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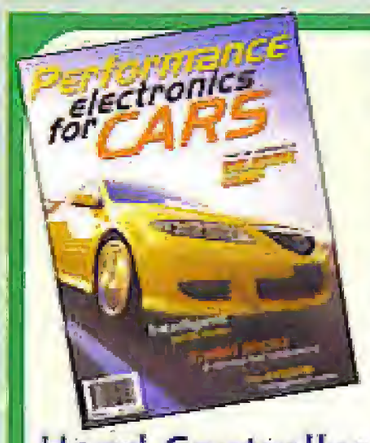

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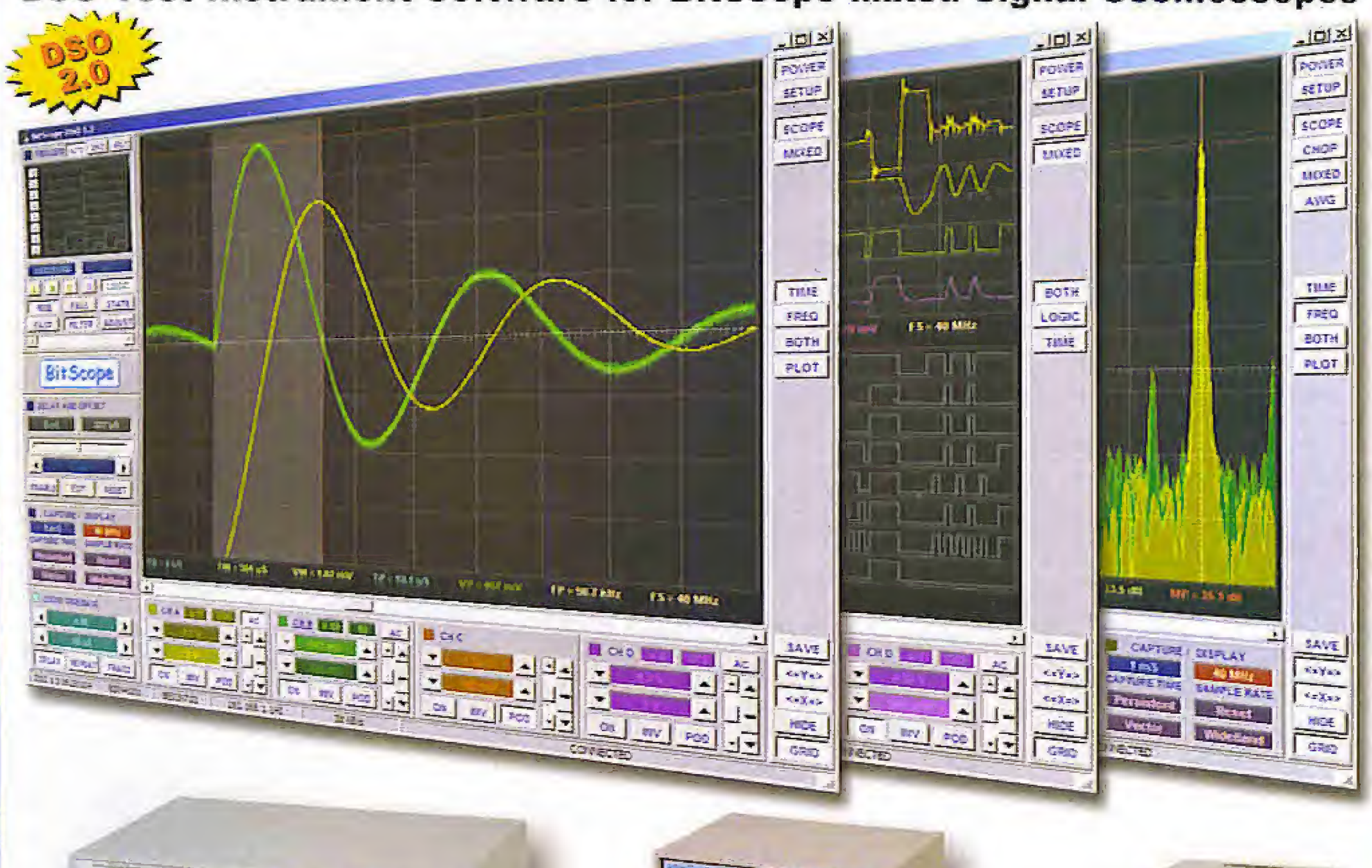

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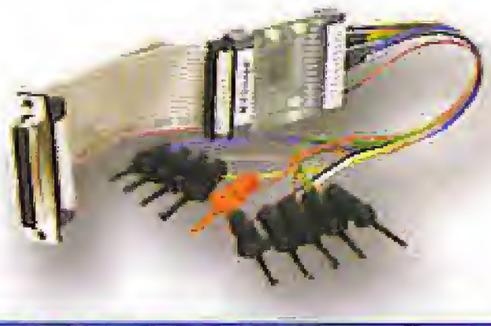

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Teaming up

If you are not in the electronics industry or without a formal qualification in the field, it may be good to realise that electronics as a pastime would be non-existent without the wide diversity of manufacturers of equipment, tools, components and, recently, software to run on your PC, not forgetting a growing number of PCB-to-order service providers.

Although some readers have expressed a desire to see a version of Elektor Electronics without any advertising pages, short discussions on the phone or by email are usually sufficient to agree that their vision is unrealistic. For one thing, our advertisers make up for a good part of our income, the other main pillars being subscribers, newsstand sales and product sales. On the other hand, from a reader viewpoint, advertisers are the gateway to services and products (including components and tools) that are essential to enjoy electronics as a pastime, or pursue it at any level in education.

Sure, old hands with a fully loaded workshop may object to seeing basically the same advertisers for years on end. But then, when I was learning about electronics at a relatively young age, I believe I got as much information and fun out of browsing adverts, comparing component prices and seeing the big names in industry, than from actually reading articles, trying to understand it all and building circuits in front of me.

I am happy to say that Elektor Electronics is attracting an increasing number of companies, big and small, advertiser or not, wishing to run projects with us. Without their input we would not have been able to publish hugely successful projects like the E-SIM DVD (October 2006; miscellaneous software suppliers), RFIDs (September 2006; Philips/ACG/Visioncard) and R8C Tom Thumb (February 2006; Renesas/Glynn) in the past year. With this January 2007 issue come two massive contributions, one from advertisers Microchip and Labcenter in the form of a free CD-ROM coupled to a 16-bit microcontroller development kit, the other from Colinbus offering a kit of parts to assemble a milling machine for use in the electronics or mechanical workshop. Both deals have taken us much effort to arrange exclusively for you — or should I say 'for your pleasure'. More is in the pipeline.

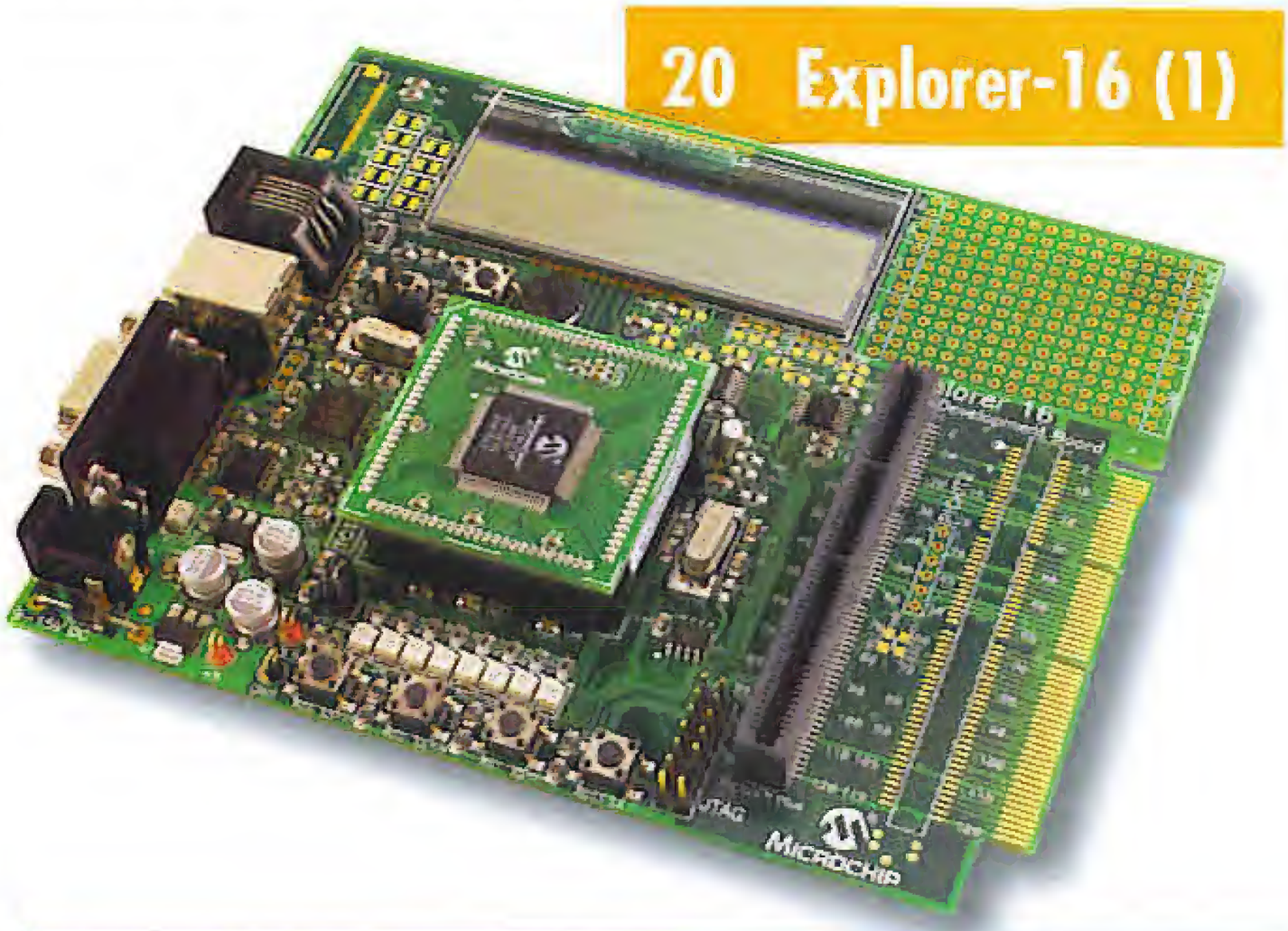
Jan Buiting, Editor

30 'Profiler' Milling Machine

If ever you dreamed of having your own milling machine in the workshop but found it just to too expensive, we have the perfect solution for you.
Working in close collaboration with Colinbus, we present *Profiler*, a construction kit that enables you to build a professional milling machine for a fraction of the cost of a ready-made model.

If ever there was a golden opportunity to move on to 16-bit microcomputing at a serious level, join Microchip, Labcenter and Elektor with their groundbreaking *Explorer-16* project. As a kick off, you get a free CD-ROM this month, allowing you to install Microchip MPLAB IDE as a development platform, MPLAB C30 for C language compiling and Proteus VSM for some really powerful simulation right up to a complete PIC24F system.

20 Explorer-16 (1)



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28 The Quest for Accuracy

The most advanced atomic clocks are breath-takingly accurate, many millions of times more so than the best quartz-based clocks. How do they manage it? Jens Nickel reports.

Fifty years after the launch the first artificial satellite, it seems fitting to build a clock in the shape of the Sputnik-1 that combines a nostalgic Nixie tube display with a modern microcontroller and a lightweight state of the high-voltage supply in a single design.

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elektor electronics

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

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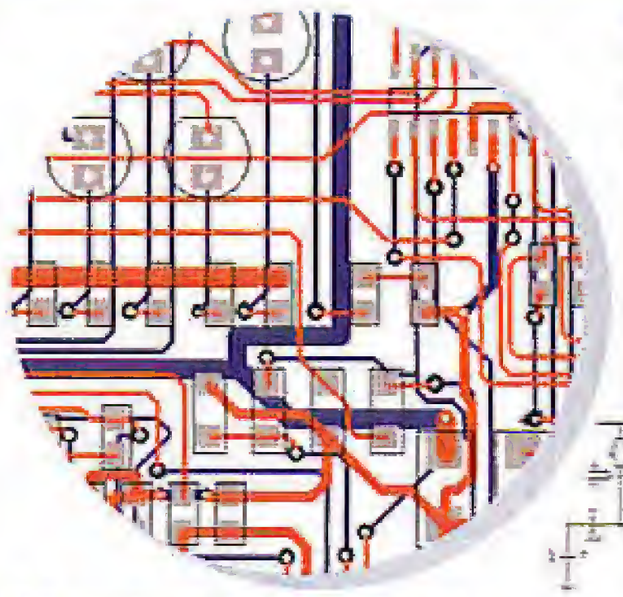

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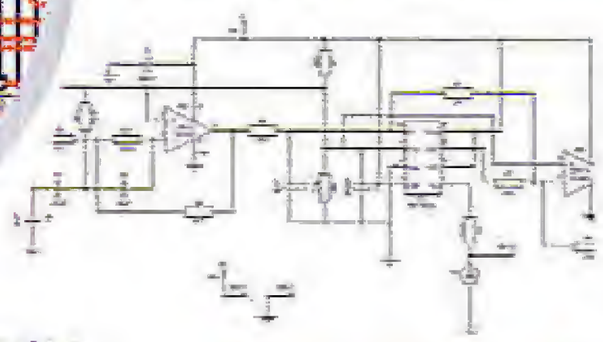

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A	4	F	E	C	0	9	8	7	3	1	5	6	2	B	D
B	7	8	2	4	D	1	A	E	F	6	0	3	9	5	C
D	6	0	3	7	2	E	5	A	C	9	B	1	4	8	F
C	5	9	1	3	B	6	F	4	2	D	8	E	7	0	A
8	9	E	4	5	3	A	1	F	D	0	6	2	B	C	7
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2	1	A	0	F	6	7	D	C	B	E	9	5	8	3	4
9	D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

Electronics for youngsters

Dear Jan — I have been subscribing to Elektor Electronics for a couple of years - and quite frankly I think you are missing a trick or two. Many of your projects are extremely clever and interesting, and in quite a few designs it anticipates the reader has acquired a PhD in Electronics or Communications Technology! The bulk of your projects are far too complex for the majority of 11-15 years olds! You need to nurture and encourage this age group — they are potentially your future readers and contributors!
My advice is to allocate 15-20% of the magazine to less complex projects that school pupils will find inspiring and eagerly want to build, test and run.

a) Each 'junior' project needs to be carefully packaged and include a comprehensive Parts List.
b) Contain a list of Test Equipment.
c) The availability of a PCB.
d) If software is included in the project — the source coding lines need labelling in an 'unambiguous' manner to explain the program steps.
e) The inclusion of a Flow Diagram would be an advantage.
f) What software and hardware are required to run the program

Finally, a good starting point for a 'junior' project, are those constructed using the Parallax BASIC Stamp I and II chips. Quite complex circuits can be designed and built, and there is an element of programming involved.
From my experience of projects in past issues of your magazine! You and your contributors might understand the gobbledegook included in some of your software listing, but an eleven year old will struggle for a while, then give up and put the magazine in the shredder and the partially tested PCB in the bin! (I imagine quite a few adult Elektor readers have gone down this route!)

David Jack (UK)

Many thanks for your email, feedback of the level you supply is few and far between and therefore much appreciated.
I agree that many of our projects are ambitious, certainly compared to those I get to see in other magazines. Having said that, I should attempt to adjust your view somewhat by pointing out the following articles that appeared in recent issues, which I believe should not deter 11-15 year olds:

1. *At least 10 to 20 items in each Summer Circuits edition published these past 31 years.*
2. *The Modding & Tweaking pages authored by student Jeroen Domburg.*
3. *Selected items from the 'Design Tips' pages in a number of recent issues.*
4. *Non-constructional articles like the ones on Cubesats, RFIDs, Electrosmog etc., which, although unlikely to be fully understood, do present a mind challenge to 11-15 year olds, as well as topical information on the role of electronics in today's society.*
5. *Lots of free downloads with published articles; even if the associated project is not actually built (or even understood), source code listings etc. are great as educational material.*
6. *A number of 'lesser' programs on our free e-SIM DVD.*
7. *All projects in our free 24-page i-TRIXX supplement supplied with the December 2006 issue. In fact a number of these circuits were supplied to us by youngsters!*

Sadly, our 'Mini Circuits' articles were discontinued due to lack of interest and feedback particularly from the age group you mention, as well as their teachers. Also, from a commercial point of view, sales of PCBs specially designed for these projects were negligible. We will, however, consider publishing Mini Circuits again.

We are grateful for encouraging us to look after the coming generation in respect of publications on electronics and hope to serve them better in the future. On another positive note I should mention that an "Elektor Beginners Kit" is being developed and hopefully goes on sale later this year.

FTP for free downloads

What about having an FTP for the free software where we can download it easily?
A well arranged FTP with every year Issues in a separate folder will be a great help to grab the free software of the whole issue by simply drag and drop using any FTP client and it will reduce the bandwidth used to browse each article and download each attached free software separately.

Also, you can enclose a link for the PCB (if exists) to direct immediately to the purchase page with the compressed files.
It will save you lots of bandwidth and save us a lot of time browsing articles and downloading & arranging files. All the best!

MAZ
(reproduced from Forum)

From a publisher's point of view, it is not desirable to revert to the system on the previous version of the website where clients could just grab a lot of free software

or PCB layout files from a single page, often without making the small effort to find out what the associated article was about. Unfortunately this system caused a lot of unnecessary queries sent to our customer services, design and editorial staff.

The current system is a little more complicated but superior in that customers at least have an idea what the magazine articles are about (through the short intro supplied) hence do not start downloading free software they will never require. Secondly, the system currently in use is a result of database-driven publishing which will be strengthened in the future to enable us to run the entire Elektor operation in ten languages with the resources and staff we have available.
Everyone is welcome to download our free software and do whatever they like with it (but subject to copyrights) — all it takes is a little effort in navigating and reading "what's on the tin" as our mothers taught us.

Vintage Elektor audio projects

Dear Jan — I have pleasure in sending you some photographs of Elektor projects I built over the years. The first shows your Portable Mixer from 1986 (I think). I actually built three of these! The circuit boards and the chassis are 100% do it yourself products and all three units still work fine after all those years. I got a lot of fun from building and using them!

The second photo shows the 100-watt audio power amp from your April 1982 issue complemented with the DC and switch-on delay from January 1983. I built ten of these amplifiers and none of them ever failed in (rough) use. Unlike some of my friends, I should add, who on occasions asked me to replace BDX66 or BDX67 power transistors as a result of short-circuiting the output or connecting loudspeakers with an impedance well below 4 ohms. As with the mixer project, the PCBs and chassis are 'home-made'.

Roger Demarsin (Belgium)

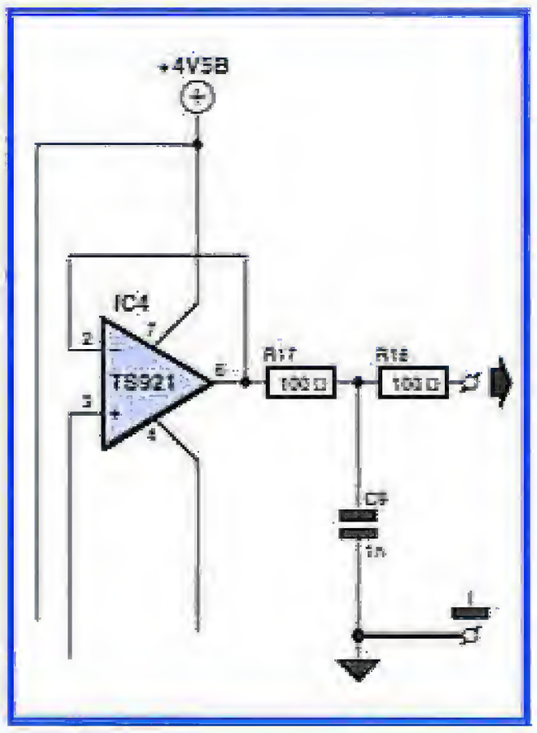
Congratulations on your projects, Roger, it goes to show how our designs stand the test of time if built properly.

Separated grounds

Dear Editor — in the article 'ECG using a Soundcard' (October 2006, Ed.) I noticed in the circuit diagram that the input and output have the same ground sign, while in actual fact electrical isolation exists between them. The design of the associated circuit board confirms that separate grounds are used. I was wondering how this should be indicated in a circuit diagram? Or is the matter I'm trying to raise largely academic?

W. Wade (UK)

It is not — in fact, it is essential for electrical safety concerns and we are grateful to you for writing in on the subject. The two electrically isolated sub-circuits are shown with two different ground symbols, a small horizontal bar and a triangle. Unfortunately, the indicators for 'input' and 'output' give rise to confusion because they all include the same ground symbol (a small bar).
In circuits drawn to our standards, the ground bar is included almost automatically with circuit inputs and outputs (open and solid arrow respectively), and that is where we went wrong in this specific case as the diagram now suggests that the input ground is the same as the output ground. With the output ground we should have printed a solid triangle (as used in the rest of the output circuitry) — this would have precluded any misconception.



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Corrections & Updates

DiSEqC Monitor

September 2006, ref. 040398-1

The value of C5 was originally 2.2nF according to the Eutelsat specs and worked okay with Nokia sets. Later it was discovered that 220 pF was required for Dreambox sets — as it turned out, this value also worked with the Nokia 9500 set. Some experimentation with the capacitor value may be required for other brands.

Pico USB scopes get a speed boost

Pico Technology have opened up a new class of applications for their PicoScope 3000 Series USB instruments by hugely increasing their data transfer speed.
The new, fast streaming mode can transfer over six million samples per second, bypassing the oscilloscope hardware's memory buffer and transferring data direct to the PC. This allows programs to capture waveforms at high sampling rates over long periods of time, resulting in very large data sets limited only by the size of the PC's physical memory. Previously, the only way to sample at high speed was to use 'block mode', which resulted in lost data due to the dead time between blocks. The new streaming mode uses high-efficiency USB 2.0 data transfers to capture data continuously without dead time.
Now it's possible to capture high-resolution data in situations such as vehicle road tests and lengthy laboratory experiments. For example, when used with a PC with 1 GB of available physical RAM, a PicoScope oscilloscope can capture over 8 minutes of data sampled at 1 million samples per second. Using functions built in to the driver, the developer can easily display this data as a single waveform representing the entire 8 minutes, or zoom in one million times to show half a millisecond of data in great detail.
Pico has released the new driver with a fully documented API and an example C++ program aimed at experienced programmers, so that developers can start to use it immediately. Like most Pico software, it is free of charge, and is available to download from the web without registration.
The PicoScope 3000 Series software can be downloaded from the Pico Technology website.

Pico Technology,
Tel. (+44) (0) 1480 396 395.
www.picotech.com

(067216-III)

Surface-mount resistor with 20 watts power rating

Providing design engineers with a thermally efficient high current resistor in a surface mount package, TT electronics BI Technologies SMT Division has developed a non-inductive power resistor rated up to 20 W. Designated the SMHP Series, the resistor is housed in a small, thin TO-263 package suitable for high density PCB installation.
The TO-263 style package is claimed to offer extremely low thermal resistance. The surface mount power resistors are particularly suitable for high precision CRT colour video amplifiers, pulse generator load resistors, in-rush current protection, and bleeder resistors.
The SMHP Series device is an extension of the company's MHP Series through-hole resistors. The MHP Series non-inductive high power resistors are available in five power ratings (20W to 140W) and three TO-style package types, including TO-126, TO-220 and TO-247.

The SMHP Series resistors are rated for 20W power dissipation, with resistance ranges from 0.01 Ω to 220 Ω with values to 51 kΩ available. TCRs range from 50ppm/°C to 250ppm/°C, with tolerances of ±5% and ±1%. Maximum operating voltage is 500 V and dielectric withstanding voltage is 2000 VDC. Thermal resistance is 3.3°C/W from the resistor's 'hot spot' to the package's metal flange and operating temperature range is –55°C to +155°C.
BI Technologies will also produce devices outside these specifications to meet customer requirements, with comprehensive application engineering and design support available for customers worldwide. Samples are available immediately for engineering evaluation and customer prototypes.
Free engineering evaluation samples of the SMHP Series power resistors and further product information are available.

TT electronics BI Technologies,
SMT Division, Telford Road,
Eastfield Industrial Park, Glenrothes,
Fife, Scotland KY7 4NX.
Tel. (+44) 1 592-662200
e-mail sales@bitechnologies.co.uk ,
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(067216-II)

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PCB POOL® with over 18000 customers is said to be Europe's largest supplier of prototype printed circuit boards (PCBs). The PCB POOL® concept convinces two hundred new customers a month to use this service, not only due to the low cost 'cost sharing' principle, but also with first class customer service.
For the past few years the possibility to track your order online has been amongst these services. Now, the innovative electronic company has spent the last 18 months developing a way to seriously increase the scope of that information.
Watch "ur" PCB ® is the result — with its help the customer doesn't just find out that an order has been processed, they can now actually watch the progress of their printed circuit board through each manufacturing stage. Customers can now log into their personal account and view high-resolution photographic images of their current order.
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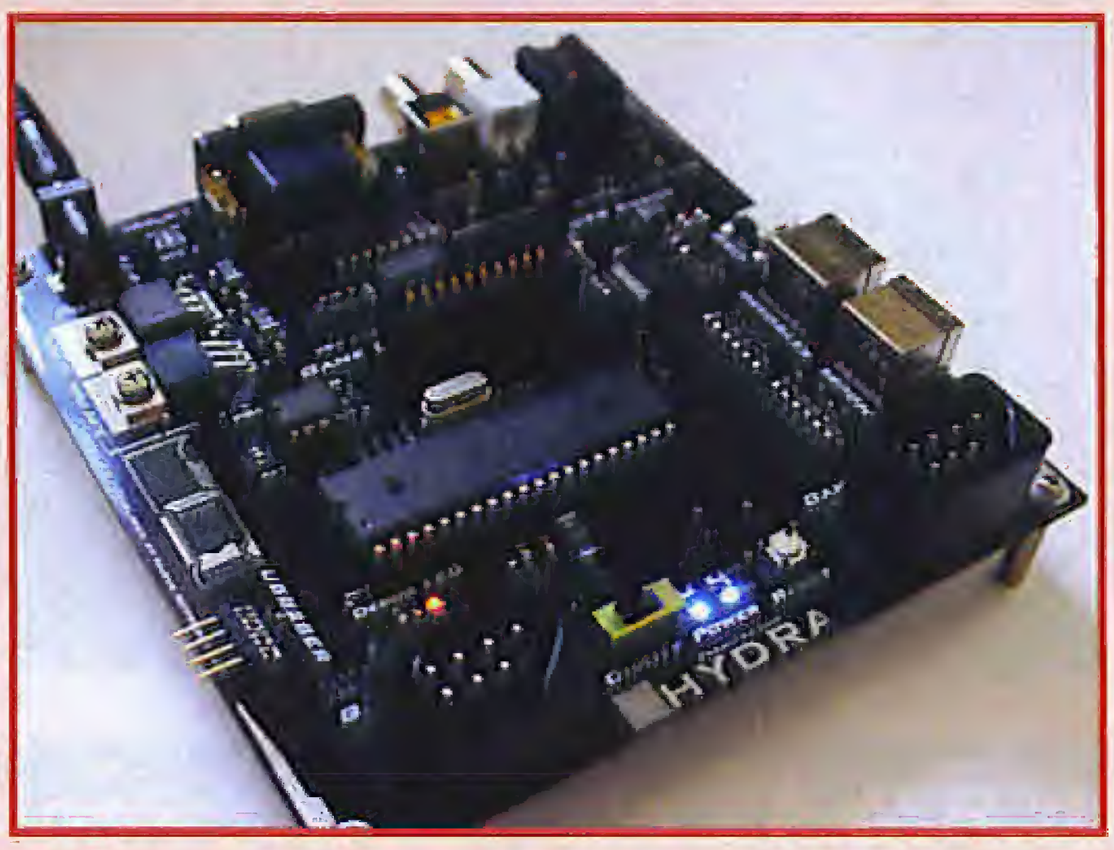
Beta Layout Ltd (PCB-POOL),
Freephone UK 0800 3898560,
www.pcb-pool.com

(067216-IV)

Become a video game developer with the Propeller powered Hydra

If you have ever thought about becoming a video game developer, now is your chance. Parallax, Inc. a privately held company located in Rocklin, CA has partnered with Nurve Networks LLC and Andre' LaMothe, best-selling game development author, to release a new Propeller powered gaming product, the HYDRA Game Console! With the HYDRA you can develop games, graphics and media applications.



For beginner to intermediate coders, you need only basic programming experience in any BASIC or C-like language. All of the hardware and software you need is included. Additionally, the HYDRA hardware is covered in detail with schematics, descriptions, dozens of games, demos, and tips allowing you to take full advantage of its resources, including its expansion port and 128K game card.

But it gets even better! The HYDRA kit also comes with *Game Programming for the Propeller Powered HYDRA*, Andre' LaMothe's latest book. This comprehensive book covers everything you need to know about game programming for the Propeller in Spin and assembly language. All aspects of the Propeller chip are introduced, from its architecture to using the Propeller Tool for programming.

The Propeller chip was released by Parallax, Inc. in April of this year. The chip, designed at the transistor level, uses a new custom-silicon design for simultaneous multi-processing. The Propeller is a 32-bit architecture consisting of eight processors which run at 3.3 V up to 80 MHz. The Propeller is programmed in both a high-level language, called Spin™, and low-level (assembly) language.

The HYDRA Game Console is available at www.parallax.com or by calling the Parallax Sales Department at (+1) 888-512-1024.

(077001-I)

See twelve cylinders of secondary ignition on your oscilloscope

Pico Technology has released the new Mixmaster secondary ignition signal mixer for automotive diagnostics. The Mixmaster can produce a parade display of up to twelve cylinders using a single channel of an automotive oscilloscope.

In the world of automotive oscilloscopes, more cylinders usually means more money. Mixmaster saves you money by letting you use just one channel of your automotive oscilloscope to show an ignition parade of up to twelve cylinders. If you have a two-channel scope, then Mixmaster can also display two engine banks separately with up to six cylinders per bank.

Mixmaster is battery-powered and conveniently portable, with a shockproof rubber case suitable for heavy-duty workshop use. It is supplied with a set of four secondary ignition leads, three BNC leads to connect to the oscilloscope, an engine-block ground lead, and an illustrated manual in English, French, Italian, German and Spanish.

Additional features include a trigger output to synchronise the scope to a known cylinder, and an 'invert' switch to deal with negative-going wasted-spark signals.

Alan Tong, Technical Director of Pico Technology, explained, "Mixmaster will enable engineers and technicians to test V8 and even V12 engines using a standard two-channel or four-channel automotive oscilloscope. Owners of our Automotive Oscilloscope Kits will be able to work on a wider range of engines without having to buy an expensive multi-channel scope."

Mixmaster is available now, priced at £197. Extra packs of four secondary ignition leads are also available at £60.

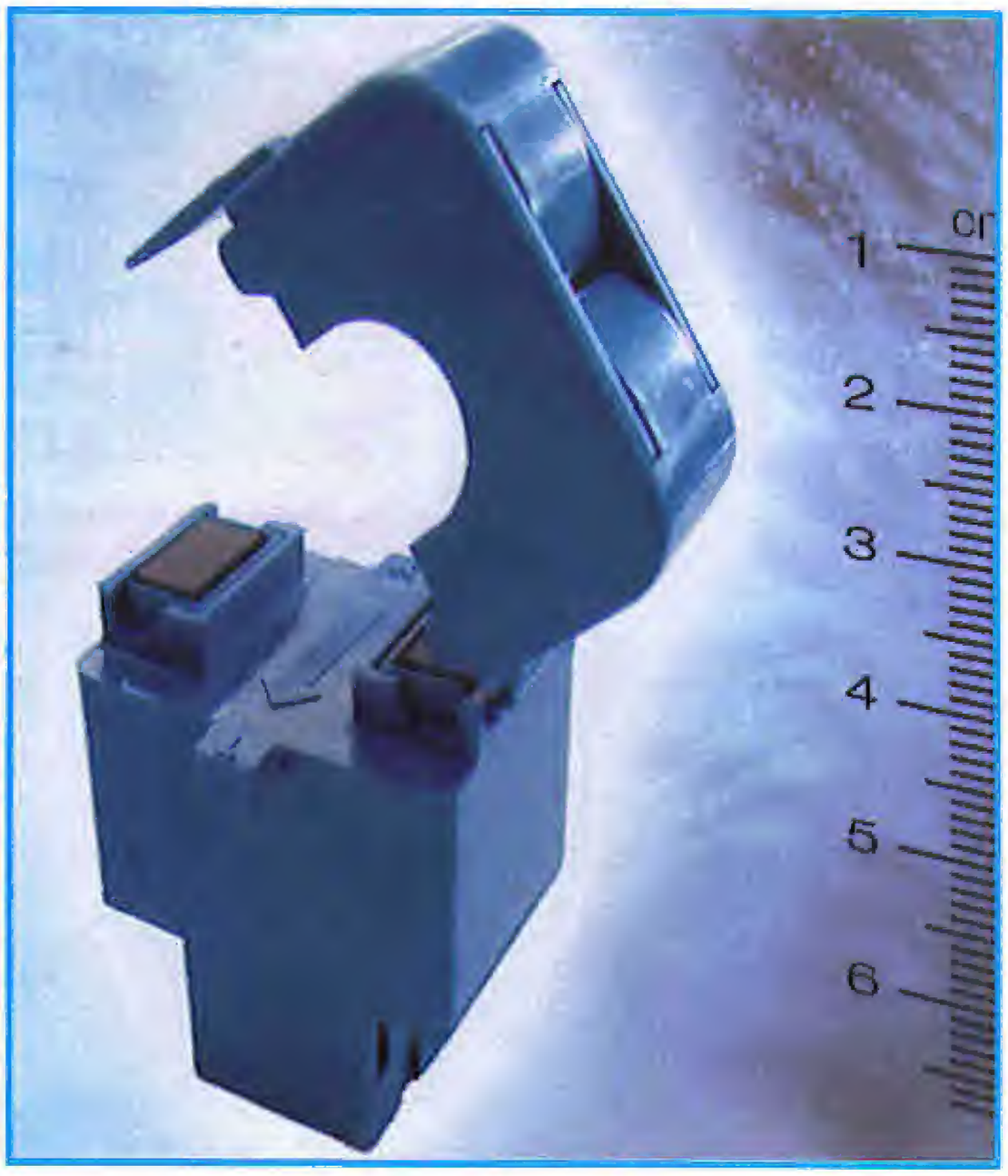
Pico Technology,
(+44) 0 1480 396 395.
www.picotech.com

(077001-II)

Advertisement

Split-core transducers for AC current measurement

LEM has introduced the AT series of AC current transducers, reducing the price point for products made to LEM's demanding quality standards. An innovative core material enables split-core current transformer technology to reach new levels of performance for this category of products.



The AT transducers combine an accurate current transformer and signal conditioning electronics in a very light and compact case to offer substantial savings in size. They measure only 44.5 x 67 x 36.5 mm with a 16-mm diameter sensing aperture for non-contact measurement and are, therefore, particularly suitable for installation in tight environments.
Being split-core and either self-powered or loop-powered they are easy to install and put into operation, which means they can be retro-fitted into existing installations without shutting down operation. This ease of mounting, coupled with the transducers' high reliability, will reduce installation and maintenance costs.
The transducers have been designed to measure 50/60Hz AC signals with RMS (average) computation. They provide an absolute accuracy better than 1.5 percent of the nominal current over a broad range of inputs. A choice of primary current measurement ranges from 5 A to 50 A are available, with a selection of industry standard output types (4-20 mA, 0-5 VDC or 0-10 VDC).

The AT integrated transducers will simplify the development of accurate, reliable and cost-effective solutions for real-time process automation, supervision and regulation. Principal applications will be in the field of industrial process control and condition monitoring of equipment such as HVAC, conveyers and pumps.

www.lem.com

(067227-NT)

ICs simplify HID ballast circuits and extend lamp life

International Rectifier introduced the IRS2453D family of integrated 600-V self-oscillating full-bridge driver ICs for HID ballast applications including general lighting, outdoor street lighting and projectors.

The new ICs utilize IR's proprietary high-voltage integrated circuit (HVIC) technology, integrating two high-side and two low-side gate drivers. This process allows improvements in device capabilities, tighter specifications, temperature stability and the integration of previously unavailable features.
The IRS2453D features a simple RC network to program the oscillator, eliminating the need to synchronize two half-bridge drivers. In contrast, solutions using two SO-8 driver ICs require a separate oscillator to drive each half-bridge, resulting in unsymmetrical voltages across the load due to mismatching of the on-time states caused by tolerances and temperature. In lighting applications, this can cause mercury migration shortening lamp life. The IRS2453D overcomes this problem by driving both half-bridge drivers with a single oscillator to guarantee accurate matching over the complete temperature and supply voltage range.

Greatly simplifying overall design, the IRS2453D integrates both a latched and non-latched shutdown input, and eliminates up to seven components. The latched shutdown allows for implementation of various protection features such as cycle-by-cycle over-current, open-load or short-circuit detection without additional components, while the non-latched shutdown allows for easy interface to a microcontroller for use in a wider variety of power management applications.
Available in 14-lead DIP and SO packages, the lead-free devices provides 50% duty cycle, fixed one micro-second (typical) internal deadtime and integrated bootstrap circuitry. While the new ICs are designed to drive the required low-frequency AC voltage in HID lamps, they can also be used as a general-purpose block for other high-frequency applications such as fluorescent ballasts and power supplies.

Other key specifications for the IRS2453D include 15.6 V Zener diode clamp on V_{CC} and typical micropower startup current of 140 µA. Noise immunity is achieved by low di/dt peak of the gate drivers and with an undervoltage lockout hysteresis of greater than 1.5 V.

www.irf.com

(067227-IV)

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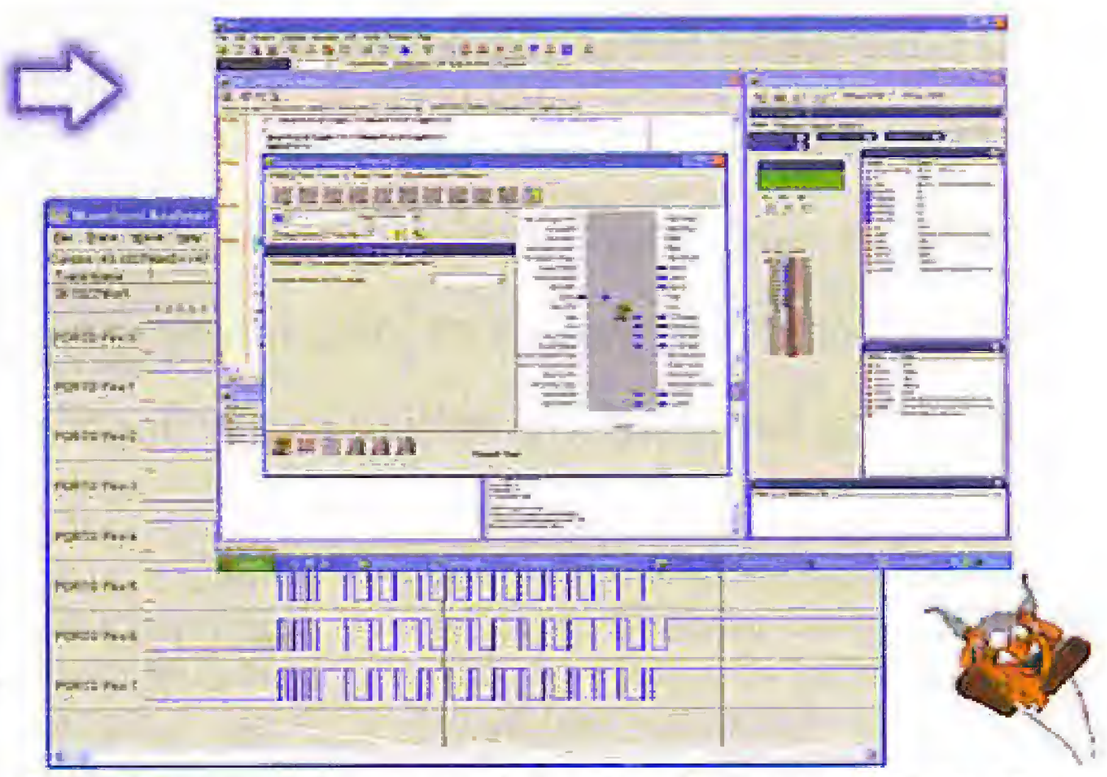

Our development systems are standalone and include RAD front end, compiler, assembler and simulaotr. All systems include elements/library functions for Timers, Ports, A/D, SPI, I2C, USART, Watchdog, Delays, USB, PWM, Capture, Compare, Oscillator functions, Voltage Ref, LCD modules, 7 Segment Displays, Graphic LCD, ANSI libraries and many more

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Profiler

Construction kit for a general-purpose milling machine

Harry Baggen

Have you always dreamed of having your own milling machine but found them just too expensive? If so, we have the perfect solution for you. Working in close collaboration with the Belgian manufacturer Colinbus, we have put together a construction kit for our readers that enables you to build a professional milling machine for a fraction of the cost of a ready-made model. This machine is suitable for a wide variety of jobs, ranging from making parts for models to milling circuit boards.

As an electronic hobbyist or professional, you have to work with more than just pure electronics, and you often have to deal with a lot of mechanical tasks. This includes jobs such as making printed circuit boards, routing wiring, and fashioning a suitable enclosure with a corresponding front panel. Some of these jobs require suitable tools if you want to achieve good results – at least if you want to do it all yourself.

Many hobbyists, as well as designers of prototypes and small development labs, would certainly be able to make good use of a small milling machine for this sort of work. Investing in such a machine may be affordable for commercial use, but the situation is a bit different for home use. A good, accurate milling machine can easily cost several thousand euros, and even then you only have a basic model without all the bells and whistles (such as vacuum swarf removal and a high-speed spindle motor).
We launched this project especially for all electronics hobbyists and professionals who regularly pursue their job and/or hobby at home. The idea for this construction project arose spontaneously during a conversation with Frank Jacops of the Belgian company Colinbus, which specialises in milling machines. When you talk with someone who not only sells milling machines but also designs them from the ground up, the conversation quickly turns to the fact that most electronics types have splendid ideas about all the nice things they could do with such a machine, but the price is an obstacle in most cases. Frank Jacops understood this immediately (he has been an avid reader of *Elektor Electronics* for many years), and he suggested offering a construction kit at a special price for a limited time, exclusively for readers of *Elektor Electronics*.

'Profiler' technical specifications

Dimensions	453 (w) x 583 (d) x 468 (h) mm
Max. working area	300 (X) x 400 (Y) x 100 (Z) mm
Interface	Serial
Power	240 V, 50–60 Hz
X/Y/Z linear transport	MultiStab guideways
X/Y/Z drive	Stepper motors
Positioning speed	60 mm/s
Mechanical resolution	0.0075 mm
Software resolution	0.025 mm
Software	Colinbus User Interface
	Conversion program for Gerber and Excellon files

Naturally, we must admit that the kit is not exactly inexpensive at £ 1099 or € 1599 plus shipping costs, but this still represents a savings of nearly £ 1400 relative to a comparable ready-assembled model. That's an attractive reward for a day or so of assembly work.

Of course, several small milling machines are also commercially available at a lower cost, but they are all quite small and have limited features. If you look at the photos in this article, you can see that we're talking about a completely different category here. Robust construction, high accuracy, and a generous working area of 30 × 40 cm — now that's something you can sink your teeth into! This machine is suitable for all sorts of jobs, such as dispensing, potting, camera inspection, boring holes in boxes, milling front panels, and even 3D modelling (using separate software). You can also mill circuit boards with this machine, although the manufacturer explicitly wishes to state that this model is not designed primarily for this purpose, since it requires even higher accuracy. However, based on our experience it yields excellent results for average PCBs, and the necessary software is included.

Assembly of the machine is quite straightforward, and the clearly written instructions practically exclude any problems. The accompanying circuit boards with the drive electronics are fully assembled and tested, so all you have to do is install and connect them.

Design

The 'Elektor Profiler', as we have christened the machine, is the smallest milling machine produced by Colinbus. Its construction is largely the same as the commercial CBR-40 model (see www.colinbus.com).
The machine is made from steel and aluminium parts. This combination of materials provides sufficient weight and stability to withstand the motion of the machine, while the accuracy of the guideways and the speed of travel are very high thanks to the use of aluminium extrusions.
The MultiStab system, which uses three rollers per edge travelling along precision steel rods pressed into aluminium extrusions, provides good mechanical guidance with minimum play. This design is used for all three axes. One roller of each set of three for each guideway assembly can be manually positioned to adjust the amount of play as necessary. Each of the three axes is driven by a spindle with a special zero-backlash nut.
The milling machine is controlled by a built-in processor board fitted with a Renesas H8/3003 and a driver board fitted with three ST L6208 ICs, which look after driving the three stepper motors. This approach makes the timing independent of the connected PC. The computer simply sends commands and coordinates to the processor board, which processes and executes the commands independently.
The processing power of the built-in microcontroller is not sufficient to drive all three stepper motors at the

Figure 1. The mechanical parts of the construction kit.

You can order the construction kit for the Profiler milling machine by filling in the Order Form on the Elektor Electronics website at www.elektor.com (click 'Milling Machine' under 'Quick Service'). The price is 1099 pounds (1599 euros) including VAT, plus shipping charges. The shipping charges depend on the country and are stated on the website Order Form.
The kit is supplied and invoiced directly and exclusively by the manufacturer, i.e. not by Elektor. There are also several optional extras available for the machine. Consult the Colinbus website for information about these options.

same time (this trick is reserved for the larger and more expensive Colinbus models), so it can only drive two at the same time. The machine can thus execute smooth motions in a two-dimensional plane. For 3D motions, it switches rapidly back and forth between two axes, which makes it appear that all three motors move simultaneously. This has little noticeable effect in practice, since the steps resulting from the interpolation are very small.
The control board in the milling machine has a serial interface, but a standard USB to RS232 adapter can be used without any problems to operate the machine via the USB port of the PC.
The spindle motor supplied with the milling machine is a fairly basic model from Ferm, which allows you to start using the machine right away. Naturally, you can also fit other types of motors, but we should remark here that a true professional-quality spindle motor can easily cost more than the entire construction kit.

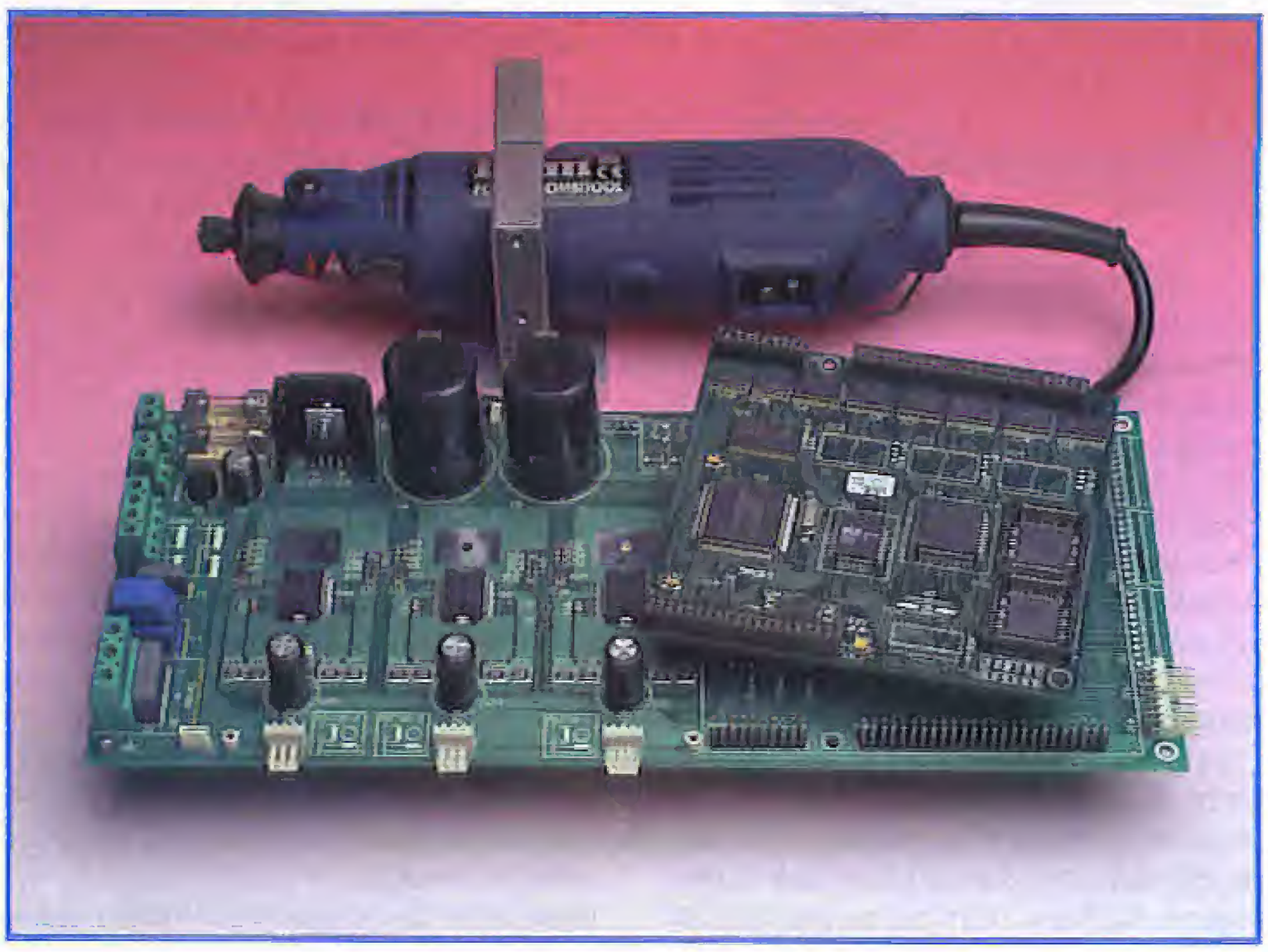

Figure 2. The assembled circuit boards and the spindle motor and bracket.

Construction kit

What do you get for the price of £1099 or 1599? The photos in **Figure 1** and **Figure 2** show almost all the parts included in the kit. They include all the mechanical parts, screws and bolts, guideway rollers, spindles, bearings, stepper motors, cables and so on, plus the drive electronics on the two pre-assembled circuit boards. The previously mentioned Ferm spindle motor (and associated bracket) is also included in the kit. A MDF panel (also included in the kit) serves as the base plate.
The companion software for the milling machine consists of two programs: a user-friendly interface for configuring and operating the machine and a conversion program for PCB layouts (see below).
The kit includes assembly instruc-

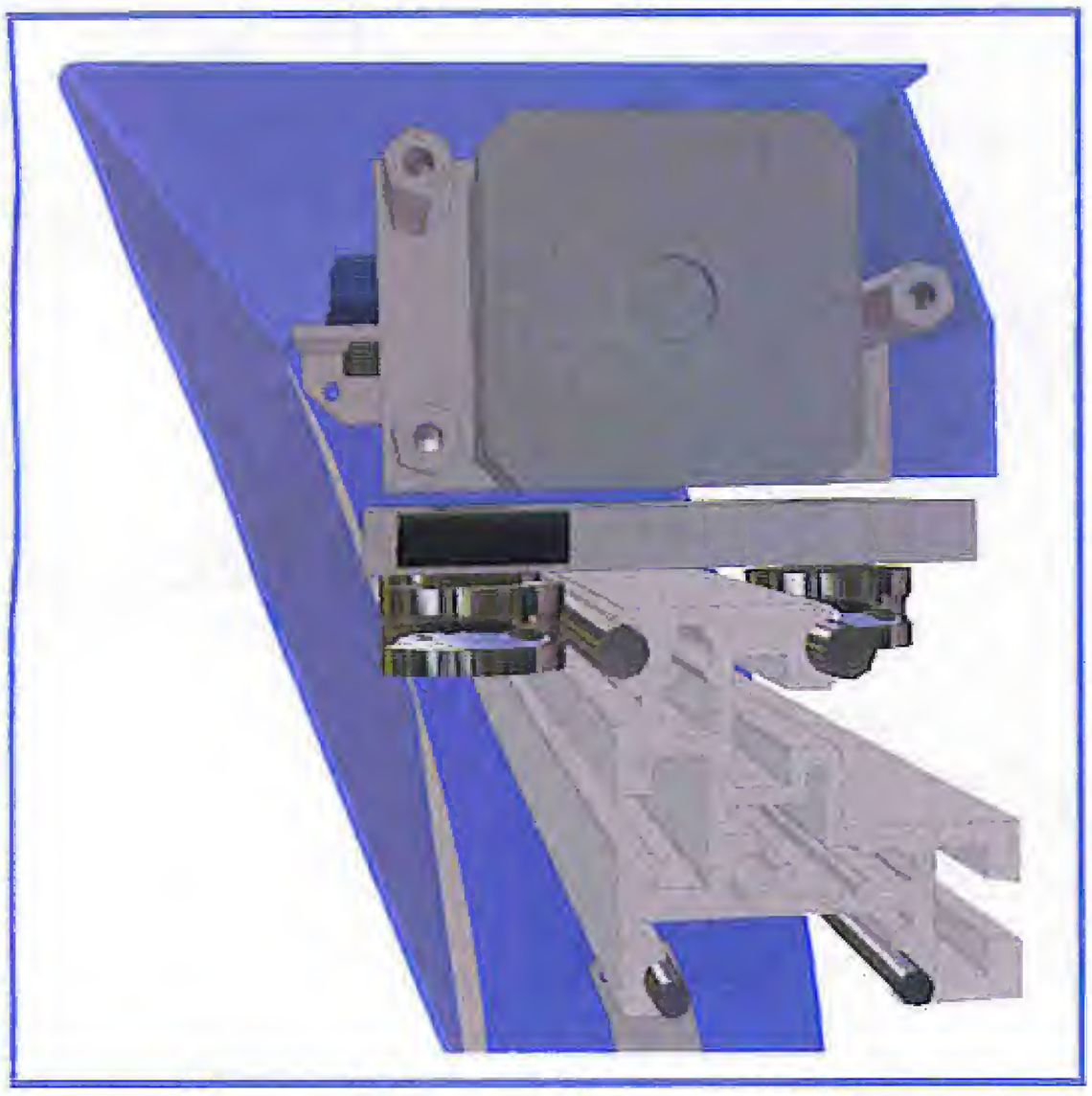

Figure 3. Cross-section drawing of the boring head mount on the bridge.

Figure 4. Detail of the plastic nut with the transverse pins, which provide a zero-play coupling.

tions that provide a step-by-step description of how to put the machine together.

There's not much that can go wrong during assembly. The various parts fit together very accurately thanks to the combination of precision holes in the steel panels and the steel rods in the aluminium extrusions, so no further alignment is necessary. You have to provide the necessary wiring for the two circuit boards for the control and drive electronics, and the connectors and transformer must be soldered in place.

All the assembly steps are clearly described in the instructions. However, we would like to clarify a few details here.

Once the machine is partially assembled, the guideways must be adjusted. The accuracy of the entire milling machine depends entirely on this adjustment. The guideways for the bridge (on the sides) have of three rollers, of which one can be adjusted using an adjustment plate. It must be adjusted so there is very little play, but it should not be made too tight, since otherwise the rollers will jam. A similar construction is also located at the top of the bridge and in the motor column, but the latter part must be partially disassembled to access the rollers.

The drives use spindles with trapezoidal threads that run in special plastic nuts (see **Figure 4**). These nuts are fitted with transverse pins that provide the coupling to the bridge or the boring column. The *X* and *Y* spindles must also be carefully aligned to achieve the specified accuracy and linearity. Note that the special plastic nuts on these spindles must be lubricated using only the special grease included with the kit. Do not use normal grease!

The rest of the assembly process is adequately described by the instructions included with the kit.

Figure 5. The boring column and the guideway in the bridge.

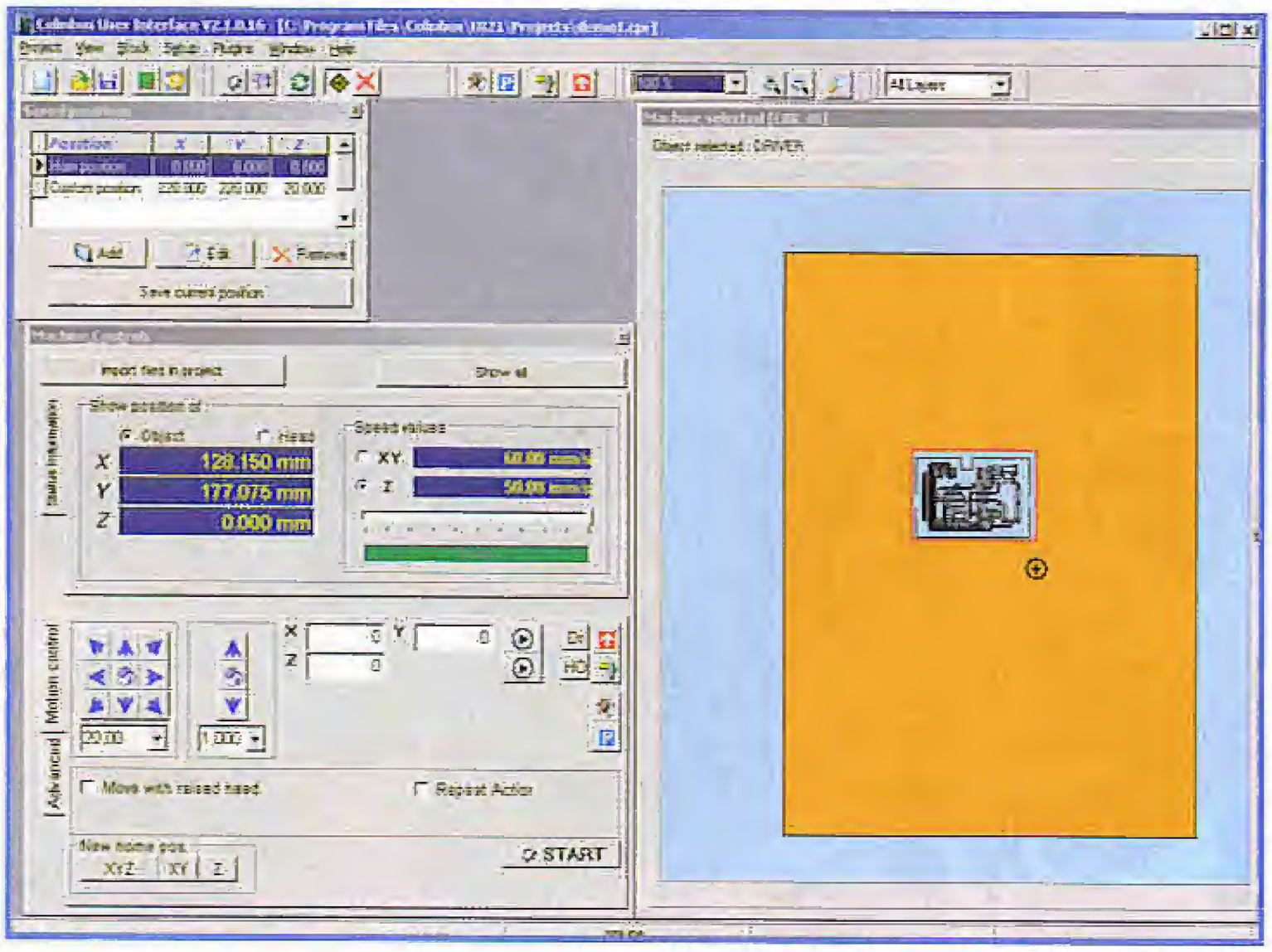

Figure 6. The user interface. The working surface of the machine is shown at the upper right.

Software

The user interface specially written for the Colinbus milling machine provides the operator interface for the machine (**Figure 6**). This program is designed such that even inexperienced users can work with it easily.

The screen is composed of several windows. The effective working surface of the machine is shown in the right-hand window. After loading a file, you can use the mouse to place the object to be machined in the desired location on this surface. The machine will then start working at exactly this position. You can also specify the values of all the settings and preferences for the machine. In addition, you can operate all machine axes manually using this program. Everything you can think of can be configured here, such as reading memory points, relative zero points and so on with micrometre accuracy.

The user interface includes a PCB contouring program (**Figure 7**), which you can use to edit and merge the Gerber and Excellon files generated by commonly used PCB programs and then convert the coordinates in these files into the contours used by the milling machine. You can manually specify the reference points to be used on the circuit board and then use them to ensure that the data in the Gerber and Excellon files are registered exactly with each other (the Gerber file contains the data for the PCB tracks, while the Excellon file contains the hole data). The file generated by the program can then be imported into the user interface program so you can see the PCB layout, which you can drag to a specific location on the working surface.

If you want to process 3D files (such as DXF files), you will need the separate RAMS3D program, which is not included in the construction kit due to the special price.

Finally, there's something for diehard DIYers: the entire command set for controlling the milling machine is freely available, so you can also write your own code.

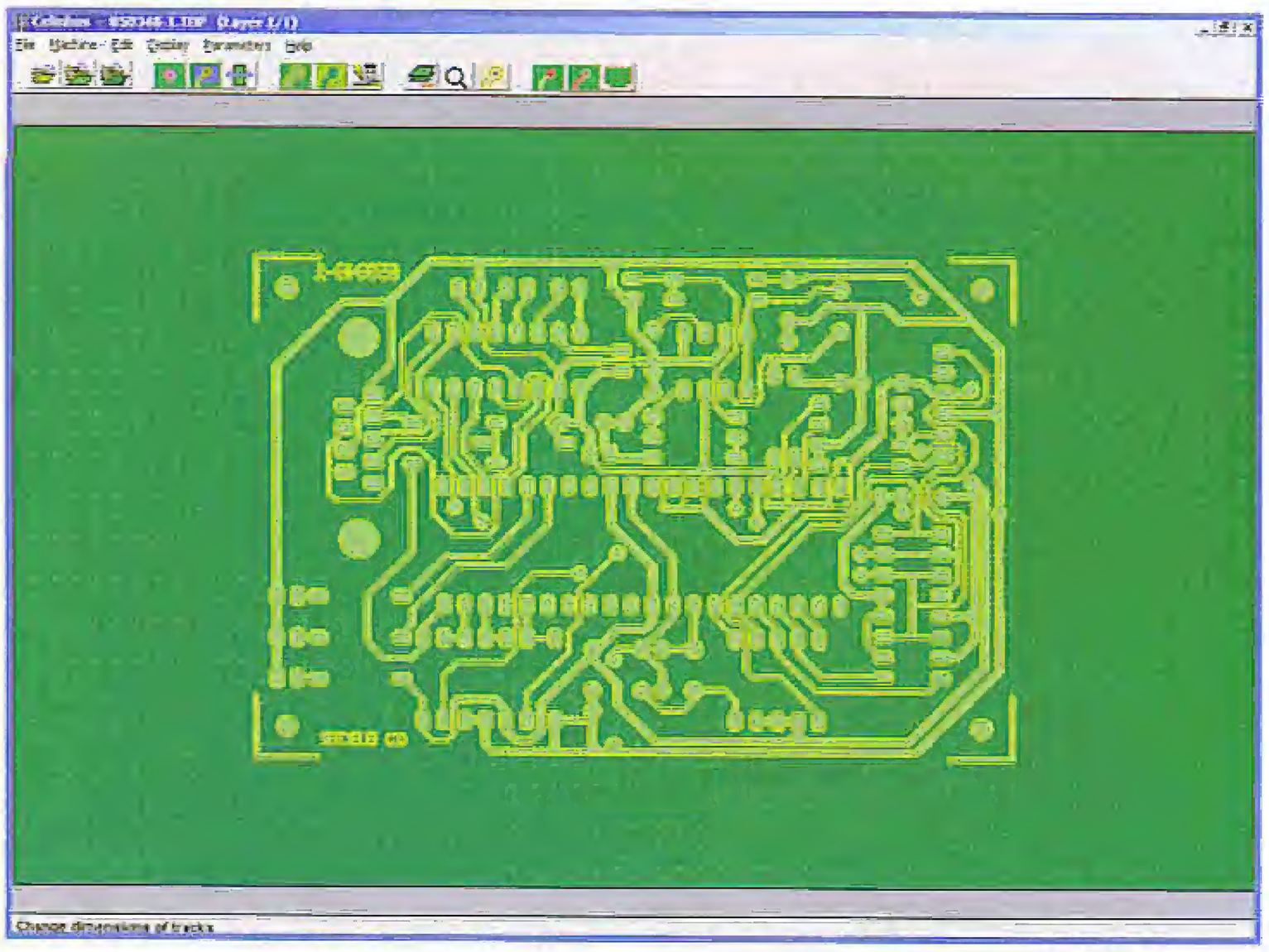

Figure 7. Gerber and Excellon files can be read in with the PCB contouring program and converted into contour data for the milling machine.

1001 jobs

This robust, versatile milling machine opens up a world of opportunities for handy hobbyists and professionals who aren't afraid to roll up their sleeves. With it, making rectangular openings in a box is a piece of cake and a machining a slot in a front panel for a slider is no sooner said than done. What's more, this milling machine is a handy tool for things that have nothing to do with electronics. For instance, you can use it to make your own parts for a model airplane or toys for your kids (and donate your jigsaw to local charity!).

In short, there are more than enough things you can do with this machine. Once you've used it, you won't want to do without it.

(060232-1)

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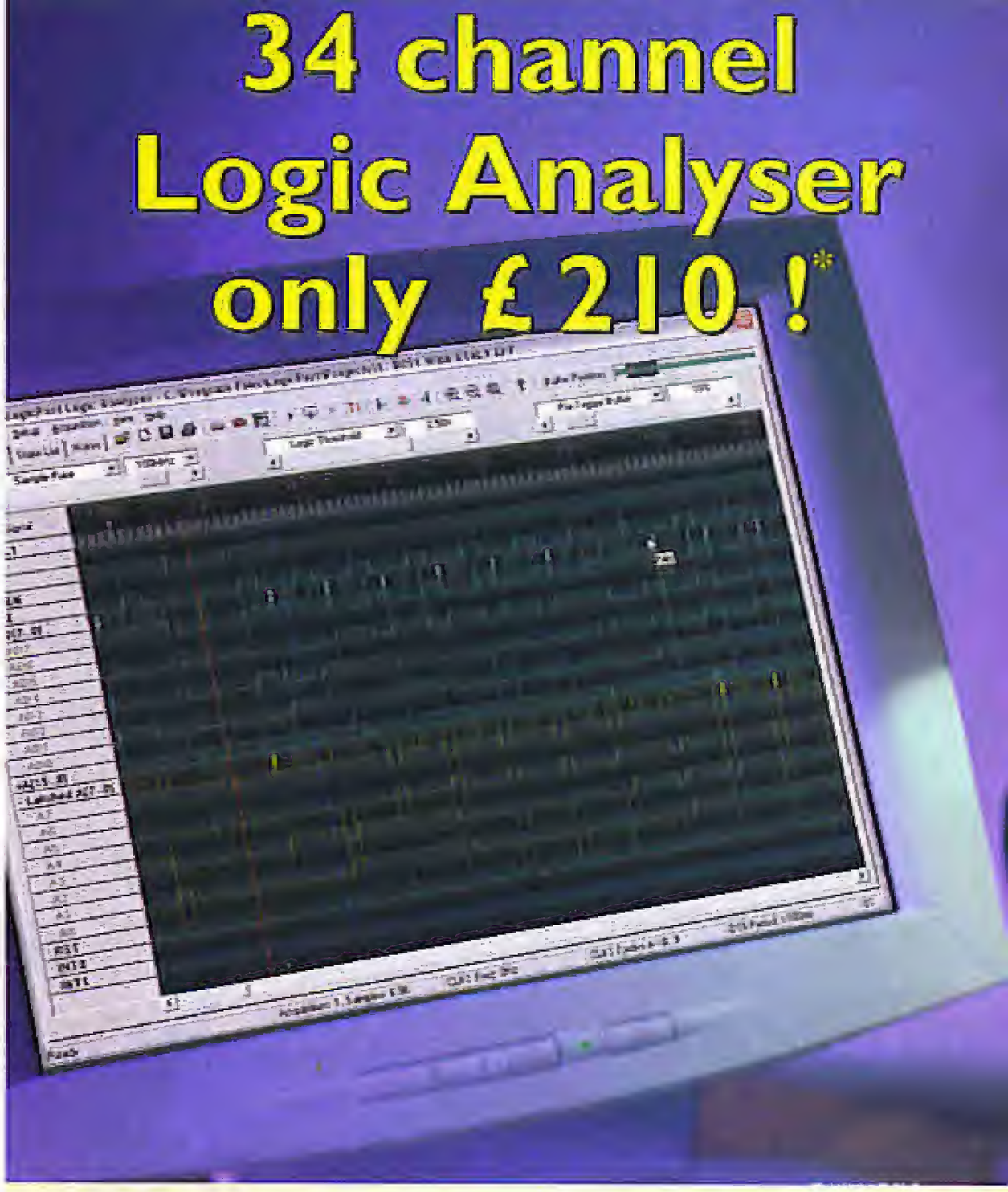

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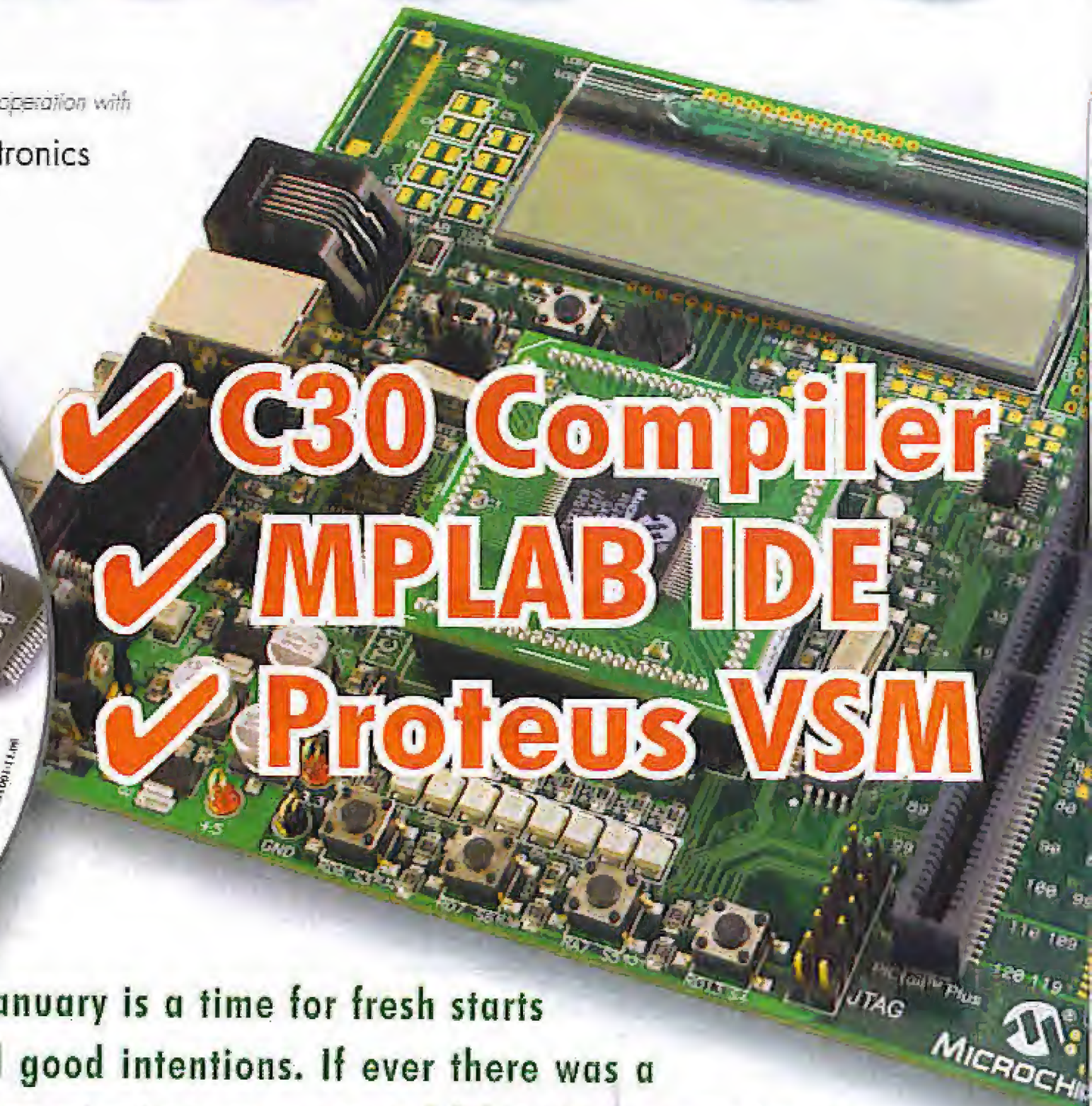
Explorer-16

Jan Buiting & Luc Lemmens, *in cooperation with*
Microchip UK & Labcenter Electronics

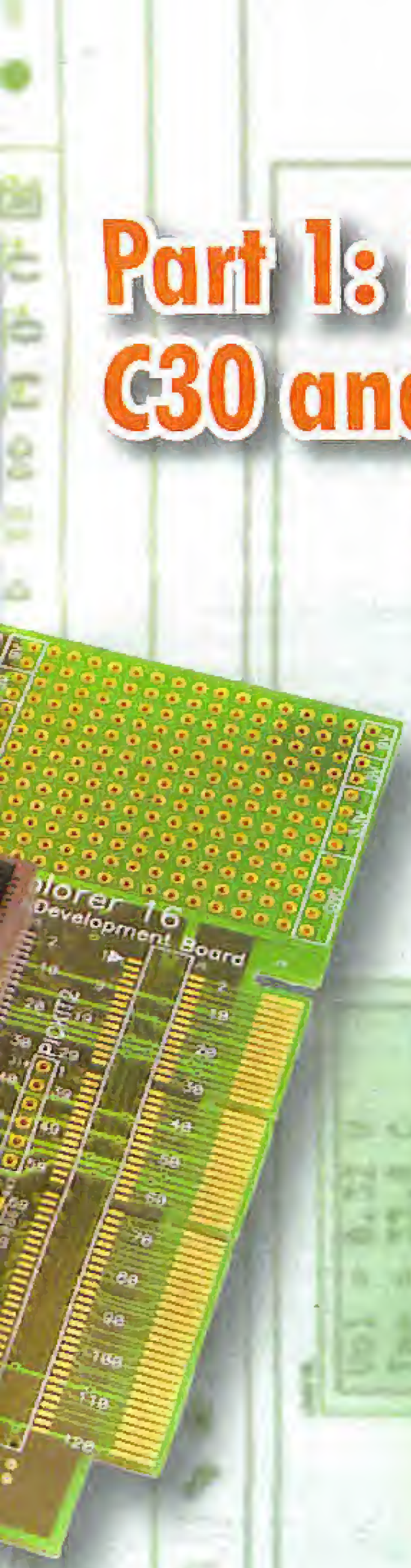


January is a time for fresh starts and good intentions. If ever there was a golden opportunity to move on to 16-bit microcomputing at a serious level, join Microchip, Labcenter and Elektor with their groundbreaking *Explorer-16* project for which a fantastic hardware offer will be made next month. And there's more in the pipeline if you like to run simulations on your PC. For now, no hardware is required. You have your free CD-ROM supplied with this issue so let's get started with installing Microchip MPLAB and C30 and then Proteus VSM.

If we say that 'Explorer-16' is the next logical step from 8-bit micros, we should hasten to add that the project is also perfect for relative newcomers who will be aware of, but need not necessarily bother about, the rock-solid foundations for popular microcomputing laid by so many 8-bit micros (including PIC® MCUs) these past 15 years or so. There's no objection to starting with 16-bit microcomputing straight away as the tools available for the job are powerful to say the least. That said, we should warn that 'Explorer-16' takes off at a fairly high level although all material to learn about programming your own 16-bit PIC micro is available as part of the project.

Regarding the choice of a PIC 16-bit microcontroller, *Elektor Electronics* being very much an independent magazine, we never went down a single road by using one and the same processor family for years on end. Through our articles we will continue to underline the wide diversity of micros available on the market today and respect every user for his or her preference of PIC, AVR, ARM, 8051 or MC9 over 'the others'. In the case of Explorer-16, the PIC MCU road offered good options and tools for a series of instructive, reader-interactive articles linking to high quality hardware that can be obtained at a discounted price, and (mostly) free software.

Part 1: introduction to MPLAB®, C30 and Proteus VSM



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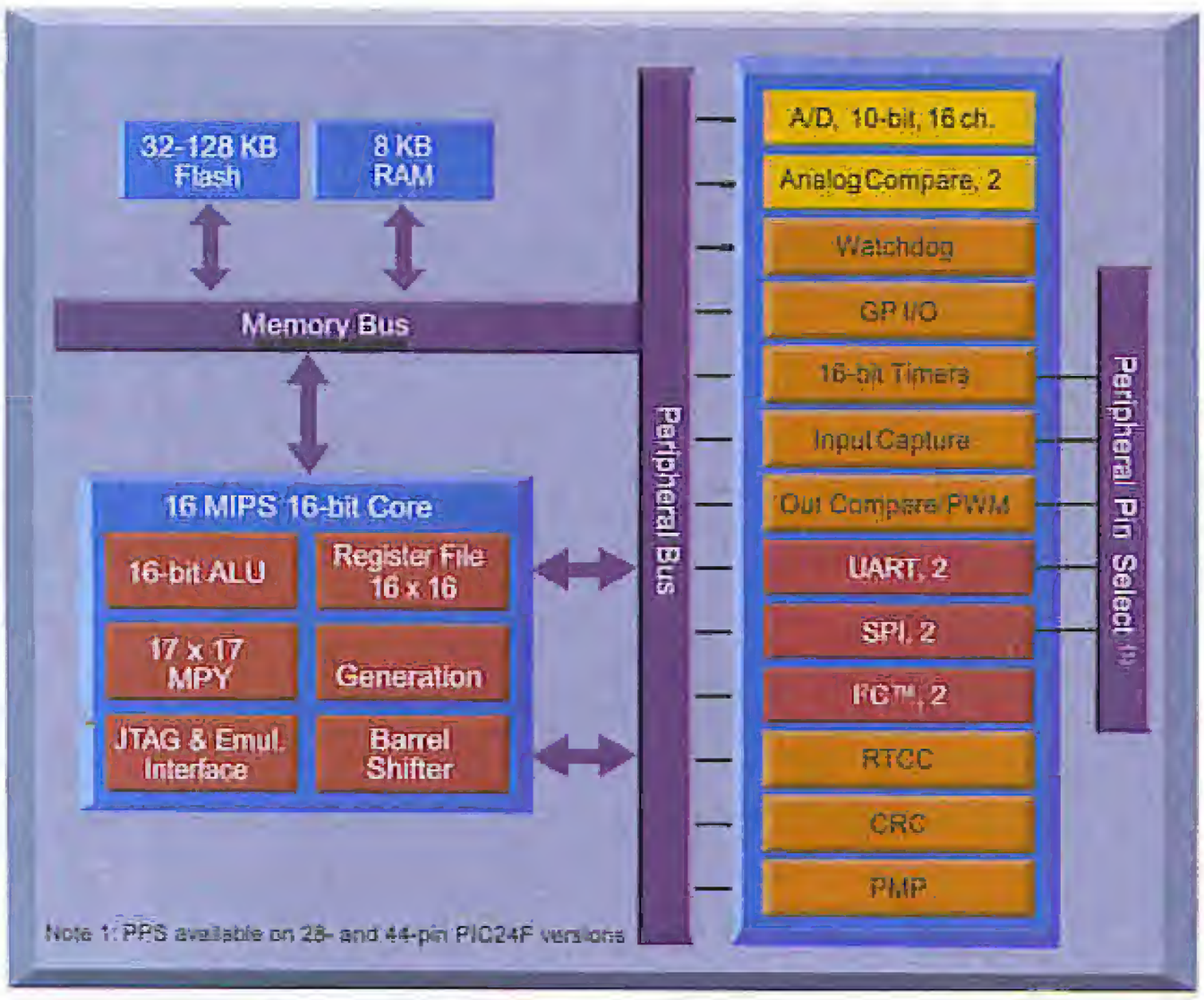


Figure 1. PIC24F functional bock diagram. This is a 16-bit micro.

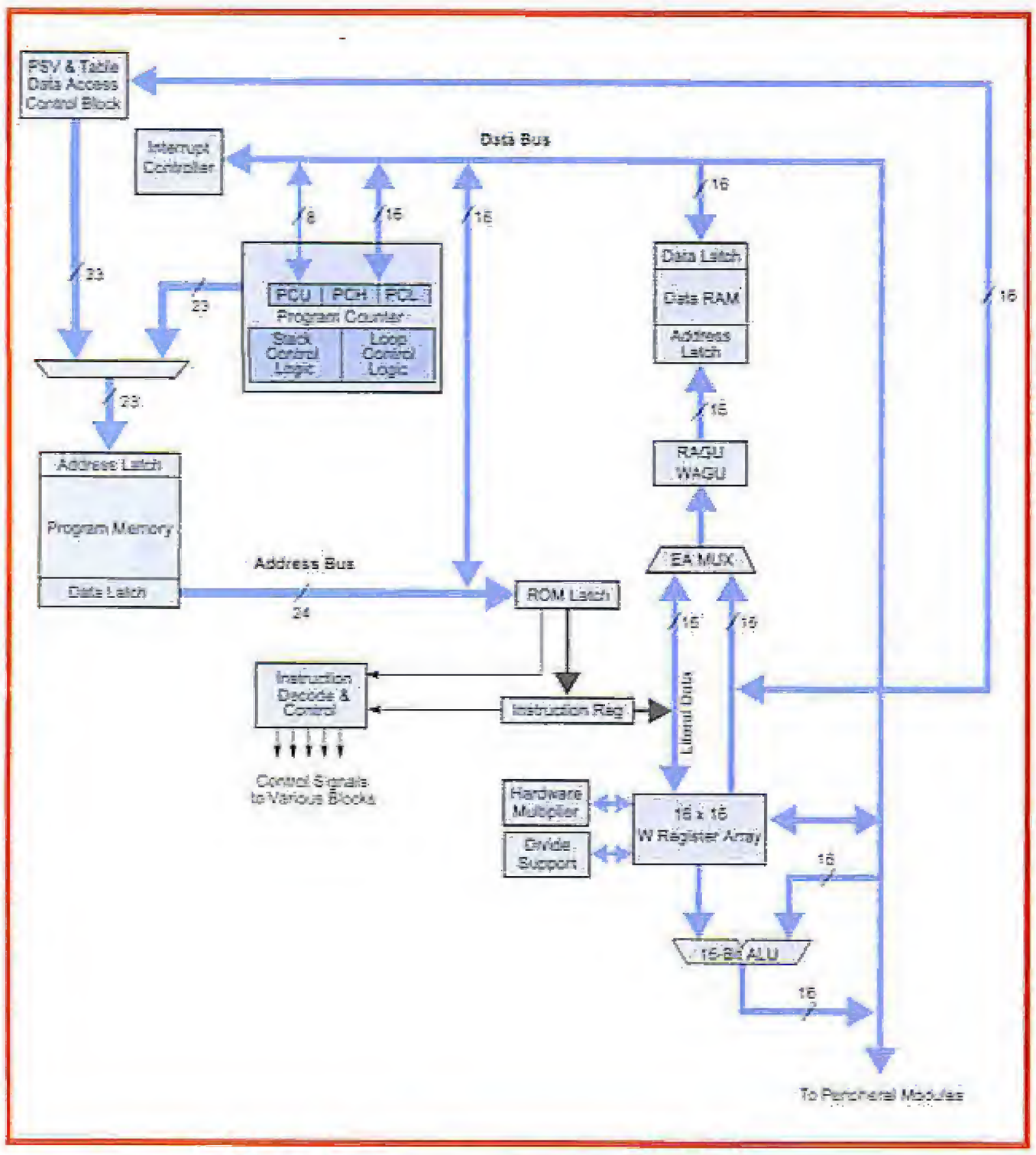


Figure 2. PIC24F CPU core block diagram.

Outlook on the series

This series of articles comprises three main ingredients which we need to mention right at the start.

1. Software

The free CD-ROM you get with this January 2007 issue contains three major pieces of software that lock together into a platform designed to help you become familiar not just with Microchip's 'PIC24F' 16-bit microcontroller, but also with the general concept of microcontroller simulation. All three components are extremely user-friendly (if not downright 'slick') programs that run on a reasonably fast PC with MS Windows installed:

- MPLAB IDE — version 7.50 of this world famous platform for PIC MCU software development.
- MPLAB C30 — version 2.05 (student edition) of the 'C' higher programming language compiler for PIC microcontrollers, complete with an array of utilities.
- Proteus VSM v. 7.00 — a special edition of the Labcenter simulation software that's so fast it can simulate a complete microcontroller board on your PC. Yes, an Explorer-16 board, too, as (for the first time) a PIC24F simulation plug-in is included free of charge to provide the link with the Explorer-16 board!

The software is valuable in itself in that you can cheerfully use it without having any hardware available except of course your PC!

2. Hardware

With the publication of the February 2007 issue, *Elektor Electronics*, the third party in the triumvirate, will offer the **Explorer-16 Development Board** with a special add-on configuration and at an unbeatable price. A preview of the board is shown in the introductory photograph. Mind you, the development board is supplied exclusively by Elektor, i.e., it's not available anywhere else in the configuration to be described in part 2.

3. Website support

File support for the project will be built on a dedicated 'Explorer-16' page of our website at www.elektor.com. Experts at Labcenter, Microchip and Elektor will be contributing and providing help as required. With Part 1 of this series an Explorer-16 topic is available on the Elektor website. The forum is open for everyone to read but only registered users can post new topics and reply to existing ones. But then, registration is free.

Three (possibly four) consecutive instalments are planned. In these we'll be running demos and doing a pretty advanced classroom exercise to explore the workings of Proteus VSM software.

PIC24F Architecture

You knew you had it coming — a functionally oriented block diagram of the PIC24F device (**Figure 1**) and the CPU Core block diagram (**Figure 2**). The good news is that this article series (and the Explorer-16 board) is based on the top-end processor in the family, the **PIC24FJ128GA010** sporting 128 kB Flash... and a 100-pin case! Its 'business card' is shown in the **PIC24F128 Quick Specs inset**. This beast has A/D, UART, SPI, I²C, RTCC, WDT ICE, ISP and POR, not forgetting advanced power-saving technology and a parallel-port master and slave functionality.

There are two pdf documents, Refs. [1] and [2], you should download straight away and store in a folder named 'Explorer-16': The PIC24F datasheet is an incredible 230 pages, fortunately the pdf has tabs to guide you to the chapters. If you migrate from the popular PIC18F to the 24F, the document in Ref. [3] is valuable.

Software installation

The Explorer-16 CD-ROM you should have received with this issue presents a welcome screen (**Figure 3**) which should pop up after inserting the disc in your CD-ROM drive or DVD drive. If the welcome screen does not appear automatically, click on Start → Run... and then use Browse to point to the file *index.htm* on the CD-ROM or DVD drive.

EXPLORER-16 is brought to you jointly and exclusively by Microchip Technology, Labcenter Electronics and Elektor Electronics. As part of the project, a free CD-ROM is included with the international print run of Elektor Electronics' January 2007 issue. The Explorer-16 Development Board and a plug-in accessory board will be on offer at a discounted price with the publication of the February 2007 issue so stay tuned.

The software installation screen you should see after leaving the welcome screen is shown in **Figure 4**. No-frills installers are used for the software components of this project. We recommend installing all three components. It should be noted that the installer employs the program installed as the *default web browser* on your PC. It was successfully used with Internet Explorer build 6.0.2900.

PIC24FJ128 Quick Specs

CPU

- Modified Harvard architecture
- Up to 16 MIPS operation @ 32 MHz
- 8 MHz internal oscillator:
  - 4x PLL option
  - Multiple divide options
- 17-bit x 17-bit single-cycle hardware Fractional/Integer Multiplier
- 32-bit by 16-bit hardware divider
- 16 x 16-bit working register array
- C compiler optimized instruction set architecture:
- 76 base instructions
  - Flexible addressing modes
- Linear program memory addressing up to 12 MBytes
- Linear data memory addressing up to 64 kBytes
- Two address generation units for separate read and write addressing of data memory

Special microcontroller features

- Operating voltage range of 2.0V to 3.6V
- Flash program memory:
  - 1000 erase/write cycles, typical
  - Flash retention 20 years, typical
- Self-reprogrammable under software control
- Selectable power management modes:
  - Sleep, idle and alternate clock modes
- Fail-safe clock monitor operation:
  - Detects clock failure and switches to on-chip, low-power RC oscillator
- On-chip LDO regulator
- JTAG boundary scan and programming support
- Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Flexible Watchdog Timer (WDT) with on-chip, low-power RC oscillator for reliable operation
- In-Circuit Serial Programming™ (ICSP™) and In-Circuit Emulation (ICE) via 2 pins

Analogue features

- 10-bit, up to 16-channel analogue-to-digital Converter (A/D)
  - 500 ksps conversion rate
  - Conversion available during sleep and idle
- Dual analogue comparators with programmable input/output configuration

Peripheral features

- Two 3-wire/4-wire SPI modules, supporting 4 Frame modes with 4-level FIFO buffer
- Two I²C™ modules support multi-master/slave mode and 7-bit/10-bit addressing
- Two UART modules:
  - Supports RS-232, RS-485 and LIN 1.2
  - Supports IrDA® with on-chip hardware encoder/decoder
  - Auto-wake-up on start bit
  - Auto-baud detect
  - 4-level FIFO buffer
- Parallel Master Slave Port (PMP/PSP):
  - Supports 8-bit or 16-bit data
  - Supports 16 address lines
- Hardware real-time clock/calendar (RTCC):
  - Provides clock, calendar and alarm functions
- Five 16-bit timers/counters with programmable prescaler
- Five 16-bit capture inputs
- Five 16-bit compare/PWM outputs
- High-current sink/source on select I/O pins: 18 mA/18 mA
- Configurable open-drain output on digital I/O pins
- Up to 5 external interrupt sources

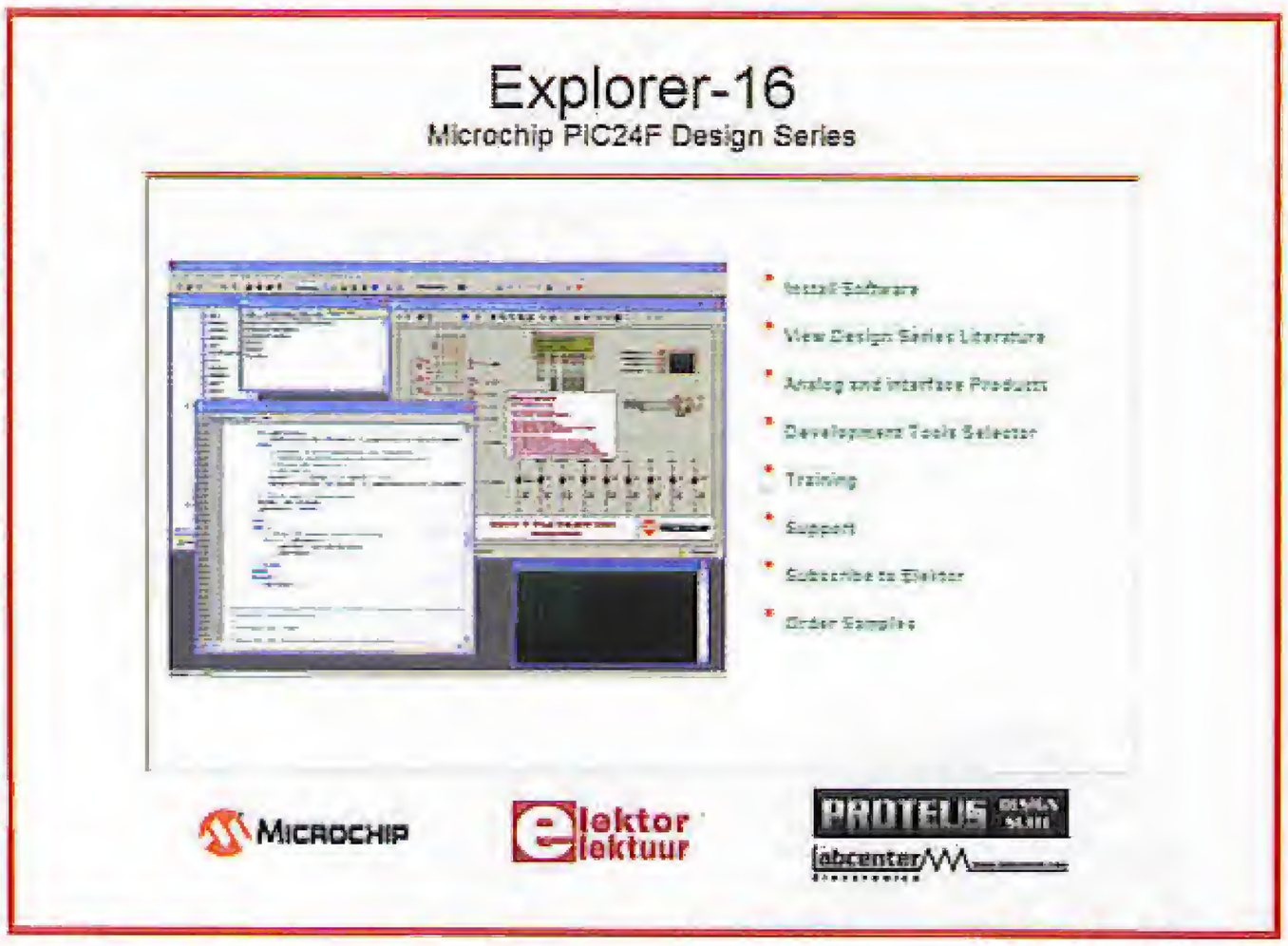


Figure 3. Apart from being a gateway to the three installers, the welcome screen contains links to know-how and documentation collected specially for the Explorer-16 project.

MPLAB IDE v. 7.50 follows a traditional Windows program install procedure. At some point you will see this message: *The publisher could not be verified. Are you sure you want to run this software?* Click Run to continue.

MPLAB C30 Compiler v 2.05 – Student Edition is a similar installation. The *Release Notes* document that's available at the end of the installation is particularly worthwhile to read (and print).

Proteus VSM 7.00 Demo is also easy to install simply by accepting the defaults suggested by the installer program. The Guided Tour of the MPLAB viewer you'll see near the end of the installation has some interesting information and shows the effort that Labcenter and Microchip have put into their cooperation for the Explorer-16 project.

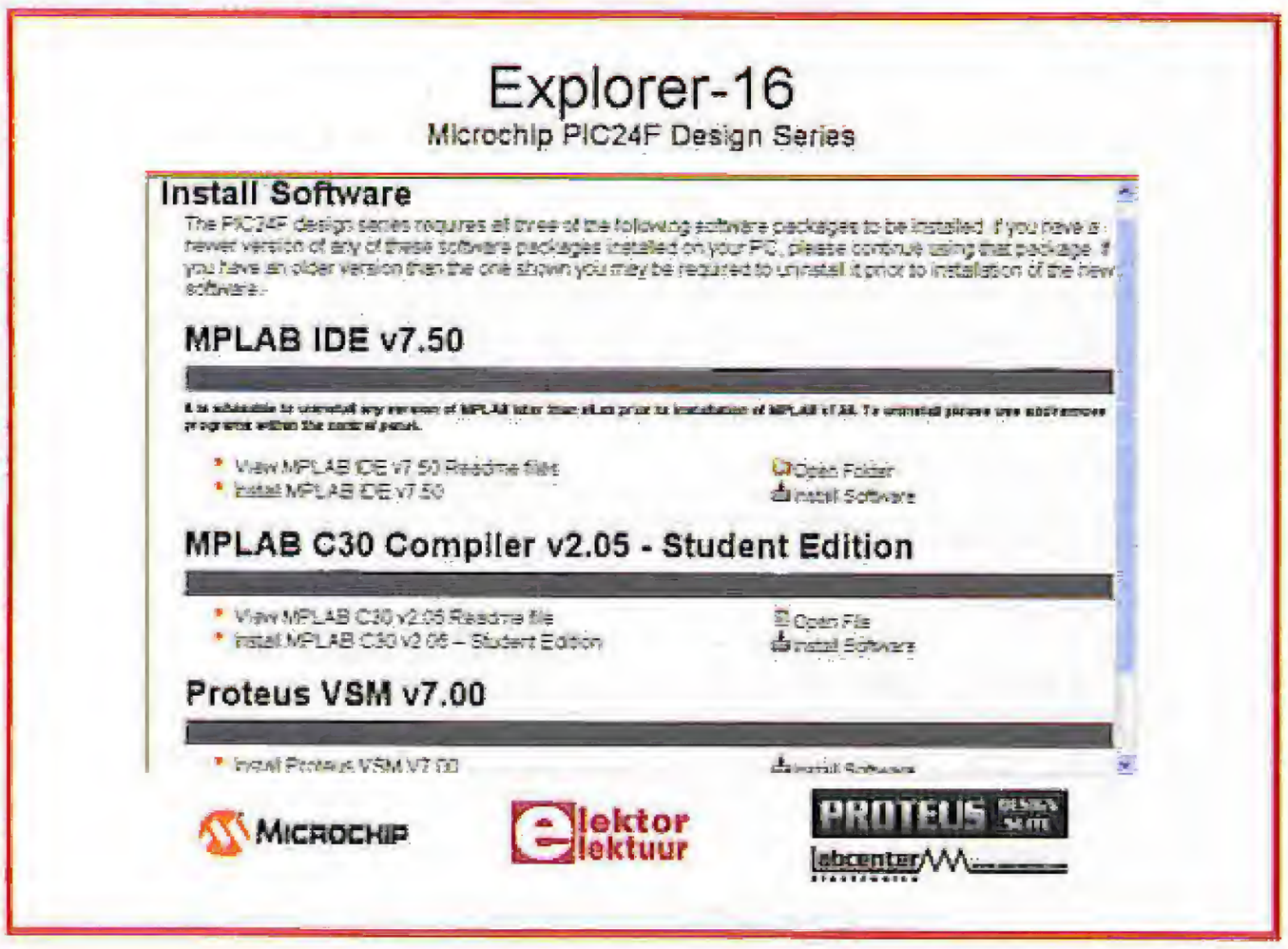


Figure 4. The component install screen for the free CD-ROM supplied with this issue.

MPLAB IDE

Paradoxically — considering its size and power — little needs to be said about this renowned PIC microcontroller development platform from Microchip. The reason is simple: MPLAB has been around for many years now and has matured into the *de facto* development platform for PIC MCUs. The program, (or suite of utilities, really), is comprehensive, user-friendly and marked by excellent support not just by virtue of the Help file functions but also through Microchip's online Forum and technical support.
MPLAB Integrated Development Environment (IDE) is a development platform for the Microchip Technology PIC MCU and dsPIC® microcontroller families.
MPLAB IDE includes the following components: MPASM™ Assembler; MPSIM™ software simulator; MPLINK™ linker; Source Level Debugger; On-line Help; Project and set-up wizards; Project Manager; Visual Device Initializer; Programmer's Editor; drivers for various hardware tools. Special versions of a number of utilities like the assembler and linker, are supplied for the dsPIC30 devices.
With MPLAB IDE you can:

- write, build and debug source code;
- automatically locate errors in source files for editing;
- debug with breakpoints;
- single-step the program with software simulator, in-circuit debugger or in-circuit emulator;
- view variables in watch windows;
- program code with certain programmers;
- find quick answers to questions using the MPLAB IDE on-line help.

MPLAB looks rather dead when launched. To see some action on the screen follow File → Open Workspace and then navigate to the 'examples' folder. Various projects can be opened there. Although not very meaningful just yet, they allow the newcomer to explore a large number of functions without 'serious consequences'.
Importantly, release notes for all utilities in MPLAB can be found at Start → All Programs → Microchip → MPLAB IDE v. 7.50 → Documentation. This screen also lists 'install and repair' utilities.
Even an introductory discussion of the features packed into MPLAB and the best way to use them for your PIC projects would easily fill an entire magazine hence is beyond the scope of this article. Not to worry, the complete *MPLAB Users Guide* and various other pdf documents are accessible via the CD-ROM install screen under 'View Design Series Literature'. Plus, there's *MPLAB Getting Started*.

MPLAB C30

The free Explorer-16 CD-ROM contains the student edition of the Microchip C30 compiler, version 2.05. This is a fully functioning C compiler for the first 60 days after which a number of the cleverest optimisations are disabled. If you start using the C30 compiler now, you will have a full version of the product all the way till the third article instalment.
The functions disabled after 60 days are described by Microchip as: *'procedural abstraction'* and *'optimisation options -02, -03 and –Os'*. Not too worrying, we'd say. Everything else works the same as the full version and

with the huge memory capacity on the PIC24F128 used, code size optimisation is unlikely to become a problem. Of course, you are free to use C30 for any smaller 16-bit PIC MCU or dsPIC® DSC you may have available, just give it a try.

The student edition of C30 may be upgraded to a full edition by purchasing a licence key from Microchip. Good news: with the publication of the February 2007 issue, buyers of the Explorer-16 Development Board will be able to purchase the full version of C30 at a discounted price by returning a voucher enclosed in the box.

MPLAB C30 seems to be a lesser known 'plug-in' of the MPLAB environment so a short introduction is given here (realising that the real work starts with coding your own C programs, compiling, debugging and finally transferring them to a PIC — but stop, do your simulation first!).

MPLAB C30 is a fully ANSI compliant compiler with standard libraries for all popular PICs including the latest dsPIC® DSC devices. It is fully integrated with the MPLAB IDE for high level debugging at the source code level.

This compiler comes complete with its own assembler, linker and librarian to write mixed-mode C and assembly programs and link the resulting object files into a single executable file.

The MPLAB C30 library includes functions for string manipulation, dynamic memory allocation, data conversion, timekeeping, and math functions (trigonometric, exponential and hyperbolic).

The 'small code model' offered by C30 takes advantage of a more efficient form of call instructions, while the 'small data model' supports the use of compact instructions for accessing data in SFR space.

Although C30 is embedded into the MPLAB environment, you still be able to run it as a separate command line program. Use the 'Open Workspace' menu item in MPLAB and navigate to MPLAB C30 → Examples → MPLAB Link30. The example 'Locate_access_EEPROM' is shown in **Figure 5** with the *Program Memory* and *File Registers* viewers open.

The complete C30 Users Guide is accessible via the menu on the CD-ROM, as discussed with MPLAB. Alternatively, navigate to the folder 'Documentation' on the CD-ROM.

Proteus VSM

The circuit simulation component of the Explorer-16 project is presented to you courtesy of our long-standing advertiser Labcenter Electronics. VSM (virtual systems modelling) is part of the Proteus Design Suite which also comprises:

- ISIS schematic capture;
- ProSPICE mixed mode simulation;
- ARES PCB design.

Specially for the Explorer-16 project, Labcenter are supplying a large number of sample designs featuring the PIC10, PIC12, PIC16, PIC18 and, of course, the PIC24F. You can run any software code you like on the samples but to experiment on your own hardware designs you will need to purchase the full Proteus VSM package. Alternatively, you can take advantage of a special offer exclusive to Elektor readers by visiting www.labcenter.co.uk/products/elektoroffer.htm.

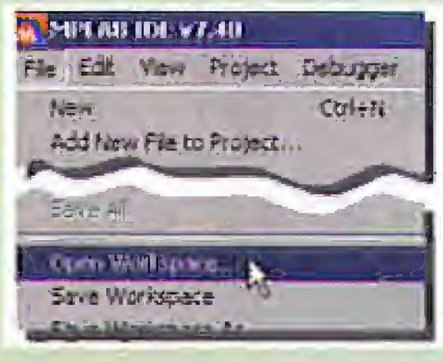
To get a taster, if you start a copy of ISIS via Start → Labcenter → Proteus 7 Demonstration → ISIS 7 Demo, you are invited to view a number of examples. Some nice ones are found in the Tutorials folder.

Kick start to Proteus VSM within MPLAB

This short demonstration will show you how the basics of how to configure and run a Proteus VSM simulation under the control of the MPLAB IDE.

1. Download the file Demo1.zip from the Explorer-16 page you can reach via *www.elektor.com*. Save the unzipped Demo1 folder the directory: c:\program files\microchip\mplab c30\examples.

2. Launch the MPLAB IDE application, go to the File menu, select the Open Workspace command, navigate into the Demo1 directory and open the Demo1.mcw workspace.



3. Go to the Debugger Menu in the MPLAB IDE, select the Select Tool command and then Proteus VSM. This configures MPLAB to use Proteus as the tool of choice for debugging.

4. You should now see that the Proteus VSM Viewer has opened inside MPLAB. Use the Open Icon on the viewer and select the Demo1 schematic from the resulting file selector.

5. Now select 'Build All' from the Debugger menu.

6. Now that we have the schematic and project we can start the simulation. Use the green button at the top of the MPLAB IDE to connect the Proteus simulation to MPLAB.

7. At this point the simulation is paused at time zero. Start the Simulation by clicking on the Play button near the top right of the MPLAB IDE. This will execute the program code and the VSM Viewer will show you the effects of your program on the design.

8. Use the red button at the top of the MPLAB IDE to disconnect the VSM Viewer from MPLAB and stop the simulation. A more detailed demonstration of debugging follows later in the series.

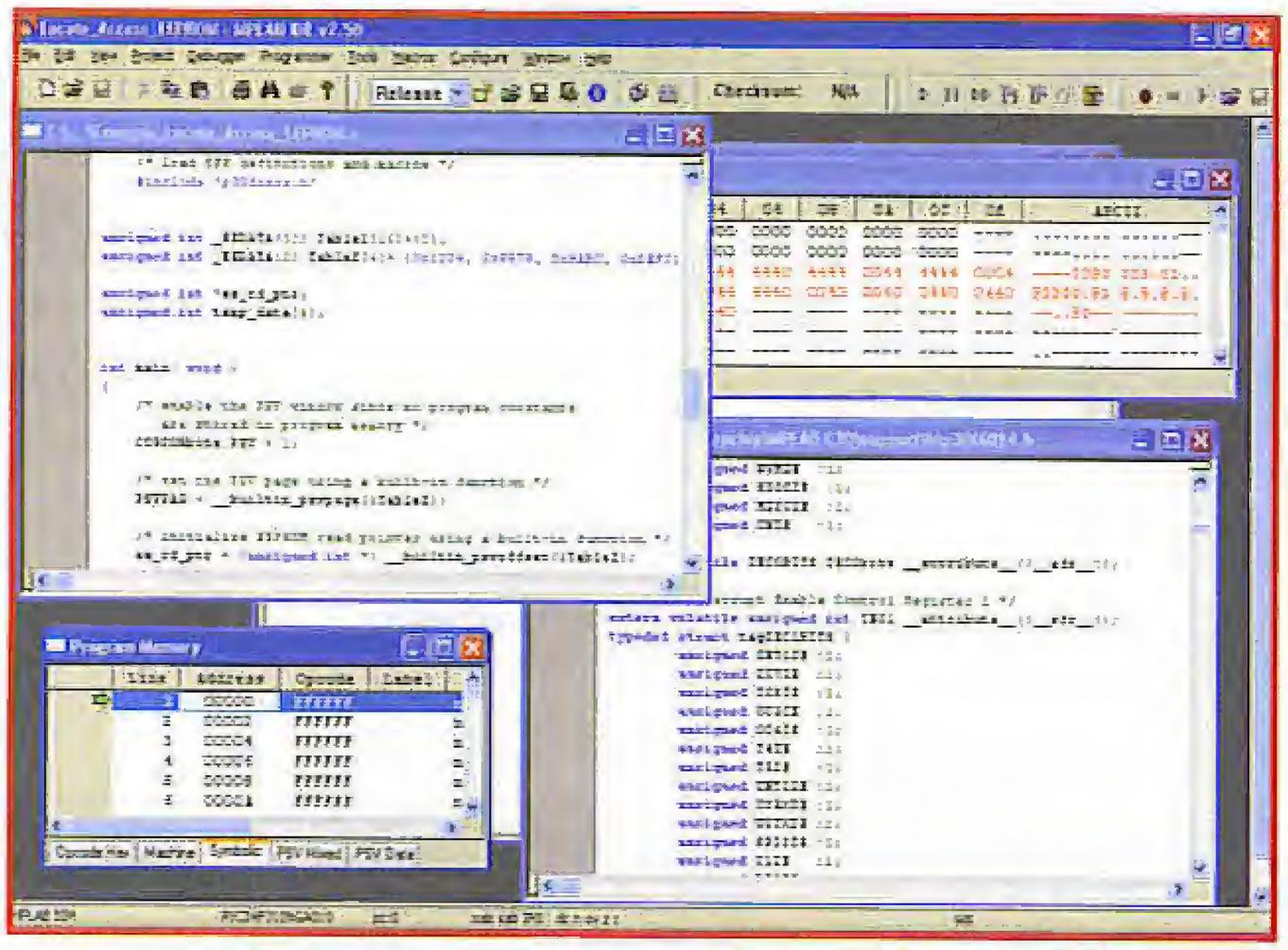


Figure 5. MPLAB C30 in action. Various windows can be opened to see what the program is doing in memory and register-wise.

Like C30, VSM is embedded in MPLAB; you'll find it under Debugger → Tool. If you are dying to see it in action at this point, follow the 8-step kick start to VSM/MPLAB shown in the **Kick start to Proteus VSM within**

MPLAB inset. This impressive demo requires an archive file called **Demo1.zip** to be downloaded from the Explorer-16 page of our website. You can also apply the same procedure to any of the pre-installed Virtual Evaluation Boards. More about VSM on [4].

Next month

We reckon the amount of software presented in this article will keep you busy for about a month. In the February 2007 issue we'll discuss the Explorer-16 hardware (on special offer then) and show its first application which is related to speech reproduction. This will take us along C30 and MPLAB to see how the software is built. We'll also delve into Proteus VSM to demonstrate that simulation is now a firmly established — if not essential — step in prototyping microcontroller circuits.

(060393-I)

Web links

[1] Microchip PIC24FJ128GA Family Data Sheet:
ww1.microchip.com/downloads/en/DeviceDoc/39747C.pdf

[2] Microchip High-Performance PIC24 Microcontroller Family overview:
ww1.microchip.com/downloads/en/DeviceDoc/39754b.pdf

[3] PIC18F to PIC24F Migration, an Overview:
ww1.microchip.com/downloads/en/DeviceDoc/39764a.pdf

[4] Proteus VSM
www.labcenter.co.uk/products/vsm_overview.htm

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See the EXPLORER-16 Hands-On PIC24F Design Series on page 20!

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The Quest for Ac

Time measurement using atomic clocks

Jens Nickel

Of all nature's physical quantities it is time that we know how to measure best. The most advanced atomic clocks are breathtakingly accurate, many millions of times more so than the best quartz-based clocks. How do they manage it?

Figure 1. Sundials are the oldest clocks known to man. In this example a magnifying glass ignites a powder charge in the tiny cannon at midday. (Photograph: German Clock Museum, Furtwangen [14])

Before we get down to business we should confess that we are going to dodge the question 'what is time?' in this article by using the rather unhelpful definition 'time is what a clock measures'. A clock lets us put a number on the duration of an event or on how long ago an event occurred. The precision of the measurement depends on how small the briefest basic interval is that the clock can resolve, and the repeatability of the measurement depends on the extent to which these basic time intervals can be kept constant. To test the repeatability of a measurement we need access to another, more accurate, clock.

The first 'clock' used by mankind was the rotation of the Earth. Over the centuries the precision of clocks based on this principle has continuously improved, from the earliest sundials (**Figure 1**) to modern astronomical

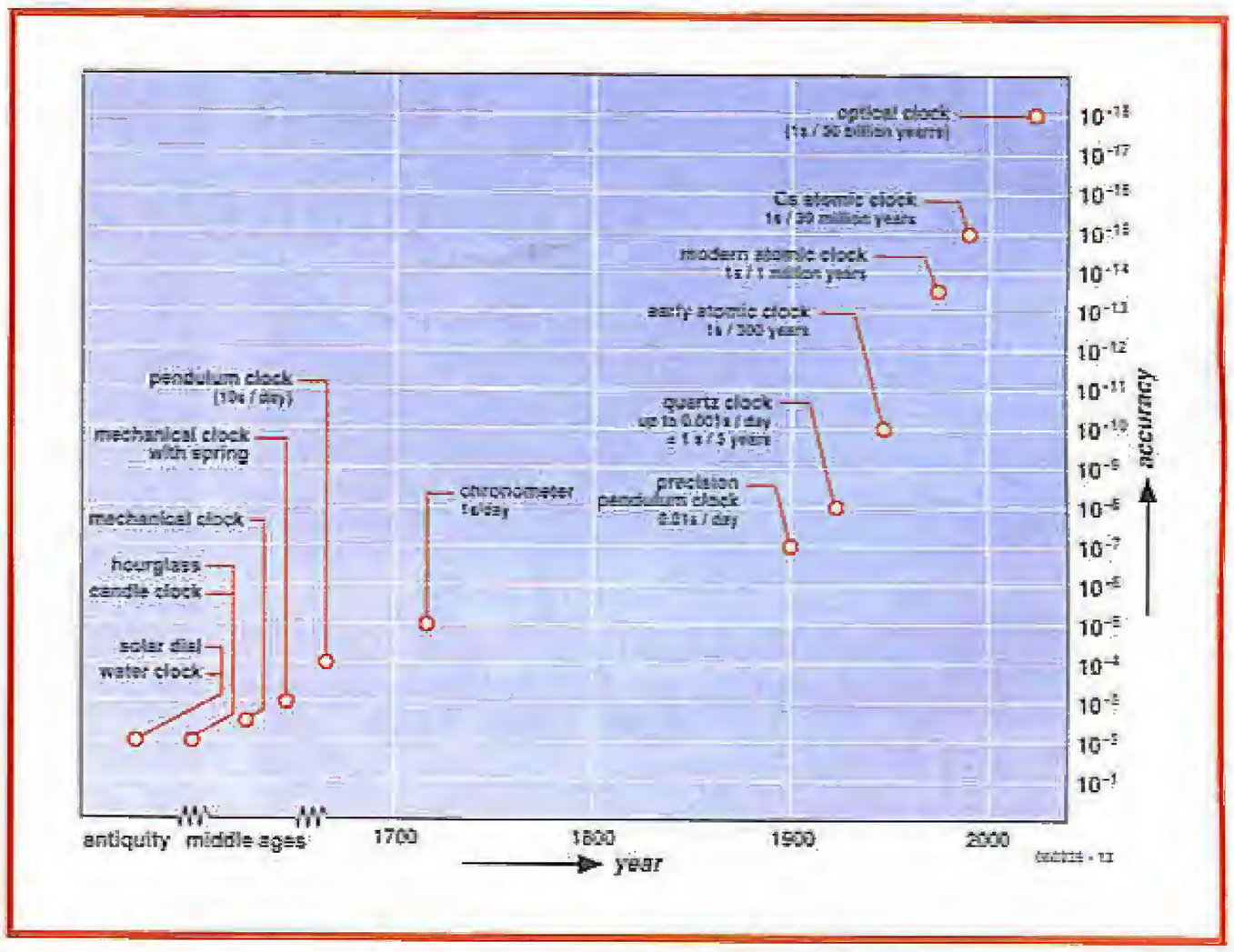


Figure 2. The accuracy of the best clocks has improved over the millennia by more than 12 orders of magnitude: a factor of one trillion.

curacy

instruments. As recently as the last century the repeatability of this measurement was considered 'perfect' and the second was defined as one 86400th of a mean solar day [1]. It was not possible to detect any changes to this period, as nothing of remotely comparable accuracy was available (**Figure 2**).

History of timekeeping

Water-clocks superseded sundials in antiquity; and in the Middle Ages glass-blowing technology improved to the point where they in turn could be replaced by sand-filled hourglasses. The first mechanical clocks date from the thirteenth century, driven first by weights and later by springs, the latter making for a more compact construction. In 1657 the Dutchman Christian Huygens developed the first functional pendulum clock, claimed to have an accuracy of around 10 s per day [2]. That may not sound very impressive, but his revolutionary design paved the way for orders of magnitude improvements in accuracy. External influences on the pendulum were identified and eliminated one by one, exactly as would later happen with electronic clocks. Among the sources of inaccuracy were temperature and feedback from the clock mechanism to the pendulum.

A driving force behind these developments was navigation: only with the help of a chronometer having good long-term stability could one determine one's longitude when on the open sea. The first electrical clock (**Figure 3**) was also based on a pendulum. Developments ultimately culminated in a highly-accurate pendulum clock using pendulums suspended in a vacuum and a kind of master-slave arrangement [3], achieving a final ac-

Figure 3. The first electrical clocks used pendulums in conjunction with electromagnets. This example, by Alexander Bain, was made in 1845. Since there was no mains electricity at that time, the maker constructed his own 'earth battery' by burying two sheets of dissimilar metals in the ground. (Photograph: German Clock Museum, Furtwangen [14])

SI Base units

Physical quantities such as resistance are measured in fixed units, in this case the Ohm. So that an Ohm represents the same resistance in every laboratory in the world its value must be defined. This is simple: if a voltage of one Volt appears across a component and a current of one Ampère flows, the resistance is one Ohm. The Ohm is therefore derived from other units, which, in turn, must of course be defined themselves. The Volt happens to be defined in terms of other units, but the Ampère is a 'base unit'. The choice here is somewhat arbitrary: the laws of physics will not change if we define the Ampere via the Ohm rather than vice versa. However, international agreement has been reached on the use of seven base units.

These SI base units [8] must be defined somehow, and there are various options available. The classical, though rather awkward, approach, is to have a 'standard' somewhere in the world. At present this is still how the kilogram is defined: one kilogram is the mass of the 'ur-kilogram', made of a special alloy and kept at the International Bureau of Weights and Measures at Sèvres near Paris, under several glass envelopes. A more elegant way to define a unit is via a measurement rule. For example, since 1967 the second has been defined as 9 192 631 770 times the period of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the 133Cs atom.

Using a caesium atomic clock allows a precise standard for the second to be available anywhere in the world — even potentially in every house!

The Ampere is defined via an experimental procedure where a carefully-controlled voltage and resistance are used [9]. The reasons why the Ampere was nevertheless chosen as a base unit are historical.

Clocks at the German Federal Institute for Physical Technology (PTB)

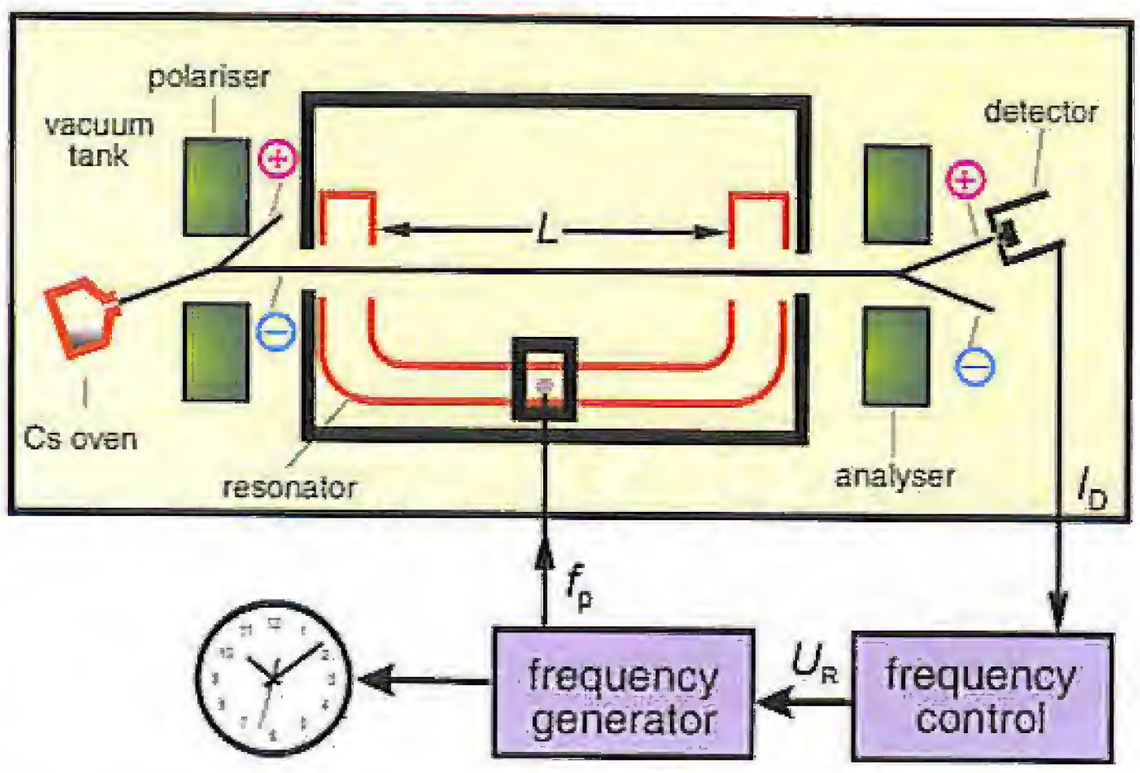
The German Federal Institute for Physical Technology (PTB) in Braunschweig is the body responsible for providing a statutory time reference for the whole of Germany. Its approximate UK counterpart is the National Physical Laboratory (NPL). The PTB has ten atomic clocks of which two are caesium atomic fountain clocks (the photograph shows the room where the clocks are kept). With relative accuracies of between 5 and $10 * 10^{-16}$ these devices are among the most accurate timepieces in the world. The PTB continues to develop the atomic fountain design, and so we can expect these figures to improve in future.

So-called optical atomic clocks are under development at the PTB. So far, the accuracy achieved has been comparable to that achievable using atomic fountain clocks, and several sources of error stand in the way of obtaining the theoretically possible accuracy of 10^{-18}. According to Robert Wynands, who runs the time standards team, 'we have to be careful that the chips do not distort with temperature and cause changes in propagation delays'.

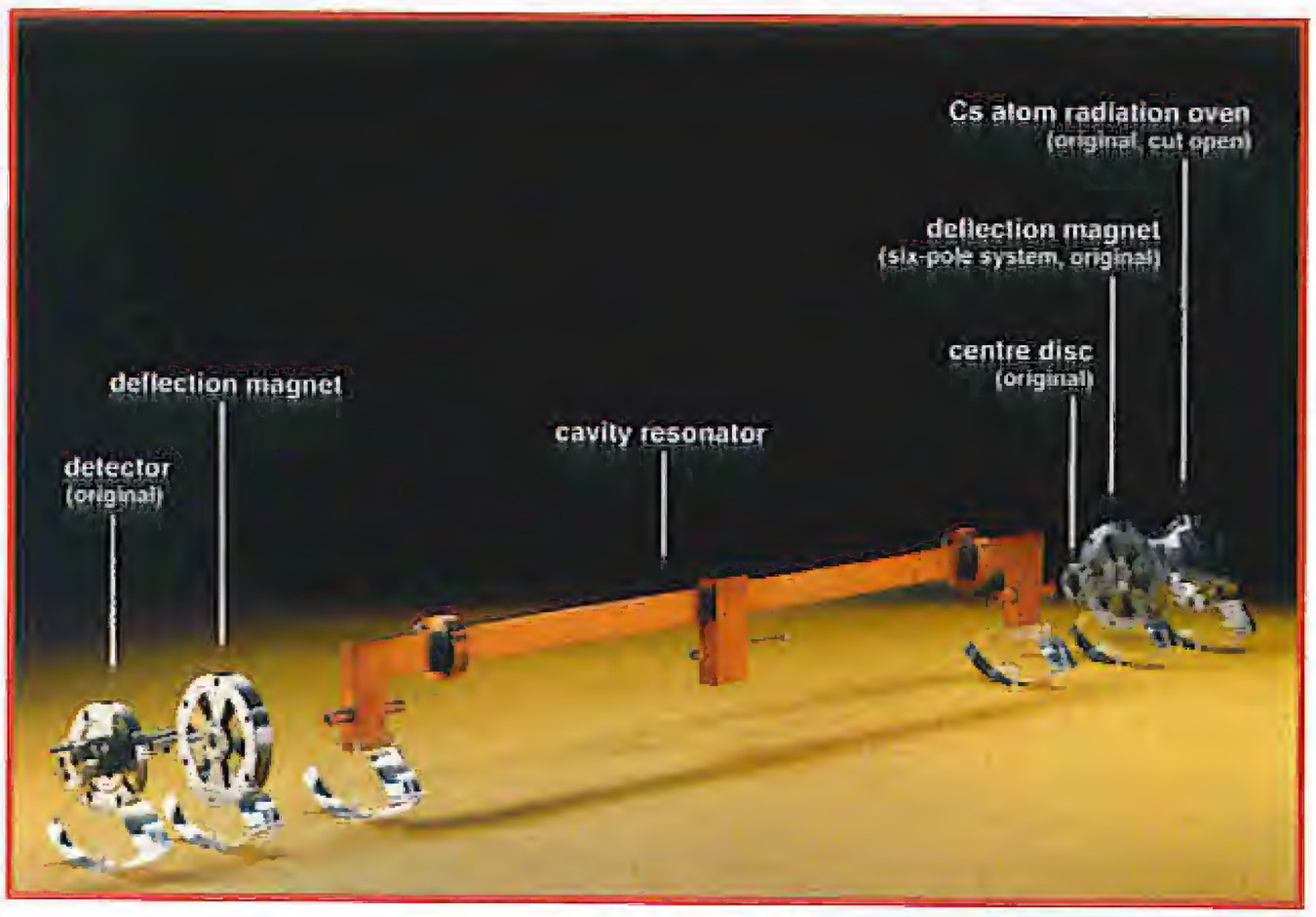
These high-precision atomic clocks and modules such as frequency generators are developed in-house at the PTB. Individual components are usually bought in as ready-made devices, although they tend to be top-of-the-range products. 'The bill for a particularly low-noise quartz crystal might run to four or five figures' says Wynands.

The PTB runs a further three atomic clocks in Mainflingen near Frankfurt. These units, bought from commercial suppliers, determine the time that is broadcast using the DCF77 signal [10]. The signal can be received by radio-controlled clocks within a radius of approximately 2000 km of the transmitter, and is of course checked in Braunschweig. If the time should depart from the true value, the Mainflingen clocks are corrected using a telephone line.

Figure 4.
In 1938 Rohde and Schwarz brought their 'portable' quartz crystal clock to market. It weighed some 60 kg! (Photograph: Rohde and Schwarz [4])



Figures 5 and 6. Diagram and internals of a classical caesium atomic clock. The frequency of an adjustable quartz VCXO is set by the control loop shown. Caesium atoms, in gaseous form, move towards a magnet (the polariser). Those atoms that are in one of the two hyperfine structure transition states (A) are deflected to a slightly different extent from those in state B, and only the former are allowed to enter the resonator. The atoms are illuminated with microwave radiation at a frequency which is a known multiple of the quartz crystal oscillator frequency. When resonance occurs many of the Cs atoms are excited from state A to state B. This can be detected by separating the atoms using the analyser magnets at the end of the resonator, and measuring the intensity of the separated beams. (Photograph and graphic: PTB [6]).



curacy of a few milliseconds per day. Only the very best quartz crystal clocks can beat this figure.

Quartz accuracy

The first quartz crystal based clock was developed in the 1920s, and the first reasonably portable device was produced in 1938 by instrument makers Rohde & Schwarz (see **Figure 4**). It used a sliver of quartz crystal as its frequency reference, made to vibrate by applying an alternating voltage to it, using the piezoelectric effect [5]. At a certain frequency the crystal resonates, and this phenomenon can be detected. Dividers convert this frequency to the desired time interval.

In the 1930s a quartz crystal clock was used to determine that the speed of rotation of the Earth is not a constant. There is a general slowing down resulting from friction due to tides as well as unexpected variations thought to be due to movements of rock within the Earth. There are also seasonal variations with relative magnitudes of the order of 10^{-8} [1].

Inside the atom

Over the last century remarkable progress has been made in physics. Sophisticated theories now explain observations over which generations of scientists had scratched their heads in puzzlement. If light is shone through a gas, it is found that certain wavelengths are absorbed. It is also observed that the gas then re-emits light of a certain wavelength in response to this stimulus.

The atom (or more precisely, the electron shells of the atom) can only take on certain defined energy levels. Consider the following analogy: the flats in a tower block are each on a definite floor, not in between floors (except in the famous John Malkovitch film). So if you throw a ball from the window of your flat, there are only certain velocities with which the ball can hit the ground. Depending on which floor the ball was thrown from, it might reach the ground travelling at 15, 30 or 55 km/h, but never at 40 km/h. Conversely, if you wish to throw the ball back from the ground so that it just reaches the window, you will have to launch it at one of the three admissible speeds. In the case of the atom, we have to provide light of a certain wavelength in order to move an electron from one energy level to another. Things are slightly more complicated in this case, since the 'floors' are not all of the same height; furthermore, there is the occasional mezzanine floor (and even mezzo-mezzanine floors!): see the text box 'Hyperfine structure'. The complete collection of observed and absorbed wavelengths (the 'spectrum') is thus rather complicated and varies from element to element, giving rise to a kind of element fingerprint.

The best part of all this is that the difference between energy levels is essentially independent of external influences. Whereas quartz crystals suffer from the effects of temperature and long-term drift, the energy levels of atoms have their origins in physical constants with essentially fixed values. This gave American physicists in the 1940s the following idea: in some atoms (for example in the alkali metal caesium) the energy levels are so close together that rather than light waves, microwave radiation is emitted, having a frequency of a few GHz. We can thus 'illuminate' a caesium atom with microwave radiation of a frequency close to this atomic resonance frequency, and

then it is a 'simple' matter of measuring our success at exciting the atoms and use this as part of a control loop to generate a highly accurate frequency.

Resonance

In practice the excitation frequency is produced using a voltage controlled crystal oscillator (VCXO) as a reference, with a frequency of perhaps around 5 MHz. A 1 Hz signal can be derived from this as in an ordinary quartz crystal clock. The reference frequency is controlled and regulated as described above. In the classical caesium atomic clock (see **Figure 5** and **Figure 6**) a caesium sample is heated in a small evacuated oven to form a gas. A fine beam of caesium gas then escapes via a small opening and passes through a magnetic field. Atoms that are in hyperfine structure state A are deflected by a slightly different amount than those in state B. Only the A atoms are allowed to enter the resonator cavity.

The atomic resonance frequency is derived from the 5 MHz reference by frequency multiplication; the microwave radiation at the relevant frequency is coupled in using a cavity resonator through which the caesium atoms pass. When the resonant frequency is hit a large number of caesium atoms make the hyperfine structure transition from state A to state B. This can be detected by separating the caesium atoms using a further magnet at the end of the resonator and measuring the intensities of the separated beams. The caesium atoms are ionised using a heated wire and the resulting current can then be amplified by several orders of magnitude using a secondary electron multiplier. All that remains is a little control theory to vary the frequency of the VCXO to maximise the measured current.

Atomic standard

Even a simple caesium atomic clock can achieve a relative accuracy of 10^{-11}, corresponding to an error of one second in 3000 years. It is something of an understatement to call this 'high precision': if we could measure distances as accurately, we would know the distance to the moon to the nearest millimetre! In 1967 the definition of the second was changed to use the caesium 'atomic' standard (see the 'Base units' text box). The use of the 'atomic' tag can probably be traced back to the more media-savvy academics of the time, aware that the word 'atom' was naturally associated with the white heat of the scientific and technical revolution. In industrialised countries atomic clocks allowed standardising bodies to provide a statutory framework for timekeeping. However, even atomic clocks drift slowly relative to one another and so regular comparisons are made, even across national boundaries. An averaging process, involving some 50 institutions and 200 individual atomic clocks, is used to produce a world time standard called International Atomic Time. Because of the (relatively!) erratic rotation of the Earth extra seconds are sometimes added at the end of June or at the end of December. This ensures that astronomically-derived time never deviates far from Atomic Time [1], [7].

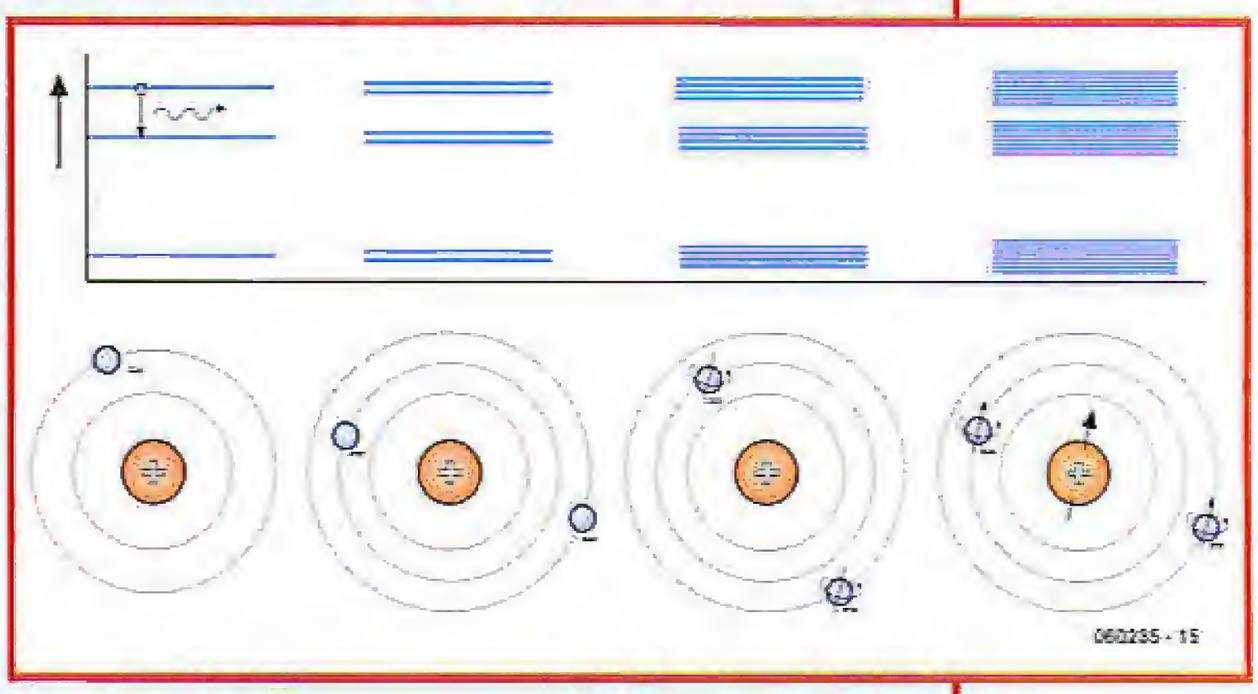
Ultra precision

The best classical caesium atomic clocks, such as those kept at the German Federal Institute for Physical Technology (PTB), achieve relative accuracies of up to 10^{-14}. When comparing clocks of such high accuracy even the smallest local variation in gravity must be taken into account, as Einstein's general theory of relativity tells us. These devices are therefore not the end of the story as far as accuracy is concerned.

Inaccuracies in the type of clock described above can be traced back to (among other things) the fact that the caesium atoms are moving rapidly through the resonator. In a so-called caesium fountain atomic clock the atoms are cooled (i.e., slowed down) using a laser and then gently

Hyperfine structure

An atom consists of a positively-charged nucleus and negatively-charged electron shells. For simplicity we can think of a number of electrons orbiting the nucleus. If an electron gets closer to the nucleus energy is released, and conversely, if an electron receives a stimulus of energy it can be moved into a higher orbit.



Observations and theoretical considerations lead us to believe that the electrons can only move in certain fixed orbits. If an electron moves from one of these orbits to a lower one, a tiny packet of light (a 'light quantum') is released, with a wavelength proportional to the difference in energy levels. The relationships are simplest in the case of the hydrogen atom, which consists of a very simple nucleus and a single electron (see drawing). If the electron moves between energy levels, perhaps from the third or second orbit to the first or vice versa, light quanta of the corresponding wavelengths will be respectively emitted or absorbed. The spectrum of light emitted by a stimulated mass of hydrogen atoms therefore consists of just a small number of distinct wavelengths, called 'lines'.

Things get more complicated when more electrons are involved. Just as a current flowing in a coil creates a magnetic field, so also do electrons circling a nucleus. The field affects the orbits with the result that a single energy level is split into two closely-spaced energy levels.

The 'spin' of an electron (an electron can be imagined as spinning on its axis) creates a further weak magnetic field which results in an obseved further splitting of the energy levels: the resulting pattern of energy levels is called 'fine structure'. Finally, the magnetic field due to the nucleus can also have a small effect on the energy levels. The lines of the so-called 'hyperfine structure' are so closely-spaced that when a transition between them is made low-energy microwave quanta, rather than light quanta, are emitted. In naturally-occurring caesium the frequency of these microwaves is 9 192 631 770 Hz.

Commercial applications

The atomic clocks used at national physical laboratories are specially made and criteria such as price, size and current consumption are not particularly important. However, there are various manufacturers producing a range of atomic clocks: for example, Symmetricom Inc. [11] offers both caesium- and rubidium-based atomic clocks which are easy to use and compact. The photograph shows such a unit, which is only a little larger than a cigarette packet and which can be used as a drop-in replacement module for a quartz crystal oscillator.

Symmetricom's rubidium clocks start at under two thousand pounds and have a relative accuracy of around 10^{-9} to 10^{-10}. Customers include telecommunications companies who use them in mobile telephony base stations. A caesium clock can be had for around twenty thousand pounds upwards while hydrogen maser clocks come in at a hundred thousand pounds. The latter exhibit a very high degree of short-term stability and good accuracy over periods of hours to days. This makes them ideal for use in navigation satellites, where the time as measured by the on-board atomic clocks can be adjusted from time to time from the ground stations. The satellites of the EU Galileo system will include hydrogen maser clocks. The first-generation American GPS satellites contain souped-up rubidium clocks while the more recent models each contain two caesium and two rubidium clocks [12].

The more accurately the satellites can keep time the more accurate the positioning system can be. The theory is explained in [13].

nudged into the resonator cavity. Like a fine water fountain they now turn back under gravity and are filtered and detected in a detection chamber. This kind of clock can achieve relative accuracies of 10^{-15} and better.

Within a few years so-called optical atomic clocks will become widespread, using light instead of microwave radiation. Relative accuracies of up to 10^{-18} are expected. With clocks of such astonishing accuracy it will become possible to determine whether the energy levels, the differences between which are calculated from physical constants, really are constant. Any drift in these physical 'constants' will give scientists something to scratch their heads about once more!

(060535)

Internet links

[1] www.npl.co.uk/time/
[2] http://en.wikipedia.org/wiki/Pendulum_clock
[3] http://en.wikipedia.org/wiki/Escapement#Free_pendulum_clock
[4] www.rohde-schwarz.com
[5] www.elektor.com/Default.aspx?tabid=27&art=52974
[6] www.ptb.de/de/org/4/44/_index.htm
[7] www.npl.co.uk/reference/time.html
[8] www.npl.co.uk/reference/
[9] www.npl.co.uk/reference/electric_current.html
[10] http://en.wikipedia.org/wiki/DCF77
[11] www.symmetricom.com
[12] ftp://tycho.usno.navy.mil/pub/gps/gpsb2.txt
[13] www.kowoma.de/en/gps/positioning.htm
[14] www.deutsches-uhrenmuseum.de/default.asp?id=1&setLanguage=eng

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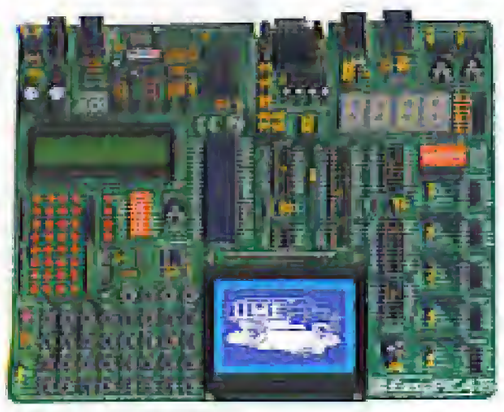

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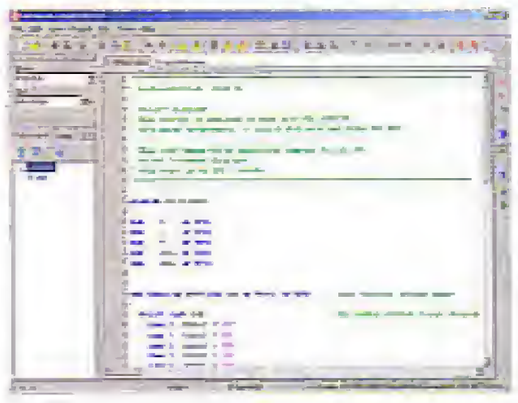

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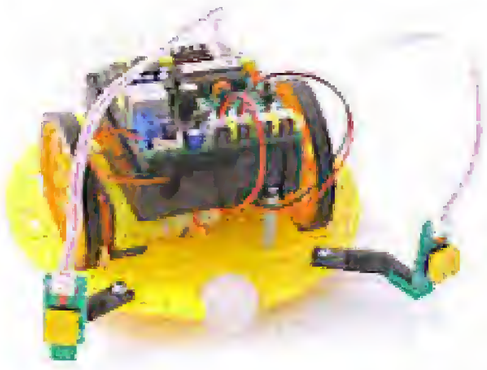

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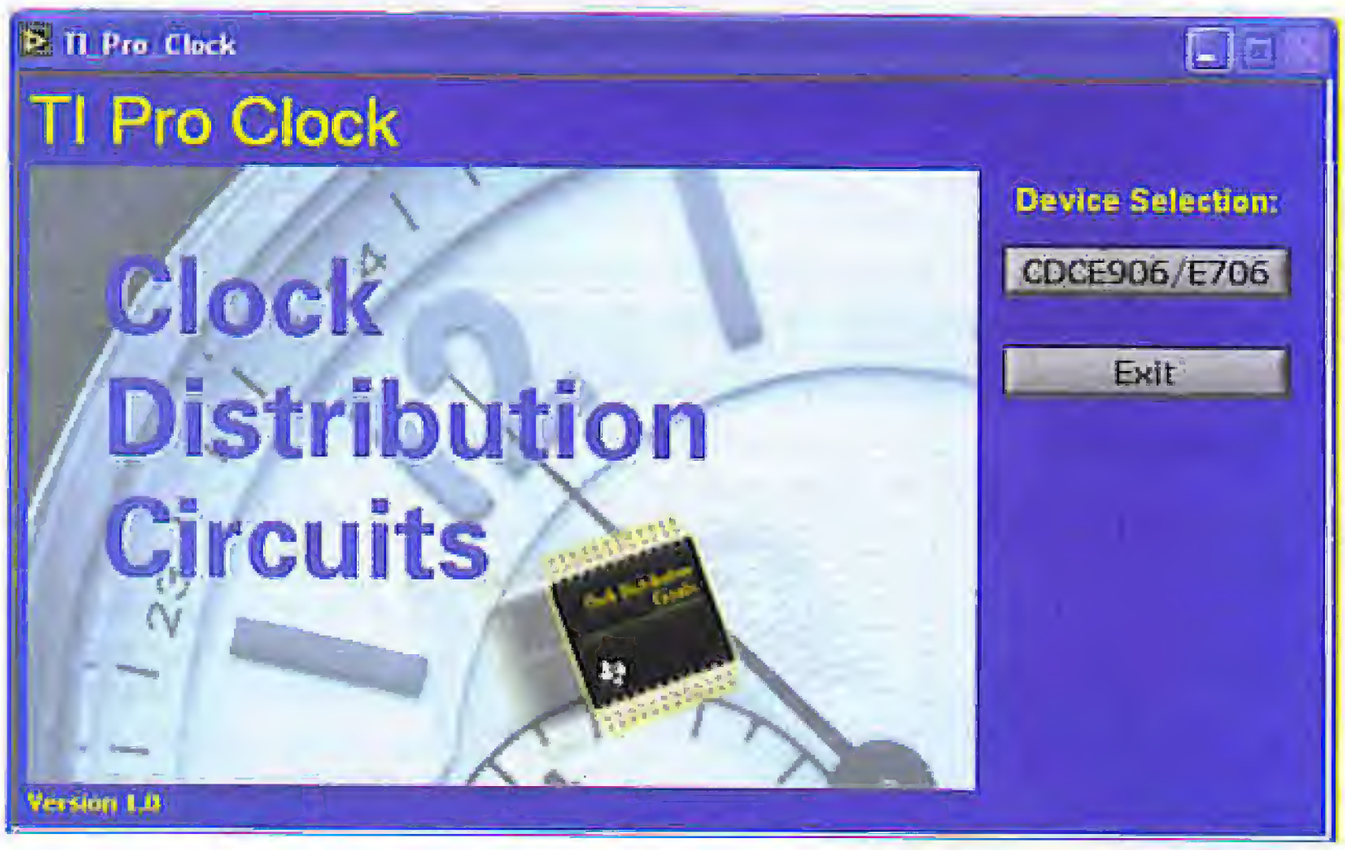
Clocking, Texas-style

A 300 MHz spread-spectrum clock generator from TI



Burkhard Kainka

The CDCE706 and CDCE906 from Texas Instruments are interesting new clock generators which include three independent PLL modules. They also feature a spread-spectrum output to help minimise EMC problems. But what are these devices like in practice?

It is often the case that a fixed-frequency clock generator is needed, but crystals of a suitable frequency are not available. The problem can be solved using a PLL device which can be used with a standard crystal to generate almost any desired frequency. The CDCE706 and CDCE906 ICs from Texas Instruments even allow the generation of frequencies above 100 MHz, which can be difficult to achieve using conventional crystal oscillators. The CDCE906 can produce a clock output with a frequency of up to 167 MHz, while the CDCE706 can operate at up to 300 MHz. The devices are in other respects compatible. They contain three entirely independent PLL modules and can be configured using an I^2C interface. Up to six different output frequencies can be obtained using dividers driven from the PLL outputs or from the input clock frequency. **Figure 1** shows the pinout of the device and **Figure 2** the functional block diagram. Using the output switch matrix (see **Figure 3**) the six outputs of the IC, Y0 to Y5, can be connected at will to the outputs of six programmable dividers. In turn, the inputs to the dividers can be connected at will to the PLL outputs or to the input crystal frequency. In a typical application the device is used with an external crystal (**Figure 4**); alternatively, an external clock signal can be fed to the device. The decoupling of the 3.3 V supply is critical: there are four pairs of adjacent V_{CC} and GND pins on the TSSOP20 package. Decoupling capacitors,

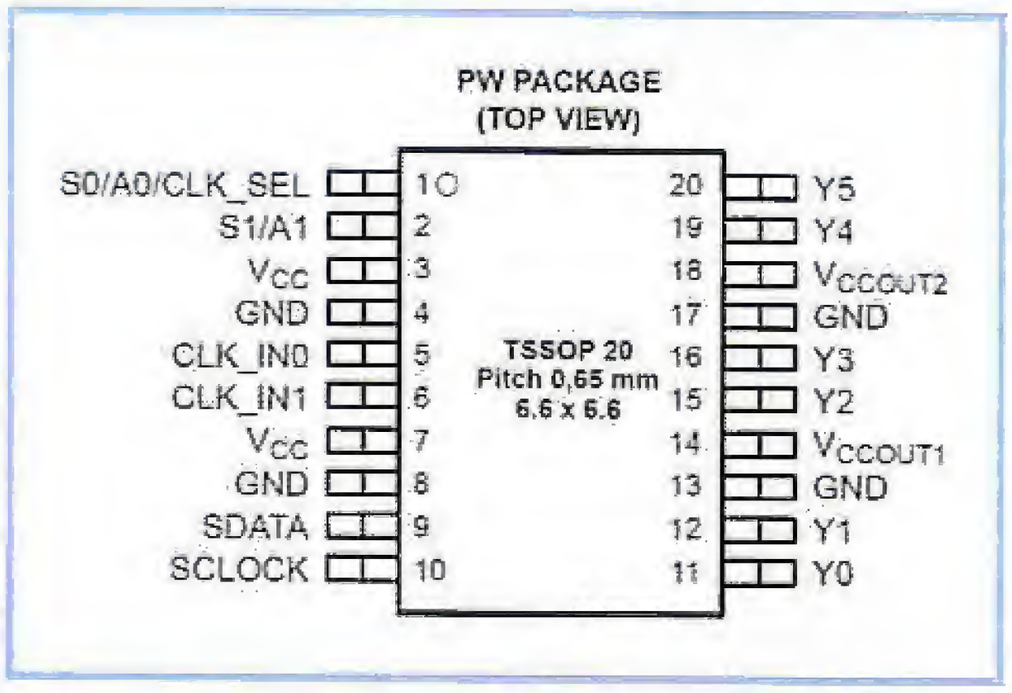


Figure 1. Pinout of the IC, in a 20-pin TSSOP package.

ideally SMDs with a value of 100 nF, should be mounted as close as possible to each pair of supply pins. This will help ensure that the internal PLLs do not affect the operation of one another.

Programming

At [2] Texas Instruments provides an overview of the products, tools and documentation available relating to the CDCE706. The 'TI Pro Clock' program that can be found there is a comprehensive tool for configuring the device. The program can drive the I²C bus directly via the printer port. Using the tool it is possible to reprogram the clock generator freely, since it writes the configuration settings directly into the device registers. There is also an option to transfer the settings to an EEPROM area in the device: settings are automatically transferred from this area into registers on power-up, so that the device can be arranged to operate using preset values without the need for permanent connection to a PC.
The program and its use are comprehensively described in application note scau017.pdf; the note also describes the evaluation board which is available.
Figure 5 shows a modified interface between printer port and I²C bus. In theory the I²C bus can be driven directly from a printer port, as described, for example, in [3]. It turns out, however, that the SCL signal in particular is susceptible to interference and an extra buffer is a worthwhile addition. We have, however, used the same printer port pins as in the TI design.

The 74HC125 quad buffer has tristate outputs which go into the high-impedance state when the $\overline{OE}$ input is high. This is necessary in the case of the SDA signal, since data can be travelling in either direction. D0 is therefore used to control the 1$\overline{OE}$ input (pin 1), while that buffer's input is tied to ground. When D0 is low SDA is also pulled low; when D0 is high the buffer goes into the high-impedance state and the 10 kΩ pull-up resistor pulls the signal high. Now the I²C slave device can pull the SDA line low, for example when it needs to generate an ACK signal. The instantaneous state of the SDA signal can be read using a further buffer driving the PE input on the printer port. Printer ports normally operate using 5 V signal levels rather than the 3.3 V used by the clock generator, and two resistors, in the D0 and D1 lines, serve to adapt the voltage levels. The protection diodes inside the 74HC125 clamp the maximum input voltage to slightly above 3.3 V.
The 'TI Pro Clock' program can be used in conjunction with this interface. Not only does the program assist with calculating the required settings for the clock generator device, it also includes a 'storage oscilloscope' to analyse the signals on the I²C bus (see **Figure 6**), which is helpful when trying to track down communications errors. The display is also very handy when developing one's own software, for example to run in a microcontroller.

In practice

When the program is started up it displays the default configuration stored in the device during manufacture (**Figure 7**). It is assumed that you will be using an input frequency of 27 MHz, and this frequency is also present on all six outputs. The signal, however, is not simply being passed straight through: it is being processed by PLL 1. The input frequency is multiplied by 8 (i.e., the PLL operates at 216 MHz) and then divided by 8 again us-

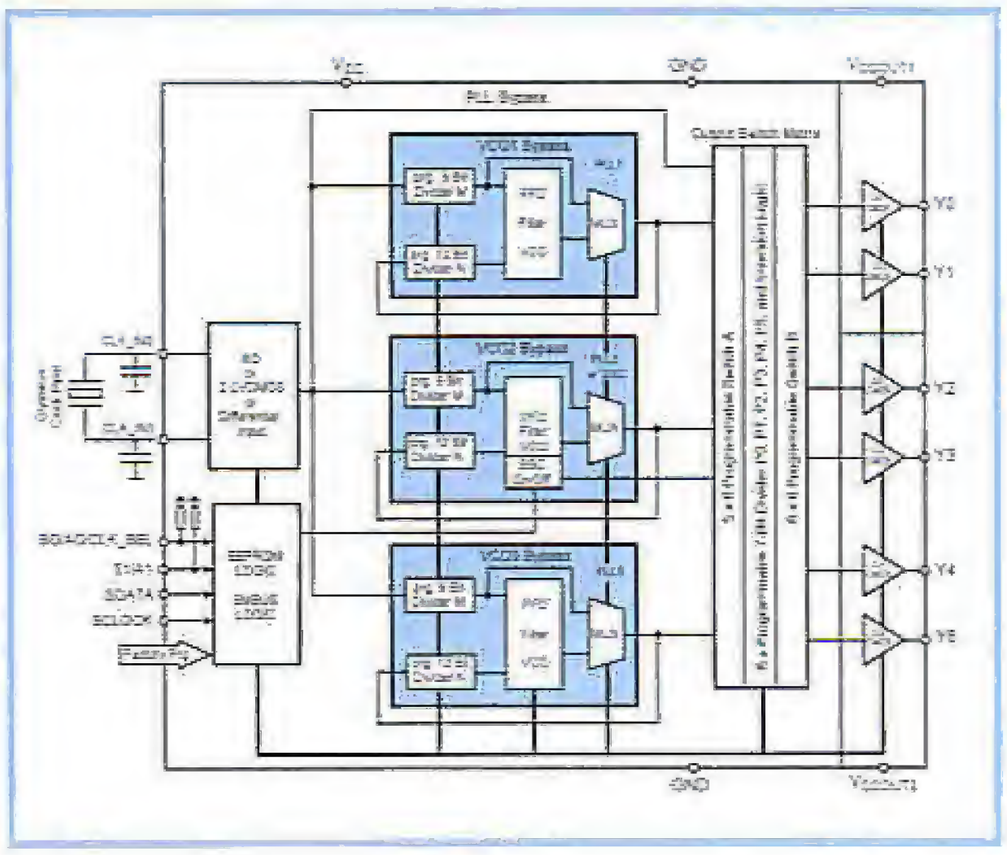


Figure 2.
Simplified block diagram of the CDCE706 and CDCE906.

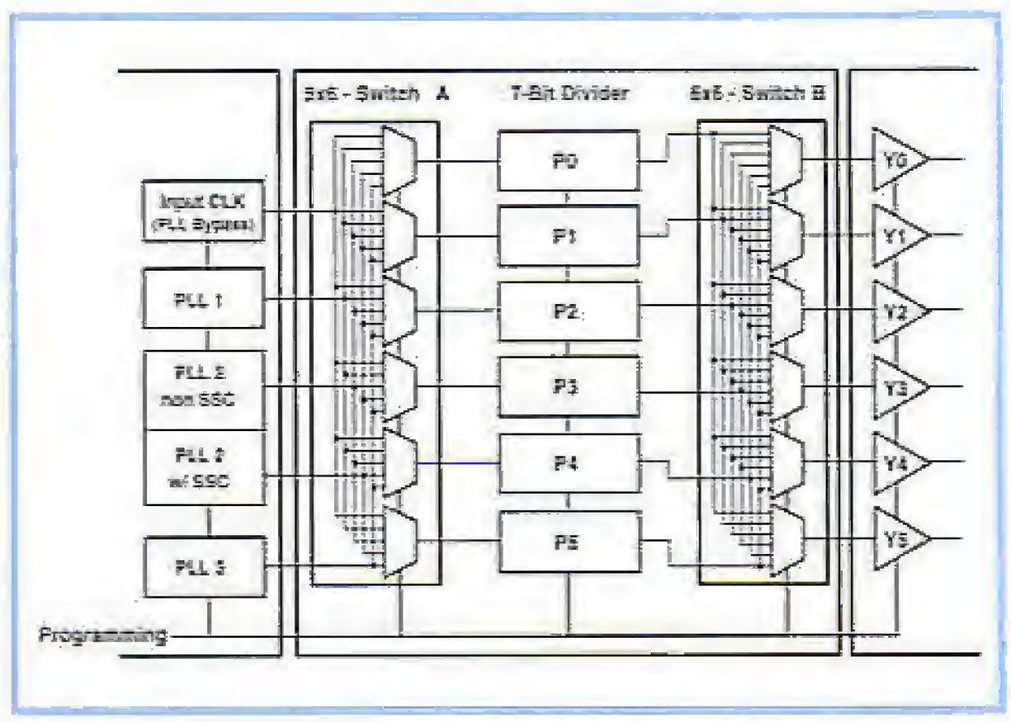


Figure 3.
Block diagram of the dividers and output switch.

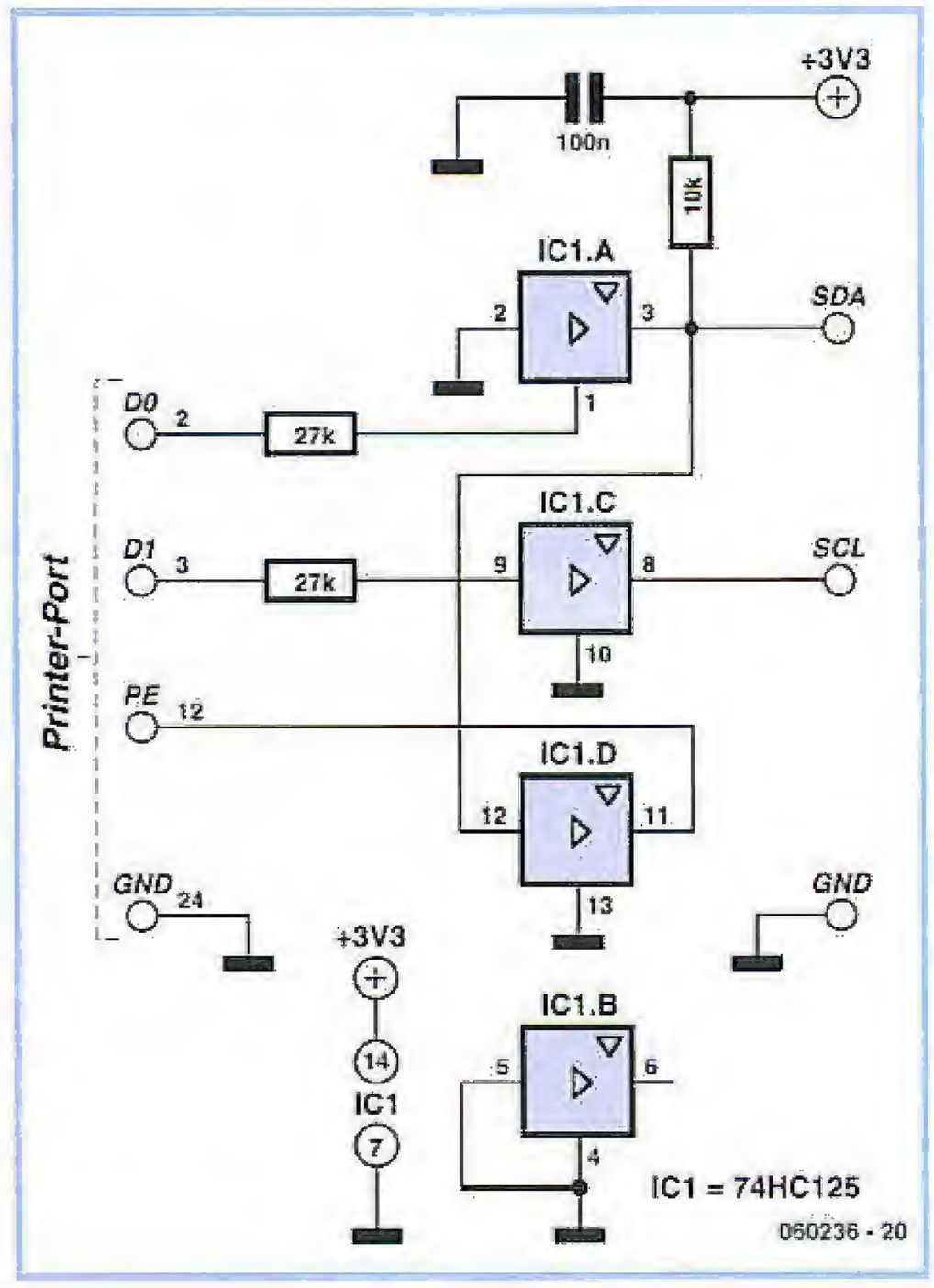


Figure 4.
Typical application circuit with external crystal.

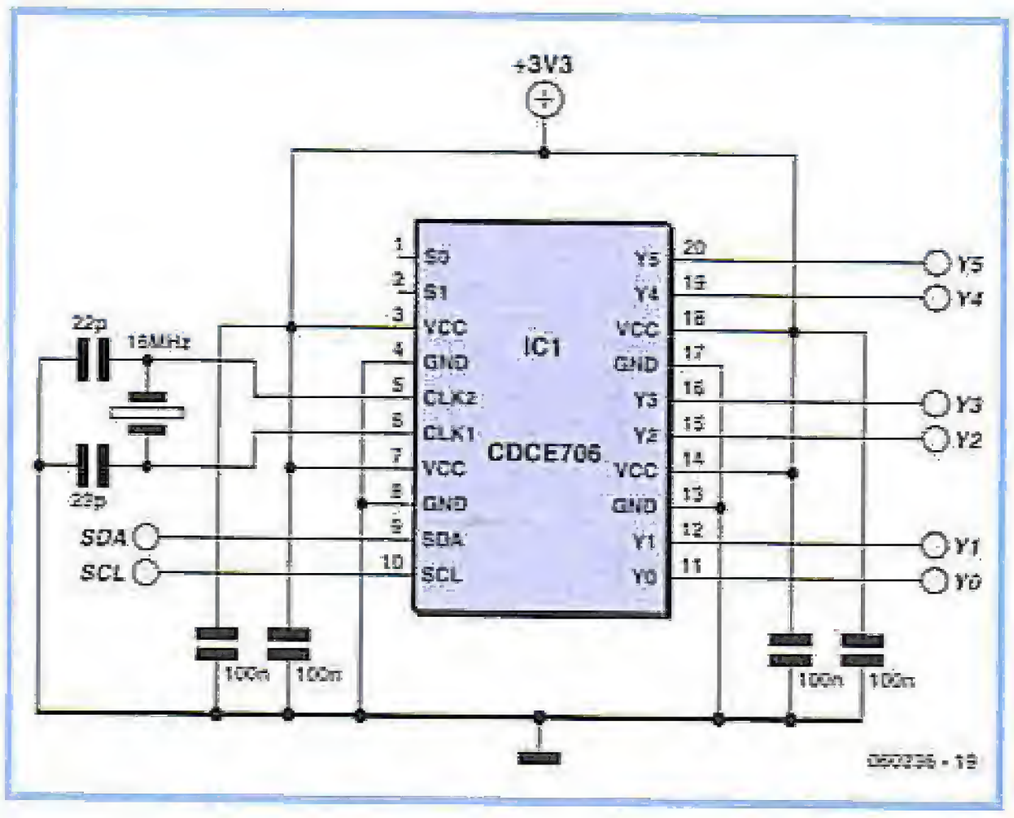


Figure 5.
Circuit diagram of a programming adaptor for connection to a parallel port.

ing divider P2. All the output buffers are connected to P2 and therefore produce identical signals. The other two PLL modules are also running, and their outputs are taken to dividers but not then connected to any outputs. This configuration is suitable for an initial test of the device, without the need for a PC to be connected. If a 16 MHz crystal is used instead, the outputs will all be oscillating at 16 MHz. We thus have a simple test that the power supply and crystal oscillator circuit are operating correctly. We can now go on to program the device to generate almost any desired frequency. In theory it is a simple matter of calculating:

$$f = f_{in} / M * N / P$$

but often a little experimentation can be helpful to find suitable settings. The PLL frequency should lie within one of two bands, either from 80 MHz to 200 MHz or from 180 MHz to 300 MHz. The software should be used to set the VCO f_{max} value to 200 MHz or 300 MHz accordingly.
In practice it is found that in 200 MHz mode the PLL oscillator can operate at well below 80 MHz, although at some detriment to the performance of the device. In particular, phase noise increases. The general rule here is that if possible the highest available comparison frequency for the PLL should be chosen. This means that the M divider ratio should be set as low as possible. For example, suppose we wish to generate an output frequency of 17 MHz from an input frequency of 16 MHz. We first set M = 16, giving a comparison frequency of 1 MHz. We then set N = 170, giving a PLL frequency of 170 MHz, which is finally divided by P = 10 down to 17 MHz.

Figure 6.
The programming software also offers a display of the I²C bus signals.

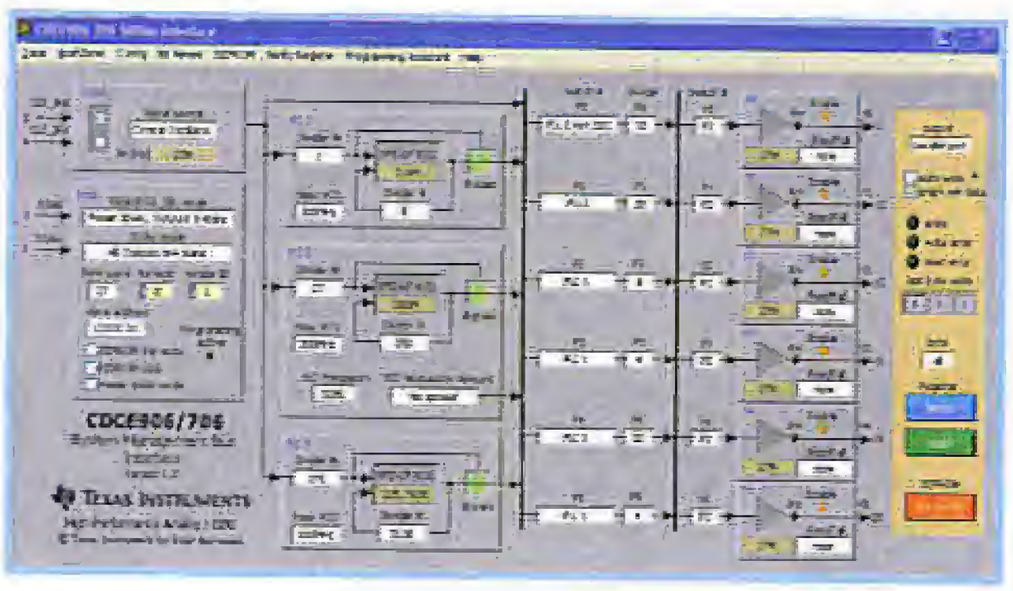


Figure 7.
Factory default settings of the IC.

Assistance

When more obscure frequencies are wanted, say 10.245 MHz for example, a little more thought is called for to find the best settings. Help is provided in the form of the 'Programming Assistant' (**Figure 8**): you can select the desired output and frequency and the assistant calculates the best settings. In this case the program suggests 16 MHz / 160 * 2049=204.9 MHz and 204.9 MHz / 20 = 10.245 MHz. This would now make a suitable oscillator for a dual-conversion superheterodyne receiver with a first IF at 10.7 MHz and a second IF at 455 kHz. PLL 2 and PLL 3 can be switched off in the interests of producing an output signal with low noise and weak sidebands.

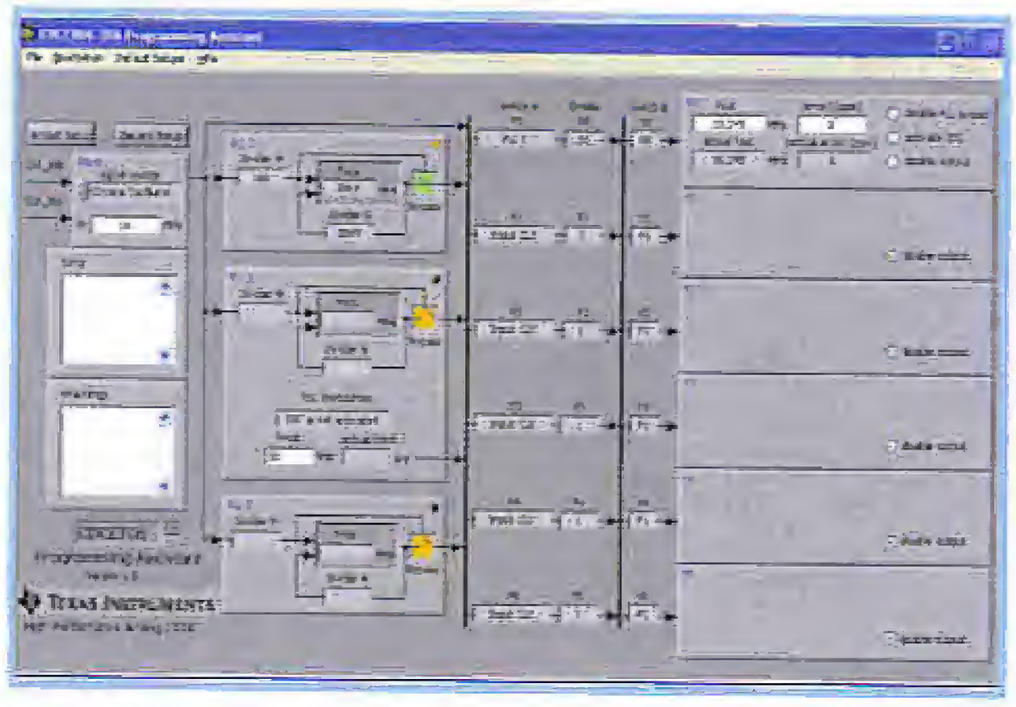


Figure 8.
Automatic calculation of divider settings.

Spread-spectrum clocking

In these days of strict EMC regulation it can often happen that a piece of equipment produces radio interference at its clock frequency (or at a harmonic of it) and hence fails emissions testing. The best defence against this is good screening and decoupling of all signals that leave the enclosure. A backup technique is to use spread-spectrum clocking. The spectrum of a signal can be 'spread out' using a kind of frequency modulation; a receiver will then not see a sharp spectral peak but rather a noisy signal with lower peak power occupying a wider region of the spectrum. PLL 2 can be configured for frequency modulation around the specified centre frequency with a deviation of up to 0.4 %, or down from the specified frequency with a deviation of up to 3 %: see **Figure 9**. Centre modulation is a good choice for generating a microcontroller clock since the average frequency will be exactly the specified value.

RF characteristics

Although the frequencies of the VCOs in the internal PLLs are determined by simple RC circuits, it is nevertheless

possible to use them to construct a clock generator with a low-noise output on a par with that achievable using a crystal oscillator. It is therefore possible to consider using this integrated clock generator in advanced RF applications, for example in a triple-conversion superheterodyne receiver with an adjustable first oscillator and two fixed-frequency IF stages. In this case any failure to decouple the PLL modules adequately from one another can reduce performance. If two PLLs are set to operate at closely-spaced frequencies, even a small amount of coupling can have a significant effect: as you can imagine, the two PLL control loops will interfere with one another, resulting in an output signal that is not clean.
In critical applications (for example in a DRM receiver) it can be a good idea to use just one of the PLLs. However, it will still be necessary to ensure that the device's supply is clean by providing good decoupling at the V_{CC} pins with very short connections to the bypass capacitors. A ground plane should also be used. Texas Instruments recommends using a four-layer printed circuit board with both V_{CC} and ground planes.

We took a simpler approach for testing, simply connecting a Sibatit ceramic capacitor directly across each pair of power pins. Setting two PLLs to two reasonably-separated frequencies we were able to obtain two clean output signals simultaneously. With all three PLLs operating at the same time it is harder to avoid a certain amount of phase noise on the outputs.

(050236-I)

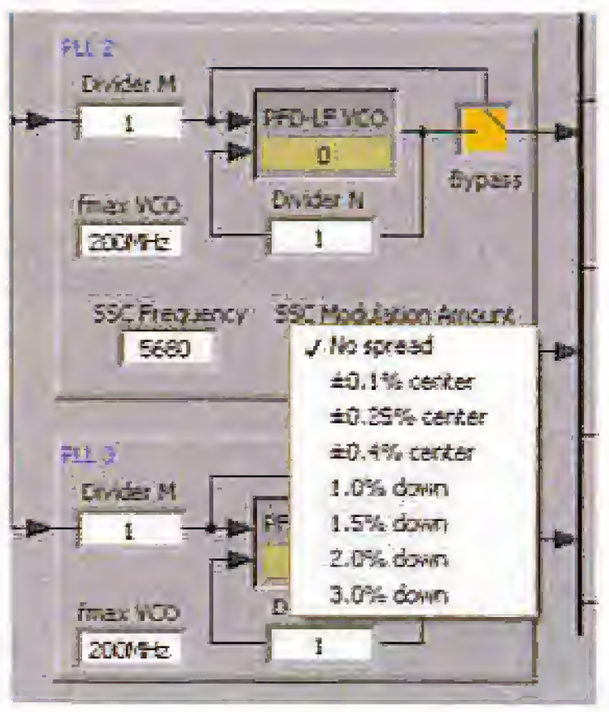


Figure 9.
Spread-spectrum settings.

[1] Burkhard Kainka,
'Serially Programmable Crystal Oscillator',
Elektor Electronics, March 2005, p. 66.

[2] http://focus.ti.com/docs/prod/folders/print/cdce706.html

[3] B. Kainka and H.-J. Berndt, 'PC Interfaces Under Windows: Measurement and Control Using Standard Ports',
Elektor Electronics Publishing, 2002.

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Turbo Tricks

Notebook and microcontroller overclocking

Dr. Thomas Scherer

It's not well known but it's quite a simple job to boost the clock rate of almost all Centrino® notebooks with Intel i915 chipsets and Pentium M CPUs. We take a look at what's required for this simple mod.

The Centrino family of processors have been a great commercial success for Intel. From the beginning of 2005 up to the present day the 915 chipset with its low power consumption and good processing power have made slim portable computers more affordable. The progression of the Pentium M processors from the first generation 'Banias' which contained a 1 MB L2 cache through to the 'Dothan' processor fabricated with the more recent 90 nm technology and offering a 2 MB L2 cache, DDR2 memory support and an FSB clock increased from 400 to 533 MHz.. The last two features are supported by the 915 series chipset family but not by the previous 855 series. More recently we have seen the introduction of dual-core processors supported by the 945 chipset but the 915 still has much to offer including low-cost and the ability to be overclocked extremely easily.

Wind up the clock

Many of you probably take the view that overclocking is the domain of geeks with too much time on their hands, they start off with a perfectly reliable notebook and end up with something that is really only good for toasting sandwiches. In reality the risks involved with this modification are quite small, no soldering is necessary and most people with an average level of technical competence would be able to identify the correct processor socket pins and fit the necessary wire jumper. The entire process should not take longer than 15 minutes and best of all the modification is reversible!

The most recent processors from Intel have a built-in (fixed) multiplier which derives the processor clock from the FSB (Front Side Bus) clock rate. These processors can therefore only be overclocked by increasing the FSB clock. The disadvantage of this modification is that it also increases the clock rate to the DDR RAM and the chipset cannot reliably handle the increased clock rate. Reports indicate that systems with this type of overclocking tend to become unstable when the acceleration approaches around 20 %. In contrast the Pentium M processors have much more in reserve.
In an effort to prevent owners from tampering with the clock speeds many notebook manufacturers define the FSB clock rate from values contained in the machines BIOS. It is usually uneconomical to attempt overclocking on these machines.

Only connect

Partly in response to competition from their rival AMD, Intel released (along with the existing Celeron processor) a low-cost variant of their Pentium M 'Dothan' processor with a reduced FSB speed of 400 MHz and half the normal L2 cache space (1 MB instead of 2 MB). This chip marked the beginning of the entry-level Pentium based

Controllers

The technique of overclocking is not necessarily confined to the PC and Laptop world; microcontrollers are also likely candidates for this type of treatment including those contained in many Elektor Electronics projects.

The microcontrollers contained in commercial equipment are best left alone because the software source files are generally not available for modification and increasing the clock speed will cut short timing loops and may cause the device to malfunction or run erratically. Our experience with off-the-shelf microcontrollers indicate that most will run quite happily (at room temperature) with a clock rate of up to 50 % higher than the maximum frequency quoted in the data sheet. Despite these findings it is time for a reality check; any competent engineer would of course be asking for trouble if their latest production design relied on over-clocking or stressing any component beyond its guaranteed operational envelope.

In most cases a controller can be tested by simply replacing the existing crystal with another of a higher frequency.

When the circuit operates incorrectly it will be necessary to make changes to the firmware, taking into account the new clock speed. Routines using timing loops or timers and serial interface drivers will require modification. In some cases if the original firmware is retained a 30 % increase in processor clock speed is likely to give a 30 % increase in baud rate. Any timing constants in the communication routines will therefore require adaptation.

Eventually the clock increase will impact on the I²C, SPI and other serial channels. Communications with peripheral equipment will not be possible until the firmware is modified.

Unlike PCs and notebooks when a microcontroller is overclocked it produces a proportional increase in current consumption and heat dissipation in the device. And if you push the clock too far it is no surprise to find that, the controller will simply refuse to work.

notebooks which would supersede the Celeron based machines. Intel uses a voltage level on a processor socket pin to indicate to the chipset whether the bus clock rate is either 400 or 533 MHz. The slower processor variants numbered 715, 725, 735 etc. leave this processor pin B16 open-circuit while the faster types 720, 730, 740 etc. connect the pin to ground (see **Figure 1**). What happens if we fix this pin to ground anyway using a wire jumper?

Well not much! At least nothing bad, according to reports on the Internet (try Googling with 'pinmod' and '735' or '725') it seems that the majority of 'pin modders' who have tried this modification on their notebooks have been successful.

The modification has no effect on the faster processors (numbers ending in zero) using a 533 MHz FSB because they already have the pin grounded. For example the mod gave no speed increase on a 1.6 GHz Pentium M 730 notebook while a 1.6 GHz 'economy' notebook using a 725 chip reported a 33% increase with the processor clock now at an unbelievable 2.13 GHz! Almost as fast as a more expensive 770 based machine. Reports from overclockers on the Internet indicate that the vast majority of overclocked 735 machines are completely stable.

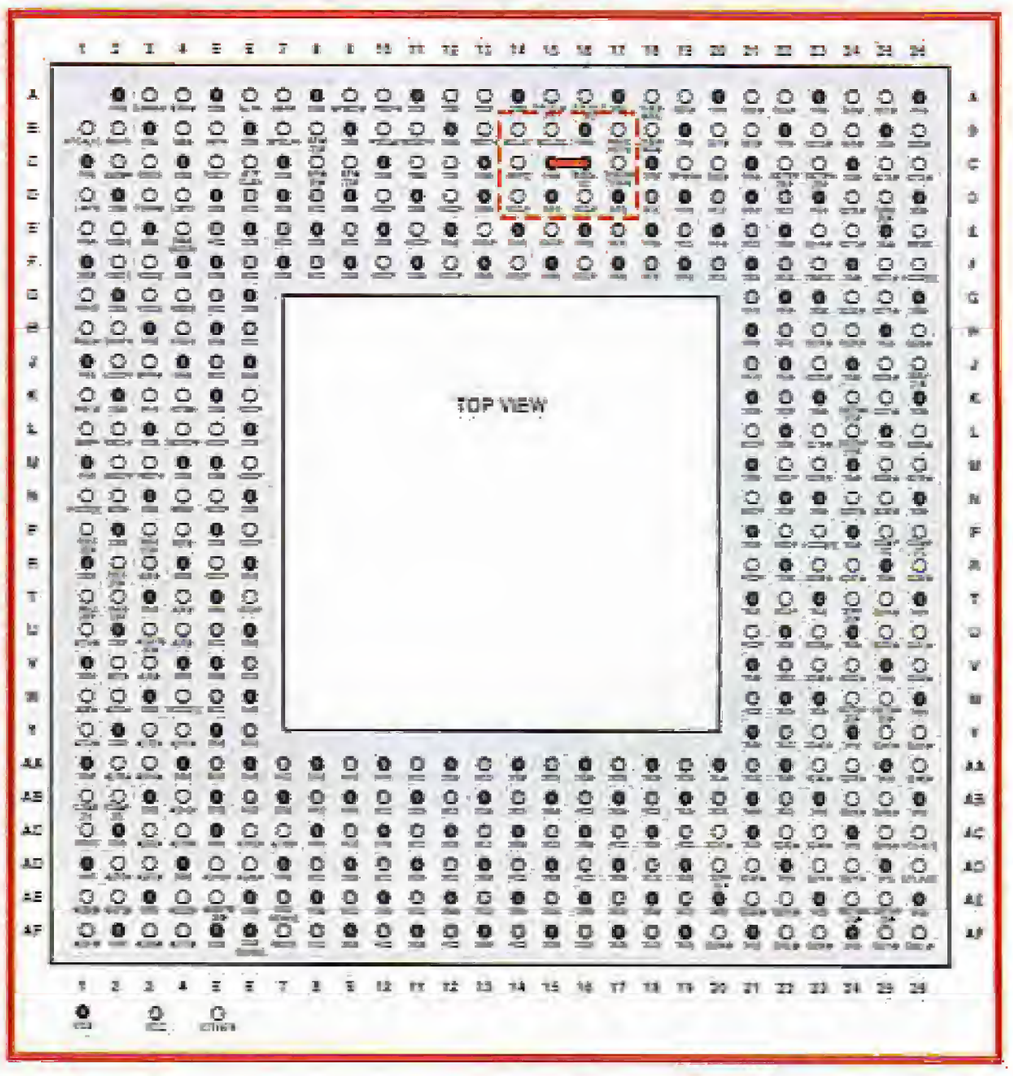

Figure 1.
Pin layout of Dothan processor (from above). The red line indicates the wire jumper position from Pin C16 to Pin C15.

Making a jumper

Figures 2 to **6** show the modifications carried out to the author's notebook which is fitted with a 725 processor. Those of you who have machines from less well known manufacturers may find that the most difficult part of this mod is finding information on how to open the notebook. Once open it should be possible to locate the processor within a few minutes. **Figure 2** shows the inside of the machine with the keyboard and processor heatsink removed. The chip in the upper centre half of the picture is the processor. A turn of the large retaining screw is enough to release the processor from the socket. One thing we noticed with this particular machine was that the protective foil over the contact area (**Figure 3**) had not been removed from the heatsink when the machine was first assembled! The wire jumper is made from a single

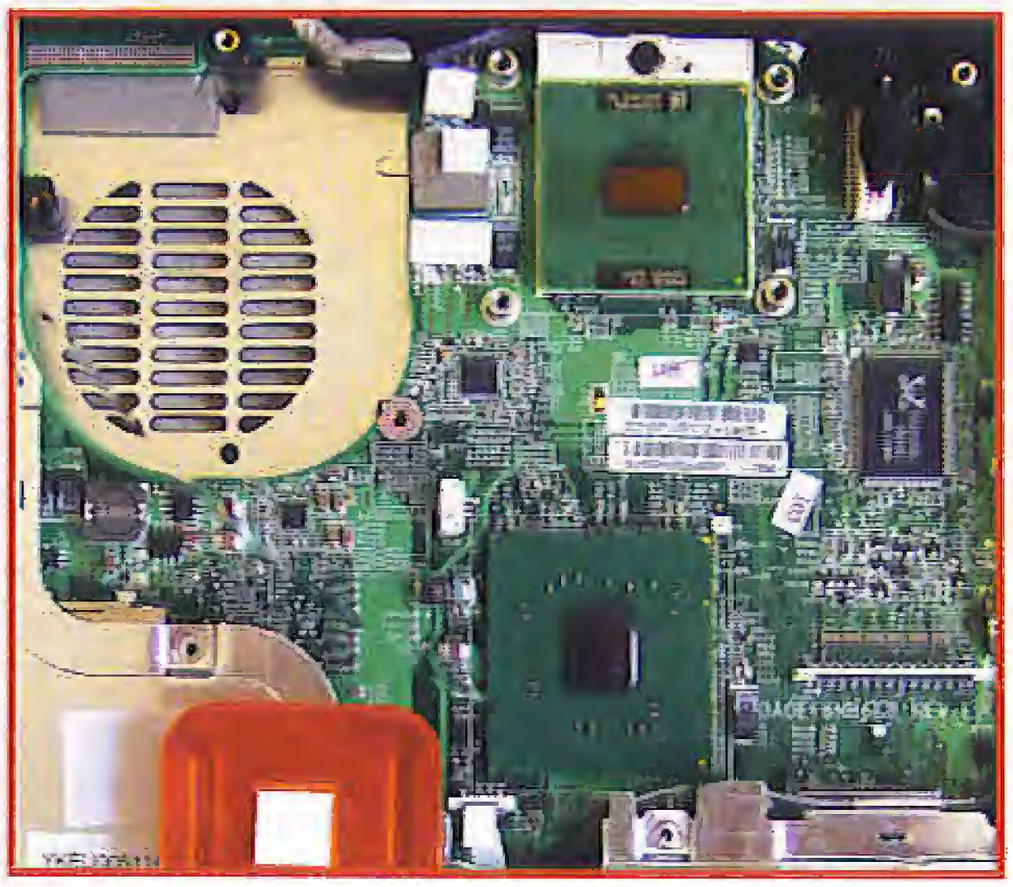

Figure 2.
The author's notebook. The large chip in the upper part of the picture is the CPU. Below is the ICH6-M southbridge.

The bottlenecks

The maximum clock frequency is limited by a number of factors. The most basic switching element in all microcontrollers and processors is the transistor, it makes up all the gates and logic functions inside the chip. Each transistor has a finite switching time which we cannot do much to improve once the chip has been fabricated. Each function block in the processor is designed to be able to complete its operation in the time between two clock pulses. When the clock frequency is increased beyond its design maximum it becomes more likely that the logic element has insufficient time (due to the fixed propagation delay in the transistors) to complete its function and the output value will be sampled before it has time to stabilise. The resulting incorrect value will cause the software to malfunction and eventually crash. For the sake of reliability and to ensure correct operation over the entire operating range and between production batches the manufacturers data sheet quotes a conservative figure for the maximum clock rate.

Temperature is also a limiting factor, each time a CMOS transistor changes state it dissipates energy. As the clock speed increases the transistor energy dissipation increases which raises the chip temperature and may lead to failure if it exceeds its rated maximum operating temperature.

An additional limitation of the transistor structure and interconnects is parasitic capacitance which must be charged and discharged when the transistor switches. With faster switching speeds the energy dissipation increases correspondingly along with the chip temperature.

The final bottleneck is the propagation speed of electrical signals along signal paths. Propagation speed can vary typically between 180 × 106 m/s and light speed (300 × 106 m/s) depending on the medium used. At first glance this would not seem to be too much of a problem but if we consider a modern CPU with a clock frequency of 3 GHz, a propagation speed of 180 × 106 m/s will dictate that a single clock period is just 6 cm long. At these elevated speeds it becomes more important to consider signal path length to ensure that data on the internal bus system is transferred when it has reached a stable state.

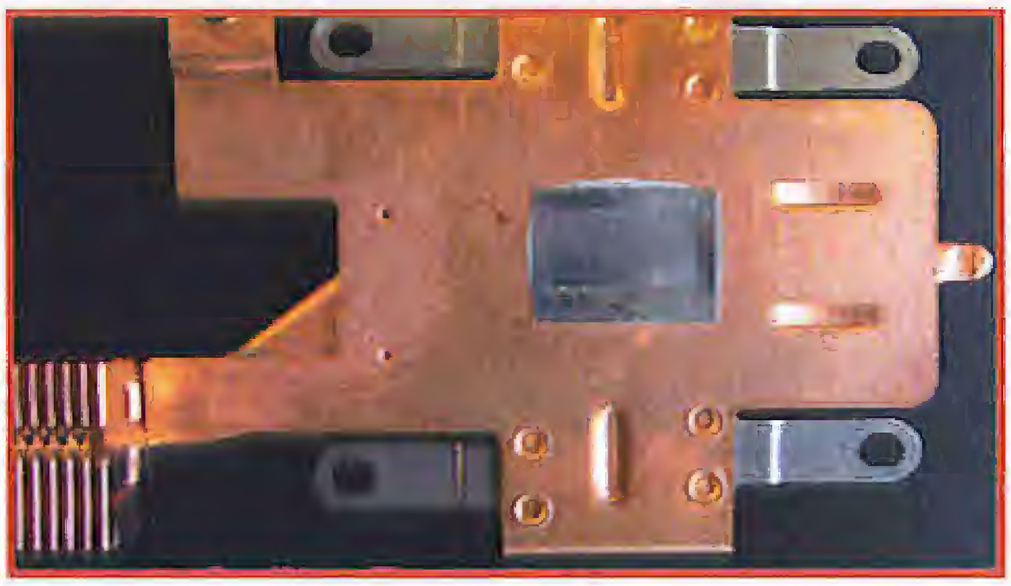

Figure 3.
The heat sink still fitted with a protective film.

strand of multicore wire shown in **Figure 4.** Cut off a 6 to 7 mm length of wire and form it into a 'U' shape (**Figure 5**) producing a leg length of around 2.5 mm. **Figure 6** shows the jumper fitted in the processor socket, the wire is fine enough so that it does not impede the processor pins when it is plugged back into the socket.
Before the processor is replaced it is a good idea to remove any pads between the chip and heatsink a place a thin layer of heat sink compound over the contact area. With the improved heat transfer properties the overclocked processor is likely to run cooler that the original configuration. The aluminium foil shown in **Figure 3** is discarded.

Supply Tweaking

The bottlenecks outlined above are a function of the chip design and the materials so there is little that can be done to circumvent them. Researchers and chip designers are however continually working to improve the technology. One avenue of research involves the use of 'faster' materials (e.g. 'strained silicon') to reduce signal delay while another area concentrates on optimising the transistor geometry to reduce switching times. The most obvious method of improving switching speed is to make the structure as small as possible, this reduces the interconnect path length, the switching energy and parasitic capacitances.

All of these techniques are inherent to the basic chip architecture and the process technology, the 'overclocker' again has no chance of making any improvements here. The most usual type of 'tweaking' used in conjunction with overclocking is to slightly raise the supply voltage to the chip (checking that the device does not become too hot). The basis for this technique is that a transistor with a higher control signal will switch more quickly. Overclocked DRAM modules respond well to increased supply voltage operation as do processors.

In cases where excess dissipation in the chip is limiting the overclocking frequency it is possible to reduce the supply voltage slightly and still squeeze an extra few megahertz out of chip. A lower supply voltage reduces the energy consumed by the device, lowering power dissipation and reducing chip temperature. It also helps diminish transistor leakage losses which can form a not insignificant part of the total power consumed by modern processors.

Modern microcontrollers have not yet achieved gigahertz clock capability so the phenomenon plays less of a role in overclocking these devices. An overclocked microcontroller which is unstable may however benefit from an increase in the supply voltage by a few percent or alternatively with the above explanation in mind, a reduction of the supply voltage!

Once the modifications have been completed and the machine reassembled a software tool such as CPU-Z can be used to measure the processor characteristics (see **Figure 7**). The test reports that the CPU type remains the same but the bus and CPU clock frequency have a new value.

To err is human...

Even though the modification suggested here should be relatively easy to perform there is undoubtedly room for error, if you are in the habit of making a sow's ear out of a silk purse then it's probably wise to keep the notebook well and truly buttoned up. Any intrepid reader planning to go ahead with the modification should at least equip themselves with a decent set of cross-headed screwdrivers (hopefully of better quality than ones you sometimes get in Christmas crackers) and some tweezers.

Reports from Internet based forums indicate that the Celeron M 350 to 380 and Pentium M 715 to 735 are good candidates for overclocking. A 735 series can be clocked to at least 2.26 GHz while 745 types can be persuaded to run at 2.4 GHz but not always reliably. Incidentally it is quite rare to find 400 MHz DDR2 RAM (specified as PC3200) fitted to notebooks, it is far more common to find the faster PC4200 memory which is suitable for use with a 533 MHz clock. Overclockers should *ensure that* their RAM can handle the speed increase. All is not lost if the processor in your machine does not have a 5 as its last digit; it has been known for owners of 730 or 740 series notebooks to sell them and buy a lower spec 725 or 735 series replacement which they then proceed to overclock. The result is a faster notebook and with any luck a small profit.

A useful free program for the intrepid pin modder is 'Notebook Hardware Control'. The program allows control of the notebook hardware components including system power management. The voltage supply to most processors is typically 1.3 V or above but it is often the case that they run reliably under full load with a supply of 1.2 V or less. The freeware program Prime95 is the overclockers' program of choice to test the stability of modified machines. The program loads the processor at 100% and the machine is assumed to be 'prime stable' if it runs the test for 24 hours without any errors. This is particularly good at detecting any instability caused by a modification to the processor supply voltage.
Finally it should be noted that tinkering with the insides of a Notebook is a good way of invalidating the guarantee, ideally the machine will not be under warranty and you must be prepared to accept full responsibility for any damage that may be caused by following any of the suggestions contained in this article.

(060293-1)

Web links

Pinmods and advice for Fujitsu-Siemens Notebooks:
www.amilo-forum.com

The 'Dothan' CPU datasheet is available from:
download.intel.com/design/mobile/datashts/30218908.pdf

The 'Notebook Hardware Control' program is available from:
www.pbus-167.com/nhc/nhc.htm

Stability testing can be performed with Prime95:
www.mersenne.org/freesoft.htm

Figure 4.
Fine multicore wire. A short strand is used as a jumper.

Figure 5.
The U shaped wire jumper approximately 2.5 mm long.

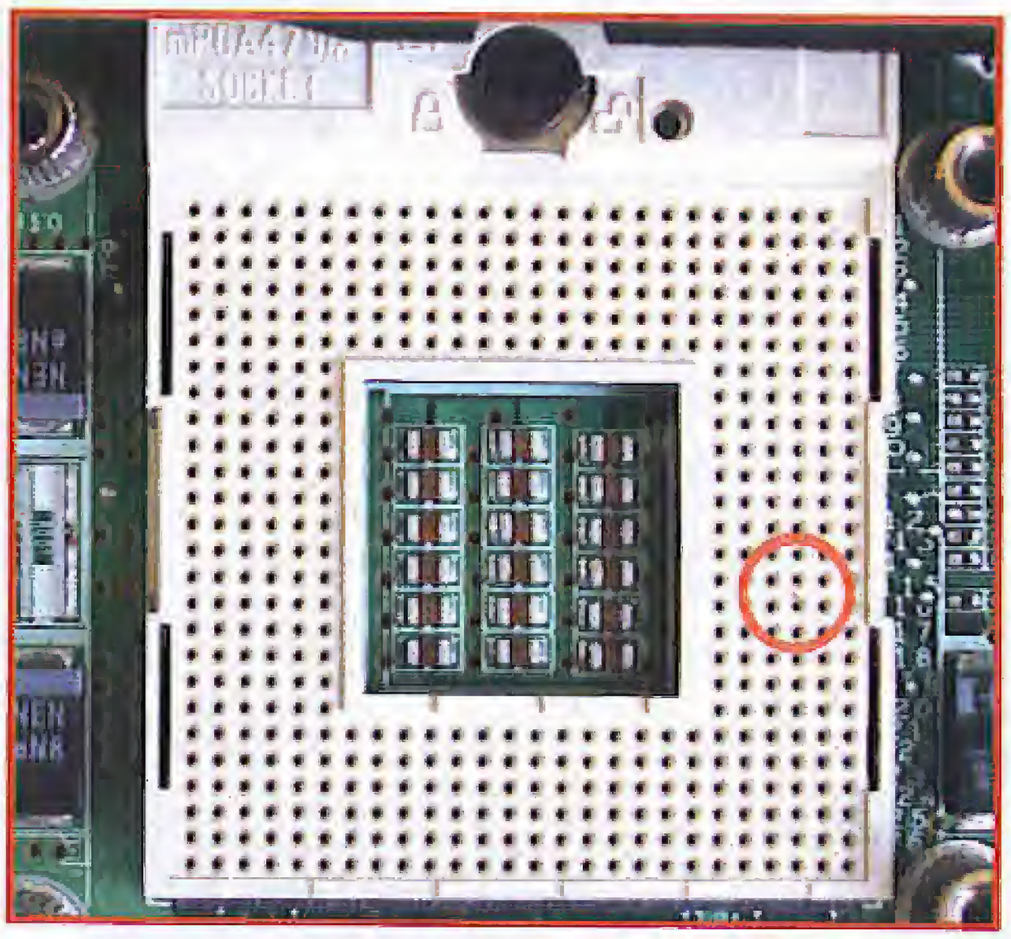

Figure 6.
The wire jumper fitted to the processor socket. You need tweezers and a steady hand for this.

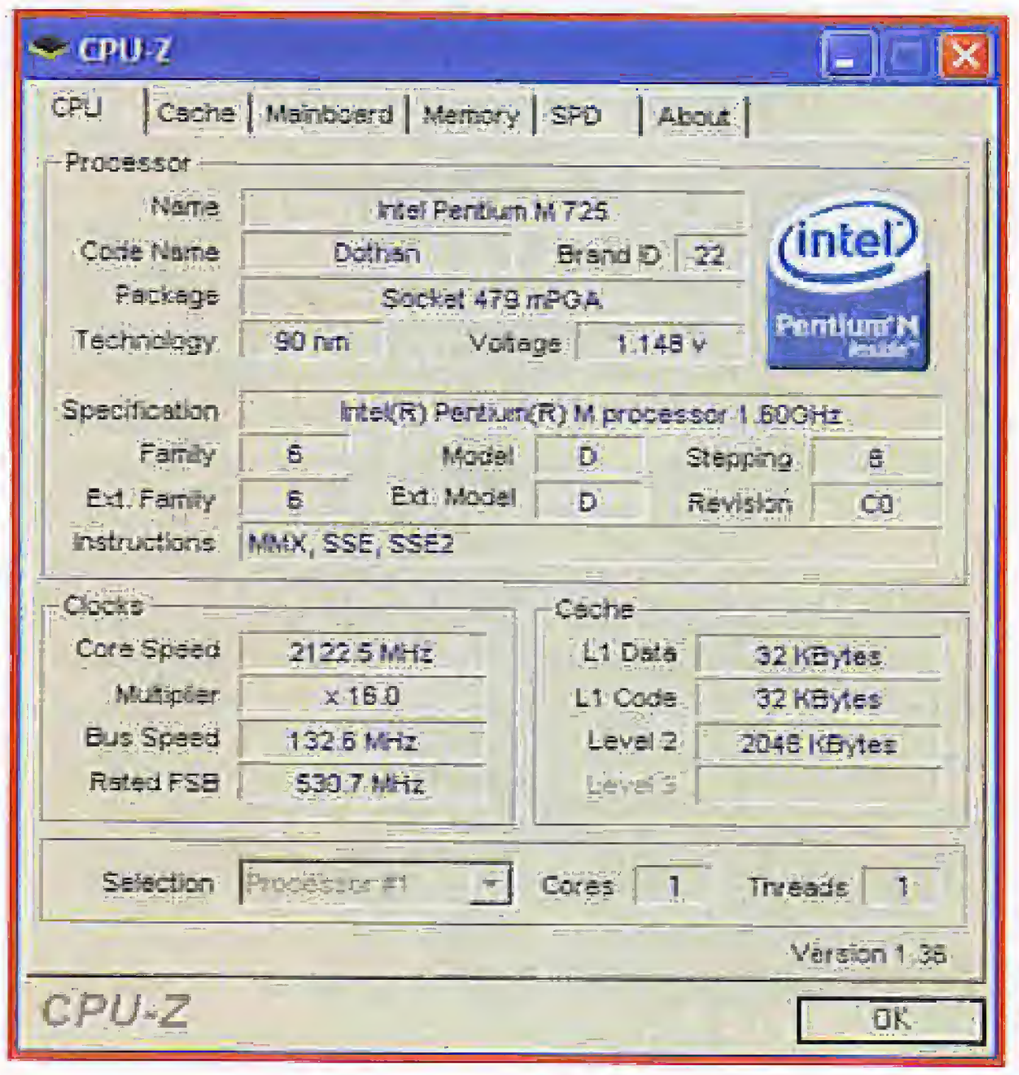

Figure 7.
CPU-Z reports that the processor is now much quicker.

Sputnik Time Machine

Nostalgia and microcontroller technology merged in a single design

Dieter Laues

Sputnik 1, the first artificial satellite, was launched in 1957. It captured the attention of the entire world with the eerie beeps it transmitted, which could be received by radio amateurs everywhere in the world. Fifty years after this historic event, it seems fitting to build a clock in the shape of the Sputnik satellite that combines a nostalgic Nixie tube display with a modern microcontroller.

Technology has changed a lot in recent decades. Launching a satellite that simply transmitted a beep signal was a major achievement in 1957, but now we routinely put satellites into orbit that can transmit hundreds of television channels.

This design uses a combination of modern and old-fashioned technology. The shape of the Sputnik and the Nixie tubes are elements of old-fashioned technology, while the low-loss switching regulators for the supply voltages and the microcontroller-based control logic are examples of modern technology.

Nixie tubes

Nixie tubes were introduced commercially in 1954 to display numbers in electronic equipment. A Nixie tube is a cold-cathode valve, which means it does not have a heated filament. The valve thus remains quite cool during operation.

The valve is also not evacuated, but instead filled with a gas mixture consisting primarily of neon. If a sufficiently high voltage is applied to the electrodes, the gas molecules around the cathode become ionized and emit light ranging in colour from reddish-orange to purplish. The valve contains a separate cathode in the form of a numeral for each digit to be displayed.

'Nixie' is a trademark name given to these valves by the Burroughs Corporation, which incidentally didn't actually develop them but instead purchased the company that developed them, Haydu Brothers Laboratories.

Schematic diagram

The clock is controlled by a small microcontroller – an Atmel 89C2051, which has 2 KB of flash memory. The digit cathodes of the Nixie tubes are driven by type 74141 driver ICs. Although these ICs may appear to be standard TTL devices, they are specially designed to handle the high voltage level of Nixie tubes. Like the Nixie tubes, they are readily available through 'regular' commercial channels. We thus strongly advise readers who want to build this clock to first see whether they can find these parts before they invest in the rest of the hardware. The first digit of the display,

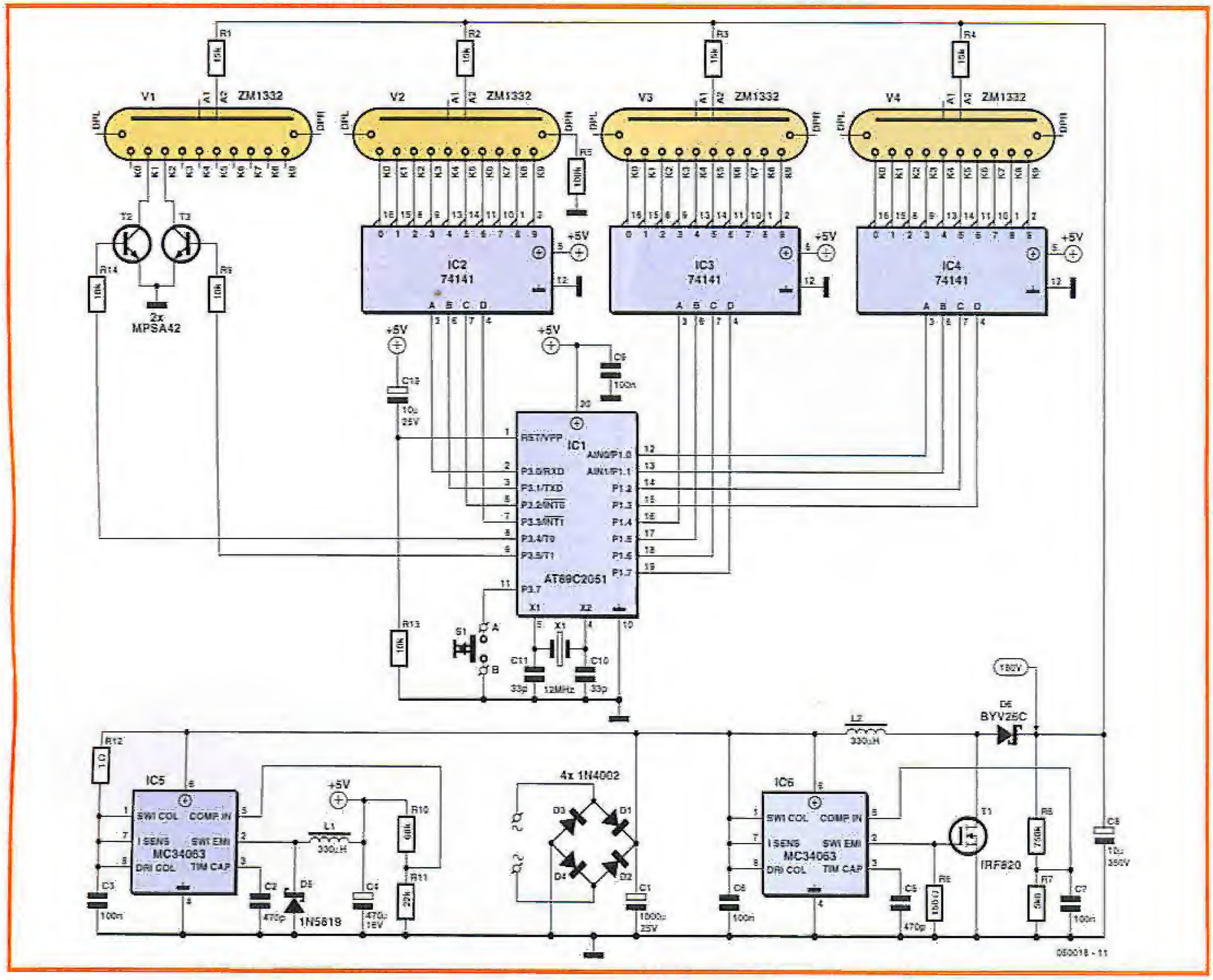

Figure 1. The circuit of the Sputnik clock consists of a microcontroller, four Nixie tubes and their drivers, and two supply voltage regulators.

which shows tens of hours, is driven by two discrete transistors instead of a driver IC – since only the numerals '1' and '2' are necessary.

The power supply section consists of two independent switching regulators, each of which is built around an MC34063 general-purpose PWM regulator IC. IC5 operates as a step-down converter and provides +5 V for the low-voltage portion of the circuit. IC6 operates as a step-up converter and provides the high voltage for the Nixie tubes. FET T1 is included in the circuit because the MC34063 is not rated for operation above 40 V. One of the advantages of not using conventional voltage regulators is that the circuit is not choosy about the raw input voltage, so an AC mains adapter with an output voltage in the range of 14–25 V can be used. In addition, this power supply arrangement generates relatively little heat. This is important because the circuit is fitted in a closed housing and would otherwise become quite warm.

Software

The software is written in assembly language. This yields a very compact program that implements a 24-hour clock, the user interface, display brightness control, and smooth display transitions in just 568 bytes of code.
The clock operates on the usual principle of dividing down the interrupt rate of the timer interrupts. The information to be displayed in hours and minutes is output in BCD format via I/O ports to the Nixie drivers. The tens of hours digit forms an exception here. As only the '1' and '2' have to be driven here, only two output lines are necessary.
There is only one user control, consisting of a pushbutton that can be used to set the time, adjust the brightness, and display the software version number. Refer to the inset for the details of the operator interface.

The brightness of the Nixie tubes is controlled by varying the duty cycle of the drive signals instead of varying the anode current. Every time the minutes display changes, the clock makes a smooth transition from the one number to the next. This is also implemented using the variable duty cycle. The duty cycle of the old number decreases gradually while the duty cy-

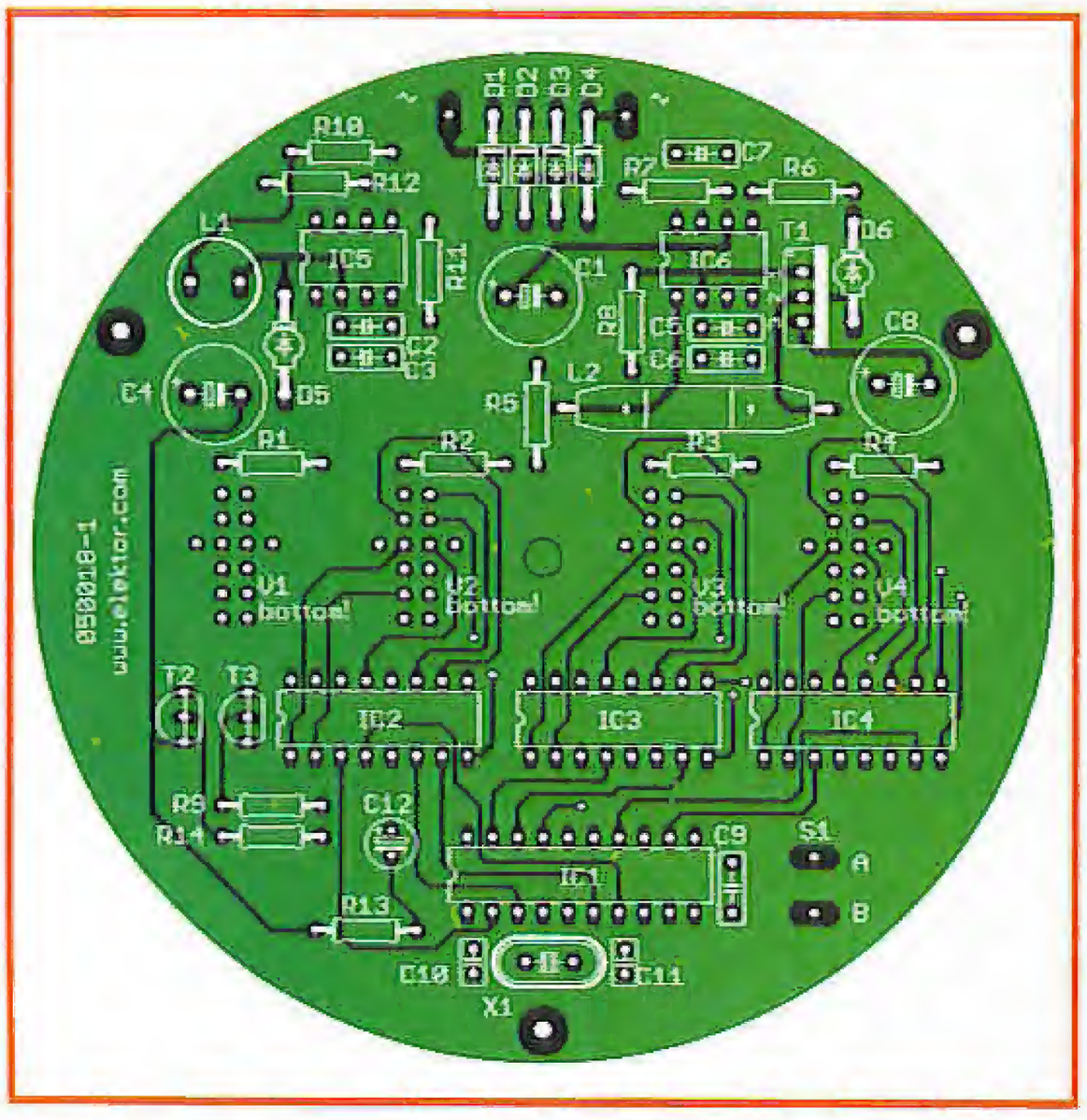

Figure 2. The double-sided PCB has a round outline so it can be fitted in a plastic ball.

cle of the new number increases gradually. The brightness setting of the display is also maintained during this transition.

Construction

Building the circuit should not present any particular difficulties. Only 'standard' components are used (no SMDs). Start by fitting all the parts on the component side of the board.

Use sockets for all of the ICs. Then turn the board over and solder the Nixie tubes on the copper side of the board. It is a good idea to trim the leads of the Nixie tubes stepwise and then insert them in the holes in pairs starting with the longest ones, since it is rather difficult to get all the leads into the holes if they all have the same length. Align each Nixie tube exactly perpendicular to be board before soldering the leads.

Initial checkout

Start by fitting only the voltage regulator ICs (IC5 and IC6) in the sockets, and check the polarity of C8 before plugging in the AC mains adapter. Then use a meter to check the supply voltages. The voltage for the low-voltage portion must be +5 V, and the voltage on C8 (for the Nixie tubes) must be approximately +180 V. If everything's OK, you can unplug the AC adapter. Be sure to give C8 enough time to discharge before proceeding further. **(Caution: high voltage!)**
After this you can fit the remaining ICs. After being powered up or after a voltage dropout, the display shows a blinking value of '0.00'. The default brightness value is set to '7'. The time is shown in the European 24-hour format. A zero in the first digit is not displayed, so this digit remains dark every morning until 10 o'clock

Mechanical construction

We know that electronics hobbyists often find it difficult to do a nice job of fitting a circuit in a rectangular enclosure, so how can we expect them to manage with a spherical enclosure? The answer is that it takes a certain amount of skill and patience.

Transparent plastic balls are available in hobby shops. For this project, we used one with a diameter of 10 cm, consisting of two hemispheres. In one of these hemispheres, we drilled holes for the three legs (along the upper rim), the control pushbutton (lower middle), and power supply connector (diagonally to the rear). You must drill carefully. The best results can be obtained using a drill press, but if necessary you can manage with a battery-powered drill. Drill the holes from the inside with the material supported on a firm surface, since otherwise the plastic can crack. The legs are made from aluminium rods, which you can buy in a DIY shop by the metre. Cut three lengths of 15 cm and bend one end of each rod in a vice (depth of bend approximately 2 cm) to give them the right shape. The angle of the bend should be approximately 100 degrees. The sharper the bend, the closer the legs will be together in the assembled clock. The legs must all have the same shape (as close as you can manage), since otherwise the finished clock will stand crooked. After bending the ends of the legs to the right angle, cut a 4-mm thread on the short end of each leg.

Cut a round cover plate for the circuit board from a sheet of plastic. Make a hole for the fastening screw in the middle and four larger holes for the display.
Before assembling the clock, paint the bottom hemisphere and (if you wish) the cover plate. Spray-paint canisters available in DIY model shops are quite suitable for this. After painting the ball black, you can use silver paint to give it a 'starry sky' effect by pressing the spray button very lightly. You can also use an airbrush to create attractive effects. Here you can give your creativity free rein, but make sure the paint

Operating instructions

Setting the time

1) Press and hold the button until the hours display starts blinking. After this, the time will be advanced by 1 hour each time you press the button briefly.
2) Press and hold the button until the minutes display starts blinking. After this, the time will be advanced by 1 minute each time you press the button briefly.
3) Press and hold the button until the display returns to non-blinking mode. The seconds are set to 0 at this time.

Setting the brightness

Press the button briefly. The current brightness setting will be displayed. The brightness setting is increased by 1 each time the button is pressed briefly, from 01 (minimum) to 09 (maximum). The clock returns to the time display mode if the button is not pressed for several seconds.

Displaying the version number

With the AC mains adapter unplugged, press and hold the button while plugging in the adapter. The version number of the software will then be displayed (such as '1.07'). After releasing the button, you can set the time as described above.

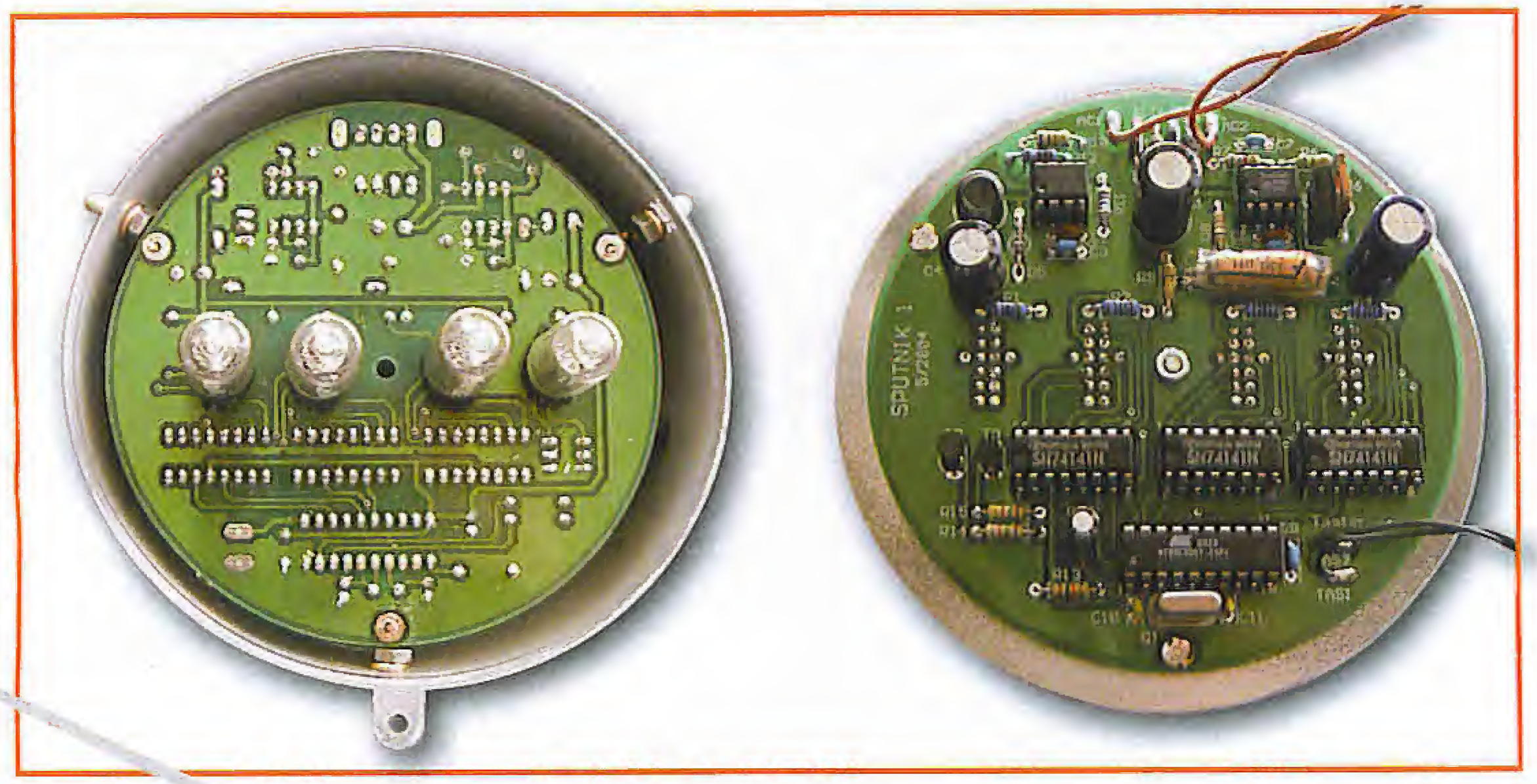

Figure 3. Top and bottom sides of the assembled circuit board.

the circuit board with flexible wire leads. Finally, align the circuit board so it is level and solder it in place on the three copper wires, and then fit the cover board.

After checking to ensure that everything works properly, you can fit the top half of the ball.

(050018-I)

Web links

Mike's Gallery – a collection of several types of Nixie clocks
www.electricstuff.co.uk/nixiegallery.html

A recording of the original Sputnik beeps
www.muenster.de/~dambergj/Sputnik.htm

you use is compatible with the plastic of the ball – otherwise you may end up with an unattractive, spotty surface.

You can also use a transparent cover coat to protect the paint against scratching. Another option is to paint the inner surface of the ball. Although the colours may not be as bright with this option, the paint coating is absolutely scratch-resistant.

After the painting is finished, you can assemble the clock Thread an M4 nut onto each of the three legs and then fit the ends of the legs through the holes in the ball. Secure each of them with a second M4 nut on the inside. Before tightening the inner nut, fit a length of copper wire with a loop formed on one end. Later on, you can solder the circuit board to these three wires to secure it in the enclosure.

Next, fit the power supply socket and the pushbutton and connect them to

COMPONENTS LIST

Resistors
R1,R2,R3,R4 = 15kΩ
R5 = 100kΩ
R6 = 750kΩ
R7 = 5kΩ6
R8 = 150Ω
R10 = 68kΩ
R11 = 22kΩ
R12 = 1Ω
R13,R14,R15 = 10kΩ

Capacitors
C1 = 1000µF 25V
C2 = 470pF
C3 = 100nF
C4 = 470µF 16V
C5 = 470pF
C6 = 100nF
C7 = 100nF
C8 = 4.7µF 400V
C9 = 100nF
C10,C11 = 33pF
C12 = 10µF

Inductors
L1,L2 = 330µH

Semiconductors
D1,D2,D3,D4 = 1N4003
D5 = 1N5819
D6 = BYV26C
T1 = IRF820
T2,T3 = MPSA42
IC1 = 89C2051, programmed, order code **050018-41**
IC2,IC3,IC4 = 74141
IC5,IC6 = MC34063

Miscellaneous
Q1 = 12.000MHz quartz crystal
AN1,AN2,AN3,AN4 = ZM1332
IC sockets: 2 off DIL 8-pin; 3 off DIL 16-pin; 1 off DIL 20-pin
PCB, ref. 050018-1 from ThePCBShop
Source and hex code files, free download # 050018-11.zip from project page at www.elektor-electronics.co.uk
Drilling templates, free download # 050018-W.zip, from project page at www.elektor-electronics.co.uk

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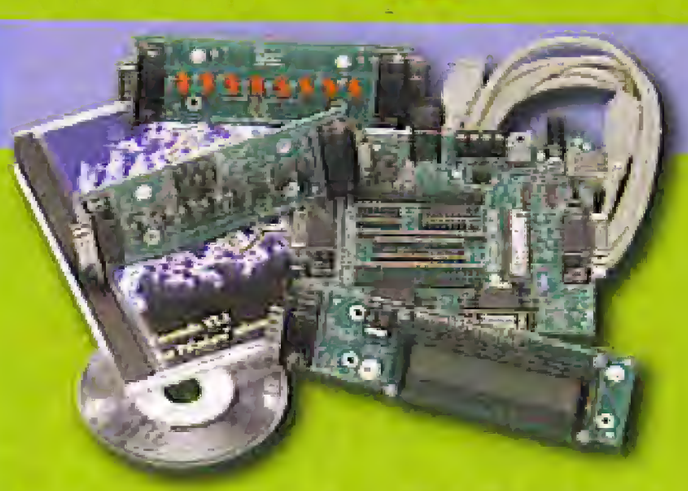

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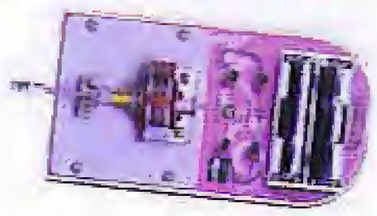

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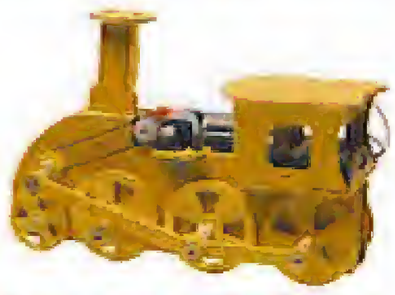

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Berlin Clock Remake

Using the SPI bus

Prof. Dr. Bernd vom Berg and Dipl.-Ing. Peter Groppe
(Georg Agricola University of Applied Sciences, Germany)

In the world of unusual timepieces one example stands out: the Berlin clock, which has been showing the time since 1975 using an ever-changing pattern of lights. Our version imitates the original using an LED display controlled over an SPI bus.

The original Berlin clock [1] was designed by local engineer and inventor Dieter Binninger as a mathematics teaching aid and was installed in 1975 in an upmarket shopping area in the city. The construction, seven metres high, shows the time using a number of lamps, mostly arranged in groups of four. At the time new mathematics teaching methods were being introduced, giving rise to heated discussions; perhaps not coincidentally the clock rapidly became famous.

By the end of the 1970s a desktop version had become available, using a Texas Instruments TMS1000 4-bit processor (the first mass-produced microcontroller); models are still for sale with almost identical external appearance [2]. A quick trawl of the Internet for 'Berlin clock' turns up not only photographs and information, but also a number of PC-based programs to emulate the clock [3].

We published a variation on the Berlin clock in the Summer Circuits issue of 1998 [4], using a DCF-77 module and a PIC16C54. In a future issue we will also describe another variation: a binary clock.

That example, designed by Professor Beutelsbacher for the 'Mathematikum', an interactive mathematics exhibition centre in Giessen, Germa-

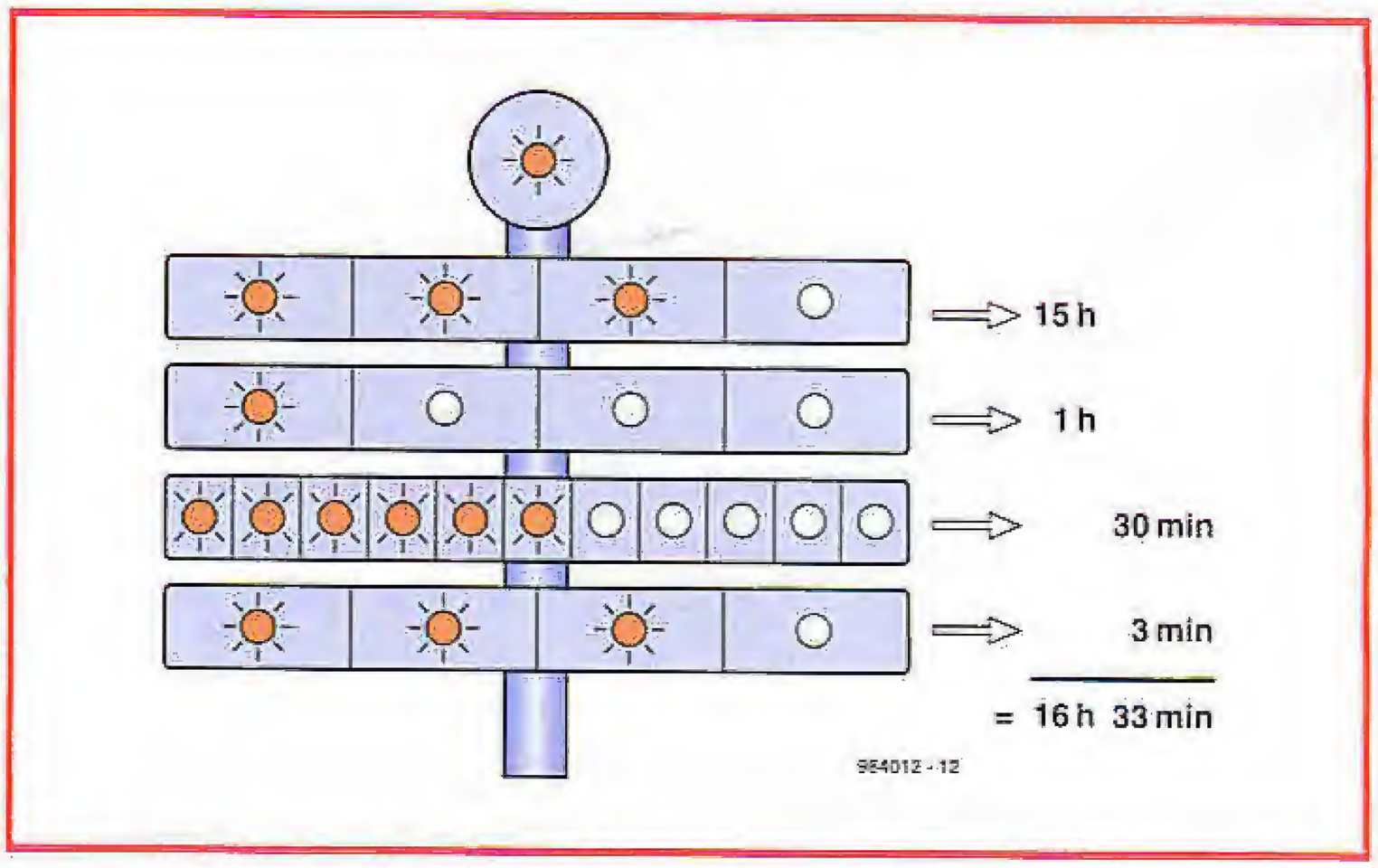

Figure 1. The top lamp of the Berlin clock flashes at 1 Hz, and the remaining lamps show the time.

Figure 2. The display of our version uses LEDs instead of lamps.

ny, was inspired by the Berlin clock. Finding the base-five system employed a little unnatural, however, he opted for a binary display.

Sign of the times

However, it is not so difficult to interpret the display of the Berlin clock, as **Figure 1** shows. The time is shown using a series of rows of lights where each lamp is assigned a 'weight'. From the top row to the bottom row each lamp represents one second, 5 hours, 1 hour, 5 minutes and 1 minute. In the version described in this article we use 24 LEDs rather than lamps, but still arranged according to the original layout (**Figure 2**). At the top centre is a green LED which flashes at 1 Hz. The second row consists of red LEDs and the third row yellow LEDs. So that it is easier to read the quarter hours from the LEDs in the third row, every third one is red rather than yellow.

Components

There are two main parts to the design: the example clock software, written in C for an 8051 microcontroller, and the clock display. **Figure 3** shows the block diagram of the system.

Almost any microcontroller system could be used, as long as it has three or four spare digital I/O port pins and either a real-time clock circuit or a radio timecode receiver. Alternatively, a real-time clock could be implemented purely in software.

The authors used a board that they developed themselves, featuring an Atmel AT89C51CC03 microcontroller from the popular 8051 family. The board also sports a 72421 real-time clock IC, although it would also be possible to receive and process DCF-77 signals.

The software reads the time from the real-time clock and generates the necessary control signals on the SPI bus, which connects to the clock display board.

The display board carries an SPI-compatible LED driver IC type MAX7219. Driving this device over a standard SPI bus gives the advantage that almost any microcontroller system can be used as the master, whether based on 8051, R8C, ATMega or PIC. The only point to bear in mind is that it must be possible to create the LOAD, CLK and DIN control signals of the SPI bus using the hardware, or that the selected microcontroller must already provide an on-chip SPI bus interface. In the latter case the communications software required is extremely straightforward.

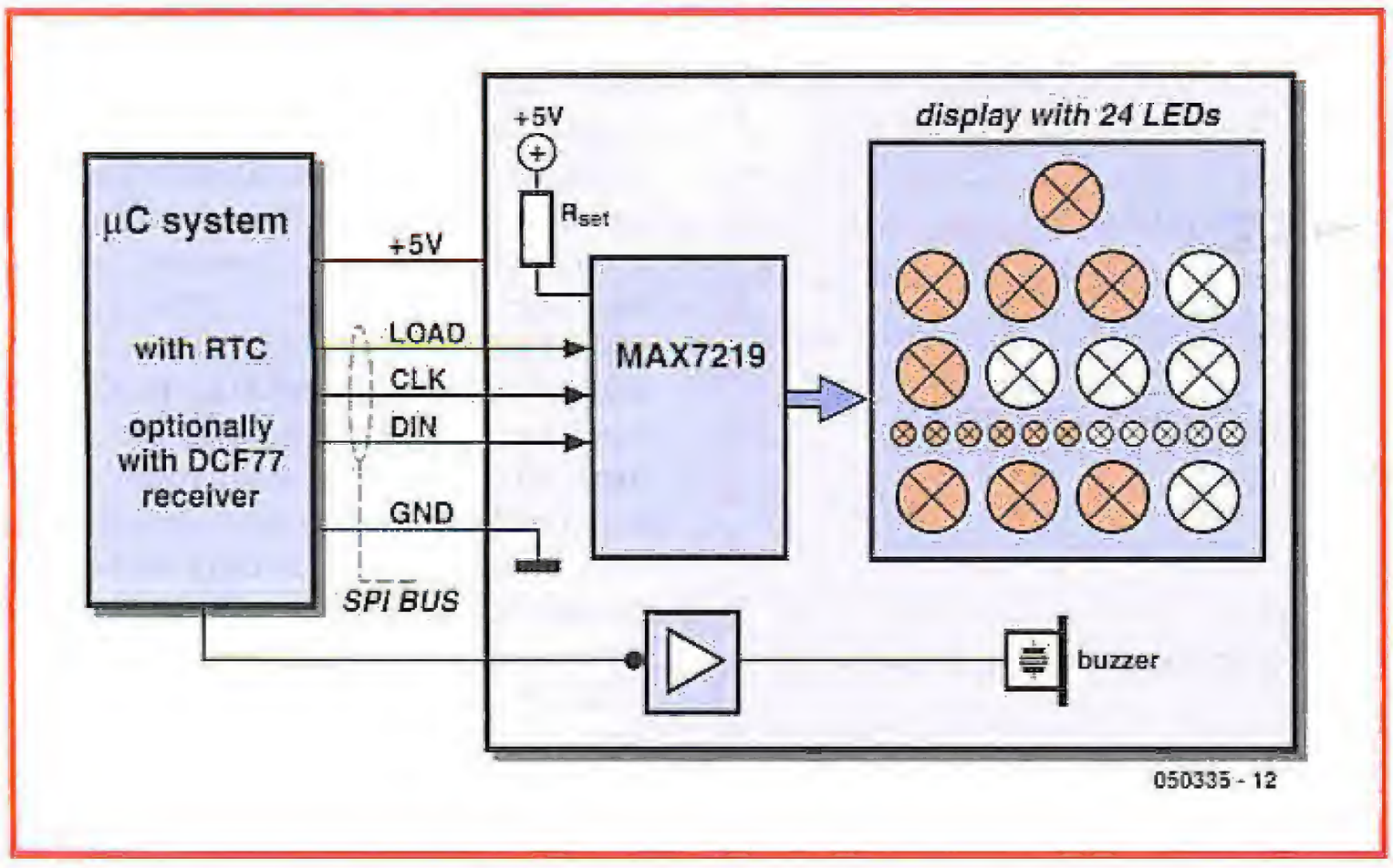

Figure 3. Block diagram of the clock. The microcontroller system drives the display using an SPI bus.

MAX7219

This device is capable of driving up to 64 individual 20 mA LEDs using a multiplexing scheme. The most important

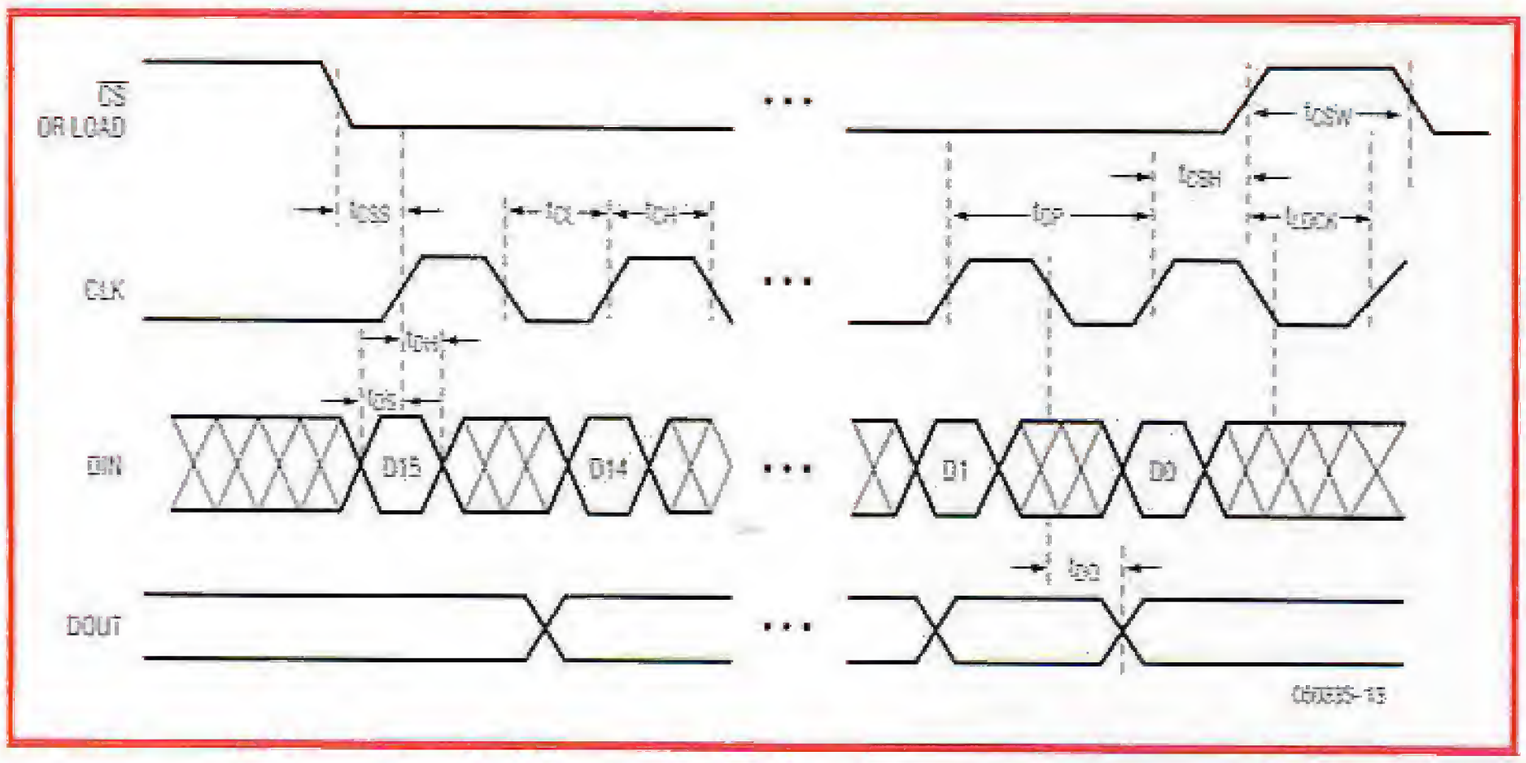

Figure 4. Timing diagram of communications with the MAX7219 over the SPI bus.

features of the MAX7219 are listed in **Table 1**, and a more thorough description of the device can be found in its datasheet [5]. We will give a brief overview here.
The basic functions of the driver IC are controlled using six registers. The LEDs are arranged in eight groups of eight LEDs each; these can either be considered as eight seven-segment displays (plus decimal points) or as 64 individual LEDs to be driven in any desired pattern. This allows for flexibility in the arrangement of the display, and the use of different-sized LEDs (although they must all be 20 mA types).

SPI bus

As we can see in Figure 3 communication between microcontroller and MAX7219 using the SPI bus requires just two power supply connections and three digital I/O port pins, namely:

- LOAD: enable/transfer signal for communicated data;
- DIN: serial data transfer;
- CLK: clock signal for data transfer.

It is very easy to control the MAX7219 from the microcontroller in software using these three signals. The basic SPI signal timing diagram is shown in **Figure 4**. Transferring data to the device proceeds in four phases:

1. Quiescent.
The LOAD and CLK control signals start in their quiescent states, LOAD being high and CLK low.

2. Initiation of data transfer.
Before the data (in the form of two-byte, or 16-bit, packets) are sent to the MAX7219 the LOAD signal is taken low.

3. Data transfer.
The microcontroller presents the first bit on the DIN data signal. The bit is written to the MAX7219 by setting the CLK signal high: on the rising edge of CLK the data bit is clocked into a shift register. The CLK signal is then taken low again. This procedure is repeated a further 15 times so that all the relevant data bits are clocked serially into the shift register. The maximum clock frequency is 10 MHz.

4. Termination of data transfer.
Immediately after the 16 data bits have been transferred the LOAD signal must be set high again. The rising edge of the LOAD signal tells the MAX7219 that the data transfer is complete and that the data bits in the receive shift register can be processed. This last step is very important: if LOAD is not returned high the data bits will remain in the shift register and not be processed.

In our application the SPI bus is driven using three spare ordinary port bits of the microcontroller using the so-called 'bit-banging' technique:

LOAD is connected to port pin P3.5,
DIN to P3.3 and
CLK to P3.4.

These port pins are available on practically every 8051-family device and so the SPI driver software can be used on most of these microcontrollers without modification. If the pins happen to be used for some other function, it is a simple matter to change the code to use other pins.

For correct operation of the MAX7219 each message must consist of two bytes (16 bits) sent consecutively on the SPI bus. The first byte contains the address of an internal control or data register in the device and the second byte contains the data to be written to it.

Full source listings and object code for the C program written for the AT89C51CC03 are available for free download from the *Elektor Electronics* website.

Table 1. Features of the MAX7219

- Drives common-cathode LED displays.
- Individual digits can be changed without the need to rewrite the data for the entire display.
- LEDs individually controlled, or via BCD-to-seven-segment decoder, selectable for each digit position.
- Programmable display size (number of active digits adjustable from one to eight).
- Display test mode, lighting all segments simultaneously.
- Digital and analogue brightness control.
- Serial SPI bus interface (up to 10 MHz).
- Low power shutdown mode (current consumption only 150 µA).
- Suitable for use in applications with:
  - multiple groups of seven- or eight-segment displays using cascade feature;
  - bargraph displays;
  - displays of any shape and size made up of individual LEDs;
  - dot matrix LED displays.

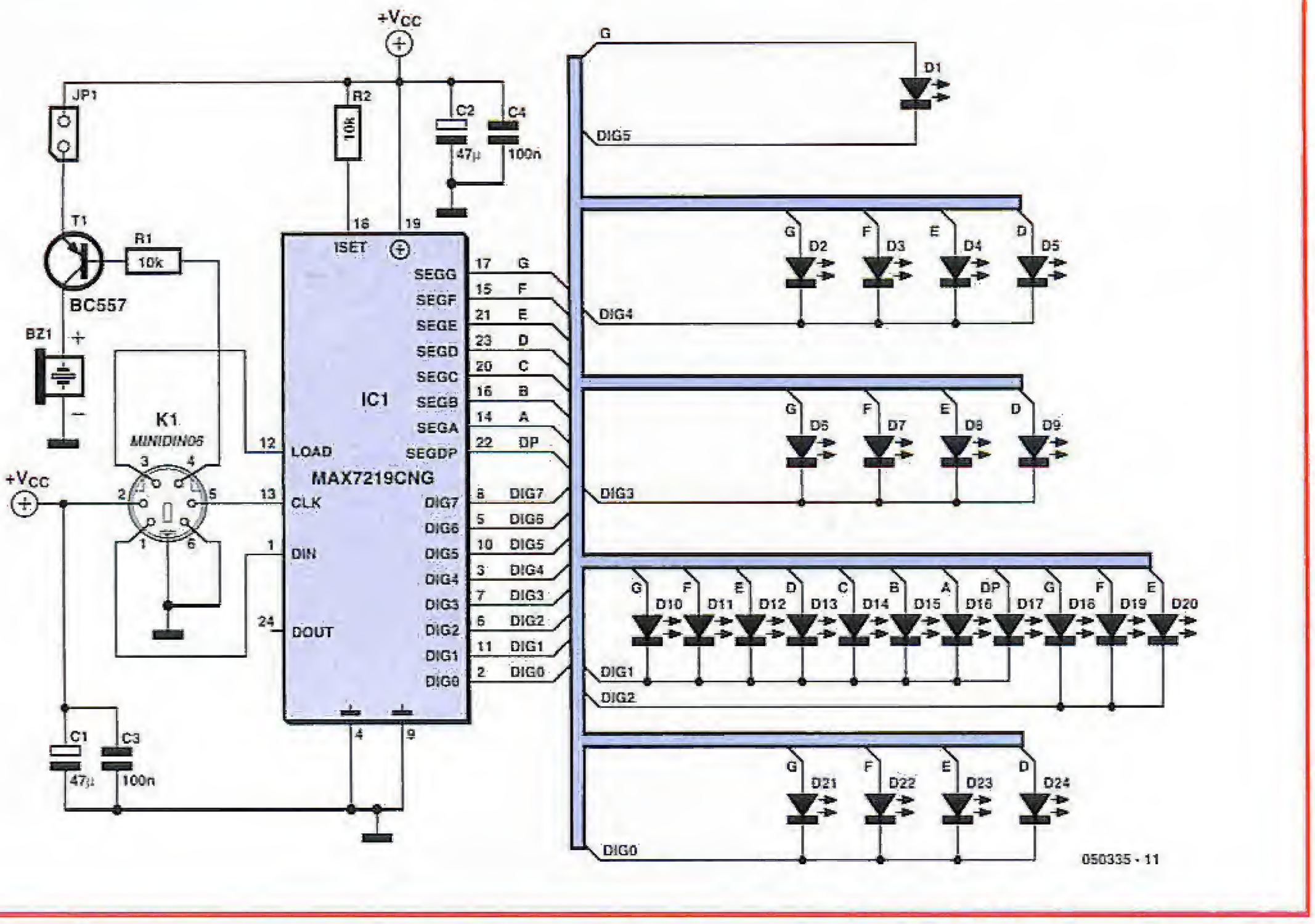

Figure 5. Circuit diagram of the display, using a MAX7219 LED driver and 24 LEDs.

Circuit diagram and printed circuit board

Thanks to the use of the SPI bus and the MAX7219 the circuit diagram (**Figure 5**) and the display printed circuit board could hardly be more simple. Besides the MAX7219 and the 24 LEDs there is also a DC piezo buzzer on the board, which allows an alarm function to be added to the clock.

A simple way to connect the display to the microcontroller master system and power supply is to use a 6-pin mini-DIN connector: this conveniently allows the use of ready-made PS/2 mouse extension cables.

The printed circuit board layouts are too large to reproduce in this article hence are available for **free download** from the *Elektor Electronics* website, www.elektor-electronics.co.uk. Note that the display board is populated on both sides, the LEDs being soldered to one side and the other components to the reverse. This has the advantage that the display can be fitted behind an attractive front panel, making the device an eye-catching and functional addition to any living room, office or desk. All you need to do now is prepare yourself to explain to every visitor how to work out what time it is!

Finally, the author can supply unpopulated circuit boards and aluminium front panels (www.palmtec.de).

(050335)

[1] Information on the original Berlin clock:
http://www.surveyor.in-berlin.de/berlin/uhr/indexe.html

http://www.europa-center-berlin.de/index.php?target=sights&page=7&lang=en

[2] Berlin clocks for sale:
http://www.berlin-uhr.com/ (in German)

[3] A Berlin clock for your PC:
http://www.tucows.com/preview/167639

http://widgets.opera.com/widget/4256

http://www.widgetgallery.com/view.php?widget=35808 (also available for Mac)

[4] Martin Raschke:
Berlin Clock, Elektor Electronics, July/August 1998, p. 87

[5] MAX7219 datasheet:
http://www.maxim-ic.com/quick_view2.cfm/qv_pk/1339

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Text at the Speed o

A secondary school project was the starting point for this ingenious creation, which uses just eight blue LEDs to produce a scrolling text display with 360-degree all-round visibility. A more economical way of building a giant display device would be hard to imagine...

Steffen Sorge

The idea for constructing this display arose at a brainstorming session on our project for the school-leaving examination, what we call an 'Abi-Denkmal' (literally 'exam memorial' in Germany. This advanced level final exam involves an assignment to create something entirely original, a task in fact that at the author's school was traditionally undertaken by the electronics students. The original stimulus arose from bedside alarm clocks that function along similar lines. However, these inexpensive products from the Far East indicate only the time, not any text.

The first prototype was created in just one day using the following parts: eight LEDs from the junk box, a switch for synchronising the start of the message display, an AT90S2313, a PP3 (6F22/R222) 9-volt battery and a few other scrap components were mounted on a small wooden batten. The whole affair was then attached to the drive shaft of a small DC motor and set in motion. After a little programming effort were we rewarded with a display reading out the word 'Hallo'.
However, this initial prototype (just like in 'Modding & Tweaking' projects — *Ed.*) had a number of shortcomings:
The LEDs were not bright enough
The life expectancy of the switch was alarmingly short (little wonder: it operated with each revolution of the motor)

Having a rotating battery was not the cleverest idea...

Problems exist to be solved. The first task was to source some ultra-bright blue LEDS with an intensity of 3500 mCd. Next problem solved was the switch; we obtained a Hall effect switch from an old printer. The battery was replaced by a proper mains power supply and a slip ring. And finally the AT90S2313 made way for an ATmega8.

A controller for eight LEDs

As the circuit diagram (**Figure 1**) indicates, the functional circuitry comprises just a microcontroller (IC1), which drives the eight LEDs and is linked to the Hall sensor (IC3). As regards external components, the controller requires only a 16 MHz crystal (X1) with

f Light

rotating message display with LEDs and an AVR micro

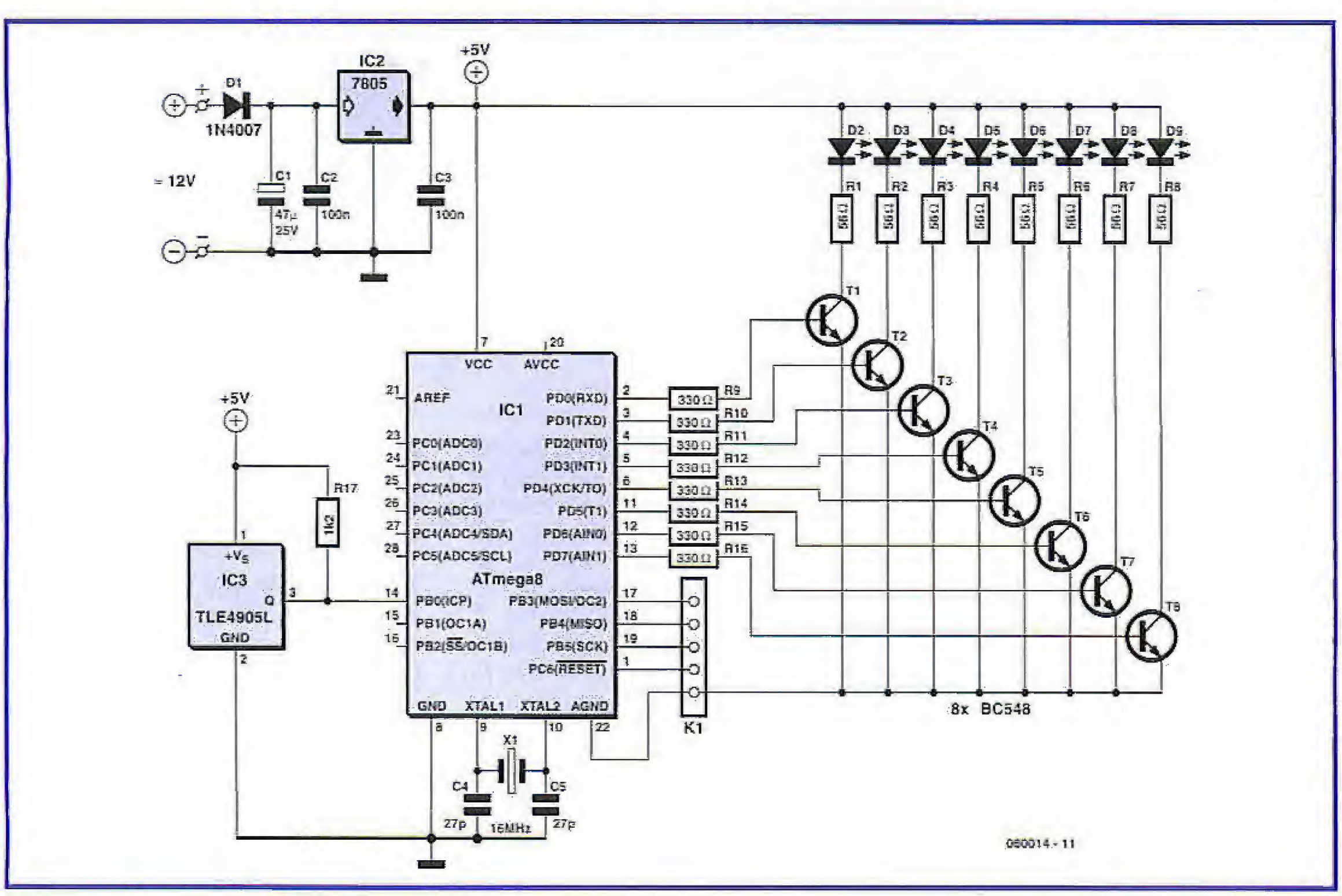


Figure 1. The circuit comprises fundamentally just an AVR controller linked to a Hall sensor (IC3) that switches the eight LEDs.

two resonating capacitors (C4 and C5). Voltage regulator is the trustworthy old 7805 (IC2).

As the microcontroller cannot source enough current for pulsing the hefty LEDs, a follower stage comprising transistors T1 to T8 is provided. The eight rotating LEDs 'write' an image built up from eight lines of light (not from left to right of course but in continuous 360-degree rotation) and for this reason the microcontroller needs to be synchronised with what in TV or computer displays we would call a frame pulse, a signal indicating the start of a new image. This task is handled by the Hall switch (IC3), which alters its output level when it detects a magnetic field (in the vicinity of a magnet in other words). Its normal state produces a 'high' output that goes 'low' on approaching a magnet. This change of level sets in motion the process of building up the image, which the software in the microcontroller looks after.

Software

The ATmega8 is an AVR controller by Atmel, belonging to the family of RISC controllers (with reduced control set). The program for the rolling text is not written in Assembler, however, but in the well-known BASCOM AVR-BASIC language.
This software, along with extremely very detailed annotations, can be downloaded freely from the Elektor Electronics website (data file 060014-11.zip).
The program produces small image elements representing text fragments relating to character strings stored in the controller. These text fragments are

What does AVR stand for?

We wondered too. Apparently Atmel says AVR is just a name and stands for nothing in particular. Another opinion states it's a play on the designers' names, an acronym for Alf (Egil Bogen) and Vegard (Wollan)'s RISC processor. The allegation that it stands for Advanced Virtual RISC sounds unlikely but you can take your choice!

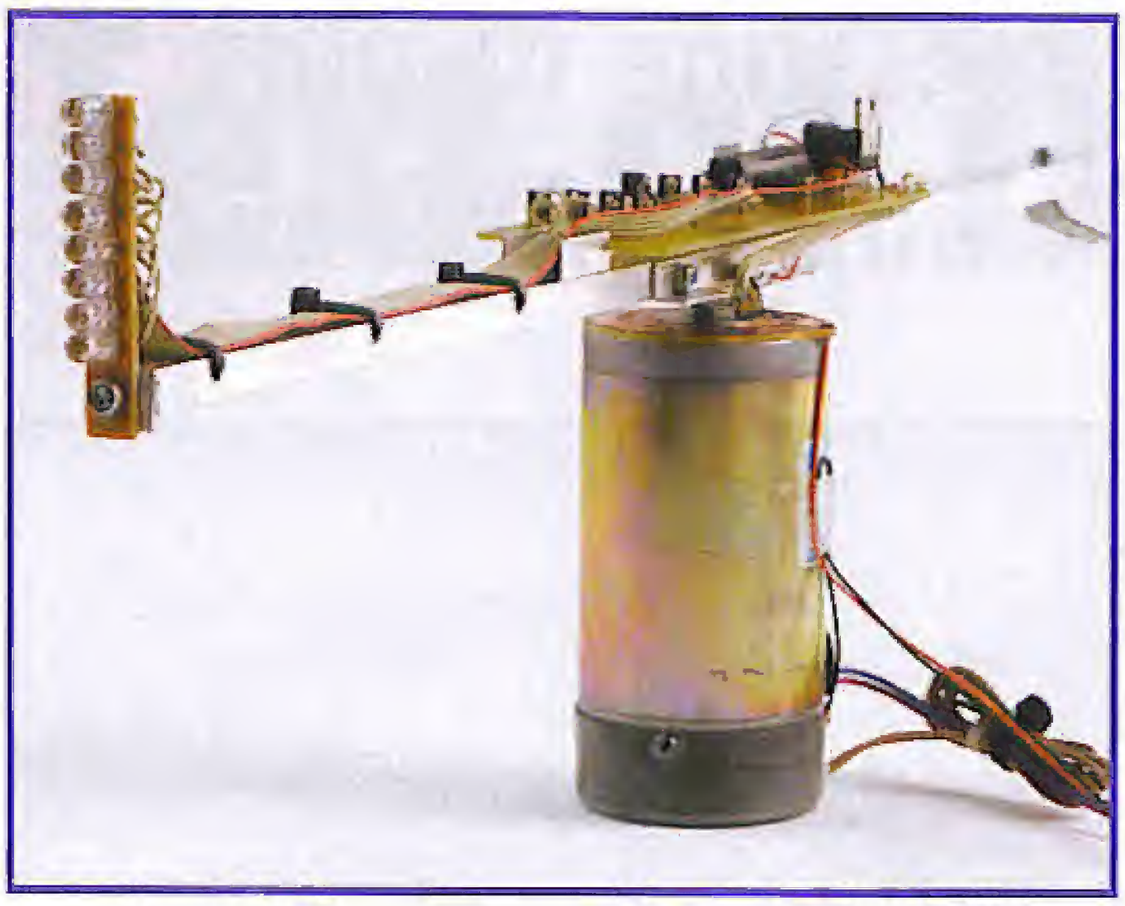


Figure 2. View of the rotating arm with the controller circuit board.

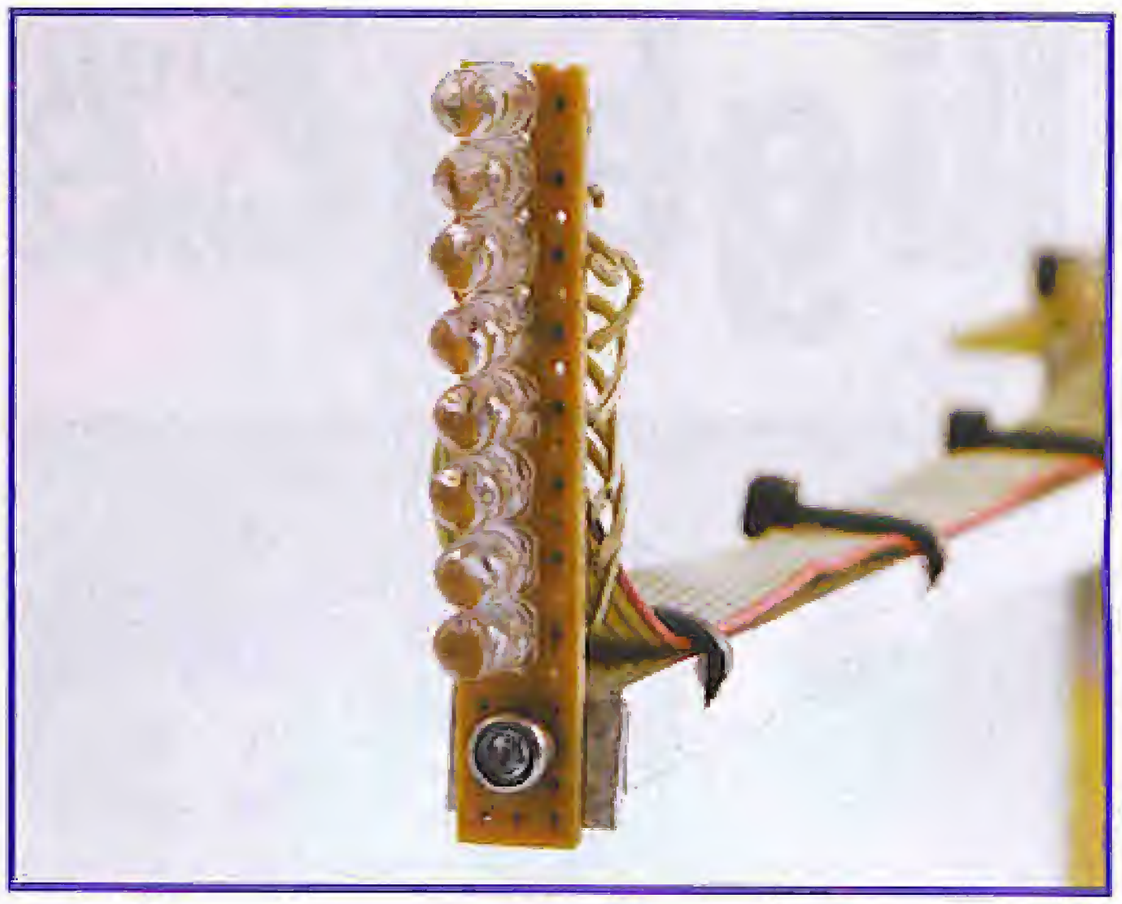


Figure 3. Configuration of the eight LEDs at the end of the rotor.

then re-written as columns and fed out to the LEDs in a defined time frame. The rotation of the motor creates the impression of text written around the periphery of a cylinder.

The controller can accept a maximum of 255 characters for the scrolling text. These characters are stored in the INSTRING array, which contains three elements (three segments of text) that are read out and displayed sequentially.

Readout of these characters is synchronised by the Hall switch already mentioned, which also provides the information whether the motor is in operation (when the motor is static the LEDs all remain unlit). The length of the rolling text in the 'display' depends on the radius of the circle created by the rotating LEDs, hence on the length of the rotor arm. The set-up illustrated in the photos operates with a text length of 30 characters. The program operates as an endless loop that is synchronised by the Hall switch and delivers 30 characters continuously.

The software produces the following characters: capital letters from A to Z (including the accented letters Ä, Ö and Ü), a null or space symbol, question mark, exclamation mark, full stop, comma and hyphen.

A subroutine is programmed for each character, making it straightforward to substitute or alter these symbols. A subroutine consists simply of multiple write commands to Port D, which controls the LEDs. Each write command is followed by a brief pause created by a Wait loop.

Each Write command creates one column of the relevant character, which is composed of several of these columns each having eight pixels vertically. This makes it easy to design a character on squared paper and transpose the columns from left to right into Bytes. If you visualise the Wait loop (subroutine 'Wa') in the source code, it is easy to work out how a character will actually. For example:

```
Sub A
Portd = &B11000000
Portd = &B00110000
Portd = &B00101110
Portd = &B00100001
Portd = &B00101110
Portd = &B00110000
Portd = &B11000000
Portd = &B00000000
Wa
Wa
End Sub
```

The last write command always has a zero value in order to extinguish the LEDs. The wait duration of the subroutine 'Wa' must be configured according to the rotational speed of the motor (just test out various values to determine the best one for you).

Playout begins with the first 30 characters of the first text segment held in INSTRING. After four revolutions of the motor (monitored by the variable 'Laufer1') the text is incremented and displaced by one character (the start position of the text is monitored in 'Laufer'). Once the end of the first text segment is reached, the next segment is selected (variable 'Strz'). At the end of the third text segment the display reverts to the first segment of text and begins again.

If you significantly vary parameters such as rotational speed and diameter of the rotating LEDs, then a few alterations need to be made to the program: Using a different radius (rotor arm length) the number of characters visible in the 'display' (diverging from 30) must be adjusted (at two locations in the program).

Alteration to the number of revolutions per minute requires adjustment of the pixel length (subroutine 'Wa').

The text readout speed (the rate at which the text scrolls) can be varied.

The number of text segments can be increased (this requires a controller with greater memory storage, however).

Circuit construction

The circuitry is relatively easy to construct by following the circuit diagram. As the DIL version of the ATmega8 is used (ATmega8-16PU), there are no surface-mounted devices or other problematic issues to contend with. Resistors R9 to R16 must be selected according to the nominal current of the LEDs used. They can be calculated simply as series resistors for 5 V. The sample set-up used a value of 56 Ω.

To assist construction you can download the author's circuit board layout and component plan together with the component list from the *Elektor Elec-*

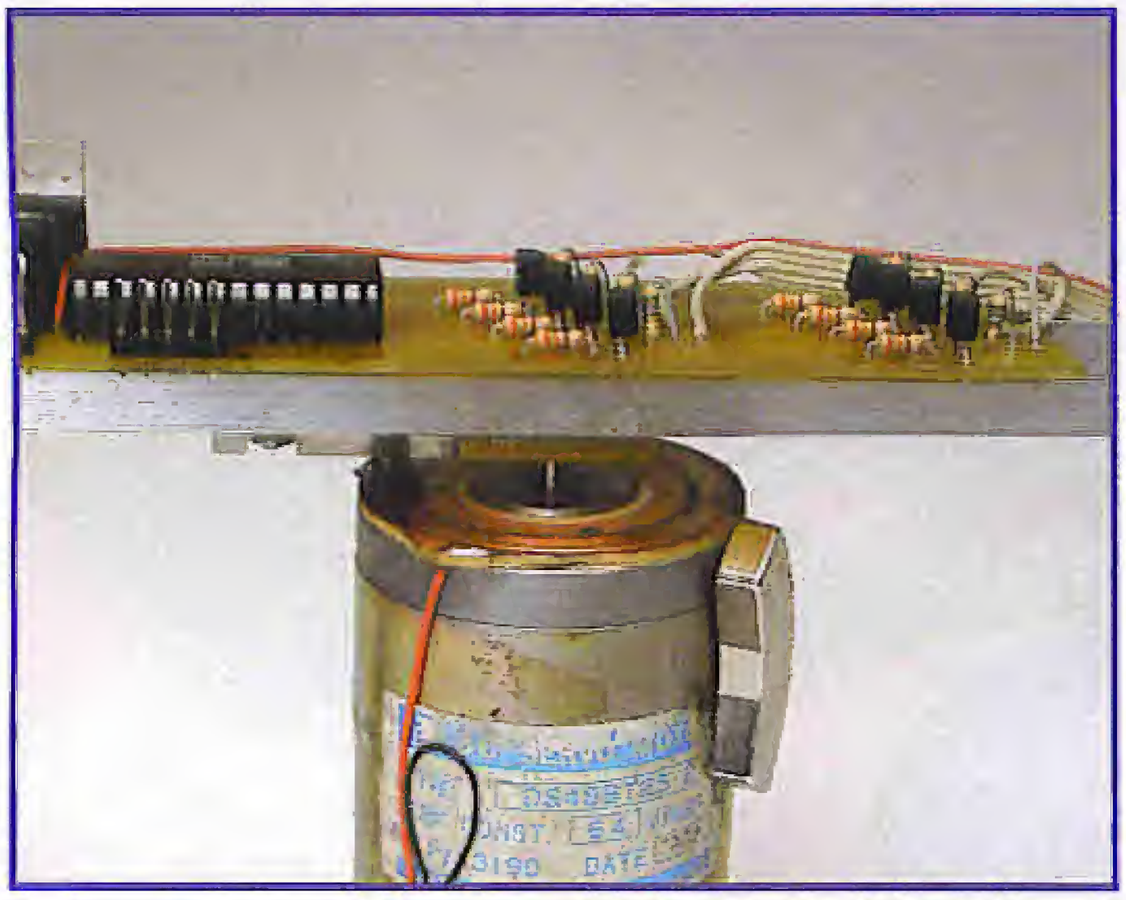


Figure 4. A slip ring provides the power supply to the rotational circuitry.

tronics website (January 2007 items). You do, however, need to note that the designations used on the component plan may either vary from those shown in the circuit diagram (Figure 1) or else may not be shown at all. However, the circuit board does correspond with the diagram electrically and can always be cross-checked in case of doubt.

A rectangular format was selected for the circuit board, matching the dimensions of the rotor arm, with a separate smaller board provided at the end of the arm for the LEDs mounted one above the other (see photos). To make the 5-mm LEDs align with the hole spacing of normal 2.54 mm-spaced perf-board, the LED bodies need to be flattened a little with a file on two opposite sides (don't overdo this). The LED board is connected to the other board using a length of 9-conductor flat ribbon cable. The anodes of the LEDs are connected with one another and to +5 V, whilst the cathodes are wired to the series resistors provided (R9 to R16). D2 (linked to R1) is the uppermost LED on the board and D9 (linked to R8) is the bottom LED. If the LED array is wired the wrong way round (D9 on top, D2 below), the text will appear upside down!

Programming

The free download **060014-11.zip** contains .bas, .hex and .bin files. The .bas file holds the source code in 'Bascom' format. The .hex or .bin data can be flashed direct into the ATMega8 and is then ready to run. The data supplied will produce scrolling text of the demonstration message programmed by the author.

If you would like to program your own text you will need Bascom. For this open the file Schrift.bas and change the contents of the array INSTRING. All that remains to do is press F7 to compile the new source code.

After connecting the operating voltage (9 to 12 V) the controller can be programmed. To do this you link the programming connections (K1 on the circuit diagram) via a suitable programmer (PonyProg for example) with the PC and flash the file Schrift.bin or Schrift.hex into the chip (set fusebits externally to 16 MHz).

If you would like to try compiling with the free BASCOM-AVR DEMO 1.11.8.3 software you will need to restrict the length of your text and avoid filling the INSTRING array with three texts, since the demonstration version will not compile more than 4 kB of code.

Mechanical matters

For the 'rotor' an arm made of sheet aluminium about 50 cm long was used. At the centre of the arm you need to fix a small bush that needs to be connected with good electrical conductivity to the drive shaft of the motor. The return wire is screwed or otherwise clamped to the casing of the motor. A slip ring of clean printed circuit board material (not the sort that is pre-coated with photosensitive lacquer) is fixed to the upper surface of the motor and wired up to the positive (plus) side of the voltage source. Above the slip ring a small carbon brush is fixed on the rotor arm in an insulated mounting to avoid contact with the aluminium sheet. Finally a magnet is fixed to the motor casing in such a position that the Hall sensor mounted on the rotor arm passes through its magnetic field at each revolution and is thus activated.

The circuit board is now fixed to the rotor arm (ideally without putting it out of balance). Power supply arrangements involve wiring the return (ground) connection on the circuit board to the bush on the drive shaft and the positive connection to the carbon brush. If the arm remains unbalanced this can be corrected by using compensating weights.

The power source (a 9 to 12 V plug-in power supply) can now be connected up to the slip ring (positive connection) and the motor casing (ground return). The current drawn by the circuit is set mainly by the total draw of the LEDs, to which you must add that of the motor if the same power supply is used for both.

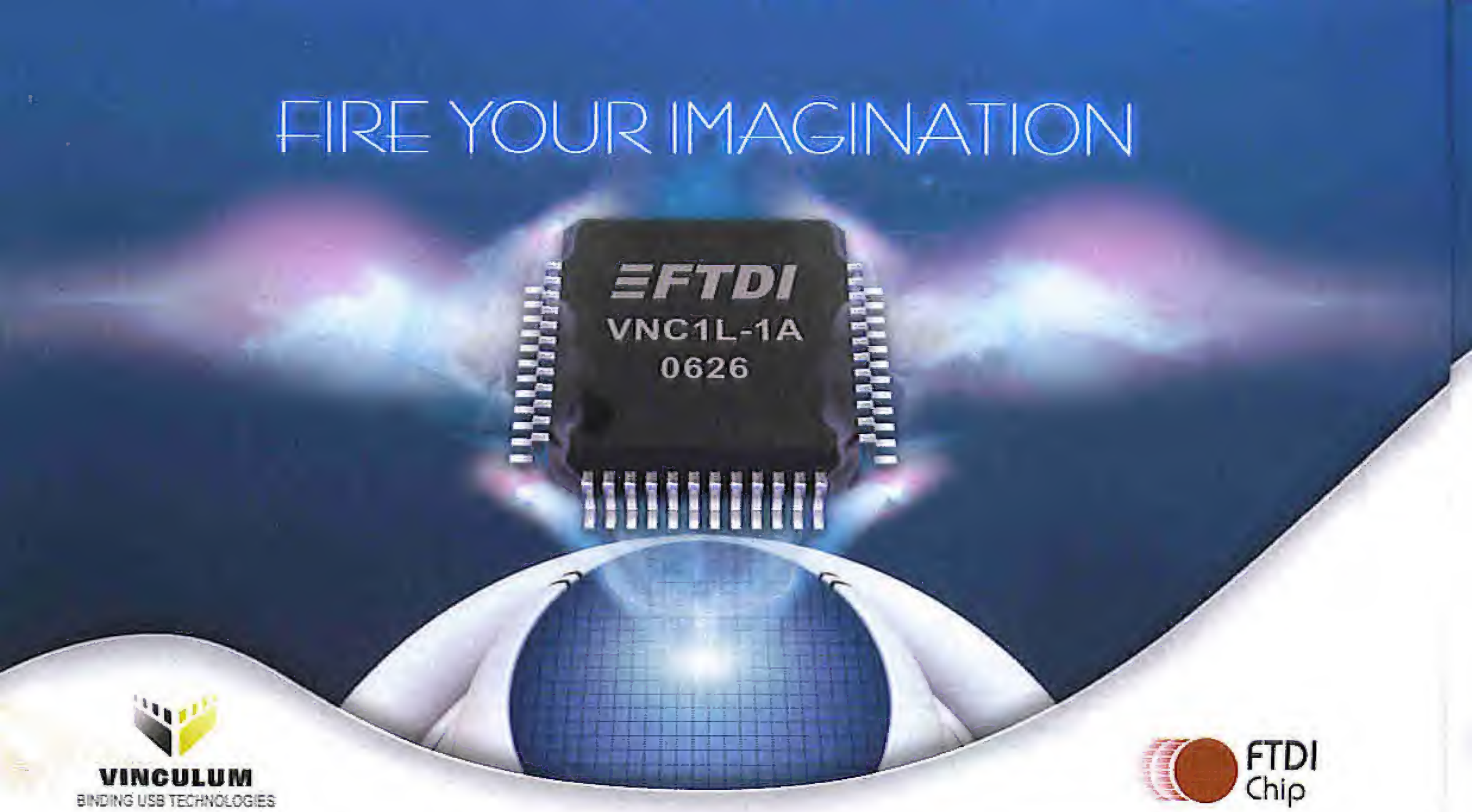
As soon as the power is connected and the arm rotates scrolling text should be visible on the 'display'—just like in the photo at the beginning of the article...

(060014-I)

PS

The author was successful not just with this special assignment but also with his final exams, and is now studying Electronics and Information Technology at the West Coast Technical College in Heide, Germany.

FIRE YOUR IMAGINATION



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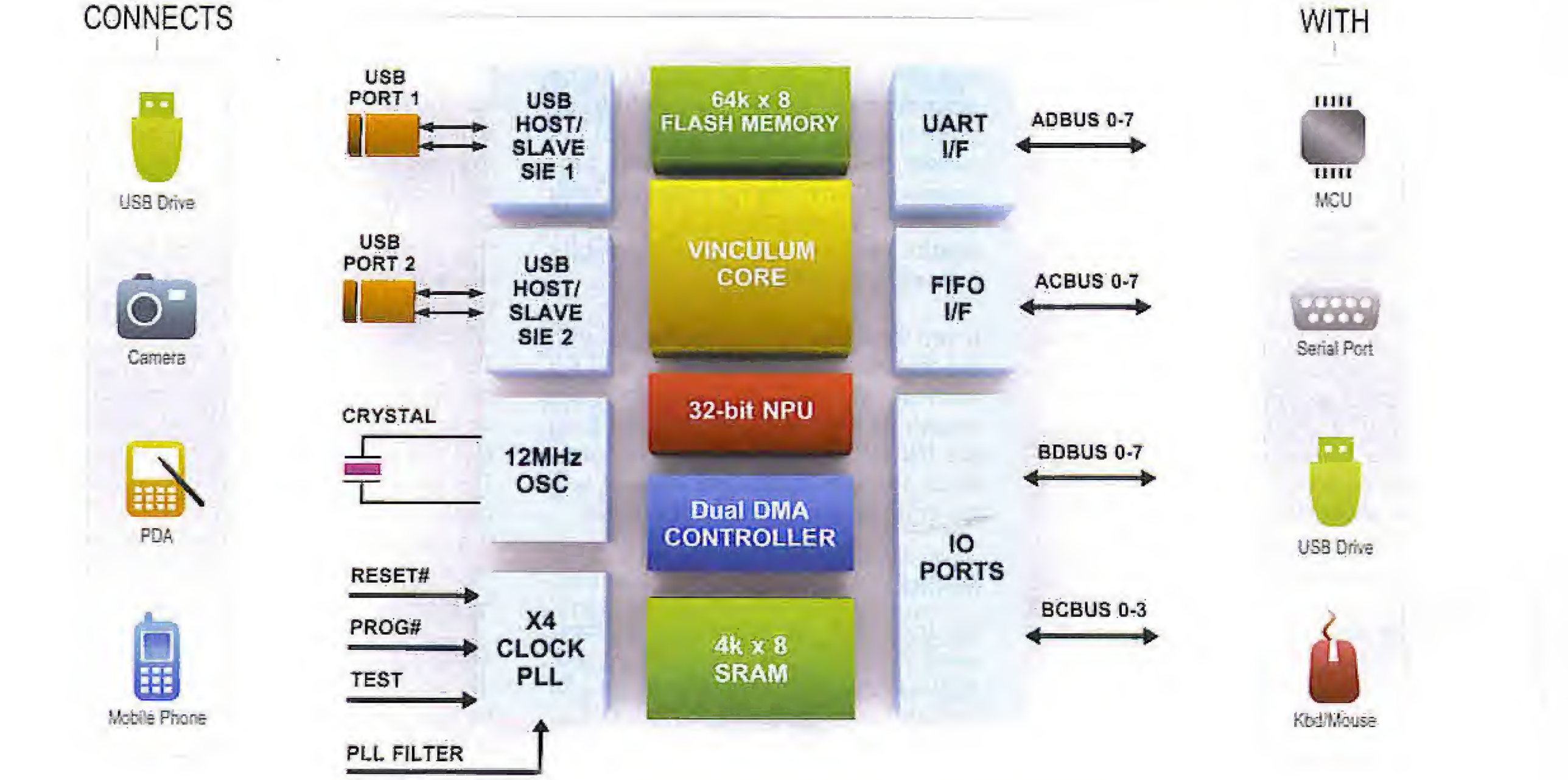

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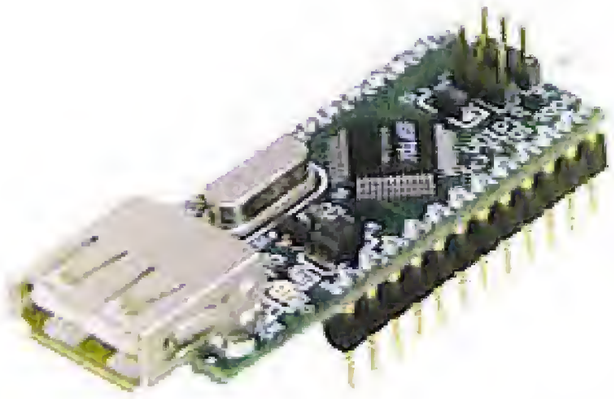

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VDRIVE1 is possibly the easiest solution for adding a USB Flash Drive interface to existing products. Only four signal lines plus 5V/GND are required to be connected.

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- Link Selectable UART or SPI interface
- Only 4 signals to connect excluding PWR/GND
- Single 5V supply required
- Easy to implement command set

VINCULUM - IMAGINE WHAT YOU COULD DESIGN WITH IT...

Scoot me up, Sco

Christian Tomanik

Engine tuning for scooters (and mopeds) has always been popular. In the past this could only be done mechanically and required a certain level of know-how. In the present electronics age there are other ways of boosting the engine power of scooters.

The number of ways in which scooters can be tuned is still relatively small compared to those for cars. There are some very innovative concepts, however. But what is practical and what do you need to do? To answer that we first take a look at the basics of tuning.

Tuning

There are two types of tuning: increasing the engine power, or limiting it. Let's start with a look at the latter.
There are many different ways of mechanically limiting the engine power, such as limiting the amount of fuel mixture fed to the engine or reducing the size of the exhaust port. But there are also electronic solutions. Many modern scooters come with electronic rev limiters. With contemporary scooters you often find they have a combination of mechanical and electronic limiters.

One way in which to limit the revs is to interrupt the ignition. Once a certain speed (and hence a certain number of revs) has been reached, the ignition is interrupted for one or more cycles of the engine. This stops the scooter from speeding up any more.
This type of limiting can be implemented with a specially designed CDI unit (see inset). But there are also other control circuits that take care of the limiting. These are fitted between the normal CDI unit and the ignition coil.
If you want to remove the limiting you'll either need to remove the control circuit or change the CDI unit. It may of course also be possible to adapt the CDI unit or control circuit via dedicated hardware and/or software.
Where a control circuit is used, it is of course very easy to bypass it. A simple switch can be used to make the scooter work with or without the limiter. However, bypassing the limiter like this is of course illegal.
Apart from the electronic limiter there is often a mechanical limiter as well, in the form of a disc that stops the Variomatic (see inset) from going into its top 'gear'. This disc should also be removed when the rev limiter is bypassed, otherwise the engine may be damaged at high revs.
These days there are better limiters available, which continuously adjust the ignition rather than interrupt it for a longer period. These reduce the production of harmful gasses and oil residues in the exhaust.

How to get started

First of all, we have to make clear that all tuning activities that change (increase) the power and maximum speed have to be approved and noted by the relevant authorities. Otherwise the scooter will be uninsured and can't be used on public roads.
In practice there is hardly any difference between the electronic tuning of scooters and chip tuning of cars. In both cases we make use of the inherent tolerances designed into the engine by the manufacturer, in order to improve the engine performance and increase its power. As an example, the ignition table is modified, with the assumption that you'll only use the proper fuel and top-grade oil.

tty Scooter tuning without getting your hands dirty

There aren't really that many parameters that can be adjusted for scooters, and certainly not as many as for cars. The most important, and often the only ones, are the previously mentioned ignition table, a few control parameters and the maximum number of revs. Electronic tuning with the aim to increase the power is therefore mainly used in scooters when mechanical changes are made at the same time. The CDI can then be adapted for these changes, to obtain the best performance from the engine.

GameBoy

As you will have gathered from several past *Elektor Electronics* projects, the Nintendo GameBoy console is not limited for use as a games computer. It is also perfectly suitable for many other applications. Taking this one step further, the German firm AlphaTechnik [2] has designed a dedicated hardware/software add-on for this games computer. The result is the SpeedController, a complete tuning and diagnostic instrument for scooter workshops. It can be used to adjust both the maximum speed as well as the power (either increasing or decreasing them).
Limiting the maximum speed doesn't automatically mean that there has to be a reduction in power. If you take a look at the graph for the power output of a Peugeot Ludix city scooter (**Figure 1**) you'll see that a (legal) speed limit of 25 km/h doesn't stop you increasing the number of HPs. The increase in power is possible because the manufacturers have designed large tolerances into the engine. A big advantage of this type of tuning is that everyday riding in traffic becomes a lot easier and the fuel consumption becomes better. After all, the throttle no longer has to be turned all the way just to get the scooter moving.

With the use of the SpeedController it is also possible to remove the speed restriction completely. This is done using a PIN number, but this can only be used one time. This means that once the restriction has been removed it is no longer possible to enable it again at a later date. This stops people from temporarily putting back the speed limiter for the MOT or police patrol or and removing it again afterwards. This is the result of a strict EU directive, which came into being to reduce the tampering with the limiting systems, or even make it impossible to make changes.

Summary

These days there are several tuning methods for scooters that are relatively easy to install and which can either increase or limit the power. You should keep in mind that bypassing, or tampering with, the limiters is illegal. In some countries it is permissible to increase the power within reason (up to about 4.5 kW or 6 HP). One advantage of this is that the fuel consumption improves, which leads to fewer harmful exhaust gas emissions. You'll also find that the riding experience is more fun, which (if we're honest) is what it's all about.

(060234)

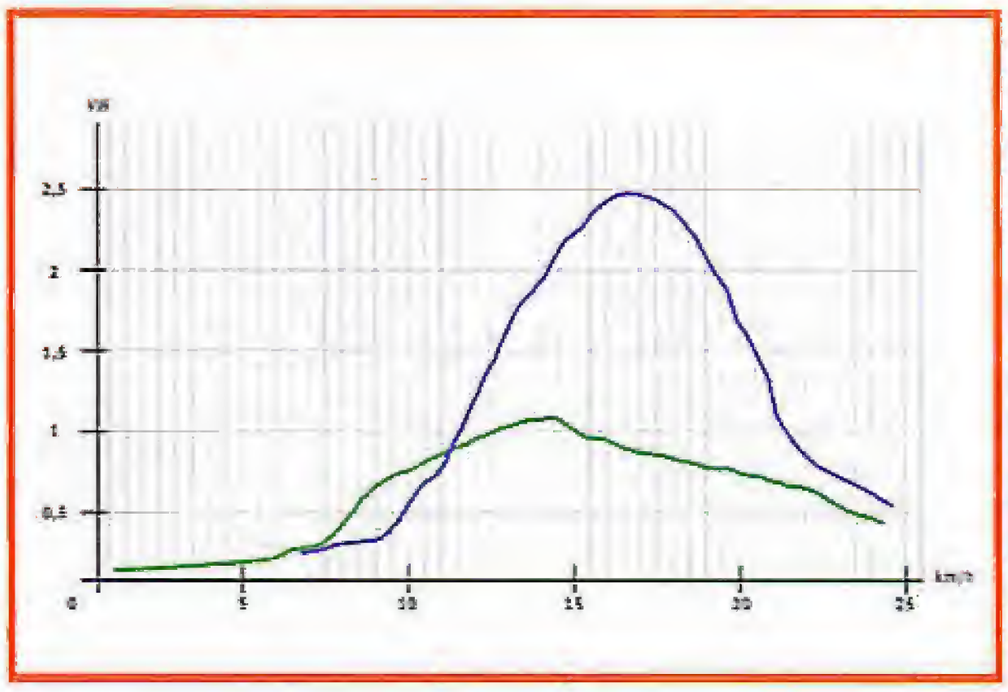


Figure 1.
This graph for the power output clearly shows what effect the tuning has. Green is before and blue is after tuning.

Web links:

[1] en.wikipedia.org/wiki/Two-stroke_engine

[2] www.alphatechnik.de

[3] en.wikipedia.org/wiki/Variomatic

See also:

www.pmtuning.co.uk

CDI

CDI stands for Capacitor Discharge Ignition. The CDI unit calculates the optimal ignition timing for the current revs. To obtain the maximum power the ignition should take place when the piston is just before the top of its stroke. Because the piston moves faster with increasing revs and the gas mixture always requires the same amount of time to fully burn, the ignition has to fire earlier with increasing revs.

Variomatic

The Variomatic is a stepless fully automatic transmission developed in the early 1960s by the Dutch car manufacturer DAF. It works as follows: the drive belt sits between two conical drums. With increasing revs the distance between the two drums changes due to centrifugal weights, which results in a stepless change in the transmission ratio (refer to [3] for more details).

One side effect of this type of transmission is that vehicles with this 'gear box' can travel just as fast backwards as they can forwards, which is funny to see and much used in amateur car races.

Nowadays this type of transmission is used mainly in scooters, quads, snowmobiles and pillar drills. A further development of this is the so-called CVT system, which is used by Audi under the name 'Multitronic' in several of its cars.

Warp Sp

Modern car engine

Henk Dijkstra

In the world of engine tuning, spanners and screwdrivers have been replaced by palmtops or PCs and flash programming routines. These days even the bonnet can remain down and the ECU need not be opened. Via OBD a quiet runabout can be transformed into a roaring sports car.

It is well-known that a modern car is filled to the brim with electronics. In 1990 there were only a couple of ECUs per vehicle. That number has now increased to 10 or 50 or even more ECUs per car. In addition to the engine controller and ABS controller we now also see dashboard-, network-, air conditioning-controllers etc. emerge. Furthermore, the computing power is ever increasing as well (see **Figure 1**).

The necessity of more computing power is driven mostly by the increased emission requirements and diagnostic abilities. Direct injection engines in particular, require a lot of computing power because of their multiphase fuel injection. An example of the tasks and processes that a modern ECU deals with are outlined in **Figure 2**. Some of the ICs that we are likely to find in an ECU are:

- a voltage regulator and processor watchdog;
- a driver IC with SPI diagnostic interface / SPI or PWM input;
- a CAN-bus interface IC;
- 2 MHz 8-bit microcontroller with 8 kilobyte flash memory on board;
- and a 40-MHz, 32-bit microcontroller with 2 MB flash memory on board.

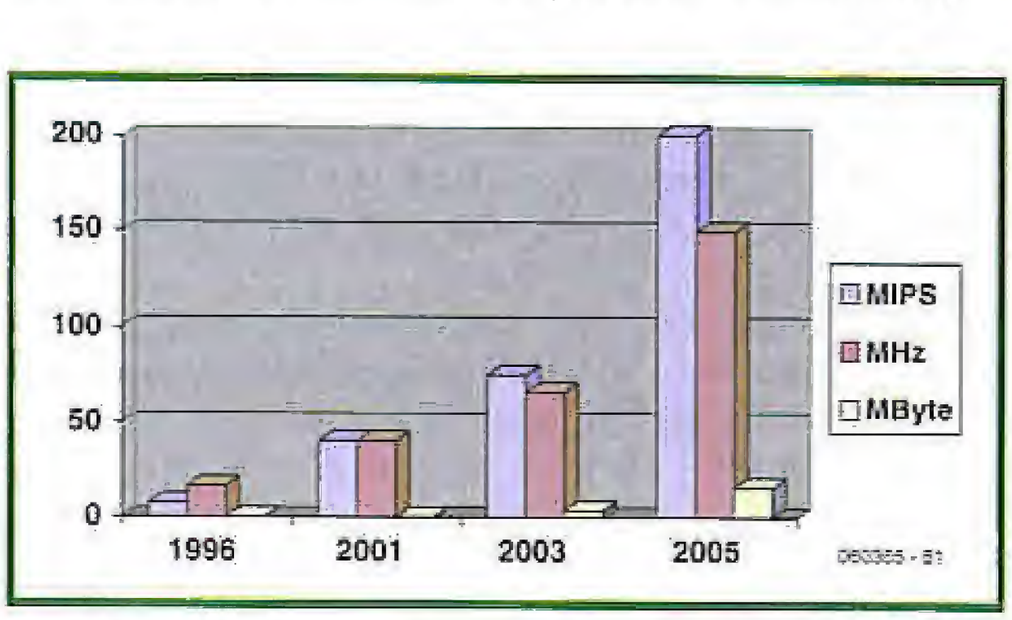


Figure 1. Average number of MIPS of microcontrollers used in ECUs.

ECU reprogramming

To improve the performance of the engine you can interfere electronically with the engine controller. Professionals with a lot of expertise can change the parameters and

eed on Demand

optimisation in the electronic garage

J2534 standard

The J2534 standard come about to enable garages that are not part of a brand franchise to carry out programming operations on ECUs without having to invest in expensive, proprietary equipment.

It is easily possible that a software update is required to ensure that a car conforms again to the emission requirements. This standard makes that easier. Unfortunately, not all manufacturers participate in this (yet).

The J2534 standard is sometimes also called the pass-thru standard. To be able to program an ECU, software from the manufacturer is required, as well as hardware that complies with the J2534 standard. The number of manufacturers that support the J2534 standard grows every year. To buy the programming software a visit to the manufacturer website often suffices, Honda for example: *http://techinfo.honda.com/rjanisis/RJAAI001_tools2.asp?home=Y*

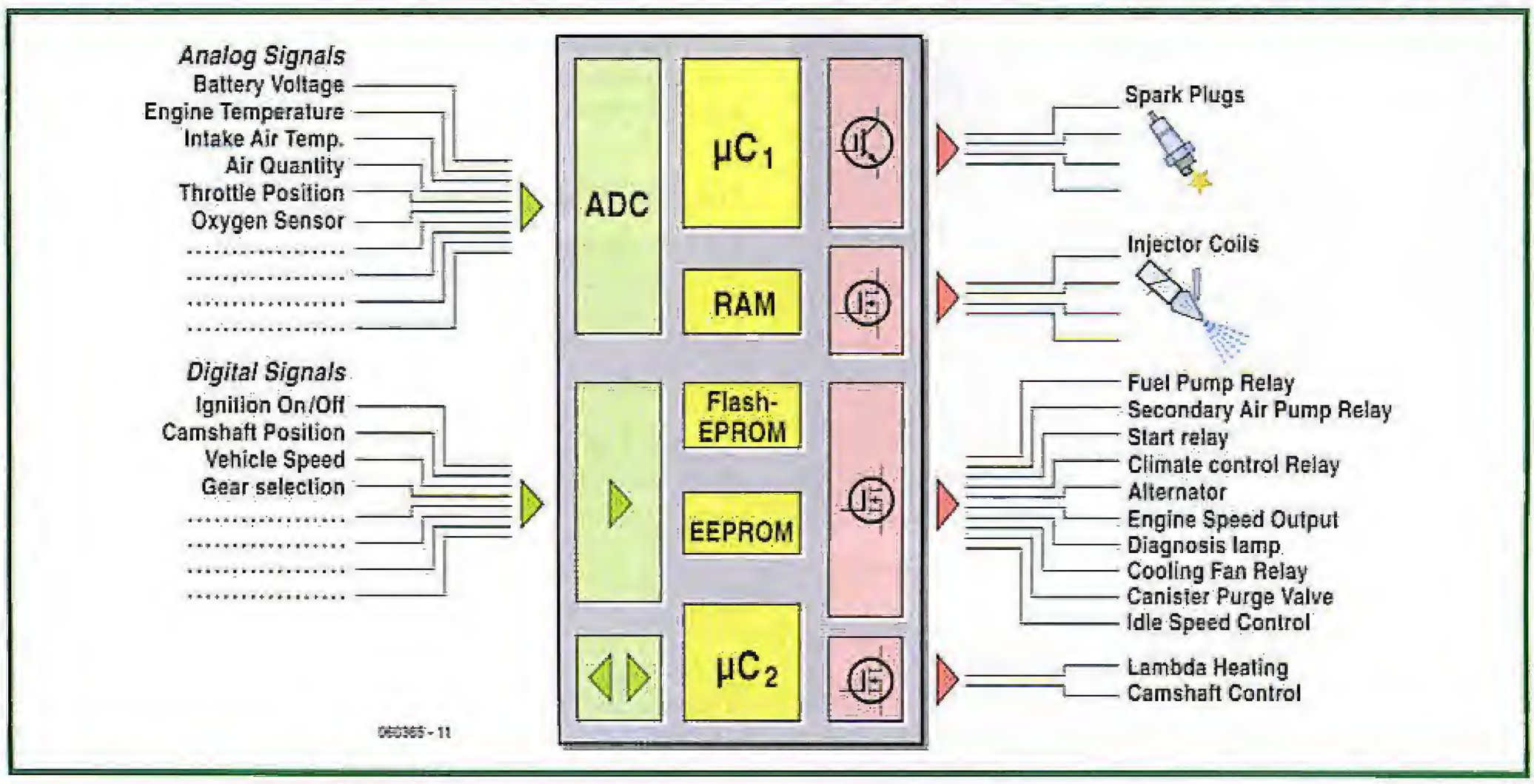


Figure 2. The Hardware Engine Controller. This keeps an eye on an ever increasing number of sensors.

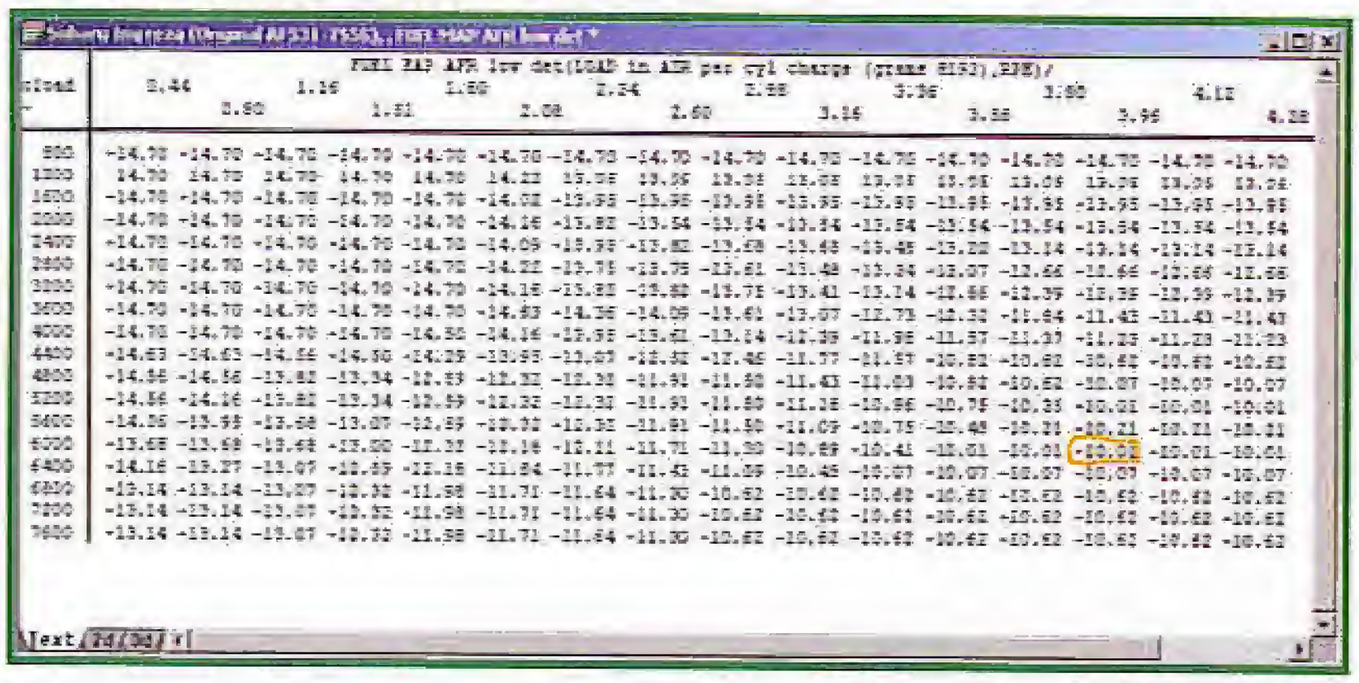
Legislation

The car manufacturer is legally required to take various precautionary measures so that unauthorised programming of the various controllers is not possible. This is mostly to prevent an increase in exhaust emissions. However, if there is a change in the aspiration of the engine, perhaps because of a change in exhaust system, it is often desirable to change the ECU calibration so that the emission requirements are again complied with.

It may not be formally permitted to change the program, but it is actually desirable to return the air/fuel ratio back to the correct value.

It is, for example, well-known that a Subaru Impreza is adjusted quite rich (here is where the manufacturer slightly overshot the concept of 'safe engine adjustment' or perhaps the shareholders of the oil sheiks) and a little bit of 'electronic meddling' can result in not only more engine power, but also – at partial load – lower fuel consumption and therefore a lower emission of CO_2!

Whatever changes are made to a car engine, in the UK, MOT approval will determine whether or not a vehicle is allowed to go on the road.



load	0.44	1.16	1.60	2.24	2.88	3.36	3.80	4.12
	0.60	1.51	2.08	2.80	3.16	3.88	3.96	4.28
800	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70	-14.70
1200	14.70	14.70	14.70	14.70	14.70	14.22	13.96	13.96	13.96	13.96	13.96	13.96	13.96	13.96	13.96	13.96
1600	-14.70	-14.70	-14.70	-14.70	-14.70	-14.02	-13.95	-13.95	-13.95	-13.95	-13.95	-13.95	-13.95	-13.95	-13.95	-13.95
2000	-14.70	-14.70	-14.70	-14.70	-14.70	-14.16	-13.82	-13.54	-13.54	-13.54	-13.54	-13.54	-13.54	-13.54	-13.54	-13.54
2400	-14.70	-14.70	-14.70	-14.70	-14.70	-14.09	-13.95	-13.82	-13.68	-13.48	-13.45	-13.28	-13.14	-13.14	-13.14	-13.14
2800	-14.70	-14.70	-14.70	-14.70	-14.70	-14.22	-13.75	-13.75	-13.61	-13.48	-13.34	-13.07	-12.66	-12.66	-12.66	-12.66
3200	-14.70	-14.70	-14.70	-14.70	-14.70	-14.16	-13.82	-13.82	-13.75	-13.41	-13.14	-12.86	-12.39	-12.39	-12.39	-12.39
3600	-14.70	-14.70	-14.70	-14.70	-14.70	-14.83	-14.36	-14.09	-13.61	-13.07	-12.73	-12.32	-11.84	-11.43	-11.43	-11.43
4000	-14.70	-14.70	-14.70	-14.70	-14.36	-14.16	-13.95	-13.61	-13.14	-12.39	-11.98	-11.57	-11.37	-11.23	-11.23	-11.23
4400	-14.63	-14.63	-14.56	-14.50	-14.29	-13.95	-13.07	-12.32	-12.46	-11.77	-11.57	-10.82	-10.62	-10.62	-10.62	-10.62
4800	-14.56	-14.56	-13.82	-13.34	-12.53	-12.32	-12.32	-11.91	-11.50	-11.43	-11.03	-10.82	-10.62	-10.07	-10.07	-10.07
5200	-14.56	-14.16	-13.82	-13.34	-12.59	-12.32	-12.32	-11.91	-11.50	-11.16	-10.96	-10.75	-10.35	-10.01	-10.01	-10.01
5600	-14.56	-13.95	-13.68	-13.07	-12.59	-12.32	-12.32	-11.91	-11.50	-11.09	-10.75	-10.48	-10.21	-10.21	-10.21	-10.21
6000	-13.68	-13.68	-13.68	-13.00	-12.32	-12.18	-12.11	-11.71	-11.30	-10.89	-10.41	-10.01	-10.01	-10.01	-10.01	-10.01
6400	-14.16	-13.27	-13.07	-12.59	-12.18	-11.84	-11.77	-11.43	-11.09	-10.48	-10.07	-10.07	-10.07	-10.07	-10.07	-10.07
6800	-13.14	-13.14	-13.07	-12.32	-11.98	-11.71	-11.64	-11.30	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62
7200	-13.14	-13.14	-13.07	-12.32	-11.98	-11.71	-11.64	-11.30	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62
7600	-13.14	-13.14	-13.07	-12.32	-11.98	-11.71	-11.64	-11.30	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62	-10.62

Figure 3. Example of a fuel table.
Based on this table the ECU looks up what the ratio between fuel and air needs to be for a certain engine load, temperature and engine speed.

Figure 4. Subaru-programming with the handheld programmer from www.fastchip.nl

tables that are stored in the ECU. These changes make it necessary to recalibrate the controller. A change in the exhaust and/or intake system changes the aspiration of the engine to such an extent that it will no longer comply with the emission standards that are legally defined. The factory settings (calibration) are, after all, based on a standard intake and exhaust system.
Now that more air is sucked into the engine — at least that is the intention if more performance is required — more fuel needs to be injected as well.
The amount of fuel supplied is typically looked up from a table by the ECU based on the following main parameters (see **Figure 3**):

- engine load;
- engine speed;
- engine temperature.

Along the Y-axis we find the engine speed and along the X-axis the engine load. The engine temperature is looked-up from another table. As an example we take 6000 rpm (revolutions per minute) and 3.96 grams of air per cylinder. We can then see that the AFR-value is 10.01. In this case therefore, 1 part fuel to every 10 parts of air. If, for example, we enter the value 9.0 in the table, then the effective injection time will increase to get more fuel into the cylinder.
Obviously the correct values have to be entered to prevent expensive engine damage and maintain conformance to emission requirements.

Programming via OBD

A lot is involved in order to program new table values into the ECU. In the past it was a case of desoldering the (E)PROM and replacing it with a version with the new code. These days all ECUs are provided with flash memory, which may or may not be a separate chip. Access to the ECU memory is always possible via OBD. This requires that the ECU is first placed into a special security mode. To put the ECU in security mode you need to ask for a 'seed'. This needs to be answered by the programmer with the correct 'key'. There are often multiple levels of security. For some cars a ready-made solution is available in the form of a handheld programmer.

Hard and software

The hardware provides for proper communication between the software and the ECU while programming. Consequently, the hardware has to have the right kind of interface, such as ISO, CAN, etc. and support non-standard baud rates such as 10,400 or 15,625 baud (bits/s). In some cases a programming voltage is also required. But in most cases standard OBD-hardware will suffice.
If the car manufacturer supports the J2534 standard, then it is enough to buy a J2534 hardware interface. See [1], for example. Software is often available from the manufacturer of the car. See also the inset *J2534-standard*.
Programming software often makes use of the service modes, as described in the SAE J2190 standard *Enhanced E/E Diagnostic Test Modes*, see [2].
The most common J2190 service modes for re-programming are:

$10 start diagnostic service
$20 stop diagnostic service
$27 ask for security access (seed, key)

$34 ask for upload to controller
$35 ask for download from controller
$36 data transmission to/from controller
$37 ask transmission exit
$3D write to memory

Although the service modes are described in the SEA J2190 standard *Enhanced E/E Diagnostic Test Modes*, the parameter identifiers (PIDs) are manufacturer specific. The manufacturer determines the programming order and security access according to their requirements.
In this way the security key could be 32 bits long, but it just as well be 128 bits long.

Reverse engineering

When the manufacturer is not prepared to supply the necessary information and also does not make available any programming software, then the only option that remains is *reverse engineering* of the controller software.
Fortunately there are ever more manufacturers who are prepared to supply programming software to allow their ECUs to be updated.
To discover the correct programming order and to obtain security access the processor code will have to be unravelled. This requires a processor dependent disassembler and interface. Because it is necessary to work at the level of assembly language, this tends to be quite a time-consuming process. Depending on the way the programming operation is implemented by the manufacturer, it may also be necessary to write a kernel and/or flash programming routines just to be able to program the flash at all. This is therefore not a job for the novice.

Car versus computer?

The present-day tuning of cars looks more like hacking than it looks like working in a garage. Because of the far-reaching integration of electronics in the car of today, an increasing number of adjustments can only be carried out electronically. To make things safe and to comply with various legal requirements, the manufacturers lock up the software as much as is possible. Subsequently, several tuning companies such as Fastchip are busy 'decoding' the software in order to be able to make 'adjustments' themselves. This sounds a little like what happens in the pc software arena: hackers who circumvent the protection mechanisms to enable them to make a backup of their beloved Xbox game...

Glossary

AFR	Air Fuel Ratio, ratio between fuel and air.
CAN-bus	Controller Area Network; asynchronous, serial bus system developed for the use in cars.
ECU	Electronic Control Unit; the 'board computer', which controls all the electronics.
MIPS	Million Instructions Per Second; Number of instructions that a controller can process per unit of time (for example, adding two numbers is one instruction).
PWM	Pulse Width Modulation; a standard for signal transmission in which the duty cycle of a rectangular wave contains the information of the signal.
OBD	On-Board Diagnostic; electronic diagnostic system for vehicles.
SPI	Serial Peripheral Interface; standard for a serial interface for a digital signal network.

The holy cow will not disappear from our driveway any time soon while the electronics becomes over more sophisticated. In all likelihood, IT will place an increasing role in the garage of the future. That's quite a promise!

(060365-I)

Web links:

[1] www.passthruxs.com
[2] www.sae.org
[3] www.fastchip.nl

The days that a mechanic got dirty hands when tuning an engine are gone...

FPGA Course (8)

Part 8: Playing with the USB port

Paul Goossens and Andreas Voggeneder

In this instalment of the course We're going to pu together our own USB microcontroller. In terms of technical features, it can certainly hold its own against commercial USB controllers such as the Cypress IC.

The specifications of our home-grown USB controller embedded into an FPGA are certainly nothing to be ashamed of:

- 8052 processor running at 48 MHz with single clock cycle per byte fetch
- full-speed USB controller with five endpoints
- 8 KB of ROM
- 4 KB of RAM

We built the USB controller by extending the familiar 8052 core with a USB controller core, which is also freely available from OpenCores (www.opencores.com). This is not the place to delve into the details of how the USB core works or its internal structure. What matters here is how it is linked to the 8052 core and how to use it in practice. The USB core is the USBHostSlave core from OpenCores (www.opencores.org/projects.cgi/web/usbhostslave/overview). It was designed by Steve Fielding, and it has the following properties:

- register-configurable low-speed / high-speed mode (1.5 Mbps or 12 Mbps)
- 4 freely available endpoints, each with a 64-byte FIFO
- support for control, bulk, interrupt, and isochronous transfers
- host mode
- 8-bit Wishbone bus interface

The USBHostSlave core is coupled to the 8052 microcontroller via the Wishbone bus. As a result, the registers of the USB core appear in the XRAM memory area (in other words, they are addressed as external SRAM), where the USB core occupies 256 addresses. **Figure 1** shows the block diagram of the overall system, while **Figure 2** depicts the memory organisation.

Registers

The USB core has a set of four registers for each endpoint:

- EP[0-4]_Control
- EP[0-4]_Status
- EP[0-4]_Transtype_Status
- EP[0-4]_NAK_Transtype_Status

The Endpoint_Control registers can be used to control or drive endpoints for purposes such as sending data, setting or clearing stall states, or setting the operating mode of an endpoint (isochronous or bulk). The Endpoint_Status registers provide information about the current status of the endpoints – for instance, whether data has been received or an error has occurred.
The Endpoint_Transtype_Status register contains information about the last successful transfer between the PC and the USB core, such as whether a setup package was received. The Endpoint_NAK__Transtype_Status register displays any errors that may have occurred during the data transfer.

Besides these four primary control registers, each endpoint has an Rx FIFO buffer and a Tx FIFO buffer, each with a depth of 64 bytes. These two FIFOs can be controlled using an additional set of six registers for each endpoint:

- EP[0–4]_Rx_Fifo_Data
- EP[0–4]_Rx_Fifo_Data_Count_MSB
- EP[0–4]_Rx_Fifo_Data_Count_LSB
- EP[0–4]_Rx_Fifo_Control
- EP[0–4]_Tx_Fifo_Data
- EP[0–4]_Tx_Fifo_Control

Among other things, these registers are used to read data received via the endpoint from the associated Rx FIFO and check the fill level of the FIFO, to write data to a Tx FIFO, and to empty (flush) the FIFOs.
There are also several general Slave Control (SC) registers, including:

- SC_Control
- SC_Line_Status
- SC_Address
- SC_Interrupt_Status / Mask

The SC_Control register can be used to enable or disable the USB slave portion and configure it in either full-speed mode (12 Mbps) or low-speed mode (1.5 Mbps). The SC_Line_Status register can be used to check the line status (link to the PC) to determine whether a link actually exists (plug connected) or the link is interrupted somewhere. The SC_Address register is used to set the slave address assigned by the PC during the enumeration process. The SC_Interrupt_Mask register specifies which interrupts are allowed (which means they can generate an 8051 interrupt) and which ones are not allowed. The microcontroller can use the SC_Interrupt_Status register to determine the source of an interrupt.

Besides these slave-specific registers, there is also a large set of registers for the USB host portion, but they are not described here. As described later on in this article, the FPGA board cannot act as a host.

Hardware

The pull-up resistance that defines the connect condition can be controlled by the microcontroller via port line P3.7. P3.7 is high after a reset. MOSFET T6 (which connects the pull-up resistor to D+) is cut off under this condition, so the PC does not see any connected device. When the software has initialised the USB core and is ready to communicate with the PC, it pulls P3.7 low. This causes the D+ to be connected to +3.3 V via the 1.5-kΩ resistor. As a result, the PC sees that a full-speed device (12 Mbps) is connected and initiates communication with the FPGA board.

The USBHostSlave core needs a 48-MHz clock. This is stipulated by the USB specification. A clock signal at this frequency is derived from the 50-MHz clock signal by a PLL in the FPGA. The USB core and the T8052 core are both driven by the 48-MHz clock signal. As the T8052 core can execute all instructions in 1 to 4 clock cycles (except the divide instruction, which takes 12 clock cycles), this provides a considerable amount of computing power (at least for an 8051).

The USB core in the FPGA handles all the tasks necessary for USB communication with the PC. All that remains to be provided is the USB physical interface (USB Phy). Its job is to provide the electrical interface (level adjustment). This task is also handled by the FPGA.

Mixed Language

Besides VHDL, there are several other ways to design a digital circuit. One of them is to use a graphic drawing package. We described this option in earlier instalments of this course.

Other entry methods include Verilog, AHDL, SystemC, and so on. Fortunately, the Quartus compiler can also handle some of these languages. Using two or more different languages is called 'mixed-language design'.

The USB core used in this instalment was designed in Verilog. Some of the other components were designed in VHDL. Our design can thus be regarded as a mixed-language design (part Verilog and part VHDL).

The main advantage of this is that you are not limited to using only VHDL cores or only Verilog cores. You can use them in combination in your designs without any problems. However, you do need to know the Verilog equivalents of some VHDL terms, such as STD_LOGIC signals.

The link between the VHDL part and the Verilog part is located in the USB.vhd file. This file is what is called a 'wrapper', and its purpose is to export Verilog signals as VHDL signals.

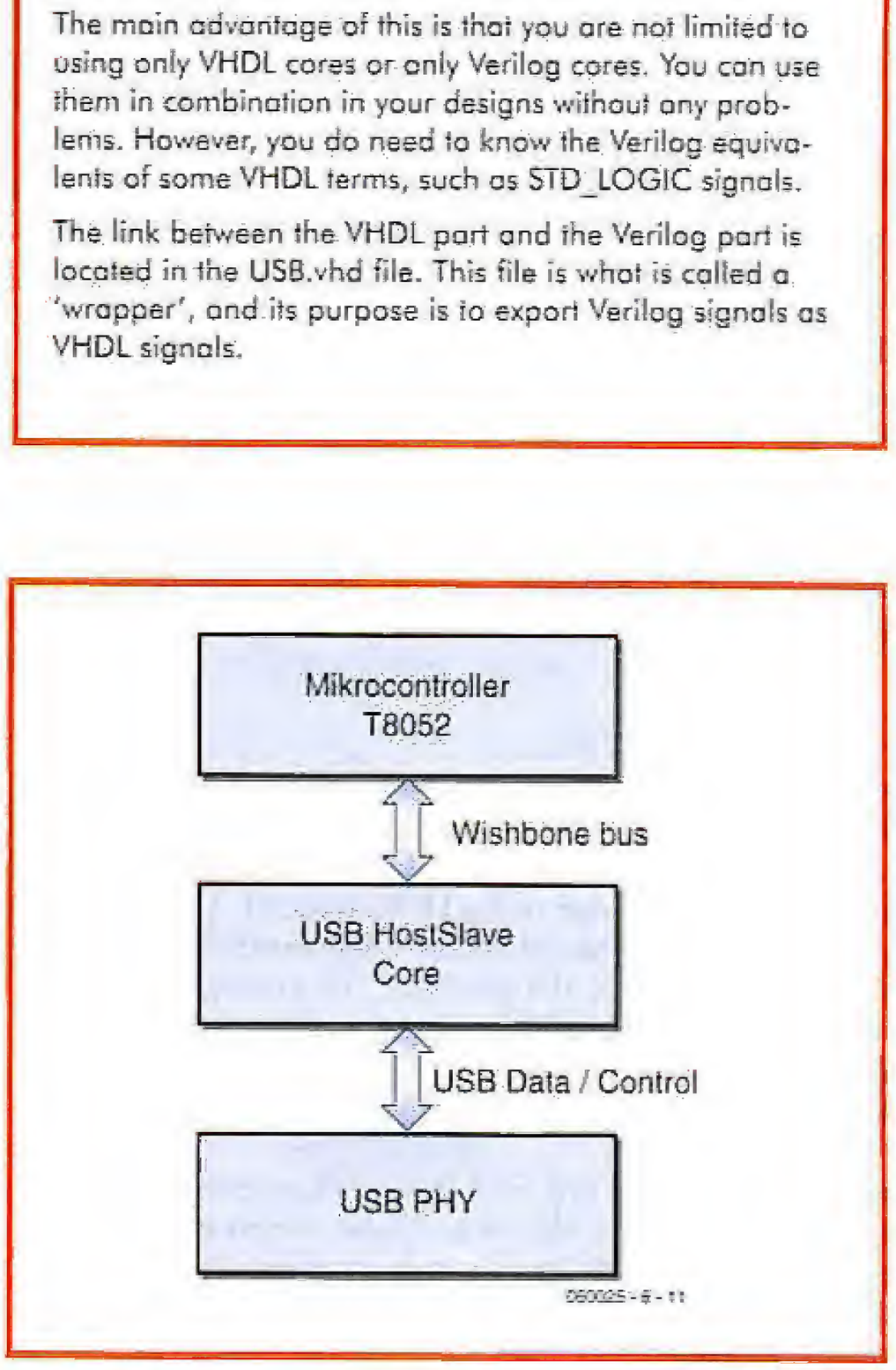


Figure 1.
The USBHostSlave core in the T8052 system.

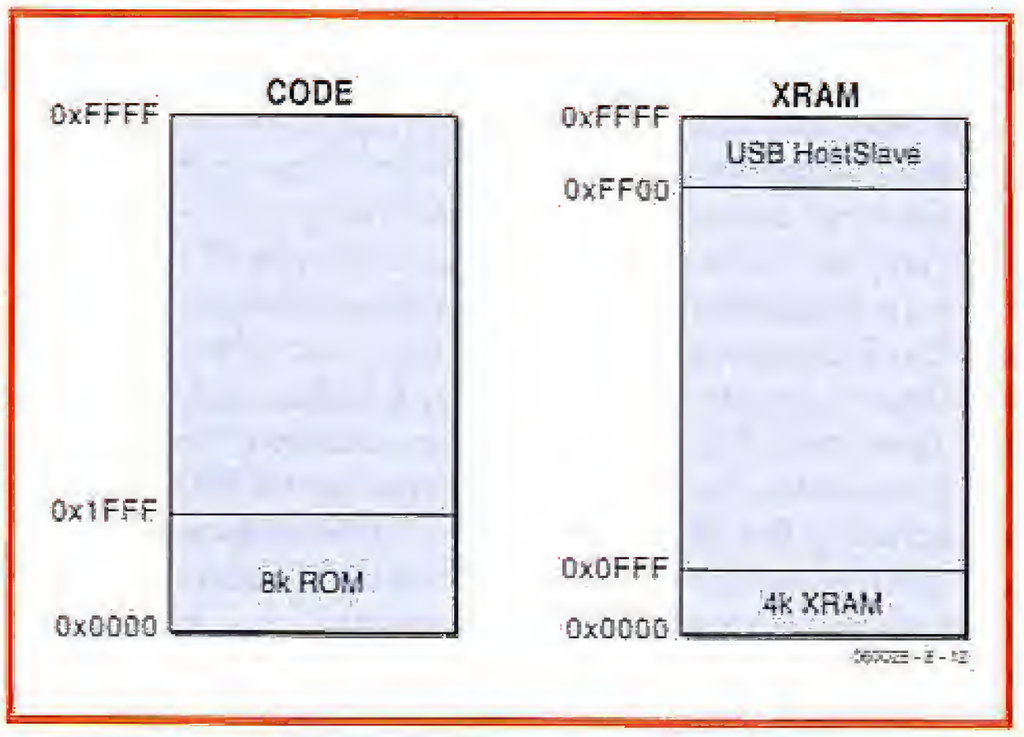


Figure 2.
T8052 memory organisation.

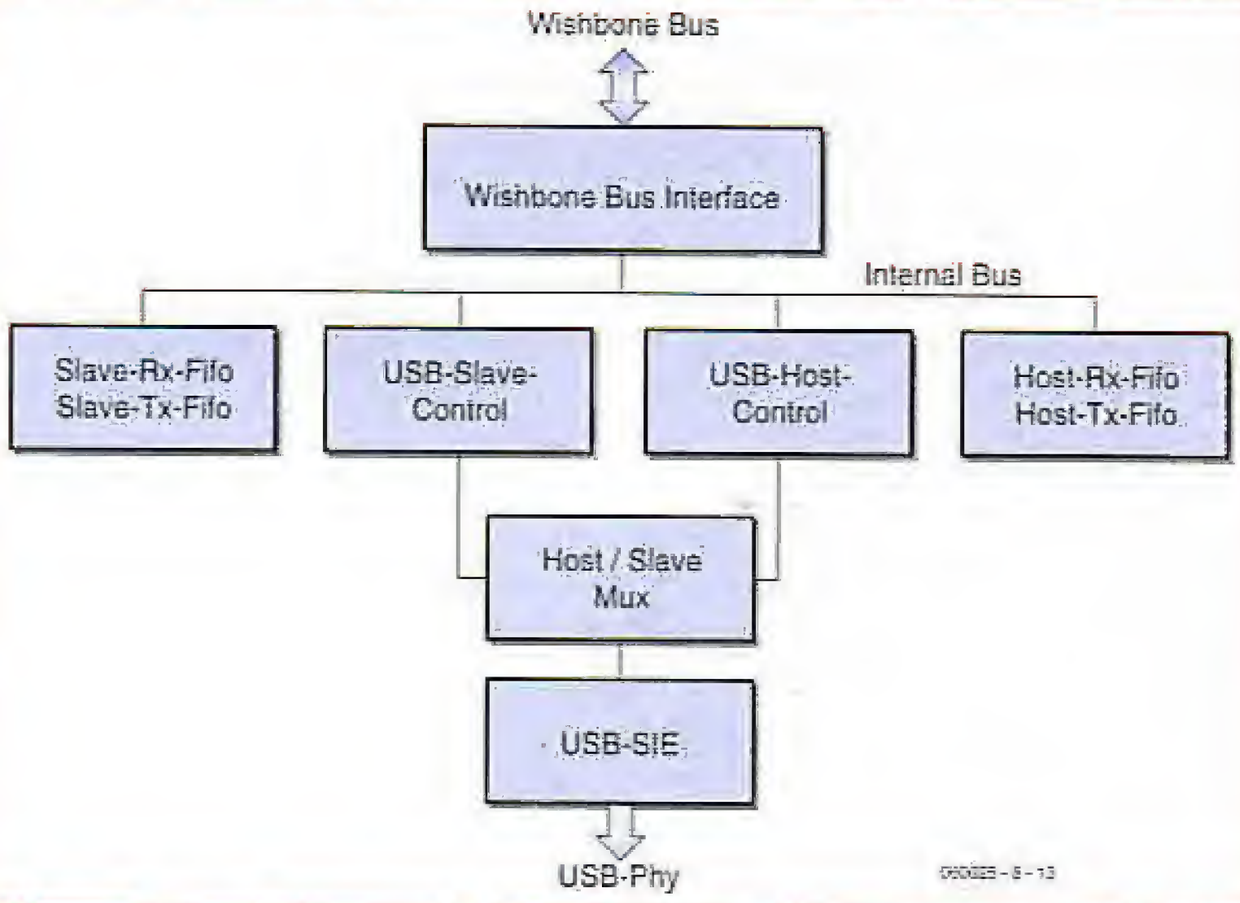


Figure 3. Block diagram of the USB core

Join the FPGA Course with the Elektor FPGA Package!

The basis of this course is an FPGA Module powered by an Altera Cyclone FPGA chip, installed on an FPGA Prototyping Board equipped with a wealth of I/O and two displays (see the March 2006 issue).

Both boards are available ready-populated and tested. Together they form a solid basis for you to try out the examples presented as part of the course and so build personal expertise and know-how in the field of FPGAs.

Further information may be found on the shop/kits & modules pages at www.elektor-electronics.co.uk

The USB core also supports host mode, which means it can act as a PC for functions such as enumerating and driving a USB mouse or other type of USB device. However, host mode cannot be used with the FPGA prototyping board because it lacks the necessary hardware (external to the FPGA). Here the USB core can only be used in slave mode with low-speed (1.5 Mbps) or full-speed (12 Mbps) data transfer.

Sample application

Our demo application here (ex22) involves connecting an HID keyboard. It identifies itself to the PC as a keyboard, which causes the PC to use the Human Interface Device (HID) protocol defined in the USB standard. The main purpose of the HID protocol is controlling input devices such as keyboards, mice and joysticks. The principal advantage of this protocol is that all major operating systems (Window, Linux and MacOS) incorporate drivers for it, so they do not have to be written for individual devices.

Endpoints 0 and 1 are used for communication with the PC. Endpoint 0 is a control endpoint, which must be present in every USB device. It is used for basic communication with the PC (enumeration). Enumeration is a process that takes place immediately after a USB device is connected to a host (PC). Each new device is recognised by the 1.5-kΩ resistor connected to the D+ or D– line in every USB device. If the resistor is connected to the D+ line, the device is a full-speed device (12 Mbps); otherwise it is a low-speed device (1.5 Mbps). The FPGA prototyping board has a switchable resistor for each of these lines, so you can configure it as desired as a full-speed or low-speed device. The PC detects the type of device during enumeration and assigns a slave address to the device. The appropriate driver is then loaded based on the Device_Descriptor data sent by the device. After this has been completed, an application can communicate with the device. In this case, the driver is the HID driver provided by the operating system. Other endpoints are not enabled until after the driver has been loaded. In the case of the HID keyboard, this is endpoint 1, which acts as an interrupt endpoint (IN = device to PC) and is used for transmitting keysirokes.

On the *Elektor Electronics* FPGA prototyping board, pushbuttons S2–S4 and the eight DIP switches in S5 are used as 'keys', with S4 serving as a Shift key. S1 acts as the reset button for resetting the 8052 and the USB core. LED 7 acts as the indicator for the Number Lock function, while LED 6 acts as the Caps Lock indicator and LED 5 as the Scroll Lock indicator.

Bonus application

Our second sample application (ex23) is a PS/2 to USB adapter. You can use this adapter to connect a keyboard with a PS/2 connector to a USB port of a PC. The PC will see the keyboard as a USB keyboard. The FPGA causes the keystrokes of the PS/2 keyboard to be transferred via the USB interface just as though they originated from a real USB keyboard.

Naturally, this example uses the PS/2 interface as well as the USB interface. This means the associated firmware is more extensive, but if you read the PS/2 instalment you should be able to understand how this application works As usual, the software for the examples described in this instalment is available on the *Elektor Electronics* website under item number 060025-8-11 (go to Magazine → January 2007 → FPGA Course Part 8).

(060025-8)

Andreas Voggeneder

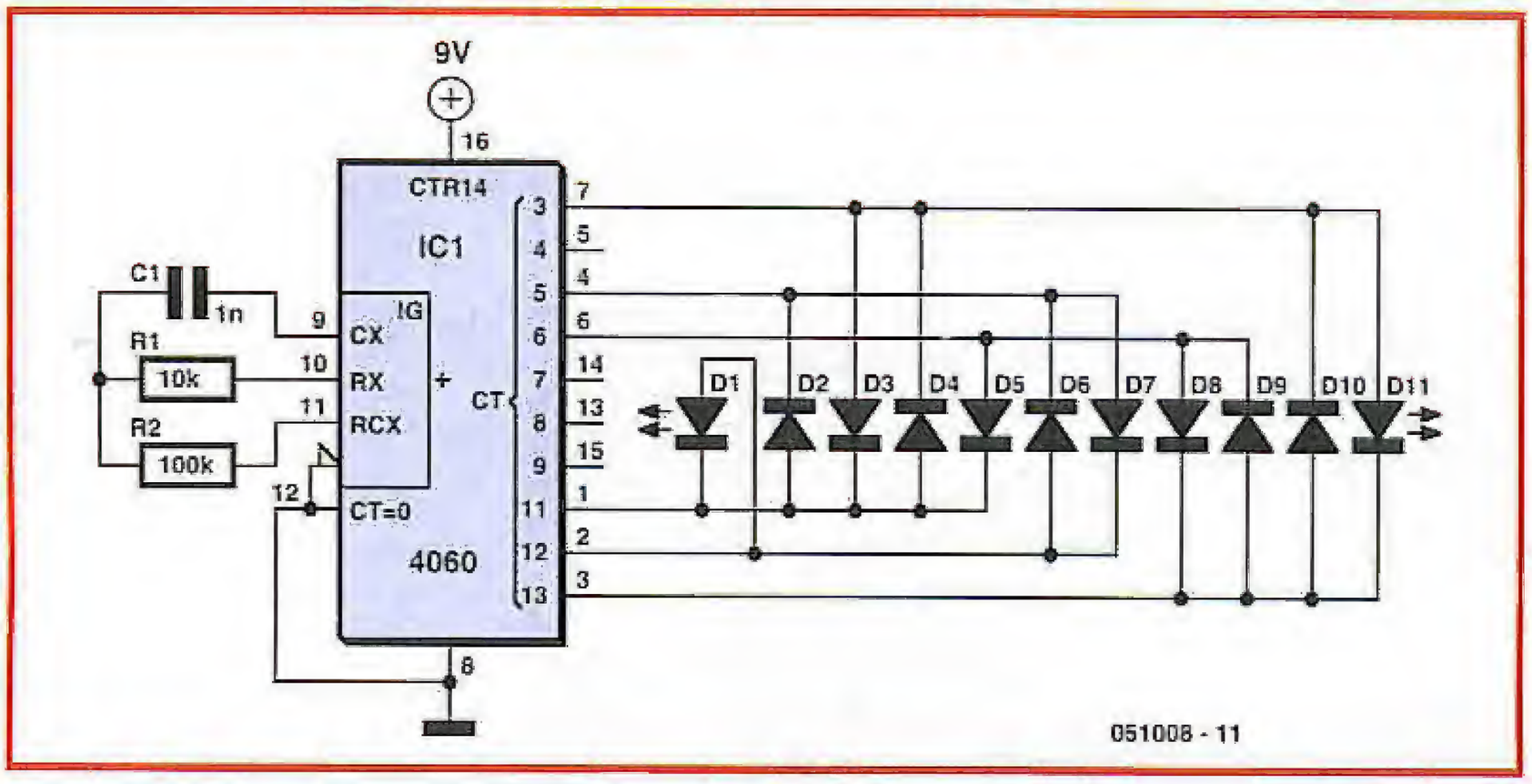
Andreas Voggeneder studied Hardware/Software Systems Engineering (HSSE) at the University of Applied Sciences in Hagenberg, Austria (**http://hsse.fh-hagenberg.at/**), where he presently still gives occasional lectures.

As an enthusiastic electronics specialist, he devotes part of his time to designing digital circuits with the help of VHDL and Verilog. He is also a moderator at OpenCores (**http://www.opencores.com/**), a forum dedicated to the freely available T51 8051 processor core used in several instalments of this course.

Blinking Christmas decoration

Dieter Folger

Have your already set up a Christmas tree in your house and decorated it with traditional lights? Build a couple of these blinking Christmas decorations to enhance the Christmas mood. The coloured LEDs blink in a seemingly random sequence and rate and create a festive appearance.



The circuit for the blinking Christmas decoration has a very simple design. It is based on a type 4060 digital counter (IC1). This IC has a built-in oscillator with a frequency set by the combination of resistor R1 and capacitor C1. The oscillator frequency is approximately 5 kHz with the component values shown here. The oscillator signal is divided by various factors by the internal digital circuitry of the IC. The division factors are designated by 'CT' in the IC drawing symbol. For instance, the signal on the CT3 output (pin 7) is a square wave with a frequency equal to 5 kHz divided by 2^3, which mean (5 kHz ÷ 8) = 625 Hz. The oscillator signal is divided by 2^4 (16) on the CT4 output, by 2^5 (32) on the CT5 output, and so on. The signals on each of the outputs thus change at different rates. Eleven LEDs are connected in three groups between six of the counter outputs, with the result that the group of LEDs flash in an apparently random pattern.

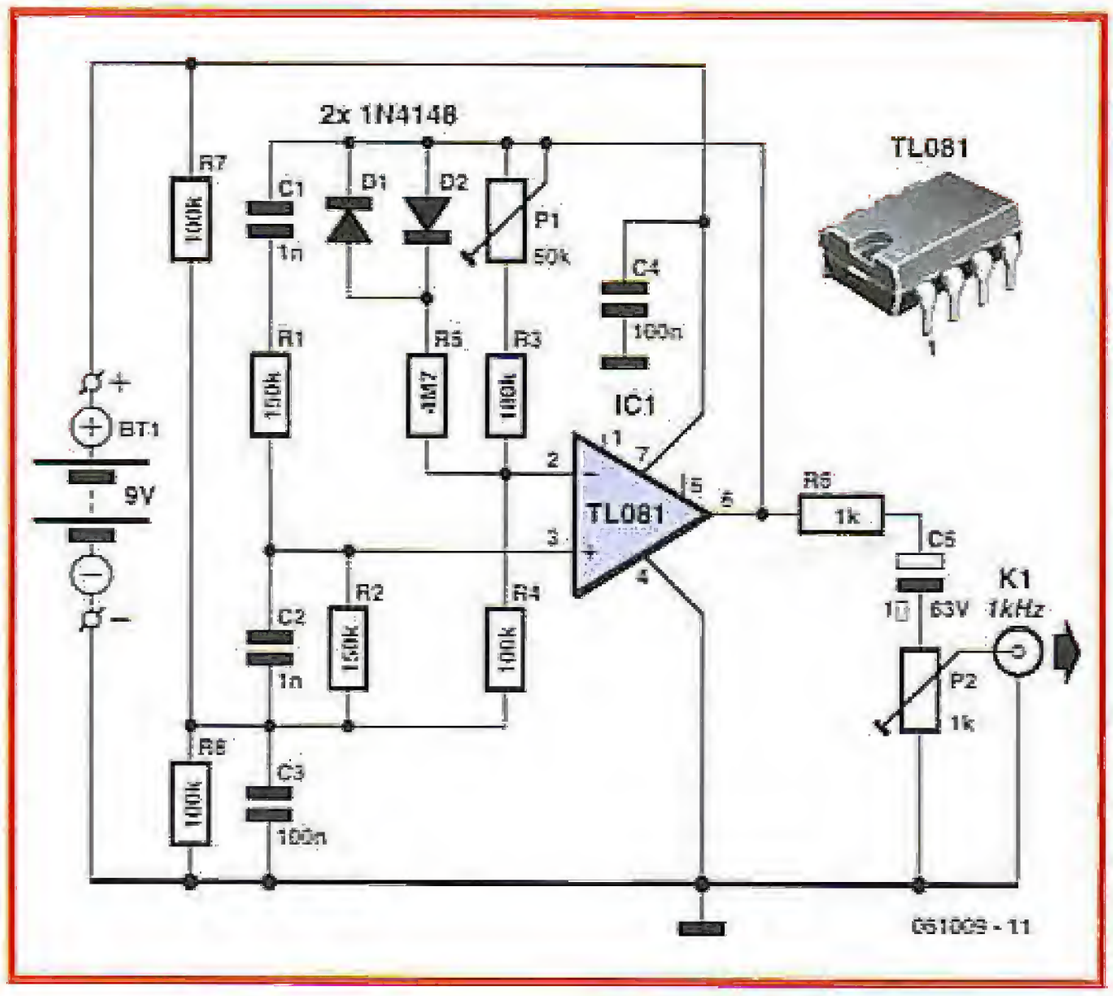
To assemble the circuit, first solder the IC socket (mind the polarity), the two resistors, the capacitor, and the battery clip to the triangular circuit board. Then fit the eleven LEDs. Pay attention to the polarity of the leads: the short lead is the cathode lead.
After a final inspection, you can connect a 9-V battery to your Christmas blinker. It should produce a festive blinking pattern!

(051008)

Test beeper for your stereo

Ton Giesberts

The test beeper generates a sinusoidal signal with a frequency of 1,000 Hz, a common test frequency for audio amplifiers. It consists of a classical Wien-Bridge oscillator (also known as a Wien-Robinson oscillator).
The network that determines the frequency consists here of a series connection of a resistor and capacitor (R1/C1) and a parallel connection (R2/C2), where the values of the resistors and capacitors are equal to each other. This network behaves, at the oscillator frequency (1 kHz in this case), as two pure resistors. The opamp (IC1) ensures that the attenuation of the network (3 times) is compensated for. In principle a gain of 3 times should have been sufficient to sustain the oscillation, but that is in theory. Because of tolerances in the values, the amplification needs to be (automatically) adjusted.



Instead of an intelligent amplitude controller we chose for a somewhat simpler solution. With P1, R3 and R4 you can adjust the gain to the point that oscillation takes place. The range of P1 (±10%) is large enough the cover the tolerance range. To sustain the oscillation, a gain of slightly more than 3 times is required, which would, however, cause the amplifier to clip (the 'round-trip' signal becomes increasingly larger, after all). To prevent this from happening, a resistor in series with two anti-parallel diodes (D1 and D2) are connected in parallel with the feedback (P1 and R3). If the voltage increases to the point that the threshold voltage of the diodes is exceeded, then these will slowly start to conduct. The consequence of this is that the total resistance of the feedback is reduced and with that also the amplitude of the signal. So D1 and D2 provide a stabilising function.
The distortion of this simple oscillator, after adjustment of P1 and an output voltage of 100 mV (P2 to maximum) is around 0,1%. You can adjust the amplitude of the output signal with P2 as required for the application. The circuit is powered from a 9-V battery. Because of the low current consumption of only 2 mA the circuit will provide many hours of service.

(050355)

Improving RFID Reader

ten picofarads are worth five centimetres

Jan Buiting

The devil's in the details, in this case, the dielectric constant of our printed circuit board material. Don't be put off! In this month's LabTalk we show how half an hour of measuring, thinking aloud and tweaking one capacitor value was rewarded by a five-fold increase in detection distance for the Elektor RFID Reader.

Having been in RF electronics for about 30 years I must have developed a special awareness for stray (that is, invisible) capacitance and inductance lurking in all kinds of circuits. Recently, when I saw my colleagues in the Elektor lab struggling to get RFID cards decoded using the September 2006 Elektor RFID Reader unit, I could not help noticing that the card distance at which the number decoding started to work, was very small indeed at just 1 cm or so. That's disappointing compared to the MiFare Light specifications which claim a far more practical distance of 5 to 7 cm.

Comparative measurements

A few facts were quickly established.

1. samples of the Elektor RFID Reader worked fine as far as the number decoding is concerned;
2. typical card distance for decoding was 1 cm but exceptions of 0.5 cm and 2 cm were observed;
3. a reader board from a Philips MiFare development system easily achieved 5 cm using the same RFID cards.

From these we can list some starting points for the investigation!

1. no problems in the digital circuitry on the Elektor RFID Reader board;
2. the RFID cards are not suspect;
3. a problem may exist in the antenna and 13.56-MHz RF sections of the Elektor RFID reader.

Trial and error

Surmising a problem with the resonance frequency of the on-board wire loop antenna, I initially got out a grid dip meter. Although a good dip was produced by the on-board antenna, the measurement was inaccurate in that the resonance frequency appeared to be dependent on the degree of coupling. So I hooked up an adjustable RF signal generator and an oscilloscope as illustrated in **Figure 1**. The 13.56-MHz test signal of 1 V_{pp} or so was fed inductively into the RFID Reader via a coupling antenna made from 20 turns of wire shaped to give a diameter of about 5 cm. A distance of about 5 cm was set up, the RFID Reader was switched on, and the oscilloscope connected to the 'hot' end of R6 (simply because the RF-IN pin of the MFRC522 chip is hard to get in touch with...). Once synchronised, the 'scope screen told me I had made a silly mistake in forgetting that the MFRC522 is not just receiving a signal at 13.56 MHz, but also generating one! As a result, the signal from the RF generator was swamped by the carrier supplied by the TX section of the MFRC chip. Now, disabling the transmitter part of the MFRC is tricky so I decided to remove the supply voltage altogether, making the measurement passive in essence. Super results this time — the inductively coupled signal from the RF generator showed up at R6 and I was able to make the coupling very light by increasing the vertical distance between the board and the coupling loop to about 5 cms. Then, the moment of truth: cheerfully turning the frequency control on the vintage HP8640B RF signal generator, the signal on the 'scope peaked at a setting of about 12.4 MHz. That's more than 1 MHz off the mark, confirming my suspicion. The resonance itself was nicely pronounced suggesting a reasonable *Q* factor of the balanced, parallel *L-C* circuit formed by the loop antenna, the 'tuning' capacitors and the components for impedance matching to the MFRC chip.

Up with the resonance frequency

Delving into the interesting part of the RFID Reader schematics (reproduced here in **Figure 2**), the solution was looked obvi-

Sensitivity

ous — I thought! From your textbooks you'll no doubt remember that making a parallel *L-C* circuit resonate at a *higher* frequency requires *lowering* the inductance (*L*) and/or the capacitance (*C*). I did not want to mess with the etched loop antenna on the board so capacitor positions C25-C28 were given a 'serious review', whilst noticing that asterisked parts C26 and C28 are not fitted. Unfortunately, in this case of a too low resonance frequency, *less capacitance* was needed, not more, so the 'padding' positions C26 and C28 were useless. Apparently, the antenna circuit had been designed, prototyped and tested using PC board material different from that actually used for volume production of the RFID Reader by the assembly company. In scholarly terms: the real ε_r value, or 'dielectric constant' was insufficiently observed.

A quick test with two 33-pF SMD Cs for C25 and C27 gave resonance at about 14.8 MHz, but the next attempt with 47 pF caps was almost spot-on. In the end, it turned out that 56 pF was the value that gave resonance as close as possible to the target frequency of 13.56 MHz.

The SMD C drawer

Mr. Murphy states that

```
10 IF 56 pF = required
20 THEN 27/33/47/68 pF = available in large
   quantities in the drawer
```

So, 27-pF caps were fitted in positions C25/C27 and two more piggy-backed on top of these to give a theoretical 54 pF. Good resonance was obtained once again, and hey presto the distance at which our RFID cards were reliably read was suddenly a good 5 cm, well within the MiFare Light specifications. Mission completed.

Do it yourself

Figure 3 shows a close-up of the PCB area in which you need to work if your RFID Reader is rather insensitive (card recognition range <2 cm) and you wish to replicate the modification. Be sure to refer to the PCB component layout printed in the original article [1] to positively identify the two 68-pF SMD capacitors C25 and C27 you need to replace. RFID Readers supplied through the Elektor SHOP now come with 56-pF SMD capacitors fitted instead of 68 pF.

Finally, it appears that the antenna on the RFID Reader board is subject to slight detuning if batteries are fitted behind it. In practice, the metal surface formed by the battery pack will cause a slightly reduced sensitivity — simply compare with the card distance obtained with the batteries removed and powering the RFID Reader from USB. If necessary, do the capacitor tweaking trick as outlined in this article to get the best possible card detection range.

(075010-I)

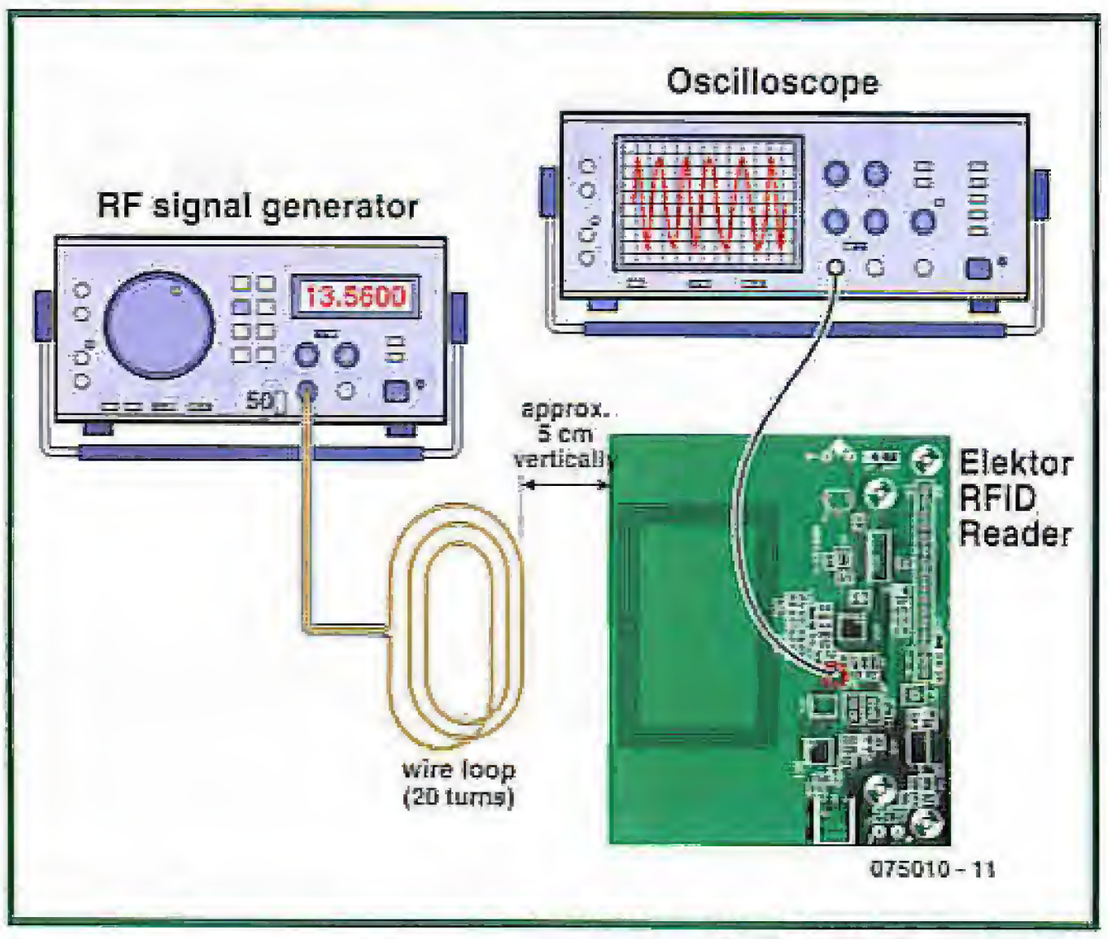


Figure 1. Test setup to find the exact resonance frequency of the antenna circuitry on the RFID Reader board.

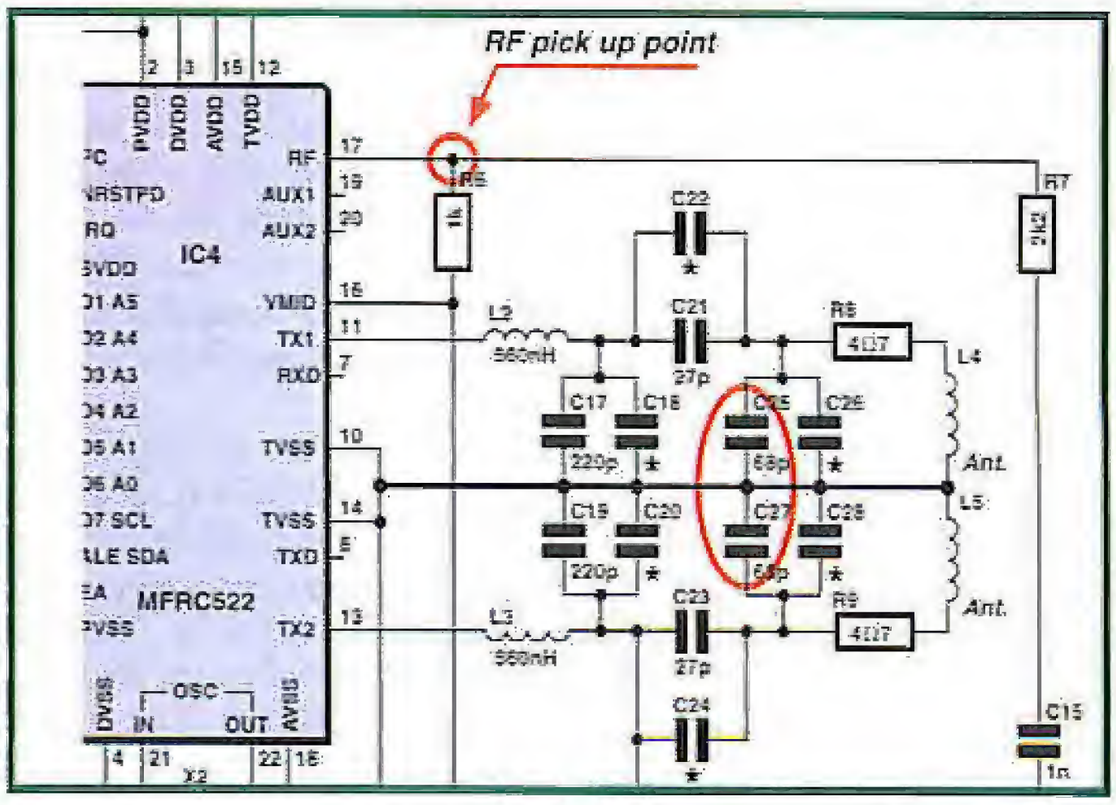


Figure 2. Showing the two capacitors involved and the pick-up point for unbalanced RF.

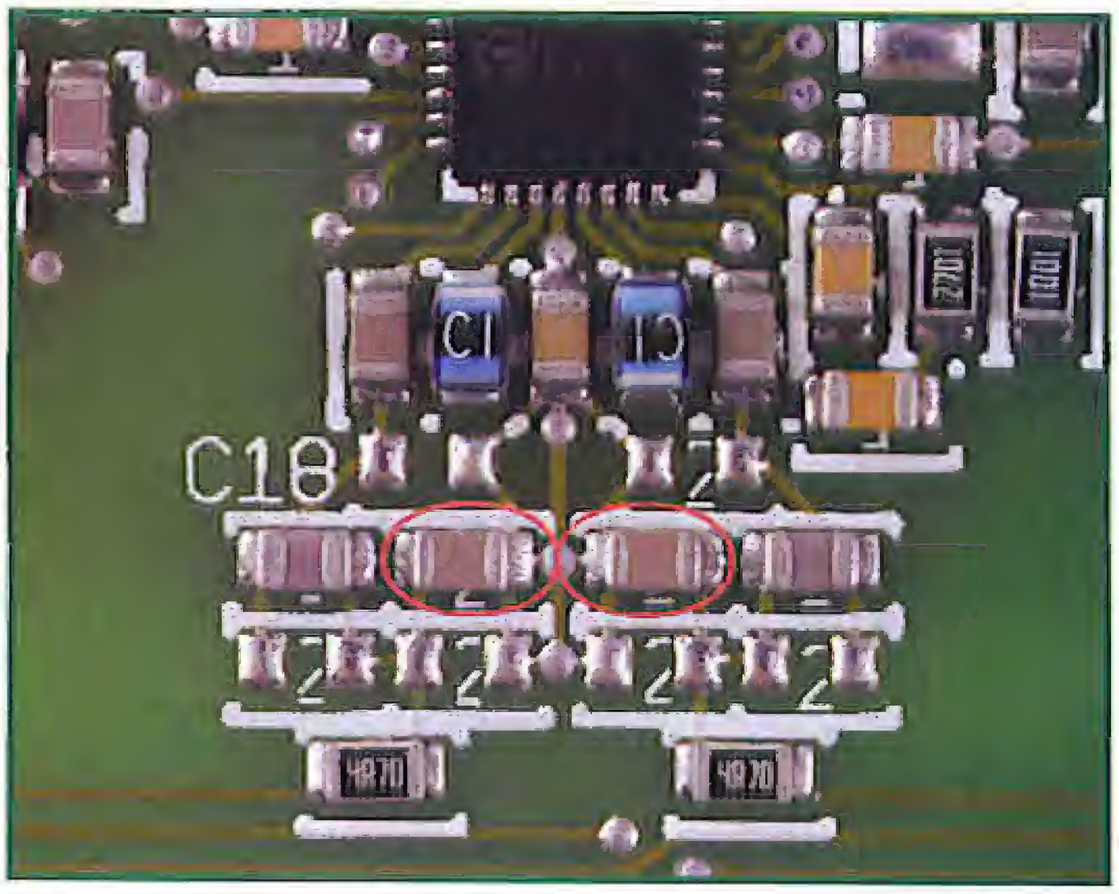


Figure 3. Close-up of the PCB area where the antenna matching and tuning capacitors are fitted. Good eyesight and a steady hand required!

Reference

[1] RFID Reader, Elektor Electronics September 2006.

Display Recycling

An el-cheapo LCD controller

Jeroen Domburg & Thijs Beckers

LCDs are in. Just about everything these days has a display somewhere. That's nice, since the displays can always be used for something else. Of course, it's a bit difficult if the LCD doesn't have a built-in controller. The controller chips are either much too small for DIY work (SMDs with way too many leads) or simply unavailable. But with a bit of ingenuity, it's always possible to devise a solution.

If you work with LCDs and microcontrollers a lot, you certainly know the feeling: you see a nifty LCD in something like a photocopier or game computer that you'd like to use in your own project. You go looking for the pin layout so you can link it to your own PC or microcontroller, but it turns out that the interface consists of an Hsync line, a Vsync line, and four or eight data lines. That means the LCD is naked (no controller).
To get something on the display in this situation, you have to send the entire image at least 50 times a second. That's not such a disaster for industrial applications, since LCD controllers are inexpensive and reasonably available from distributors, but it can be a real problem for electronics hobbyists. The controller ICs are usually only available in tiny SMD packages – if they're available at all. Fortunately, you can use modern technology to build your own rudimentary LCD controller using parts that are easier to come by.

How it works

Here the idea is to operate the display in serial mode. You need several things for this: a video memory to store the image, a means to send the image to the LCD several dozen times per second (including driving Hsync, Vsync, and the other signal lines), and some way to update the data in the video memory. Discrete logic is normally used for the latter two functions, but as regular readers of this topic know, a lot of problems can be solved using an AVR. In this project, we managed to 'compact' a whole lot of electronics that would normally be implemented in discrete logic into software running in an ATTiny2313. The Tiny2313 is nice device, but the downside is that it has only 15 I/O pins. This is nowhere near enough if you want to use SRAM for the video memory. It takes a 16-kB RAM chip just to feed a display with 320 × 240 pixels, which means 14 lines for the address data alone, and then you still need data lines, memory control lines, and control lines for the LCD. This would make a larger AVR necessary, but that's not what you want.
Fortunately, there's another way to tackle this problem by using another type of RAM that is used much less often by the average hobbyist: DRAM. The drawback of this sort of RAM is that it must be refreshed continually. In addition, it can't be connected to a standard address bus. In this application, neither of these drawbacks presents a problem. If the DRAM is used as a video memory, it will be read out (and thus refreshed) every 200 ms, and you aren't using a standard address bus here anyhow. (See the inset 'How DRAM works' for a general explanation of DRAM operation.)

Intelligent use

With a DRAM, you have to drive a total of eight address lines plus a set data lines (four lines in this arrangement). The two address bytes are latched on the falling edges of $\overline{RAS}$ and $\overline{CAS}$. This should mean that the address lines can have any desired value when $\overline{WE}$ or $\overline{OE}$ goes low. It's thus possible to use the address lines for data, which means you can omit the data lines. This reduces the total number of multiplexed lines to eight (plus four control lines). That's not bad if you consider that you're driving 64 kB with just 12 lines!
Naturally, the idea is to link all this to an LCD. A type that can be used with this sort of circuit has at most eight data lines, plus a line that marks the start of a frame (FLM), a line that marks the start of a line (LP), a line for the sampling clock (XSCL), and possibly some other stuff, such as a display-enable line or a line that has to be toggled after each frame. With a bit of luck, there will only be three control lines, and even then it's possible to combine one of the signals with one of the RAM lines. This means you need only 14 lines in total. If you use the last available line as a serial port to write data to the RAM, you use all the available ports of the ATTiny.

Bad luck

We needed only 14 lines and two quite common ICs for the first prototype of the display controller and the first display. That's not bad for something that normally requires dedicated hardware.
Unfortunately, things aren't always so easy. No matter

About the author

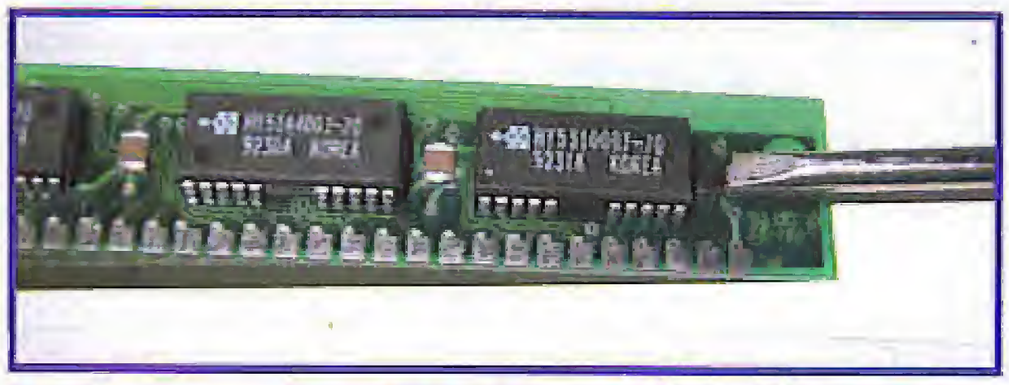
Jeroen Domburg is a student at the Saxion Technical University in Enschede, the Netherlands. Jeroen is an enthusiastic hobbyist, with interests in microcontrollers, electronics and computers.

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

how careful you are, a single wrong connection can be the kiss of death for your hardware, and displays are no exception to the rule. To make a long story short: our first display landed in the rubbish bin along with a set of vaporised line drivers. The replacement display turned out to need an extra line. Naturally, this could be solved by using a large microcontroller, but this would probably mean that the firmware would have to be revised from the ground up. We thus had to come up with a different solution. We augmented the already highly multifunctional address/data lines for the RAM with a latch to provide eight more outputs. This brought the total number of ICs in final version of the circuit to three, which is still a respectably low number.

Hardware

We've already more or less revealed the overall architecture, so the schematic diagram in Figure 1 shouldn't contain any surprises. Input buffer R1/R2/T1 converts the RS232 signal to a TTL level, and it can be omitted if the circuit is connected directly to another microcontroller. IC1 drives the rest of the chips and transfers the data on



The main component is the DRAM. Of course, you can buy it new, but you can salvage it from old PC memory modules. Make sure you pull off the right chip: for instance, if there are three chips on a 30-pin SIMM, each one of them provides only 1 bit.

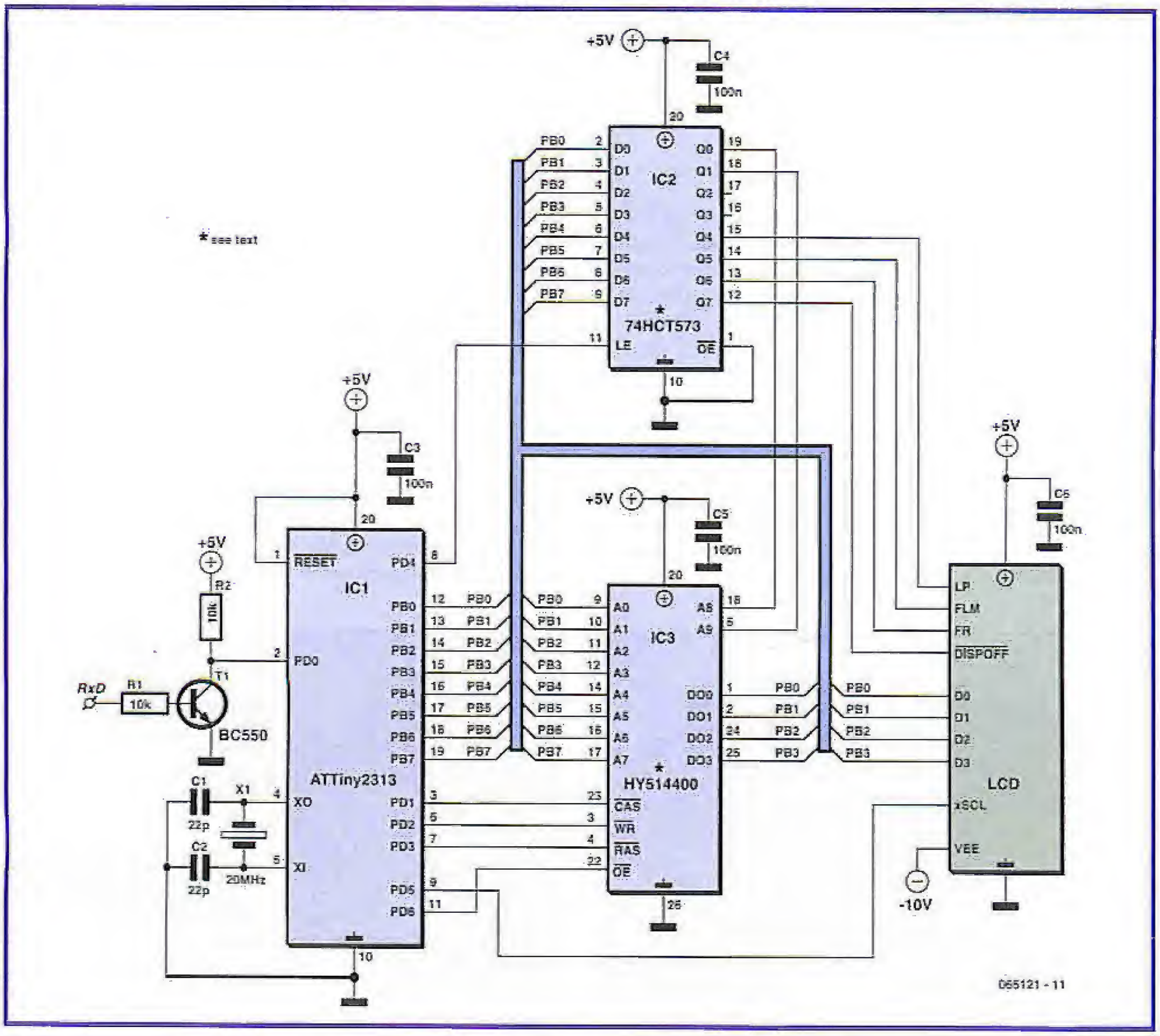
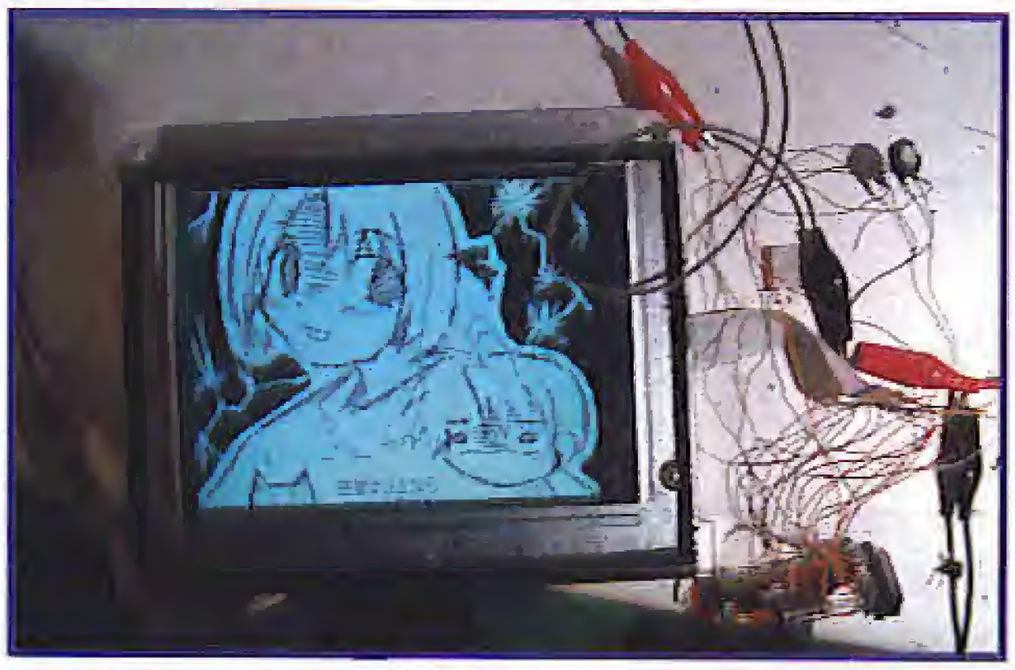
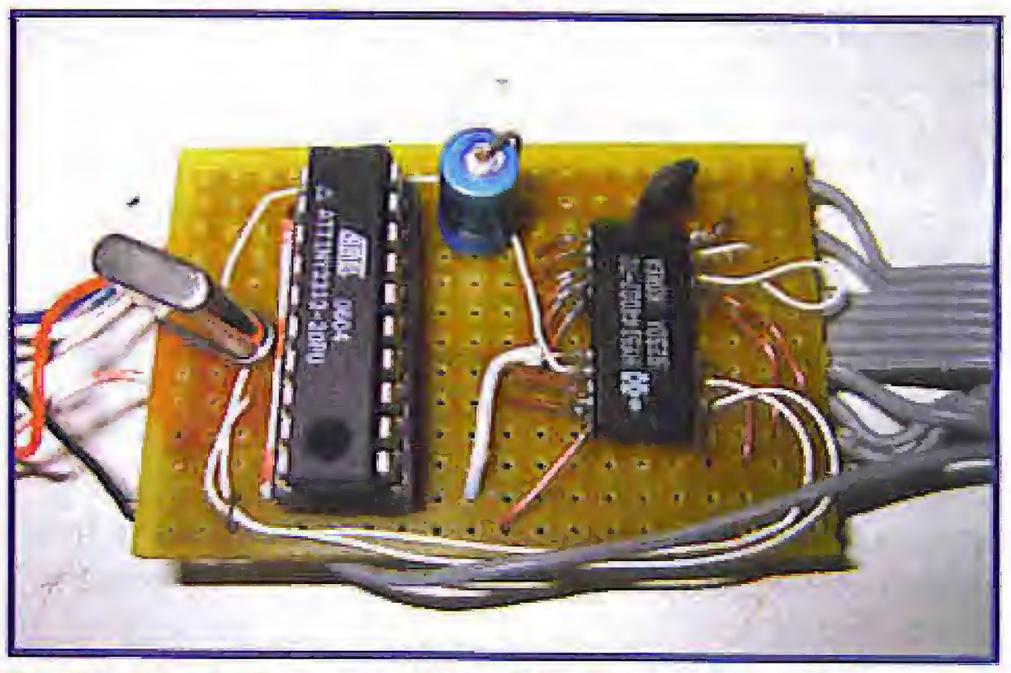


Figure 1. The schematic diagram consists primarily of ICs and data lines. You can count the other parts on the fingers of one hand.



The first test of the feasibility of the idea. This prototype was put together with a lot of flying leads and a nifty 320 × 240 backlit display.



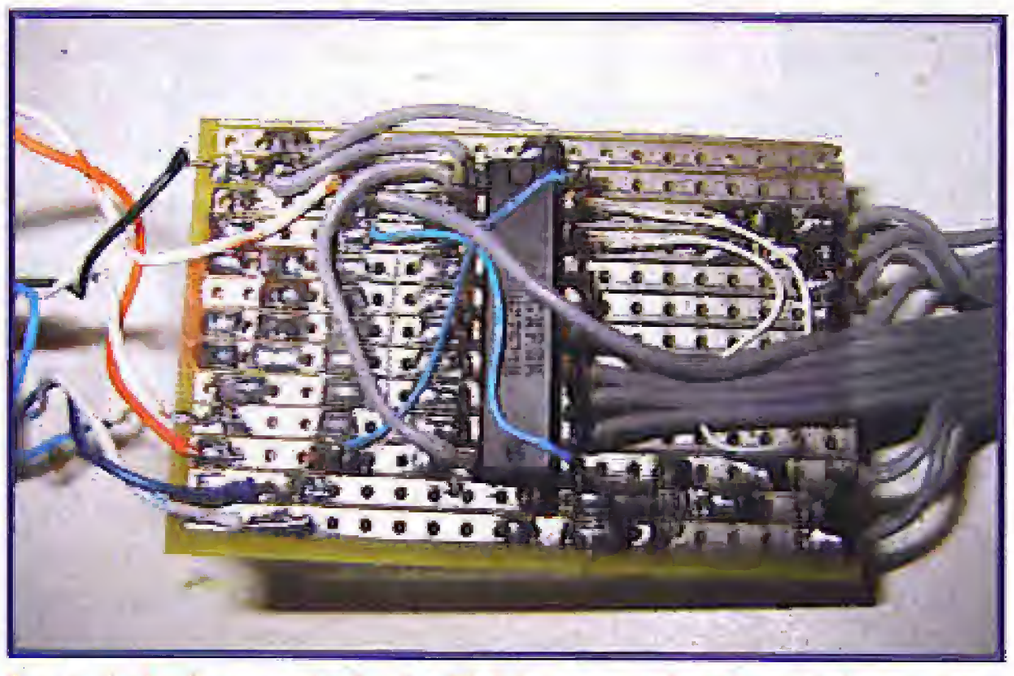
The circuit was built on a circuit board for the second (and final) version as described in the text. And by the way, you don't necessarily have to etch a special circuit board to use SMD parts.

the serial interface port to the video memory. IC2 is a latch. In principle, a 74HC373 could be used just as well here if the different pin layout makes things easier. Finally, IC3 is the DRAM – in this case a HY514400, which was salvaged from an EDO RAM module from an old PC. In principle, any RAM with a capacity of at least 64 k words and a 4-bit data bus could be used here.
The interface lines of the LCD used here are labelled LP, FLM, FR and XSCL, but other labels such as HSYNC, VSYNC, and M or CP1, CP2 and S are often used. Find the data sheet of the LCD you want to use and see which signals it uses. Also check to see how they have to be connected.

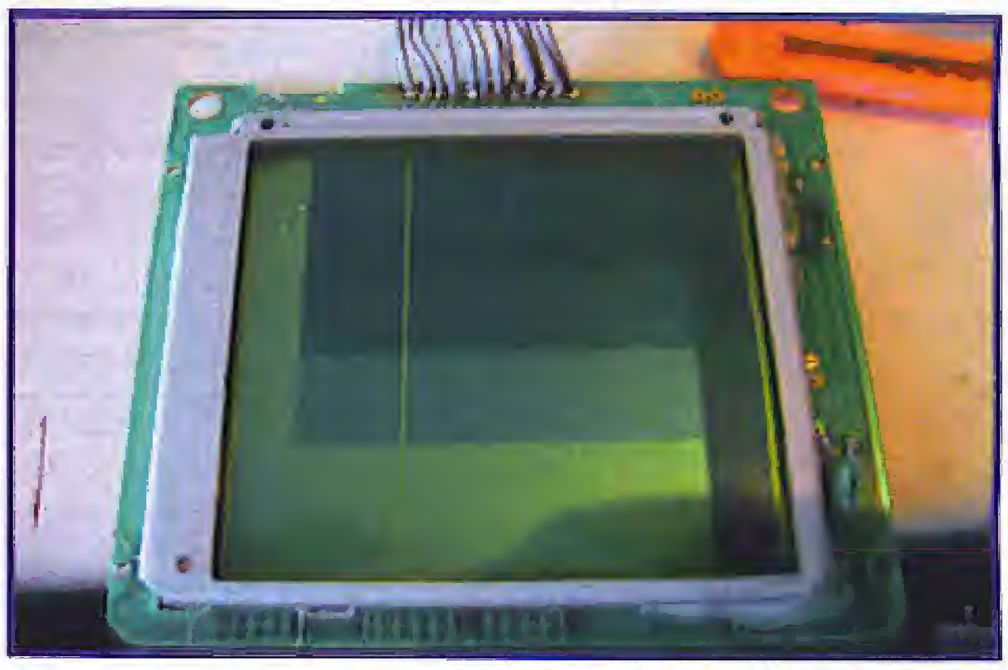
Software

The software in the microcontroller uses a couple of tricks to make everything go a bit smoother. The program spends most of its time feeding data to the LCD. The line number to be sent out is set in the RAM by the falling edge of $\overline{\text{RAS}}$. The actual line content is address using only $\overline{\text{CAS}}$ edges. This saves a lot of extra decision loops, which makes it possible to maintain a high frame rate. This means it's not possible to interrupt the transfer of a line to the LCD to write a byte from the serial port to the DRAM, so data received on the serial port is first stored in a buffer in the AVR. When the AVR is finished sending bits to the display, the bits in the buffer are then written to the RAM in a single go. This minimises the visible effect on display refreshing.

The schematic diagram also includes an extension: two address lines of the RAM (A8 and A9) are connected to the latch. This makes it possible to select a 'page' in memory. If the address bits on these lines are changed, the display receives data from a completely different memory area. You may be wondering what this is good for. Well, if the firmware is configured so that it always displays two frames from page 0 and then a frame from page 1, you can generate grey tones. If a pixel is set in both pages, it will have an average 'on' time of 100% in the display. If it is only set in page 0, its average 'on' time will be only 66%, and the 'on' time drops to 33% if it is only set in page 1. Thanks to the high frame rate, your eye will hardly notice that the pixels are being switched on or off constantly, with the result that it sees a nice grey tone. The only disadvantage is that twice as much data has to be transferred to the controller. For the 160 × 160 display used here, the transfer takes almost a full second.
As a test, we also incorporated modes with three and four pages, which give pixel depths of 3 and 4 bits per pixel (bpp). This produces surprisingly good results. At 4 bpp with dithering enabled, the steps between the grey levels are hardly visible and each image is displayed like a black and white photo.
There are also disadvantages to this technique – in particular, the frame rate is reduced by 50% for each extra page. As a result, the lightest and darkest tones appear to flicker a lot more. For this reason, the number of bits per pixel is configurable in the final version of the software, so you can decide for each application or even for each



Due to lack of space, the latch added later on is fitted on the bottom of the board. This at least keeps everything nice and compact – the whole thing is not much larger than a matchbox.



A test with 2 bpp. Unfortunately, one of the line driver outputs of the display is dead, which explains the vertical white line in the image. Oh well, there are still 159 left.

1 bpp.

2 bpp.

transferred image what balance you want to have between the number of grey tones and the frame rate and transfer time.
The serial interface to the PC is quite simple. Use a terminal emulator program such as HyperTerminal for Windows or vTerm for Linux. Set the communication parameters to 115,200 baud, 8 bits, no parity, and 1 stop bit. The data is transferred in binary form one line at a time. The first byte is a synchronisation byte with the value 0xA5, which is followed by a byte that specifies the page where the line is to be stored. This is followed in turn by a byte with the Y coordinate of the line of pixels to be transferred, and then by the pixel data.
You can configure the number of bits per pixel by inserting an extra set if byies after the synchronisation byte. The first byte has a value of 0xFE, and the next one states the number of bits per pixel in binary notation. If you're a bit uncertain about all this, have a look at the sample code at [1] and [2]. The firmware can also be downloaded from these sources.

Extensions

Although the circuit and the firmware are based on a 4-bit LCD and 4-bit RAM, there are no hardware obstacles to extending the design to 8 bits. If you use a RAM with an 8-bit data bus, the concept will still work with a few modifications to the software. An 8-bit RAM can also be formed using two 4-bit chips. In this case, tie together all the signals except the data lines and use the two 4-bit data busses as a single 8-bit bus to create an 8-bit memory. Incidentally, you can use the same principle to make a 4-bit DRAM from 1-bit chips, but in this case you will naturally need four ICs. The firmware will also have to be modified in this case.

(060121-1)

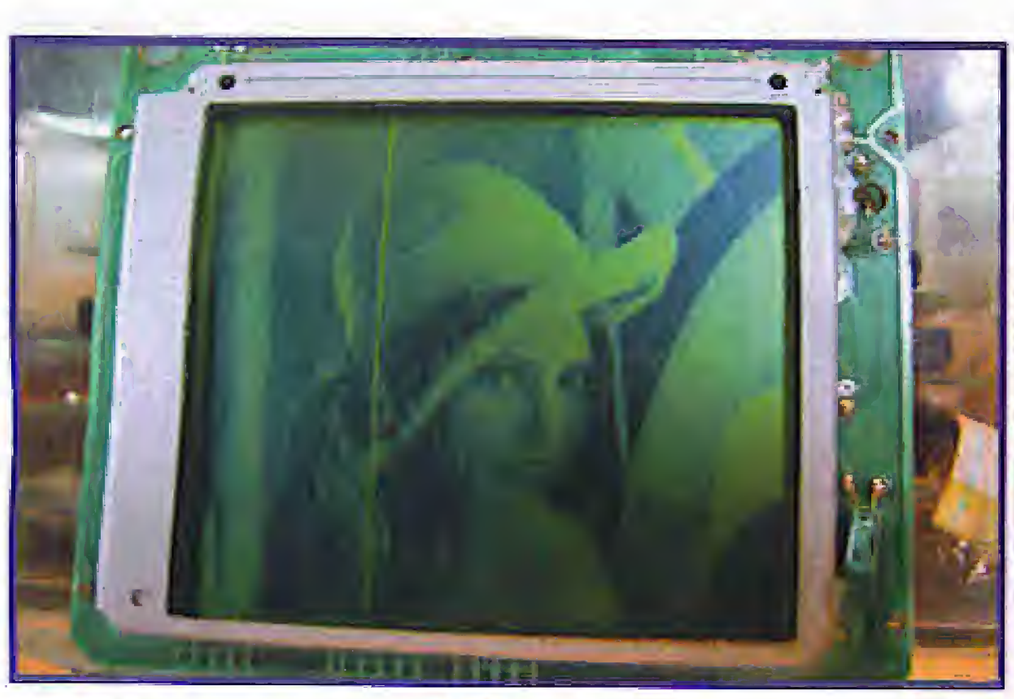
Web links

[1] sprite.student.utwente.nl/~jeroen/projects/lcdc-avr

[2] www.elektorcom

How DRAM works

DRAM has several control lines ($\overline{RAS}$, $\overline{CAS}$, $\overline{OE}$ and $\overline{WE}$) in addition to the address lines. And of course, it also has a set of data lines. The address lines of DRAM chips are multiplexed, so a chip with 64 k words has only eight address lines. The address is set by first placing the first eight bits of the address on the lines and pulling $\overline{RAS}$ low, and then placing the second eight bits on the lines and pulling $\overline{CAS}$ low. The data can then be read by pulling $\overline{OE}$ low. To write data, you place the data on the data lines and then pull $\overline{WE}$ low.



3 bpp.

4 bpp.

Electromechanical switching technology

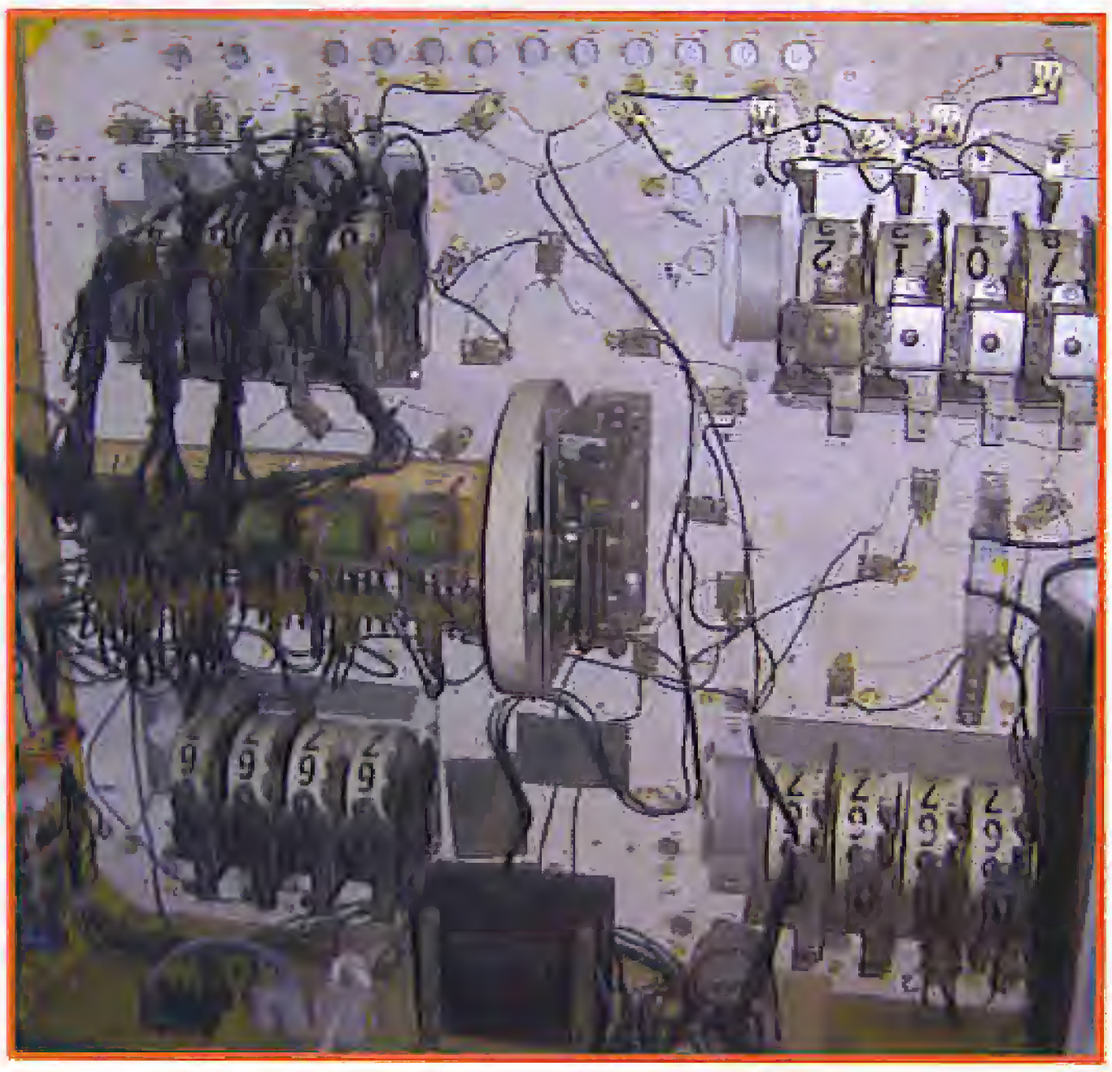
Luc Lemmens

What do you do with a large pile of electromechanical counters from the scrap parts bin? Exactly the same as with other display devices from the past: you turn them into a clock, just like the Nixie-tube clock elsewhere in this issue. Such components from the old parts box are eminently suitable for all kinds of designer timepieces, the combination of old and new technology has a certain appeal. The picture of the clock that we are describing here immediately reveals the origin of the counters, that is, an old electromechanical pinball machine. The clock is built into the so-called backglass. The five large relays underneath the counters are the control logic for the number wheels, the PCB at bottom left provides the clock ticks and is with its CMOS-technology an anachronism. But with EM-technology a pulse generator is indispensable. In the case of a clock you need a pulse every minute (start of a new event) followed by a few quick ones after that to get all the number wheels in the correct position (processing the event). In an EM-pinball machine the 'start' is caused by a target that has been hit by the ball, which then starts a score-motor which in turn generates the required pulses and – depending on the state of various relays – ensures the correct processing of the points scored and then finally stops again.

(Electro-)mechanical calculators existed long before the creation of semiconductor electronics. But while the development of modern calculators and computers have long included tubes, transistors and even ICs, it would take until about the mid seventies before the gaming machine industry finally embraced the microcontroller. After all, relay technology was reasonably robust and over many years had proved itself as a control system for pinball machines and other gaming machines. In the spirit of 'never change a winning team', this technology was held onto for many years. But in the end the power and flexibility of digital electronics was recognised, and the new possibilities that it offered, in particular the increase in processing speed. That is because the combination of relays and score-motor is very slow: every counter required a certain amount of time to change one step, every relay in the circuit caused a delay and the speed of the score-motor could not be increased with impunity.

A glance at the second picture shows how this was a very complex assembly of relays, switching contacts, so-called stepper units, motors and of course the wiring. The 'programming' of a pinball machine was fixed entirely in hardware and it must have been an immense liberation for the designers when the reprogramming of a design became a matter of just plugging in a couple of new EPROMs. For the players the disappearance of all the rattling and ticking was something to get used to, but time moves fast: the first electronic pinball machines are now already part of nostalgia!

(070303-1)



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

Hexadoku

Puzzle with an electronic touch

Hexadoku has proved very successful so we cheerfully continue producing and publishing the puzzle instalments in the new year. Some of you may need a day to solve Hexadoku, others less than half an hour (they say).

No matter as long as you're having fun.

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

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

Participate!

Please send your solution (the numbers in the grey boxes) by email, fax or post to:

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1000 Great West Road
Brentford TW8 9HH
United Kingdom.
Fax (+44)(0)208 2614447
Email:
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Subject: hexadoku 1-2007.

The closing date is
1 February 2006.

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

Prize winners

The solution of the November 2006 Hexadoku is: **1AC70**.

The **E-blocks Starter Kit Professional** goes to:
Paul Keers
(Heworth).

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

Greg Eaton (Victoria, Canada);

Franz Klein (Bishops Cleeve, UK);

Guy Savage (West Walton, UK).

Congratulations everybody!

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

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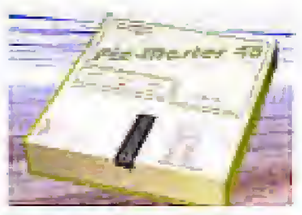

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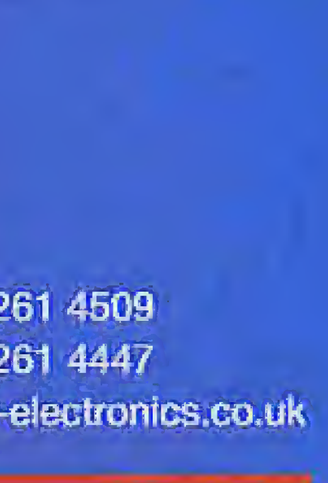

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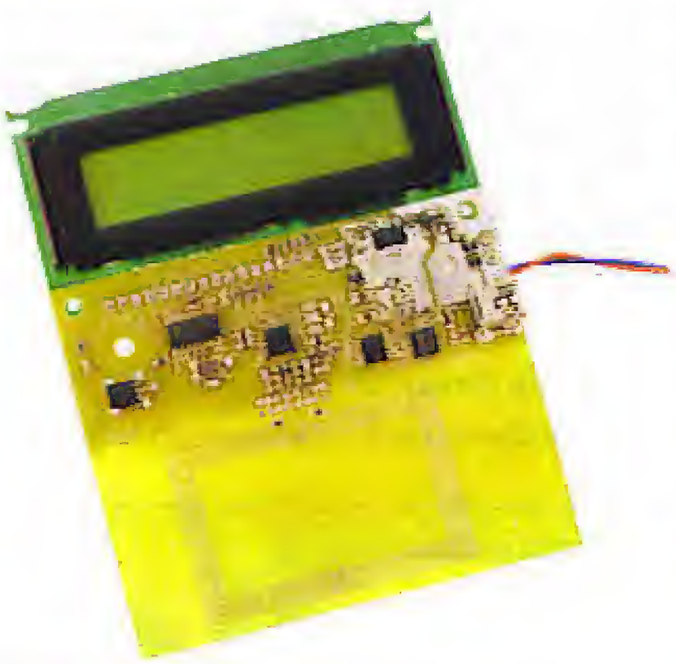

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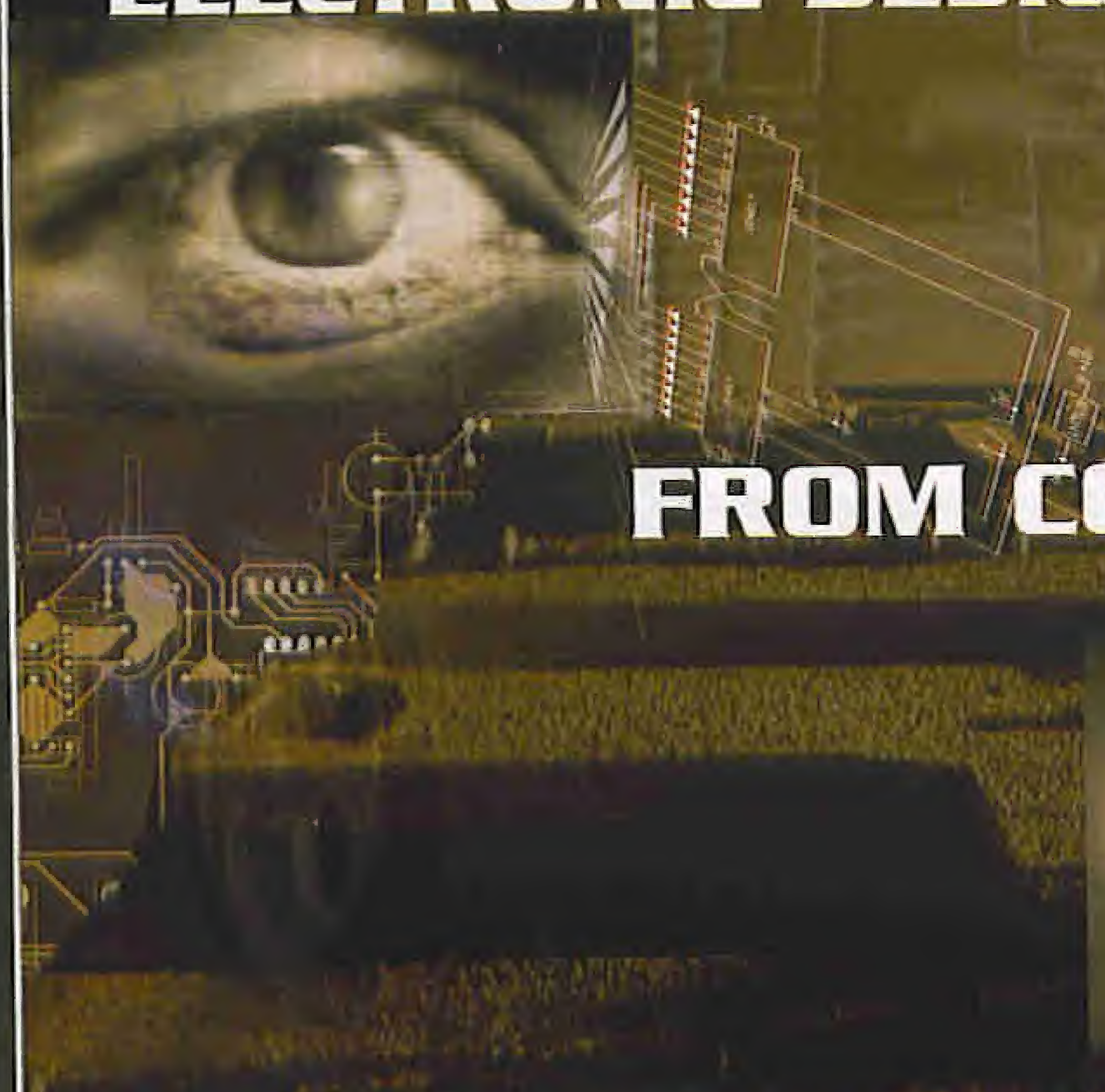

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