal output channels. Trinamic in Hamburg have developed a control module for use with the piezo

motors produced by the Swedish manufacturer Piezomotor [6]. It generates four phase-shifted periodic signals with a programmable waveshape at a resolution of eight bits (**Figure 4**).

Travelling waves

The principle of the travelling wave motor, developed in the early 1980s in Japan, can be used to obtain precise rotational motion. The annular stator is made up of individual piezoelectric elements with alternate polarisations, connected together with a continuous metal contact. If a DC voltage in the region of 200 V is applied, the elements alternately expand and contract, deforming the stator ring into an undulating shape. A sinusoidal alternating voltage sets up standing waves. In order to create a travelling wave the ring is partitioned into two (or more) electrically isolated and separately stimulated zones. If sinusoidal signals are applied to the two zones with the same frequency but with a phase offset the standing waves superimpose to create travelling waves. The generally cross-shaped rotor, the same size as the stator, is pressed onto the stator by a spring such that there are always several moving points of contact (**Figure 5**). The advantage of this high-friction arrangement is that the travelling wave motor retains its position when power is removed, dispensing with the need for a brake. The rotor is driven round by the tangential component of the force from the travelling wave: the greater the force, the greater its movement. The speed of the rotor can therefore be controlled by adjusting the mark-space ratio of the drive signal: a higher mark-space ratio implies a greater displacement. Practical motors from various manufacturers achieve torques from 0.0003 Nm to 2 Nm with stator diameters from 3 mm to 90 mm. Rotational speed lies in the range from 2000 rpm down to 70 rpm with operating frequencies from 650 kHz down to 42 kHz.

This type of piezoelectric motor is distinguished by its excellent dynamics. Only small masses are being moved, which allows for high acceleration. Also, at very low rotational speeds, travelling wave motors can develop relatively high torque and a gearbox is often unnecessary. An alternative to this type of motor with rotating bending-mode waves is to use a stator with thickness extension mode oscillations; in yet another design a bending-mode wave is set up in a cylindrical stator. Usually microcontrollers are used for control, with a power output stage and possibly also a transformer to further increase the output voltage.

One application for such travelling wave ultrasound motors is in autofocus lenses. To produce a sharp picture, the individual elements of the lens must be moved together, usually on a worm-type drive. Since great agility is required but the distances involved are relatively short, the situation is ideal for a piezoelectric motor. Applications for piezoelectric motors are not yet exhausted provided their power can be increased further. They will shortly be used in aviation (for moving aircraft control surfaces) and in robotics. There is no technical reason why they could not also be used in such general-purpose applications as windscreen wiper motors or electric windows, but here the mass-produced conventional motor still have the upper hand in terms of mass-production costs.

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Applications of the direct and the inverse piezo effect

Direct piezo effect   (pressure to voltage)

Sensors (for pressure and acceleration)
Keyboards
Pick-up arms
Microphones
Spark production (gas lighters)

Inverse piezo effect   (voltage to pressure)

Resonators and sound
Ultrasound sources (liquid level measurement, flow rate measurement etc.) [5]
Piezoelectric loudspeakers
Frequency references
(quartz crystals, ceramic resonators)
Ceramic filters

Piezo actuators
Micropumps (Injection nozzles, inkjet printers, chemical analysis etc.)
Active damping systems
Consumer electronics (see text)

Piezo motors
Autofocus lenses
Sliding stages
(microscopes, medicine, tools etc.)
Modelling
Other applications still under development

References and links

[1] www.piceramic.com/piezoeffekt.html

[2] www.piceramic.com/technologie.html

[3] www.elliptec.com

[4] http://www.siemens.com/index.jsp?sdc_p=d1187140 i1184346lmn1184101o1184346pFEcfs5u20z1&sdc_sid= 32992667905&

[5] www.physikinstrumente.de/products/section7/ piezo_motor_index.htm

[6] www.piezomotor.se/

[7] Dynamics of Ultrasonic Motors, Thomas Sattel, dissertation, Darmstadt 2003.

A 16-bit Tom Th
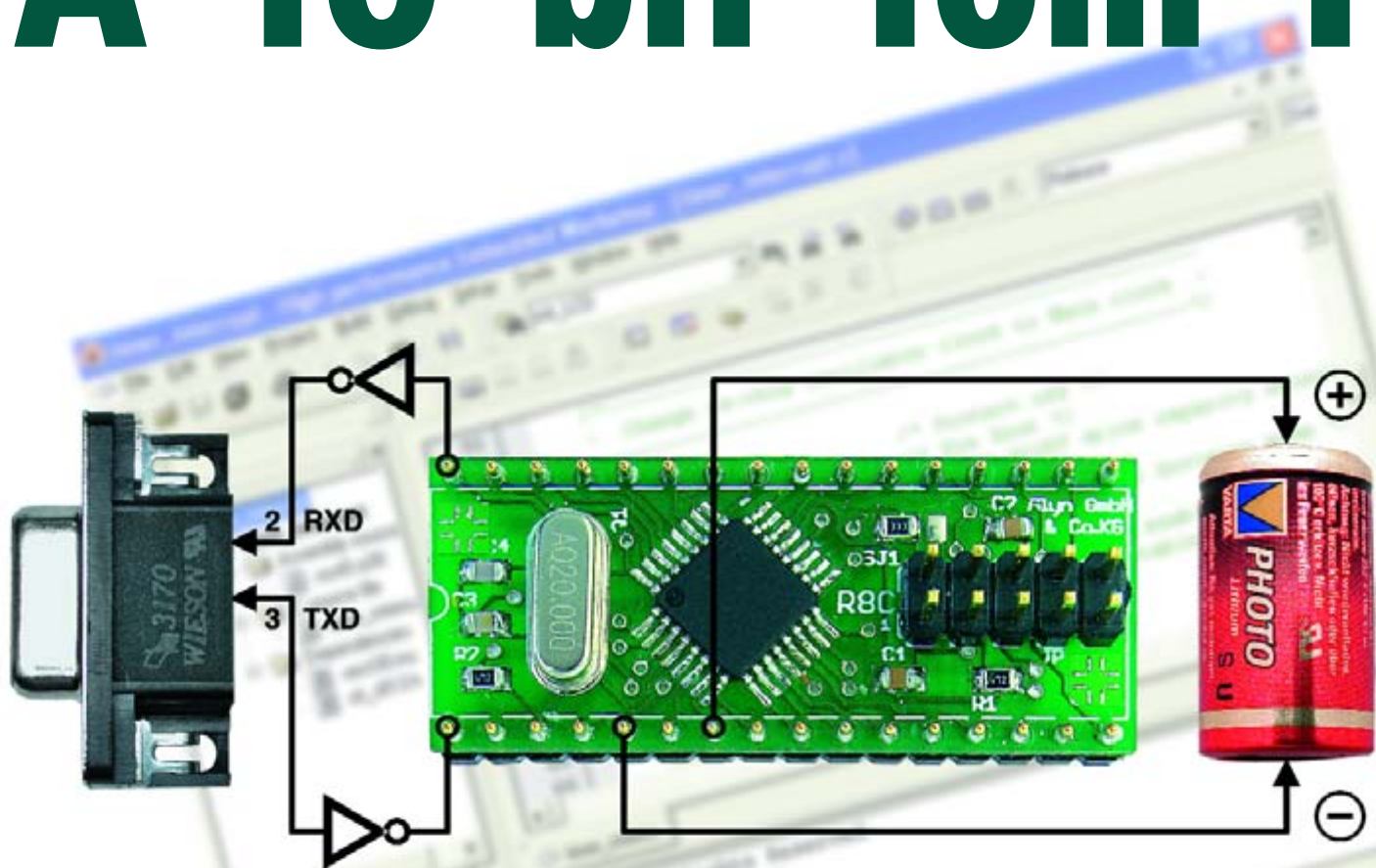
Gunther Ewald and Burkhard Kainka

Thanks to the efforts of Elektor Electronics and Glyn, for the first time now a European electronics magazine supplies a complete microcontroller starter board and accompanying software CD-ROM at a very attractive price. We already introduced the Renesas R8C in the last issue. Now it's time to start using it.

Now it's for real – from this issue you can order a circuit board with an R8C/13 microcontroller and the necessary software, at price consisting of P&P and handling only. **The service is strictly limited to stocks and provided exclusively for** *Elektor Electronics* **readers in co-operation with Glyn**. So if you want to grab an R8C starter kit, order it straight away — the online method using our website is by far the fastest.

There are three good reasons for using the Renesas R8C/Tiny family: first, it provides 16-bit computing power at a low price; second, it comes with a free but nevertheless very capable C compiler; and third, no programming hardware is necessary, because code can be easily downloaded to flash memory via the RS232 port. We already introduced the board and the software in the January 2006 issue. If you missed that article, you can download it free of charge from the *Elektor Electronics* website at www.elektor-electronics.co.uk (select the Magazine tab, then January 2006). Our objective in this article is to help you start using the board.

numb

Our R8C starter kit is available – now you can get going!

The software

When installing the necessary software, follow the instructions exactly as given in order to ensure that what you later see on your PC matches what we describe here. Install the KD30 monitor/debugger first, followed by the NC30 C compiler with the HEW development environment and an update. Installation in this order is important so the HEW will find the debugger already installed and link it in properly. Next, install the debugger package in order to integrate the debugger into the development environment. Later on, you only need to start the HEW in order to have everything together on your screen. Finally, you have to install the Renesas Flash Development Toolkit (FDT), which enables you to download finished programs to the microcontroller.

After you insert the CD, a product summary in PDF format will be displayed first. You should see the main directory of the CD after you close the product summary. Alternatively, you can right-click on the drive icon and select 'Open' in order to skip the PDF intro. The most important directories on the CD are \Software and \Sample_NC30. They contain all the necessary programs (which should now be installed) and the initial sample projects.

1. KD30
The executable installer file KD30V410R1_E_20041203.exe. is located in the \Software\kd30400r1\ directory on the CD. Start the installation and confirm the default path C:\MTOOL\.

2. NC30
Run the setup file nc30wav530r02_2_ev.exe in the \Software\ nc30v530r0_hew\ directory on the CD. First you have to select whether you want to install the Japanese version or the English version. Most of our readers will probably prefer the English version. The program suggests C:\Program Files\Renesas as the default installation path. You should confirm this path.

A second default path is shown for the tool chain: C:\Renesas\NC30WA\V530R02. You should also accept the default path name, as well as all subsequent default path names.

At the end of the installation, an individual site code is displayed. You can ignore it, because it is only necessary for registering the software. If you purchase the full version of the compiler, you will automatically receive a CD with your own
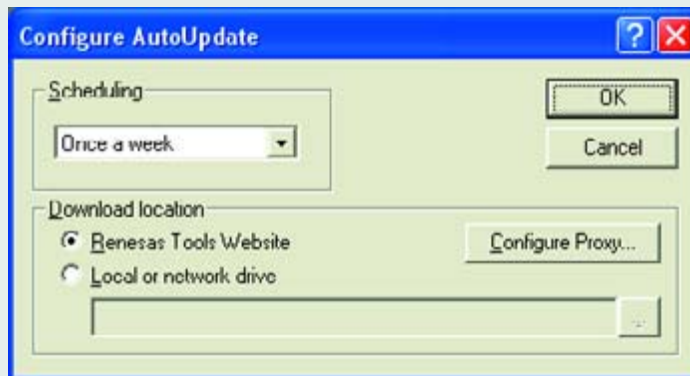
code for enabling the software.

After you have installed the HEW, you have to run the installer for the AutoUpdate program. As shown in the figure, confirm that you wish to receive weekly updates from the Renesas Tools website. That enables you to keep your software 'fresh' all the time. If the PC on which your software is installed does not have access to the Internet, you can cancel installation of AutoUpdate without causing any problems. The most recent update file is on the CD, and it must be installed next.

After being installed, the updater immediately checks to see whether there is anything new and automatically downloads the latest changes. The first update will then be installed automatically. The PC must then be restarted before you continue.

3. Update HEW
This step is only necessary if you have not already downloaded the latest update from the Internet and installed it. Run the first HEW update from the CD by starting hewv40003u.exe in the \Software\HEW_V.4.00.03.001_Update directory on the CD. That will update your compiler to the latest version (Database Version 7.0). That is important, because the sample projects have been generated for this version. Although you can use the new version to load older projects, which will then be updated automatically, regressing to an older version of the compiler is not that easy.

4. Debugger package
Run the installer file m16cdebuggerv100r01.exe in the \Software\Debugger Package\ directory on the CD. Follow the instructions of the installer program and confirm your agreement to the licence conditions. Everything else is automatic. You must restart the computer after this installation.

5. Flash Development Toolkit
Install the FDT by running the installer file fdtv304r00.exe in the \Software\Flasher_FDT directory on the CD. Confirm all default settings. Everything else is automatic.

When everything has been installed, you will find the Renesas program group under Start / All Programs. The two relevant programs in the group are High-performance Embedded Workshop and Flash Development Toolkit.

Figure 1. The hardware you can order from us at low cost forms a complete microcontroller system.

Figure 2. The fully assembled board with the pin headers fitted.
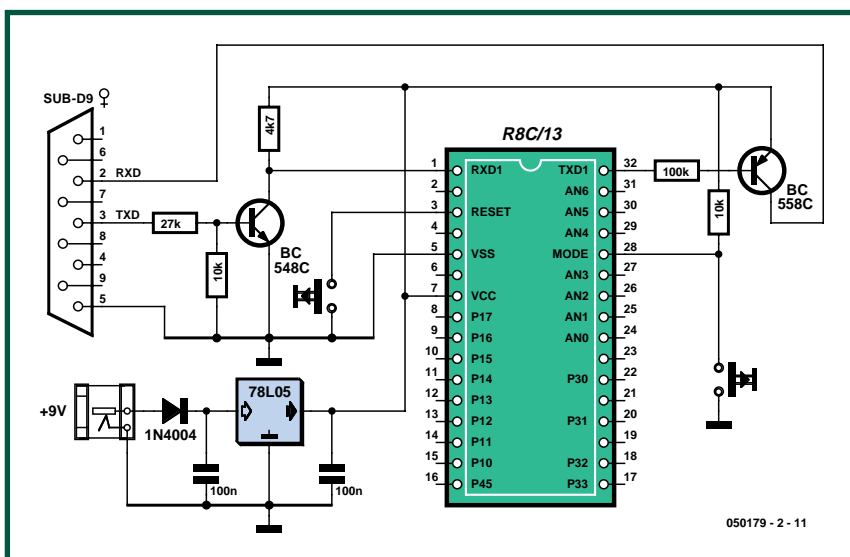
Figure 3. The circuit diagram of a minimal system for initial tests.

The hardware

The low-profile PCB with pre-assembled SMD components is supplied with two pin headers that you must fit and solder yourself (**Figure 1**). That yields a complete processor module in the format of a 32-pin DIL IC (**Figure 2**). There is also space reserved on the board for a 14-way pin header, but it does not have to fitted right away because it is only needed for the E8 debugger.

The actual microcontroller (the R8C/13) is contained in the 32-pin LQPF SMD package, which measures 7 by 7 mm and has a lead spacing of 0.8 mm. The marking 'R5F21134FP#U0' reveals that it is an R8C/13 with 16 KB of flash ROM. We selected the R8C/13 because it has the same characteristics as its 'siblings' (R8C/10, R8C/11 and R8C/12). The board also comes fitted with a 20-MHz crystal and the necessary capacitors, as well as several other capacitors and resistors. Altogether, this amounts to a complete microcontroller system. Once a program has been loaded, all you have to do is connect a 3.3-V or 5-V supply voltage and you've got a working system. Program code can be loaded using a serial interface; no special programming hardware is necessary. That's because the microcontroller has a debug interface and a corresponding boot program that can be used to copy the software into the flash ROM.

First contact

In the next issue of *Elektor Electronics*, we will describe a complete development system with RS232 and USB interfaces. But you naturally don't want to wait that long to try out the board. For that reason, we describe a solution here that only requires a few components from your parts bin:

• a source of 5-V power, preferably stabilised by a voltage regulator
• an inverting level converter for connection to the RS232 port
• a pushbutton reset switch
• a mode switch to select the programming mode

The microcontroller board feeds out all the microcontroller leads one to one. As we already mentioned, a crystal, a few capacitors and some resistors are fitted on the board. The schematic diagram in **Figure 3** shows only the con-

nections that are essential for a 'quick start', so you can get your bearings as fast as possible. The connections not shown in the figure must always remain open. **Figure 4** shows an experimental setup on a prototyping board. The serial port of the PC is connected here via transistor inverters. Although a MAX232 could be used just as well for this purpose, the transistors will probably be easier to find in your parts bin. A BC548C NPN transistor inverts the TXD signal from the PC and feeds it to the RXD1 input of the microcontroller. This input does not have an internal pull-up, so the collector resistor is essential. In the opposite direction, TXD1 drives a BC558C PNP transistor. The RXD input of the PC has its own pull-down, so the collector resistor can be omitted here.

The MODE input of the microcontroller determines whether the internal boot program or a downloaded user program is run after a reset. The MODE input is pulled high by a 10-kΩ resistor when the switch is open, which causes the user program to be started. If you want to load a program into the flash memory, you first have to close the switch in order to pull MODE low. Then you must briefly press the Reset switch. That causes the microcontroller to start up in the debug mode, which allows new software to be loaded into the flash ROM. After the software has been transferred, open the Mode switch and press the Reset switch again. That causes the downloaded program to be started. However, duty comes before pleasure, and in this case the duty is installing the software on the PC. That's described step-by-step in the inset. Follow the instructions exactly as given in order to ensure that what you later see on your PC matches what we describe here.

Ready, set, flash!

The first thing you should do is to try out the Flash Development Toolkit (FDT) by downloading a finished program to the microcontroller. For the time being, we'll skip the process of developing you own programs, so you can enjoy some tangible results as soon as possible.

After installing the Renesas software package, you will find the FDT program in the Windows 'Start' menu. The program is shown there in two versions: a full version and a compact
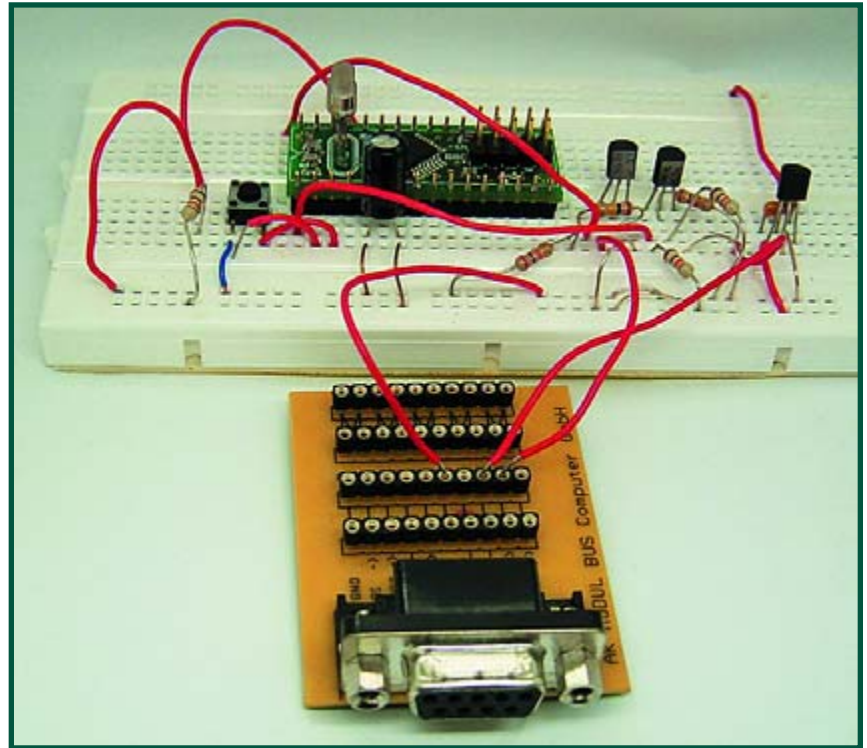
Figure 4. A prototype of the test system built on a lab prototyping board.

'Basic' version. Start 'Flash Development Toolkit Basic' (**Figure 5**).
You must configure several settings the first time you start the program. If necessary, you can access them later on via the Options / New Settings menu. Select 'R5F21134' as the microcontroller type, and select the upper of the two core protocol options (**Figure 6**).
In the next window, select the serial interface port from the range COM1–COM4. The third window asks you to specify a baud rate for the link to the microcontroller. Enter '9600 baud' here (**Figure 7**).
Finally, you have to specify whether you want to enable readout protection for the microcontroller. As the risk of criminal industrial espionage is rather small with the initial familiarisation programs, you can dispense with any form of protection. Save the settings as shown in **Figure 8**. That completes the preparations.

Hurrah, it blinks!

Now connect the board to the specified COM port on your PC. Close the Mode switch and briefly press the Reset switch. The microcontroller will enter boot mode and wait for you to send it data.
The next step is to download a fully

compiled program to the microcontroller. On the CD, you will find the 'Sample NC30' folder with several sample projects. That includes the project folder 'Sample_NC30\ port_toggle', which contains the folder 'port_toggle\ Release'. The file port_toggle.mot is located in the latter folder. It is a program in Motorola hex format that can be downloaded directly to the microcontroller.

Specify the path to this file, and then start the download process by selecting 'Program Flash'. The download takes around two seconds. The flash memory is first erased, and the new program is then copied over. If everything goes properly, the message 'Image successfully written to device' will be displayed. Open the Mode switch and briefly press the Reset switch. That will start the program that you just downloaded.

The program toggles the first four lines of Port 1 (P1_0 to P1_4) at a slow rate, so you can observe their states using a LED with a series resistor. The ports of the R8C and the other M16 microcontrollers have a low impedance in the output direction, regardless of whether they are in the high or low state. That means you must always use a series resistor (1 kΩ, for

Figure 5. The Flash Development Toolkit, Basic version.

example) when connecting a LED to them (**Figure 9**).

All of the sample programs described below can be copied to the microcontroller in the manner just described. If the R8C cannot be flashed due to a communication error, it must be left without power for one minute to erase the internal RAM loader. This error can occur if you have been working with the debugger before attempting to download a program.

The R8C as a musician

Like to try another hardware test? Then download the 'Jingle_Bells' Motorola file from the R8C project to the microcontroller. Connect a small 8-Ω loudspeaker or a headphone with a 1-kΩ series resistor to the board (**Figure 10**), and then start the microcontroller. You will hear a simple melody. Incidentally, this program uses the internal high-speed ring oscillator (8 MHz) and does not require the crystal oscillator. If you touch an oscilloscope probe to the crystal lead Xin (pin 6) or Xout (pin 4), you will see that no clock signal is present (in contrast to the situation with the port_toggle project). As you can hear from the absence of any sour notes coming from the speaker, the internal RC oscillator is fully adequate for this task. That means you could flash the program into an R8C/13, connect it to a piezo-electric speaker and a 3-V button cell, and hang it from your Christmas tree or insert it in a Christmas card.

Now that you know the hardware is OK, your fingers are probably itching to start programming something, aren't they? OK, it's time to start up the integrated hardware development environment (HEW). In order to keep things fairly simple at first, let's start by making a few changes to an existing project. We'll also work without the debugger to start with.

High C

You can use HEW to generate assembly-language projects. However, programming the R8C in assembly language is significantly more difficult than programming it in C, because there are so many different data formats and addressing modes. The C compiler looks after all that for you. You don't even have to know whether the microcontroller is processing a word, a byte or a bit. In this case, C is easier than assembly language even for people who are only used to working in assembly language. The unfamiliar notation will quickly become second nature after you work through a few examples, so there's no need to be afraid of C!

First copy the entire 'port_toggle' project from the CD to your PC. When you start a new project, use a directory such as C:\WorkSpace, which is also the default directory suggested by HEW. In the Renesas program group, start the 'High-Performance Embedded Workshop' program. A selection window is displayed when the program starts, and you can specify whether you want to generate a new project or open an existing project.

Use File/ Open Workspace to open the port_toggle file. All the files belonging to the project will then be shown at the left. Click on port_toggle.c to open the source code file. Everything should then appear as shown in **Figure 11**.

Next, you should try to compile the project, just for the exercise. First you have to decide whether you want to generate a debug version or a release version. You should work without the debugger for now, which means you should select the 'Release' option
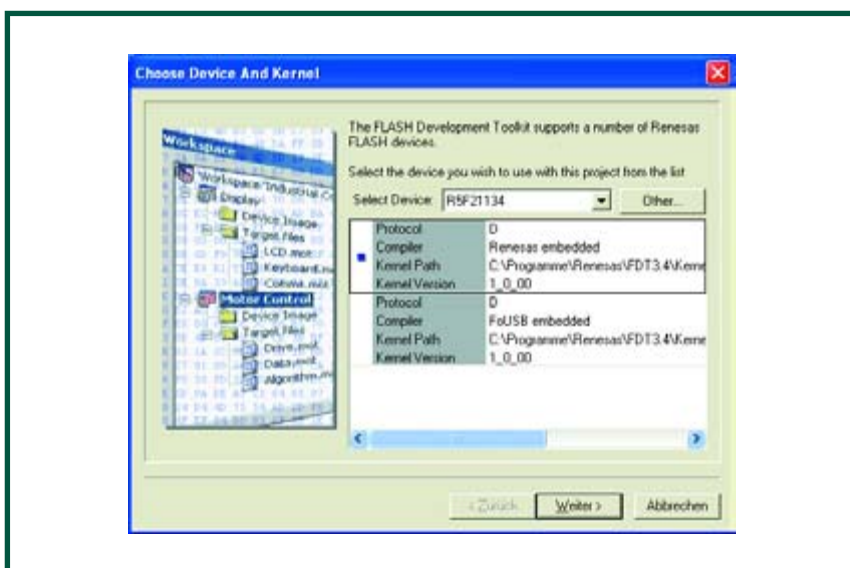
Figure 6. Selecting the microcontroller type and transmission protocol.

under Build / Build Configurations. Then start the compilation by selecting Build / Build All. The C source code will be compiled, linked, and written to the output directory \Release in the form of a Motorola hex file. The entire process is listed at the bottom of the Build window. At the end, you'll see the longed-for message that signals success:

Build Finished
0 Errors, 1 Warning

No errors – that's very good! Warnings occur relatively often and aren't all that dramatic. In this case, the warning reads: 'Warning (ln30): License has expired, code limited to 64K (10000H) byte(s)'. You don't have to worry about that, because you're using the free version of the compiler, and 64 kB is anyhow more than R8C/13 can hold. If you wish, you can download the output file to the microcontroller again and run the program. It will work just as well as the Motorola hex file on the CD.

Now let's have a look at the source code:

```
while (1)          /* Loop */
    {
    p1_0 = 0;
    p1_1 = 0;
    p1_2 = 0;
    p1_3 = 0;
    for (t=0; t<50000; t++);
    p1_0 = 1;
    p1_1 = 1;
    p1_2 = 1;
    p1_3 = 1;
    for (t=0; t<50000; t++);
    }
```

The core of the program consists of a simple, self-explanatory loop. First the ports are enabled, then there is a wait loop, then the bits are disabled, and finally there is another wait. Even if you don't have any experience with C, you can right away see where you could make some changes. For instance, you could shorten the wait loops to make everything run a bit faster. For example, you could set the count to 25,000 instead of 50,000. You could also try reducing the count to 2 and see how fast it runs then. You can even remove the wait loops entirely by using the comment sign '//' to render them ineffective. Of course, you won't be able to use a LED any more to check the signals, but an oscilloscope will show a high-frequency square-wave signal. Each time you modify the
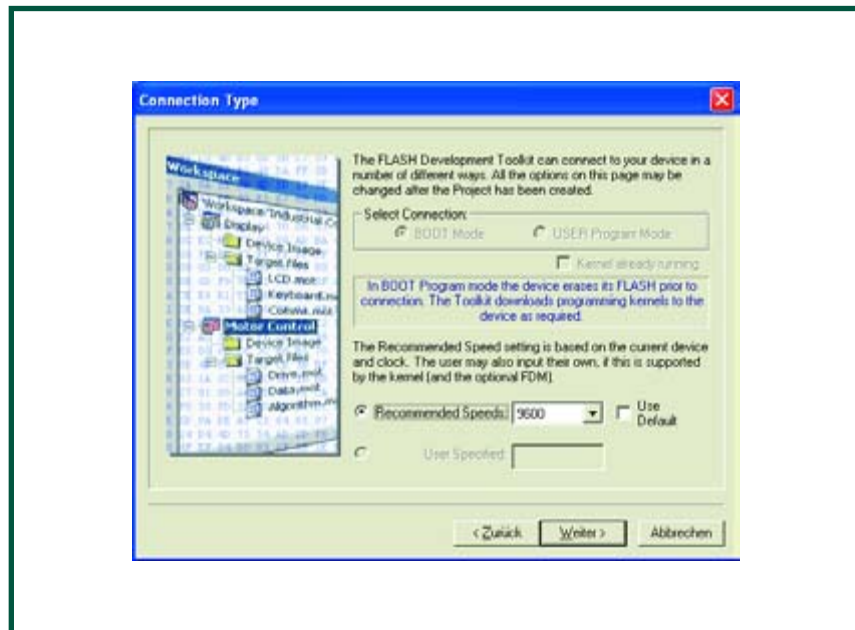
Figure 7. Selecting the baud rate.

program, you must use Build All to compile the program and then use FDT to download it to the microcontroller again.

A sense of time

Now we come to the crystal oscillator of the microcontroller. The port_toggle sample program uses the crystal oscillator, which runs at 20 MHz. As already mentioned, there are also two internal RC oscillators with frequencies of 125 kHz and 8 MHz, respectively. In fact, the microcontroller always starts up with the low-speed ring oscillator enabled. If you look at the data sheet for the R8C/13, you will see the complicated clock-generation arrangement for the R8C, with a total of three oscillators and several optional divider stages.

The port_toggle sample project demonstrates how to switch from the 125-kHz oscillator to the crystal oscillator:

```
prc0 = 1;    /* Protect off */
cm13 = 1;    /* Xin Xout */
cm15 = 1;    /* XCIN–XCOUT
drive capacity select bit : HIGH
*/
```
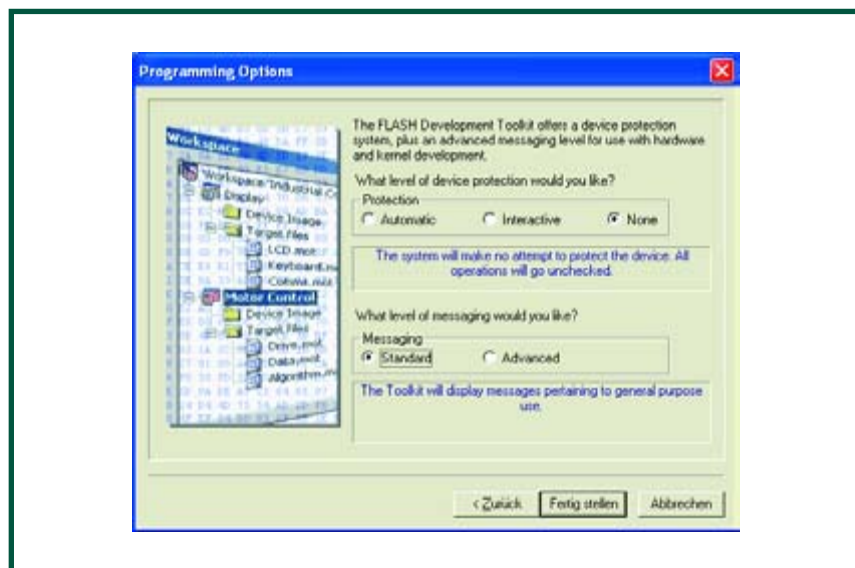

Figure 8. Readout protection is unnecessary.
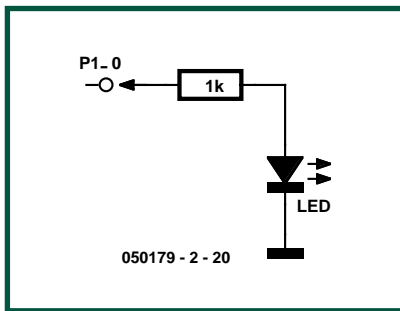
Figure 9. Connecting a LED to P1_0.
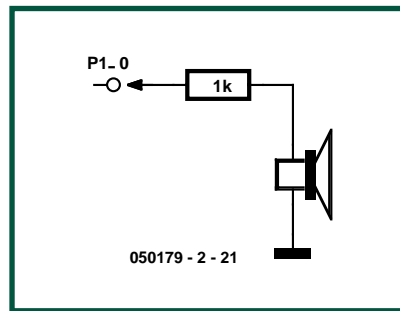
Figure 10. Connecting a loudspeaker to the microcontroller.

```
    cm05 = 0;    /* Xin on */
    cm16 = 0;    /* Main clock = No
division mode */
    cm17 = 0;
    cm06 = 0;    /* CM16 and CM17
enable */
    asm("nop"); /* Waiting for
stable oscillation */
    asm("nop");
    asm("nop");
    asm("nop");
    ocd2 = 0;    /* Main clock
change */
    prc0 = 0;    /* Protect on */
```

The above listing shows the relevant instruction lines at the beginning of the source code. It's necessary to change a few control bits in System Clock Control Registers 0 and 1, but they are initially in protected mode. This protection is disabled in the first line so the relevant control bits can be altered. After the bits have been switched, we have to wait a little while for the oscillator to stabilise after being started up. After this, the clock source is changed and write protection is re-enabled. From now on, all programs will run at 20 MHz.

If you now remove this entire block of code from the listing, including prc0 = 1 and prc0 = 0, the oscillator will not be changed and the microcontroller will continue operating at 125 kHz. To make it possible to observe the result within a finite length of time, you must also shorten the wait loops by a factor of 100:

```
void main(void)
{
    pd1 = 0x0F;  /* Set Port 1.0 –
1.3 be used for output*/

    while (1)      /* Loop */
        {
        p1_0 = 0;
```

```
        p1_1 = 0;
        p1_2 = 0;
        p1_3 = 0;
        for (t=0; t<500; t++);
        p1_0 = 1;
        p1_1 = 1;
        p1_2 = 1;
        p1_3 = 1;
        for (t=0; t<500; t++);
        }
}
```

The LED will blink somewhat more slowly now, but the microcontroller will run with very low power consumption.

The internal high-speed ring oscillator, which runs at 8 MHz, provides a compromise between really fast and really slow. The Jingle_Bells sample project shows how you can use it. Copy the following relevant instruction lines into your program:

```
    prc0 = 1;            // Enable
High Speed Oscillator (8 MHz)
    hr00 = 1;
    asm("NOP");
    asm("NOP");
    hr01 = 1;
    prc0 = 0;
```

You should also have a look at the Timer_Interrupt project. If you're trying to use a timer for the first time, you can of course pore through the R8C/13 data sheet, but it's better to start with a working bit of code from a sample program and then read the relevant portions of the data sheet while trying out your own modifications. Besides timer initialisation, the Timer_Interrupt sample program shows how to implement an interrupt function in C. You'll find even more sample programs in the application notes on the CD.

If you're now eager to generate your own personal project, you can find the necessary information on the *Elektor Electronics* website at www.elektor-electronics.co.uk (look for the R8C link in the right-hand column). There you will find a simple example that explains in step-by-step fashion how to generate your own application program without relying on an existing project. And if you still have questions, a dedicated **Forum topic** for the R8C starter kit has been set up on the *Elektor Electronics* website.

(050179-2)
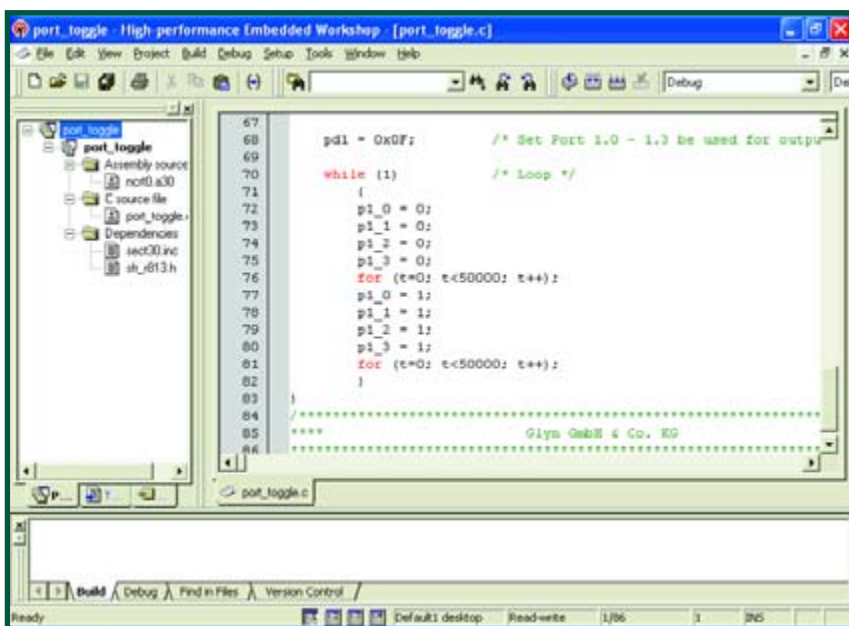
Figure 11. The port_toggle project in the development environment.

Reference
www.glyn.com

Inexpensive (web)
Modify a router/switch — Mo

Jeroen Domburg & Thijs Beckers

Do you have an (old) PC that functions as a server and is turned on 24 hours per day? That takes quite a lot of energy. It can be done much cheaper, using a modified router. We do need to add some extra storage space, but that isn't a problem! In this article we'll show you how you can add a USB port to an inexpensive router. Apart from providing the required memory expansion it also offers the possibility for many other applications...

The UK and many other counties are currently swamped with (A)DSL and cable Internet connections. Most of these connections only permit one PC at a time to connect to the Internet. There are several ways round this problem, allowing a number of PCs to use the Internet simultaneously. The most popular solution makes use of a so-called 'router'. This is a small box into which the Internet cable plugs. A number of PCs can also be connected, all of which then have access to the Internet. These boxes are often considered as 'black boxes'. It does what it's designed to do and it doesn't really matter what's inside. They're rarely opened, since it hardly makes sense to repair them. For less than twenty pounds you can get a new one. Because of this, only a few people are aware that such a router is in fact a small computer with a proper operating system on board.

There are five Ethernet ports, one power connector and a reset button, but no USB socket... and we do need one of these. We have to do something about that.

Inside the box: there is some space left on the board where components have not been mounted, which will come in very useful.

Close-up of the 5 V supply (still to be built). This is required for the USB port. The empty space suggests that the voltage would be regulated by U10 and a handful of passive components...

server
dding pays!

One of the cheapest routers that is currently available is the Sweex LB000021. This router is for sale for as little as £19. It is a low-cost router that uses Linux for its operating system. Linux, and a few other tools running inside the router, are open-source programs under the GPL licence. The most important requirement of this license is that the source code used in the product has to be included with it. The fact that the source code is openly available makes it possible for the router to be used in applications that weren't even considered by the manufacturer.

From the outside the device doesn't look special. It is a small box with only six connectors: a power input for the supplied power-supply, an Ethernet socket for the cable from the ADSL or Cable modem and four Ethernet sockets for connecting the PCs. What can't be seen from the outside is that there are two other useful connectors hidden inside the router, which have not been used by the manufacturer.

When we open the router (which is easily done by unscrewing four cross-headed screws from the underside of the case), we can take a look at the PCB. The design is typical of many embedded products. We can see RAM and ROM chips, the baluns for the Ethernet connections and an ADM5120P at the heart of the router. This chip contains everything required to implement a router: a MIPS based processor, an embedded switching system for the four local Ethernet connections, two MACs for the Ethernet communications, two USB ports, a serial port and a handful of general-purpose I/O lines. Not all of these can be accessed from the outside of the router. The two most obvious missing connectors are the two USB ports. This can however be rectified. If you take a look at the PCB inside the router, you'll see that some space has been reserved for the USB ports. It's just that the parts for these weren't mounted during the manufacturing process. It's therefore possible to add these USB ports yourself (see inset).

USB ports are obviously a nice addition, but what can you do with them?

...but we don't need to supply a lot of power so instead of the elegant circuit that the manufacturer had in mind, we'll use a 7805. The centre pin is the negative connection and for C91 we'll use 100 µF.

Apart from 5 V, the controller also requires a clock signal, which is supplied by X1. According to the datasheet this little package should be a 48 MHz type. R16 (1 kW) also needs to be mounted.

It's not the end of the world if you can only get the crystal in a rectangular package. If you just solder the two leftmost connections normally...
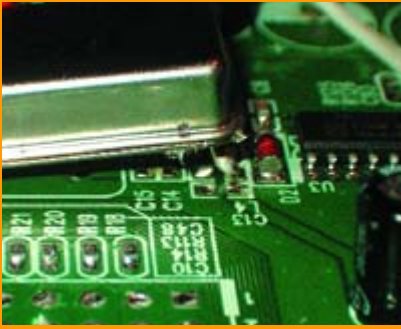
...you can solder the bottom-right connection to the right-hand pad of L4. The remaining connection (top-right) isn't required and can be cut off.
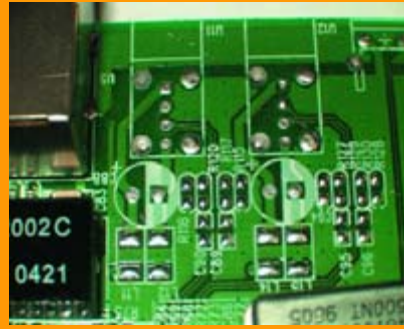
Now it's the turn of the components around the USB port. Although there is room for two USB ports, we only build one.
If you want to use more USB devices it is easier to use an external USB hub.

From left to right: an electrolytic capacitor (10 mF) and four resistors (15 k, 22 W, 22 W and 15 k). L1 and L2 should really be inductors, but it works just as well if you use wire links. C95 and C96 can also be left out.

As it is, the router can be easily hacked by modifying or replacing the programs stored in its Flash memory. A number of people have done this already and have added several functions to the firmware. Details can be found in references [1] and [2].

One problem you come up against when adding software to the Flash memory is that the available memory is fairly sparse. The Flash-ROM inside the router is 'just' 2 Megabytes. This is microscopic compared to modern hard drives in PCs, which can easily be 100,000 times as big. It's therefore not possible to add many programs if you just make use of the Flash memory.

Luckily there is a way round this problem. When you connect a USB drive to the (just added) USB port of the router, the router can use this as a hard drive. If this USB drive is a card reader or a

USB memory stick, the resulting server will be smaller than a lunch box. On this server it should be possible to install all applications that can be installed on a normal server. On top of this, when you use Samba (Windows Network access for Linux) the USB drives can be made accessible to everybody on the network, without having a power-hungry PC on day and night. The router can also function as a web server. The files required to implement this can be found on our website at www.elektor-electronics.co.uk (click on 'Magazine', then underneath 'Archive' click on the arrow next to the year and choose the required month). With the right programs and hardware it is even possible to build domotica projects. This will be covered in the next instalment.

(050360-I)

Web links:
[1] www.norocketscience.com/router
[2] http://midge.vlad.org.ua/wiki

About the author:

Jeroen Domburg is currently studying electronic engineering at the Saxion University in Enschede, The Netherlands. He is an enthusiastic hobbyist, who spends much of his spare time on microcontrollers, electronics and computers. In this section we will be able to examine and build some of his projects. This project can also be found on the Internet at http://sprite.student.utwente.nl/~jeroen/projects/lb000021

Female USB connectors aren't easy to get hold of, but you could also use a socket from a USB extension cable. Do take care that the socket doesn't make contact with the pads of SW1.

We still need to make a hole in the case for the USB socket. Since we've already invalidated the warranty by modifying the PCB, it doesn't really matter if we add a hole to the case as well.

Now the router has a fully functioning USB port. We recommend that you use a 512 MB Compact Flash card as hard drive, which will contain all programs and data.

Audio Amplifier w

Design flaw or IC manufacturer fiasco?

A few months while scrutin-
ising a great design for a pulse-width modulated audio
amplifier with a 2x100 W power rating and a very small
enclosure, we were immediately very enthusiastic and
thought this design would certainly deserve a place
in *Elektor Electronics*. So our resident audio
designer was going to put the circuit through
its paces. The results were most unusual and
this led to an extensive investigation of
what was wrong with the amplifier.
Was there a fault in the design
or was something else the
matter? This turned out to
be quite a quest…

ith Problems

Ton Giesberts
Design: Stefan Wicki
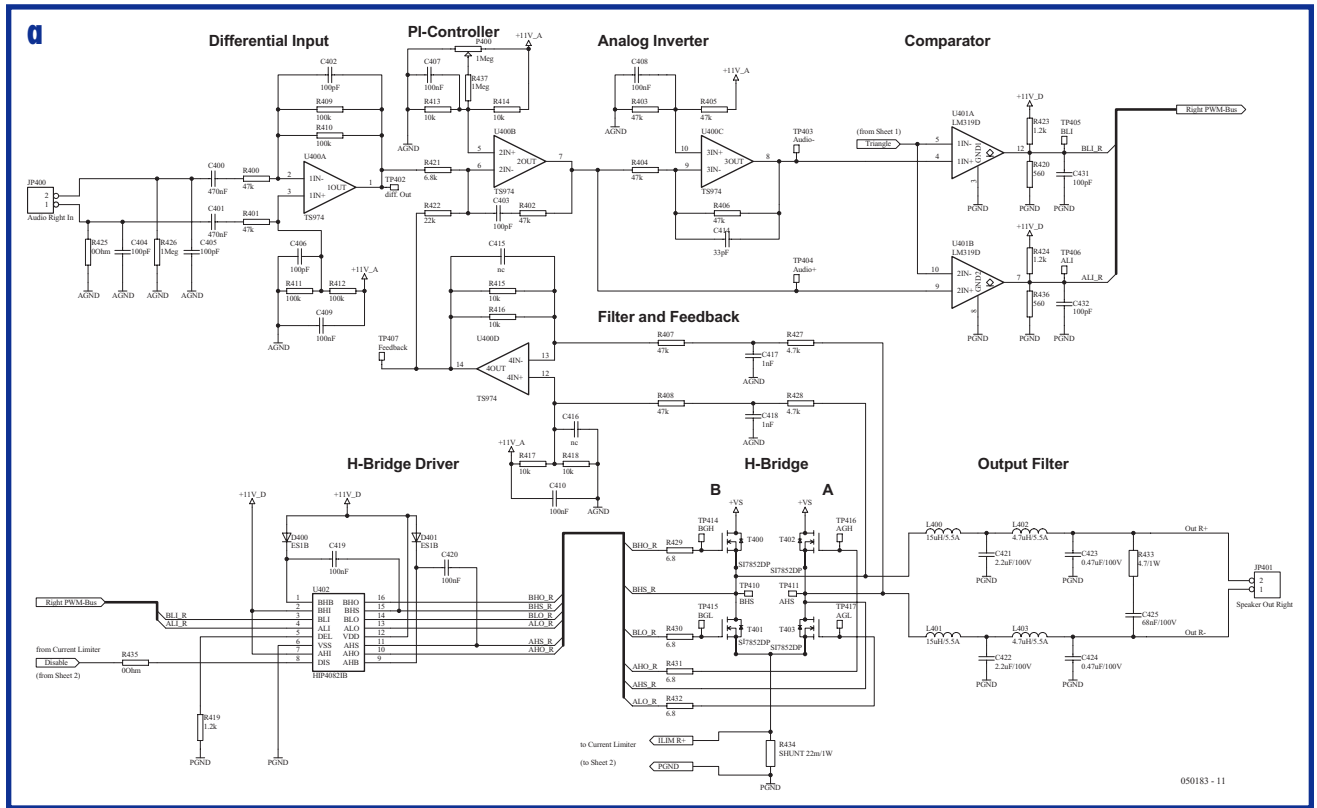
Figure 1. One channel of the CDAMP designed by Mr. Wicki (a) and the accompanying triangle generator (b).

First impressions looked so promising! The Swiss lecturer in electronics Mr. Stefan Wicki offered us a design for a power amplifier (the 'CDAMP') that he had developed and uses as a construction project for his students at the University of Applied Sciences in Aargau. The schematics and photos looked very promising and the prototype in a very small enclosure arrived in due course.

The amplifier appeared to have been well thought through, both externally as well as internally (see photo). All connections are located on the rear. On the front you will find two LEDs and the on/off-switch. The amplifier is almost completely built with SMD parts and is well presented. The enclosure is made entirely from aluminium and as a result has a solid look. One detail that attracted our attention however was the way the input signal was routed from the input to the PCB.
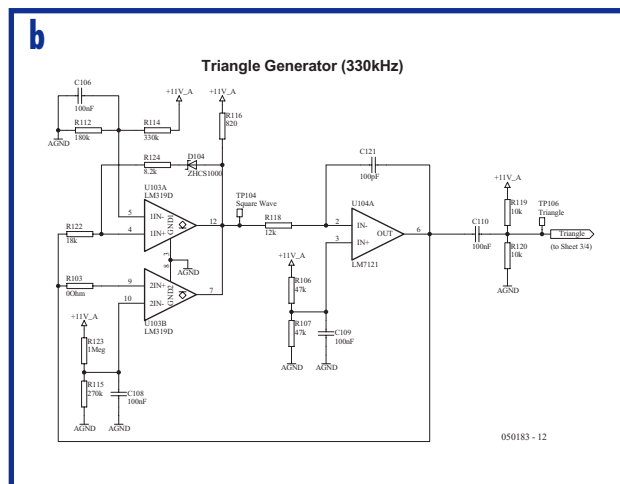
Here two thin twisted litz-wires are used per channel, but these were seen to run right over the top of the output filters and final power stages!

Schematic

The amplifier was accompanied by a detailed circuit description, which explained the operation of all parts at length. In **Figure 1a** we show the schematic of one output stage (as drawn by the author). This clearly illustrates the design of the amplifier together with the triangular-wave generator (**Figure 1b**). For clarity, we have left out all the other parts (other channel, power supply, protection, etc.). The audio signal goes to an input buffer first, and is then combined in a pi-style regulator with the feedback signal from the output stage. The signal then continues on to two comparators operating in anti-phase, which compare the voltage with the signal from the triangle generator. The comparators supply the PWM signal that is used to drive the final stage. The final stage consists of a bridge of four power FETs. The loudspeaker is connected between the FETs via an output filter. A special H-bridge IC from Intersil provides the

gate drive for the FETs. In addition to generating the correct drive signals, the IC also inserts a brief 'dead' time at the switching edges to prevent the two series-connected FETs from conducting at the same time during the transition. This is the whirlwind overview of the design. Complete schematics and a detailed description are available from the designer's own website (www.wictronic.ch).

First measurements

According to the accompanying technical specifications, the distortion from the amplifier would amount to 0.05% (THD) and that sure is a very good value for a class-D amplifier. We were therefore curious what the outcome of our own measurements would be. So we went to work in the *Elektor Electronics* lab with our Audio Precision System Two analyser.

The first measurement was to determine the distortion of one half of the bridge into a load of 4 Ω. It is common practice to measure the distortion at 1 kHz with an output power of 1 W. To our surprise this turned out to be several percent, measured from one half of the bridge to ground. Also, when viewing the signal on a 'scope, the distortion was clearly visible. The sine shape was flattened on top quite early on. Measuring symmetrically, between the two half-bridges, the signal was reasonable, however. But even then the distortion was still more than a worrying 0.5%. Is there something wrong with the prototype; perhaps it is not

adjusted properly? Since the amplifier only operates from a single supply voltage, both the FET outputs have to be at half the power supply voltage for optimal output. This appeared to be correct and this was also the only adjustable parameter in the entire design.

The fact that the symmetrically measured distortion is lower can be explained by the fact of the symmetrically implemented negative feedback. Any errors in the signal processing are then reduced depending on the amount of negative feedback. But since the schematic clearly shows that both halves of the bridge are identical and are driven by identical (antiphase-) signals, the difference between the outputs (apart from the phase) and therefore the distortion, should be minimal. Each of the bridge halves actually produced a signal with different amplitude and distortion. So the plot thickens.

In order to see exactly what was going on, the amplifier was driven a little harder, supplying 10 W into 4 Ω (see **Figure 2**). The scope now displayed the output signal getting stuck at around 20 V. It appeared that there was clipping in the output stage, but this could not be possible because the power supply voltage was set to 30 V. Despite the 'clipping' phenomenon, the amplifier could be driven further (to 50 W into 4 Ω, see **Figure 3**).

In the waveform of **Figure 3** there appears to be crossover distortion. However we're dealing here with a class-D amplifier here, not with a class-B output stage! As a result of our
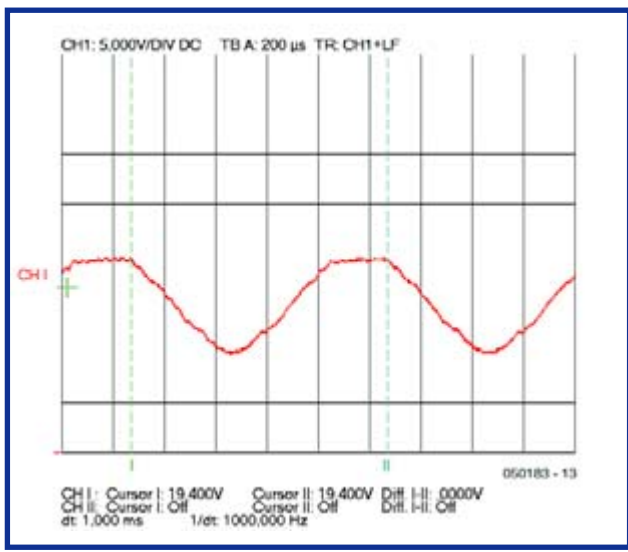
Figure 2. At an output of 10 W into 4 Ω
the output signal gets stuck at about 20 V.
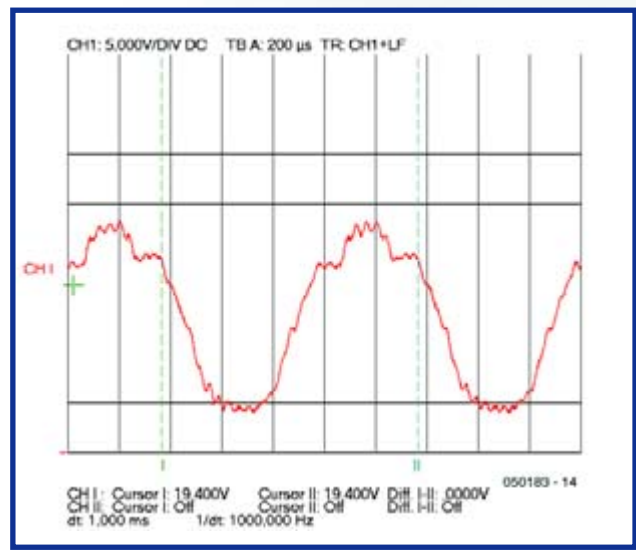
Figure 3. At increased drive (50 W/4 Ω),
a type of cross-over distortion seems to occur.

measurements we got the feeling that something was not right with this amplifier. Perhaps a component was defective? However, we could quickly rule that one out, since the other channel provided similar measurement results. What was going on here?

Back to the designer

Consulting with the designer of the circuit caused a reaction of disbelief over our measurements. He also asked us to assess the amplifier acoustically. The latter turned out – no surprise here – to be rather bad. During the listening test we also kept an eye on the speaker signal with an oscilloscope, and even then the crossover distortion in the bridge halves was visible.

We were also asked to confirm that the duty cycle of the amplifier equalled 50% without an input signal. This was correct and can be determined from the oscilloscope picture that clearly shows that the output is at half supply voltage. Next item on the checklist: was the power supply capable enough? That could surely not be the problem, we had used a big lab power supply that is capable of delivering at least 40 A.

After reporting our results we were asked to make a few more measurements on the amplifier, such as power supply voltage, differential input amplifier, the triangle amplitude and (again) the symmetrical output signal between the bridge halves. These were all correct, except for the output signal, as we had established earlier.

The designer also suggested overshoot in the output filter as a possible cause for the strong distortion, but in our opinion the output filter could never cause distortion this bad.

We were not making much progress here! According to the designer everything was in order (all the samples that he had built gave him comparable measuring results), but according to us something didn't smell right.

More measurements

After we had spent all this time on this amplifier we could not just abandon it and we decided to investigate further to determine the cause of the amplifier behaviour. The preceding measurements gave the impression that the input amplifier, the internal regulated power supply and the PWM-modulator were all largely correct. But there was still no explanation for the severely distorted output signal from the bridge halves. To check the signals to the driver IC for the MOSFETs, we measured those via a small low-pass filter (10 kΩ/100 pF).

The signal (**Figure 4**) did not show any asymmetry on either input to the HIP4082 (the noise is the remainder of the PWM-modulation). This signal is not quite sinusoidal because the negative feedback in the output stage compensates and this results in a deviating curve.

This led is to the conclusion that the driver IC, a HIP4082 from Intersil, had to be responsible for the problems in the output stage.
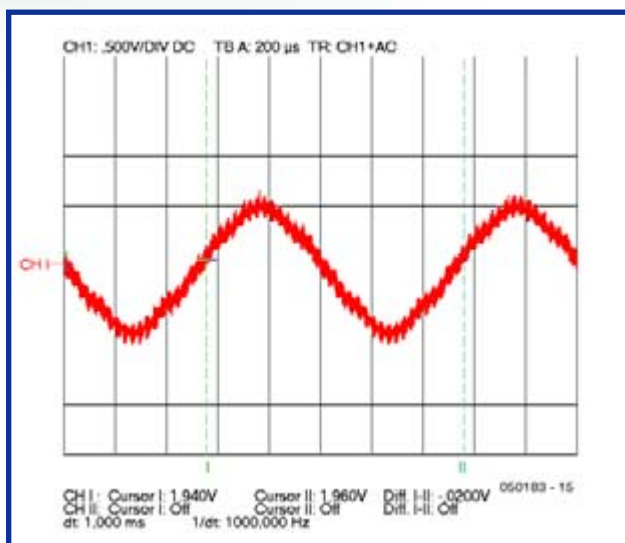
Figure 4. The integrated control signal that drives the HIP4082 is not quite sinusoidal because of the negative feedback that is present.
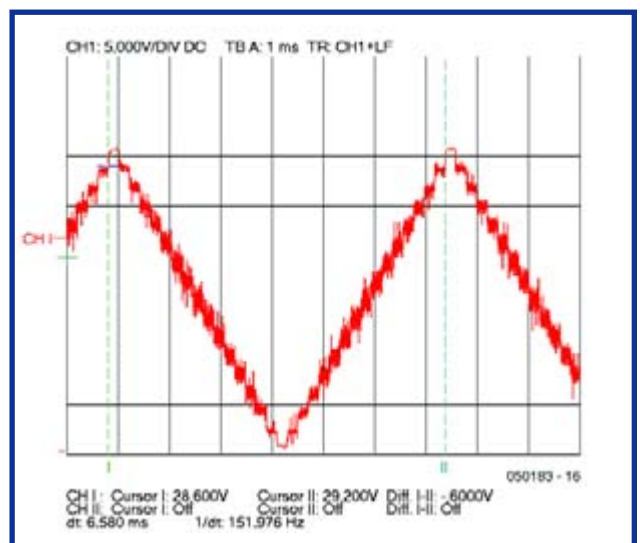
Figure 5. After a few modifications, the output signal from our test circuit finally started to resemble the input signal.

Test circuit

We were now in so deep that the phenomenon would not let go of us any more. We decided to order a few of the driver ICs from Intersil and built our own test circuit. We simply had to know what was going on!

For our own version of the output stage we bought the DIP version of the IC (HIP4082IP) instead of the SMD version. For the MOSFETs we used TO220 types (IRF530 from ST). We used standard parts for the remainder of the circuit as well. Of course, as a result the active part of the circuit turned out a little larger than the original amplifier, but our test circuit should nevertheless give comparable test results. We deliberately did not put the output filter on the PCB so that it was easier to experiment with the core of the circuit. On the (single-sided) test PCB the dead time was made adjustable by connecting a potentiometer in series with the resistor at the DIL-pin, so that we could measure the effect of this. For the signal generator we designed a purely digital circuit specifically for this test that generated a maximum modulated PWM signal. The generator supplies two clock pulses in antiphase, the duty cycle of which can be varied in 16 steps from 0 to 100%. This modulation is synchronous with the clock frequency, which should result in a clean triangle signal at the output (measured via a steep filter). With this signal every defect should be immediately obvious.

Disappointing results

With the original values (100 nF for the bootstrap capacitors) the output signal was far from ideal, collapsing to about half the supply voltage.

For the clock signal we chose about the same frequency as in the CDAMP, namely 313 kHz. This frequency is much higher than the recommended upper limit of 200 kHz in the datasheet. But in the CDAMP we had already halved the clock frequency at one stage and that made no difference then, so we now stuck to the same frequency. As a minimum resistance for the dead time we used 2.5 kΩ, since this theoretically would result in a maximum current of 4 mA. The IC is powered from 12 V, so that the voltage across the resistor should amount to V_{DD}–2 V. Unfortunately that was not the case in practice. At a smaller resistance value, the voltage was also reduced. The maximum current, 5 mA, was found to flow when the resistance was 1.2 kΩ. The voltage was then only about 6 V. This is something that is not mentioned in the datasheet, the value of the dead-time can only be read from a graph.

When increasing the dead time, the output voltage appeared to collapse and reach some sort of limit. It was much better when the bootstrap capacitor was increased and after increasing the supply voltage to 15 V the output signal finally took the shape that was expected (**Figure 5**). Measurements were made without a load through a simple first-order RC-filter, so that the remains of the pulse width modulation are still clearly visible on the oscilloscope. Why the remainder of the positive output voltage, when the power supply voltage is increased, passes unhindered through the FETs is still a mystery. Increasing the power supply voltage to the bridge made no difference to the operation.

Our test circuit did exhibit a similar behaviour as we had observed with the CDAMP sample when the power supply voltage was lowered. During our experiments, half of the bridge in the IC burned out spontaneously on two occasions. The first time it was not entirely clear what caused the malfunction. The second time it happened when increasing the dead time when a 4 Ω load was connected. This signalled that it was time to stop with this experiment.

Conclusion

Considering the results from our test circuit, it is not likely that we will use the HIP4082 in a new design. The only thing the IC needs to do, is to turn the MOSFETs on and off making sure that both FETs in one half of the bridge do not conduct simultaneously. Unfortunately in practice this IC does not appear to be sufficiently robust to fault situations and the IC is also the cause of the poor measurement results of the CDAMP amplifier. Perhaps comparable ICs from different manufacturers are better behaved, for example the MIC4102 from Micrel (100 V Half Bridge MOSFET Driver with Anti-Shoot Through protection).

(050183-1)

The HIP4082

First, something about the driver IC, the HIP4082 from Intersil. This H-Bridge FET-driver-IC can be used for typical frequencies and voltages and is suitable for PWM-controlled motors, switching power supplies and class-D amplifiers. The IC has an adjustable dead-time and a disable input, which when active, forces all outputs to a low level. The dead time is there to prevent the two MOSFETs in a half bridge from conducting at the same time (part of the 'Shoot Through Protection'). The IC also has a protection feature that senses when the power supply voltage is too low. The outputs have a reduced capability compared to other ICs from the same family (HIP4080/81) so that the package can be smaller. An additional advantage is that there is less interference from peak currents when charging and discharging the gate capacitance.

050183 - 18
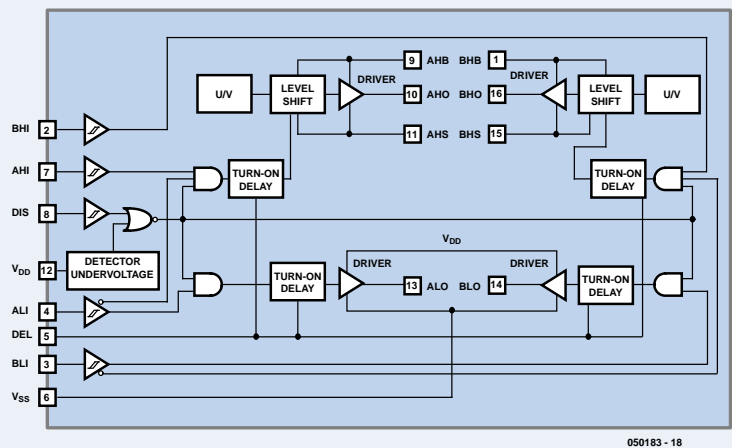
The IC uses a bootstrap circuit to drive the upper MOSFET. That requires only a diode and capacitor for each half bridge. Internally, the output stage for the upper MOSFET is driven via a level shifter. The power supply for the output stage (effectively the bootstrap capacitor) goes up with the source of the upper MOSFET when this one goes into conduction (pins AHS/BHS). When the bottom MOSFET conducts, the bootstrap capacitor is charged via the diode and bottom MOSFET from the low voltage power supply. The power supply for the bridge may be up to a maximum of 80 V and at the maximum supply voltage for the IC of 15 V (V_{DD}), the power supply voltage for the upper drive stages can reach up to 95 V (pins AHB/BHB). The datasheet is not very clear as to the exact operation of the IC. More information can be found in application note an9611 (A DC-AC Isolated Battery Inverter using the HIP4082).

The time that the bootstrap capacitor is allowed to charge up is clearly only determined by the pulse width of the input signal, that is, the length of time that the input is low. When the input signal is high, the bootstrap capacitor will discharge and as a result the gate drive voltage of the upper MOSFET also reduces. Intersil indicates that for the HP4082, as a rule of thumb, that this capacitor should be 10 times bigger than the capacitance of the MOSFET. Viewed logically, the size of the capacitor at 100% modulation is more dependent on the low frequency modulation of the PWM signal. You could, of course, specify a minimum pulse width per period of the PWM signal, but another solution is to just increase the capacitance.

While testing, it appeared that increasing the capacitance from 100 nF to 780 nF (an additional 680 nF in parallel) prevented collapse of the signal on the top side as shown in the measurement of **Figure 1**. During the time that the output is low, this larger capacitance is charged and then holds its voltage for a longer period. This increases the requirements for the diode and MOSFET because of the charging current, particularly when first starting up. The board layout also becomes more critical with regard to peak currents and interference pulses that can wreak havoc with other parts of the circuit or the IC itself.

When you read the FAQ on the Intersil website, you will notice that it is very critical to apply this IC properly and that many designers get into trouble. To reduce the risk of glitches it may be necessary to add or increase the gate resistors. In addition there are strong recommendations for the board layout and the MOSFETs have to be decoupled with 1 µF ceramic capacitors. A common problem is glitches that cause the bottom MOSFET to conduct when the gate capacitance of the upper MOSFET is being charged. All of this makes us suspicious that the problems of the CDAMP could be related to the PCB layout, even though the PCB used in this design is a multilayer one.

Crossover distortion in a PWM amplifier?

There is one more interesting measurement that we made on our test circuit that we would like to share with you, namely the result from the output voltage measurement with a load of 4 Ω (see 'scope picture).

Clearly visible is some sort of crossover distortion phenomenon that resembles a class-AB amplifier. This is caused mainly by the unavoidable dead time when switching from one half of the FET bridge leg to the other. This time is relatively large (at 2k5 about 300 ns). We can actually state that this class-D output stage behaves as if it was analogue and negative feedback is a necessity. Apart from a high efficiency and small heatsink there is really no advantage when compared to a good class-AB amplifier. It is also better not to mention the measures that are required to prevent the amplifier from interfering with itself or its surroundings, such as the output filter that is often placed outside the feedback loop and can only affect the signal in the negative sense. Just to be clear: all oscilloscope pictures are measurements of a half bridge (that is, measured with respect to ground).
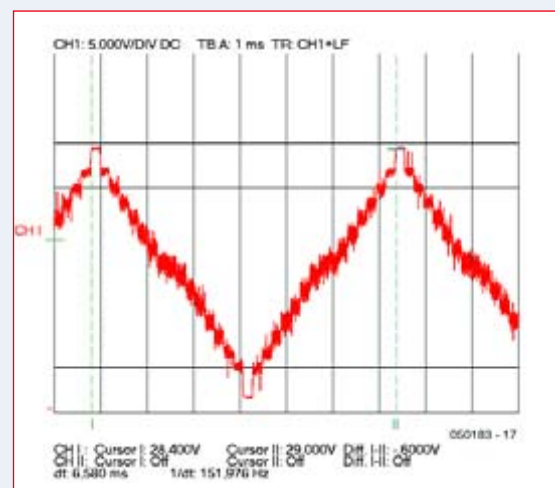
E-blocks – now yo

The CAN bus is a resilient, high data rate bus for communicating between electronic devices in situations where high data reliability is required. One use of the CAN bus is in the automotive industry where it is being used as a substitute for copper wiring looms in cars. In this article we refresh our CAN bus basics and show you how E-blocks and Flowcode allow you to easily implement CAN.

CAN stands for Controller Area Network denoting an international standard for serial communication used to control devices on a network. The CAN standard governs some of the physical attributes of the network as well as

Figure 1.
Heavily simplified CAN data structure.

Message ID	DATA

065030 - 11
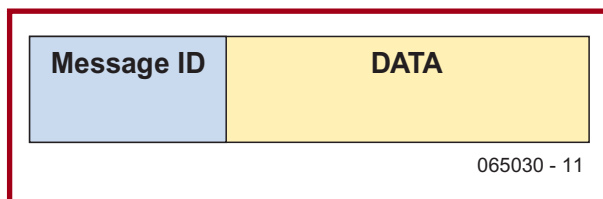
Figure 2.
A Typical CAN node.

065030 - 12

Figure 3.
Example of interconnected ECUs in a car.

065030 - 13

the low level software communication protocols. Physically, the CAN bus itself consists of a twisted pair of wires which use differential voltages for data transmission — there is no earth (ground) wire in CAN and differential voltages make the system very immune to noise. CAN is designed primarily for control and hence the messages used are small at just eight bytes maximum.

As illustrated in **Figure 1**, the basic message structure contains two parts: a message identity and message data. The actual structure is a little more complicated than this, with error detection, synchronization and other bits being embedded into each message. However, one of the great benefits of CAN is that the ICs used take care of these details for you and provide you simply with message and data information.

Functional overview

Figure 2 shows a typical CAN node on a network. All nodes have a microcontroller with I/O circuitry, a CAN controller and a line driver which interfaces the CAN-L and CAN-H differential connections to the CAN controller. Some microcontrollers have the CAN controller embedded (i.e., on-chip) which reduces the cost of the node. These devices can be seen on the image of the **EB018 E-blocks board** shown in the introductory photograph. You can see that the connections to the CAN node are Power, Ground, CAN-H, CAN-L and then other connections to I/O as required.

In order to understand how CAN works at a higher level let's consider **Figure 3** which shows some of the possible CAN nodes in a car. In this context where a node is a complete functioning unit, the node is often referred to as an *Electronic Control Unit* or ECU. Here you can see five ECUs: an engine temperature sensor, an instrument panel, a switch on a brake pedal and ECUs for the left and right hand rear light clusters. Although the wires are not shown here all power and grounds are connected, and all CAN-H and CAN-L terminals are connected by 100-ohm terminated twisted pair wires. In practice you may find the foot brake connected to the instrument panel ECU etc., but for illustrating how CAN works let's just assume the system is as shown.

A key feature of CAN is reliability, and this is kept to a maximum by keeping traffic on the CAN bus to a mini-

u CAN
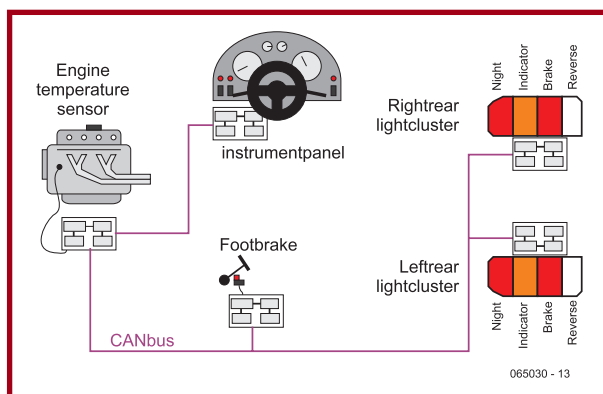
A complex system made transparent

mum. In a conventional network you might think that the foot pedal would tell the central processor on the instrument panel that it has been pushed down, and the instrument panel would then tell the light cluster ECUs to turn the brake lights on, and so on! Surprise — CAN works differently. When the pedal is depressed the brake pedal ECU issues a message effectively stating *"brake pedal pressed"*. This message is issued to the **whole bus**. The light cluster ECUs are programmed so that when they see the *"brake pedal pressed"* message on the CAN bus they power up the appropriate lamp. This has kept message flow to a minimum, and if the instrument panel ECU — or any other ECU — is not working then the core important functions of the network are still active.

This is an example of one type of data exchange for important 'mission critical' data: if your brake lights don't come on then you could run into trouble, or it would run into you! However if this method was employed by all devices connected to the bus then the traffic would be quite large — with more traffic meaning reduced reliability. So, a second technique for data exchange is used. Looking at temperature monitoring, for example, the central instrument cluster wants to know what the temperature of the block is so 'temperature' can be displayed on the instrument console and — if necessary — the warning light activated. The designers of the system will have decided that the temperature needs to be monitored at, say, five second intervals. So, every five seconds, the central console will issue a message saying *"can anyone tell me what the block temperature is?"* The ECU on the block is programmed to look for the message *"can anyone tell me what the block temperature is?"*, to then measure the temperature, and reply with a message stating *"the block temperature is"* followed by the temperature data.

A key problem

Having understood the basic principles behind CAN, the next question is "exactly how is the basic message structure used to communicate all this information?". Here is a key difficulty of CAN. Whilst the general CAN methodology, the electrical connections, packet structure, error correction and low level software are fully specified, all the rest is left up to you. In practice this has meant that every automotive manufacturer has chosen their own proprietary protocols. Massey Ferguson will be different to Audi will be different to BMW, and so on. The reason for this is probably twofold: firstly, automotive companies don't want unauthorized people tapping into the bus that manages all the safety-critical electronic devices in the vehicle; and secondly diagnostic equipment and training are valuable revenue streams.

Delving deeper in

To understand how the messages in a CAN system are constructed, let's consider the temperature dialogue ear-

lier. Every message has an ID (identification). The system designer needs to designate each ID with a function. So, let's say the ID for *can anyone tell "me what the block temperature is?"* is ID 400. Correspondingly, let's say the ID for *"the block temperature is"* is ID 401. The system designer then has to decide how to use the data-bytes transmitted to transfer information. To keep things simple, we can say that the first data byte is 0 for positive temperatures, and 1 for negative temperatures. We can then say that the next three bytes are used for 100s of C, 10s of C and units of C. Now in practice, this would rarely be the case, but as we are interested in teaching automotive technicians — among others — it might be a good idea to avoid hexadecimal notation and 16-bit numbers at this point. So, if the temperature is 76 degrees Celsius then the message data would be 0076. For this dialogue the transactions on the bus would therefore be:

	ID	Data
Console ECU	400	-
Block ECU	401	0076

Here we can see the Console ECU requesting the temperature and the block replying with the data, the console then displays the data on the dashboard.

CAN Flowcode and E-blocks do it?

The simple example above shows that at a very high level, the way CAN works is very simple. One of the real strengths of the Flowcode software supplied with E-blocks is that it allows all of the complex parts of CAN to be taken care of in the background and only exposes users to the messaging parts of CAN.

Within Flowcode some custom macros have been written for the E-blocks CAN controller board that allows it to be easily controlled by those with little programming skill. The macros provided allow the ID and data to be easily set up in the transmit screen (**Figure 4)**, which is invoked in a single Flowcode icon. Similarly, in the receive dialogue screen (**Figure 5**), the ID and data can be picked up by a single Flowcode icon, and placed in user variables. In the receive dialogue screen, more advanced users can click on the 'details' button to access further advanced functions like filters and masks, as well as view the CAN data string, but for most users these details aren't terribly important.

Putting this together

The screendump in **Figure 6** shows a Flowcode program for a notional brake pedal in a car. Here we are using the E-blocks Multiprogrammer with a 40-pin

PIC16F877A with internal USART. Onto this we place the CAN board on port C, and our brake switch goes onto bit 0 of Port B. The first icon in the program initializes the CAN board. Then we have an endless loop. In the loop we get the input from the brake pedal, and if it is at logic 1, or the brake is pressed, we transmit the CAN message corresponding to the brake being pressed.

A very similar program in the receiving ECU has an endless loop that constantly monitors the receive buffer and takes appropriate action.
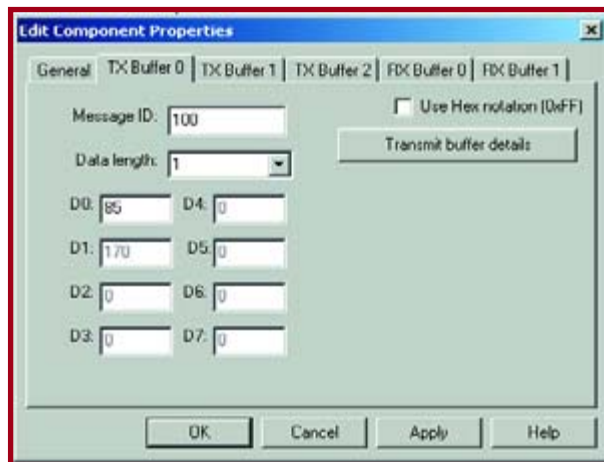
Figure 4.
Transmit dialogue
screen.
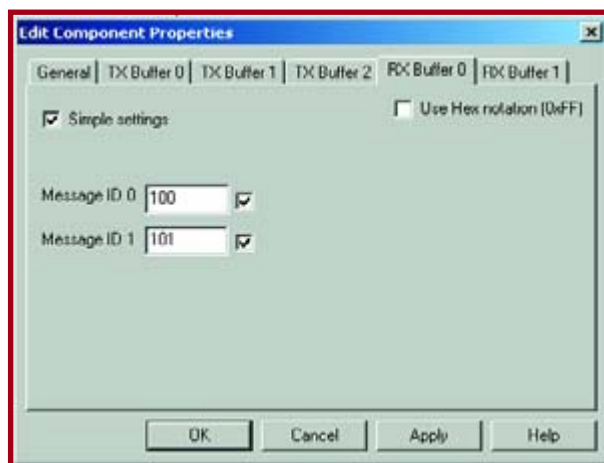
Figure 5.
Receiver dialogue
screen.
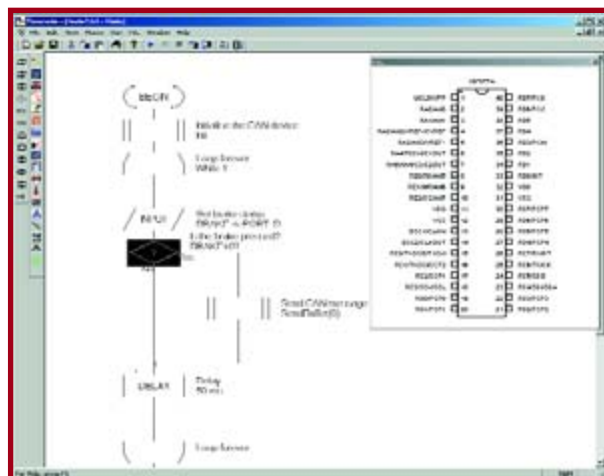
Figure 6.
A simple Flowcode
program that sends
CAN messages when
the brake pedal is
activated.

Conclusion

CAN is a complex protocol that has many detailed features designed to provide a high data rate, high reliability control network between lots of separate processors. Implementing CAN is a complex task in languages like C, but doing so with Flowcode and E-blocks is actually very simple. Applications that you might want to consider include a wide variety of home automation tasks, control of outdoor train sets, burglar alarms, and many others. The Flowcode CAN component is a free download from the Elektor web site and will operate with all Professional versions of Flowcode.

(065030-1)

Earlier in this series

Electronic Building Blocks, November 2005.

E-blocks and Flowcode, December 2005.

E-blocks in Cyberspace, January 2006.

Articles may be downloaded individually from our website.

Two offers you CAN't resist

This month as a special offer to encourage you to investigate CAN we are making available an **Easy CAN Kit** consisting of:

- Two PICmicro Multiprogrammers with USB cables;
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- Two CAN boards;
- One Switch board;
- One LED board;
- Two LCD boards;
- Flowcode 2.1 Pro version.

For a discounted price of **£ 299.00** or **€ 449.00**.

Also, to support last month's article on using embedded microcontrollers to develop web pages we are making an **Easy Embedded Internet kit** available which includes:
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For a discounted price of **£ 232.50** or **€ 349.00**.

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Sparks 'n Ar

Some people find electric arcs scary, while others find them especially fascinating. If you're not afraid of a few kilovolts and observe due safety precautions, you can use the circuit described here for some interesting experiments. However, you must always remain alert and keep safety in mind, because the voltages and currents generated by the circuit can have nasty consequences.

Ton Giesberts

If you search the Internet for things related to high voltage, you quickly encounter terms such as 'Tesla coil' and 'Jacob's Ladder'. In its original form as invented by Nikola Tesla, a Tesla coil is an air-coupled tansformer that works entirely on the principle of resonance and can easily generate potentials of several hundred thousand volts or even a few million volts. At such voltages, electric arcs jump randomly to surrounding objects, and we do not regard that type of experiment-

ing as something that can be responsibly suggested as an example.

When the subject of high-voltage experiments is mentioned, many people have a mental image of two spheres with sparks jumping between them. An example of such a device is the Van De Graaf generator, which was built by Dr Robert J. Van de Graaf and could generate 5 million volts.
Our ambition here is quite a bit more modest. A device that produces a well-

defined arc between two conductors spaced a small distance apart is safer. A nice example of this is the Jacob's ladder. An electric arc between two long conductors heats the air if it has sufficient energy, and the hot air produces enough convection to cause the arc to move upward. If the two conductors are arranged in the form of an extended V, with the distance between the conductors increasing in the upward direction, the applied voltage will ultimately be too low to maintain
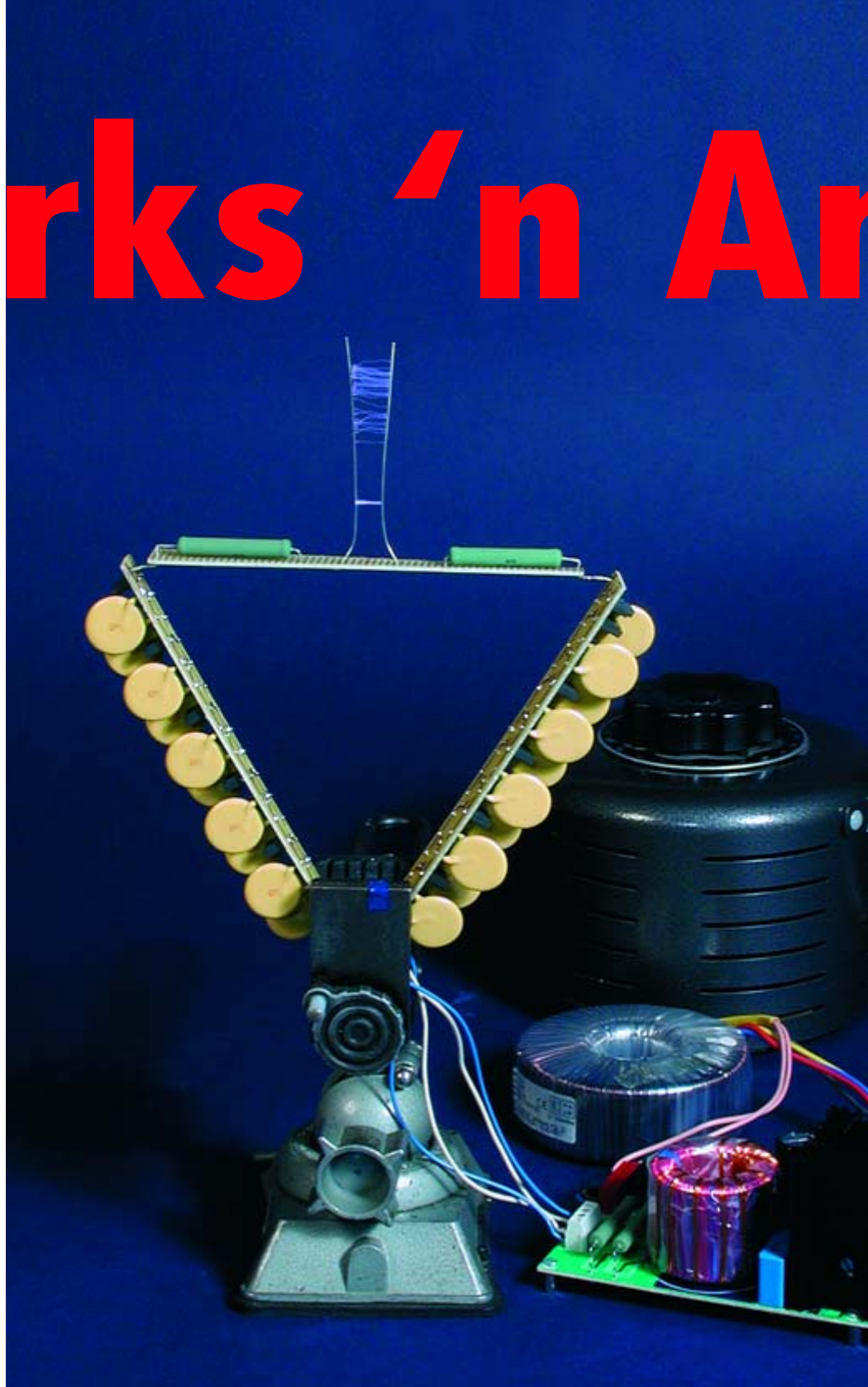
Experimenting with a Jacob's Ladder

the arc. After the arc is extinguished, a new arc will be formed again at the bottom.

In principle, this can be achieved with little or no electronics. All that's needed is a power supply that can provide 10–15 kV at 20–40 mA, which amounts to a hefty mains transformer that can deliver sufficient voltage and power. Of course, the transformer must meet rather demanding requirements, such as adequate insulation and a high leakage inductance in order to limit the current, because the arc is practically a short circuit.

A circuit consisting of nothing more than a transformer is not particularly interesting for a magazine dedicated to electronics. It's more educational to see how the voltage can be generated in a different manner. Here we deliberately decided to use a DC voltage, because a DC arc has a nice blue colour, instead of the white arc generated by an AC voltage. In retrospect, that was not such a good decision, but we'll say more about that later.

The circuit

Despite what we just said, we use a transformer to generate the high voltage. However, the dimensions of the

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WARNING. Working with high voltage can be fatal. The circuit described here is not for beginners. Do not build or use it unless you are experienced in dealing with high voltages.

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transformer can be kept modest, even though it provides a fair amount of power, by using a frequency that is considerably higher than the mains frequency. One of the problems in making a DIY transformer for extremely high voltages is the insulation and the breakdown voltage of the materials that are used. On top of that, we have to ensure that it's reasonably easy to build the circuit as a DIY project.

For that reason, we decided to use an output voltage of 'only' 1000 V. We also decided to use a mains transformer to provide a lower input voltage. That at least makes the primary side of the transformer a bit safer. We chose a supply voltage of 80 V to prevent the turns ratio of the transformer from being too high. That saves quite a few turns on the secondary side. The primary winding requires two sets of 12 turns, and the secondary requires a total of two times 75 turns. We decided to ground the centre of the secondary winding, so the voltage between the ends of the secondary winding and ground is 'only' 500 V. That keeps the maximum voltage between the primary and secondary windings within reasonable limits. Of course, you're free to wind the secondary as a single winding so it floats with respect to ground. If you do that, it's a good idea to double the insulation between the primary and the secondary.

To keep the electronics relatively simple, the transformer has two identical primary windings so it can be driven in push–pull mode. That's easy to do with a toroidal-core transformer by using a bifilar winding (two wires in parallel). The details of the transformer construction are described further on in this article. The push–pull configuration allows the transformer to provide the maximum amount of power that is possible with the selected core.

A brief guide to working with high voltage

- Always switch off the voltage before making any circuit modifications.
- In case of doubt, always discharge the capacitors – not only in the cascade stages, but also in the main power supply.
- Ensure that all metal parts that are not connected to the circuit are properly earthed (box, etc.).
- Always stay a safe distance away from the electrodes when the circuit is switched on.
- Regard all voltages as potentially lethal.
- Never replace the fuses by types with current ratings higher than the specified ratings.

- Ensure that the circuit cannot be switched on unintentionally or by unauthorised persons.
- After you have checked everything, check everything once again.
- Do not conduct experiments in damp or humid surroundings.
- If you must make adjustments to a live circuit, always work with only one hand.

Source: http://www.pupman.com/safety.htm
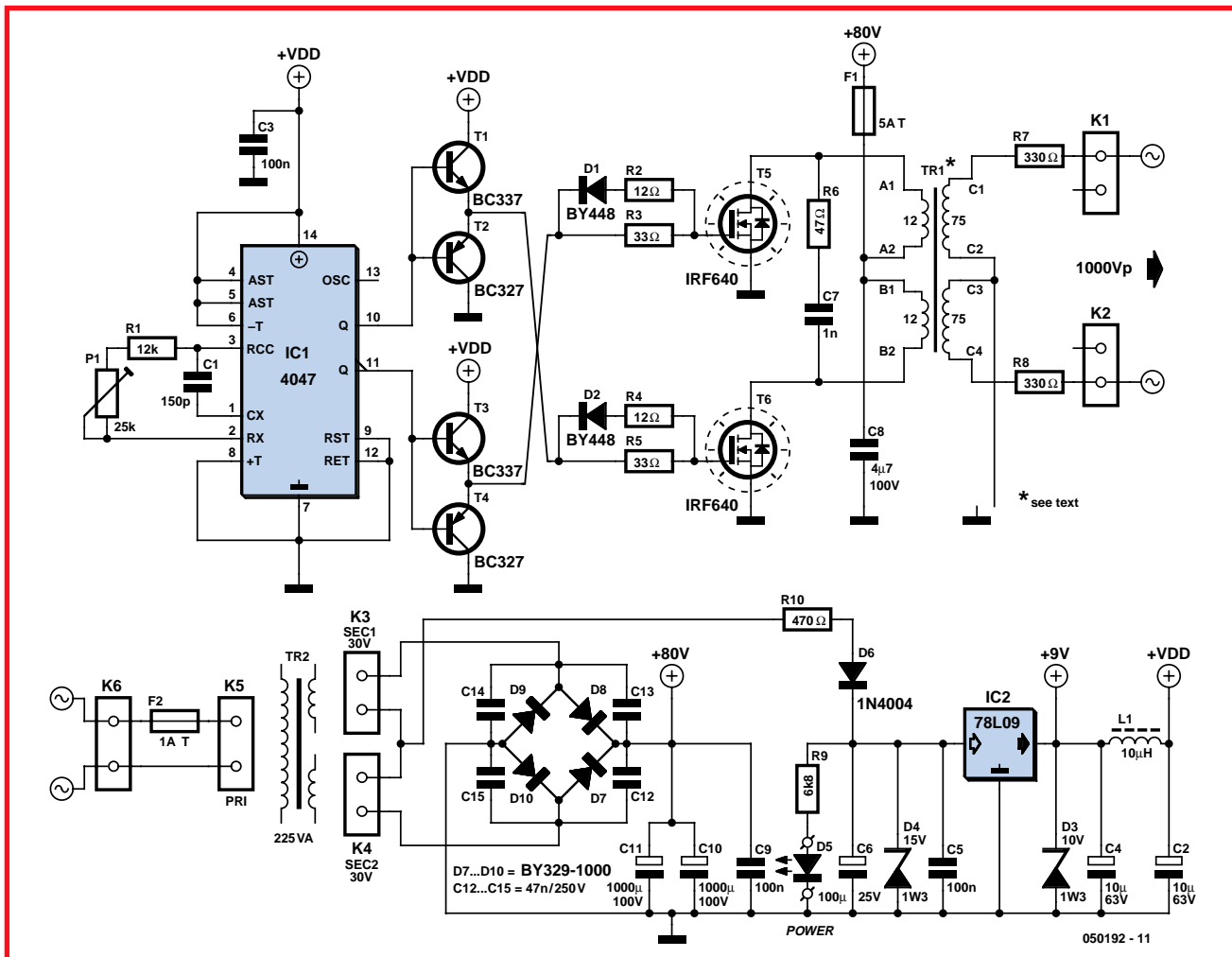
Figure 1. Except for the fast diodes and the transformer, the circuit is built using standard components.

In practice, the centre tap of the primary winding is connected to the positive supply voltage. Each of the other two ends is alternately connected to ground by transistor switches. To ensure that the two transistors are never conducting at the same time, they are switched off faster than they are switched on. The time when neither of the transistors is conducting is called the 'dead time'. The disadvantage of this arrangement is that each transistor must withstand twice the supply voltage when the other one is conducting, because the two halves of
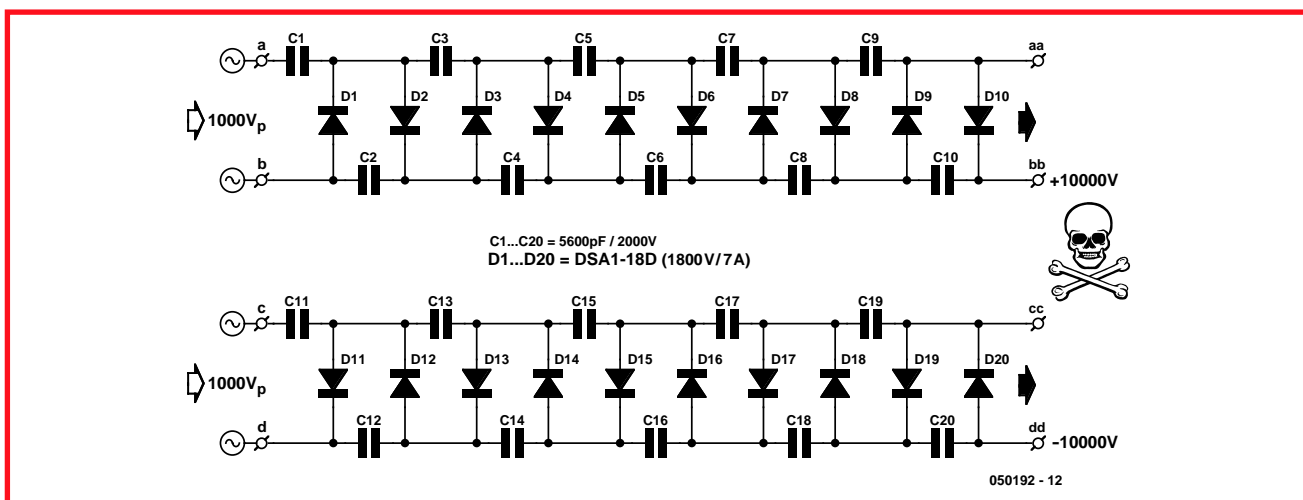
Figure 2. The schematic of the cascade stage is also standard.

the primary winding have opposite polarity. In this case, that means each transistor must be able to switch more than 160 V.

We chose an inexpensive transistor type, the IRF640, for our experiments. It has a breakdown voltage of 200 V, a channel resistance of 0.18 Ω, and a continuous switching current rating of 18 A. However, if you find yourself blowing up MOSFETs too often in the enthusiasm of your experimenting (and that's bound to happen), you may want to try using the IRFB260N. It is considerably more robust, but it's also a good deal more expensive. The maximum continuous current rating of the latter type is a hefty 56 A (and that in a TO220 package!), and the maximum junction temperature is 175 °C. The channel resistance is also considerably lower: less than 0.04 Ω. One drawback is that the input capacitance is a factor of 3.5 greater, so switching losses will be increased. The buffer stage for driving the MOSFETs is not actually designed to handle that.

The drive circuitry (**Figure 1**) is built around a nearly antique IC from the 4000 family, the 4047, which is described as a 'monostable / astable multivibrator'. It has a separate output (OSC) for the internal astable multivibrator, and it also has a divide-by-2 circuit with two antiphase outputs. P1 allows the frequency at the divider outputs to be adjusted over a range of approximately 35–110 kHz. That makes it possible to select a different core material or change the number of turns, if so desired. In our tests, we were able to leave the frequency at the lowest setting (P1 turned fully anti-clockwise). The IC is operated in the astable mode. The two antiphase outputs are quite convenient for driving the MOSFETs. Unfortunately, a 4000-series output cannot provide very much current, so separate buffer stages are necessary to drive the high gate capacitances of the MOSFETs.

The buffer stages consist of a pair of complementary emitter followers formed by T1–T4. Type BC337 and BC327 transistors are used for the NPN/PNP pairs. They have a peak switching rating of 1 A and sufficient gain. The switch-off time of the MOS-FETs is reduced by a factor of around 3 by connecting an extra resistor and diode across R3 and R5. That ensures that the two MOSFETs will never be conducting at the same time, which would amount to a short circuit. The

RC network R6/C7 damps any over-shoots that may result from switching the MOSFETs. C8 provides additional decoupling for the transformer supply voltage, and it must be fitted as close as possible to the associated leads.

R7 and R8 protect the transformer against hard shorts, but they also have another function: if the arc conductors are placed closer together than necessary for the maximum voltage generated by the circuit, the input of the cascade stage forms a sort of high-voltage Zener. The distance between the conductors determines the maximum charge voltage of the capacitors. Any voltage above that level is converted into heat by R7 and R8. Fuse F1 protects the high-voltage transformer against long-term overloads, and fuse F2 for the mains transformer protects the entire circuit.

The supply voltage for the high-voltage transformer is provided by a 2 × 30-V transformer. Transformers with 60-V secondaries are not standard items, and a supplementary benefit is that the centre tap can be used to increase the efficiency of the auxiliary supply circuit for the 4047 (due to the lower voltage drop). R10, D6 and D4 convert the centre-tapped secondary voltage into a raw 15-V DC voltage in order to keep the dissipation of the 78L09 regulator reasonably low. The output voltage of the 78L09 is further filtered and buffered by L1, C2 and C3, because the peak currents for switching the MOSFETs are greater than what the IC can supply. D3 protects the output of the 78L09 against any spikes that may be present, and D4 does the same thing for the input voltage of the voltage regulator.

The main supply voltage is provide by four fast rectifier diodes, which can handle 7 A at a voltage of 1,000 V. This working voltage is more than what is strictly necessary, but it was chosen to be on the safe side. The diodes are located next to each other at the edge of the circuit board, so they can be easily fitted to a small aluminium plate for cooling if necessary (electrically isolated, of course). C12–C15 filter the diode switching spikes. Standard MKT capacitors are used for this purpose, because they have higher working voltages than normal ceramic types.

Three terminal blocks (K3–K5) are located on the circuit board for connecting the mains transformer. The fourth terminal block (K6) is used to connect the mains transformer to the

mains circuit (via fuse F2).

Now let's return to the output of the converter. One way to convert an AC voltage to a high DC voltage using standard components is to use what is called a 'cascade circuit'. That consists of a series of diode/capacitor pairs that increase the output voltage by the peak value of the applied AC voltage for each section of the cascade (see **Figure 2**). A drawback of this arrangement is that the capacitive load on the AC source increases with each section, while the apparent capacitance of the high-voltage output decreases in the same ratio. All the capacitors are actually connected in series, and with a cascade circuit having ten identical sections, the output capacitance is only one-tenth of the value of each individual capacitor. In other words, the output impedance increases significantly. One way to counteract this is to drive the cascade with a high-frequency voltage and ensure that the transformer supplies a hard AC voltage.

We used the same philosophy for the cascade stage as for the secondary winding of the transformer. Instead of using a single cascade to generate the output voltage, we decided to use two cascades. Each one supplies half the desired voltage, but they have opposite polarities. The full voltage is thus present between their two outputs, but the voltage with respect to the surroundings is only half as much. Of course, that doesn't mean the circuit is safe to touch, but it does make it a bit safer.

The approach we took (using a DC output) proved to present a problem in practice. Despite the high switching frequency, the output voltage turns out to not be hard enough, so spikes at the output of TR1 can charge the capacitors in the cascade to a higher voltage than what we expected. We also found that the voltage across the diodes can rise to a dangerous level. When an arc is struck between the two conductors or electrodes, the voltage on the capacitors drops to a lower value. That causes the arc to be briefly interrupted, which allows the voltage on the capacitors be built up again. That creates a repetitive effect.

As already mentioned, R7 and R8 limit the 'short-circuit' current. That brings us to the snag: the transformer, which is nearly ideal, turns out to be the problem. Too much heat is dissipated in R7 and R8 in order to maintain an arc, and there is even a chance that the transformer may become overloaded. If that happens, the core will be driven

into saturation and immediately create a short circuit, and T5 and T6 will be dead well before fuse F1 blows. It's thus a good idea to choose a distance between the electrodes that causes a prudently repetitive arc (bear in mind the rule of thumb of 10 kV per centimetre). That still provides a nice effect, and besides nice blue sparks it generates a considerable amount of noise and, unfortunately, a good deal of ozone. That means your experimenting area must be well ventilated. The main circuit should preferably be fitted in a well-earthed metal box with forced-air cooling, in order to dissipate the heat generated by R7, R8, Tr1, and the heatsink for T5 and T6.
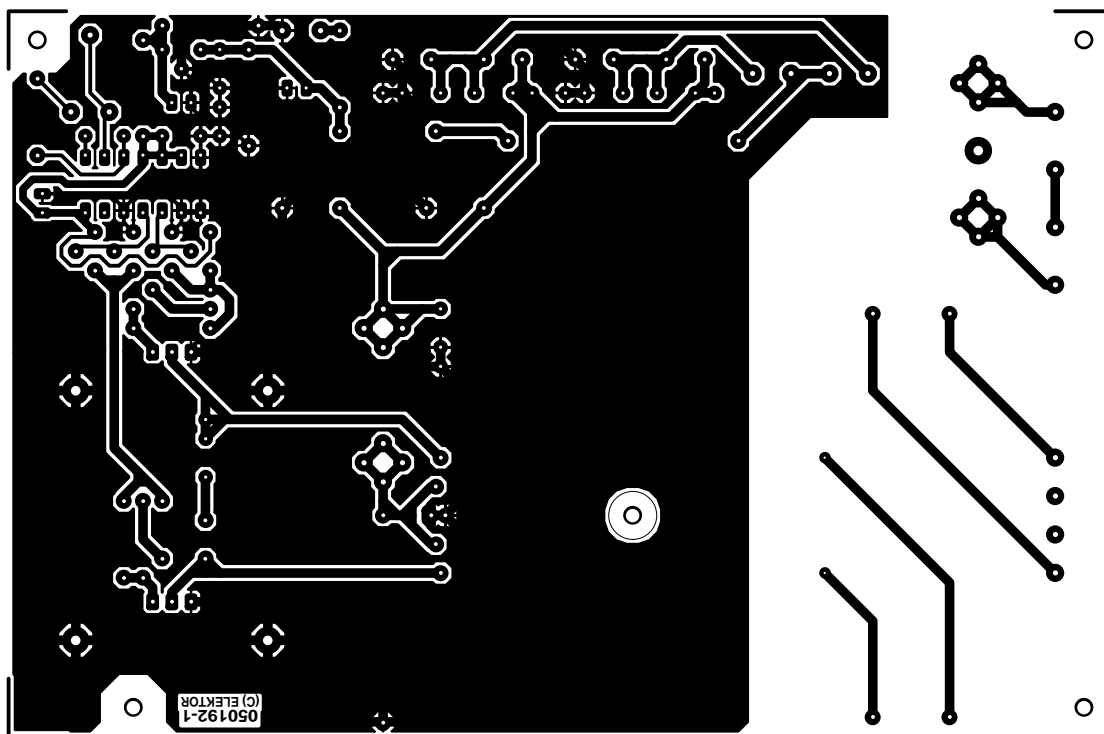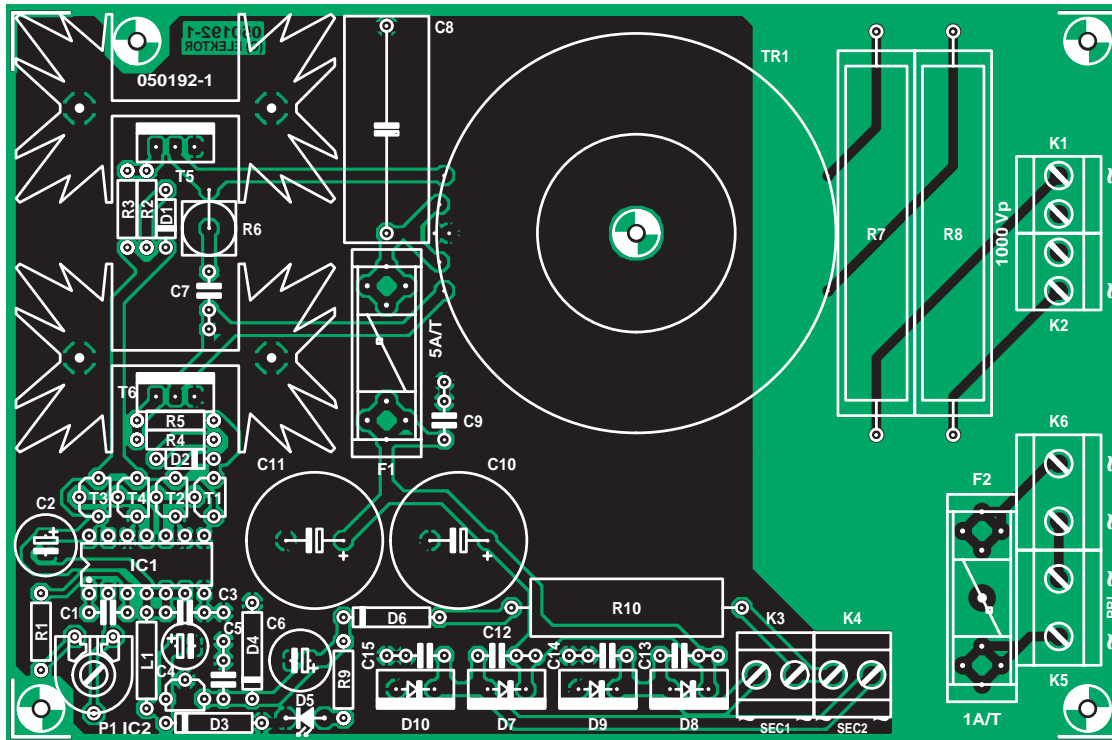
Figure 3. The main circuit board is reasonably compact. When assembling the board, ensure that R7 and R8 are placed sufficiently distant from the board to provide adequate cooling.

Construction

Fitting the components to the main circuit board should not present any problems (see **Figure 3** and **Figure 4**). However, fitting the leads of the DIY transformer is a bit fiddly. Small bends must be formed in the leads of transistors T5 and T6 so they can be fitted to heat sinks. After that, the transistors should be attached to the heat sinks using insulating washers. Solder the heat sinks in place first, followed by the transistor leads.

As R7 and R8 generate a considerable amount of heat, they must be fitted spaced above the circuit board. Try to maintain a clearance of 1 cm. If they
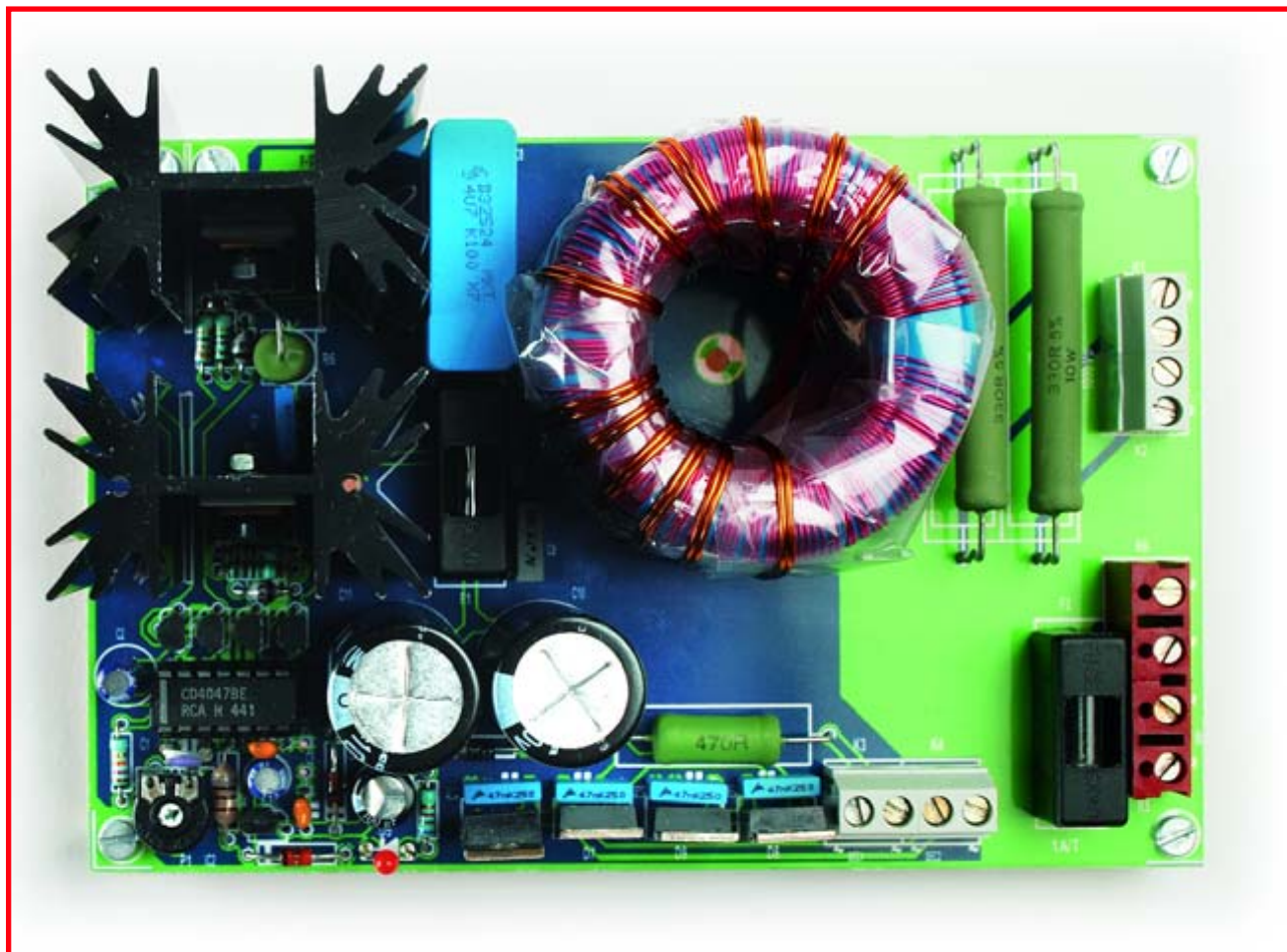
Figure 4. The prototype. Despite its moderate dimensions, this circuit delivers around 200 W at 1000 V. We tried to keep the circuit as simple as possible to make DIY construction reasonably easy.

COMPONENTS LIST
Supply board

Resistors:
R1 = 12kΩ
R2,R4 = 12Ω
R3,R5 = 33Ω
R6 = 47Ω 5W
R7,R8 = 330Ω 10W
R9 = 6kΩ8
R10 = 470Ω 5W
P1 = 25kΩ preset

Capacitors:
C1 = 150pF
C2,C4 = 10µF 63V radial
C3,C5 = 100nF ceramic
C6 = 100µF 25V radial
C7 = 1nF 400V MKT
C8 = 4µF7 100V MKT, lead pitch 27.5mm
C9 = 100nF 100V MKT
C10,C11 = 1000µF 100V radial, max. diameter 18mm
C12-C15 = 47nF 250V MKT

Inductor:
L1 = 10µH

Semiconductors:
D1,D2 = BY448
D3 = zener diode 10V 1.3W
D4 = zener diode 15V 1.3W
D5 = LED, low-current
D6 = 1N4004
D7-D10 = BY329-1000
T1,T3 = BC337
T2,T4 = BC327
T5,T6 = IRF640 or IRFB260N
IC1 = 4047
IC2 = 78L09

Miscellaneous:
K1-K4 = 2-way PCB terminal block, lead pitch 5mm
K5,K6 = -way PCB terminal block, lead pitch 7.5mm
TR1 = 2 x core B64290-L82-X830 (N30, 50 x 20 mm)*, e.g.. Epcos (Schuricht cat. no.: 330603); 2 x 12 turns. 0.8mm ECW primary (approx. 2 times 1.5m); 2 x 75 turns. 0.5mm ECW secondary (approx. 2 times 8m)F1 = fuse 5A/T (slow) with PCB mount holder
F2 = fuse 1A/T (slow) with PCB mount holder
2 x heatsink type SK129 63,5 STS (Fischer/Dau Components) (63.5mm high, 4.5K/W)
Mains transformer, secondary 2 x 30V @ 225VA, e.g. Amplimo/Jaytee # 68017
PCB, ref. 050192-1 from The PCBShop

* see text
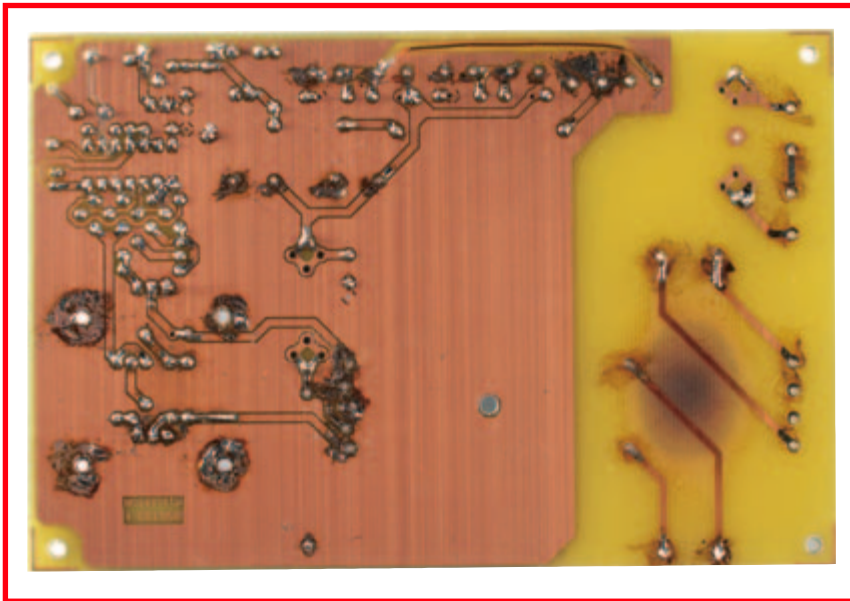
Figure 5. This is what can happen if R7 and R8 are too close to the circuit board.

you can use types other than the IXYS type DSA 1-18D that we used (1800 V / 7 A) Besides the relatively common TO220 types, you can also use SMD types in an SMB package, such as the STTH112. We first tried the latter type of diode in a cascade with somewhat smaller capacitor values. However, we found that it gave up the ghost fairly often during our experiments. It's possible to find diodes that can handle relatively high voltages, such as the SM6500 series from VMI, but they are difficult to obtain.

During our experiments, it became apparent that the impedance of a cascade of ten diode/capacitor pairs is especially high. We thus decided to use 5600-pF capacitors instead of the 1800-pF types we were using up to then. Both types come from the Panasonic line of high-voltage ceramic disc capacitors, which are characterised by low losses and are specifically intended to be used in switching applications with high voltages. We select a series with a working voltage of 2 kV in order to avoid any problems from the spikes at the output of the transformer.

are closer to the board, they may cause charring of the PCB (**Figure 5**). Other types of rectifier diodes may possibly be used, as long as they are pin-compatible types in TO220 packages and

can handle at least 200 V and 7 A. Assembling the cascade boards is quite straightforward (see **Figure 6** and **Figure 7**). A combined 'shape' is used on the board for the diodes, so

COMPONENTS LIST
Cascade board

Capacitors:
C1-C20 = 5600pF 2000V, Panasonic
  (High Voltage Disk Capacitor (Y5P)

ECK3D562KBP), Digi-Key # P9574-ND

Semiconductors:
D1-D20 = DSA 1-18D (1800 V/7 A)
  IXYS, Digi-Key # DSA1-18D-ND

Miscellaneous:
PCB, ref. 050192-2, from The PCBShop
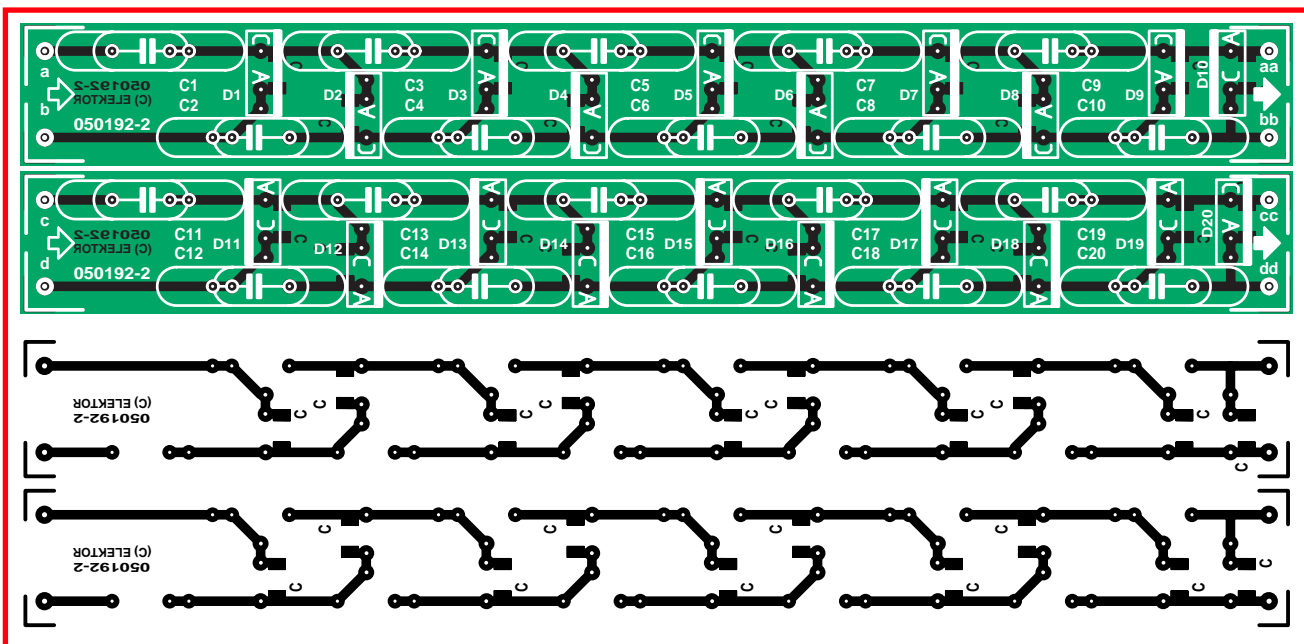
Figure 6. The two circuit boards for the cascade stages are nearly the same. The only difference between the two is that the diodes are oriented in opposite directions.

Alternatives

A collection of alternatives is described at http://www.geocities.com/CapeCanaveral/Lab/5322/hv2.html. For example, neon-lamp transformers, microwave oven power supplies and ignition coils can be used for a Jacob's ladder. Besides Jacob's ladder applications, this site describes other high-voltage projects and supplies. An example is making your own high-voltage capacitors (Leiden jars).

Several high-voltage projects are also described at www.uoguelph.ca/~antoon/circ/hv/hv.html.

The www.teslamania.com/ has spectacular photos and film clips of high-voltage perils. The operation of the 'quarter shrinker' is also described there. That's certainly entertaining reading.

Additional designs and photos can be found at www.richieburnett.co.uk/tesla.shtml. That site also gives considerable attention to the theoretical background of generating high voltages.

If you still have an appetite for more, have a look at http://tesladownunder.iinet.net.au/index.html. There's also a lot of experimenting going on 'down under'. Besides demonstrating high-voltage applications, this site shows several other remarkable phenomena, such as fer-romagnetic fluids and other magnetic gadgets.

illustration courtesy of Resonance Research Corporation, www.resonanceresearch.com

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The cascade circuits are suitable for use with all values in this product series (ECKA3DxxxKBP). The shape was chosen to match the largest dimension (5600 pF). The lead spacing is 7.5 mm for the smaller values and 10 mm for the larger ones. Of course, the cascade circuits are so simple you might consider building them using point-to-point wiring, but a more robust construction such as this is certainly safer. That's why we designed a separate circuit board for the cascade stages. We also added the option of extending the cascades: the circuit boards for the same polarity can be connected in series. That means the output voltage can be increased by 10 kV for each board. In that case, inputs a and b (or c and d) must be connected to aa and bb (or cc and dd). The output of each board is bb or dd, respectively. Bear in mind that the no-load voltage per board is a bit more than 10 kV.

The high-voltage transformer

The most difficult part of building any sort of converter that uses inductive components (or more honestly, the most bothersome part) is winding the coil or transformer if it's not possible to use ready-made components. In this case, we chose the most difficult option possible by deciding to use a toroidal core. If you want to wind a coil on a toroidal core by hand, you must first calculate the length of wire necessary for the required number of windings. Of course, it's a good idea to take a bit more than necessary.

The toroidal core is not the only obstacle; the winding method is also difficult. The reason we chose a toroidal core is the high secondary voltage. To make it possible to use standard material and avoid using expensive high-voltage wire, we decided to wind the secondary in a single layer. That's the only way to ensure that the voltage between adjacent turns is as low as possible. If we assume that spikes up
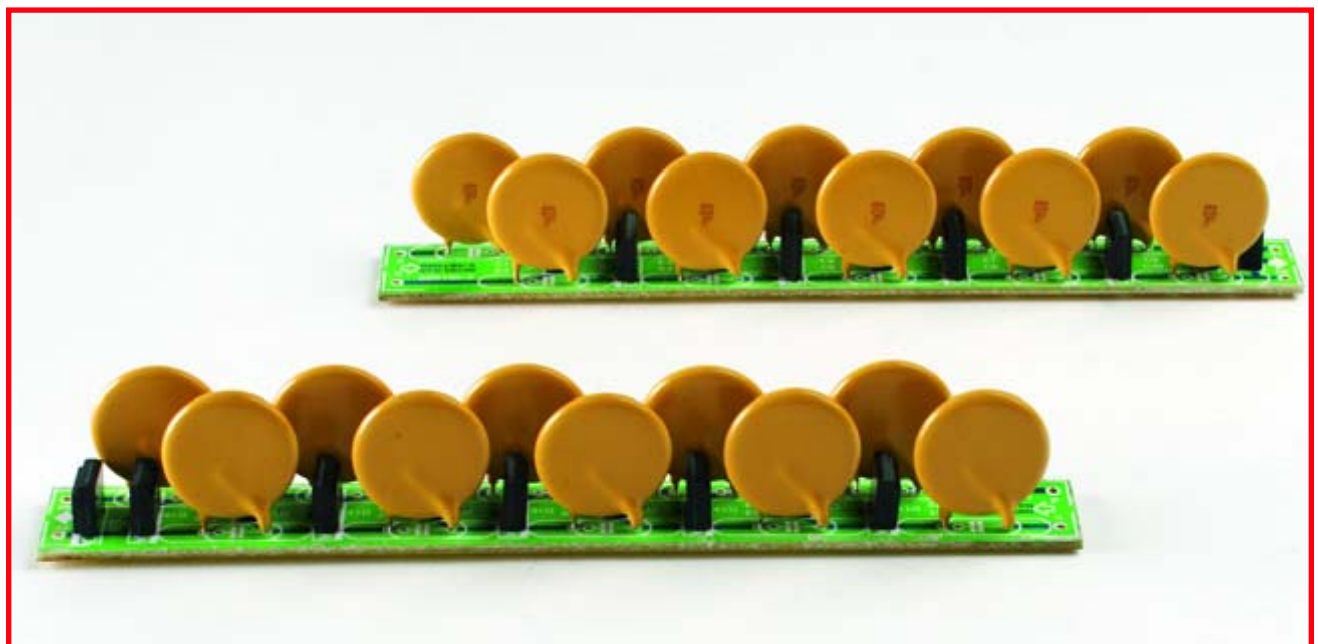
Figure 7. A fully assembled cascade board. Small, but (highly) dangerous!

to nearly 2 kV occur, the voltage between two turns of the secondary winding is only 13 V. In order to have a well-defined voltage between the primary and secondary windings, we wound the secondary with a centre tap that is connected to circuit ground. The secondary winding is wound first, in two stages, which is why two connection points for the centre tap are provided in the ground plane. Each turn requires approximately 105 mm of wire. In total, you thus need two 8-m lengths of 0.5-mm enamelled copper wire. It's not critical to have exactly 75 turns in each half of the winding; a few turns more or less won't matter. What's important is to wind the turns patiently and place them tightly together on the core. Be careful to avoid putting a kink in the wire. Make sure that the two ends of the secondary winding emerge at a certain distance apart so they fit well to the circuit board. The same applies to the two ends for the centre tap.

Once the secondary is wound, it must be insulated. You'll have to buy special insulating film for that. Do not use adhesive tape, electrician's tape or anything of that sort. The insulation must have a certain mechanical strength and electrical insulation rating, and it must be able to handle a thermal load.

The symmetric primary winding is considerably easier to wind. To ensure good symmetry, wind the two wires in parallel (see **Figure 8**). Two 1.5-m lengths of 0.8-mm enamelled copper wire will be adequate for the primary winding. Start the winding next to the centre tap of the secondary and wind in the direction of one end of the secondary winding. After six turns, cross over to a point on the core at the same distance from the other end of the secondary as where you stopped with the sixth turn. Give the two wires a twist during the crossover so the polarity of the primary winding is correct. Otherwise you'll create a solid short circuit, because the core will immediately become saturated. Finish the primary by winding the remaining six turns to arrive back at the centre tap of the secondary. The transformer should have a reasonably symmetric appearance.

For our first test, we used a core with a diameter of 50 mm and a height of 20 mm, with N30 core material (www.schuricht.de). Unfortunately, it proved to not provide sufficient power, so we glued two cores together using two-component epoxy glue (see the photo of the assembled board).

Practical setup

Use well-insulated wires to connect the cascade boards to the main board. If necessary, fit them in one or more lengths of electrical wiring conduit. The distance between the two inputs of the two cascade boards does not have to be all that large. Two to three centimetres is more than enough. The distance between the outputs must naturally be larger. The voltage difference just before the arc strikes can be considerably more than 20 kV. As a rule, spontaneous breakdown occurs at around 10 kV/cm.

We used a small bench vice with insulated jaws to hold the two cascade boards for our experiments. To avoid a hard short-circuit between the cascade boards when an arc is struck, we fitted two 1800-Ω, 10-W resistors (from the Vishay AC10 series) in series with the electrodes in our provisional setup. They proved to be especially good at handling the high voltage. To avoid creating secondary breakdown sites, we soldered thin wires in series with them and bent the wires so the solder joints were sufficiently distant from the arc location. That's because high-voltage breakdowns tend to originate on small or pointed surfaces, even if the distance between them is relatively large.

A transparent plastic housing is the best choice for maximum safety. That also makes it easy to mount the electrodes with adequate insulation.

During our tests, we used a Variac to adjust the voltage of the circuit. That made it easy to vary the output voltage. If you use a normal transformer, we recommend using a switch-on delay circuit, such as the 'mains on delay circuit' published on page 74 of the July/August 1997 issue of *Elektor Electronics*. You can also power the circuit from a 'normal' regulated power supply. Of course, the supply must be able to provide 80 V and a couple of ampères, and current limiting is probably desirable to increase the useful life of various things. If you use such a supply, the value of R10 should be increased to 1 kΩ or somewhat more, as otherwise the dissipation of R10 will be too high (as will the current through D4).

(050192-1)

Figure 8. This shows how you should wind the transformer. Although this is version 2.0 of the transformer (as opposed to version 3.0 in the photo of the prototype), the winding method is the same.
Legend: ① = C4 in the schematic; ② = C1; ③ = B2; ④ = A2; ⑤ = C2 and C3; ⑥ = B1; ⑦ = A1.

Our components
Component choice for Elektor projects

Karel Walraven

Newcomers to this magazine quite often send us emails with lots of questions about the component choice for projects described in the magazine. Although photographs of our prototypes provide lots of clues, they can't tell the whole story of how we picked such and such a component for a specific function. Some additional information is given in this article.

Resistor, SFR25 (Vishay BComponents), 0.4W, 250V, 5%, metal film axial.
Capacitor (Vishay BComponents), 1pF8, 50V, 5%; NPO radial mono-cap ceramic.
Capacitor, MKT (Epcos), 100nF 63V 5% polyester radial
Decoupling capacitor (Epcos) 100nF 50V 10% radial leaded multilayer ceramic X7R.
Axial electrolytic capacitor 4µF7 63V.
Radial electrolytic capacitor 4µF7 63V.

In the parts lists printed with construction articles in this magazine, most components lack an exact description. That's not only because the application is not particularly demanding in respect of component ratings, but also because we assume that you, the electronics enthusiast, know perfectly well what we mean. However, many less confident readers have problems deciding which parameters are tight and which are 'fairly loose'.

Resistors

We normally use resistors specified at 0.25 watts, 5% tolerance and a maximum working voltage of 200 volts. Of course, you are free to use better-specified components like metal film resistors, 2% or 1% close tolerance, or types rated for 250 V or 300 V. The same for the power dissipation specification; 0.33 watt or 0.5 watt will also fine as long as the relevant components fit on the board.

A specific problem with resistor values comes from the fact that different systems for number notation are used throughout the world. A number of countries on the European Continent use a comma (,) rather than a point (.) for the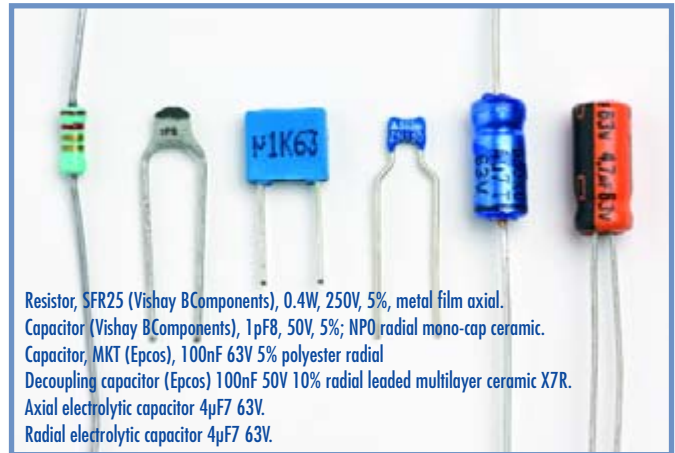 decimal separator. Because Elektor is read all over the world, we needed to solve the problem and did so by omitting the separator altogether, printing the 'k' (for kilo) or 'M' (for mega) in its place. As an added advantage, it improves the general legibility, as a decimal point (or comma) may easily disappear with poor printing or on a bad photocopy. So, for the past 30 years or so we've written '4kΩ7', not 4.7kΩ, 4700Ω or 4,700Ω.

Capacitors

These can be subdivided into three classes depending on their value.

The first group is formed by radial (single-ended) ceramic capacitors with a value of (almost) zero pF (picofarards) to 1000 pF. If no further indication is given, they have to be able to withstand at least 50 V while the temperature coefficient is not an issue. The typical tolerance in this group is enormous at up to ±20%. The lead pitch is usually 5 mm, although 2.5 mm also occurs in RF circuits.

The second group has a value of 1 nF (one nanofarad or 1000 pF) to about 1 µF (one microfarad). For these we usually employ radial devices with a polyester dielectric and a tolerance of ±10%. The working voltage is again 50 V. These caps are produced by many different manufacturers and are generally uncritical in the application (unless otherwise noted of course). Our printed circuit boards allow polyester capacitors with a lead pitch of 5 mm or 7.5 mm to be fitted. In some case, only 5-mm devices can be accommodated, and this is expressly stated in the parts list. The third group is formed by electrolytic capacitors with values (generally) below 1 µF. Here the tolerances are huge, of the order of –20% to +50%. The working voltage may be anything between 3 and a couple of hundred volts. In general, an electrolytic capacitor does not require a higher voltage specification than the circuit supply voltage (this incidentally applies to all components). Electrolytic caps come from tens of different suppliers, and their electrical properties may show up vast differences. We attempt to design our circuits in such a way that nearly every type of modern electrolytic capacitor can be used. One of the few exceptions are switch-mode power supplies in which massive peak currents and high switching frequencies occur. The high internal resistance of a 'bad' electrolytic in a critical spot in an SMPSU causes ripple on the output voltage. Plus the cap will run very hot, and believe it or not: there exist electrolytics with a life expectancy of 1000 hours at 80 degrees C! However, these are exceptions and we will always provide an indication where special parameters are required.

As already mentioned, we specify minimum values, like 10 µF, 10 V. Your supplier may not have this particular device in stock, offering you '10 µF 35V', or '10 µF 63V' instead. Fine alternatives, it would seem, because a higher voltage does no harm. However, do keep an eye on the device size as the alternative may no longer fit the board. Not all manufacturers produce every combination of value and working voltage because it often happens that a 10 µF, 10 V electrolytic cap is just as large (and has the same price) as a 10 µF, 35 V type. When purchasing parts for use in out laboratory we purposely select devices with a relatively large size, so that alternative brands will also fit the board we've designed. With just a few exceptions — duly mentioned in the parts list —electrolytic capacitors are now radial types.

(050315-1)

6 V Dynamo Reg

For vintage motorbikes

Ulf Schneider

This 'bulletproof' electronic regulator was originally designed to replace the troublesome original electromechanical regulator on the author's vintage BMW/EMW R35 motorbike. A large number of BMW/EMW devotees have since successfully tested this unit on their machines without problem.

The design is universal and should be suitable for all bikes using the same switched-earth field regulation method.

The author designed this regulator for his EMW R35-3 motorbike. The bike was built by Eisenacher Motoren Werken (EMW) based upon the pre-war R35 machine from BMW. Production of the bike continued for many years after 1945.

This electronic regulator design uses semiconductor switches instead of the unreliable electromechanical regulator. Vintage purists may dismiss the modification as 'non original' but the original unit was always unreliable and notoriously difficult to set up; adjust the regulator under no load conditions and the battery becomes drained when the machine is driven with the headlight on (which these days is essential). Adjust the regulator under load and the battery 'boils up' when the engine is run with the lights off. The electronic regulator goes a long

way to solving this problem.

The design is suitable for all 6-V dynamos with a rating up to 75 W where the field coils are switched to ground. The regulator draws less than 250 μA quiescent current.

A potential divider network allows the terminal charging voltage to be adjusted to suit the type of cell fitted to the bike (**Table 1**). The regulator exhibits a temperature coefficient of approximately –7 mV/ ºC which is closely matched to lead-acid battery characteristics.

The original

A diagram of the original regulator circuit is shown in **Figure 1**. With the dynamo at rest the reverse-current switch (contacts 4/5) is open and the wiper of the field current switch (2) provides a path to earth for the field winding through contact 1. When the dynamo begins to rotate there is sufficient residual magnetism in the field

cores to ensure an induced voltage in the rotating armature coils. This voltage finds a path to earth through the field coil, reinforcing the field magnetism and producing a higher output voltage and strengthening the excitation field. The armature output voltage increases as the rotational speed increases until it reaches approximately 6.5 V when the reverse-current coil pulls in contacts 4 and 5 connecting the dynamo output to the bike electrics including the battery. The output voltage continues to rise with increased rotation until the level at the voltage regulator coil is sufficient to pull the field connection contact 2 away from 1 (earth). Current through the field winding can now only travel to earth through the 6 Ω wirewound resistor mounted on the dynamo stator. Current through the field coil drops, reducing the output voltage. With increasing speed, dynamo output continues to rise until the voltage at the regulator coil is sufficient to pull con-

ulator

tact 2 all the way up to contact 3, effectively shorting out the field winding and reducing the excitation field to a minimum. This process repeats 50 to 250 times per second and regulates the output voltage to around 7 V. The reverse current coil consists of a few turns of thick wire wound (in the opposite direction) over the top of the regulator coil so that current through the coil reduces the regulator field. At low speed when the dynamo output is less than the battery voltage the field produced by the reverse current pushes open contacts 4 and 5 to prevent the battery discharging into the dynamo.

A 21st century alternative

Figure 2 shows our contact-less semiconductor replacement for the pre-war vibrating regulator. A MOSFET is used to switch the field winding to ground instead of the regulator contact. Electronic regulation means that we can dispense with the second regulation stage and 6 Ω resistor in series with the field coil. The field current through T1 is controlled by IC1, a micropower comparator type MAX921 which contains a voltage reference source (see **Figure 3**). The comparator is permanently connected to the battery via connection 51 of the bikes wiring so it was important to use this IC for minimum quiescent current.

The lion's share of this quiescent current flows through D1, D2 and the voltage divider formed by R1 and R2. The zener voltage of D2 (5.1 V approx) together with the voltage drop across D1 (0.6 V approx) should be fairly close to the 6 V battery voltage in order to keep the quiescent current to a minimum. With a 6-V battery the quiescent current for the entire circuit is less than 250 µA, to put this figure in perspective it is less than the battery's self discharge current i.e. even with nothing connected, more charge leaks away through internal losses in the battery than this circuit requires. Current through the voltage divider chain increases proportionally once the dynamo output voltage goes over 7 V. The voltage divider defines the regulator's output charging voltage and the resistor values are chosen so that

the output voltage is at the required level when the comparator input voltage at pin 4 is the same as the reference at pin 3.

R4 and R5 define the level of switching hysteresis and ensure that the MOSFET switches quickly with low losses. D3 and D4 protect the comparator from any voltage spikes induced on the bikes wiring system.

C1 introduces a time constant to the voltage sense level and help to reduce electrical noise produced by the commutator brushes. It controls the repetition rate of the two stage regulator

and its value can be changed if the dynamo requires a different switching frequency.

D5 is a fast switching flywheel diode used to suppress the back-emf generated across the field coil when T1 switches.

The charging current is adjusted dynamically owing to the high inductance of the field coil and the flywheel diode action. Diode D6 is a Schottky double diode with very low forward conduction voltage and can comfortably handle the generators short circuit output current, it replaces the

Figure 1. The original dynamo circuit.

Figure 2. Circuit diagram of the electronic regulator.
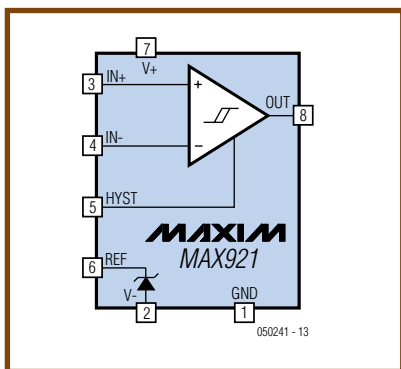
Figure 3. Block diagram of the MAX921 low power comparator.

Figure 4. SMD components ensure a compact PCB.

COMPONENTS LIST

Resistors:
(SMD case 1206)
R1 = 6kΩ8 (see text)
R2,R5 = 4kΩ7
R3 = 100Ω
R4 = 1MΩ5
R6 = S05K20 (varistor)

Capacitors:
(SMD case 1206)
C1 = 4nF7
C2 = 3µF3 (ceramic multilayer)

Semiconductors:
D1 = LL4148
D2,D3 = zener diode 5V1 (SMD)
D4 = zener diode 9V1 (SMD)
D5 = EGP50D
D6 = BYV32E-100
T1 = BTS115A
IC1 = MAX291
PCB, ref. 050241-1 from The PCB
    Shop

reverse-current actuator in the original regulator circuit.

VaristorR6 protects the FET drain connection from any high voltage spikes that may be present. The BTS115A TEMPFET has a very low 'ON' resistance and contains a non destructive device shutdown mechanism when the case gets too hot. Diode D6 can also benefit from this if it is thermally coupled to T1, for this reason they should be mounted as clo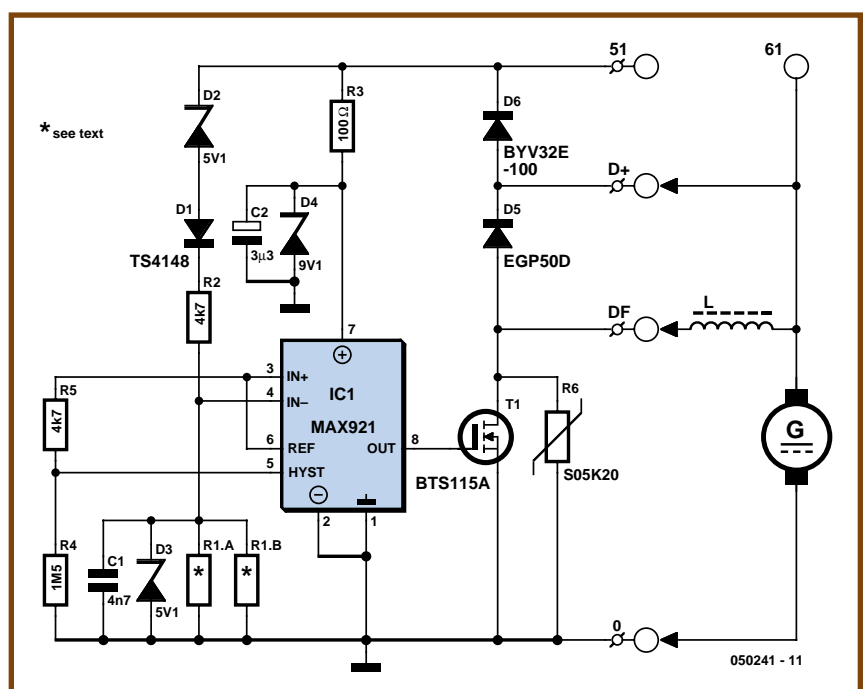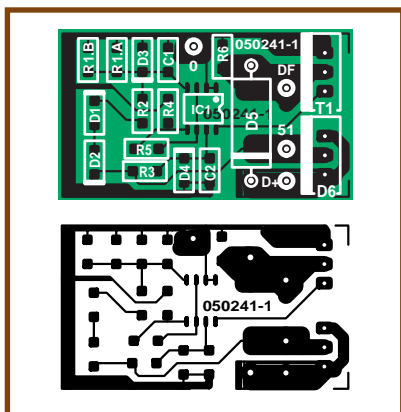se together as possible on the heatsink. Excessive heat in D6 will also trigger T1 to shut down and protect the regulator.

Putting it all together

Figure 4 shows the regulator PCB assembly. Lack of space inside the dynamo casing means that some SMD components are needed for the design. Electrolytic capacitors have poor reliability at high temperatures so a multi-layer ceramic capacitor is specified for C2. The regulator will spend its life in a reasonably hostile environment so it is a good idea to protect it as much as possible from the ingress of oil/water and general highway crud by 'potting' it inside an insulating casting. However before we get to this stage it is necessary to do a bit of tweaking on the test bench. The two resistors R1.A and R1.B are connected in parallel in the circuit. The value of R1.A is specified as 6.8 kΩ while R1.B needs to be determined empirically with the help

of a 470 kΩ variable resistor, a good quality (low ripple), finely adjustable power supply with an accurate voltage display (or DVM) and an LED together with a series resistor to act as an indicator light. During adjustment diode D6 needs to be bridged by connecting a wire link between D+ and 51, next connect the LED together with its series resistor between D+ and DF (Anode to D+). Connect two leads to the 470 kΩ variable resistor, one to the wiper and the other to one end of the track; now solder the other ends of these leads to the pads where R1.B will be positioned.

The power supply should be connected between 51 and earth of the regulator connections. Adjust the output voltage according to the type of battery which will eventually be fitted (see **Table 1**). If the bike isn't used regularly you can afford to increase this voltage level by 100 mV without harming the battery, alternatively if it's in regular use the level can be decreased by around 100 mV. With this regulator the output voltage is still not completely independent of load but it is hugely improved compared to the original unit. Rotate the variable resistor until the LED comes on then back off until it just goes out. The variable resistor is now set to the value necessary for R1.B so carefully remove its leads from the PCB and measure its value. Choose a resistor from the E24 or E48 series of resistors closest to the measured value and fit to

Figure 5. The author's prototype fitted to the R35 dynamo mounting plate.

Table 1
Recommended charging voltage

Cell Type	Fully charged terminal voltage (V)
Gel lead-acid	7.25
Wet lead-acid	7.35
Wet NiCd	7.40

Figure 6. The 'potted' unit fitted to the dynamo.

position R1.B on the PCB.

Once you are satisfied that the unit is working correctly the complete PCB can be fitted to a suitable dynamo mounting plate and encapsulated in potting compound; the authors finished regulator is shown in **Figure 5**. It is advisable to thoroughly check the dynamo before the unit is fitted and ensure that the earth lead is first disconnected before the unit is wired up, not forgetting to reconnect once everything is in position. The electronic unit will not work with a deeply discharged battery or with no battery fit-

ted to the bike but apart from this restriction the regulator should provide many thousands of miles of reliable operation, keeping the battery

healthily charged and thanks to the improved lighting, giving a much clearer view of the road ahead!

(050241-1)

Automatic Gain Control for DRM Receiver

Burkhard Kainkar

A DRM receiver typically supplies an intermediate frequency (IF) output signal of 12 kHz to the PC soundcard. Demodulation is handled by software running on the PC, taking into account that large signal level differences may occur. Using an AGC (automatic gain control) circuit we achieve the best possible signal level applied to the sound card under all receive conditions. Particularly with extreme fieldstrength variations (due to fading etc.), an AGC guarantees fewer hiccups in the decoding process. The DRT1 receiver from Sat Schneider (www.sat-sc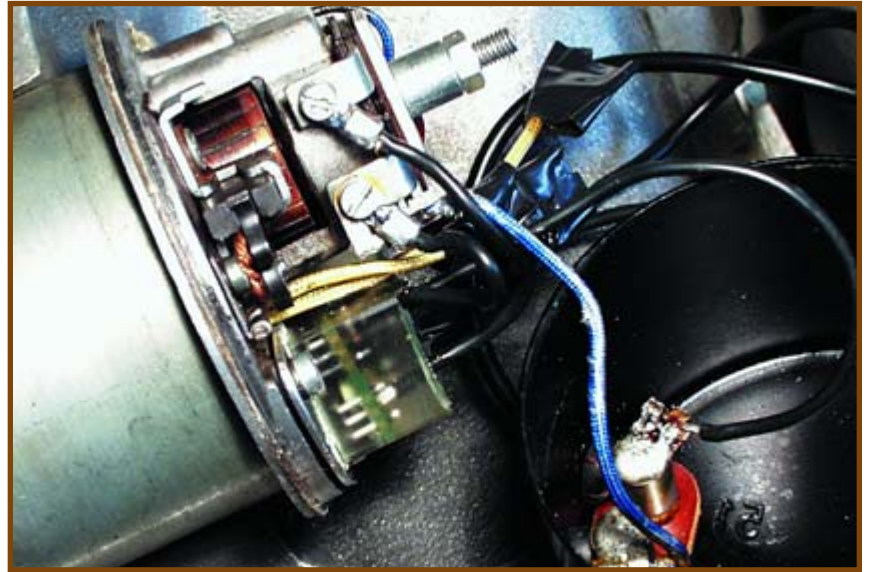hneider.de) already has an input for gain control. Using the VGC_IN terminal on the receiver, the gain may be controlled with a slope of 25 dB/V. With the *Elektor Electronics* DRM receiver, AGC is also fairly easy to install as an upgrade, see the relevant Design Tip.
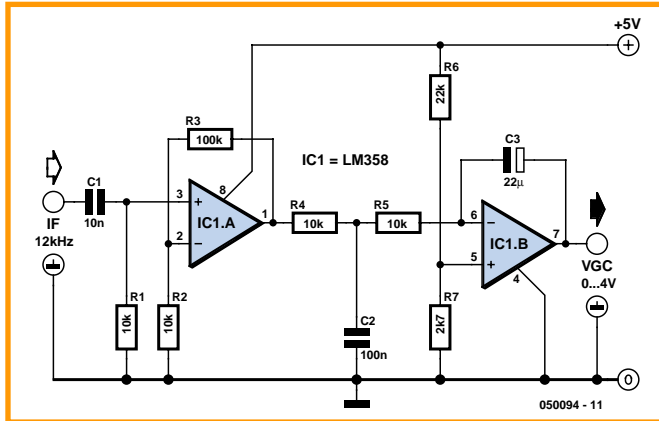
A control amplifier for DRM needs to comply with some special requirements to make sure the signal is not corrupted. Fast level changes in particular must be avoided. The circuit presented here accepts the 12-kHz IF signal from the DRM receiver and turns it into a control voltage. The first stage is a half-wave rectifier. At first blush it would appear that a diode is missing. The rectifier operates as an amplifier with output signal range limiting. Positive half cycles are amplified about 10 times. At the negative half cycles, however, the output voltage is zero because the LM358 operates from a single 5-V supply rail, hence cannot supply drive in the negative range. The upshot is that we have a very basic half-wave rectifier that's not hindered by any threshold voltage as usual from diodes.

The rectifier output signal is applied to an inverting integrator. An average direct voltage exceeding 0.5 V at the input causes a falling voltage at the integrator output; a smaller voltage, a rising output voltage. The complete regulation loop consisting of the gain control in the DRM receiver and the gain-controlled amplifier regulates the receiver output voltage to a constant level of about 100 mV. The governing factor is the control loop time constant that prevents abrupt level changes. The circuit is not only useful with DRM reception — AM and SSB modes will also benefit from it. In connection with the DRT1, the gain span is about 115 dB, ensuring that the optimum gain is available at all times.

(050235-1)

050094 - 11

FBI siren with flashing light

Arthur Schilp

This ultra-simple circuit will produce the familiar sound of sirens used by US police cars on emergency calls. A small lamp will also flash synchronously with the siren sound. The circuit is capable of powering loads greater than 1 A for one or more lamps or a powerful loudspeaker, the kit producing quite a bit of noise and light. The circuit is built from two astable multivibrators, in this case the familiar 555 of which two are present in an NE556 case. Of course, you are free to use two 555s if that suits you better. Both timer ICs are configured to operate as astable multivibrators.

The first timer is configured with R1, R2 and C2 to supply a rectangular signal of about 2 Hz at pin 9. The lamp is switched on and off by way of power transistor T1. The second 555 is configured using R4, R5 and C5, and supplies a square wave at pin 5 that drives the loudspeaker. The toggling voltage at the output of the first timer (pin 9) causes electrolytic capacitor C3 to be partly charged and discharged, periodically, via resistor R3. C3 is connected to the control input of the second timer (pin 3), causing it to work as a VCO (voltage controlled amplifier). The upshot is that the frequency of the square wave applied to the loudspeaker rises and falls periodically, rendering a good imitation of the wailing sound of the US police car siren (we hear too often in movies).

The small number of dead-standard components used enables this circuit to be built on Veroboard without problems.

(050349-1)

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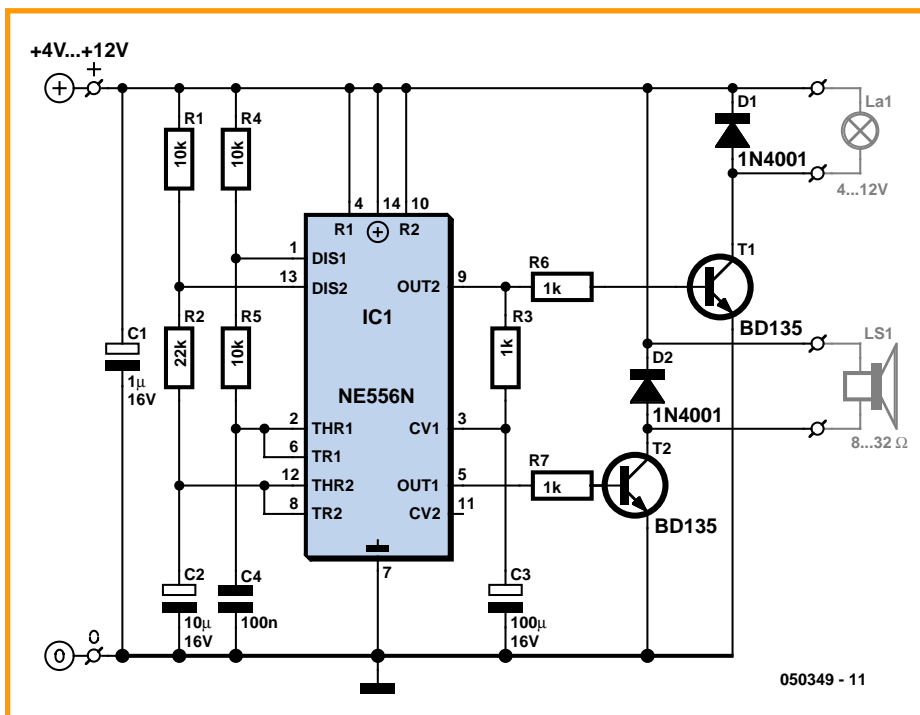
Parallel resistor calculations

Ton Giesberts

This design tip describes a simple equation to compose a desired resistance from two parallel connected resistors.

The formula for parallel connection of two resistors may be found in any electronics textbook and reads:

$$R_{eq} = R1\ R2 / (R1 + R2)$$

In many cases, a theoretical value required in a circuit will deviate somewhat from off the shelf values in the E-series. In analogue filters, for example, maintaining the exact value is a must and even an E96 value is usually too inaccurate. The obvious solution to the problem is then to take the next higher E96 value and connect a high value in parallel in order to arrive at the computed value. In those cases you know the desired value as well as the nearest E96 value. A formula similar to the one above may then be used to calculate the required parallel resistor, where

R is the desired value;
R_E is the E-series value (e.g. E96, but equally E12 or E24);
R_P is the unknown resistance.

From the above basic formula we can derive

$$R = R_E\ R_P / (R_E + R_P)$$
$$R_E\ R_P = R_E\ R + R_P\ R$$
$$R_E\ R_P - R_P\ R = R_E\ R$$

So, we get for R_P:

$$R_P = R_E\ R / (R_E - R)$$

where $R_E > R$.

This equation should be easy to remember as it looks very much like the textbook version for parallel resistances. Of course there are programs to calculate all possible combinations, but using a simple desktop calculator is often quicker and more convenient.

When the second resistor becomes too large, for example, larger than 1 MΩ or 10 MΩ, you may decide to take a slightly higher value as a starting pint for the E series calculation. Parallel connection of resistors i.e. preferred over series connection in the case of modifications to an existing circuit or PCB layout, as
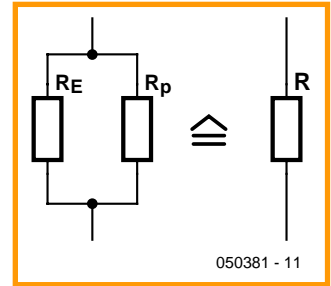
050381 - 11

it is usually easier to connect a parallel resistor.

The added resistor R_P does not have to be a close tolerance type as it has less influence on the equivalent value. In most cases a 5% tolerance type will be more than adequate.

(050381-1)

Gain control for Elektor DRM receiver
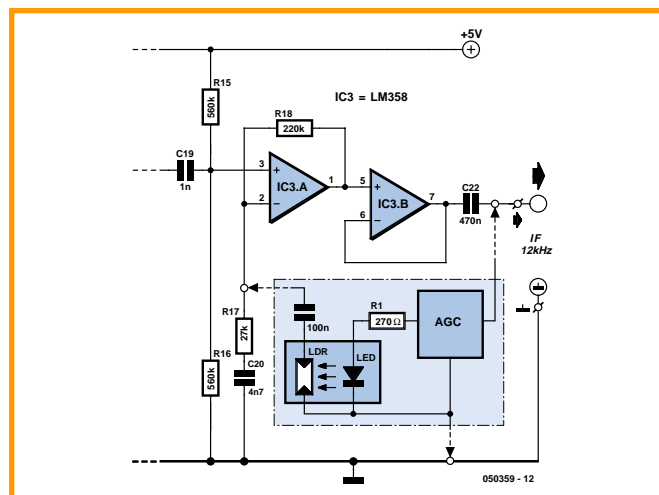
Burkhard Kainka

Adding automatic gain control (AGC) to the *Elektor Electronics* DRM Receiver (March 2004) is a useful undertaking. The original receiver was designed to have fixed gain for the strongest signals, with some headroom afforded by the large dynamic range of the sound card. Admittedly weaker signals we would like to boost a little, if only that were possible.

A gain control add-on would be desirable, provided its addition does not compromise the linearity of the receiver. The extension proposed here employs a homemade optocoupler consisting of a superbright red LED and an LDR. The construction of the coupler in an aluminium tube (Figure 1) was taken from the Photoelectrical Oscillator (PEO), a 'Rejektor' circuit shown in Mailbox, *Elektor* January 2006, on page 8. The governing advantage of this LDR/LED combination is the pure ohmic resistance of the LDR, which guarantees low distortion. In the DRM receiver, the LDR/LED assembly is inserted into the feedback path of the 12-kHz amplifier as shown in the circuit detail in **Figure 2**. The drive signal comes from a circuit contained in the box

LED1, LED2, LED3 = low current, red
LDR1, LDR2 = 1k ... 40k

050359 - 11
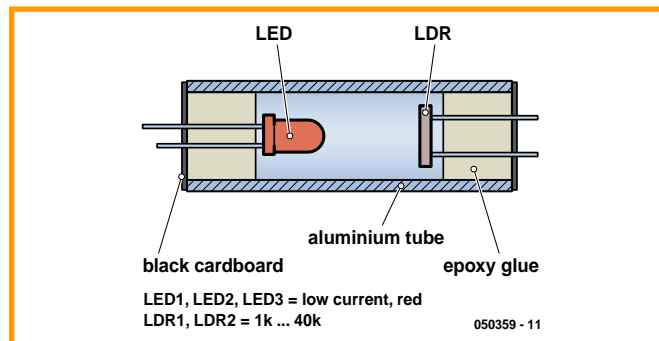
marked 'AGC', this is an AGC amplifier copied from another Design Tip, 'Automatic Gain Control for Elektor DRM Receiver'. This sub-circuit was originally developed for the DRT1 receiver. Here, its output voltage (0-4 V) controls the LED brightness. The dashed lines denote the connections between the existing *Elektor* DRM receiver and the add-on circuit for automatic gain control.

Depending on the degree of illumination by the LED, the LDR resistance will vary between about 1 kΩ and 1 MΩ. The feedback network in the receiver fixes the gain at about 9 times. At an LDR resistance of 1 kΩ, the gain rises to about 220 times. This system provides a gain range of 27 dB. That's just about right for this receiver, raising the sensitivity without the risk of overloading by stronger signals.

The AGC improves the performance of the *Elektor* DRM Receiver in respect of weaker signals. Adding it is worthwhile in almost all cases, but even more so if the receiver is used to listen to analogue (AM) broadcasts. For that application, we found Peter Carnegie's 'G88JCFSDR' program (www.g8jcf.dyndns.org) very useful. This 'software defined radio' excels in filters with adjustable bandwidth, software AGC, S-meter, spectrum readout and various demodulators, all of which provide great enhancements to the receiver.

(050395-1)

050359 - 12

Digital sinewave reference generator

050353 - 11
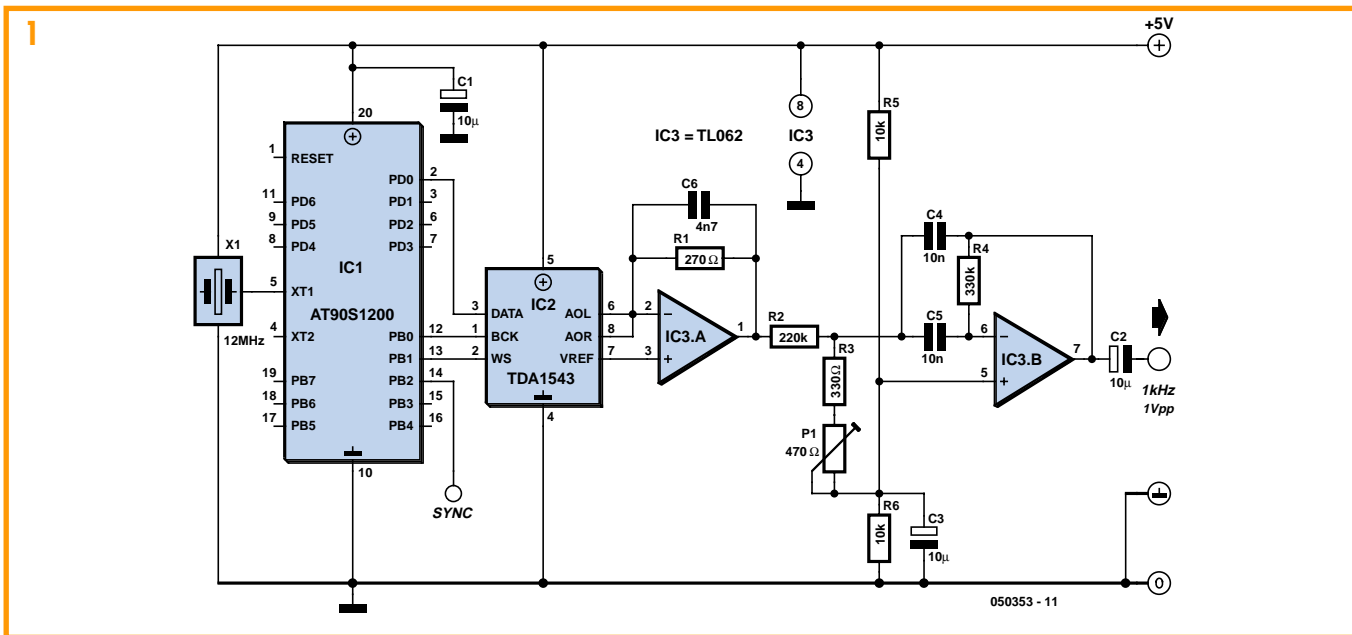
Martin Ossmann

When it comes to testing and measuring audio circuitry, a very clean and stable 1-kHz signal is often required. The Wien Bridge has been the preferred circuit configuration for many years. In the digital age however there are alternative means available. A low-cost microcontroller drives a D/A converter, whose output signal is filtered using a bandpass in order to suppress alias frequencies. This setup guarantees an output signal that's spectrally pure as well as stable in respect of amplitude and frequency — everything you would like to have for spot-frequency measurements.

Figure 1 shows the way the above concept has been turned into a practical circuit. The 16-bit D/A converter is remarkably cheap at less than 80 p from Reichelt, Germany, which helps to keep the cost of the circuit as low as possible. Microcontroller IC1 generates 74 samples in I^{2}S format in every 1-kHz period. This creates a sampling rate of 74 kHz — much higher than your average CD player. The two current outputs of the DAC IC2 have been connected in parallel to maximize the signal-to-noise ratio. The first opamp of the TL062 acts as a current-to-voltage converter. The second opamp is configured as a bandpass element. Preset P1

is used to adjust the circuit for maximum output voltage.

The measured spectrum is shown in **Figure 2**. The first and second harmonics are more than 80 dB down with respect to the 1-kHz signal. The alias frequencies around 74 kHz are suppressed to the extent that it's difficult to prove their existence.

The circuit is quickly built on a piece of Veroboard (**Figure 3**). In order to prevent ground loops, it is recommended to power the circuit from a set of (rechargeable) batteries. Here, four NiMH batteries are used.

In conclusion, the simple battery-powered 1-kHz generator described here can be built for

less than three pounds. It is free from complex adjustments, precision capacitors and inductors. The software to program into the microcontroller is available as a Free Download from www.elektor-electronics.co.uk; the file number is **050353-11.zip**.

(050353-1)

Note.
Although the AT90S1200 is no longer produced by Atmel, it is still widely available from retail outlets like Reichelt, Segor and Sander. A successor type is available, see Atmel's application note no. AVR093: 'Replacing AT90S1200 by ATtiny2313'.
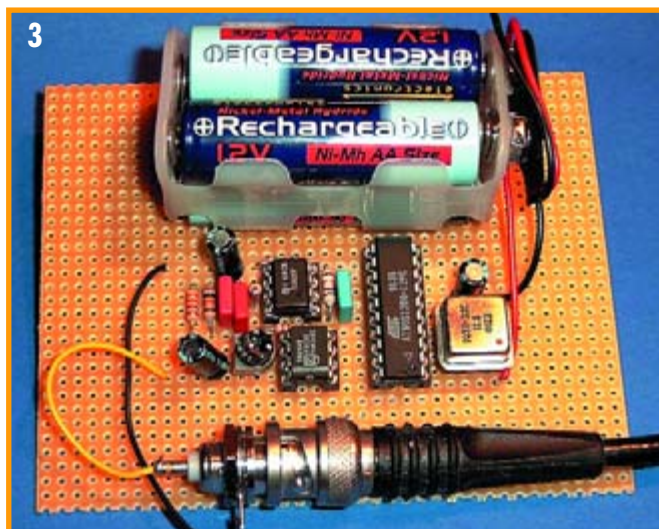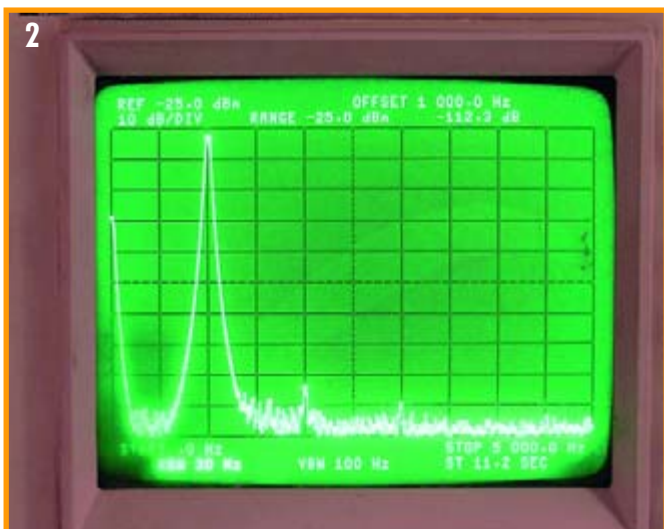
The Old Physics Lesson

Jan Buiting

Magnetism lies at the root of electricity which in turn is at the root of (nearly) all electronics. The subject of this month's instalment of *Retronics* is a small brownish suitcase which, when first opened (**Figure 1**), took me back instantly to physics classes about 30 years ago, in particular those aimed at teaching me the principles of electricity and magnetism. The suitcase was shown to me by a retired classroom assistant who had kept it in safe storage for more years that he could remember. In fact, he had two of these suitcases, one incomplete, the other, complete, unused and in pristine condition as shown here.

The 'Electricity and Magnetism Demonstration Set for Physics Classes" (**Figure 2**) contains two large coils (one with a lamp fitting on it); a centre-zero moving coil meter, its needle so large it can easily be read it from the back of the classroom; a magnetic rod with North and South poles; a sheet of hard plastic; a slab of soft iron, a 6-V lamp; a 4.5 V battery, an assortment of resistance wire; test tubes containing iron powder and (I think) copper filings; an adapter/holder for the resistance wire; a mains cord and last but not least a copiously illustrated teacher's manual. The suitcases and the components inside are hand made to very high standards, with metal clamps and pieces of wood carefully secured at critical places inside to prevent damage to the highly prized contents. The meter and coils have a bright green lacquer finish immediately recognised as 'techie'.

Without any attempt at exhaustiveness, I will describe a couple of experiments that can be performed by the physics teacher and/or his assistant in front of a classroom full of (hopefully) attentive pupils. **Figure 3** shows the most elementary setup described in the manual. When the magnet rotates through the coil with the thinner wire on it, alternating current is indicated by the meter needle swinging to and fro. Yes Mike it's AC (alternating current), "*which nobody can deny*". DC, then, is proven beyond reason-

able doubt by connecting the meter to the battery and reversing the + and – connections. The coil with the thicker wire can be stacked on top of the other one, the 6-V lamp screwed into its socket, the mains cord plugged into the socket on the lower coil and… nothing happens! That is, until you insert the iron slab vertically into the coil openings and hey presto the lamp lights. You've actually built a transformer consisting of a primary (thin wire), a secondary (thick wire), and magnetic coupling, stepping down the 230 V mains voltage to a safe level. The lamp intensity can be varied by vertically moving the iron slab in the coil openings. Next up you can replace the lamp by a length of resistance wire secured between the arms of special Perspex adapter and watch the thinner wire burn out — an odd smell and there's your basic fuse.

These suitcases reportedly were made between 1960 and 1965 and the one that's complete and in new condition must be priceless. Maybe one day it will make it to FlogIt!

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.

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Hexadoku

Puzzle with an electronic touch

Judging from the large number of correct solutions we received by email and regular post, our new Hexadoku puzzle launched in last January's issue has met with great interest. The puzzle also appears to be well liked by family members and friends of the electronics fans buying Elektor or subscribing to it, probably because of the extra challenge posed by the hexadecimal number series.

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

Solve Hexadoku and win!

Correct solutions qualify for an

E-blocks Starter Kit Professional

Elektor's new brainteaser for the electronics enthusiast and keen reader of the magazine appeared to be fairly difficult to solve. Many readers report having spent quite a few hours completing the thing, and were happy to rise to the challenge.

The instructions for the puzzle are straightforward. In the diagram composed of 16×16 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 4×4 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 → February).

(065043-1)

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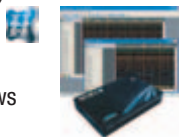Call today for free samples and pricing
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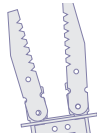
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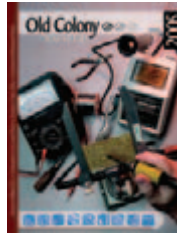
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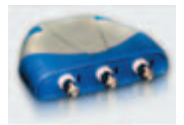- GSM/GPS antennas
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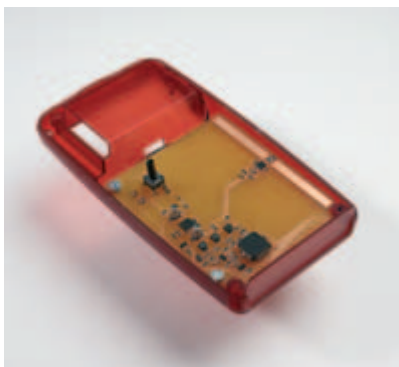long cable, CD with
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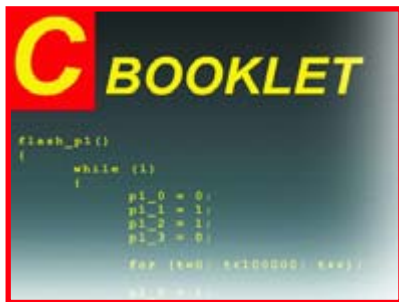
C Programming Mini Course

Many electronics enthusiast have not only embraced microcontrollers but also written the odd program. Although assembly code is great for relatively short programs, when it comes to large software projects or subprograms involving maths and other advanced functions, it is often better to turn to a higher programming language like C, which has been the industry standard for a number of years already. The March 2006 issue of Elektor Electronics comes with a free booklet that teaches you the basic elements of programming in C, including a few noteworthy examples for our low-cost R8C microcontroller board.

Application Board for R8C

The R8C/13 module used for the initial experiments in this issue may be small but it has a lot of potential. However, this can only be unleashed if you have a motherboard that opens up the full connectivity of the micro board. The R8C Application Board described in the March 2006 issue offers two serial ports, a USB connector, a connector for an LCD module, a stabilised power supply, an array of LEDs and last but not least a handy prototyping area.

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Also...
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