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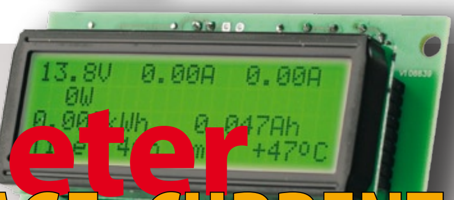
CO_2
detect stuffy air before you doze off

TEST
ENERGY METERS COMPARED



DC Power Meter
VOLTAGE, CURRENT & Wh

- Wireless energy transmission: myth or reality?
- Anti-Standby: down with energy wasters!
- E-blocks: Toyota Prius does 100 mpg

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$CO_2$008

As the editorial staff approach the print deadline for this, yet another fine issue of Elektor magazine, the glass wall of my office gets decorated with proof pages of the articles they want to 'run'. There's a CO_2 meter, a test of electrical energy meters, an article about energy transmission and a fair number of projects. The CO_2 meter was discussed at length — what to do with an instrument like that and just what appears on the readout? CO_2 is 'hot' in more than one sense — everyone's talking about it, but what about the concentration of those one-carbon-two-oxygen molecules in the environment we live and work in? Clearly, when approaching the 8-10% CO_2 level in a room, an acute need is felt to open a window (or two), or take more drastic measures to clean the air. As far as I am concerned this meter deserves a place right beside the thermometer and hygrometer.

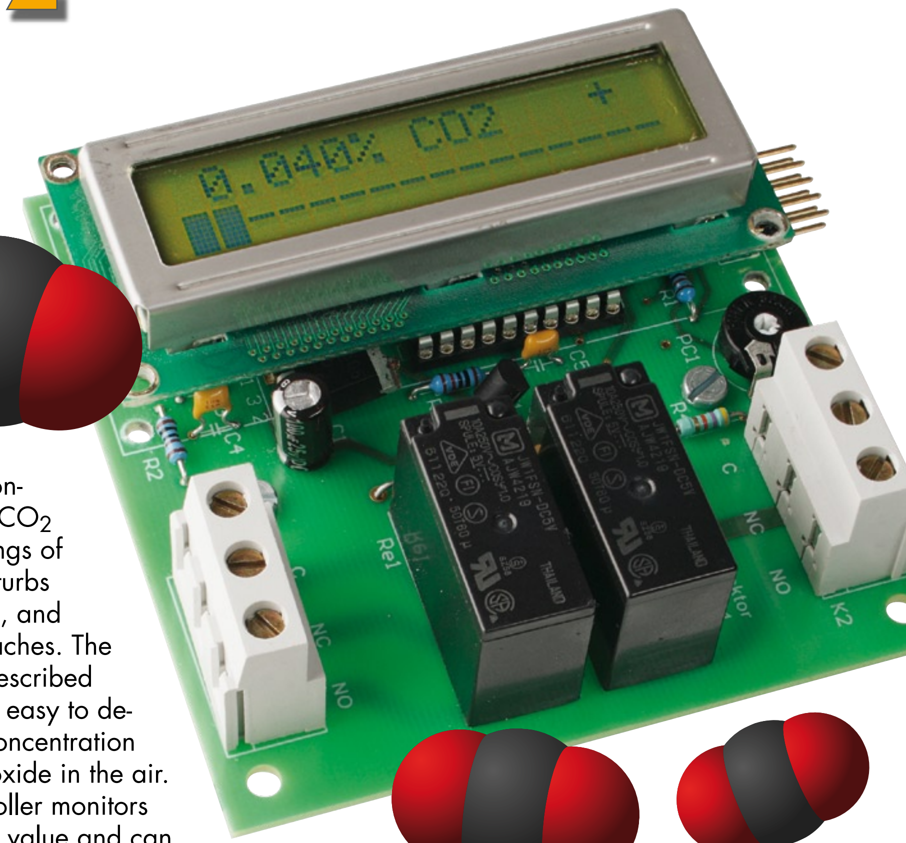
This issue of Elektor is all about energy consumption and practical ways to reduce it. But there's more. As I write this, Greenpeace clamours for attention for the E-waste problem. Because consumers want to have all the latest in mobiles, PCs and e-gizmos all the time, the amount of electronics waste goes sky high (literally), especially in China. Should Elektor readers feel a special responsibility for that? After all, they, like no other, are not only aware of the real amount of energy consumed by all that modern electronic kit seen in the home and office, but they also know of clever ways to save energy and reuse it. Knowledge creates responsibilities, they say, and I would sure like to hear from you on that — just use the Feedback form accessible on our websites (look for the 'Service' tab).

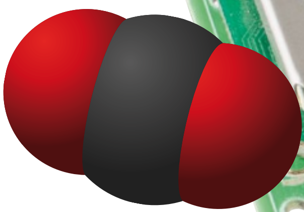
Talking of websites, I am glad to announce the recent launch of the www.elektor.es website. This new, fully Elektor-compatible channel now provides news, products and services to our Spanish readers all over the world — most certainly worth a visit.

With the best wishes from the complete Elektor team and hoping for a clean and interesting year to come,

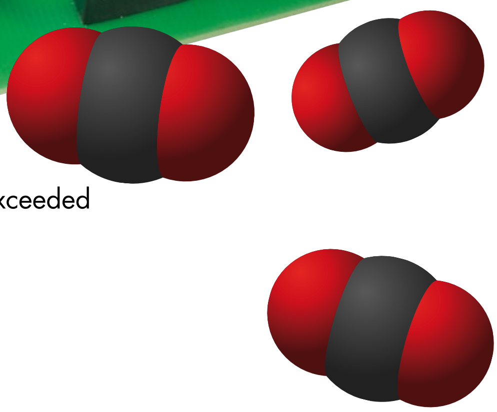
Wisse Hettinga
International Editor in Chief

CO_2 Measurement





Too high a concentration of CO_2 leads to feelings of tiredness, disturbs concentration, and causes headaches. The CO_2 meter described here makes it easy to determine the concentration of carbon dioxide in the air. A microcontroller monitors the measured value and can trigger an alarm or start up a ventilation system when a preset threshold is exceeded



Handy energy meters are available that can just be plugged into a power point and then indicate on a display how much power the appliance uses. How accurate are these meters and what can you actually measure with them? We examined a few of these meters in the Elektor laboratory.

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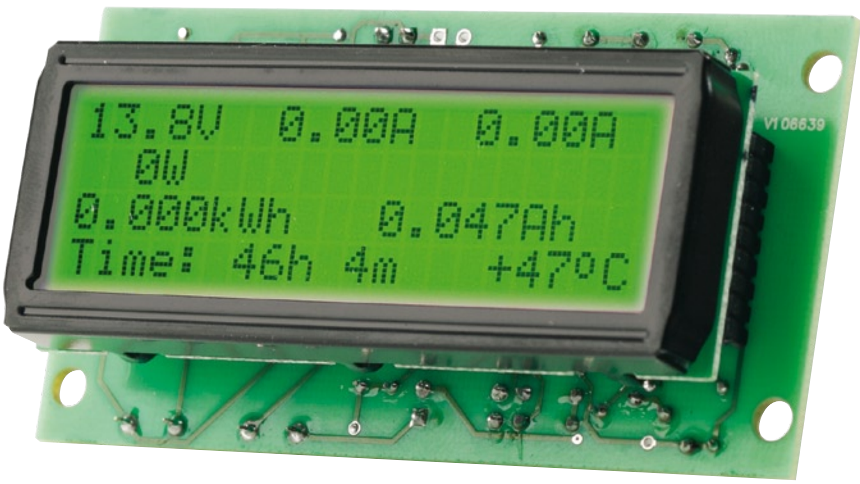
January 2008
no. 373

24 Anti-Standby Switch

Energy Saving may well be a must-have feature for home entertainment products sold today but there are still millions of older and even not-so-old appliances that are guzzling far too much juice in the all too convenient standby mode. The anti-standby switch described here saves the planet's energy—and yours too!

30 Versatile DC Power Meter



This compact DC power supply instrument module can be used with new supplies and older types lacking this capability. And thanks to microcontroller technology, it offers some bonus features.

projects

technology

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elektor international media

Elektor International Media provides a multimedia and interactive platform for everyone interested in electronics.
From professionals passionate about their work to enthusiasts with professional ambitions.
From beginner to diehard, from student to lecturer. Information, education, inspiration and entertainment.
Analogue and digital; practical and theoretical; software and hardware.

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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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ECD 4

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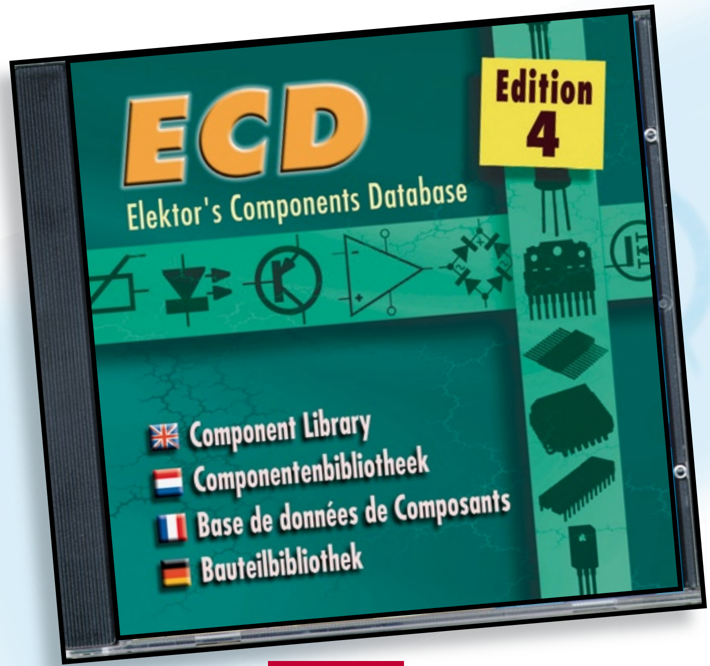

The program package consists of eight databanks covering ICs, germanium and silicon transistors, FETs, diodes, thyristors, triacs and optocouplers. A further eleven applications cover the calculation of, for example, LED series droppers, zener diode series resistors, voltage regulators and AMVs. A colour band decoder is included for determining resistor and inductor values. ECD 4 gives instant access to data on more than 68,000 components. All databank applications are fully interactive, allowing the user to add, edit and complete component data.

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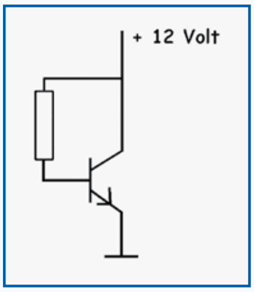
2N3055 travel water heater

Dear Elektor people — in the past few years, I have gone through about seven of those spiral immersion water heaters that operate from 12 V DC. Most of them didn't even last as long as a trip by car to and from the south of France.
After a bit of experimenting with resistors, incandescent lamps and other electronic components that can give off heat and might be able to last longer than these immersion-type travel water heaters, I found the answer in the form of the trusty 2N3055 transistor in its TO-5 package. It has a maximum operating temperature of 200 °C and a maximum rated dissipation of around 115 watts.



The power level can be set with a single resistor between the collector and the base, so the circuit consists of just two components aside from the cable and plug.
The advantage of using a 2N3055 is it is available everywhere and is very cheap. A disadvantage is that the gain is terribly low, and on top of that it varies widely from one device to the next. This means that that the resistance value must be determined for each transistor individually, and there is a good chance that the resistor will become fairly hot. If the 2N3055 is biased to dissipate 50 W and it has a DC gain (h_{FE}) of 20, for example, the resistor will dissipate 2.5 W.
The solution to this problem is to select a transistor with high h_{FE} or use a Darlington pair.

Construction

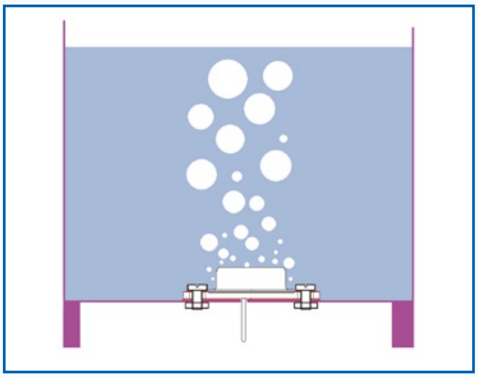
Drill four holes in the bottom of a water jug: two for the fixing screws and two for the base and emitter leads. Fit a thin layer of silicone rubber (cut from a silicone baking cup or baking mould) between the mating surfaces of the transistor and the bottom of the water jug. This material is suitable for use in contact with foods and beverages, and it can withstand temperatures up to nearly 200 degrees Celsius. The chromium of the 2N3055 package also appears to have no harmful effects on health, since immersion heaters are also chrome-plated.
Based on experience, the silicone rubber provides an adequately water-tight seal.
Fit the bias resistor under the bottom of the jug, which will have to be fitted with small feet for this purpose.

My 2N3055 heater has been working well for some time now, and I'm free of the problem of burnt-out immersion heaters. The silicon of the 2N3055 can obviously take the heat better than the material used to make the heater wires.

This principle can also be used for an aquarium heater or any other device where a liquid has to be heated to a certain temperature. In addition, you can use a temperature sensor to control the dissipation of the 2N3055 by regulating its base current and thus keep the liquid at a specific temperature.
J. G. Geradts (Netherlands)

This is a handy tip that can be put to a variety of uses. If you use a 2N3055 to heat drinking water or foods, be sure to use the chrome-plated version instead of the version with a matte metal package, which is also commonly available.

(070879-1)



PC-based logic analyser

Dear Editor(s) — for many years now I have been using a four-channel logic analyser circuit that connects to the parallel port of a PC (published in Elektor Electronics Extra, November 1997). I purchased the software from Elektor (floppy disk 976012-1).

The program worked perfectly on my old Pentium-I PC, but on a Pentium-II, Pentium-III or Pentium-IV machine the 'logic-an' software generates an error message: 'Runtime error 200 at 14DB:0091'. I would like to know where there is an updated version for newer PCs, or whether software for my logic analyser can be found on the Web.
Joseph Maes (Belgium)

Unfortunately, no updated version of the software for faster PCs has been developed for this circuit.
You could try posting a request on our on-line forum to see whether any of our readers has written an updated version of the software and would be willing to send you a copy.
If you still have a Pentium-I PC, you could of course continue using it as a logic analyser.

Conflict between compact OBD2 analyser and car diagnostic system

Hi Jan — when I use the Compact OBD2 analyser (Elektor Electronics, June 2007) to zap through live data, some sort of conflict between the analyser and the car occurs on the bus.

This causes faults to be registered by the diagnostic system of the car, such as 'ESP/ASR fault' or 'Engine temperature too high'. I have tried three different analysers, and the problem occurred with all three of them. At first I though the problem was due to zapping through the live data too fast, but it also occurs with slow zapping, although not as quickly.

I have tried this on two cars: a Citroen C5 type 2, 2.0i 16V with Navidrive etc. and my own car, a Citroen C4 Coupe VTS 2.0i 16V (130 kW-model), also with Navidrive etc.

Alternative and original uses for the LED driver board (September 2007 issue)

Car key

Your free driver board is a really good idea, but it is a bit too large for my intended use, so I used pruning shears to trim it to size. If you would like to see the result, visit the following website:

http://freenet-homepage.de/woodman45/Elektor/

Horst

Now we know how to fit a LED lamp with the PR4401 into a car key. Where there's a will, there's a way!

Corrections & Updates

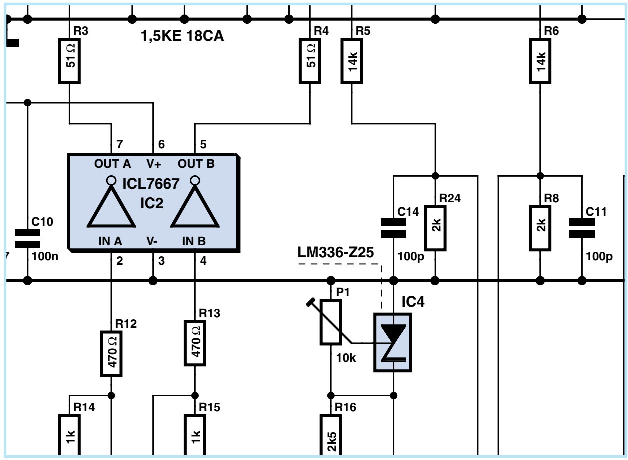
Low² Cost USB Demo Board

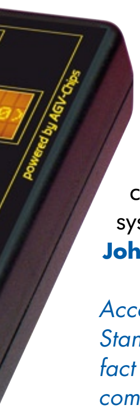
July/August 2007, p. 75, ref. 060342-I

Capacitor C6 should be connected to the VUSB terminal of the PIC18F4550 (pin 18), not to RC7/Rx (pin 26) as shown in the circuit diagram.

Power On Tap - December2007, p. 84, ref. 070462-I)

In the circuit diagram, the lower terminal of resistor R24 should be connected to ground instead of to pin 3 of the microcontroller. Pin 3 then goes to junction R5/R24/C14. The illustration shows the relevant section of the diagram.





Both cars were built in 2005. I also tried the ELM323 and the Mobidic on both cars, in each case without any problems. Are you also aware of this problem? And by the way, the faults are not stored in the ECU; they disappear when the car is restarted. However, the system does respond to the 'Engine temperature too high' fault and switches off various electronic systems.

John Bowman (UK)

According to the author Folkert Stange, this has to do with the fact that the car maker does not comply fully with the EOBD specifications. The main problem is in the timeouts between the various frames. The ELM323 and Mobidic units accept timeouts that are longer than what is specified in the protocol, which is why they work OK. The author is presently developing a remedy. Also view the relevant topic on the Elektor forum.

i-TRIXX: All in hand!

Dear Jan — the pupils in the science class I'm teaching really liked the i-TRIXX supplement (December 2007, Ed.) not just because it was free but also for its — ermm, unconventional — presentation of the projects using that 'wild' typesetting and use of colours. Two pupils were curious about the 'scrap yard' robot hand pictured on the front page (p. 45 in the magazine, Ed.) and have started to collect defunct electronics parts and other bits to build one themselves. Do you have a prototype of the hand?

Dwayne Houseman (US)

It's for real; Dwayne, see the picture of the application the builder, Aart Vroegop, had in mind for his creation.

Variable-capacitance diodes

I would like to build the RDS test transmitter described in the May 2007 issue. All components are readily accessible except the BB909B variable-capacitance diode, which according to the manufacturer is no longer being made. Is there a replacement or equivalent circuit for this diode?

Achim Hoffmann

The BB909A, which has practically the same characteristics, is a direct replacement. We found it in the current version of the ELV 2008 catalogue (www.elv.de), at close to the old price (£ 0.72, or around 45 p). A large selection of variable-capacitance diodes is also available from www.hinkel-elektronik.de, although with a significant 'rare component' surcharge. There you have to pay a couple of pounds per diode.

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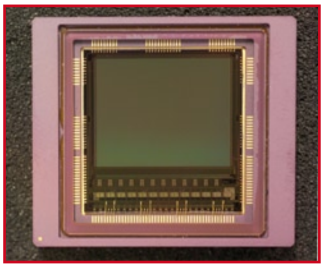
High-Speed SXGA CMOS image sensor has snapshot shutter and LVDS

Cypress Semiconductor Corp. announced the commercial sampling of a high-sensitivity, high-speed SXGA (Super Extended Graphics Array) resolution CMOS image sensor. The new 1.3-megapixel LUPA-1300-2 sensor is the industry's first to offer a triggered and pipelined synchronous shutter and on-chip digital LVDS (Low Voltage Differential Signalling) outputs. Developed for machine vision and motion analysis applications, the image sensor features a high frame rate of 500 frames-per-second (fps) and windowing capability that delivers undistorted images and fast readout.

The LUPA-1300-2 features a fully synchronous snapshot shutter, making it possible to read one image while the next is being acquired and to capture moving objects without distortion. The sensor has 12, 10-bit digital LVDS outputs that allow image data to be transferred over longer distances on the circuit board, thus simplifying layout. The windowing capability enables the user to read out only regions of interest in the image, increasing the effective frame rate. It also has a multiple slope capability to maintain good contrast in shadowed regions without saturating bright areas in scenes with a high contrast ratio.

The LUPA-1300-2 has 1280 x 1024 pixels with 14µm x 14 µm pixel size. The image sensor integrates a programmable offset and gain amplifier for each channel of the LVDS outputs. Each channel runs at a 61 MHz pixel rate, which results in 500 fps frame rate at full resolution. Higher frame rates can be achieved by windowed or subsampled readout modes, which are all programmable over the SPI interface. All internal exposure and read-out timings are generated by an on-board sequencer. The intra-scene dynamic range can be increased by using the flexible multiple slope operation mode. The LUPA-1300-2 also features a 10-bit on-chip analog-to-digital converter (ADC) for digital output and on-chip timing control for easy application development. The image sensor is currently available in monochrome with an RGB version in development.



www.cypress.com.

(070819-IX)

MIMO RF Test Solution

Keithley Instruments has released the industry's leading 4x4 MIMO (multiple-input, multiple-output) RF test system for R&D and production testing of next generation RF communications equipment and devices. Keithley's MIMO RF test system consists of its new Model 2920 Vector Signal Generator (VSG) and Model 2820 Vector Signal Analyzer (VSA), Model 2895 MIMO Synchronization Unit, and powerful MIMO Signal Analysis Software. No other MIMO test system in the industry offers:

- support for 4x4 MIMO applications
- support for a multitude of commercial standards, including cellular, WiMAX, and WLAN
- ±1 nanosecond signal sampler synchronization
- less then 1 nanosecond peak-to-peak signal sampler jitter
- less than 1 degree of peak-to-peak RF-carrier phase jitter.

By allowing for tight multi-unit synchronization with these high performance measurement specifications, the new Keithley system can support MIMO measurements on demanding signals such as 802.11n 40MHz WLAN MIMO and 802.16e Wave 2 Mobile WiMAX.

MIMO is a growing technology that uses multiple radios for both transmitting and receiving data. In RF communication devices, it increases data throughput rates without the need for additional bandwidth. Keithley's 4X4 MIMO test capability provides the most advanced, high performance MIMO testing platform available for future product development with the ability to test the most complex signal structures, including WiMAX Wave 2 and 4G LTE (long term evolution) and UMB (ultra mobile broadband), with a simple software upgrade.

Keithley's new Model 2820 Vector Signal Analyzer comes with 40MHz of bandwidth as standard in either a 4GHz or 6GHz configuration. The Model 2820 is highly versatile and can test a range of signals, including GSM, EDGE, W-CDMA (uplink/downlink), and cdma2000, along with a multitude of WLAN signals, including the 802.11n 40MHz WLAN MIMO signal in both MIMO and SISO configurations.

www.keithley.com

(070819-XI)

PSoC® FirstTouch™ kit in USB thumbdrive format

Cypress Semiconductor Corp. recently introduced the PSoC® FirstTouch™ Starter Kit, a USB thumbdrive kit that provides a quick, easy and affordable way for embedded customers to evaluate the integration, flexibility, and real mixed-signal programmability of PSoC mixed-signal arrays.

Wihout writing or debugging a single line of C or Assembly code, the PSoC FirstTouch Starter Kit, working with Cypress's PSoC Express™ visual embedded system design tool, provides designers with CapSense touch, temperature, light and CapSense proximity sensing right out of the box. Customers can also experiment with many more designs available on a dedicated web page or build their own in minutes via PSoC Express. They can also add all of this functionality directly to their own development systems via the detachable expansion card.

The PSoC FirstTouch Starter Kit includes two small boards — a main system board that interfaces with a computer over USB, and a detachable multifunction expansion card. The expansion card includes inputs and outputs for the many applications supported by the kit. No other thumbdrive kit offers such an extensive array of applications.

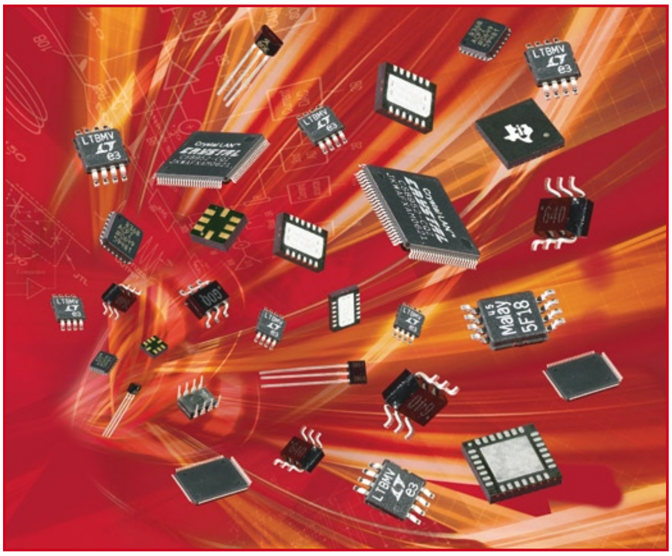
The PSoC FirstTouch Starter Kit is available from the Online Store at the web page below and from Cypress's distribution partners worldwide. The kit is priced at US$29.95.

www.cypress.com/go/firsttouch

(070819-XII)

Farnell increases focus on signal chain with over 1,000 new products

Farnell globally has added over 1,000 new products to its signal chain portfolio in the last three months.
The expansion takes the total number of signal chain products available from stock to over 35,000. Products include data converters, multiplexers, switches, amplifiers, comparators and sensors from some of the world's foremost high-performance analogue suppliers such as Analog Devices, Freescale Semiconductor, Linear Technology, Maxim, ON Semiconductor, National Semiconductor, STMicroelectronics and Texas Instruments.
The product line expansion recognises significant advances in signal



chain technology. It is supported by comprehensive technical data plus links to manufacturer's websites via Farnell's 'Technology First' programme. This programme includes a Technology First online resource on the Farnell website that is dedicated to bringing information on the latest technologies to electronics design engineers as soon as it is available. By providing this resource, Farnell can support engineers with component selection and design choices as well as providing a streamlined system to purchase products.

www.farnell.co.uk

(070904-I)

Correction

Boards for PIC, ARM and Embedded Linux (SK Pang Electronics; News & New Products, December 2007, p. 12).

The first sentence of this news item should have read:

SK Pang Electronics announce three new products.

We apologise to SK Pang Electronics for the typing errors in the original.

Dual output pot for guitar foot pedal

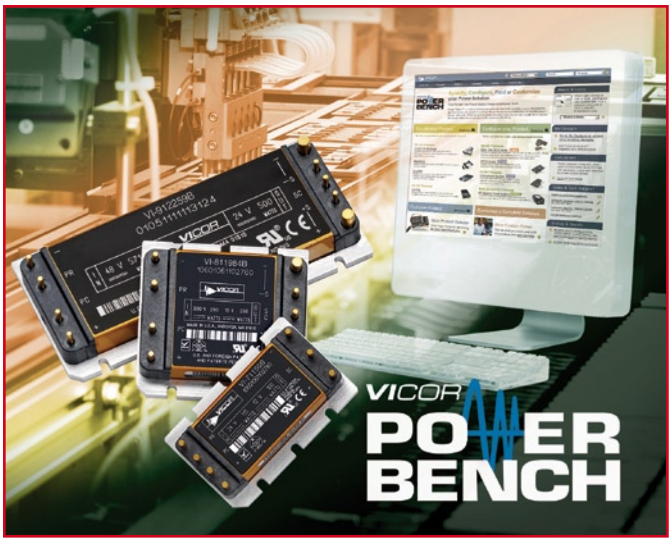
TT electronics' BI Technologies Electronic Components Division's Model P232 rotary potentiometer has been specified for use by a leading manufacturer of guitar foot pedals.
The 24 mm RoHS-compliant P232 'wah' pedal potentiometer features a life cycle of 2 million rotations and is offered with audio and reverse audio tapers, along with custom audio tapers.

(070904-II)

Power supply design tools

Vicor announces the launch of PowerBench™, a unique suite of enhanced online power supply design tools that helps ensure designers select the best power supply to meet their requirements. If an appropriate standard product does not already exist, engineers can use PowerBench to design a customer-specific product, allowing them to focus on their ideas rather than the constraints dictated by power supply availability.

PowerBench enables engineers to determine whether a standard, existing non-standard or customer-specific specification power supply will best meet the needs of their application. Vicor is the only power supply company to manufacture all products – whether standard or customer-specific – using the same production line and process. This reduces NRE, costs and lead times, ensuring comparable pricing for standard and non-standard supplies as well as the same outstanding levels of quality and reliability for all products.
Engineers use PowerBench's module design system to specify online



the exact power supply they need and verify in real time its performance and attributes. This eliminates the risk of specifying the wrong power supply for the application. Customer-specific products specified using PowerBench offer cost-effective NRE costs (typically $3500 for a new product), and prototype quantities are usually delivered in less than six weeks, reducing time-to-market for the end system.

The PowerBench suite of tools encompasses the design of DC-DC converters, AC-DC and DC-DC partitioned power architecture (VI-PAC and VIPAC Arrays), and a broad range of power-factor corrected AC-DC power supplies.

www.vicoreurope.com/powerbench

(070904-III)

Turn on the heat in new hockey skates

Cypress Semiconductor Corp. announced that its PSoC(R) CapSense(TM) solution for capacitive sensing is employed in the revolutionary new heated hockey blades made by Therma Blade, Inc. Therma Blades are technologically advanced skate blades that use electronics to heat the blade, thereby reducing friction between the blade and ice surface, creating a smoother feel, and improved skating performance.

The PSoC solution allows the heat to be turned on and off using touch sensitive controls, eliminating the need for mechanical buttons that can be broken or pressed accidentally, an important feature considering the very physical nature of hockey. The CapSense solution is also waterproof, a feature that is useful for hockey, as well as white goods such as washing machines and dishwashers, and industrial equipment. The skate takes advantage of a CapSense-PLUS device in which the PSoC solution does much more than just on and off controls. The CapSense device also heats the skate blade and powers down the system during periods of inactivity to extend battery life.

The new product, an aftermarket blade that attaches to any conventional hockey skate boot, was recently launched to the retail market, endorsed by hockey legend Wayne Gretzky.

A single CapSense device can replace dozens of mechanical switches and controls with a simple, touch-sensitive interface. CapSense-based 'button' and 'slider' controls are more reliable than their mechanical counterparts because they are not prone to the environmental wear-and-tear that affects exposed buttons and switches. Cypress has garnered well over 100 CapSense design wins worldwide in applications that include mobile handsets, portable media players, white goods, computers, printers and automotive, among others.

www.cypress.com/capsense
www.cypress.com/psoc
www.thermablade.com

(070904-IV)

Students and educational institutions get 20% discount on SchmartBoard

SchmartBoard has announced a new education discount program. Electronics Education generally teaches electronics theory, but not hand soldering skills. Despite this, electronics students must still figure out how to design and assemble circuits that use advanced component packaging, which requires expert soldering skills to prototype. SchmartBoard|ez technology alleviates this challenge by making it easy to hand solder these types of advanced surface mount components. SchmartBoard thus opens up the scenario for students to successfully utilize today's advanced technology for senior projects and other class requirements.

SchmartBoard will now offer a 20% discount to high schools, colleges, trade schools universities and their students. Other advantages are available to institutions that sign up for the program including some demo boards for in-school lab's to demo the technology to students.

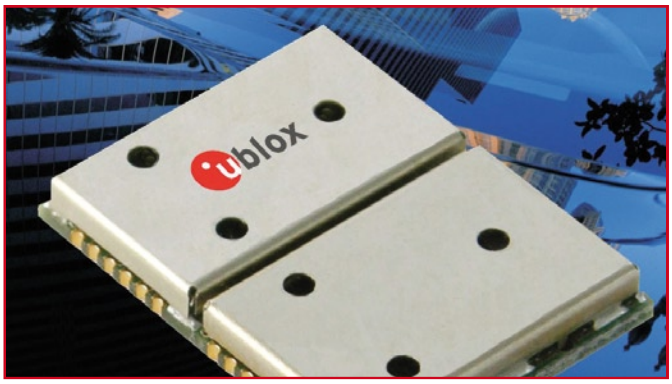
Details of the program can be found at:
www.schmartboard.com/index.asp?page=schmartland_education

(070904-VI)

50-channel LEA-5 GPS module series

u-blox AG announced the launch of two GPS modules that set new benchmarks in terms of speed, sensitivity and ease of integration. The LEA-5 GPS module series is based on u-blox' fifth generation positioning engine, u-blox 5, which boasts an acquisition performance of less than one second.

These versatile, stand-alone GPS receivers combine an extensive array of features with flexible connectivity options. Their ease of integration results in fast times-to-market for a wide range of automotive, consumer and industrial applications with strict size and cost requirements.



u-blox 5 offers an ultra-fast acquisition time thanks to its 50-channel GPS architecture with over 1 million correlators and separate acquisition and tracking engines, capable of massively parallel searches. Combined with u-blox' AssistNow A-GPS service, the u-blox 5 chip and module generation acquires satellites in less than one second.

The LEA-5 GPS module series is lead free and has an industrial temperature range of –40 to 85°C.

Its small form factor and SMT pads allow for fully automatic assembly processes with standard pick-and-place equipment and reflow soldering, enabling cost-efficient, high-volume production.

The LEA-5H GPS module comes with a Flash EPROM that enables easy firmware upgrades and set-up configuration saving options. The ROM-based LEA-5S offers further cost efficiencies. Both modules feature u-blox' OMA SUPL compliant A-GPS interface and support AssistNow Online and AssistNow Offline A-GPS services.

www.u-blox.com

(070904-VIII)

2.4GHz transceivers with card-sized RF keypads

Nordic Semiconductor ASA (OSE: NOD) today announced that Turning Technologies LLC has standardized on Nordic Semiconductor 2.4 GHz transceivers in its TurningPoint® software and credit card-sized RF ResponseCard® wireless keypads. The transceivers are used in the brand new XR ResponseCard (that employs the Nordic Semiconductor nRF24L01 and includes an LCD screen) and the existing RF ResponseCard (Nordic nRF24E1) that has an installed base of over one million units.
The TurningPoint audience response system integrates seamlessly with Microsoft Office programs to allow audiences and students to participate in presentations or lectures by wirelessly submitting voting responses to interactive questions using a ResponseCard keypad.
These responses can then be automatically collated and statistically assessed/displayed in real-time for use by the presenter or teacher. The real-time feedback means presentations or classes become far more engaging, interactive and measurable. Indeed, the TurningPoint system has proved so popular in the US education market that many textbook publishers have begun distributing ResponseCards alongside their textbooks and selling them in campus bookstores.

In operation a Nordic Semiconductor 2.4 GHz transceiver located in a USB dongle simply plugs into the presenter's PC. Each dongle can wirelessly communicate with up to 1000 uniquely identifiable ResponseCards that can be retained by a single user for use in different venues or classes. By using additional dongles, there is no practical upper limit to the number of ResponseCards that can be used in a single presentation session or class.
The existing RF ResponseCard adopts a keypad-only format with 12 keys and a multi-color LED that provides feedback to users.
It will run for between 6 to 12 months off dual 3 V CR2032 coin cells and uses a Nordic Semiconductor nRF24E1 with embedded 8051 compatible microcontroller and 9-channel, 12-bit, 100 kSample/s ADC (see About Nordic Semiconductor nRF24E1 for more information) to manage all on-board processing functions from keypad decoding to RF comms.
The entire product weighs just 1-ounce (28 g) including the coin cell. Range for a single USB dongle receiver is up to 200 feet (60 m).

The nRF24E1 is a 2.4-GHz, single chip, true GFSK transceiver with embedded 8051 compatible microcontroller and 9-channel, 12-bit, 100 kSample/s ADC plus 1 Mbit/s maximum data rate. It comes pre-integrated with all necessary peripherals, inductors and filters and requires only three external components: a crystal, resistor and low cost 4-KByte EEPROM (for initial program storage).
The nRF24E1 also features DuoCeiver™ technology for simultaneous dual receiver topologies and a ShockBurst™ mode for ultra low-power operation and relaxed MCU performance. Power supply range is 1.9 to 3.6 V, supply current is just 10.5 mA peak (TX) at –5 dBm output power at full 1 Mbit/s, and 19 mA peak (RX) in receive mode (one channel at 1 Mbit/s). In complete system standby (sleep) mode (wake up from timer or external pin) the nRF24E1 consumes just 2 µA.
The nRF24E1 is supplied in a small 36-pin QFN 6x6 mm package and supports frequency hopping across up to 125 channels with a sub-200 µs switching time, including clock recovery of data plus CRC computation in receive (RX) mode. Operating temperature range is –40 to +85 ºC.
Prime applications include wireless mouse, keyboards and joysticks/gamepads, remote controllers, alarm and security systems, phone peripherals, PC peripherals, home and building automation, telemetry, wireless tags, intelligent sports equipment (e.g. wrist watches and associated sensors), industrial sensors and toys.

The nRF24L01 is a wireless solution for compact, battery operated applications with stringent requirements on battery lifetime and cost. The transceiver operates in the license free worldwide 2.4 GHz ISM band and provides a 2 Mbps (Mega bits per second) air data rate.
Supplied in a compact 4×4mm QFN package, the nRF24L01 integrates a complete 2.4 GHz RF transceiver, an RF synthesizer, full baseband logic including the unique Enhanced ShockBurst™ hardware link layer, advanced power management and a high-speed SPI for the host controller interface. No external loop filters, resonators or VCO varactor diodes are required, only a low cost ±60 ppm 16 MHz crystal, matching circuitry and the antenna.
The nRF24L01 has a unique combination of four features that enable the implementation of ultra-low power wireless connectivity:

- A sub 13 mA TX and RX active current that permits coin-cell battery operation
- An advanced power management with power saving idle mode plus rapid active mode startup
- A high 2 Mbps air data rate that minimizes the amount of time the transceiver has spend in the relatively more power consuming active on-air mode in order to achieve a given effective data rate
- An Enhanced ShockBurst™ link layer that minimizes processing load on the host microcontroller reducing average current consumption

The nRF24L01 includes Nordic's Enhanced ShockBurst™ hardware link layer. This features both automatic packet handling and automatic packet transaction handling.
Automatic packet handling key features include:

- Packet assembly
- Packet detection and validation
- Dynamic payload length
- MultiCeiver™ support for up to 6 bi-directional logical links for 1:6 star network topologies

Automatic packet transaction handling key features include:

- Acknowledgment of received packages
- Payload in acknowledgment packet
- Retransmission of lost packages

www.nordicsemi.com
www.turningtechnologies.com
www.responsiveinnovations.com

(070904-V)

New PIC32 Family

Microchip announces the PIC32 family of 32-bit microcontrollers (MCUs), adding more performance and memory while maintaining pin, peripheral and development compatibility with Microchip's 16-bit MCU/DSC families. The new PIC32 family is fully supported by Microchip's free MPLAB® Integrated Development Environment (IDE) which now offers compatibility by supporting Microchip's complete portfolio of 8-, 16- and 32-bit devices.

Launching with seven general-purpose devices, the PIC32 family operates at up to 72 MHz and offers ample code- and data-space with up to 512 kB Flash and 32 kB RAM. The PIC32 family also includes a rich set of integrated peripherals including a variety of communication peripherals and a 16-bit Parallel Master Port supporting additional memory and displays.
The PIC32 family is based on the industry-standard MIPS32® architecture, with its leading combination of high performance, low power consumption, fast interrupt response and extensive industry tool support. The PIC32's high-performance MIPS32 M4K® core can achieve 1.5 DMIPS/MHz operation, due to its efficient instruction-set architecture, 5-stage pipeline, hardware multiply/accumulate unit and up to eight sets of 32 core registers. In addition, to reduce memory requirements, the PIC32 supports the MIPS16e™ 16 bit ISA — enabling code-size reductions of up to 40%.
All PIC32 products are supported by Microchip's development tools, including the MPLAB IDE, the new MPLAB C32 C compiler, the MPLAB REAL ICE™ emulation system, the MPLAB ICD 2 in-circuit debugger and the (Elektor) Explorer 16 development board.
The PIC32 is also launching with broad MIPS-based tool support throughout the industry. Complete tool chains are available from Ashling, Green Hills and Hi-Tech — including C and C++ compilers, IDEs and debuggers. RTOS support is available from various vendors including CMX, Express Logic, FreeRTOS, Micrium, Segger and Pumpkin. In addition, graphics display tools providers include EasyGUI, Segger, RamTeX and Micrium. A full list of third-party support for the PIC32 family can be found at the website below.
The PIC32 Starter Kit comes complete with everything that developers need to get started, including the USB-powered MCU board, MPLAB IDE and the MPLAB C32 C compiler, documentation, sample projects with tutorials, schematics, and 16-bit compatible peripheral libraries. Application expansion boards are also being made available, which plug into the expansion slot on the bottom of the MCU board. The PIC32 Starter Kit (part number DM320001) is available now at microchipdirect.com, for only $49.
The first devices in the PIC32 family come in 64- or 100-pin TQFP packages. The new family has been sampling into early adopter designs, and is now available for general sampling. Volume production for all seven initial devices is expected in Q2 2008.

For additional information, visit: www.microchip.com/PIC32

(070904-VII)

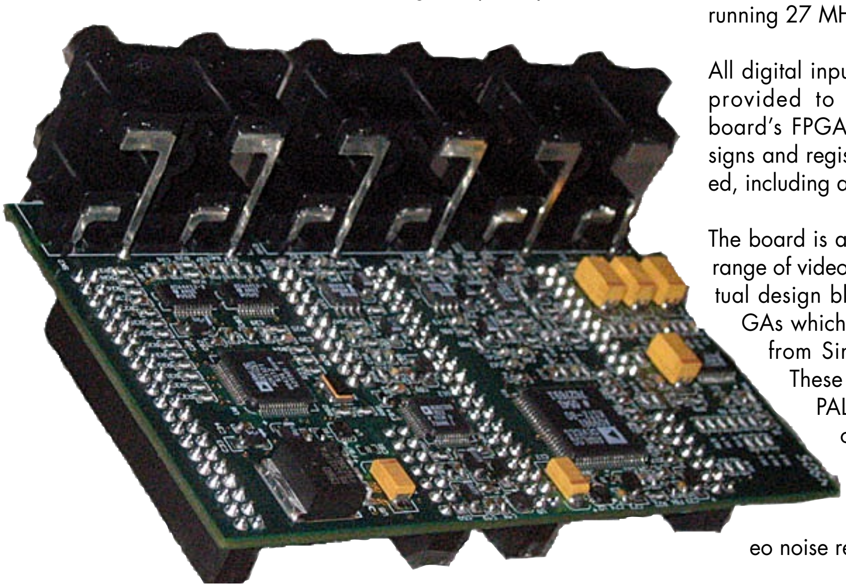
Analogue connectivity to Altera and 3rd party FPGA dev boards...

… utilizing the Santa Cruz connector set. SingMai's new DP1 board provides a high quality analogue/digital interface capability for the development of audio and video processing algorithms for applications in consumer electronics, security, broadcast and general purpose image processing.

DP1 provides three 10-bit video ADCs using the Analog Devices AD9981 IC that allow conversion of SD and HD analogue video in a variety of formats to digital video for processing by the development board FPGA. In addition clocks and sync signals can be extracted from the input video.

Output video processing is provided the ADI ADV7321 which provides simultaneous RGB/YPbPr outputs, again for SD and HD video, as well as composite video outputs.

Audio interfacing is provided via another ADI codec. Stereo analogue audio is converted to I2S using a 24-bit ADC whilst a high quality stereo DAC provides output analogue capability.



The board provides all the necessary input and output buffering, power and interfacing for these ICs and also incorporates a free-running 27 MHz crystal output.

All digital inputs and outputs are provided to the development board's FPGA and example designs and register sets are provided, including a simple I2C driver.

The board is also supported by a range of video and audio intellectual design blocks for Altera FPGAs which are also available from SingMai Electronics. These include NTSC and PAL decoders and encoders, video character generators and pattern generators, and video noise reduction.

www.singmai.com/index.htm

(070904-IX)

CO_2 Measurement

Stuffy air alert

Carbon dioxide (CO2) is not just a threat to the environment, it is also an important and often ignored factor in determining air quality in the office and at home. Too high a concentration of CO2 leads to feelings of tiredness, disturbs concentration, and causes headaches. The CO2 meter described here makes it easy to determine the concentration of carbon dioxide in the air. A microcontroller monitors the measured value and can trigger an alarm or start up a ventilation system when a preset threshold is exceeded.

Characteristics (using CDM4161 module)

- measures ambient CO_2 concentration in air to monitor indoor air quality
- Insensitive to other gases, temperature and humidity
- CO_2 concentration measurement range: fresh air (approximately 400 ppm) to 4000 ppm (0.04 % to 0.4 %)
- Switching output rated for 10 A at 230 V to control ventilation system, with four preset CO_2 concentration thresholds
- Switching output rated for 10 A at 230 V to activate alarm or emergency ventilation
- Concentration reading displayed on LCD in digital and analogue form
- Trend indication
- No adjustments required (automatic calibration)
- Simple power supply requirement using mains adaptor

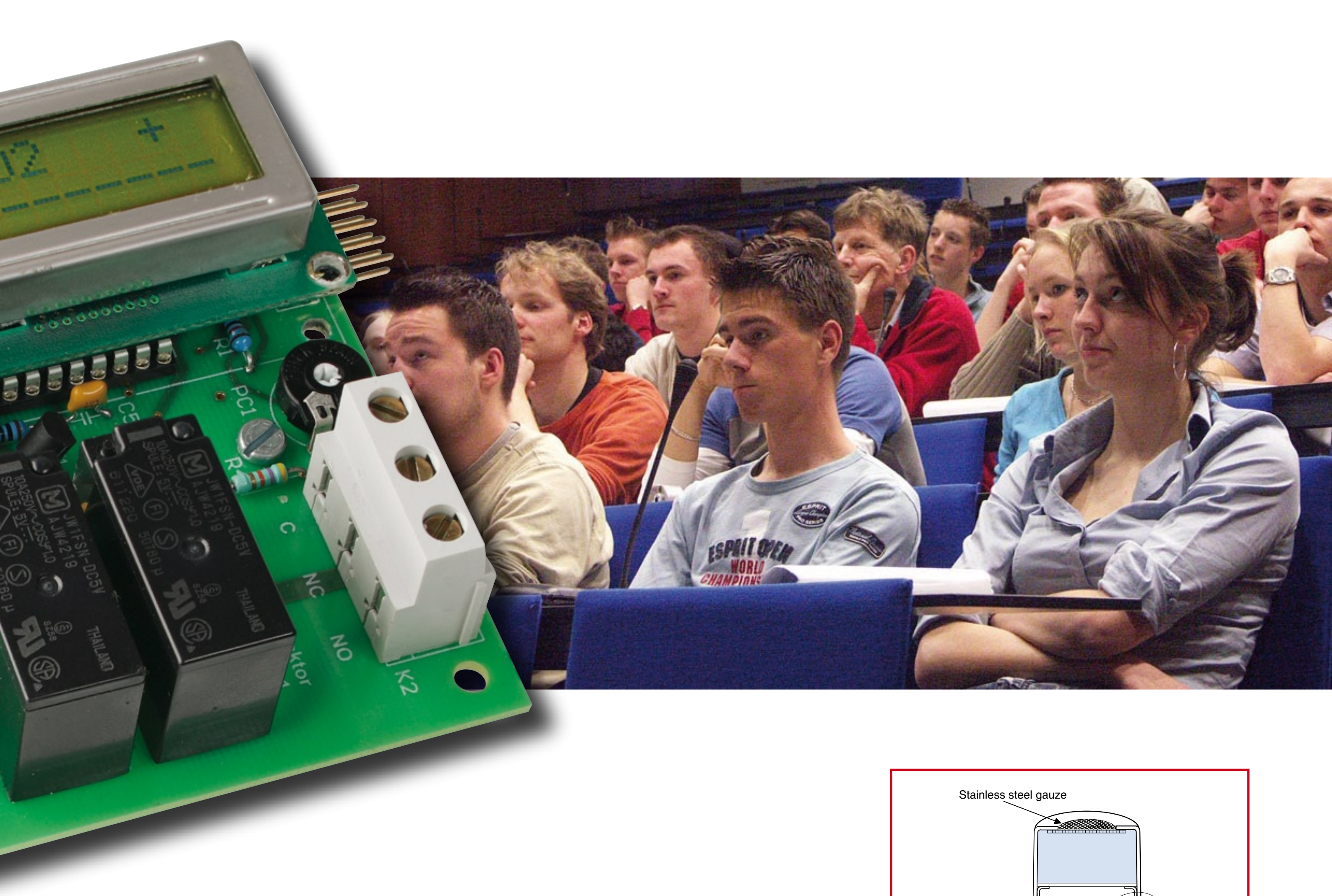
The large **text box** discusses the properties, effects and side-effects of this highly stable compound of one carbon atom with two oxygen atoms. The motivation for building the CO_2 meter described here is not climate research: it is rather aimed at monitoring and, if necessary, improving indoor air quality. CO_2 concentration is a good indicator of air quality in the office or home. An elevated level of CO_2 indicates that ventilation is necessary. However, our CO_2 meter does not just give a direct display of the CO_2 level, but also compares it to a threshold, activating a relay when the threshold is exceeded. This can be used to control a fan motor, for example, or to open and close a ventilation flap.

Sensor technology

The best-known method for measuring CO_2 concentration is called the NDIR (non-dispersive infrared absorption) method. This uses the fact that CO_2 absorbs infrared light with a wavelength of 4270 nm. This allows a very selective and accurate measurement of the CO_2 partial pressure, especially at high concentrations. The measurement of low CO_2 concentrations requires a long optical path through the gas, implying a physically large sensor and, because of the precision optics involved, high cost.

Wet electrolyte CO_2 sensors are more compact but because of their limited stability and durability are not used in ventilation applications. Gas sensors using a solid electrolyte are more suitable. However, because of poor stability and reproducibility, and an output strongly dependent on ambient humidity, effective mass production has been difficult to achieve. Just a few years ago Figaro, a well-known manufacturer of semiconductor gas sensors, succeeded in developing a process for making long-term stable CO_2 sensors with reproducible characteristics and low humidity dependence as standard components. The result was the TGS4160 gas sensor, which was described in *Elektor Electronics* in October 2004.

For the CO_2 meter described here an updated and miniaturised version of the TGS4160, the TGS4161, has been



chosen. **Figure 1** shows the construction of the sensor, which is made from a solid electrolyte sensitive to CO_2 on a ceramic substrate. The other side of the substrate is heated to minimise the effect of ambient temperature variations.

A permanent current flow through the high-impedance sensor cell will damage it, and so the input impedance of the measurement circuit should be over 100 MΩ with a bias current of less than 1 pA. This can be achieved using commercially-available CMOS operational amplifiers (see **Figure 2**).

The cold resistance of the heating element is around 70 Ω: it can be connected directly to a 5 V supply, from which it will draw around 50 mA, therefore dissipating approximately 250 mW.

The sensor cell develops an EMF whose value depends on the CO_2 concentration in the air. The absolute value depends on the particular device and on how it is stored. However, the difference between the EMF developed in a CO_2 concentration of 350 ppm ('fresh air') and that developed in higher concentrations is very stable. This EMF difference, plotted against CO_2 concentration on a logarithmic scale, gives a straight line (**Figure 3**). The figure also illustrates that the sensor is not sensitive to carbon monoxide or to ethanol.

Measurement module

As already indicated, the sensor may suffer from drift and so is not ideal for measuring absolute CO_2 concentrations. However, it is very suitable for measuring the CO_2 concentration relative to that of fresh air. The cell voltage is taken to a microcontroller, where signal conditioning is performed using a specially-developed algorithm, which derives and then uses the fresh air EMF value. To simplify use of the CO_2 sensor Figaro produces two modules which, as well as the TGS4161 sensor, include a complete factory-calibrated signal conditioning circuit based on a microcontroller. In the CDM4161 module (**Figure 4**) this is a PIC16LF88. **Table 1** gives the most important characteristics of the unit, and the pinout is given in **Table 2**.

The analogue output (pin 2) delivers a DC level between 0 V and 4 V, corresponding to a CO_2 concentration of between 0 ppm and 4000 ppm (0 % to 0.4 %). Pin 3 provides a switching signal which goes from low to high (0 V to 5 V) when a CO_2 concentration threshold value is exceeded. A pair of jump-

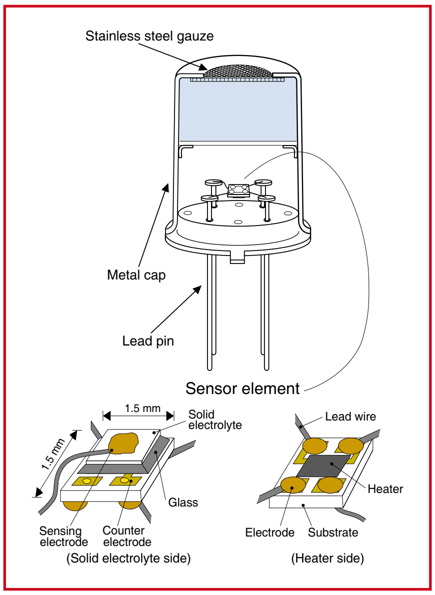


Figure 1. Construction of the sensor. The cathode (detection electrode) consists of a layer of lithium carbonate (Li_2CO_3) on gold, while the anode (reference electrode) is just gold. In between is the solid electrolyte.

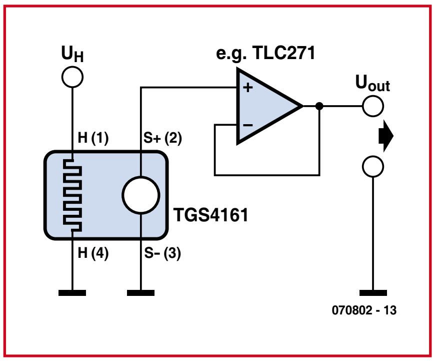


Figure 2. The sensor element must be connected to a very high impedance input.

Table 1. CDM4161 CO_2 measurement module characteristics in brief

Measurement range:	approximately 400 ppm (fresh air) to 4000 ppm
CO_2 sensor:	TGS4161 with solid electrolyte (10 year life under normal operating conditions)
Operating temperature range:	–10 °C to +40 °C
Operating humidity range:	5 % to 70 % relative humidity (non-condensing)
Warm-up/calibration time:	2 hours
Response time:	2 minutes (to 90 % of change)
Accuracy:	approximately ±20 % of final value
Measurement cycle time:	1 second
Power consumption:	approximately 300 mW
Nominal supply voltage:	5 V (see Table 2)

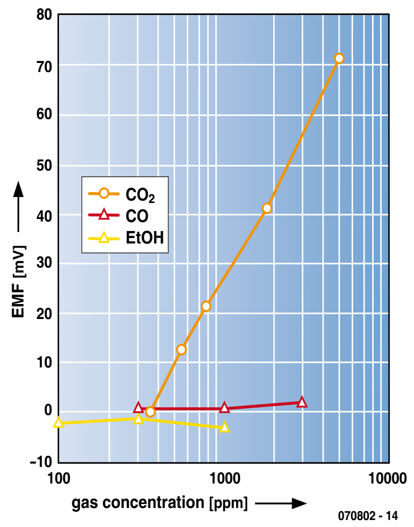


Figure 3. CO_2 sensitivity of the TGS4161 (and lack of sensitivity to carbon monoxide and ethanol).

ers allow the selection of one of four pre-programmed threshold values (see **Table 3**).

The module also sports three indicator LEDs to indicate its status (see the text box for more details).

When power is applied (5 V on pin 1) a two-hour warm-up and calibration phase starts. During this period the module should be placed in fresh air so that the microcontroller can calibrate the circuit to the correct level. The green LED flashes during this period, and the output voltage on pin 2 remains constant at 0.4 V. When the sequence is complete the green LED lights continuously. The CO_2 concentration experienced by the sensor during the warm-up phase forms the reference level (or 'baseline') at which the circuit will output a voltage of 400 mV on pin 2: the microcontroller is thus assuming that the CO_2 concentration during the warm-up phase is approximately 400 ppm. For every 1 ppm variation away from this reference level the output voltage changes by approximately 1 mV. If the ambient CO_2 concentration is not 400 ppm during the warm-up phase, the reference level will be incorrectly determined and there will be a corresponding offset error in the output of the circuit and in the switching thresholds that apply for pin 3. To avoid a general gradual drift in the calibration of the circuit, the module should from time to time be exposed to fresh air with a CO_2 concentration of 400 ppm. A pushbutton on the printed circuit board allows the reference level to be reset manually. When the button is pressed the microcontroller takes the current measured value as the new reference level, corresponding to 400 ppm. This also happens if the button is pressed during the warm-up phase. In this case the green LED stops flashing immediately, and the module assumes that warm-up is complete and switches into normal operation mode.

The trimmer potentiometer on the board is only used for factory calibration and should not be adjusted. There are two test points on the board that may be of interest: the buffered output voltage of the TGS4161 sensor appears on CP3, and CP4 gives a temperature-dependent voltage derived from an NTC thermistor used for temperature compensation of the sensor.

Mini module

The newer CDM4161A (**Figure 5**) mini module can be used in place of the CDM4161 in the CO_2 meter. The main differences are in its use of SMD components and in its lower price compared to its bigger brother. The PIC in the CDM4161 is replaced by a physically smaller Renesas R5F211B1SP 16-bit microcontroller.

The main functions are identical, but there is a small number of differences to be aware of.

1. The connectors are somewhat smaller.
2. There is no reset button on the board.
3. Pin 4 is no longer a fault signal output; it is now a reset input. A button connected between pin 4 and 5 V will have the same function as the button fitted to the larger module. Alternatively, pin 4 can be driven high by an external circuit for the same effect.

Table 2. CDM4161 CO_2 measurement module pinout

Pin number	Function	Details
1	Supply voltage + U_B	3.5 V to 5.5 V, 5 V typical, maximum current consumption 60 mA
2	Measurement output	0.4 V to 4 V DC (at 400 ppm to 4000 ppm CO_2 concentration)
3	Switched output	For switching behaviour see Table 3; low =. 0.2 V, high = +U_B – 0.6 V (typical at 1 mA load), maximum voltage 5.5 V, maximum load 25 mA
4	Fault output	Open-collector output, maximum IC = 100 mA, maximum UCE = 50 V, switched to ground when sensor heating element is open circuit or when threshold is exceeded

4. Since no direct fault signal is available, pins 2 and 3 are now used jointly to indicate a fault condition: pin 2 goes low (to 0 V) and pin 3 goes high. A fan enabled by the output on pin 3 will therefore be turned on the event of a fault, just as it would in the event of excessive CO_2 concentration.
5. In the warm-up phase pin 2 (measured CO_2 concentration, 0 V to 4.2 V) goes to 4.5 V, rather than 0.4 V in the case of the larger module.
6. There are no jumpers on the printed circuit board, and so there is just a single fixed threshold voltage for the pin 3 output. The thresholds are 1000 ppm for switching from low to high, and 900 ppm for switching from high to low.
7. There are no LEDs on the board.

LED indicators

(CDM4161 module)

Green LED:
Flashes after power is applied during the two-hour warm-up and calibration phase; then glows continuously while the module is in operation.

Yellow LED:
Fault LED flashes when the fault output is active (see Table 1).

Red LED:
Indicates when the preset CO_2 concentration threshold value is exceeded: flashes when the switching output on pin 3 is high (see Table 2).

Base board

The circuit proper of the CO_2 meter is shown in **Figure 6**, and its printed circuit board is shown in **Figure 7**. The CO_2 measurement module is attached to K7 and a two-line LCD panel is attached to K8. There are sockets for both module variants (CDM4161 and CDM4161A). If the CDM4161A module is to be used, there are a couple of changes in construction compared to the CDM4161. If a reset button is required, it must be added externally (to pin 4) and the optional relay Re2 is omitted.

The circuit itself is straightforward. The ATtiny26 microcontroller (IC2) has the simple job of reading the ana-

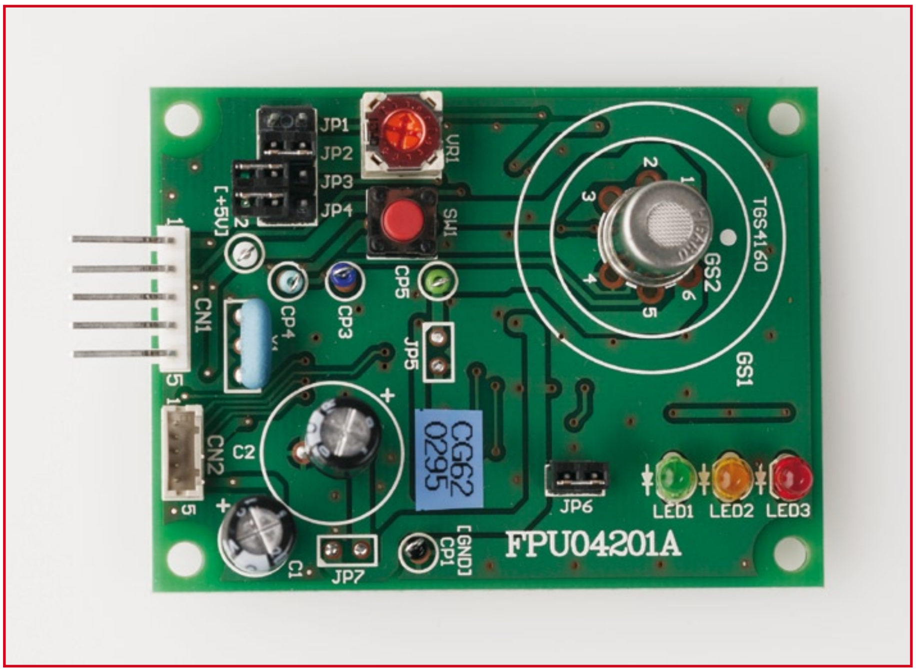


Figure 4. The Figaro CDM4161 module includes a TGS4161 sensor and a complete factory-calibrated signal conditioning circuit based on a PIC16LF88 microcontroller.

Table 3. Jumper settings for selecting threshold CO2 concentrations for switching output (CDM4161 module only)

Setting	JP3	JP4	CO_2 threshold value (ppm)	Switching output (pin 3)	Relay Re1 contact
I	open	open	800 720	Low to high High to low	closed open
II	open	closed	1000 900	Low to high High to low	closed open
III	closed	open	1500 1350	Low to high High to low	closed open
IV	closed	closed	2000 1800	Low to high High to low	closed open

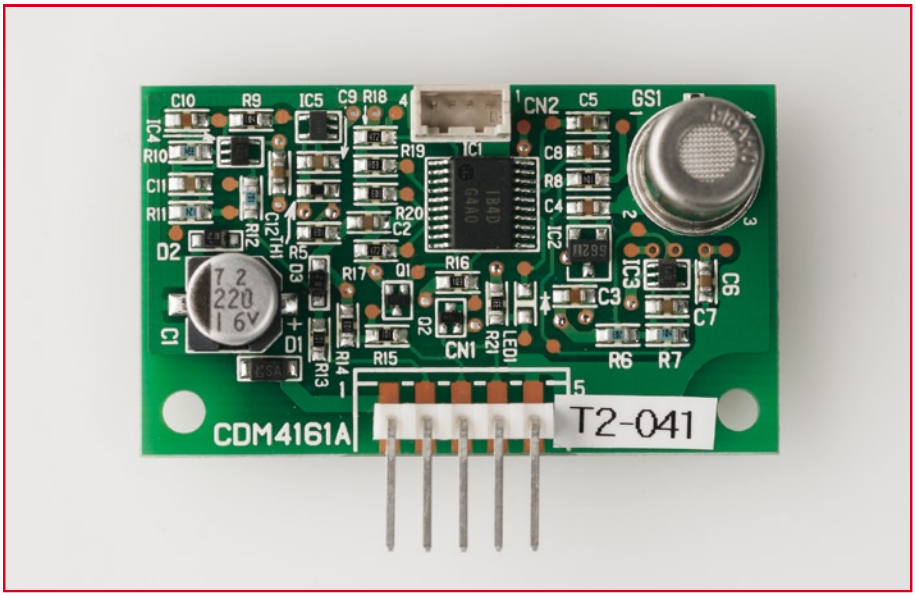


Figure 5. The circuit of the CDM4161A variant differs in that it uses SMD components and is smaller and cheaper than the version shown in Figure 4.

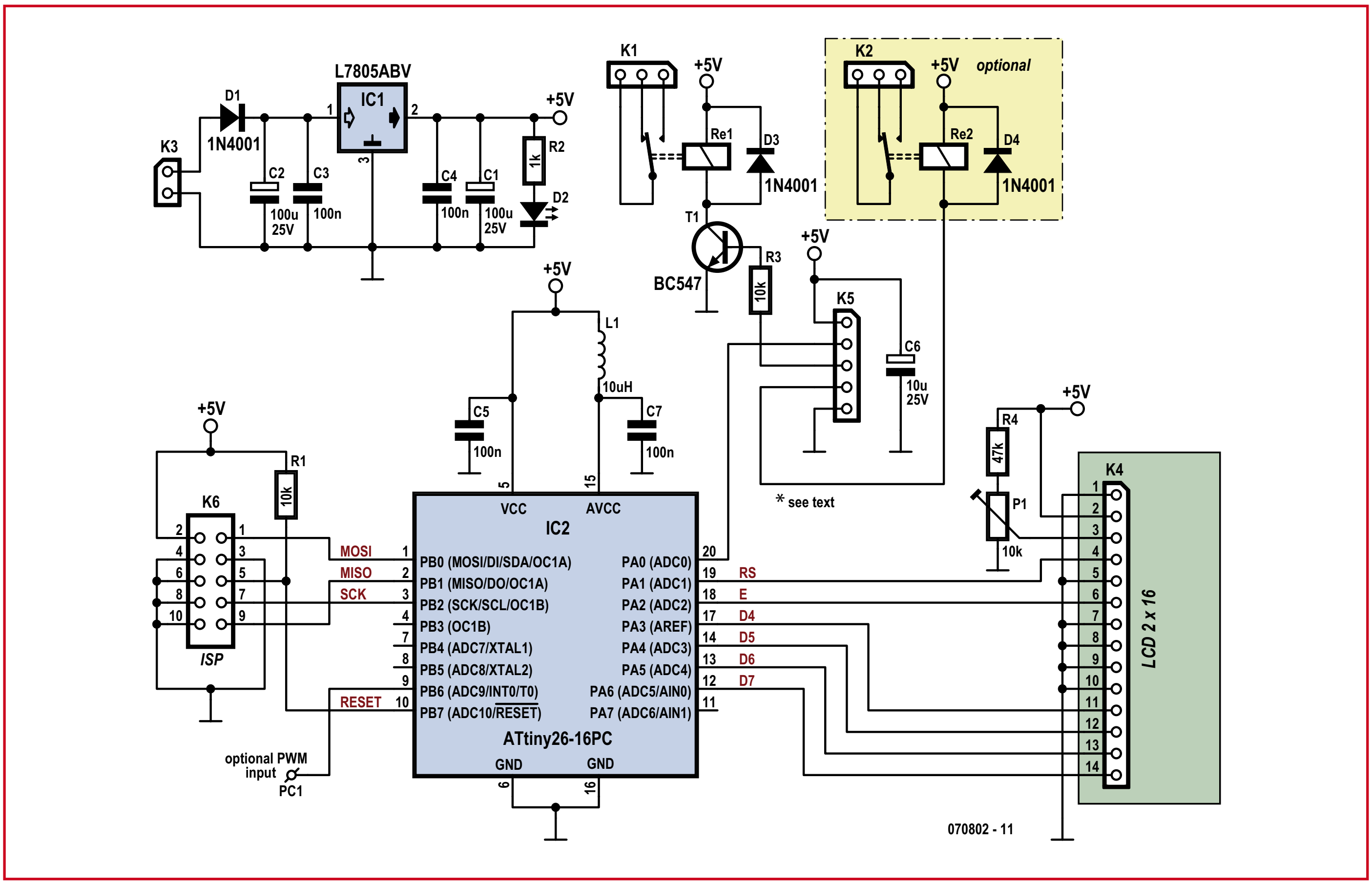


Figure 6. Circuit diagram of the CO_2 meter using an ATtiny26 microcontroller, which digitises the analogue output of the module on K7 and drives a two-line LCD panel.

logue output of the measurement module (on pin 2 of K7), digitising it, and displaying the result on the two-line LCD panel. The upper line of the display shows the current reading and the trend, indicated by a plus sign (if the CO_2 concentration is increasing) or a minus sign (if the CO_2 concentration is decreasing). The lower line displays the reading in analogue style as a bar graph stretching over the full range from 0 ppm to 4000 ppm. P1 adjusts the display contrast.

The power supply for the circuit, including the module, is provided by 5 V voltage regulator IC1, which expects a DC input voltage on K3 of between 8 V and 14 V. The maximum current consumption of the circuit is around 150 mA.

As well as displaying the CO_2 concentration the CO_2 meter offers a threshold switching function using relay Re1, controlled by pin 3 of K7. This allows a ventilation system to be switched on when the threshold value is exceeded. The optional second relay Re2 is controlled by pin 4 of K7. This relay is energised in the event of a fault, for example to sound a warning alarm or enable a stand-by ventilation system. As already indicated, this relay can only be fitted if the larger module is used, since in the smaller module pin 4 of K7 is a reset input.
The relays suggested in the parts list can switch up to 10 A at 230 V.

Programming and use

Building the circuit is reasonably straightforward if the printed circuit board shown in Figure 7 is used. The microcontroller is available ready-programmed from the Elektor Shop (see the parts list), or you can program it yourself. As (almost) always, the source code and hex file are available for download from the Elektor website. The downloaded files contain very important information regarding how the configuration fuses of the ATtiny26 microcontroller should be programmed.
The microcontroller should in any case be fitted in a socket so that it can easily be exchanged or removed for external reprogramming. An in-system programming connector (K6) is also available on the board, allowing the microcontroller to be reflashed in situ using suitable programming hardware, such as the USBprog project published in the October 2007 issue of *Elektor*.

Before fitting microcontroller, LCD and CO_2 module to the board, check again that all the other components are fitted correctly and that the solder joints are satisfactory. Then connect a mains adaptor (8 V to 14 V, 150 mA) to K3. Verify that LED D2 lights and that 5 V appears on the relevant pins of IC2 (pins 5 and 15), on K7 (pin 1), K8 (pin 2), and K6 (pin 2). Disconnect the mains adaptor and fit IC2, the LCD and the CO_2 module. Check everything again one last time and reconnect the mains adaptor to K3. The green LED on the module board will flash and the LCD will show a CO_2 concentration of 0.04 %. If the display appears blank, try adjusting the contrast using P1.

If you now press the module reset button the green LED will stop flashing

CO_2: not just a climate threat

Carbon dioxide (CO_2) is a colourless and odourless gas. One cubic meter has a mass of approximately 2 kg (the same volume of air has a mass of 1.3 kg in comparison). CO_2 is produced by the burning or decomposition of carbon-based substances such as wood (or similar biomass), oil and coal and their derivatives, and by the respiration of humans and animals. On the other hand, plants extract CO_2 from the air and the carbon is used in the growth of the organism. There is therefore an equilibrium in the atmosphere that is, as we know from analysis of glacial ice, subject to noticeable variation over time even without the influence of Man.

Since the beginning of industrialisation in Europe at the start of the nineteenth century there has been a continuous rise in the atmospheric CO_2 concentration resulting from Man's activities as we burn fossil fuels, which are of course simply converted biomass and therefore forms of carbon storage. Burning one litre of heating oil or diesel creates (in addition to around 10 kWh of energy) 2.6 kg of CO_2; burning 0.9 m^3 of natural gas (which also produces around 10 kWh) creates 2.1 kg of CO_2. Worldwide emissions are of the order of 36 billion tonnes annually. CO_2 levels are now at their highest for at least four hundred thousand years, which, in combination with other greenhouse gases such as methane (chiefly arising from agriculture), is leading to global warming at an unprecedented speed.

Some more figures: in fresh outside air the world average CO_2 concentration by volume is around 380 ppm (1 ppm, or part per million, is equal to 0.0001 %). This is rising at between 1.5 ppm and 2 ppm per year. In comparison, the atmospheric CO_2 concentration 20000 years ago was only approximately 220 ppm, and near the beginning of the industrial era (in 1850) it was around 260 ppm. In urban areas concentrations are of course higher than 380 ppm, mostly as a result of heating systems in buildings and traffic. Typical values are around 700 ppm and above.

In enclosed areas, however, these values are often considerably exceeded, especially when a number of people gather in a room. The CO_2 concentration in human exhaled air is around 4 % to 5 %, which, if directly inhaled by another, would lead to dizziness. Each breath exhaled by an adult contains approximately 30 ml of carbon dioxide, which at 16 breaths per minute adds up to about 30 litres per hour. Ten people in an 80 m^2 room 3 m high will double the CO_2 concentration from 500 ppm to 1000 ppm within just 1.5 hours. Forty people in the same room (still far from tightly packed in!) will take the CO_2 concentration up to 3000 ppm within an hour. In practice concentrations of 4000 ppm have been measured in classrooms after a lesson, and peak concentrations of up to 7000 ppm have been measured in cinemas.

What are the implications for health? In normal concentrations carbon dioxide is not poisonous. The maximum allowable concentration in the workplace in the UK (the eight hour long term 'workplace exposure limit', or WEL) is 0.5 % or 5000 ppm. Short term exposures of up to 15000 ppm, or 1.5 %, are permitted. At 3 % people start to have difficulty breathing, and at 6 % people exhibit signs of paralysis. The lethal level is between 8 % and 10 %. Deaths occur in wells, cellars, silos (especially as a result of fermentation processes), mines and the like. As with considerably more poisonous gases such as carbon monoxide (which is often produced in fires) and hydrogen sulphide (from cesspits and biogas plants) you should in the event of an accident on no account attempt to save someone who has fallen unconscious, as the gases are denser than air and collect in hollows, valleys and low-lying areas. There was a carbon dioxide catastrophe in Cameroon in 1986 when the Nyos volcanic lake erupted, ejecting some 1.6 million tonnes of the gas. The gas flowed into two low-lying valleys killing around 1700 people and countless animals.

Although in this case oxygen-rich air was displaced by CO_2, this is not the only way in which it has a harmful effect. Even a CO_2 concentration exceeding just 2 % can interfere with breathing. Further, more CO_2 is dissolved in the blood which makes it more acidic (think of the slightly acidic taste of sparkling water, which is just water with additional dissolved CO_2). This in turn impairs the ability of haemoglobin molecules in red blood cells to capture oxygen. The two effects lead to a reduced supply of oxygen to the body's cells, even though the concentration of oxygen in the air may be normal (at around 21 %). A candle does not therefore make a reliable sensor!

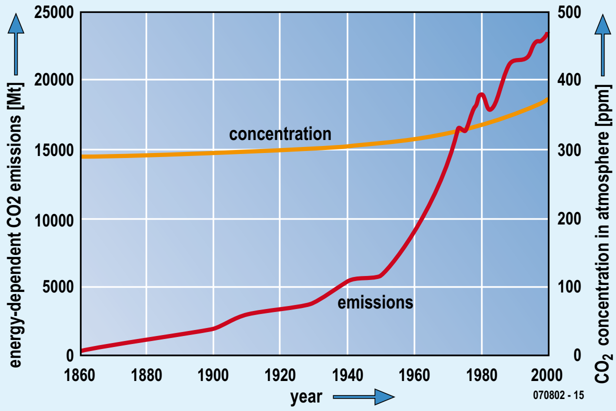


Photo source: http://www.volker-quaschning.de

CO_2 concentration by volume and its effects (values in %)	
0.038	world mean value (= 380 ppm)
0.07	urban air (outdoors)
0.08	increased olfactory sensitivity
0.14	urban air (indoors)
0.4	maximum value in classrooms
0.5	long term workplace exposure limit (= 5000 ppm)
2	short term workplace exposure limit
2.5	intoxication-like effects on divers
3	increased difficulty breathing
4 - 5.2	exhaled air
5	onset of dizziness and unconsciousness
6 - 8	signs of paralysis
8 - 10	lethal dose

Even at much lower CO_2 concentrations there are effects on health and well-being. At 800 ppm sensitivity to smell starts to increase, giving the subjective impression of 'bad air'. There are of course various other substances that impair air quality, but nevertheless CO_2 concentration can be considered the most important factor in the perception of indoor air quality. On entering a 'stuffy' room it can provoke an immediate desire for fresh air: the so-called 'conference room effect'. Conversely, if you are sitting in such a room, you may in some circumstances not perceive the steadily increasing CO_2 concentration. In such cases our meter may prove useful, especially with its indication of trend alongside absolute carbon dioxide concentration value.

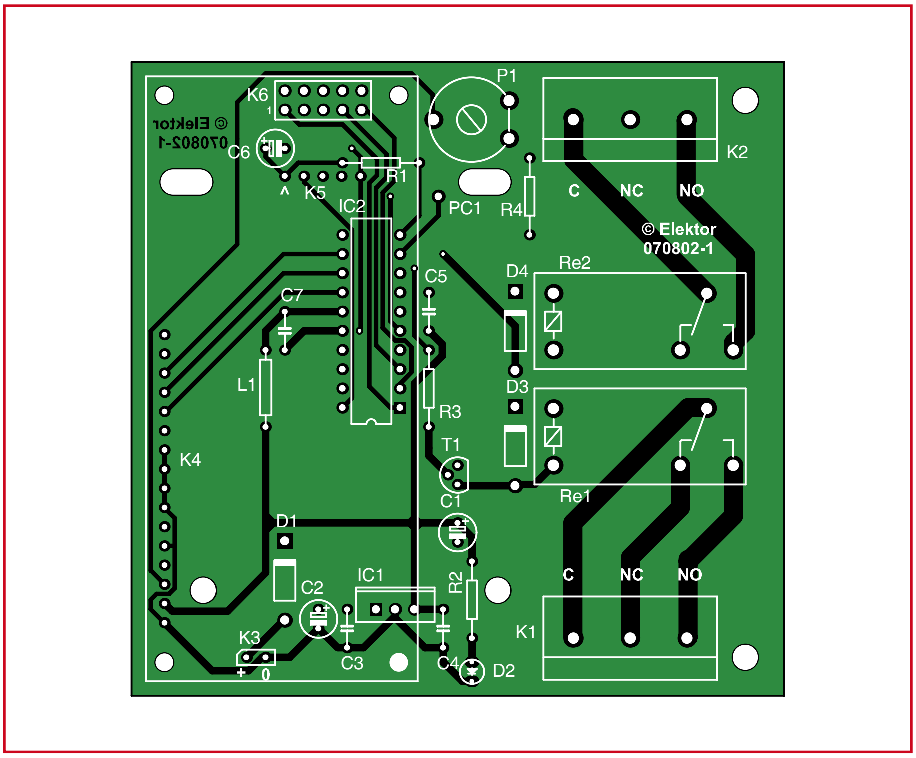


Figure 7. The main components fitted to the printed circuit board are the measurement module, the LCD panel, the microcontroller and one or two relays.

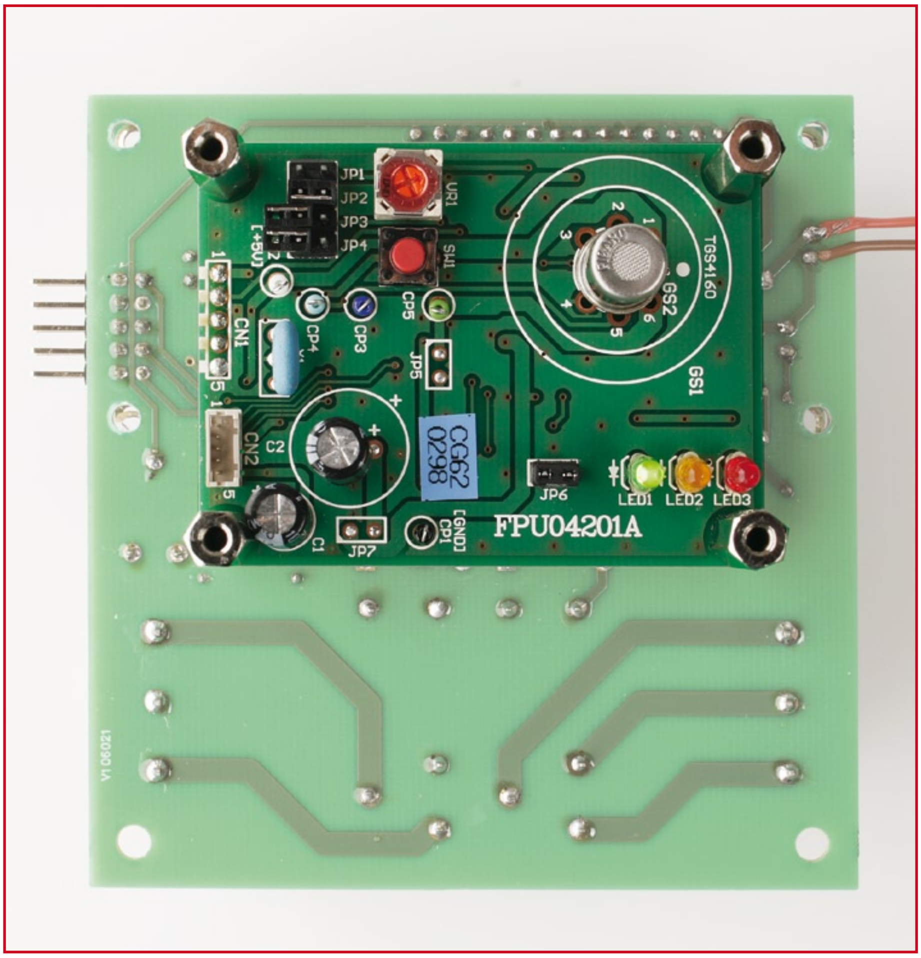


Figure 8. The laboratory prototype with the CDM4161 sensor board secured to the solder side of the main board. Note the wide tracks for the connections to the relay contacts.

and light continuously. At the same time the displayed reading will start to change. If you now expose the sensor to exhaled air, the displayed reading will rise rapidly.

If everything works so far, you can now take the meter out into the fresh air and allow it to go through its two-hour warm-up and calibration process. After that, leave the unit switched on: the CO_2 meter is ready for duty!

(070802-I)

Web Links

http://www.figaro.co.jp/en/make_html/item_2_sen_112115.html (data sheets)

http://www.sensorsandtransmitters.com (UK distributor for Figaro)

COMPONENTS LIST

Resistors

R1,R3 = 10kΩ
R2 = 1kΩ
R4 = 47kΩ
P1 = 10kΩ preset

Capacitors

C1,C2 = 10µF 25V radial
C3,C4,C5,C7 = 100nF
C6 = 10µF 25V radial

Semiconductors

D1,D3,D4 = 1N4001
D2 = LED, low-current
T1 = BC547B
IC1 = 7805
IC2 = ATtiny26-16PC, programmed, Elektor Shop # **070802-41**

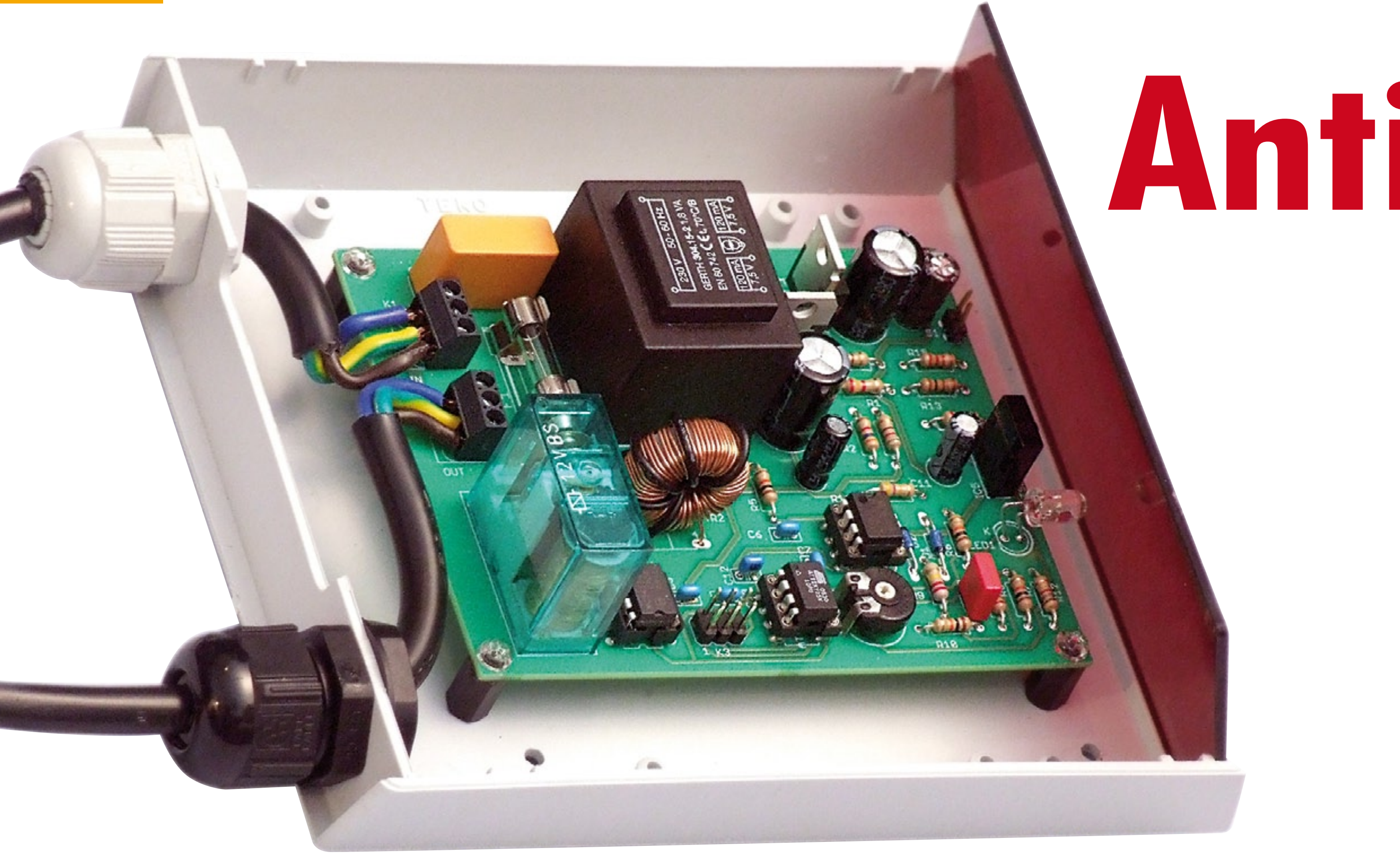
Inductor

L1 = 10µH

Miscellaneous

Re1,Re2 = 5V-Relay, SPDT, 250V/10A AC, e.g. Panasonic JW1FSN-5V
LC Display, 2x16 characters, e.g. Displaytech 162
Figaro CO_2 measurement module type CDM4161 or CDM4161A (see text)
PCB, Elektor Shop # **070802-1** or kit of parts # **070802-71** (all parts, PCB, programmed ATtiny, and CO_2 module)
Project software and PCB layout: free downloads from www.elektor.com

Anti



If the green movement had its way, the standby function of electrical gadgets would be banned outright. There would be outcries from users if this were to become reality but it's clear there needs to be far better understanding of all the issues involved. Even though a law of this kind might create a healthier lifestyle for couch potatoes addicted to watching non-stop sport every evening and would definitely also benefit the environment and the economy, the question still remains whether the population at large could tolerate the abolition of the remote control TVs of today. Hell would more likely freeze over first...

Squanderers...

In reality far too many home entertainment devices are very poorly provided for in the standby state department. Low-cost satellite receivers for instance are not in the main provided with a wall-wart (mains adaptor) that recognises standby operation. Often, major chunks of the electronic circuitry remain powered all the time, with only the front panel display extinguished for cosmetic reasons. Circuit sloppiness of this kind is obvious even to touch alone; the device remains significantly warm to the feel even in standby mode, so it's obvious that considerable current is still being drawn. A more scientific assessment (well not entirely: don't forget effective values and phase shift) is naturally to measure energy consumption.

It's not only cheap and cheerful products from the Far East that suck up the juice. There are plenty of brand-name TV receivers from the CRT era still in service that are hardly blameless, consuming several watts even when they are doing absolutely nothing. And ditching a fully functional television set purely on account of its high standby current consumption does not make economic sense, when manufacturing a replacement and transporting it halfway around the world would burn up even more energy. Equally crass is the fact that computers and their peripherals, arguably the pinnacle of high-tech achievement, commit the worst—and most avertable—ecology 'crimes' of all. The vast majority of these today have no genuine off-switch but are instead equipped with standby circuitry over which users have no direct control. The main power switch controls only the low voltage circuitry and even when the machine appears to be off, it is still consuming a few watts without any logic or purpose at all. Laptops are worse than desktop machines in this respect; the outboard power units of modern examples have absolutely no switch at all. Unless you unplug them altogether, these power units remain permanently connected to the mains.

...and savers

Right now, price pressure and consumer ignorance make this a no-go area for politicians. The notion of forcing manufacturers to implement proper energy saving (with truly zero or near-zero power consumption) is not a vote-winner and the public shows no real desire to adopt energy-saving measures... However, the way prices for domestic electricity are rising now and look set to explode much further, the 'small beer' amount of energy wasted by devices on standby is nevertheless energy that's easy to identify and save. And when people feel the pain in their pocket maybe they will become less thoughtless. Even if they continue to feel there's nothing they can do about this and 'green' logic doesn't convince them, there are still ways that smart electronics can help reduce this spendthrift waste of energy without us having to return to Stone Age circumstances.

Where PCs and their peripherals are concerned, expecting customers to check out the 'green' credentials of energy efficiency before they make a new acquisition is probably too much to ex-

i-Standby Switch

Also works with a remote control!

Dr. Thomas Scherer

Energy Saving may well be a must-have feature for home entertainment products sold today but there are still millions of older and even not-so-old appliances that are guzzling far too much juice in the all too convenient standby mode. The anti-standby switch described here saves the planet's energy—and yours too!

pect. But the solution is quite simple. Intelligent mains extension leads that switch off power to peripherals automatically when the computer is turned off, or, failing that, a socket strip with a single master on-off switch will banish the problem from the world. People who don't feel like delving beneath the desk (but don't want mains cables trailing over their working surface) can opt for the upmarket version that you're able to 'kill' with a hand-held remote control.

Solutions like the switchable mains outlet strip have a distinct disadvantage in home entertainment applications: convenience goes out of the window if you can no longer switch the telly on or off simply by zapping it with the remote control handset. Equipment is then likely to be left on longer than necessary or forgotten entirely. For the forgetful among us there do exist special intermediate switches (Standby-Switch, Standby-Saver etc.) that monitor current flow in the appliance and shortly after it falls back to standby mode, cut the juice altogether. Solutions of this kind have the key advantage that hardly any power is ever wasted on standby current. The downside is that you can no longer wake up the telly with its remote control. With these semi-intelligent standby switches you need to press an onboard button to rouse them again, wiping out half the attraction.

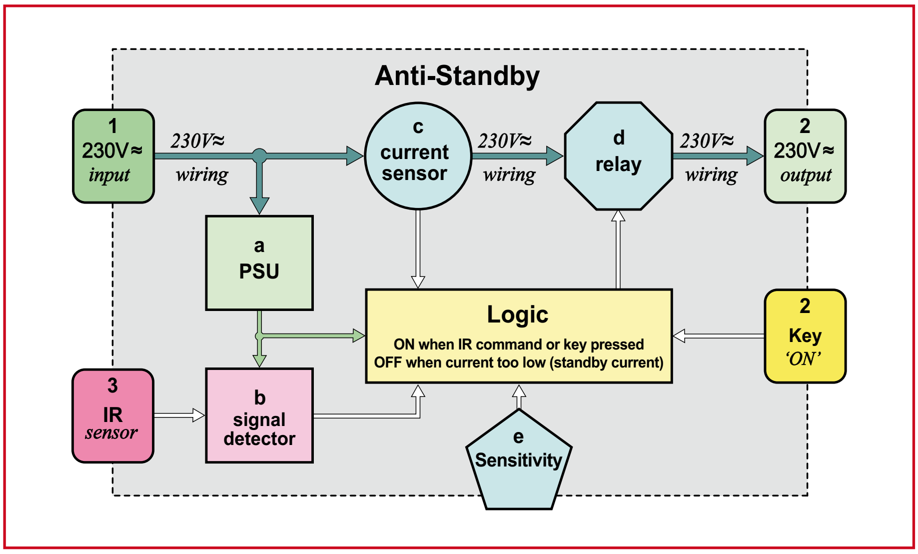


Figure 1. Block diagram of the anti-standby switch.

If we agree the 'all-electronic' way is the best way, then a truly intelligent (and convenient) standby switch should react to infrared remote control zappers and deliver power at the same time as switching on the device itself without further user intervention. In this way luxury and ecology can be combined ingeniously—and that is precisely what the circuit described here does.

Anti-standby adapter

It's not a huge leap of thought to realise that an adapter with quiescent current cut-off and infrared wake-up is in principle no more than an outboard standby switch going by another name. And so it is.

The key difference between 'general purpose' and 'bespoke' standby solutions is that the circuit presented here has been tailor-made with energy saving in mind. What's more, it reacts to

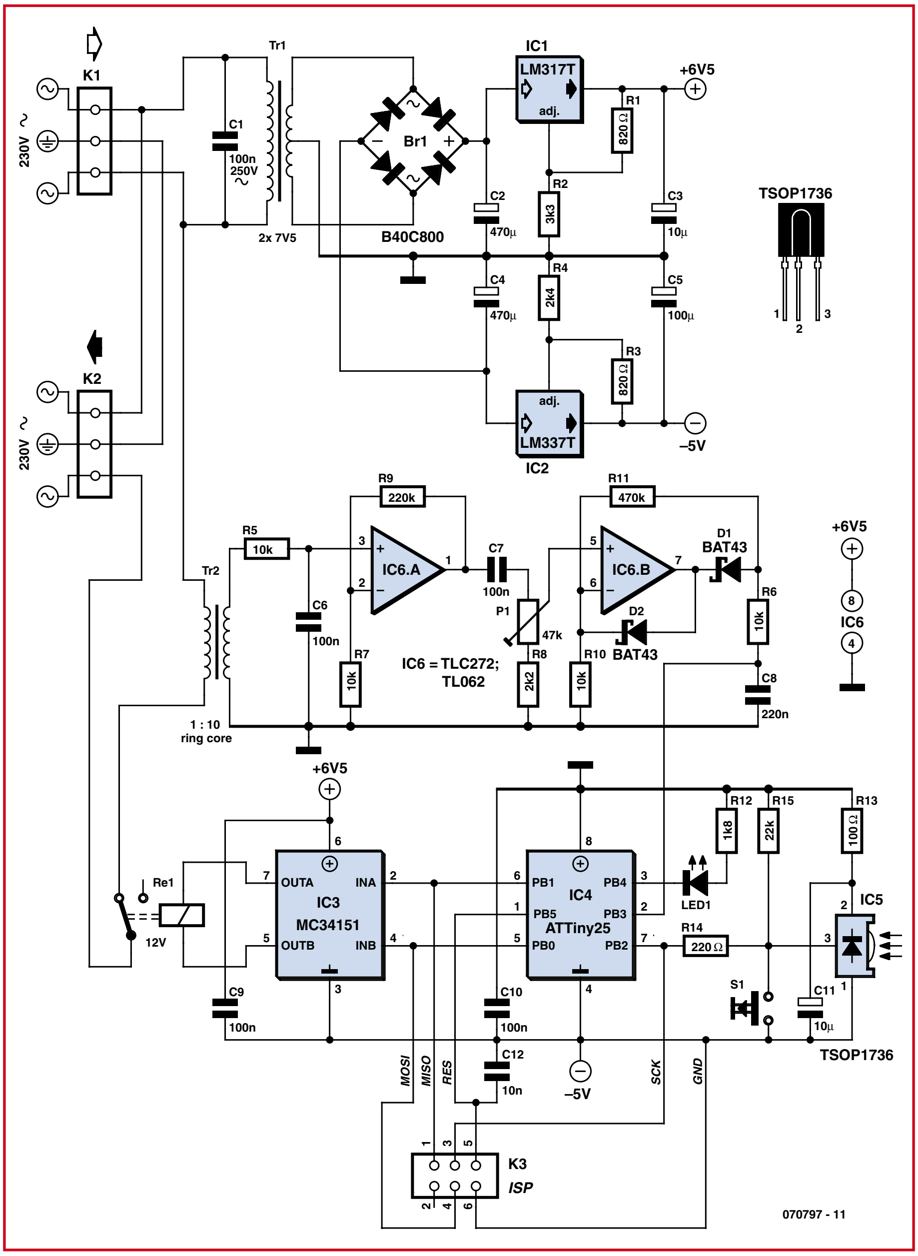


Figure 2. The circuit of the anti-standby switch includes two voltage regulators, three 8-pin ICs and one bistable relay.

virtually any key press of almost every infrared remote control on the market. It enables you to upgrade an existing appliance with poor standby characteristics by a bolt-on solution that's extremely thrifty, reducing standby current very significantly. Another way of describing our anti-standby switch is a *standby enhancer*. And since it reacts to all remote control handsets, it needs no installation or prior configuration whatsoever—it's a genuine 'plug and play' solution.

Having set out the prime function of this adapter let's check out how it works. **Figure 1** shows the vital functions in detail. The interface to the outside world comprises a 230-VAC mains input and output together with an infrared sensor and a press button for manual operation — just four functional elements in total.

When a button is pressed on the infrared handset and is registered by the IR sensor (3), the signal detector delivers a trigger pulse (or more than one) to the circuit's control logic. This operates the relay (d) and the 230-VAC outlet (2) is powered. Additionally, current flow is monitored for a number of seconds (c). If the logic recognises normal operation, the relay remains activated. If the current drops below a threshold level preset by (e), the relay is deactivated after a few seconds and the mains outlet is powered down. The press button (3) allows you to simulate the remote control handset manually. Since electronics don't work without a source of volts we also need a power supply (a). That's how simple the block diagram turns out!

Frugal electronics

It's not difficult to trace in our circuit how the functional criteria just described (low energy consumption in particular) have been translated into a concrete form of electronics—and without any 'special' components at all.

K1 and K2 in **Figure 2** correspond to the 230-VAC input and out put of Figure 1. Even the type of power supply is important for energy conservation. Were we to use a conventional voltage regulator of the 78xx or 79xx kind, we would be left with a residual current of 5 to 6 mA, which with a good 20 V input voltage (after rectification and smoothing) could easily amount to more than 100 mW. As low-overhead regulators are relatively expensive and not available everywhere we have opted for their presettable variants. These deliver a satisfactorily stable output voltage with a quiescent current of around just 1.5 mA (= 30 mW).

Further energy-saving considerations guided our choice of relay. Solid state relays admittedly require very little energy to control them but their residual voltage of about 1 V in operated state with a 1 A load (in a largish TV set) will fritter away 1 watt needlessly. In comparison, a conventional relay draws current continuously while operated. The types available with proper 230-VAC contacts can easily consume a whole watt of energy. Avoiding these predicaments calls for an unconventional relay, specifically a bistable one (see the **Bistable Relays inset**). A bistable relay consumes energy only for an instant during the action of latching or unlatching, meaning we can ignore the consumption of the relay altogether.

Use of a resistor as a current sensor is ruled out because it might cause other components nearby to overheat. Instead we use a homebrew transformer based on a conventional ring-core suppressor coil (**Figure 3**), the primary winding of which is made up of three or four windings that you produce yourself from insulated strands of wire with 0.5 mm² cross sectional area (c.s.a.). Self-inductance is not terribly relevant in this application and since coils of this type generally use 30 to 40 turns, we end up with a current-sniffing transformer with a turns ratio of around 1:10. The secondary voltage

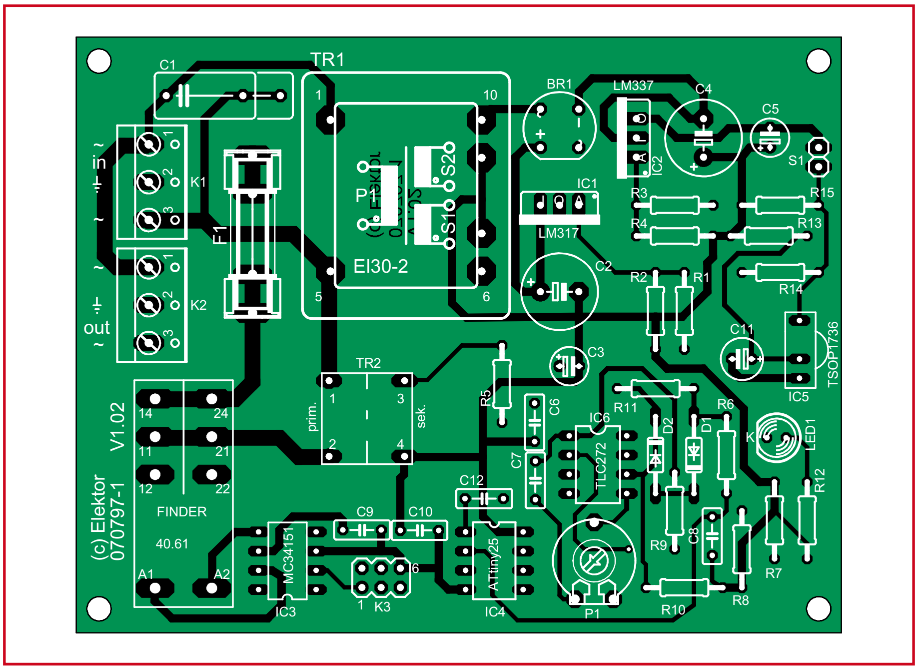


Figure 4. This is how the components are arranged on the PCB (PDF of the layout diagram available as free download at www.elektor.com).

is multiplied around 23-fold by A1 and further amplified by a factor of 48 in A2 and one-way rectified. The overall amplification can be set between 50 and 1,000 by the sensitivity regulator P1. Since the internal threshold value of IC4 for standby operation lies around -0.5 V (the voltage at C8, a voltage drop of around 0.1 mV at the primary winding of Tr2 is adequate. If you find the sensitivity insufficient, you can increase R8 or dig into the software and reduce the sensitivity constant there; values below 50 should be avoided, however. C8 is the reservoir capacitor for the DC voltage corresponding to the current (threshold value: –0.5 V) that with the sum of R6, R10 und R11 creates a time constant of 50 ms. R6

Figure 3. In this design, Tr2 is made up of a small ring-core suppressor coil with three or four additional windings overlaid on it.

serves purely to limit pulsating charging currents.
The IR sensor and signal detector are combined in IC5, which requires typically less than 1 mA at 5 V. There are differing versions of this IC, which display maximum sensitivities between 30 and 56 kHz. Experiment has shown that they are not really so narrowband, however. Using a total of eight different remote control handsets of the author plus three borrowed from his neighbour produced ranges of constantly more than 10 metres with the 36 kHz version of the IC. In reality you can use more or less any type.
Now for the logic. Functionality may be a more important consideration than current consumption when it comes to microcontrollers but in any case the 8-pin ATtiny25 example from AVR that we are using here requires less than 100 μA, when operated at the conveniently slow 128 kHz design frequency. The six I/O pins and low clock frequency are more than adequate for this modest assignment. If you feel like making the software more complex, take a look at a model with more internal program memory such as the ATtiny45 (4 kB) or ATtiny85 (8 kB) types. The software supplied will work on all three without alteration in just 800 bytes.
Since the microcontroller cannot deliver sufficient power direct from its output pins, we use another CMOS driver module that demands only a few μA of quiescent current and simultaneously takes care of the necessary level conversion

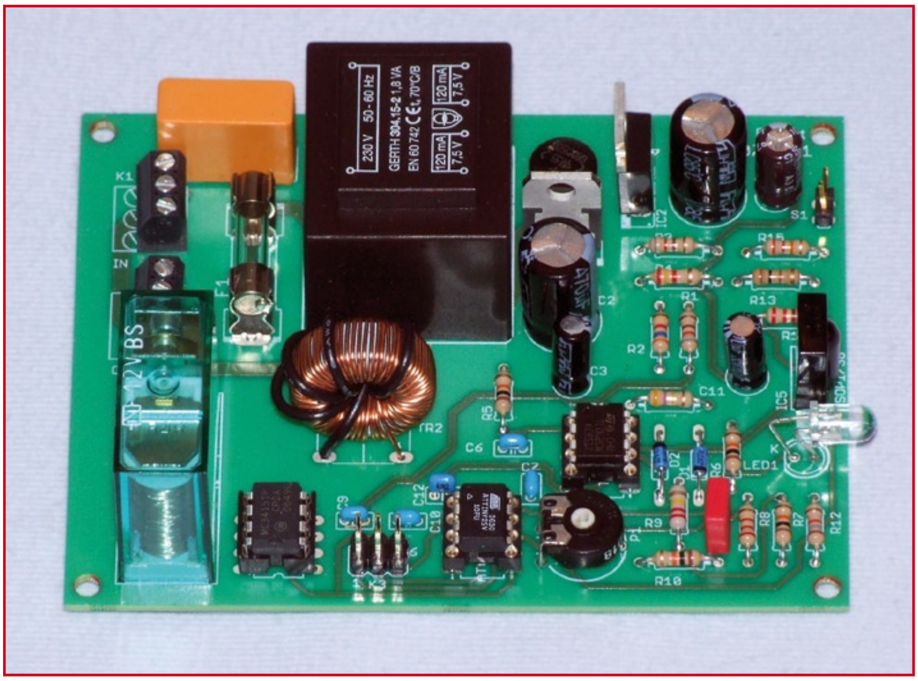


Figure 5. Anti-standby switch as constructed.

COMPONENTS LIST

Resistors
R1,R3 = 820Ω
R2 = 3kΩ3
R4 = 2kΩ4, 1%
R5,R6,R7,R10 = 10kΩ
R8 = 2kΩ2
R9 = 220kΩ
R11 = 470kΩ
R12 = 1kΩ8
R13 = 100Ω
R14 = 220Ω
R15 = 22kΩ
P1 = 47kΩ

Capacitors
C1 = 100nF (250VAC)
C2,C4 = 470µF (16V)
C3,C11 = 10µF (16V)
C5 = 100µF (16V)
C6,C7,C9,C10 = 100nF (63V)
C8 = 220nF (63V)
C12 = 10nF (63V)

Semiconductors
D1,D2 = BAT43 (Schottky)
LED1 = LED, 5 mm, red
Br1 = B40C800, round case, 40V piv, 0.8A)
IC1 = LM317T (T0220 case)
IC2 = LM337T (T0220 case)
IC3 = MC34151
IC4 = ATtiny25-10V*, programmed, order code **070797-41** from Elektor Shop
IC5 = TSOP 1736 (36 kHz IR-receiver*)
IC6 = TLC272 or TL062*

Miscellaneous
F1 = fuse 3.15AT (slow) with PCB mount holder and cap
Re1 = 12V bistable* (1 x co) with 16-A contact, e.g. Finder # 40.61.6 12V (www.reichelt.de)
S1 = pushbutton, 1 make contact
Tr1 = mains transformer, 2×7.5V* @ 1.5 VA
Tr2 = 2A ring-core suppressor coil (with 4 turns 0.5 mm²)*
K1,K2 = 3-way PCN terminal block
K3 = 6-way DIL pinheader (2×3 pins)
PCB, order code **070797-1** from the Elektor Shop, www.elektor.com

* see text

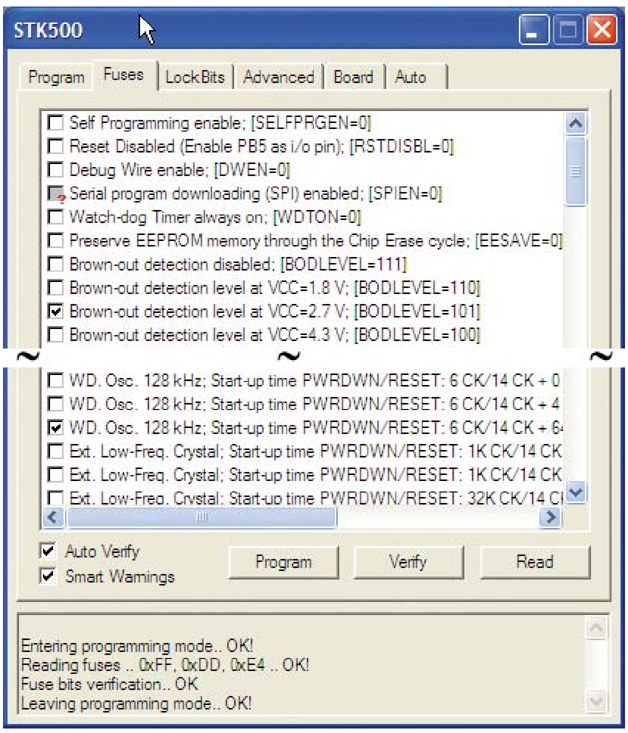


Figure 6. The 'fuses' of the ATtiny25 microcontroller are blown in this fashion.

```
Remote_isr:                     'Button from remote control pressed
    If Relay = 0 Then           'If relay is reset
       Waitms 1
       If PINB.2 = 0 Then       'Blocks sporadic short pulses from TSOP13XX
          Relay = 1             'Relay should be set
       End If
    End If
Return
```

Figure 7. Extract from the dedicated software. This Interrupt routine suppresses any interference pulses that might be generated by IC5.

from 5 V to 12 V. This little driver cannot provide more than 2x1.5 A of current maximum! Push-pull operation avoids the need for protection diodes despite the inductance of the relay coil.

For the two op-amps we have selected low-current variants (a TLC272 with around 1.5 mA or a TL062 with about 0.2 mA), meaning that the entire electronics draw around 50 to 80 mW. Compared with the energy requirement of conventional standby switches this is truly negligible. Over a year it would not even add up to a single kilowatt-hour were it not for the transformer! These themselves have improved continuously over the last few decades, although for the miniature ones in the 1 to 2-VA range one has to reckon with losses of the order of 100 to 400 mW in the transformer itself. Using a good quality item makes good sense therefore. This aside, it should not cost a fortune to build this project.

Construction and programming

Construction of the project is pretty straightforward thanks to the printed circuit board in **Figure 4**. Sockets are recommended for the ICs and most definitely for the microcontroller (if you are looking to program it externally). Thanks to connector K3 you can also 'burn' IC4 in-situ on the PCB using an ISP programmer such as the USB-Prog in the October 2007 of *Elektor*.

The software you need is in the file ANTI-STANDBY.HEX along with a commentated source text ANTI-STANDBY.BAS, both of which you can find on the web page relating to this article. And as you are probably thinking already, the source text is intended for the BASCOM-AVR compiler, of which the free demo version [6] is entirely adequate. The implementation in BASIC means that any tweaks you may wish to make are not going to be a problem. In the listing you will find a location (**Figure 7**), where a cosmetic error relating to IC5 is ironed out. This IC produces sporadic interference pulses of a few μs duration, which the patch renders inconsequential.

If you are planning to use the relay and fuse to their maximum capacity for switching heavy loads it would be worth 'strengthening' the tracks that carry 230 VAC with copper wire soldered on top of the tracks and selecting the value of the fuse accordingly. It goes without saying that circuitry carrying mains power needs to be carried out very tidily with due attention paid to electrical safety.

If you plan to use a bistable relay other than the model suggested in the parts list (one with twin coils) you should read the notes in the inset.

Once all components have been soldered in place and IC 4 has been programmed, you can fit the circuit into an ABS case. It's best to use one provided with a transparent red plastic front (**Figure 8**), to enable the IR rays to find their way to IC 5. Probably the simplest way of handling the mains wiring is to connect the anti-standby switch in series with its own dedicated strip of mains outlets (our photo shows one designed for Continental plugs). A four-outlet strip will be fine for a TV receiver plus set-top boxes for DVB-T (Freeview), satellite or cable receivers and a VCR or DVD recorder. After cabling and switching on (without any load connected) the LED should remain off. Pressing button S1 or operating the remote control handset should result in an audible click from the relay and the LED should come on. After 10 seconds, another click should be heard, with the LED going out. If your switch does this too, you have probably got everything right.

(070797-I)

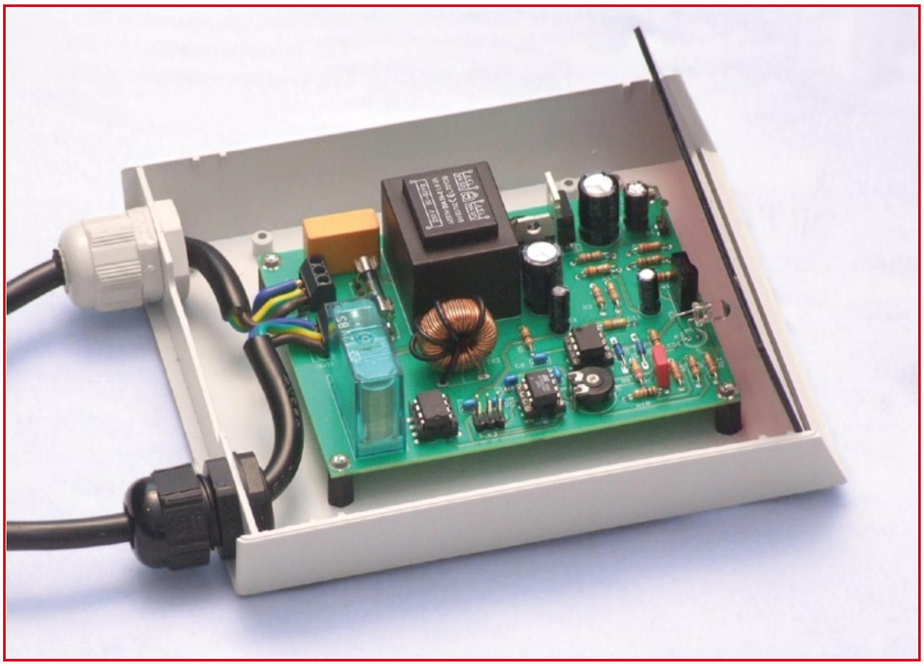


Figure 8. The anti-standby switch in its plastic housing with transparent red front panel.

Web Links

[1] ATtiny25 data sheet:
http://www.datasheets.org.uk/pdf/attiny25-datasheet/attiny25-datasheet.html

[2] TSOP17XX data sheet:
www.vishay.com/docs/82030/82030.pdf

[3] MC34151 data sheet:
http://www.onsemi.com/pub/Collateral/MC34151-D.PDF

[4] Relay data sheet:
www.finder.de/comuni/pdf/S40DE.pdf

[5] How a remanent relay works:
http://www.schrackrelays.com/lexicon/MagnetSystemE.asp

[6] BASCOM-AVR-Compiler:
www.mcselec.com

Bistable relays

To avoid frittering away energy in this Anti-Standby Switch we selected a special relay that draws current only during the brief moment of switchover. Two types of bistable relay satisfy this requirement: the latching relay (which is held in position by a mechanical catch or spring pressure until reversed) and the remanent or remanence relay (which is operated by an energizing direct current and is then held in this position by the remanence in the magnetic circuit until reversed when current flows in the opposite direction). With remanent relays a reverse current flow of between 10 and 25 per cent of the operating current value is generally sufficient to reset the relay.

In our application the operating and deactivating voltages for the relay are the same and use both time duration and polarity as differentiators. The software grants the relay a pulse of 100 ms duration (with typically 100 mA) to set (latch up) whilst a reverse impulse of 10 ms suffices for resetting (unlatching).

Beside the recommended relay (Figure 9) you can also employ a remanent relay with two separate coil windings. In this case one coil serves to latch and the other to unlatch. One end of each winding is connected to –5 V then. The two other ends are connected to Pin 7 (Latch) and Pin 5 (Unlatch) of IC 3. If the relay fails to unlatch then one winding must be wired back-to-front and/or the width of the unlatch pulse (a constant in the software) should be increased.

Figure 9. The bistable remanent relay used on our prototype.

Versatile DC Power M

Voltage, current, and even m

Oliver Micic

Every power supply worthy of the name should display the voltage and current. This compact DC power supply instrument module can be used with new supplies and older types lacking this capability. And thanks to microcontroller technology, it offers some bonus features.

Technical data

- Voltage range: 0–30 V
- Maximum current: 5 A or 50 A
- Peak current (Ip)
- Power range: 1–999 W
- Power measuring range (depending on JP1): 150 W / 800 W
- Electrical power in kWh
- Battery charge in Ah
- Operating time in hours or minutes (in days after 1 week)
- Bargraph display for power
- Selected display option stored in EEPROM
- Jumper-selectable Ah / Ip display; selection also possible during operation
- LCD backlight
- Optional temperature sensor with software calibration
- Sandwich module (LCD and PCB)
- Firmware versions available for 2x16 and 4x20 LCD modules

You rarely reach for a soldering iron when you have to fit a power supply with a voltage and current displays. After all, suitable modules are dirt cheap and a DIY solution would certainly be more expensive. However, a DIY instrument that has additional attractive and useful features not available in commercial modules might give you grounds for thinking twice about this option.

The instrument module described here has a backlit two-row or four-row LC display that shows the measured voltage and current in digital form as numbers and in analogue form as a bargraph display. The measuring range is 0–30 V for voltage and either 0–5 A or 0–50 A for current, depending on the sense (shunt) resistor used.

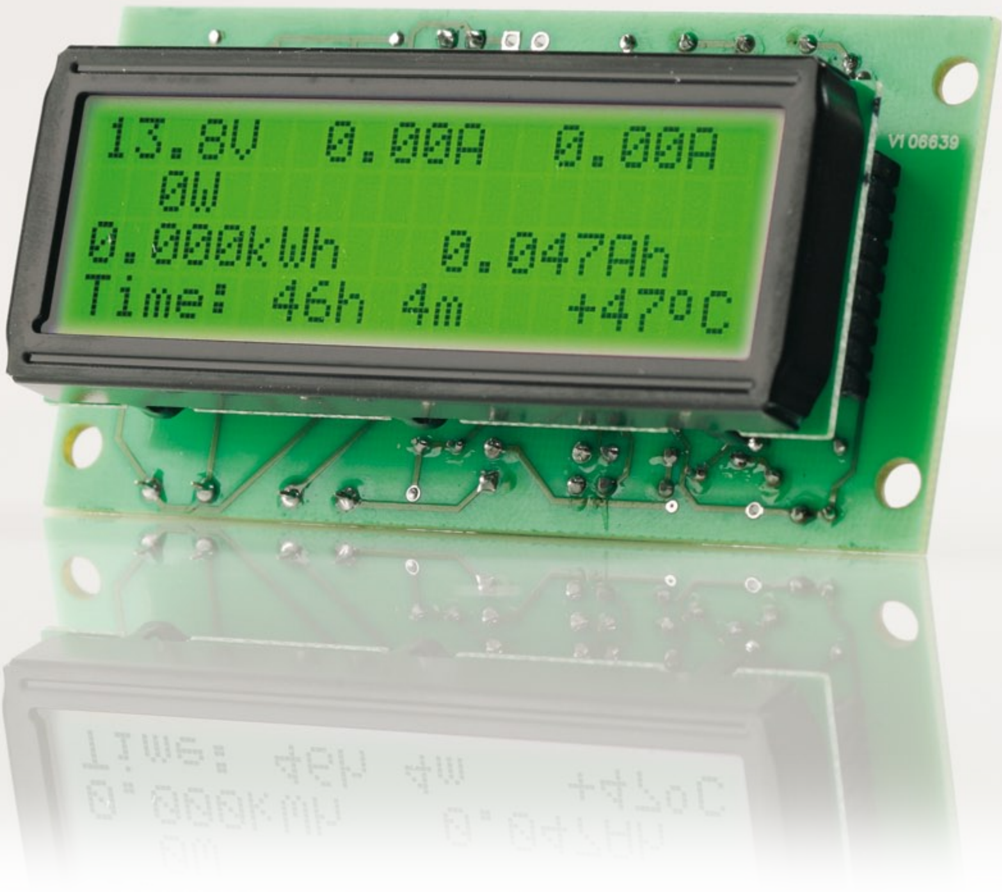
But that's not all: thanks to the microcontroller, it can also display the peak value of the output current, the output power, the amount of charge supplied in ampère-hours (for battery charging or battery operation), and the amount of energy supplied in kilowatt-hours (kWh).

It is also possible to program a switch-on time, and you can use a temperature sensor to monitor the power supply heat-sink temperature or the battery temperature, allowing the supply to be switched off by a relay. If no sensor is connected, the message 'no sensor' is shown on the display (or 'no tmp' when the 2×16 character LCD is used). The **list of technical features** speaks for itself. Additional functions are already in the planning stage, and they can be implemented easily by firmware updates.

Microcontroller with ADC

The instrument module consists of a DIP LCD with pin headers at both ends and an instrument PCB with socket headers for plugging in the LCD. As the objective is to avoid using SMDs in the instrument module, the number of components in the circuit (see **Figure 1**) must be kept to a minimum so all the electronics can fit underneath the LCD. This makes a high-performance microcontroller with an integrated analogue-to-digital converter a natural choice. We decided on the Atmel AVR ATMega28-16PC in the 28-pin DIL package. This microcontroller has three nearly independent ports and six port eter

ore



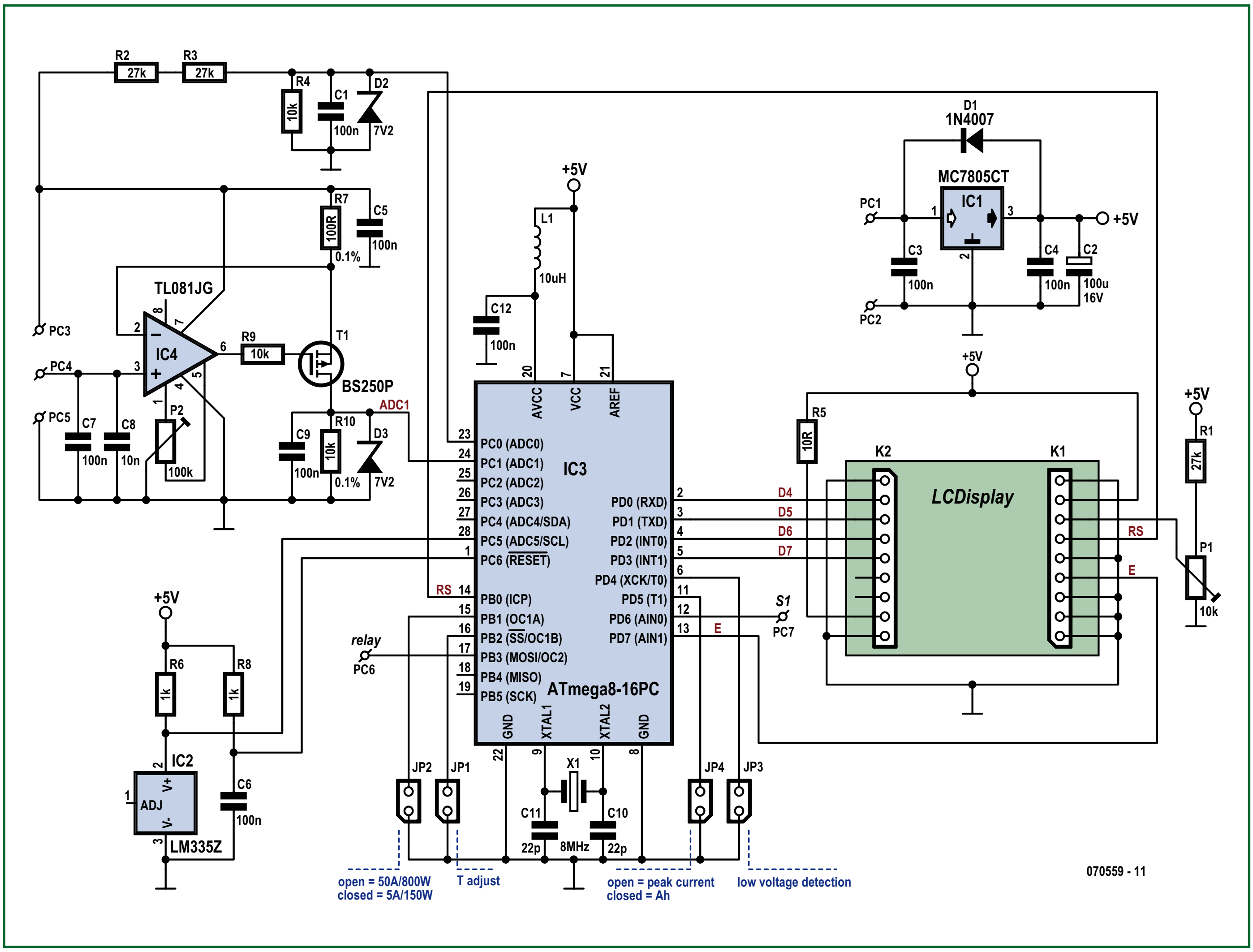


Figure 1. A microcontroller with a bit of signal conditioning circuitry.

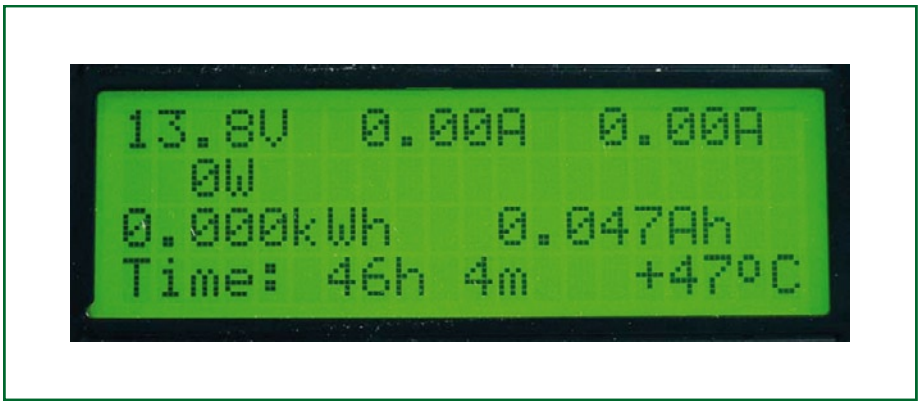


Figure 2. The measured values shown on the LC display.

lines, to which the display module is connected (using six port lines) along with the usual external components: a quartz crystal (X1), two capacitors (C10 and C11) for the clock, and a power-up reset (POR) network (R8/C6). Operation of the microcontroller is controlled by a set of jumpers **JP1–JP4**, as follows.

JP1 is only necessary for calibrating the temperature sensor as described further on.

Jumper **JP2** selects the current range (open = 50 A / 800 W; closed = 5 A / 150 W). The actual measuring range is determined by the value of the sense resistor.

The undervoltage monitoring function is disabled by default because it is not necessary in a power supply. However, if you use the instrument module in a different application, such as in battery-operated equipment to monitor the power source, you can enable it with jumper **JP3**. Port line PB3 (pin 17) goes active if the voltage drops below 10.8 V and returns to the inactive state if it rises above 11.8 V. This monitoring function prevents complete discharge of the power source by using a relay driven by a transistor stage to switch off the power. The amount of hysteresis is sufficient to prevent relay chattering. The LCD shows the measured battery discharge instead of the current in this configuration, and this indication disappears when the voltage drops below 11.8 V.

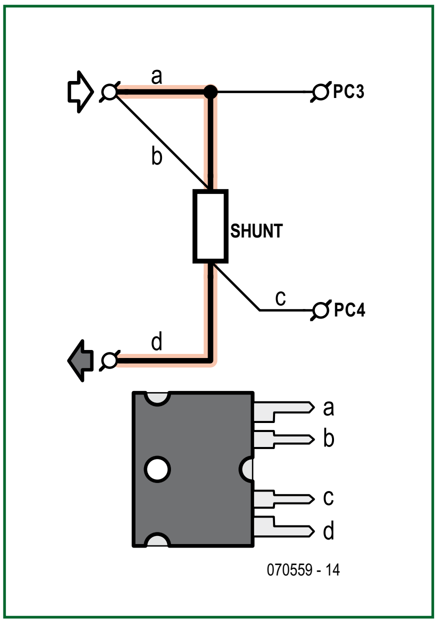


Figure 3. Shunt resistor connections.

Jumper **JP4** determines whether the 2×16 character display shows the peak current (jumper open) or the amount of charge drawn in ampère-hours (jumper closed). In normal operation (JP4 open), the following quantities are shown: voltage, current, peak current, and power. To conserve space, the peak current is shown at the upper right without a units symbol. The value is constantly updated to track measured value until it start declining, and peak value obtained this way is held for 2 seconds. This jumper can also be fitted while the module is operating, since the ampère-hour value is constantly measured in the background. You can also use a toggle switch on the front panel if you want to switch between the two functions relatively often.

As a small 2-row by 16-character ('2×16') LCD naturally does not have enough room to display all the parameters, switch S1 switches between the peak power bargraph, electrical energy, ampère-hours, operating time, and temperature. Measuring the operating time makes it possible to relate the electrical power directly to the elapsed time in hours or days. All parameters can be displayed a the same time if you use a 4-row by 20-character ('4×20') LCD (**Figure 2**), in which case this switch is unnecessary and can be omitted.

Analogue instrumentation electronics

The analogue-to-digital converter of the microcontroller communicates with the outside world via pins 23–28 of port D. Here ADC0 (pin 23) calculates the voltage and ADC1 (pin 24) calculates the current.

As the DC power meter is intended to display voltages up to 30 V, the voltage being measured first has to be reduced. A voltage divider consisting of R2 and R3 in combination with R4 yields a maximum voltage of just less than 4.7 V, which falls within the microcontroller specifications. Zener diode D2 clips voltage peaks to prevent them from damaging the microcontroller.
Measuring the current is not so straightforward. The output current of the power supply flows through a sense resistor with a very low resistance, which is connected between the positive output of the power supply electronics and the output terminal of the unit (see **Figure 3**). Depending on the desired current measuring range, the sense resistor has a value of 1 mΩ (for 50 A) or 10 mΩ (for 5 A).

The sense resistor has two sense leads that are connected to an opamp (IC4). The TL081 operates as a standard non-inverting voltage amplifier, although the way it is powered is a bit unconventional. Pin 4 of the opamp is connected to ground as usual, and the highest available clean DC voltage from the power supply, which is the voltage at the positive output terminal of the power supply, is used for $+U_b$.
This high-side measuring arrangement avoids offsetting the ground level of the power supply. This doesn't matter to the TL081, but it does mean that current measurement is only possible with an output voltage of around 4.5 V or more. The output offset of the opamp can only be adjusted using an external trimpot. The output voltage of the opamp is fed to ADC1 of the microcontroller for digitisation.
The resolution is 50 mA per digit with the larger current measuring range

(50 A), since the A/D converter has a maximum resolution of 10 bits. On top of this there is an error of ±1 to ±2 digits due to quantisation noise. The resulting error is 1% at an output current of 10 A. The resolution is 10 times better (5 mA) with the 5-A range. Voltage measurement is somewhat more accurate with a resolution of 30 mV per digit. These accuracy figures are perfectly okay we believe for a workbench instrument.

What else is there? The supply voltage for the analogue portion of the microcontroller has additional filtering in the form of L1 and C12. The optional temperature sensor (IC2), an LM335Z, is connected directly to ADC5 (pin 28).

Naturally, the microcontroller needs a clean 5-V supply. It is provided by fixed voltage regulator IC1 and the surrounding components. Solder pin PC1 on the board for the measurement module supply voltage is connected directly to the input of the voltage regulator. The regulator requires an input voltage of at least 8 V and can tolerate a maximum input voltage of 30 V. This voltage must be tapped off from somewhere in the power supply. If a 12-V battery is used, it will also power the measurement module. In the case of supply voltages over 15 V, the size of the heatsink has to be increased proportionally.

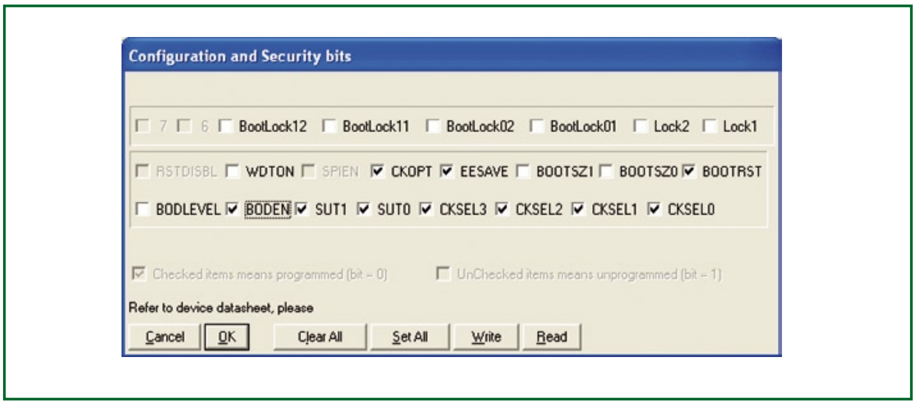


Figure 4. Settings with PonyProg.

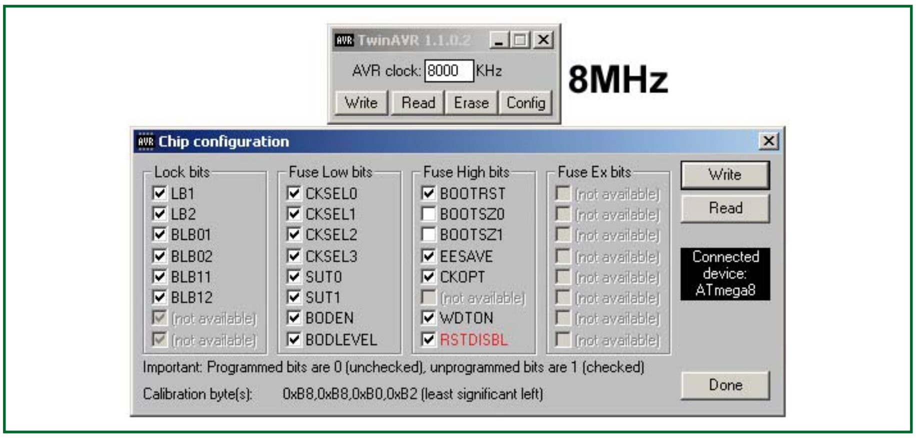


Figure 5. Chip configuration with TwinAVR.

Microcontroller programming

If you want to program the microcontroller yourself, you can download a Zip file from the Elektor website. It contains the V1.16a version of the firmware in .bin and .hex formats for an LCD with 2 rows of 16 characters or one with 4 rows of 20 characters. The ready-programmed microcontroller listed in the Elektor Shop contains the firmware for a display with 4 lines of 20 characters.

If you do your own microcontroller programming you must configure certain settings of the fuse bits so the program will run correctly. **Figures 4** and **5** show the proper settings in the configuration windows of TwinAVR and PonyProg. If you perform a firmware update, you should right away set the bit that prevents EEPROM erasure during programming. This way the original settings will be maintained.

Assembly, alignment, and installation

As no SMDs are used in the circuit, assembling it on the small PCB shown in **Figure 6** is easy, especially since the microcontroller and opamp can be inserted in precision sockets. Fortunately, all displays of the type indicated in the parts list have the same dimensions and pinout, so no problems in that department. The temperature sensor can be fitted on the board or connected by a short length of screened cable.

One of the outer terminals of the shunt is connected straight to the positive (+) output terminal of the PSU (or the + terminal of the battery). The sense terminal next to it is connected to PC4 on the power meter using light duty wire. The high-current terminal at the other side of the resistor is connected to the electrical output of the PSU using a piece of heavy-duty cable or wire that's kept as short as possible. Finally, PC3 on the power meter is connected to the second sense output of the resistor, also to the output of the supply.

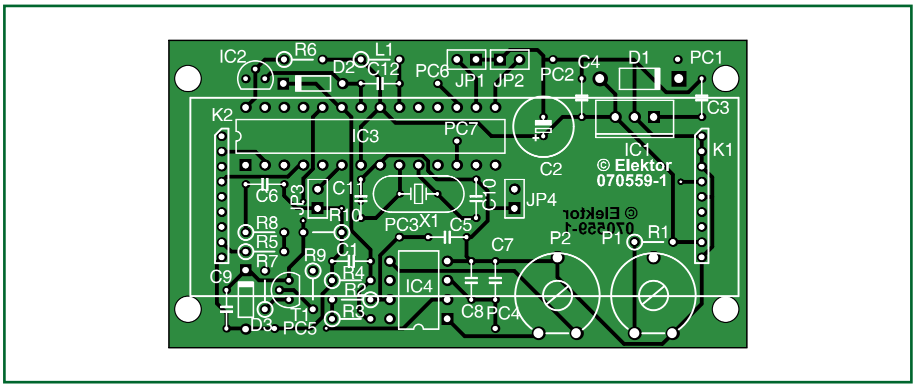


Figure 6. Component side of the prototype PCB.

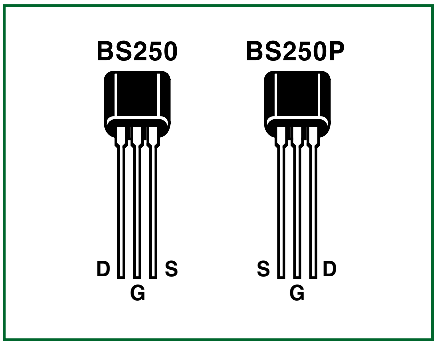


Figure 7. The BS250 FET comes in two versions with different pinouts!

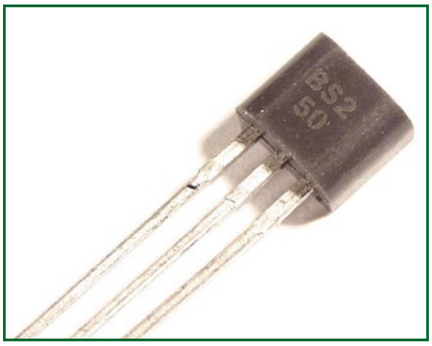


Figure 8. This specimen definitely has the pinning of the P version, but not the matching print on the device!

COMPONENTS LIST

Resistors
R1 = 27kΩ
R2,R3 = 27kΩ, 1%
R4 = 10kΩ, 1%
R5 = 10Ω
R6,R8 = 1kΩ
R7 = 100Ω 0.1%
R9 = 10kΩ
R10 = 10kΩ 0.1%
P1 = 10kΩ preset
P2 = 100kΩ cermet preset
Precision shunt 1 mΩ 50 A, 0.5%* or 10 mΩ/5 A, 0.5%*, Isabellenhütte type PBV R001 or R01 (Conrad Electronics # 447315 or # 447323)

Capacitors
(all 2.5mm lead pitch)
C1,C3-C7,C9,C12 = 100nF
C2 = 100µF 16V
C8 = 10nF
C10,C11 = 22pF ceramic

Semiconductors
D1 = 1N4004
D2,D3 = zener diode 7V2, 500 mW
T1= BS250*
IC1 = 7805 (TO220)
IC2 = LM335 (TO92)
IC3 = ATMega8PC, programmed for 4x20-LCD, order code **070559-41****
IC4 = TL081P (DIL)

Inductor
L1 = 10µH

Miscellaneous
X1 = 8MHz quartz crystal
One 8-way turned-pin IC socket
One 28-way turned-pin IC socket
LCD 2x16 or 4x20, DIP, with backlight, Electronic Assembly (Conrad Electronics # 181755 resp. # 181863)
JP1 = (temporary) pushbutton
JP2,JP3 = jumper or wire link
JP4 = jumper or switch, 1 make contact*
U-profile heatsink, 12 K/W for TO220 (IC1)
4 M3i/M3a spacers, length 18mm
Two 10-way socket strip, lead pitch 2.0mm (remove 1 pin)
PCB, order code **070559-1****
Project software and PCB layout freely downloadable from www.elektor.com

*see text
**see Elektor Shop pages or www.elektor.com

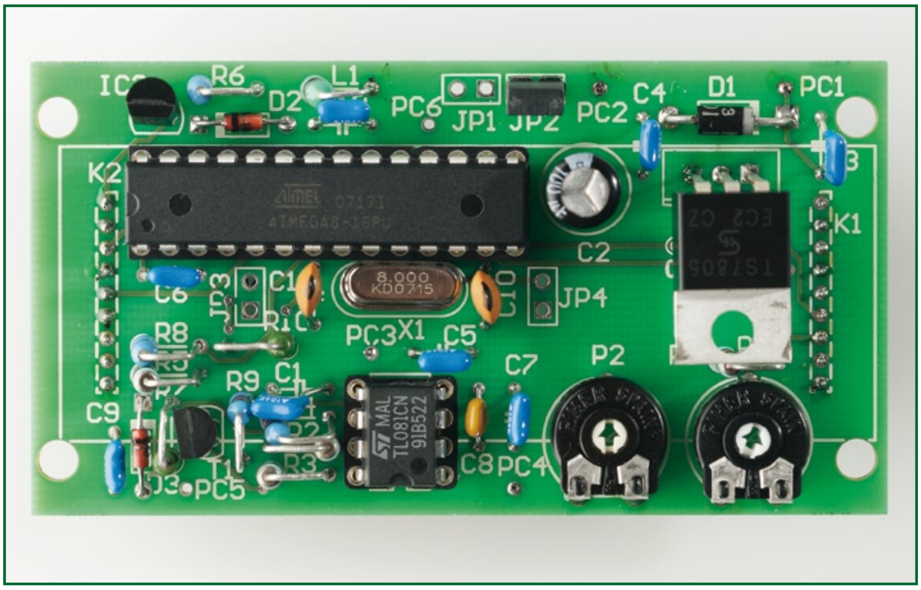


Figure 9. Component mounting plan of the prototype board.

The FET type BS250 comes in two different versions called BS250 and BS250P, which have different pin functions as illustrated in **Figure 7**. On the P version the source and drain terminals are swapped as compared with the 'normal' version. Beware, however, as there are P versions around with a 'BS250' print on them (i.e. **no P!**), see also the photo in **Figure 8**. If a BS250 is soldered in with its drain and source pins the wrong way around, the A/D converter in the microcontroller is in acute danger of damage!

For an initial test of the populated and visually inspected power meter, it is best connected to a 12-V lead acid battery or a PSU set to 13.8 V, with no load connected.

When you switch on the module the first time, you will be requested to calibrate the voltage if the accuracy of resistors R2–R4 (1% types) is not sufficient. To do this, connect a multimeter to the output and a pushbutton switch to JP1, and then press this switch repeatedly until the value shown by the LCD matches the value shown by the multimeter. This should be done at 13.8 V with no load. After you have set the voltage, the calibration is accepted after 10 seconds and stored in the EEPROM. If you want to repeat this process, hold the pushbutton pressed during switch-on until the corresponding message is shown on the LCD.

Next, you have to adjust P2 for the current measurement (symmetry adjustment of opamp IC4). To do this, connect a load to the supply (or the battery), measure the current with a multimeter and adjust P2 for an equal reading on the LCD.

If you use the LM335 temperature sensor, you will also have to determine a calibration factor for it. To do so, use a reference thermometer to measure the temperature and briefly press the switch connected to JP1 as often as necessary (pulling pin 6 of the micro to ground) to reach the correct value (1 °C increment; rolls over to 0 °C after reaching 20 °C). This value is also stored in the internal EEPROM.

Finally, use P1 to adjust the contrast of the LCD. This completes the alignment process.

Planned upgrades

Work is currently in progress on a firmware adaptation for the new ATMega88 or ATMega168, which are pin-compatible but have more flash program memory. The following functions are planned or already under development:

- Memory function for operating time, kWh and Ah with memory-clear function;
- Freely selectable sense resistor (1 mΩ, 10 mΩ, or 60-mV DIN shunts).

Check the Elektor website occasionally to see whether new firmware is available. Updates will also be announced in the relevant section on the monthly Mailbox pages, but these appear with considerable delay compared to our website.

(070559-I)

Web Links

Author's website:
http://www.dg7xo.de/selbstbau/nt-power-modul.html

BS250 information:
http://www.dg7xo.de/selbstbau/dc-power-meter_info_bs250.pdf

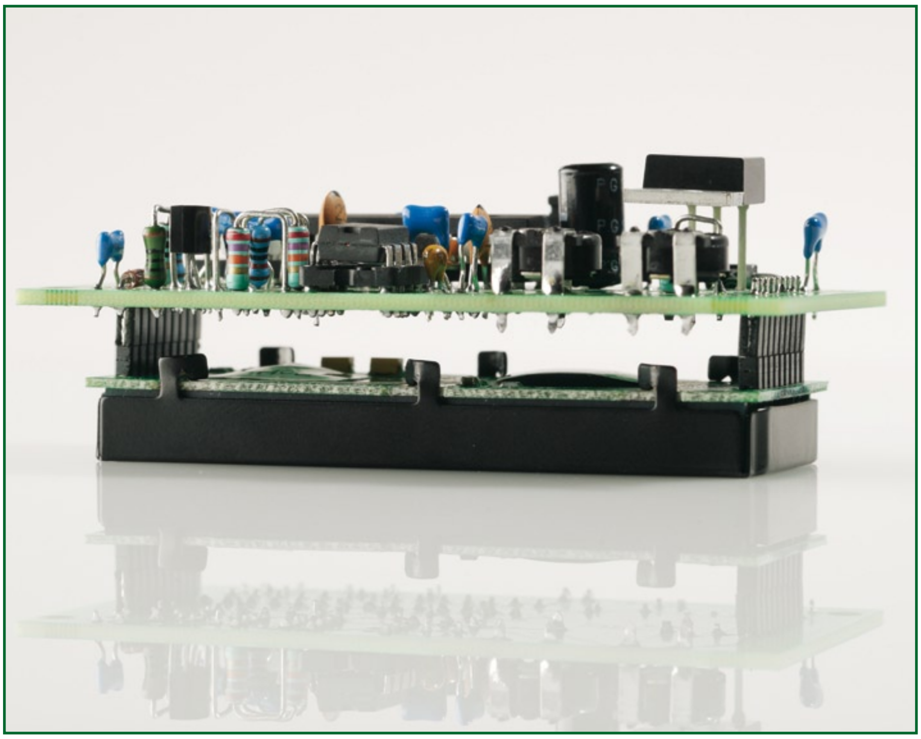


Figure 10. The LC display module plugs into the PCB.

Ballast for Energy-s

CFL preheats, ignites and lights on singl

T. A. Babu

For sure, the incandescent bulb that's been with us for well over a century will be banned soon to the realms of Big Energy Wasters, and from there, to Oblivion. Its function, lighting our desks, streets and rooms is to be taken over, they say, by energy-saving light sources like CFLs (compact fluorescent lamps). As opposed to the good old light bulb, a CFL needs an amount of electronics to start and light properly. Here we show a suitable circuit.

This compact ballast is intended for driving a 20-watt 'bare' CFL tube or bulb, that is, one **without** a driver circuit built into its socket that makes it ready to screw into an existing lamp socket. Bare CFLs come in many shapes and sizes and usually have four connecting pins. By contrast, (consumer) CFLs sold as direct replacements for the good old incandescent bulb (to be banned shortly, it's official!) have a ceramic or ABS base and a traditional 'E' screw base (where 'E' stands for 'Edison'). These contemporary lamps of which an example is shown in **Figure 1**, are often referred to as 'screw-base', 'internally ballasted' or 'self-ballasted' CFLs and can be bought for £ 3.00 to £ 7.00 (€ 4.50 to € 10) depending on the shape and wattage. Our circuit is a separate ballast control for 'pin-base' CFLs (**Figure 2**) more usually found in the industry (already, they're superseding mercury lighting). Pin-base CFLs are designed to be used with a separate ballast. As with a linear fluorescent system, the lamp and ballast must be compatible. Pin-base CFLs are available in low-power versions to replace incandescent light bulbs and in medium- and high-power versions to take over from linear fluorescent lamps or even high-intensity discharge (HID) lamps. If you want to know more about CFLs and associated ballast circuits, have a look at ref. [1].

Figure 1. CFL lamp with an E-style screw base that makes it a direct replacement for incandescent bulbs.

aving Lamps

le-chip ballast

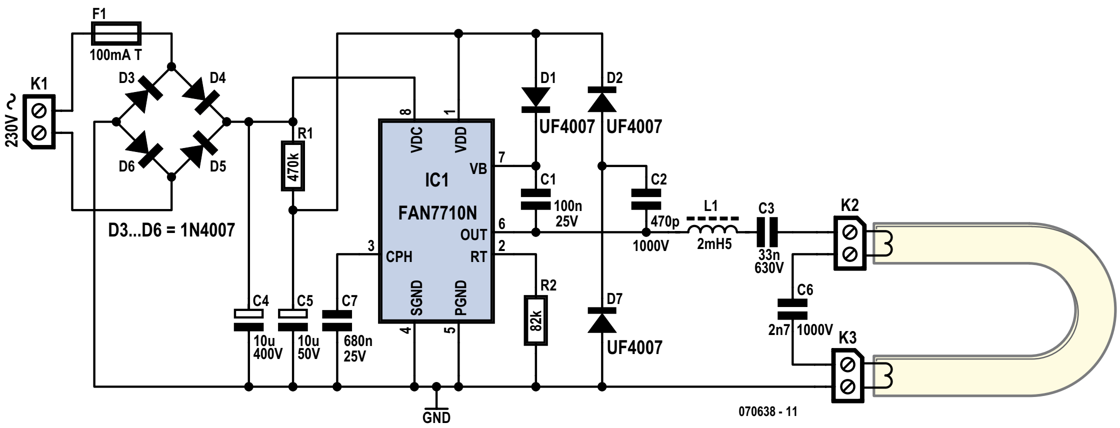


Figure 3. Circuit diagram of the CFL Ballast. A FAN7710 IC pretty much does it all here. Thanks Fairchild!

Figure 2. Example of a pin-base CFL. This one has just two pins instead of four but then the capacitor is in the protruding part between the pins.

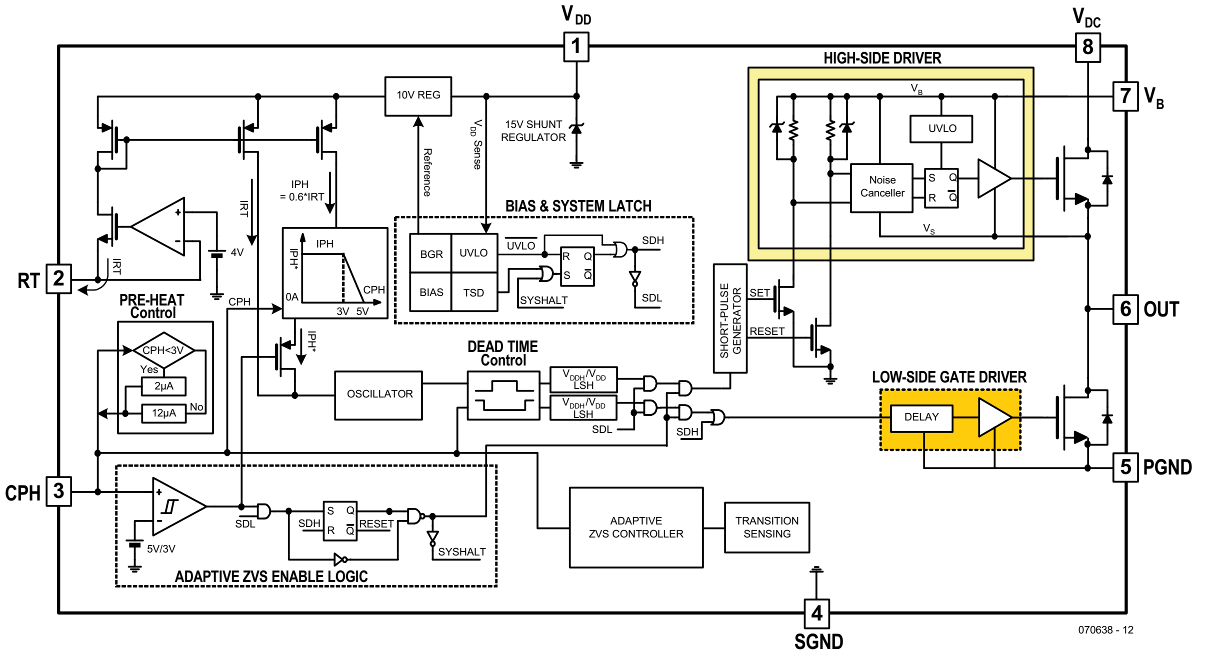


Figure 4. Functional block diagram of the FAN7710 (Fairchild).

If we are to believe what's written on the box, a 20-watt CFL achieves the same light intensity as a 100 watt incandescent bulb, hence represents an energy saving of at least 75%. However, there are no formal methods to substantiate such claims! Although a CFL, pin-based or self-ballasted, is sure to last much longer than its wolfram-based predecessor, the price/lifetime tradeoff is a matter of fierce debates about 'all things green (and beautiful)'. In this article we will limit ourselves to technical aspects of controlling pin-base CFLs.

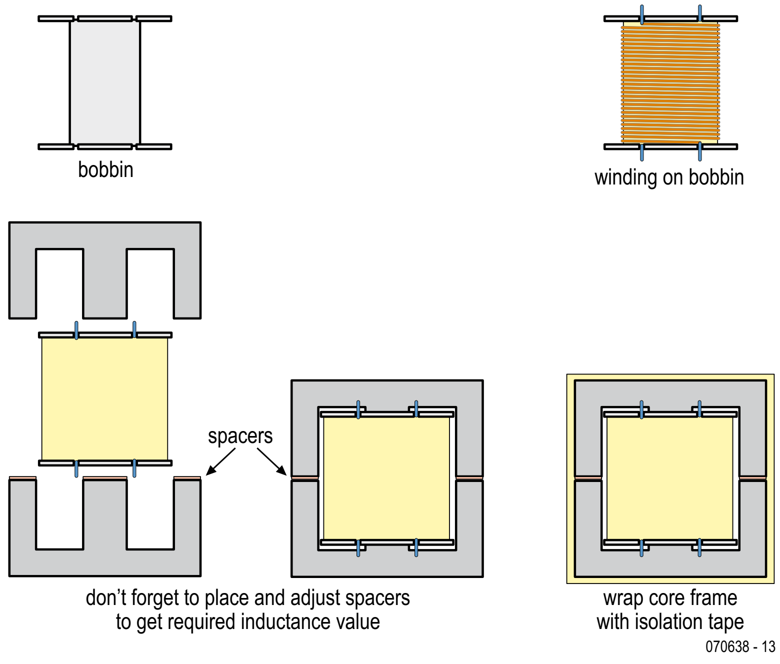


Figure 5. Clear the kitchen table, but not for dinner! Construction and assembly of the inductor in the circuit.

Making a pin-base CFL light

The circuit shown in **Figure 3** uses a dedicated integrated circuit type FAN7710 from our friends at Fairchild. As illustrated in **Figure 4**, this device combines one high-side 625-V gate driver circuit, two 550-V MOSFETs, a frequency control circuit and a shunt regulator –– plus active ZVS control and an open lamp detection function, all crammed into one ultra-compact 8-way DIP package. Its high functionality and built-in protection features save board space, reduce power dissipation and guarantee enhanced reliability in end systems. Good!

The AC line input voltage (here, 230 VAC 50 Hz) is rectified to provide a bus voltage of approximately 320 volts DC. Startup resistor R1 supplies initial (micro-) power to the FAN7710 IC. The IC begins to oscillate and the charge pump circuit consisting of C2, D2 and D7 supplies the current to the V_{DD} pin, which gets regulated through the internal 15-V shunt regulator.

The FAN7710's oscillator circuitry employs three discrete frequencies: one to pre-heat the CFL gas; one to ignite it and one for the on state — see the **inset** for the associated (simple) maths. In addition to this, it protects the ballast circuitry from low AC as well as lamp removal conditions.

Fuse F1 in the input power supply prevents electric hazards.

Making the inductor

The bare PCB, FAN7710N IC and the 2.5-millihenry inductor used in the circuit come as a set from the Elektor Shop. However we would not discourage anyone from purchasing the inductor parts and making it yourself.
Let's first carefully write down the specifications:

Inductance:	2.5 mH
Core material:	Epcos N19 or equivalent
Core size:	20 / 10 / 6
Bobbin:	E19
Gap:	1.5 mm
Wire gauge:	0.2 mm (SWG #32)
Number of turns:	280

Now look at **Figure 5** for the construction details.
First, wind the 280 turns of enamelled copper wire (ECW) on the E19 bobbin. Bare the wire ends for about 5 mm by scratching with a scalpel, then pre-tin. Check continuity of the coil. Put the E-core halves over the bobbin as shown, then insert and adjust the spacers to get the required air gap of 1.5 mm which is essential to achieve the required inductance. The final step is to wrap electrical isolation tape around the core frame.

The board

Elektor labs have designed a circuit board for the project; the component mounting plan is shown in **Figure 6.** The copper track layout is available as a free .pdf file from our website at www.elektor.com for those wishing to etch their own circuit board. Reflected and non-reflected artwork is included in the .pdf file for your convenience.
Component stuffing is a breeze as only normal size leaded components are used on a spacious board. The wiring to the mains and the lamp, and all connections and connectors in between, should comply with electrical safety guidelines.

Caution

The circuit is connected directly to the mains and presents lethal voltages. Relevant electrical safety precautions must be observed to prevent any component being touched while the circuit is in operation.

(070638-I)

Web Link

[1] www.pavouk.org/hw/lamp/en_index.html

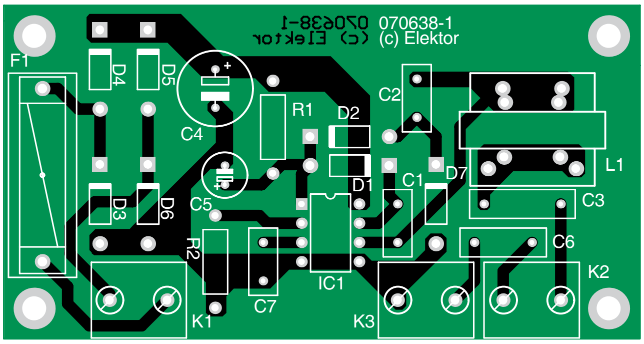


Figure 6. Component mounting plan of the CFL Ballast board. The track layout caters for electrical safety.

COMPONENTS LIST

Resistors
R1 = 470kΩ
R2 = 82kΩ

Inductor
L1 = 2.5mH (see below)

Capacitors
C1 = 100nF 25V
C2 = 470pF 1000V
C3 = 33nF 630V
C4 = 10µF 400V
C5 = 10µF 50V
C6 = 2nF7 1000V

Semiconductors
D1,D2,D7 = UF4007
D3-D6 = 1N4007
IC1 = FAN7710N (Fairchild)

Miscellaneous
K1,K2,K3 = PCB terminal block, 7.5mm lead pitch
F1 = fuse, 100mAT (slow)
PCB, FAN7710N IC and 2.5 mH coil; order code **070638-71** from the Elektor Shop.

Three frequencies

In normal operation, the frequency of oscillation of the FAN7710 equals

$$f_{osc} = 4 \times 10^9 / R_T$$

where $R_T = R2 = 82\ k\Omega$.

The pre-heat frequency is much higher however and calculated from

$$f_{pre} = 1.6 \times f_{osc}$$

And finally there's the ignition frequency, you get it from

$$f_{ign} = [0.3 \times (5 - V_{CPH}) + 1] \times f_{osc}$$

where V_{CPH} is the voltage on C3.

Low Power Efficier

a practical guide

Michael Day and Jatan Nalk, Texas Instruments

Overall system efficiency is a critical design parameter in battery power systems. It affects both the battery capacity requirement and the end product's run time. Proper system efficiency and run time calculations can be achieved only when the power supply's efficiency measurements are accurate.

Most battery powered systems take advantage of a power supply feature called pulse frequency modulation (PFM) to improve power supply efficiency at light loads. The same characteristics that help PFM mode achieve high power supply efficiencies also create several challenges for properly measuring the efficiency.

When performing measurements on DC/DC converters utilizing PFM, proper care must be taken to ensure that the measurements are accurate. Due to the nature of a converter operating in the PFM mode, its test setup is different from that of a converter operating in the PWM mode. In fact, an improper test setup can result in incorrect efficiency measurement data that varies considerably from data sheet specifications. This article discusses PFM mode and how it helps to maintain high efficiencies at light loads. It also provides guidelines to assist the engineer in acquiring accurate efficiency measurements

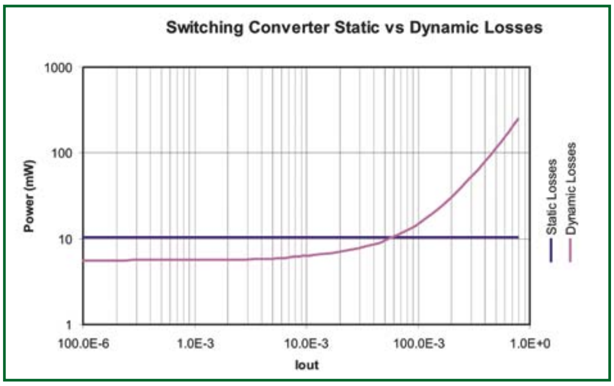


Figure 1. Comparison of a switcher's static versus dynamic losses.

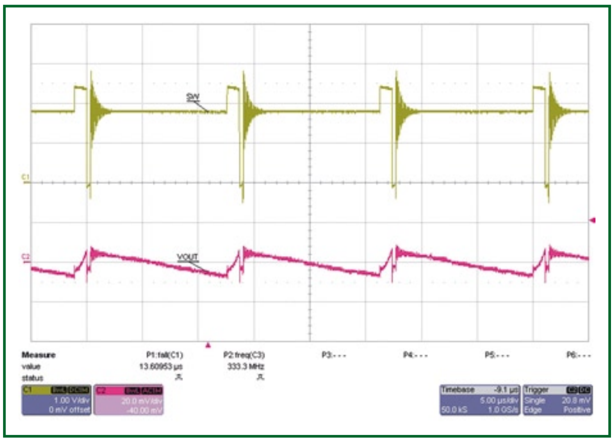


Figure 2. SW(itch) node operating in PFM mode.

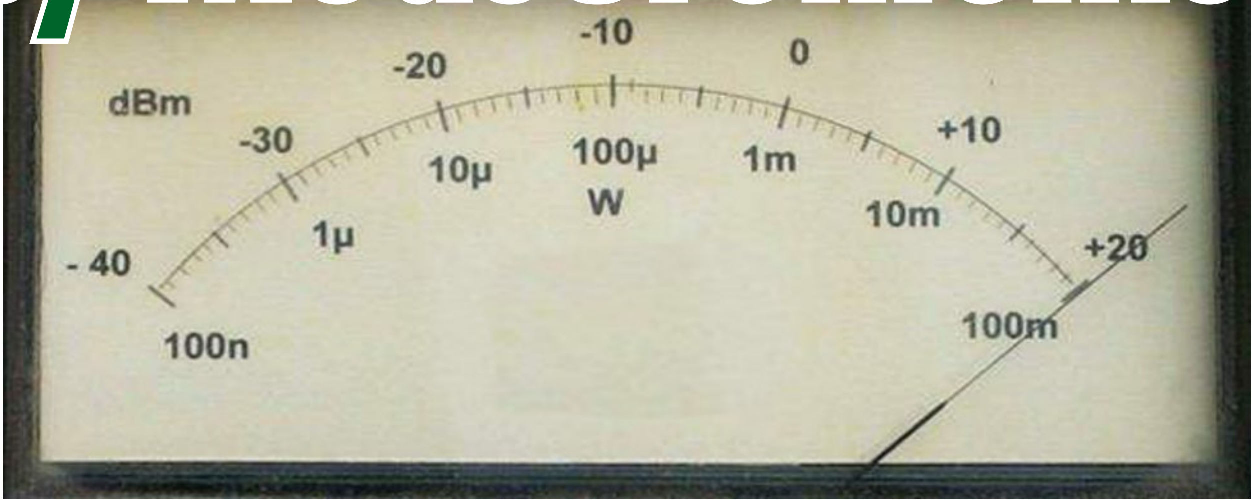
Pulse Frequency Modulation (PFM)

Pulse Frequency Modulation is a switching method commonly used in DC/DC voltage converters to improve efficiency at light loads. This method is also referred to as burst mode and power save mode (PSM). There is one primary advantage that PSM has over traditional PWM schemes: it reduces the power dissipation of the converter at light loads.
A switching converter has two types of power losses: static and dynamic. Static losses are constant, regardless of load current. Alternatively, dynamic losses increase with load current. An example of a static loss is the quiescent current going into an IC. This current is used to power internal circuitry such as bandgap references, operational amplifiers (op amps), internal clocks, etc. In turn, dynamic losses can be classified by two categories: conduction losses and switching losses. Conduction losses are load dependent and include losses caused by voltage drops across a power supply's power MOSFETs and inductor. Higher load currents result in higher conduction losses. A converter also has frequency dependent switching losses that include the MOSFETs' turn-on and turn-off losses, gate drive losses, and body diode losses that occur each switching cycle. As the name implies, these losses are proportional to the switching frequency. Most of these losses are also dependent on load. **Figure 1** shows the static and dynamic power losses for low-power ICs. This figure shows that dynamic losses are dominant at higher output currents, while static losses are dominant at lower output currents.

Power save mode (PSM)

In an effort to reduce power loss at light loads, many converters operate in a 'power save' mode. This mode utilizes

ncy Measurements



a PFM-type of operation at light load currents. This type of operation uses several power saving schemes to maintain high efficiency at light loads. In contrast to PWM mode, in which the converter is continuously switching, PFM mode allows the converter to switch in short bursts. The TPS62350 from Texas Instruments optimizes efficiency over its full input voltage operating range by changing the load current where it enters PFM mode. The PFM load current threshold is $V_{in}/25\ \Omega$. While in PFM mode, the converter only switches as necessary to service the load and maintain the output voltage. When the output voltage drops below its set point, the IC begins switching. As the IC switches, the output voltage rises. This may take one or several switching cycles. Once the output rises above the regulation threshold, the converter stops switching. The output voltage then drops as the output capacitor supplies the load current. When the output voltage drops below the threshold, the converter starts up and switches again. Significant power savings are achieved during the time the converter is not switching. **Figure 2** shows this switching function.

When not switching, the converter significantly reduces its quiescent current by shutting down all unnecessary internal circuitry. The only active internal circuitry is the bandgap reference and a comparator to monitor the output voltage. With no switching, all switching losses go to zero. Most converters operate in discontinuous conduction mode (DCM) while in PFM mode. DCM mode keeps the inductor current from going negative, which would otherwise generate unnecessary conduction losses in both the inductor and power switches. The effect of these power saving schemes is a significant increase in light load efficiency versus standard PWM operation. **Figure 3** shows efficiency in both PWM and PFM modes. PFM mode has a 55 percent increase in efficiency versus PWM mode at 1 mA.

PWM and PFM, measured

The power saving benefits of PFM mode are critical to extending the operating times of battery-based applications. However, in order to properly model system efficiency and run times, power supply efficiency in both PWM and PFM modes must be properly measured. When measuring the efficiency of DC/DC converters, it is important to properly connect the voltage and current meters to achieve accurate measurements.

Figure 4 shows the setup that should be used to perform efficiency measurements in PWM mode. This figure shows the critical placement of the voltage and current meters for each measurement. Most lab power supplies display their voltage output setting, but it is important not to use the voltage displayed on the lab power supply for efficiency calculations. Instead, connect a separate voltmeter directly across

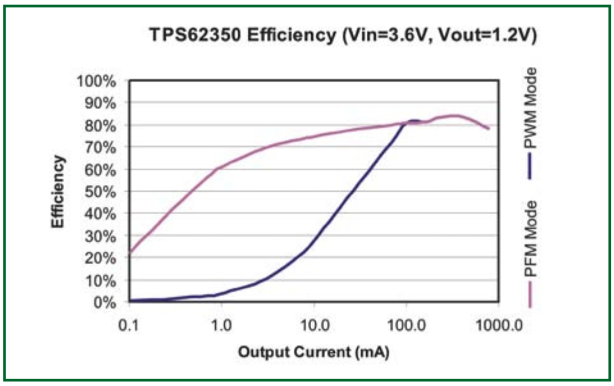


Figure 3.
Efficiency comparison between PFM and PWM modes performing accurate efficiency measurements.

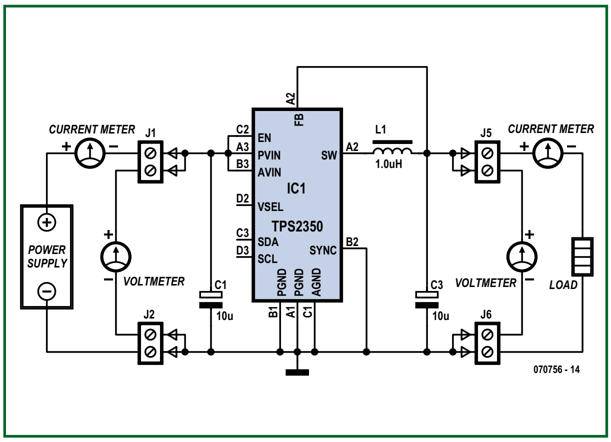


Figure 4.
PWM mode efficiency measurement setup.

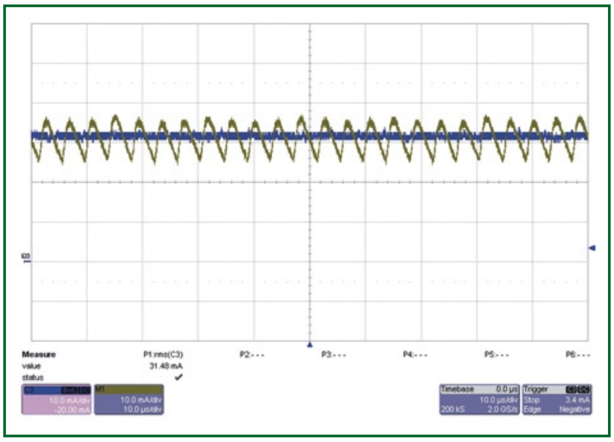


Figure 5.
Input current waveforms.

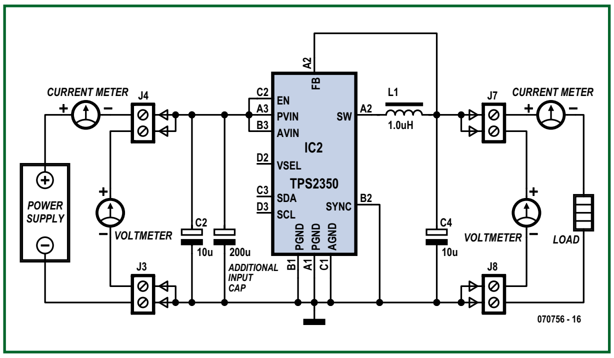


Figure 6.
PFM mode efficiency measurement setup.

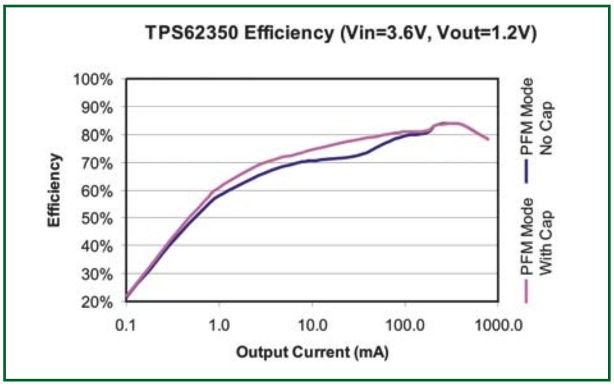


Figure 7.
PFM mode comparison with and without input capacitor.

the inputs of the device under test (DUT). This ensures that the measured voltage is the true voltage at the input of the DUT, and does not include additional voltage drops across the current meter or the wires from the input lab supply. The current meter must be placed between the lab supply and the input voltage measurement location. Similarly, a separate voltmeter must be connected directly across the output of the DUT to properly measure the output voltage values. The output voltage should be measured at the point of regulation on the power supply, not at the load. Note that both the input and output voltages are measured with Kelvin connections on the connector. This eliminates measurement error due to IR drops across the connector. Connecting the output current meter in series with the load as shown in Figure 4 provides the correct load current measurement.

Efficiency, measured

The same features that result in high PFM mode efficiency also make it more difficult to accurately measure efficiency. In **Figure 5**, the triangular waveform represents the input current of a converter operating in PFM mode. The converter only pulls current when it is switching. Most digital multimeters do not correctly measure the average input current of a power supply switching in PFM mode. Instead of measuring average current, they measure RMS current, which is always higher than the average current. The exception to this statement is when the waveform is purely DC. The engineer can only obtain accurate efficiency measurement by measuring the average input current. This is easily accomplished by adding a large capacitor to the input of the DUT as shown in **Figure 6**. The lab power supply now delivers a DC current to the DUT. The average input current to the DUT has not changed. The added capacitor filters the AC component of the current required by the DUT and allows the lab supply to source only the average DC current.
The DC waveform in Figure 5 shows the input current with an additional capacitor across the input of the DUT as shown in Figure 6. Proper placement of the input current meter allows it to accurately measure the average input current. Although the current waveform through the meter is purely DC, the current provided by the added capacitor is similar to the triangular waveform above, without a DC offset. Thus, the role of the capacitor can be viewed as separating the input current into DC and AC. A good starting point for determining the value of the added input capacitor is to make it 20 times larger than the power supply's input capacitor. Measure the lab supply current with a current meter and an oscilloscope to ensure that it is a DC waveform. If it still has an AC component, add additional capacitance. The added capacitors should have a fairly low ESR (<100 mohm).

Using the test setup shown in Figure 4 to measure PFM efficiency may result in incorrect data that varies by as much as 15 percent from the actual efficiency. This disparity is most evident at low input voltages and light load currents. **Figure 7** compares efficiency measurements taken with and without the additional input capacitor. The need for the additional input capacitor is evident by the fact that the measurements without this input capacitor average five percent lower efficiency than the measurements with the capacitor.

Conclusion

Light load efficiency is critical to extending battery life in portable applications. PFM mode uses several techniques to improve light load efficiency, but the benefits can be masked by incorrectly measuring efficiency under these light load conditions. Care must be taken when measuring the efficiency of DC/DC voltage converters to achieve accurate measurements. The placement of sensing instruments is critical, regardless of whether the converter is operating in PFM or PWM mode. Additionally, a large capacitor should be added across the input of the converter to ensure that PFM mode efficiency measurements are properly taken.

(070756-I)

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Wireless Power Transmission

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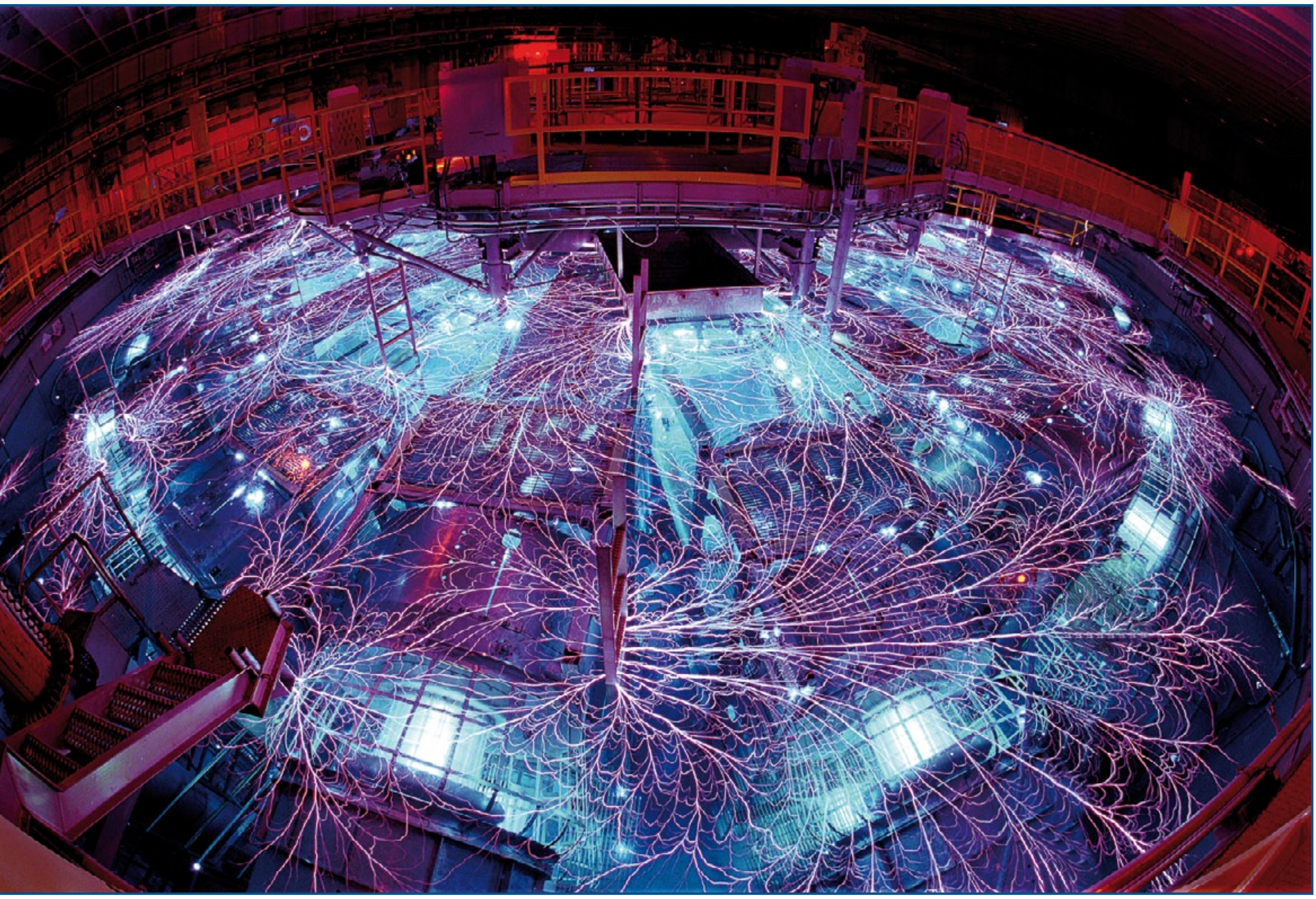


Martin Ossmann

Wireless power transmission is already used in many applications, including electric toothbrushes, RFID tags and 'refuelling' electric cars. There are also plans for powering mobile phones and laptop computers from desktop pads using wireless power transmission. This article describes how wireless power transmission works and the aspects that must be taken into account. In addition to describing the theoretical principles, it presents actual figures from practical designs.

Information supply is going 'wireless' at a rapid pace; radio, TV, mobile phones, WLAN and Zigbee show beyond doubt that radio-based data transfer and exchange is well-proven and technically sound. However if you look at the sad jungle of wires from mains adapters on your desk you may start to dream about wireless power transmission to arrive some day. In this article we show that the dream is not so easy to realise.

Wavelengths

When people talk about wireless power transmission, they also often talk about antenna systems used to transmit this 'wireless power'. As is well known, effective antenna operation is only possible if the geometric dimensions of the antenna have the same order of magnitude as the wavelength of the signal being transmitted. It is also well known that radiation effects in terms of power transmission are negligible if the antenna structure is small relative to the wavelength. For this reason, it is a good idea to examine the relationship between the frequencies used in practice, which range from a few kilohertz to several gigahertz, and their equivalent wavelengths as shown in **Table 1**. If we assume that the antenna system has to be smaller than 1 metre, you can see that even at 13.56 MHz (which is used in ISM and RFID applications) the antenna system is small relative to the wavelength. Systems of this sort are exactly what we want to examine in more detail here.

Table 1	
Frequency	Wavelength
10 kHz	30 km
100 kHz	3 km
1 MHz	300 m
10 MHz	30 m
100 MHz	3 m
1 GHz	30 cm

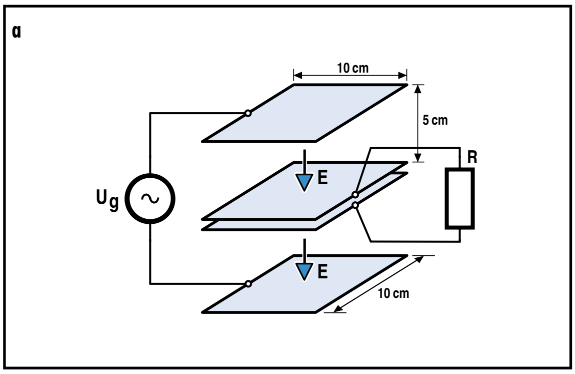
With such systems, everything is located in what is called the 'near-field region' in antenna theory. The near-field region is characterised by a nearly 90-degree phase offset between the electrical (E) and magnetic (H) fields. This essentially means that reactive power is being transmitted, so the amount of real power transmitted is relatively small.
Systems that are small relative to the wavelength can generally be described without having to take wave propagation into account. This essentially means that there is not a strong interaction between the electrical and magnetic fields. Consequently, it is normally possible to distinguish systems that work with inductive coupling from systems that work with capacitive coupling. The basic idea of a capacitive coupling system is shown in the **Capacitive power transmission inset**. As the dielectric constant of air (or vacuum as the case may be) is very small, it is relatively difficult to transmission power using capacitive coupling. Consequently, most practical systems use inductive coupling.

Inductive coupling

As previously mentioned, wave propagation is not a significant factor here, so in the case of inductively coupled systems it is important to have a good understanding of how a transformer works. We thus need to examine this topic here in more detail. An equivalent circuit makes this

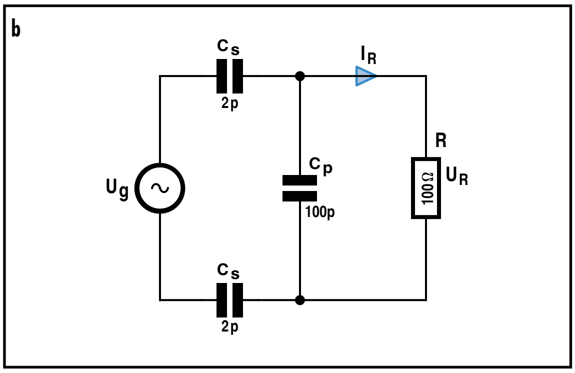
[Inset 1]
Capacitive power transmission

A hypothetical system for capacitive power transmission at 13.5 MHz in a cubical volume with an edge length of 10 cm could take the form shown in the following figure, with the top and bottom consisting of two metal plates. They form the 'transmit capacitor' and are connected to the power source. Two capacitor plates with a spacing of 1 mm are located in the middle, separated from the top and bottom plates by 5 cm. They serve to extract power from the system. The power drawn from the system is fed to a resistance R with a value of 100 Ω . The objective is to transmit a power P1 of 1 W to this resistor.



Structure of a capacitive system.

How difficult this is can quickly be seen by examining the equivalent circuit shown in the figure below and calculating the approximate component values. For this purpose, we assume that the capacitors are ideal flat-plate capacitors and stray fields can be neglected. This yields the following equivalent circuit in the following illustration:



Equivalent circuit of the capacitive system.

The voltage across the resistor is $U_R = \sqrt{(P \times R)} = 10$ V. The current through the resistor is $I_R = (U_R \div R) = 0.1$ A.

The impedance of the parallel-plate capacitor is approximately 100 Ω at 13.56 MHz, which means that the current through the (very small) series capacitors is approximately $I_S = 0.14$ A. The problem is now clear: the power source must produce a voltage that is high enough to cause a current of 140 mA to flow through the two 2-pF series capacitors. At 13.56 MHz, this requires a voltage of approximately 1.4 kV – just to transmission 1 watt of power.

[Inset 2]

Transformer equivalent circuits

A transformer with identical primary and secondary windings (and with an open-circuit inductance L) can be represented by the equivalent circuit shown in ***Figure 2a***. Conventional transformers normally have a high coupling factor (k ≈ 1), so the stray inductance L_s is small relative to the main inductance L_m. The magnetisation current I_m, which in a manner of speaking does not contribute to power transmission, can be kept small by using a suitable number of turns for the winding.

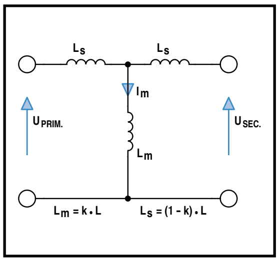


Figure 2a

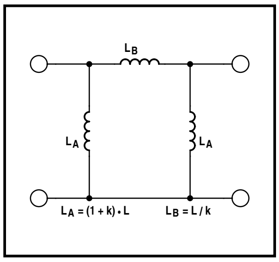


Figure 2b

Wireless power transmission systems typically have a low coupling factor, in which case L_m is small relative to L_s. The magnetisation current appears as large 'useless' quadrature current. The equivalent Π circuit shown in ***Figure 2b*** corresponds to the equivalent T circuit in terms of its electrical behaviour. If the transformer does not have a symmetric structure, an ideal transformer must be added to each of these equivalent circuits as shown in ***Figure 2c***. It essentially represents the transformer turns ratio n resulting from the different numbers of turns on the two windings.

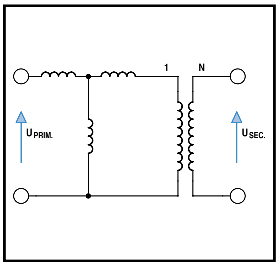


Figure 2c

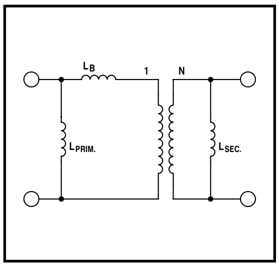


Figure 2d

The ideal transformer can be used to shift the secondary inductance of the equivalent Π circuit to the secondary side (taking into account the transformer turns ratio n). This yields the equivalent circuit shown in ***Figure 2d***, whose elements can be interpreted relatively easily in physical terms.

The inductance L_{pri} is essentially the inductance of the primary winding measured with the secondary winding located infinitely far away (zero coupling). L_{sec} is the inductance of the secondary winding under the same conditions. If the two windings are brought closer together, the series inductance L_B comes into play. It corresponds to the coupling capacity of the magnetic flux, and it is very large with weak coupling. In practice, this makes it difficult to transport a high current without producing a large voltage drop across the poorly coupled transformer. Finally, the ideal transformer element represents the relationship between the primary and secondary voltages and currents, which can be modified by altering the turns ratio.

[Inset 3]

Coupling factor

Two PS47 x 14.9 coil forms were wound with 70 turns each using 30 x 0.1 mm stranded wire (see photo).

This yielded an inductance (L) of 150 μH for each coil. The inside diameter was approximately 30 mm, the outside diameter was approximately 32 mm, and the coil height was approximately 9 mm. The coupling factor k was measured by measuring the voltage ratio under no-load conditions.

This yielded the following results for the coupling factor as a function of distance between the coils:

Distance in mm	k
0	0,33
3	0,17
10	0,11
20	0,05
32	0,02
45	0,01

easier to understand. The various equivalent circuits used here are described in the **Transformer equivalent circuits inset**.

The circuit shown in **Figure 2d** provides a fairly good representation of the situation in a system with weak inductive coupling, although its parameters can also be converted into an equivalent T circuit.

Transformers

For our first example, let's consider two circular coils with the same number of turns located a certain distance apart. These coils are coupled magnetically. The behaviour of a transformer of this sort can be described by its equivalent circuit. There are several options for this; here we use the symmetric equivalent Π and T circuits. They exhibit the same behaviour, but sometimes one or the other is better suited for understanding a particular aspect. First let's consider the equivalent T circuit. If we measure the primary inductance under no-load conditions, we obtain the value $L = L_s + L_m$. This value is useful in practice, and it is often simply called the inductance of the transformer. A decisive aspect here with regard to wireless power transmission is that the prima-

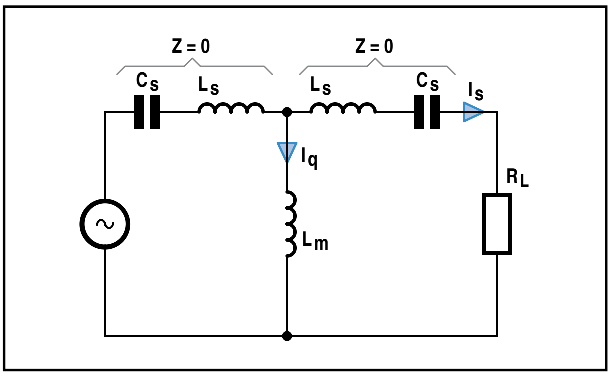


Figure 1. Series compensation.

ry and secondary coils are loosely coupled. The coupling is described by the coupling factor *k*, which decreases as the distance between the coils increases. We measured the coupling factor at various distances, and the results are presented in the **Transformer equivalent circuits inset**. In our case (with identical primary and secondary windings), the coupling factor is the same as the voltage ratio under no-load conditions, as can be seen from the equivalent circuit. A coupling factor higher than 0.4 is rare with wireless power transmission. As can be seen from the table, the value is often much lower, in contrast to a conventional transformer where the coupling factor is often higher than 0.95. Now we need to examine the consequences of this low coupling factor.

Resonant operation

When the coupling factor is low, the stray inductance (L_s) of the equivalent T circuit is nearly the same as the inductance L and thus presents a high impedance to the current. One way to attempt to avoid this problem is to use a series capacitance C_s to compensate for the series inductance. This is shown in **Figure 1**.
This creates two series-resonant circuits, which in the ideal case reduce the series impedance to zero at the resonant frequency. However, there is still a problem because the inductance L_m is also small when the coupling factor is small. This gives rise to a quadrature current I_q in addition to the desired current I_s. Some examples with actual numbers are shown in the insets describing a **10-watt halogen lamp supply**, **reading Mifare RFID cards at distance**, and a **wireless LED supply**.
Systems such as this can only be used within a narrow frequency range due to their resonant nature, which is a disadvantage. The inductors and capacitors in such systems are high-power components and thus not easy to adjust (and not at all during operation), for instance in order to compensate for drift at elevated temperatures.

Reactive power

The idea of using extra components to form resonant circuits in order to compensate for reactive components (inductors or capacitors) has a decisive disadvantage, which is that it results in an additional exchange of reactive power between these components. In actual contactless power transmission systems, the reactive power is several times as high as the transported real power (see also our introductory remark regarding the near-field and far-field regions of antennas). This reactive power leads to significantly higher voltages and currents. This would not be a problem if the components were lossless, but unfortunately we have to use real components. The example of a **10-watt halogen lamp supply** with a wireless link described in the inset indicates the magnitude of the values that can be expected.

As you can see, here it is necessary to use high-voltage capacitors. At the same time, the capacitors must have very low effective series resistance, as otherwise the power dissipated in the capacitors would be higher than the transported real power. The losses from component dissipation due to the reactive power make it very difficult to achieve good efficiency. Here we should examine a few loss mechanisms in more detail.

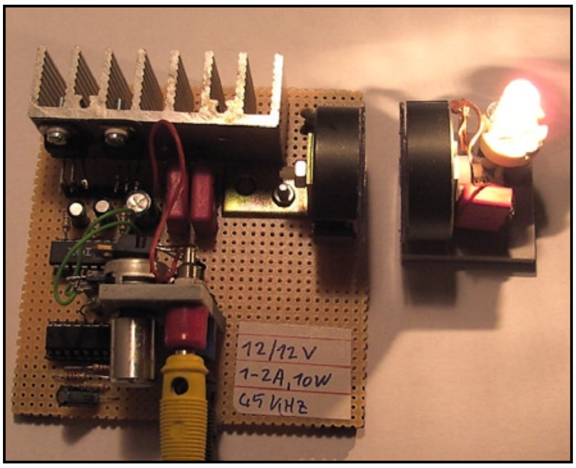
Loss mechanisms

With regard to the coils, eddy-current losses are often the

[Inset 4]

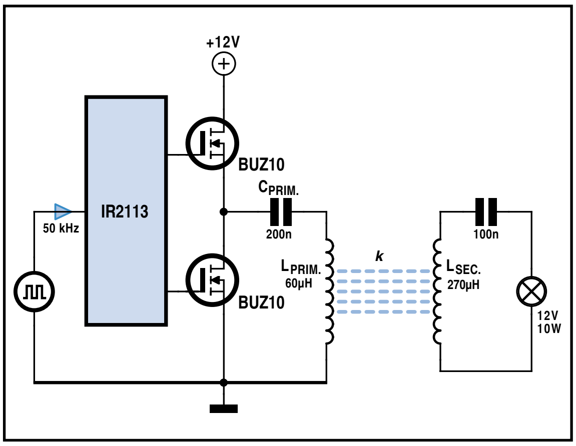
10-watt halogen lamp supply

The photo shows a system that can power a 12 V / 10 W halogen lamp across an air gap of 3 to 8 mm. As can be seen from the basic schematic diagram, the primary resonant circuit is driven by pair of MOSFETs operating in push-pull mode. The primary and secondary windings are located in the two halves of a PM36 core. The primary winding consists of 26 turns of RF litz wire (60 x 0.1 mm). Its inductance L_{pri} is 60 µH. The capacitor in the primary circuit is a 0.2-µF MKP10 type. The BUZ10 transistors (R_{DSon} = 0.07 Ω) are driven by an IR2113 drive IC. The circuit is powered by a 12-V DC supply.



Contactless power supply for a 10-W halogen lamp.

The secondary has 55 turns and an inductance L_{sec} of 270 µH. This turns ratio allows the 12-V lamp to be operated at or close to its rated voltage. The capacitor in the secondary circuit is a 0.1-µF MKP10 type. The halogen lamp (12 V; 10 W) is powered directly by the secondary winding at the operating frequency of approximately 50 kHz.



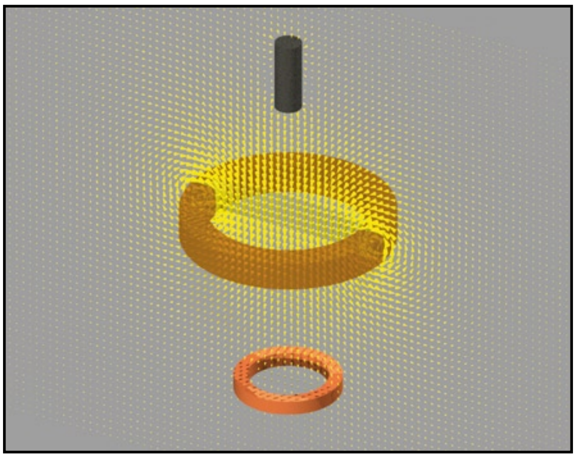
Basic schematic diagram of the transmission system.

The primary current is around 5 A (effective) in normal operation. The reactive power in the primary capacitor is thus N = 400 VA (= $I^2 \times Z_C$, where Z_C = 16 Ω). This means that the reactive power is 40 times as high as the transferred real power, even though the air gap is relatively small.

[Inset 5]

Field simulation

Analytic calculation of the fields in actual wireless power transmission systems is often not possible. Field simulation is frequently helpful in such cases, at least for estimating the effects. The result of such a simulation is shown in the following figure.



Magnetic field of a transmit coil

A current-conducting ring representing the transmit coil is located in the middle. It generates a magnetic field. A small ferrite rod is simulated above this 'transmitter'. As can be seen, it does not alter the field of the transmit coil significantly, although it does 'absorb' the field in its immediate vicinity. This means that at long distances it is not possible to markedly increase the coupling factor, even if ferrite cores are used, for the simple reason that a large part of the magnetic flux generated by the transmitter cannot be directed to the receiver. A copper shorting ring is simulated below the transmit coil. It also only affects the field in its immediate vicinity. From this it can be concluded that air-core coils are even less suitable for achieving good coupling factors.

A large part of the field of the transmit coil is not affected by any receiver objects that may be present,. and the magnetic field behaves essentially the same way as the field of an undisturbed coil. The associated field power simply appears in the overall system as additional reactive power that must be supplied to the system. This reactive power is accompanied by a current, and this additional current causes additional losses in all resistive elements of the circuit.

It is often possible to derive relatively reliable values for inductance and coupling factor from a field simulation. It is also possible to obtain indications of the losses to be expected due to eddy currents. With this information, it is possible to estimate the efficiency of the system in the early stages of the design. However, a good estimate of all the losses in the system is decisive for a realistic assessment, and this is often very difficult to do.

decisive factor for wireless power transmission. The coils are often air-core coils or coils with what is called a 'very large air gap'. If we only consider the classical skin effect, which means concentration of the current on the surface of a conductor due to its own magnetic field, we obtain much too optimistic values for the increased impedance. Here the winding is located in its own strong overall field, which causes heavy eddy-current losses even at very low frequencies. These losses are often called 'proximity losses'. An example curve is shown in the **Proximity effect inset**. Magnetic hysteresis losses in ferrite cores also become noticeable at higher frequencies. Switching losses in the transistors of the transmitter output stage must also be taken into account. This often requires careful design in order to

[Inset 6]

Reading Mifare RFID cards at a distance

The Mifare cards described in the September 2006 issue of Elektor Electronics are near-field cards, and the manufacturer says that it is impossible to read them at long distance. To see how difficult this would be, we can make a few rough calculations. We assume that the transmit antenna is a circular loop antenna with a radius R of 1 metre and a single winding (N = 1). The magnetic field strength H as a function of distance d (see the figure below) can be calculated using the following formula:

$$H = \frac{N\,I}{2} \frac{R^2}{\left(R^2 + d^2\right)^{3/2}}$$

According to the ISO 1443-2 standard, this type of RFID card operates with a magnetic field strength in the range of H_{min} = 1.5 A/m to H_{max} = 7.5 A/m.

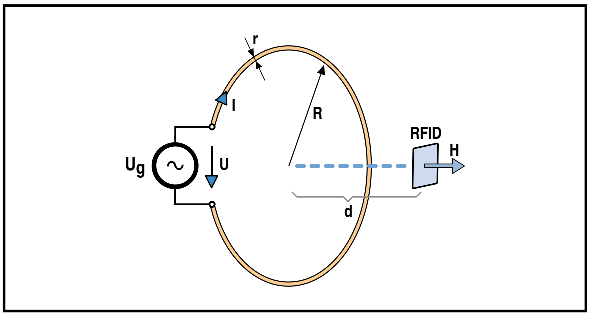
If we want to achieve a field strength of 1 A/m, we can calculate that this requires a current I = 5.64 A.

This current must flow through the transmit antenna at a frequency f of 13.56 MHz. If we assume that the coil consists of one turn of wire with a wire radius r of 1 mm. the inductance of the transmit antenna can be calculated approximately using the formula

$$L \approx \mu_0 \left(ln \frac{8R}{r} - 2 \right) \approx 8{,}8\,\mu H$$

At a frequency f of 13.56 MHz, this yields a coil impedance Z_L of approximately 750 Ω. This means that the voltage U across the antenna must be approximately 750 Ω × 5.46 A = 4.2 kV, which is nothing to sneeze at. The associated oscillating reactive power N is equal to U × I = (4.2 × 5.64) kVA ≈ 24 kVA.

As can be seen from this numerical example, it's not especially easy to read a Mifare RFID card at a relatively long distance.



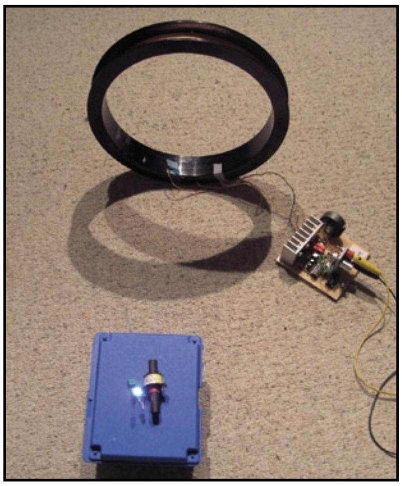
[Inset 7]

Wireless LED supply

The photo shows an arrangement for supplying power to a white LED. The maximum distance for which the LED still emits any light with this arrangement is quite large: 1.3 m.

The power transmitter uses the same push-pull circuit as the ***10-watt halogen lamp supply*** inset. The transmit coil (transformer primary) consists of 15 turns of HF litz wire (90 x 0.1 mm) wound on a circular form with a diameter of 22 cm. Its inductance is 100 µH, and the resonant capacitor (type MKP10) has a value of 0.1 µF. The operating frequency is 50 kHz. The resulting impedance of both the coil and the capacitor is 31.4 Ω. The reactive power is $I^2 \times Z_0 \approx 1.2$ kVA, although the primary current is only 6 A_{eff}.

The transmit coil has a DC resistance of 0.25 Ω, which causes a power dissipation of approximately $(6\ A)^2 \times 0.25\ \Omega = 9$ W, although the LED receives only a few milliwatts of power. The switching losses are at least $(36\ A)^2 \times 0.07\ \Omega = 2.5$ W. The voltage across the capacitor is $I_{eff} \times Z_0 \approx 200$ V. The receive coil consist of 250 turns of 0.2-mm copper wire wound on a ferrite rod with a diameter of 10 mm and a length of 60 mm. It has an inductance of 4.6 mH, which resonates with a capacitance of 2.2 nF at 50 kHz. The load consists of a white LED. The separation in the photo is around 30 cm, and at that distance the LED is very bright. The maximum distance before the LED goes dark is approximately 1.3 m. Without the ferrite rod, the maximum distance is approximately 20 cm, with an inductance of 680 µH and a capacitance of 15 nF.



Powering an LED at a distance of 30 cm.

minimise the net loss. Dielectric losses in insulators become a significant factor in systems operating at relatively high frequencies.

If electrically conductive materials are in the vicinity, eddy currents will of course be induced in them, which leads to warming. This is a desirable result for inductive cooking, but with other types of systems care must be taken to prevent the magnetic fields from harming other equipment or even people. Naturally, such losses also reduce the efficiency that can be achieved in practice. Screening is often not possible with long-range systems, since otherwise the useful field would be attenuated too much.

The next important topic is the resonance capacitors that are used. They conduct large currents, which in turn lead to high voltages (several hundred volts to a few kilovolts). It is usually necessary to use low-loss ('high-*Q*') capacitors. The power P_C that a capacitor with a Q factor Q_C dissipates due to its reactive power N_C is given approximately by the formula $P_C \approx N_C \div Q_C$. In our case, the difficulty arises from the fact that the reactive power N_C is often several times as large as the real power to be transferred. As a result, the power dissipated in the reactive components can be as large as the transported real power, despite the use of very good capacitors.

Summary

We have described several mechanisms that play a role in the design of inductively coupled wireless power transmission systems. Actual applications require careful weighing of all the parameters. And in conclusion, someday soon you may be able to use your notebook computer without a battery thanks to wireless power transmission.

(070825-I)

Web Links

http://web.mit.edu/newsoffice/2007/wireless-0607.html
http://en.wikipedia.org/wiki/WiTricity
http://www.witricitynet.com/

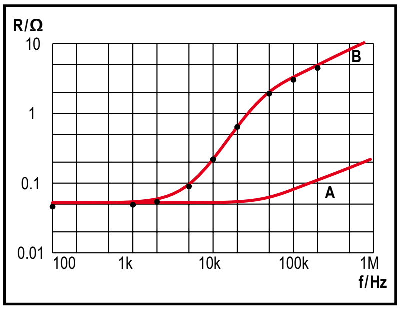
[Inset 8]

Proximity effect

Coils used in wireless power transport systems typically operate with relatively high magnetic field strengths, which also affect the turns of the coils. If we only take into account the increased impedance due to the skin effect arising from the magnetic field of the conductor, we obtain curve A in the following chart, which suggests that the coils could easily be used at frequencies below 100 kHz.

If we measure the impedance (equivalent serial impedance), we obtain curve B drawn through the measured points. This curve shows the actual impedance characteristic, because it takes the strong total field into account (proximity effect). As you can see, the impedance at 10 kHz is already significantly higher than the DC resistance. It would thus be better to use HF litz wire in this case. In order to obtain similarly reliable predictions for determining the best type of wire, it is necessary to use a good field simulation program.

This example demonstrates the importance of taking system losses into account.



Impedance characteristic with skin effect (A) and proximity effect (B) (• = measured value)

Economical with Energy

We are all exceedingly energy conscious these days but it is often difficult to estimate whether an appliance uses a little or a lot of energy. It is obvious to electronic engineers to look at the power consumption of various electrical and electronic appliances. Especially at home and at the office there are numerous appliances that require power continuously. How can we reduce that? To find that out, you first need to know how much power an appliance uses when it is in the off state and how much when it is in use. This is not very difficult with an incandescent lamp, which pretty much uses the nominal power that is printed on it. And when the lamp is switched off with a switch then it is also truly off. However, this is not so easy with many other appliances. Although the nominal power is normally displayed on the name plate this is not necessarily the continuous power. Also, the power consumption in the idle state of many devices is not known either. Appliances such as computer, monitor, TV and video recorder do not have a real mains on/off switch any more, only a kind of standby button. Appliances that are turned on and off with a remote control may be different still.

Another example of 'stealth consumers' in the home are mains power adapters which are, rightly or wrongly, in common use these days. The design of the relevant appliance is significantly simplified when an external power adaptor is used, since the appliance itself does not have to comply with stringent electrical safety requirements. With many portable devices, such as MP3 players and mobile phones, the mains adapter is only used when charging the batteries and can be unplugged when finished. But with many appliances the mains adapter is plugged in continuously. And this costs energy! Linear mains adapters in particular can consume several watts in the no-load state. This can add up significantly if you have, say, 10 or 15 mains adapters around the house (count them!).

Measuring

With the aid of a small investment you can easily discover how much power each individual appliance uses when in use and when in the off (standby) state. There are various so-called energy meters on offer, small devices in the form of an intermediate plug and socket. There is a plug on one side and a socket on the other side. In addition, the device has a display and a number of operating buttons. You plug the energy meter into the wall socket where the appliance you want to measure is normally plugged in and then you plug the appliance into the socket on the energy meter. The display on these little meters now shows a number of measured values, such as real-time mains voltage, current draw, power consumption, sometimes also cos-φ (see sidebar) plus the number of kilowatt-hours used since the meter was plugged in. In addition most of these devices can also show you how much this has cost you; for this purpose you can enter the kilowatt-hour price, on some of them even separate day and night tariffs.

Many utilities recommend the use of such an energy meter, so that the consumer is more aware of the energy use of various appliances in the home. There have haven been campaigns where utilities have made these meters available to their consumers for a few weeks at no cost.

But there is no reason to refrain from buying one yourself because of the cost, there are models available from only about £ 7 (€ 10, $14) from builders markets, highstreet electronics retailers and the like and you will quickly recoup the cost once you identify the worst culprits.

On offer

For this article we looked at nine energy meters that are currently offered for sale. Nearly all the meters are of the same design (as we have just described).

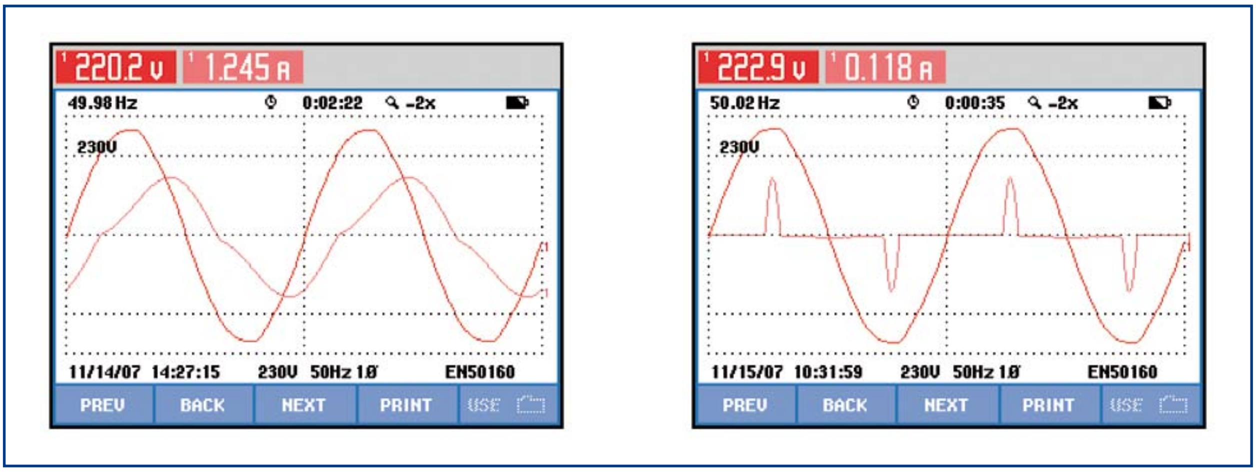
Two devices are different: the Energy Control 3000 from Voltcraft (a wireless measuring station with various types of sensors) and the Energy-Monitor EM600 from ELV Germany (a two-part measuring system where the display half can be placed in a different location). Refer to the accompanying individual descriptions for each of the meters.

The energy meter is only useful to you if it gives a reliable

Test of popular energy meters

Harry Baggen

How much power does your modern LCD or plasma TV use when it is on? And how much when it is supposed to be 'off'? If you want to be economical with energy at home then you need to know how much power each appliance uses. Handy energy meters are available for this purpose that can just be plugged into a power point and then indicate on a display how much power the appliance uses. How accurate are these meters and what can you actually measure with them? We examined a few of these meters in the Elektor laboratory.



On the left is shown the inductive current waveform from a fluorescent light fitting with ballast, on the right the pulse shaped load created by a somewhat older DVD-player.

indication. Most of these meters have (according to their manuals) an accuracy of 1% ±1 W, which would be more than adequate in practice.

However, in practice there are a few considerations that definitely need to be taken into account. When measuring an incandescent lamp rated at 150 W each of these meters will likely indicate the correct value quite accurately. It is different when measuring signals with a phase shift (such as fluorescent lamp ballasts and washing machines). It is possible that the meter may deviate more from the correct reading when the cos-φ (cosine-phi) value is poor.

A big problem are appliances with switching power supplies. With these there is often a combination of waveform distortion and phase shift and this makes measuring the power considerably more difficult.

Finally, the accuracy at very small loads can be inadequate. After all, with many electronic appliances you want to measure the power consumption in the standby state. So, does that PC monitor draw 1 W or 5 W when it is switched off? Some of the meters examined here don't have a clue and just jump back and forth between a couple of values or give a completely wrong value. In some cases the manufacturer indicates in the manual that the meter is not suitable for measuring small powers, but it would be nice to know that before you purchase the meter.

Test

To find out how useful these cheap energy meters really are we tested them in the Elektor lab with the aid of a few standard loads and compared them to a professional power meter made by Fluke, the Power Quality Analyzer type 434 (see photo). The latter, with a price tag of more than £ 2750 (€ 4000, $ 5500), is obviously in a completely dif-

RMS value and cos-φ

Measuring the power used by a load is, in principle, very easy: you only need to multiply the RMS value of voltage and current:

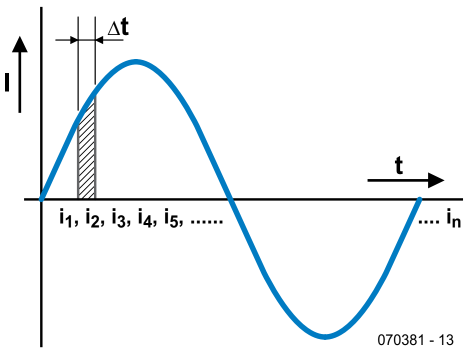
P = U × I

You could do this with two multimeters.

The mains voltage has normally a fixed value and this is (reasonably) sinusoidal. The amount of current then determines the power consumption. The definition of this is:

The RMS value of a varying current is equal to a DC current that generates the same amount of heat in the same constant resistor for the same length of time.

Energy meters used to work on this basis in the past.



The RMS value can be calculated by integrating the current over a half period, or in other words, by dividing it in small sections and calculating the power of each small part. These then have to be combined to give the total value:

$$I_{eff} = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 \ldots i_n^2}{n}}$$

The RMS value of the current is therefore equal to the square root of the average of the squares.

With a sinusoidal current the equation can be simplified to:

$$I_{eff} = \frac{\hat{i}}{\sqrt{2}}$$

When the load is no longer pure ohmic or a phase controller (light dimmer) is used, it becomes a lot more difficult for a meter to indicate the RMS value, and some meters will no longer display the correct value.

When there is a phase shift between the current and the voltage, for example with a motor (inductive load), not all the current drawn will be converter into real power. Part of the current is used to generate the magnetic field, or is used to charge and discharge capacitors. This current will lead or lag the mains voltage. The phase difference is expressed as a cos-φ value (1 = no phase shift, lower values indicate a larger phase shift). This 'wasted' part is also called the reactive power. This, however, still has to be supplied by the utility.

For the domestic consumer there are no consequences for the power bill for having a poor cos-φ, that is because the kilowatt-hour meter in the meter box measures only real power. Some of the tested meters also indicate the cos-φ of the load.

The Fluke meter used as a reference for our tests.

ferent league than the devices costing a few tens of pounds, but it provides very accurate measuring results that we used as a reference. Fluke in Eindhoven, The Netherlands, were kind enough to loan us such an instrument for a few days to allow us to do these tests.

What have we tested? For starters we used a few ohmic loads for measuring the accuracy at small and large loads. For this we chose values of 2 W, 100 W and 1000 W. We also measured an inductive load in the form of a fluorescent light fitting to check whether a poor cos-φ influences the measurement. And finally we measured a switching power supply from a DVD player which draws mainly short current pulses from the mains. On the basis of these measurements it is possible to make a good assessment as to the usefulness and measuring quality of these meters.

Test results

We have listed all the measurement results in the table.

The first thing to notice is that practically all meters – even the cheapest at less than £ 10 – produce very useful results when measuring the power of an appliance when it is switched on. Inductive and capacitive loads are also measured with respectable accuracy. If you only want to measure how much an appliance uses and how much that costs then just about any of these meter will work. The somewhat more expensive types have more adjustment and indication capabilities, such as separate day and night tariffs and a cost estimate over a certain period. Some models (Olympia Energy meter EKM 2000, Pro-Elec Power & Energy Monitor PL09564, Voltcraft Energy Monitor 3000) also indicate cos-φ. This gives a good indication of the type of load the appliance presents to the mains. The value measured by the Olympia does not appear the very reliable however. Measuring inductive and pulse loads doesn't appear to be a problem with most of these meters either, as we expected. Only the Olympia and the Peaktech meters have difficulties with inductive loads and are therefore quite a bit wrong.

Measuring small powers is considerably harder. It is particularly interesting how much an appliance uses in the standby or off state. Several manufacturers already indicate in their specifications that their meter is not suitable for that purpose (usually starting from about 4 to 5 watts). There are only four meters that can do this well, the two from ELV and both from Voltcraft.

Most, but not all, meters come with an English-language manual. Also, only the Pro-Elec meter from Farnell is specifically designed for British BS style 3-pin mains plugs.

After making hundreds of measurements with all these meters we have one clear favourite: the Voltcraft Energy Monitor 3000. This meter costs only £ 28 (€ 40; $ 75) and offers a clear three-line display, many measuring functions, and adjustment options. It is one of the most accurate meters in this group and in addition it was the only meter where the cos-φ indication of all measurements corresponded closely with the measurements from our Fluke reference. In respect of accuracy the Pro-Elec instrument from Farnell does equally well but has fewer adjustment options and no backup battery.

Finally there is the measuring station Voltcraft Energy Control 3000. This is the odd one out in this review. It is a wireless measuring system that can be fitted with up to 12 sensors. We did not include this system in the test since the version we looked at was provided with a transmitter for the kilowatt-hour meter in the meter box. And this counts only the number of revolutions of the disc! This is a fantastic system for data logging, etc. in particular because the base station can also be connected to a PC.

(070831-I)

Manufacturer/supplier addresses:

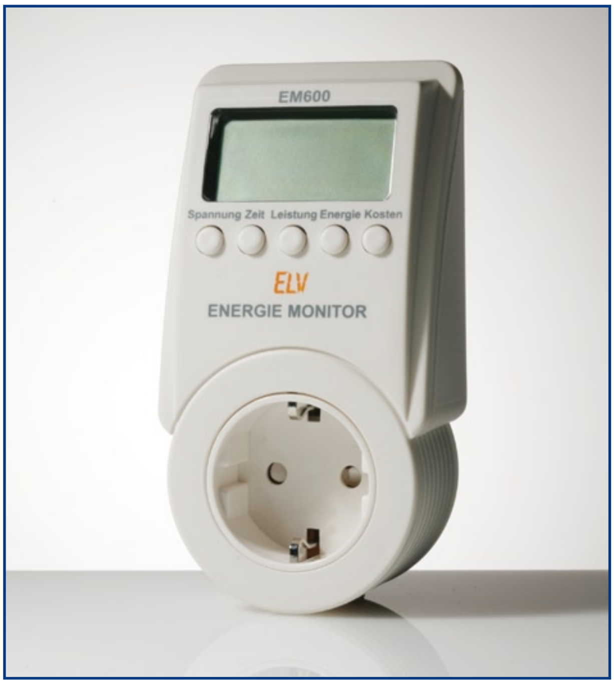
ELV: www.elv.de
Velleman: www.velleman.be
Olympia, Peaktech: www.reichelt.de
Pro Elec: http://uk.farnell.com
Voltcraft: www.conrad.com

Pro-Elec Power & Energy Monitor PL09564 (Farnell, £ 13.99 + VAT)

- meter without backup battery
- Single-line (large) display
- Measures voltage, current, frequency, real power, apparent power, cos-φ, energy use
- Power range up to 3.7 kW

ELV Energy Monitor EM600-2 (ELV, £ 18.00)

- Meter without backup-battery
- Single-line (large) display
- Measures voltage, power, energy use, duration, estimated usage cost per week, month, year (EM800 version also measures current, cos-φ, frequency and apparent power)
- Power range 1 W to 4 kW
- Complete calibration of the meter is described in the manual



ELV Energy Monitor EM600 Expert II (ELV, £ 28.75)

- Meter without backup battery
- Single-line (large) display
- Two-part implementation with separate measuring unit and plug/socket unit, for measuring poorly accessible connections such as behind the washing machine (also Expert I version available without plug/socket part, with cable for fixed connection)
- Measures voltage, power, energy use, duration, usage cost, estimate usage cost per week, month, year (EM800 version also measures current, cos-φ, frequency and apparent power)
- Power range 1 W to 4 kW
- Complete calibration of the meter is described in the manual

Olympia Energy meter EKM 2000 (Reichelt, £ 15.95)

- Meter with backup-battery
- Three-line display
- Measures voltage, current, frequency, cos-φ, max. measured current or power, energy use, duration and usage cost
- Overload-indication for current or power, with user-defined values
- Power range 4.5 W to 3.7 kW
- Day and night tariff possible
- Measuring duration max. 10,000 hours
- built-in clock

Peaktech Energy-Meter 9024 (Reichelt, £ 11.50)

- Meter with backup-battery
- Three-line display
- Measures voltage, current, power, max. measured current and power, energy use, duration and usage cost
- Overload-indication for current or power, with user-defined values
- Power range 4.5 W to 3.7 kW
- Measuring duration max. 10,000 hours

Technoline Cost Control (ELV, £ 7.00)

- Simple meter with backup-battery
- Single-line display
- Measures power, max. power, energy use, estimated cost per day, month, year
- Power range 4 W to 3.6 kW
- Technically identical to BaseTech Power Monitor

Velleman Energymeter (type NETBSEM, Velleman, £ 11.00)

- Meter with internal backup battery
- Three-line display
- Measures power, energy use, duration, usage costs
- Measuring range 0 W to 1 kW
- built in clock with day of week indication
- Day and night tariff possible with adjustable tariff times
- Measuring duration max. 9,999 hours

Voltcraft Energy Check 3000 (Conrad, £ 17.50)

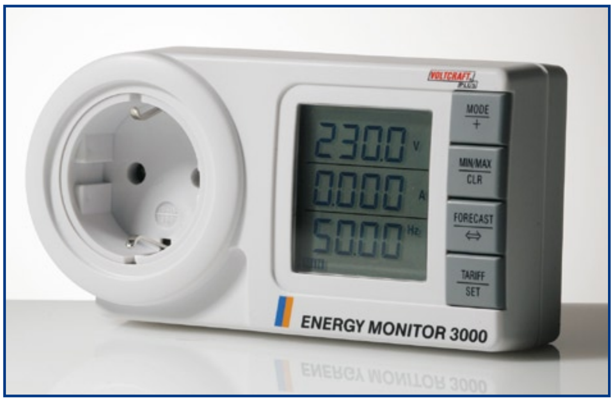
- Meter without backup-battery
- Two-line display
- Measures power, highest and lowest power, energy use, duration, usage cost, separate Record-function
- Power range 1.5 W to 3 kW
- Day and night tariff possible
- Measuring duration max. 99 days

Voltcraft Energy Control 3000 measuring system (Conrad; kit comprising a central unit, software & 1 sensor: about £ 75)

- Wireless measuring system with central unit and up to 12 sensors
- Central unit can be connected to a PC via a USB cable
- PC-software supplied for the management of measured data
- separate sensors available: ES-1 (mains socket sensor), ES-2 (kilowatt-hour meter sensor), ES-3 (DIN-rail sensor), ES-4 (gas meter sensor) and ES-5 (solar panel current sensor)
- Measures power, energy use, energy costs and estimation, gas consumption, gas costs and estimation
- Data logger memory for 108 days (one sensor)
- Alarm when pre-set power values are exceeded
- Time and date indication
- Technically identical to EM-1000 system from ELV

Voltcraft Energy Monitor 3000 (Conrad, £ 28.50)

- Meter with backup battery and automatic off-switching after 1 minute.
- Three-line display
- Measures voltage, current frequency, real power, apparent power, cos-φ (inductive and capacitive) highest



and lowest power, energy use, set tariff and usage cost, min. and max. indication of all measured values, separate Record function, estimated cost per week, month, year

- Power range 1.5 W to 3 kW
- Day and night tariff possible
- Measuring duration max. 99 days

Table 1. Test results

Belasting	U_{mains} 230 VAC	2 W	100 W	800 W	Inductive. load (140 W, cos φ = 0.50)	Pulse load (12 W, cos φ = 0.45)
Basetech Power Monitor	-	0	100	805	144	11
ELV Energie Monitor EM600-2	229	1,8	102	797	139	12,1
ELV Energie Monitor EM600 Expert II	228	1,5	101	798	139	12,2
Olympia Energy meter EKM 2000	233	0	97	814	163 cos φ = 0,60	11 cos φ = 1,0
Peaktech Energy-Meter 9024	232	0	101	804	185	15
Technoline Cost Control	-	0	100	804	145	12
Voltcraft Energy Check 3000	-	1,4	99	801	139	11,3
Voltcraft Energy Monitor 3000	230	1,9	99	796	139 cos φ = 0,50	12,2 cos φ = 0,47
Velleman	-	0	99	797	137	12

Energy saving tips

- Switch off all appliances in the home that are not really necessary.
- Switch an appliance off (if possible) with a mains switch and not with a standby button or remote control.
- Compact fluorescent lamps are a lot more economical then incandescent lamps (but you knew that already!), this has the biggest impact in places where the light is on for the whole evening.
- Switch the computer off via a plug box with manual switch and connect all the other computer peripherals such as monitor, scanner and printer to the same plug box.
- Mains power adapters also use power when nothing is connected to them. Remove them from the wall socket when they are not in use.
- For appliances that are continuously powered from a mains adapter it helps considerably if the old (linear) mains adapter is replaced with a modern (switching) version. These have a higher efficiency and use much less power in the idle state.
- Some appliances consume just as much power in the stand-by-state as in the on-state (for example a cable TV receiver). It is therefore pointless to switch these from one state to the other.
- Wireless routers are not used the whole day. Switch them off when you don't need them
- Finally, look at the total energy consumption of your whole house on a quiet afternoon (when no appliances are manually turned on) by noting the reading of the kilowatt-hour meter in your meter box and check the reading again an hour later. This will give a good overview of all the 'silent' consumers in your house.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E-blocks: more than 10

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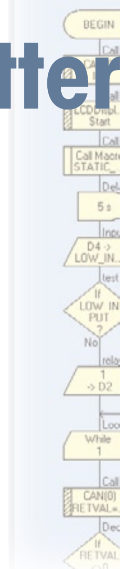


Jim Fell

The interesting thing about the Prius is that it can run for a limited period as an electrical vehicle (EV). Fine, but with the existing NiMH battery pack, the electric motor can take the car only about one mile at less than 31 mph. By the addition of a large Li-Ion pack, the fuel consumption of the Prius can be reduced from 60 mpg to 100 mpg, a massive cost saving! This article described how it was achieved using E-blocks and Flowcode as a control system.

I first converted a car to purely electric operation in 1999 and after several improvements, particularly to the battery pack, the car was moderately successful. I was generally able to travel about 50 miles (80 kms) on a charge and considerable more if care was taken. The car completed the London to Brighton Electric Vehicle (EV) Run in 2005 and 2006.

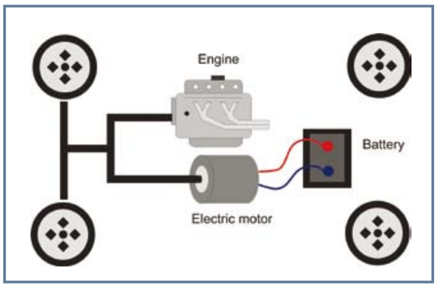


Figure 1. The basic topology of the Prius drive system.

Unfortunately the Achilles heel of the EV is still the battery pack. With low cost, traditionally lead acid, batteries the range is severely limited and a long, cross-country run, must be planned like a military campaign. There must be charging points every 50 miles or so and you need to stop for a couple of hours at each to restore some charge.

In 2005 I started looking at the hybrid cars that were available and the Toyota Prius in particular.

How it works

Figure 1 shows how the original Toyota Prius works: essentially it is a normal car with the addition of an electric motor/generator in the drive train. When the driver needs to slow down the brake pedal puts the 'motor' into generator mode which charges the battery up. Conversely, at low speeds the motor is used to assist the conventional petrol engine which decreases fuel consumption.

When I started the project a few groups in the USA were experimenting with supplementary battery packs to increase the range of the Prius [2]. The Toyota, along with most modern cars, has a very complex electronic control system. The part that deals with drive and battery management uses CAN bus. The operation of the drive amongst other things is based on the State Of Charge (SOC) of the battery pack. If the SOC is low the management system will recharge when descending a hill, braking or use any surplus energy from the engine. If the SOC is high then the battery pack will be used to drive the car at low speed, or to supplement the engine when driving, climbing hills or overtaking. In practice the SOC is moving about the entire time dependent upon traffic and driving pattern.

Add a battery or two

I saw two main problems in adding a large battery pack in parallel with the existing battery. The first was: what would the reaction be from the Toyota vehicle management system if, out of the blue, the existing battery started receiving charge from an outside source — the second battery? The second problem was: how to control this external charging source?

The control system needed to be such that the existing batteries' SOC could be manipulated so that the Toyota management system saw a high SOC and used the battery instead of the engine wherever possible.

The first problem was simple. I connected my EV charger across the Toyota battery pack and charged the pack. The SOC increased up to fully charged (about 80% SOC). The battery manager took into account the pack temperature and voltage and computed the SOC quite happily.

So, solving the second problem – transferring energy to the Toyota's battery – was the main area of work.

Circuit details

I was lucky enough to have acquired a set of 56 (!) Thunder Sky Li-Ion cells which I could use as a second battery. These are connected in series to give a resulting DC voltage of around 210 V and more than 50 Ah nominal capacity. The Toyota's own NiMH battery produces around 240 V DC so I knew that I would need an inverter to allow

0 mpg from a Toyota Prius

y management

the additional battery pack to charge the Toyota's own battery. In addition I wanted to be able to recharge the Li-Ion batteries overnight so I needed a recharge circuit. I also needed a circuit to control the flow of charge into the Prius's own battery. You can see the circuit in **Figure 2**.

The means of connecting the extra battery pack to the existing pack was by using four single-pole high-voltage power contactors and a high power dc/dc converter.

The DC-DC converter is actually a battery charger which has a bridge rectifier as the first component to convert the normal AC mains input to DC. Of course you can just feed it with DC. The DC-DC onboard converter is used to charge the Li-Ions if required but that's another story.

The converter had a two-stage, selectable, output. In High the converter would try to lift the existing pack to a high voltage and thus a high SOC. In Low this voltage was lower and allowed the existing pack to lose charge, allowing the SOC percentage (SOC%) to drop.

The output of the DC-DC converter is controlled by switching in one of two sets of points. When the battery is being charged overnight, it is isolated from Toyota circuit by a second set of points.

The NiMH to Li-Ion battery contactors would be energised the whole time, during vehicle operation, until the extra battery pack was fully discharged and no longer able to contribute – at which time the batteries were disconnected.

CAN it be done?

Controlling this system meant hacking into the Toyota CAN bus system. The car has many devices on the CAN bus network and fortunately they all broadcast their data onto the bus. The devices that need the data simply read it and react accordingly. As far as I am aware no device solicits information from another device.

What was needed was a custom CAN bus device that could read parameters on the system and move charge into the existing battery pack at the right time.

At this time I read an article in *Elektor* on Flowcode (February 2006), this re-

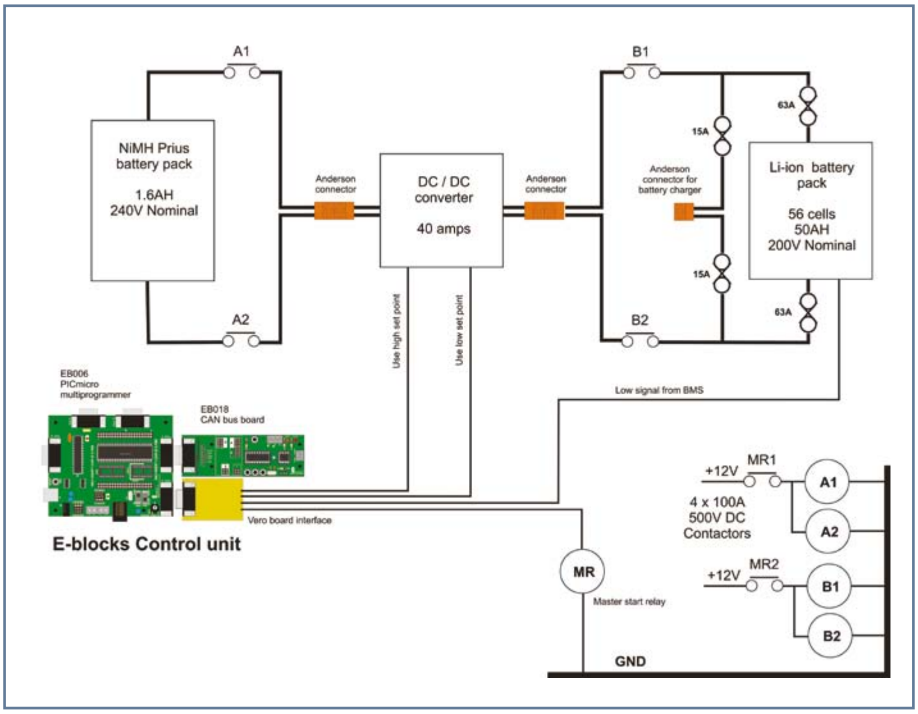


Figure 2. **Block schematic of the system.**

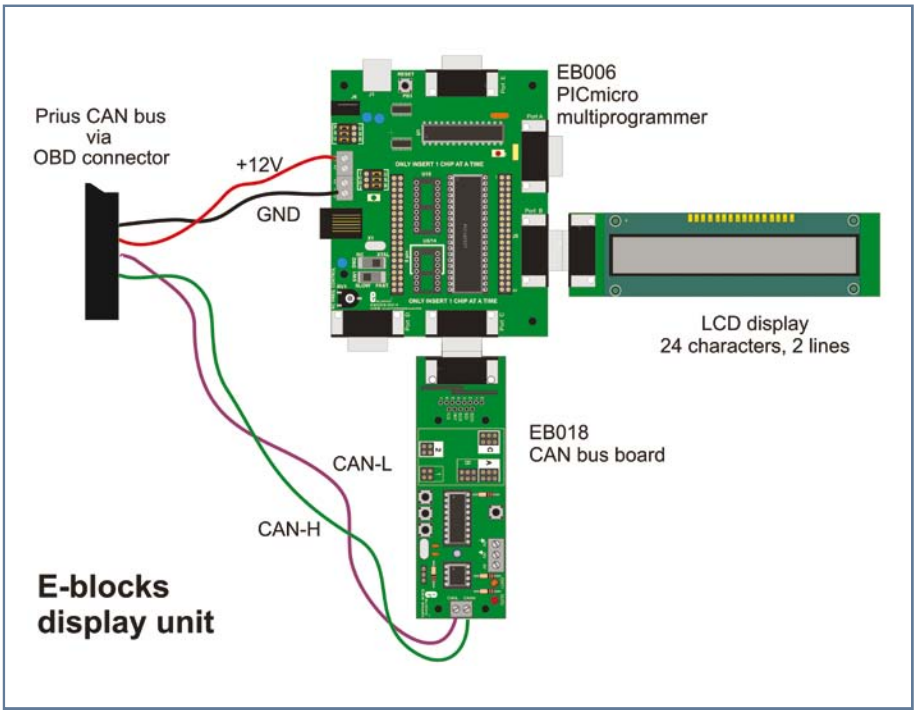


Figure 3. The block diagram of the display unit.

Figure 4. The LCD display.

ferred to a CAN bus system consisting of two nodes of a network. From past experience with other bus systems I knew it can take a long time to get a system up and running. I have a bit of experience with Microchip PIC devices and there is a wealth of information on their website on CAN bus. The datasheet on the CAN interface chip (MCP2515) runs to a whopping 81 pages [3].

I ordered the Flowcode CAN system and saw immediately all the hard work of using the CAN bus had already been done. Setting up the parameters for the bus and reading specific messages is carried out by prewritten macro commands. Getting the communication between two points was very straightforward.

In order to determine the CAN bus messages the Prius emits containing data on the SOC a Kvaser Light CAN to USB unit was used to look at the traffic on the CAN bus.

There is a convenient OBD-2 connector with 12 V power located just under the steering wheel in the Prius. There is some documentation regarding the messages on the bus on the Internet. The format of the data varies and a bit of manipulation is needed to convert the data to a form which can be displayed on an LCD.

Step by step

With some idea of what I wanted initially from the bus, I set up a system in the workshop mimicking the function of the CAN bus in the Prius: one of the E-blocks systems continuously transmitted an SOC message in the same format as the Toyota message, the other system was set up as a display unit which showed the system parameters on an LCD display. The setup is shown diagrammatically in **Figure 3**. This was used in the development and commissioning phases of the project on the bench, and eventually fitted into the radio compartment of the car as you can see in **Figure 4**. The display shows the Battery Current, Battery Voltage (charging/discharging), State of Charge %, Charge Current Limit, Discharge Current Limit, Max. Battery Temperature, Min. Battery Temperature. In this way the whole system could be built up and tested away from the car.

The second stage of the program used only one of the items (SOC%) and gave out one of two outputs, high or low, depending on the value of SOC. In order to maintain the existing battery SOC at around 70%, a simple pair of decision instructions in Flowcode put on the low output if SOC% >70 (and disconnected the Li-Ion cells from the charge circuit) and put on the high output if SOC%<65 (which switched the Li-Ion cells into the circuit and charged the

Figure 5. 'Before' (left) and 'after' (right) pictures of the battery system.

Figure 6. The inverter in the boot.

NiMH Prius battery). In each case the opposite output would be turned off. One additional output was used to drive a relay, which in turn energised the four main contactors. This output would come on 5 seconds after the system powered up and would go off in response to the additional battery pack becoming discharged.

Real life results

There was no need for a display on the final controller and this now lives in an enclosure in the boot next to the extra batteries and power contactors.

The addition battery pack is a set of 56 Thunder Sky Li-ion cells. These cells are about two years old and vary in capacity, the worst cell being about 50 Ah at 20 degrees C when discharged at 25 amps (electronics fans r u still there?). The worst cell defines the pack capacity, so with the current limit set to 25 amps the car will run for two to three hours in assist mode until the battery pack switches off. The car then runs in normal hybrid mode as before.

This is the drawback of the system – these batteries are still very expensive, and physically quite large. If you were to buy these batteries new then the cost would be several thousand pounds. Another drawback of the system is that the batteries also take up some of the boot space as you can see in **Figure 5**.
In summer the car will return about 60 mpg (4.7 l/100 km) in normal hybrid mode and about 100 mpg (2.8 l/100 km) in battery boost mode.

Now try this at home

The Flowcode program developed for the application is called Prius_04_Receive_PFC40.fcf. It is available free of charge as a download from the project page for this article at www.elektor.com.

The Easy CAN bus pack (see Elektor SHOP pages and website section) includes a copy of Flowcode, two PICmicro Multiprogrammers, two CAN bus boards, a LCD display, switch board, LED boards and accessories.

It can do (even) better

Unfortunately the Prius' readout only goes to 99.9 mpg so you are a bit blind as to how well it's really doing. In **Figure 6** you can see a photograph of the Toyota's display which shows that the car has achieved at least 99.9 mpg.
Another job for Flowcode will be to read the instantaneous fuel flow from the bus along with the speed and compute the real fuel consumption.

Further gains can also be made by reading the bus speed signal and pulsing a relay when the speed drops below 30 mph to force the car into EV mode. The relay would be pulsed again on the speed rising to 30 mph to take the car out of EV mode — another fine job for Flowcode.

(075103-I)

References

[1] E-blocks — now you CAN,
Elektor Electronics February 2006

[2] Plug in Prius Wiki group:
www.eaa-phev.org/wiki/Main_Page (follow links to plug in hybrids, then Prius)

[3] Microchip:
ww1.microchip.com/downloads/en/DeviceDoc/21801d.pdf

Figure 7. A close up of the Prius display showing the 99.9 mpg achieved.

Ener

The global consumption of energy continues to rise every year. The Energy Information Administration foretells an increase of world consumption by 57% between 2002 and 2025. The rapid growth of the Asian economy means they need more and more energy. For 2007, the growth rate for China is anticipated to be 11%. This consumption is not only down to Asia, but even to Eastern Europe. The Ukraine for example had an estimated growth rate of 7% for 2007 and Slovenia's rate is 5%.

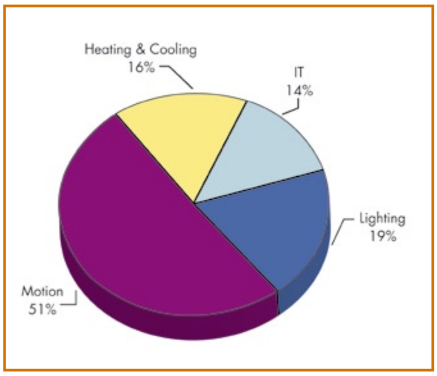


Figure 1. Motion devices like motors consume more than half the amount of electrical energy produced globally (source: EPRI).

The European Union has published the "Energy using Products" (EuP) directive, which requires a reduction of 39 million tonnes of CO_2 for electrical drives (like motors). Significant savings can be realized through maximizing efficiency, reducing standby power and increasing the power factor. Therefore a more rational use of resources is mandatory. According to the SAVE reports of the EU, the increasing use of high efficiency energy-saving motors and frequency converters reduces the CO_2 output by 4 and 12 million tonnes, respectively. The IMS research (ref. EPRI) reports that half of electrical energy is consumed by electrical drives (**Figure 1**).

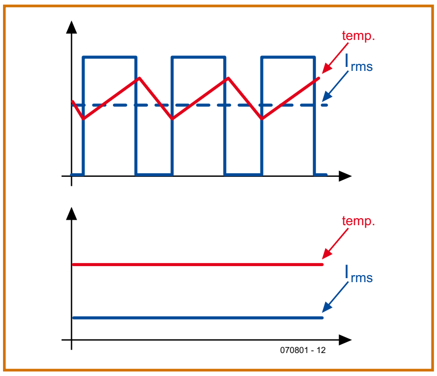


Figure 2. (above) Current and temperature with two-point regulation; (below) current and temperature in an inverter controlled application.

Pumping and circulating

Let's have a look at a water pump. Traditionally the amount of water is controlled by a choke or valve. This means the electrical motor is running at maximum possible output power while at the same time the effective output power is throttled by the choke device. As soon as chokes are used to control the output, the efficiency of the drive drops dramatically.

The diagram in **Figure 2** shows a two-point regulation (on/off), which is often used in home appliances like refrigerators. The temperature of the cooling chamber is measured. The upper graph illustrates the current and temperature characteristic for a non-inverter driven motor. During the 'on' state of the motor the cooling temperature falls but in the same period the temperature of the drive rises. If the cooling temperature reaches the lower threshold level, the

gy Saving through Motor Control

smarter, more efficient, less EMI

Dr Stephan Chmielus, Fairchild Semiconductor, Germany

The amount of electronics in industrial and domestic areas increases worldwide, but on the other hand fossil resources, our basic sources of energy, are limited and unequally distributed. Renewable energies get increasing momentum and, as a result, global concerns about energy shortages are driving regulations to save power and achieve higher efficiency. Lots of power goes to motors of all sorts, including pumps. How can economies be achieved in this area?

motor stops and the cooling temperature rises until the motor begins to refrigerate the cooling chamber once again. Using this kind of control the semiconductor switches have to withstand an increase in thermal stress due to the high fluctuation of the junction temperature. This results in a reduction of lifetime.

Changing from induction motors to modern brushless motors improves the efficiency, reliability and performance. The lower graph shows the characteristic for an inverter-controlled appliance. It is possible to control the load precisely, and the temperature of the drive is stable. Furthermore, due to the higher efficiency of brushless motors and reduced maximum current, the rms (effective) current of an inverter-driven motor is reduced at the same output power compared to a conventional two-point regulation.

Smart(er) drive systems

Moving from non-inverter AC drives to inverter-controlled drives can save as much energy as 20%. Using modern brushless motors fed by inverter saves up to 40% with reference to the non-inverter drive (ref.: EPRI). Intelligent power modules are a current trend in low-power motor drives fitted in consumer appliances and general industrial applications. Fairchild Semiconductor has a comprehensive portfolio of intelligent power modules called Motion-SPM™ modules, enabling designers to realize energy-saving drives. The main benefits of using SPMs are high performance, increased reliability and durability. **Figure 3** shows that different kinds of housing exist, starting with the Tiny-DIP/SMD for low output power up to 150 W, then the Mini-DIP for medium

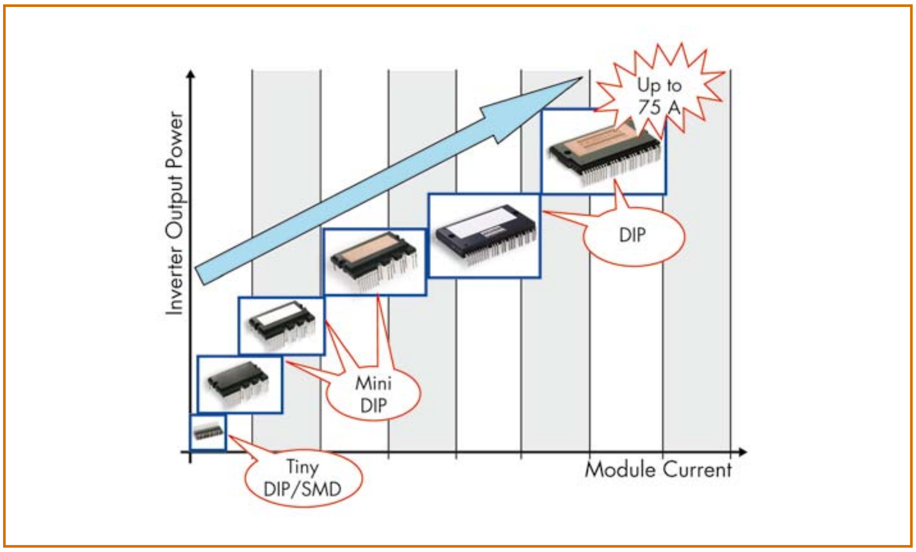


Figure 3. Motion SPMs come in different cases, depending on their power rating.

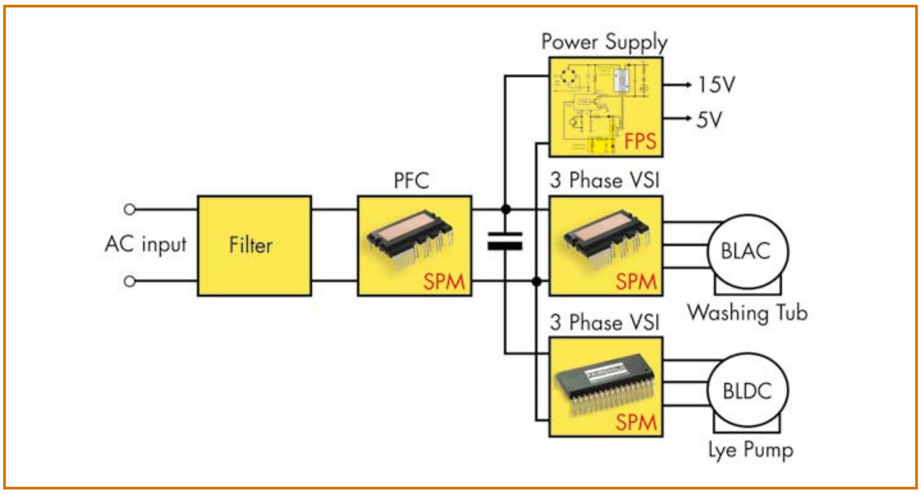
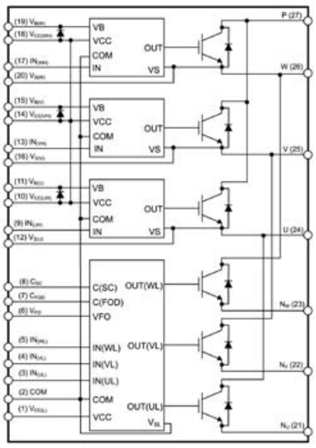


Figure 4. Up to date, energy-efficient motor control in a washing machine.



Motion-Smart Power Module FSBxyCH60B

MiniDIP package
x: F=Full Pack, B=DBC
y: Current Rating 3-30A @600V

2500 V isolation voltage
Low Loss IGBT Technology
Built-in Bootstrap Diode
OCP, UVLP, TSD
small size & large pin-to-pin spacing
44 mm x 26.8 mm

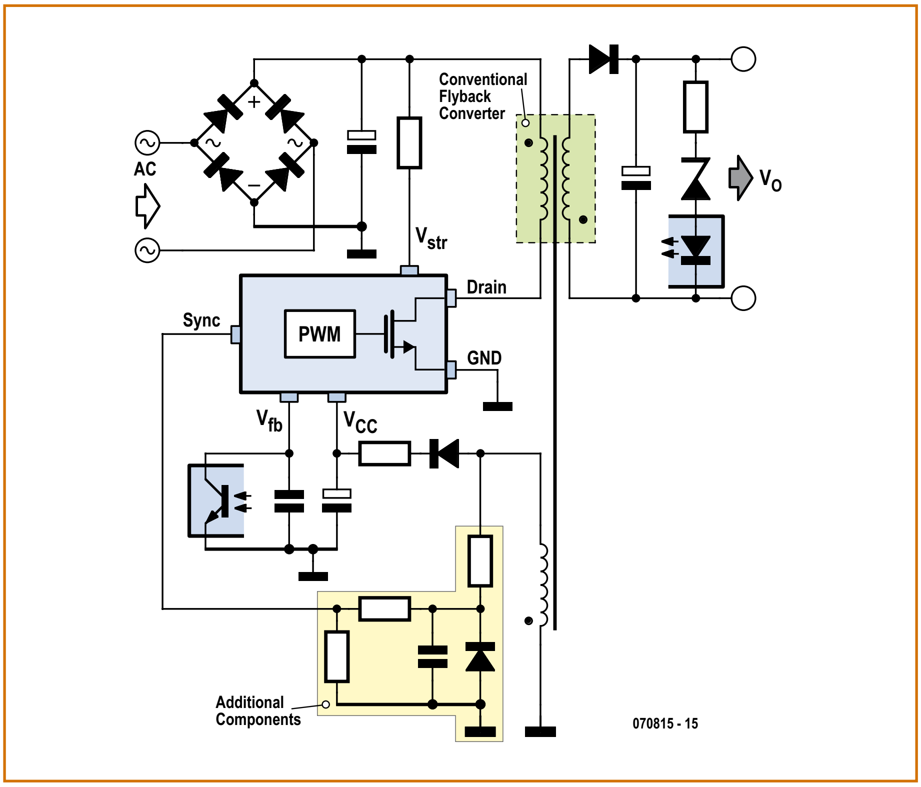


Figure 5. The components in the highlighted area help to improve the operation of a flyback converter in several ways.

output power (3 kW) and finally the DIP package for powers up to 7 kW.
In general, a Motion-SPM contains a 3-phase VSI including a fine-tuned gate driver and additional protection functions. Some Motion-SPMs are available with built-in bootstrap diodes, built-in thermistor and thermal shutdown. Even SMD packages are offered for easier mounting on the board. To fulfil the requirements set for harmonic regulation, PFC-SPM modules were developed specifically for this purpose. According to the international standard EN61000-3-2, home appliances (except Class D appliances) and 3-phase applications have to meet the Class A regulation. For active power factor regulation, the use of a bridge rectifier and a boost converter is an accepted way. This topology including gate driver, thermistor and protection functions is implemented in a Mini-DIP package and suitable for 85-260 VAC single-phase input. Using only two boost converters – one for the positive half cycle of the input voltage and the other one for the opposite half cycle – the bridge rectifier can be conveniently omitted. Hence only two diodes are in series during the power transfer to the output, and the IGBTs innards can be made smaller compared to the conventional solution as a result of the two boost converters. This topology is available in Mini-DIP too.

In the household

A washing machine may be considered a typical appliance in which energy-saving challenges exist. As illustrated in **Figure 4**, modern washing machines use BLAC motors to drive the washing/spinning tub. Fairchild recently launched the new generation of Mini-DIP SPM (FSBxyCH60B). A brief overview of its technical specifications is given in the **inset** — the device looks ideal for this appliance. The new modules show lower switching losses compared to the previous generation. Hence, efficiency is increased and smaller heatsinks can be selected. In addition, the internal bootstrap diodes as well as the internal connection of VS and HS-Emitter simplify the inverter design.
To pump the washing machine dry, a BLDC motor is used that can be controlled by a Motion-SPM in Tiny-DIP packaging or SMD packaging. This module, which is optimized for low EMI characteristics, contains MOSFETs instead of IGBTs. The very small

package (29×17 mm) enables the designer to place the VSI close to the motor, minimizing stray radiation as well as board size.

Green FPS

The required bias voltages can be generated by the Green FPS™ e-Series™ power switches. The FPS contains a PWM controller and a sense MOSFET integrated into one package — see **Figure 5**. By adding a few components (3 resistors, 1 capacitor and 1 diode) the conventional flyback converter can be changed into quasi-resonant flyback converter, which generally shows lower EMI and higher power conversion efficiency than a conventional hard-switched converter with a fixed switching frequency. In this case, quasi-resonant means that the PWM controller detects the minimum blocking voltage of the MOSFET during the discontinuous conduction mode in order to switch on the MOSFET. Therefore, the lower dV/dt plus the inherent frequency modulation results in reduced EMI, while due to the lower blocking voltage the switching losses are reduced as well, resulting in lower IC temperature. The implemented burst mode ensures very low stand-by power consumption. Consequently the Green FPS e-Series products provide a basic platform that's well suited for cost-effective and high efficiency design of flyback converters as well as other kind of SMPS like SEPIC.

Conclusion

Nowadays the trend in motion control is towards higher efficiency and better performance. Motion-Smart Power Modules offer 3-phase voltage source inverters with additional function that give comfort and reliability. Smart Power Modules for improved PFC (power factor correction) allow power distribution to operate at its maximum efficiency. Fairchild Power Switch is the integrated power switch for SMPS using quasi-resonant switching. What these solutions have in common is that the total efficiency of the entire system is improved dramatically — for all the world to benefit from.

(070801-I)

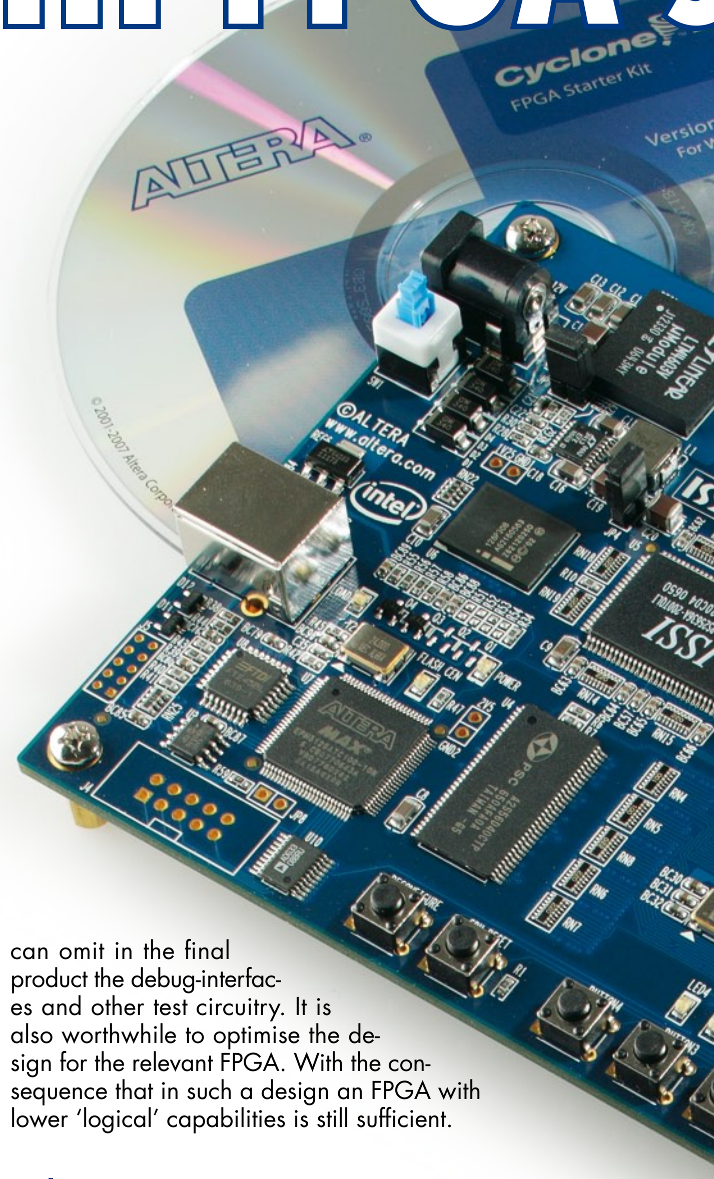
Acronyms

BLAC	brushless alternating current
BLDC	brushless direct current
CO_2	carbon dioxide
DIP	dual (line) in plastic
EMI	electromagnetic interference
EPR	Electric Power Research Institute
EU	European Union
FPS	Fairchild Power Switch
IGBT	insulated gate bipolar transistor
IMS	intelligent management system
MOSFET	metal-oxide silicon field effect transistor
PFC	power factor correction
PWM	pulse-width modulation
SAVE	specific actions for vigorous energy efficiency
SEPIC	single-ended primary inductance converter
SMD	surface mounted device
SMPS(U)	switch mode power supply (unit)
SPM™	smart power module
VSI	voltage source inverter

Groundbreaking or storm in a teac

Cyclone III FPGA s

Paul Goossens



FPGA manufacturers are engaged in an intense battle for the favour of electronics engineers. In the last few years the conflict has moved from the high-end to the low-cost users. The newest weapon from Altera in this struggle is the Cyclone III FPGA. We took a closer look at the accompanying launch platform (the so-called starter kit).

A decade or so ago, working with FPGAs was reserved to a relatively small group of electronics engineers. A typical application for FPGAs was for them to be used as a prototype platform for a new chip design. Speed of the internal circuitry, size (measured in a vague term as equivalent gate count) and large numbers of I/O-connections were high on the wish-list of designers. Nobody worried about such things as power consumption and management didn't lose any sleep over the exorbitant high price of each FPGA. It was, after all, only a prototype and it was still many times cheaper than the manufacture of a prototype chip.

Mainstream

A big shift in the market for FPGAs occurred when manufacturers produced smaller and cheaper versions. This made it attractive to use a small (and cheap) FPGA to replace all the chips in a device that has only limited production numbers.

The selection of an FPGA for such a design requires a completely different set of criteria. This wish-list is just about the opposite of the wish-list from the first group of FPGA users. To keep costs down, the first requirement is that the chip doesn't cost much. The power consumption also has to be within limits. It is obvious that the FPGA has to be big enough to contain the design. When designing a digital circuit that will ultimately be realised in a FPGA, we can omit in the final product the debug-interfaces and other test circuitry. It is also worthwhile to optimise the design for the relevant FPGA. With the consequence that in such a design an FPGA with lower 'logical' capabilities is still sufficient.

Cyclone III

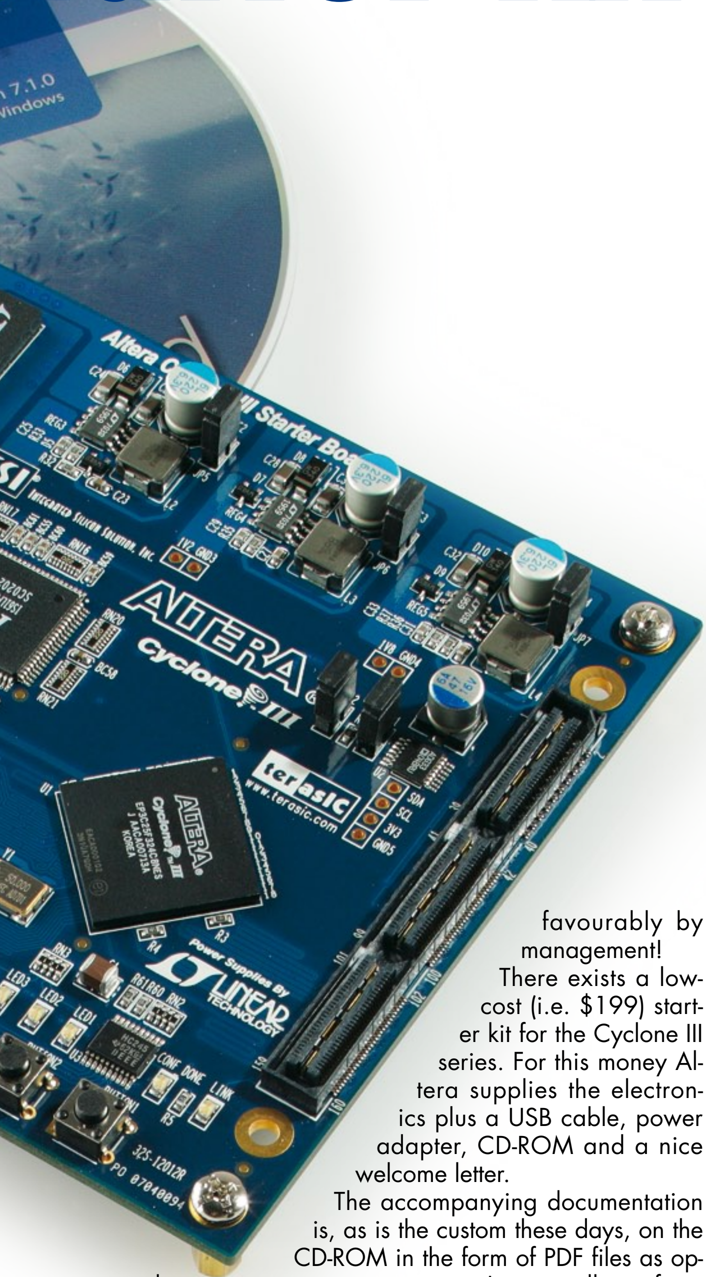
FPGA manufacturers have produced separate series of FPGAs to specifically target this group of users. Altera manufactures a series of FPGAs which are named 'Cyclone', to serve this market. The third generation (designated Cyclone III) is now a fact. Compared to the previous generation, the main difference is that the chip is now produced using 65-nm technology, so that the chip uses even less power than the Cyclone II FPGAs. The dimensions of the chip are also a little smaller, which contributes to a further cost saving.

Starter kit

A new generation of chips obviously needs to be accompanied by a new starter kit. Engineers simply prefer hands-on experience. A starter kit can also accelerate the design project considerably, which is, of course, looked upon

up?

starter kit



favourably by management!

There exists a low-cost (i.e. $199) starter kit for the Cyclone III series. For this money Altera supplies the electronics plus a USB cable, power adapter, CD-ROM and a nice welcome letter.

The accompanying documentation is, as is the custom these days, on the CD-ROM in the form of PDF files as opposed to a paper version. I personally prefer it this way, looking after the environment is important, but simply being able to search for things is a big advantage. In addition to the documentation the CD-ROM also contains four examples. The actual design software is not on the supplied CD-ROM however. This has to be downloaded from the manufacturer's website. How to do this is, of course, described in the manual.

The electronics

The most important part is obviously the electronics. The leading role is reserved for the FPGA, an EP3C25. This chip has 25,000 logic gates at its disposal (the exact meth-

Important characteristics

- Cyclone III EP3C25F324 FPGA
- 256 Mbit DDR SDRAM
- 1 Mbyte SRAM
- 16 Mbyte flash
- 6 push buttons, 4 of which are freely available for use
- 7 LEDs, 4 of which are freely available for use
- 50 MHz oscillator
- High-speed connector
- Built in USB programming interface

Embedded multipliers

FPGAs are normally put to work on 'number crunching' applications for which a typical microcontroller has insufficient computing power. Examples of this are audio/video processing, encryption of data and digital radio. The applications often require several multiplying units (multipliers). You can create such circuits, just like any other circuits, from the logic elements in an FPGA.

Because most FPGA designs require several multipliers it is a logical step to build in a few multipliers on-chip from the start. Such units have acquired the name 'embedded multipliers'.

The advantage of using these 'embedded multipliers' is that they take up much less surface area on the chip compared to realising a multiplier using the programmable parts of the FPGA.

In addition these multipliers are also much faster than multipliers that are built from programmable logic.

The multipliers are often a bottleneck in an FPGA design, so a fast implementation ensures that the computing power of the FPGA is increased significantly. These FPGA designs also need much fewer logic blocks, so that the designer can select a smaller FPGA. This benefits the cost and power consumption of the end product.

High-speed signals

A fast sports car cannot do without a decent set of tyres. Likewise, a fast FPGA cannot function well without fast signals to and from the outside world.

Fast internal operation serves little purpose when the outside interface cannot provide sufficient information to be transferred to or from the FPGA.

The latest chips in the application areas of digital television, fast A/D converters and modern communication methods increasingly make use of serial communication channels, often in the form of differential signal pairs such as LVDS. The DDR memory also makes use of fast signals.

FPGAs, even the low-cost types, are therefore provided with connections that are suitable for sending and receiving these high-speed signals. In the case of the Cyclone III FPGAs there are also a few connections that are suitable for processing DDR memory signals.

In addition there are connections which are suitable for LVDS signals with a speed of no less than 875 megabits per second! This should be sufficient in most cases to satisfy the thirst for data...

od of arriving at this number is rather vague and complex however). In any case, you can accept as fact that reasonably large digital circuits can be realised with this chip. In addition this FPGA has an internal 594 kbit memory and no fewer than 66 embedded multipliers.

There is also no shortage of additional memory on this circuit board. What do you think about 256 Mbit of DDR SRAM, 1 Mbyte SRAM and 16 Mbyte of flash memory? So considering the amount of memory and processing capacity this board is pretty good.

If you expect that a board with this much potential has a lot of I/O than you will be disappointed however.

'Out-of-the-box' this board contains four LEDs that can be controlled by the FPGA. The input facility comprises four pushbuttons. In addition you can also use the JTAG interface to interact with the board.

You will look in vain for an audio-codec, video in/out, LCD or internet connection, for example. Such things are likely to be found in products that are typical applications for these FPGAs.

There is fortunately a high-speed connector that can be used to expand the electronics with additional hardware. This special connector is suitable transferring signals at high speeds without difficulties. You can therefore add your own hardware, which could operate, for example, with an LVDS signal interface.

To round out the electronics, there are also the necessary power supply circuits that provide the various power supply voltages for the board.

And, appreciating life's little conveniences, the board can be programmed via a USB connection. This also works under Windows Vista without problems.

Expansions

In view of the limited number of I/O options it is nice to know that a number of expansion boards are available. There is a prototype board available (for $ 210!) that consists of a 0.1" prototyping grid and makes all signals from the high speed connector accessible. For $ 230 you can buy a DVI expansion board, which contains both a DVI input and a DVI output.

The manufacturer's website shows an overview of the currently available expansion boards.

Conclusion

This starter kit is suitable for people who use FPGAs professionally. From a technology perspective the new Cyclone III FPGA is certainly a powerful bit of engineering. Together with the generous amount of fast memory this starter kit can be used for some powerful applications. There is nothing wrong with the price, 199 US dollars is not too much.

Unfortunately the built-in I/O is rather spartan. Expanding the cheap starter kit is possible via the high-speed connector. However, the prices of expansion boards are a bit steep, which makes a total cost that compares unfavourably with, for example, a Cyclone II starter kit.

If you intend to develop your own expansion board or are prepared to buy one, then this kit is definitely recommended.

(070787-I)

hasta la vista XP (or perhaps not?)

Vista in the lab

Paul Goossens

It will come as no surprise to anyone when I reveal that most of the work in the Elektor lab takes place in front of a computer. The complete design is first of all developed with the aid of a computer. Only when that is finished does the soldering iron get warmed up to build and test the first prototype.

A computer is without doubt the most important and most useful tool in our lab (and where not, really?). It is therefore exceedingly annoying when your computer gives up the ghost. Such a mishap can strike in silence with only a simple error message on the screen. Or the event can take place with a loud bang. The latter happened to me on my first day back after the summer holidays.

As is customary, on the first day back the most memorable events are discussed in depth. In the meantime I turned on my PC, so that it could go through the process of booting up. Quite quickly our discussion was disturbed by a loud bang. Somebody on the floor above us probably fell of a chair, was our opinion.

A while later I noticed that my PC was not turned on. Had I perhaps pushed the reset-button instead of the power-button? This can happen, so I pushed the power-button again.
Quite promptly the sound of more bangs filled the office. The chance that a colleague fell of a chair repeatedly so quickly appeared quite remote to us. We also noticed that there was some smoke coming from under the table. We quickly disconnected the power to prevent further damage.

The cause appeared obvious to us. The power supply in my PC was ready for the rubbish bin. A new power supply was quickly found and a few minutes later I could turn my PC back on. Unfortunately without a satisfactory result. In addition to the power supply it appeared that the motherboard had also become completely useless.
After some deliberation it was decided that we had to get a new PC. That same day a new PC was ready for use. The biggest difference with my previous PC is that the new one, reluctantly, runs Windows Vista instead of Windows XP. Now I had read a number of reports about this new operating system, but no one in the lab had any practical experience with Vista.

The logical next step was the installation of the various software packages. This all worked without any notable problems. The connection to our network was also a piece of cake. To be honest, this was all a lot easier than we expected.
The second day my PC was ready again for its daily tasks. That's fortunate, because deadlines do not move because of a faulty PC!

My first job was writing the firmware for the Reflow Control project in the December 2007 magazine. The prototype had already been built and I had already tested the programming interface before I went on holiday. Except, there was a small problem: my new PC had to do without a parallel port. And you can see this coming: the programming interface for the Reflow Control needs a parallel port. Fortunately these interface boards can be bought just about anywhere. So in very short order my PC was fitted with a new parallel port.

This was the moment when all the misery started. The operating system happily reported that the parallel port was functioning properly. Alas, my programming interface had a different opinion about that. Searching on the Iinternet and some experimenting did not result in a working solution.

Time was running out and there was no solution in sight. Fortunately I could use the PC (with Window XP) of a colleague, since he was away for a few days. With the help of his XP machine I could at least program my prototype. In practice this meant that I went back and forth between my new PC (for writing and compiling the software) and the second PC to test the result on the prototype.
This solution was not much to my liking. Firstly, because the original problem hadn't been solved yet. In addition, all that back and forth walking was also rather absurd.

For the second problem we quickly found a 'nerd-like' solution: via our network and 'Windows remote' I could control my colleague's PC. The prototype (next to my monitor) was connected with a cable to the parallel port of the second computer. In this way I was able to program the prototype from my own computer.
The firmware for the Reflow Control oven controller is now finished, but the problem with the parallel port and Windows Vista is still not solved.
Various messages on the Internet indicate that Microsoft only supports parallel ports if they are integrated on the motherboard. Expansion boards with a parallel port appear to be unwelcome under Windows Vista. We won't leave it at this. Hopefully we can report in a future LabTalk instalment how we solved this problem...

(070788-I)

Levitating Cube

amazing results from just a few co

Franz Raemy

For the first time in this series we present a project that is not based around a microcontroller. Instead, we look at an experiment that has enchanted audiences for decades, updated with a laser diode and minimal control electronics.

Before we start: this project sits firmly in the category of 'classical experiments'. Anyone with a scientific background will surely have seen, performed, or at least thought about a similar trick before. Faithful *Elektor* readers who have been with us since the late 1970s (and from our postbag and e-mail inbox we know there are many of you) may well remember a certain 'Levitator'. In the June 1977 issue of *Elektor* designer Loys Nachtmann published a circuit that levitated a ball or sheet of metal using a precisely-controlled force provided by an electromagnet mounted above it. We hope we will not offend our former colleague too much if we say that he was not responsible for inventing the basic principles of operation of the circuit himself: they are discussed in practically every control theory textbook.

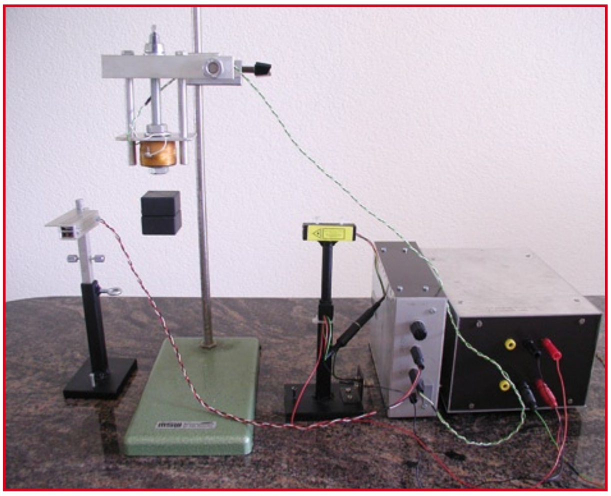


Figure 1. Overview of construction. On the left is the light sensor, and the retort stand supports the electromagnet. The 'ball' (here made from square permanent magnets) levitates below the electromagnet. The laser diode module light source can be seen in the middle of the picture. The boxes to the right hold the control electronics and the power supply.

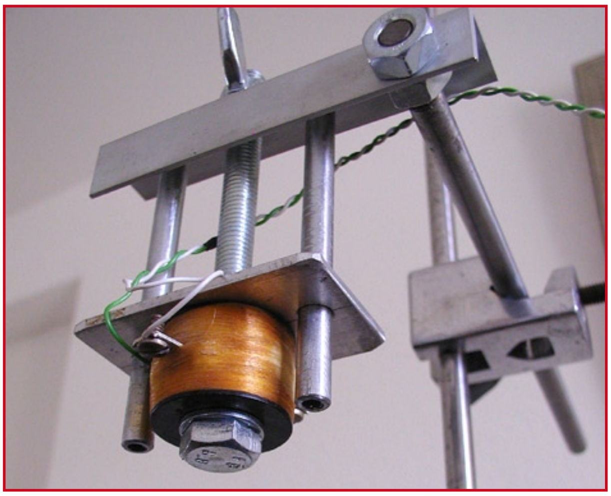


Figure 2. Adjustment is made much easier if the height of the electromagnet can be adjusted using a butterfly nut.

Theory

The force which the electromagnet exerts on the metal object must be equal in magnitude to that exerted on it by Earth's gravity. The force is proportional to the current through the magnet and reduces as the distance between magnet and levitating object increases. And so, as this distance increases, we have to increase the magnet current, and vice versa. The distance is detected using a form of light gate where the levitating object can move in and out of the light path. A simple light sensor then measures the amount of light that can pass the object. Between the output of the light sensor and the electromagnet driver sits the control circuitry, often taking the form of a PID (proportional, integral and differential) controller. Thirty years ago Loys Nachtmann took the safe option: his 'levitator' was designed strictly along PID principles using three operational amplifiers and no fewer than six potentiometers, allowing every aspect of operation to be adjusted. Two further operational amplifiers formed a voltage-to-current converter at the output. (For readers interested in the original 1977 article, this can be downloaded from [1].)

The effect of the 'levitating ball' is astonishing (and the trick also works with differently-shaped objects such as blocks or screws). Some may find equally surprising the fact that the effect can be achieved using just two operational amplifiers and a single power transistor. The author (who has a PhD in physics, a passion for hobby electronics and 25 years of experience teaching phys-

mponents

ics and mathematics) has developed a control circuit that requires, as they say, just a handful of components. The circuit was originally constructed for a physics class and has also been a great success at open days. Below we describe how it works; as ever, the *Elektor* community is invited to come up with modifications and improvements to the design!

Mechanics

Figure 1 shows all the components of the system. On the left is the light sensor and the retort stand holds the electromagnet with the 'ball' suspended immediately below. The 'ball' shown here is made from square permanent magnets (2 cm by 2 cm by 1 cm). The light source can be seen in the middle of the picture. Thirty years ago *Elektor* enthusiasts had to arrange a lens in front of a lamp to obtain a reasonably collimated beam; these days we have it easy, as we can make use of a laser diode module (available from any of the major component stockists). The boxes to the right contain the control electronics and the power supply, which provides 5 V for the laser diode and 12 V to 18 V for the controller.

The electromagnet, the light sensor and the laser diode module are all fixed to retort stands (which can be obtained from laboratory or teaching equipment suppliers, or found on eBay [2], [3]). The other mechanical components can be obtained from a hardware shop.

A large relay was cannibalised to provide the electromagnet. If your junk box does not stretch to such devices, they can be purchased reasonably cheaply. This is a simpler solution than that suggested thirty years ago, of dismantling an old transformer. If you do decide to go down this route and use a laminated transformer, you will need to remove all the I-shaped laminations and turn the E-shaped laminations around so that they all face the same way. Then connect to the secondary winding (which should be rated for at least 2 A). The electromagnet is fixed to a retort stand so that its height can be adjusted, ideally in such a way that it can be released and re-fixed using a

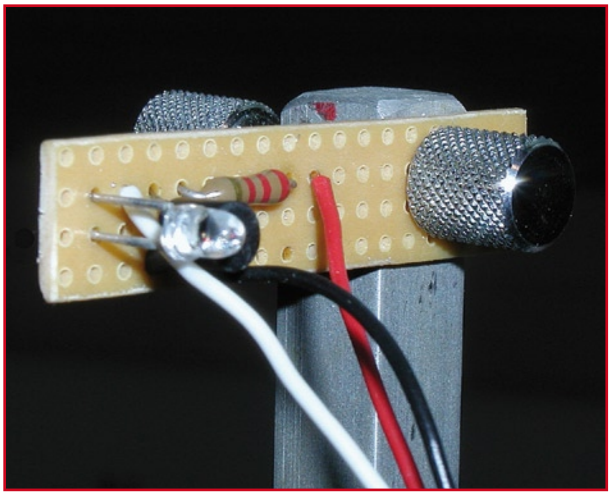


Figure 3.
The photodiode, with BC547 hidden behind.

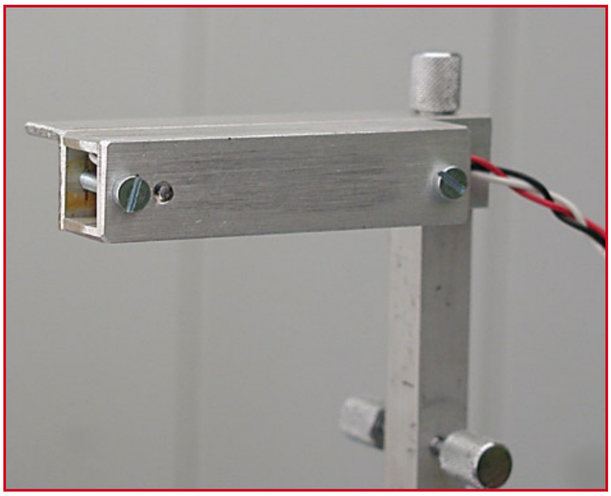


Figure 4.
The light sensor in its enclosure.

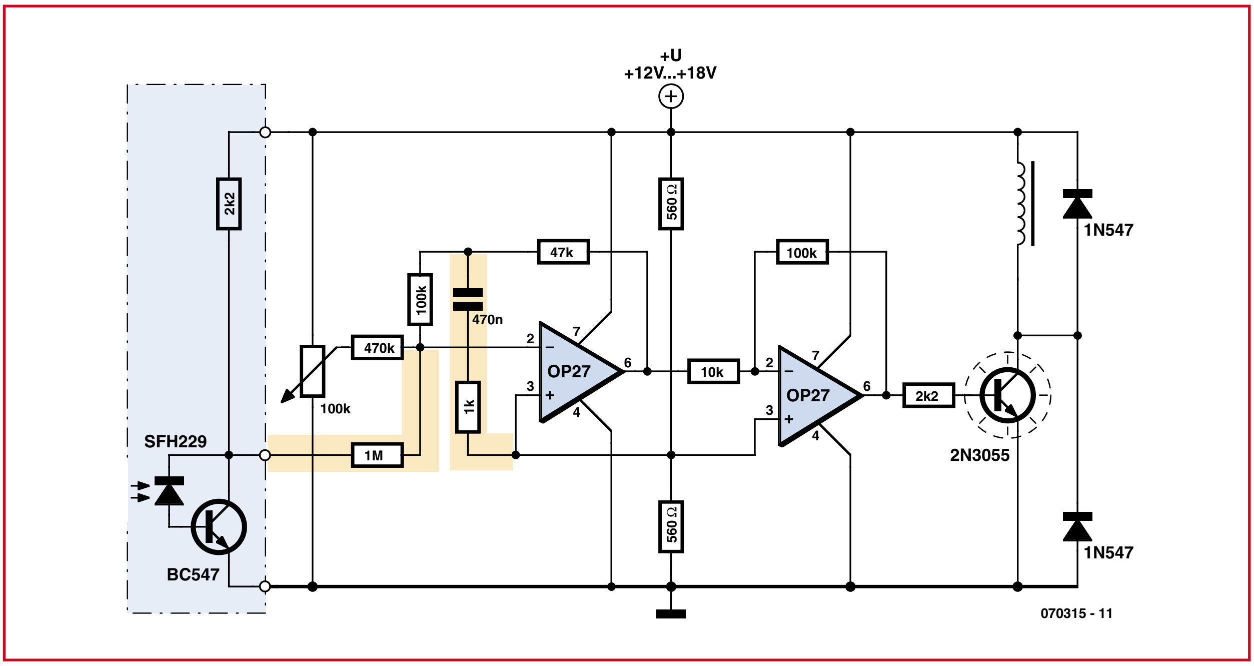


Figure 5. The circuit diagram shows the measurement, control and power electronics. Without the indicated components the circuit is simply an electromagnet driver where the current can be set manually using a potentiometer. Add the sensor and three extra components and the control loop is completed.

single screw. It is even better if you can arrange things so that the height of the electromagnet can be adjusted gradually up and down by turning a butterfly nut (**Figure 2**).

Electronics

Two further retort stands carry the laser diode module and the photodiode (**Figure 3**). The SFH229 photodiode should be mounted in a small enclosure to minimise the effect of stray light. **Figure 4** shows how two short lengths of aluminium extrusion screwed together can do the job, with a small hole acting as a window. As well as the light sensor, the enclosure also contains a BC547 transistor and a resistor, forming an amplifier. Three wires (supply, ground and signal) then run to the circuit board carrying the control electronics proper. This arrangement makes the system less sensitive to external interference.

The circuit diagram in **Figure 5** shows an overview of the measurement, control and power electronics, and the finished circuit board is shown in **Figure 6**. The coil of the electromagnet is driven via a good old 2N3055 power transistor. The two diodes to the right protect the circuit: the magnetic field produced by the electromagnet is very strong, and when the drive is switched off currents of several amps can be induced in the coil as the field collapses. These currents are diverted via the two 1N547 diodes. Other diodes, such as type 1N4007, can be used in place of these components as long as they are capable of withstanding the induced currents.

The opamp to the right is configured as an (inverting) amplifier with fixed gain. It can be considered as part of the power output stage. The opamp to the left and associated potentiometer form an amplifier which (if we imagine the three wires to the light sensor and the capacitor to be disconnected) allows a preset constant current to pass through the coil. When setting up the unit this constant current should be adjusted so that the force exerted by the magnet on the object when it is the desired distance away is equal in magnitude to the force exerted on it by gravity (see below). Of course, the equilibrium that can be achieved is unstable, since there is no control loop in place. With the slightest disturbance the object will either fall to the floor or fly towards the electromagnet.
With the addition of the sensor and just three passive components we can create the required control loop. The 1 kΩ resistor attenuates the negative feedback and so increases the gain. The capacitor ensures that the gain is applied only to the AC component of the light sensor current so that the system responds to small deviations from the equilibrium state: this corresponds to a differential term in the control loop.

Experience indicates that the component values are not particularly critical and that the device will work as long as the component values used are reasonably close to those shown. Component values in the output driver stage must of course be adjusted so that a suitable current (around 1 A to 1.5 A is typical) flows through the electromagnet.

The author's prototype regulates at a frequency of around 300 Hz to 400 Hz. Using an oscilloscope it is possible

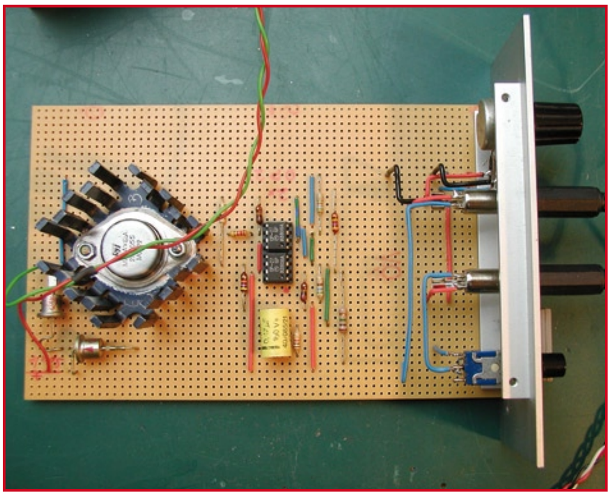


Figure 6. The photograph shows the control electronics. On the far left is the power transistor with its heatsink, and the two opamps are in the middle. On the right is the input from the light sensor and the output to the electromagnet. The potentiometer at the top sets the DC component of the output current, and below is a switch to turn the magnetic field on and off.

to observe oscillations in the electromagnet current of the order of 0.1 A, which we can ascribe to the simplicity of the design of the control circuit. The corresponding motion of the levitated object is normally just a fraction of a millimetre. It is essential to use an adequately stable support for the electromagnet (a heavy retort stand and a short clamp arm) as otherwise it is likely to wobble excessively. In the extreme case the vibrations will be enough to destabilise the system. If this happens the stand should be made more rigid, or a different magnetic or magnetisable object should be used.

In practice

To set up the device first set the potentiometer to its mid-position. Hold the object to be levitated so that it just blocks the light beam and adjust the height of the magnet (and thus the distance between the magnet and the object) so that the object is apparently weightless: this is easily felt in the hand. With a typical electromagnet the gap will be a few centimetres. It should go without saying that the object should not be too heavy (at most an ounce or so) as otherwise the gap will have to be very small and the force from the electromagnet very large, and the system will probably be unstable.

Fine adjustment is then carried out using the potentiometer. The optimum position for the object is when it blocks exactly half of the light incident on the light sensor. If an oscillation with increasing amplitude is observed, the distance (and then, using the potentiometer, the constant current) must be adjusted. If all else fails, try using a different magnetic or magnetisable object.

The author has managed to levitate a 22 mm ball bearing and a variety of screws. A screw, with its slot hanging downwards, will turn as it gently rises and falls along its axis. Now, when the slot of the screw is in line with the laser beam it will allow the light to pass and the screw will fall; when the slot is not aligned with the beam, the screw will rise. Positioning is easier if the object consists of a permanent magnet with the screw attached, hanging below it. This stabilises the system, as a longer object topples over less readily than a short one. It is obviously not desirable for the object to tumble about a horizontal axis.

On the basis of this device the author is well prepared for his next project: a model maglev train. Preliminary results are very promising!

(070315-I)

Web Links

[1] www.elektor.com/levitator

[2] www.camlab.co.uk/

[3] www.ebay.co.uk/

Battery Booster

Ralf Schmiedel

The inspiration for this design came from the author's experience with a mini model helicopter (from Silverlit). This particular model has a hand-held transmitter powered by six AA batteries which acts as a charging station in between flights to recharge the helicopter's LiPo battery.
Even alkaline batteries become discharged relatively quickly because of the energy demands of the helicopter. Replacing the alkaline cells with six rechargeable NiMH batteries brought its own problems; the cell voltage is around 1.4 V after recharging but this quickly levels-out to 1.2 V once you begin drawing energy and this proved to be too low to recharge the helicopter battery. What is needed here is a voltage converter design small enough to fit into the space taken up by an AA battery which pumps up the voltage from the (now five rechargeable cells) up to the level produced by six alkaline batteries. The author was not satisfied with the most simple design solution to the problem; it would be more useful if this booster cell could be used in any battery compartment irrespective of the number of cells. The number of batteries (n) would then be replaced by n–1 rechargeable cells (with one cell position taken up by the booster) giving an output voltage the same as if n primary cells were fitted.
The circuit described here can be used in applications requiring four to ten primary cells. With the booster fitted, only three to nine rechargeable cells would be required. The use of (more bulky) electrolytic capacitors with a 35 V rating would allow the booster to be used in applications of up to 20 batteries.
In principle almost any switching regulator IC can be used in this way. The power output from this circuit with a LT1172 regulator is around 500 mA but it can be increased to 2 A for example by using the LT1170 instead.
Figure 1 shows the circuit built on a small piece of prototyping PCB used in a four-cell battery compartment. The battery booster should always be fitted in the most positive cell position in the compartment (see **Figure 2**). The remaining battery positions can then be fitted with NiMH rechargeable cells. The booster circuit produces a voltage U_{Boost}, which is added to the input voltage U_{IN} to give U_{OUT}. The **table** (below) indicates the necessary boost voltage relative to the number of cells used. The maximum number of cells is limited by the voltage rating of the electrolytic capacitors. The LT1172 itself is rated up to 36 V but to save space 16 V electrolytics are fitted which limits the output to 13.5 V (8 rechargeable cells replacing 9 alkaline cells).
To calculate the value of the boost voltage required U_{Boost}:

U_{Boost} = 2.4 V + (0.3 V * (n – 3))

where n = 4 to 10 rechargeable cells. Or:

U_{Boost} = 2.4 V + (U_{IN} – 3.6 V) * 0.3 V / 1.2 V

The output voltage is given by:

$U_{OUT} = U_{IN} + U_{Boost}$

The author has used the simulation software Spice and SwitcherCad III (Freeware from LT) with the design and the LTSpice und ASC files from SwitcherCad III are available to download free from the Elektor website so that any interested reader can simulate and modify the design. The Spice model includes inductor L3 which is not shown in the circuit diagram (**Figure 3)** this simulates the earth wire inductance. A ferrite bead can be used on this lead.
The LT1172 operates in this design as a buck-converter. In contrast to the typical configuration where a potential divider network at the output U_{OUT} is be used to produce a feedback voltage to the regulator, here the boost voltage U_{Boost} (see **Figure 2**) is regulated. Transistor T1 together with R1 forms a current source where output current is proportional to the voltage difference (U_{Boost}–0.7 V)/R1. As long as the voltage at the emitter of T1 is below the reverse breakdown voltage of the zener diode D3, all of the current will flow through R2 to ground. The resulting voltage drop across R2 is referenced to the 1.24 V reference in the LT1172. With R2 equal to 1.24 kΩ a current of 1 mA flows through R1, T1 and R2 when the circuit is in balance. This current produces a 1.69 V drop across R1 which together with the 0.7 V base-emitter voltage U_{BE} gives a U_{Boost} of 2.4 V, the voltage necessary in a 4-cell application using three rechargeable cells plus the booster (see **Table**). With this number of cells the circuit operation corresponds to the negative-to-positive buck-boost converter configuration shown in the LT1172 data sheet.
For each additional cell the value of U_{Boost} must now be increased by 0.3 V and this is achieved by D3 and R4. When the emitter voltage of T1 is greater than 4.3 V (the sum of U_{IN} and U_{BE}) D3 conducts and a proportion of the current through R1 is diverted through R4 and D3. The voltage across R4 will be the input voltage U_{in} above 3.6 V, the level produced by three rechargeable cells. The value of R4 can be calculated so that for every additional 1.2 V increase in U_{IN} the U_{Boost} level increases by 0.3 V or 25 % (0.3 V / 1.2 V × 100).

1

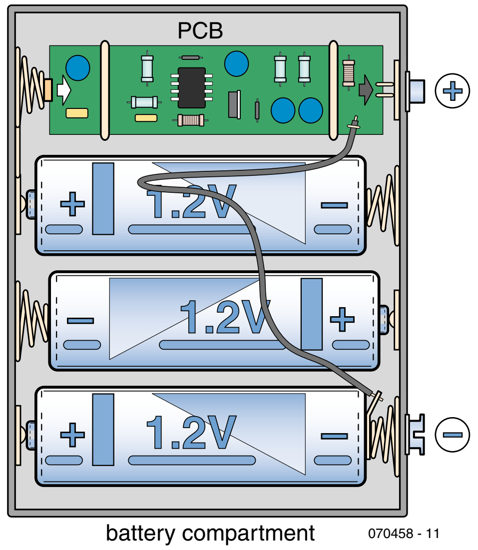


Figure 1. The booster fits in place of one rechargeable battery and boosts the output voltage up to the equivalent of four alkaline batteries (4 x 1.5 V = 6 V).

2

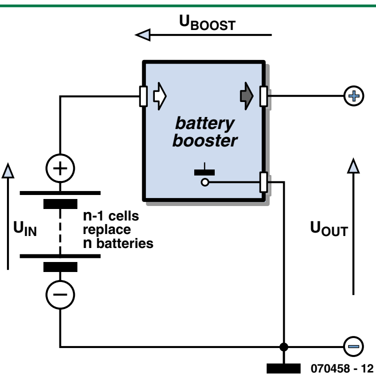


Figure 2. The Battery Booster operating principle.

U_{Boost} is U_{R1} + 0.7 V. To increase U_{Boost} by 0.3 V, this voltage must also be dropped across R1.
To find the value of R4:

n × 0.3 V / 1.69 kΩ = n × 1.2 V / R4

n can be cancelled giving:

R4 = 1.2 V / 0.3 V × 1.69 kΩ = 6.8 kΩ

So R4 = 6.8 kΩ and U_Z = 4.3 V.
In the simulation U_Z was chosen as 4.3 V and R4 as 6.2 kΩ to improve the output voltage level for this application. (A 4.3 V zener is not listed in the SwCad library).
As mentioned earlier, different types of buck regulator ICs can be used in a similar configuration. Some types can for example allow the circuit to operate from just a single cell while others supply higher output current.

The battery booster can be turned off with a switch in the earth lead.

(070458-I)

Table

Number of batteries n	Number of rechargeable cells n–1	Battery voltage $U_{Batt} = U_{OUT}$	Voltage from rechargeable cells U_{IN}	Boost voltage $U_{Boost} = U_{OUT} - U_{IN}$
4	3	6 V	3.6 V	2.4 V
5	4	7,5 V	4.8 V	2.7 V
6	5	9 V	6 V	3.0 V
7	6	10.5 V	7.2 V	3.3 V
8	7	12 V	8.4 V	3.6 V
9	8	13.5 V	9.6 V	3.9 V
(10)	9	15 V	10.8 V	4.2 V
max. 20*				

* see text

3

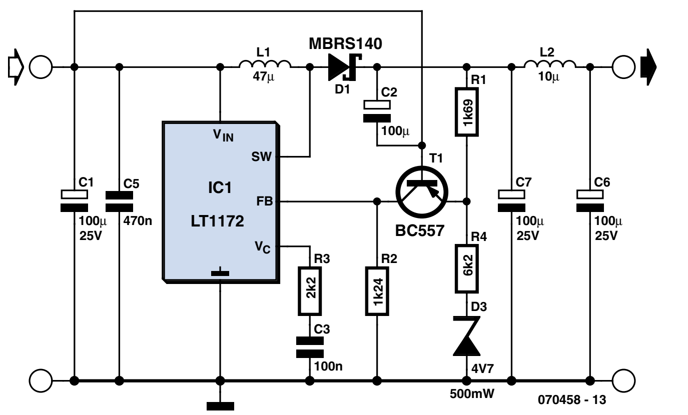
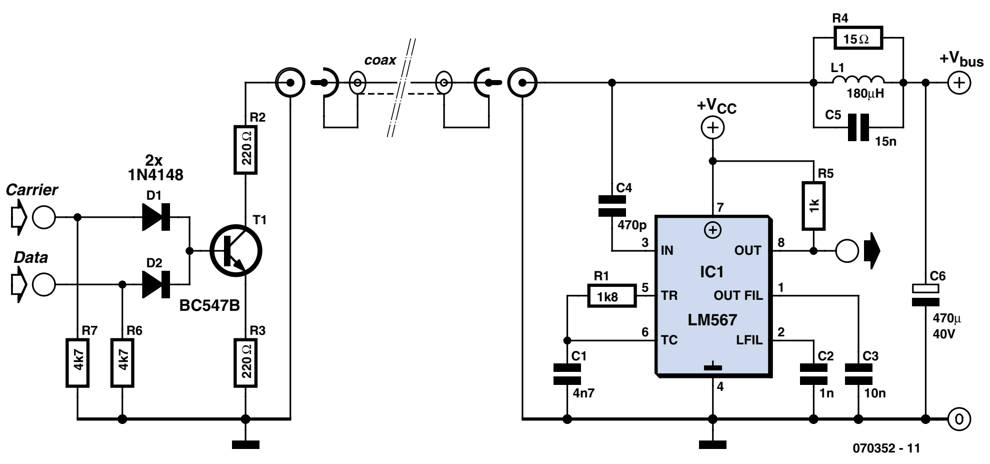


Figure 3. The circuit diagram and simulation files are available from our website at www.elektor.com

Data Transceiver for LNB Cable

Sajjad Moosavi



This circuit was designed and used to transmit commands over LNB coaxial cable. An LNB (or LNC) is a low-noise block downconverter typically used for satellite TV reception. It's fitted in the focal point of a satellite dish.
The circuit is based on generating a modulated signal on the bus which can be decoded by a tone decoder IC like the familiar LM567 from National Semiconductor. Data and carrier signals are ORed using D1 and D2. T1 acts as a current source whose current depends mainly on the value of R3.
L1 and C5 form a (damped) resonance circuit for the centre frequency of the carrier. C6 acts as a very low impedance bypass, so the impedance seen by T1 at the carrier frequency equals roughly R4. As the current passes through R4, the voltage generated across it can be detected by IC1 which has its input coupled to the bus via C4. The low DC resistance of inductor L1 allows current to flow to the circuitry connected to the bus.
Components R1 and C1 control the centre frequency of the decoder, and C2 the bandwidth. Relevant formulas may be found in the LM567 datasheets. C3 is output filter and its value depends on the 'data' frequency.
In accordance to what's found in the LM567 datasheet, the carrier frequency must be at least 20 times higher than the frequency of the 'data' signal. The maximum detectable carrier frequency is about 500 kHz. R5 is just a load for IC1, whose output is signal in phase with 'data'.
The Carrier frequency can be generated using any simple square wave generator.
In the author's application, the carrier frequency was 100 kHz with 1200 bps data, both generated by a microcontroller. The transmitter and receiver were installed at each side of the LNB cable to create a half-duplex transceiver.

(070352-I)

Hexadoku

Puzzle with an electronics touch

Right away at the start of the new year you get your dose of brain training. With Elektor's Hexadoku, 16 x 16 boxes are good for several hours of intellectual stimulation. Correct answers again enter a prize draw for one of the prizes: an E-blocks Starter Kit Professional and three Elektor Shop vouchers.

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.

SOLVE HEXADOKU AND WIN!

Correct solutions received enter a prize draw for an

E-blocks Starter Kit Professional

worth **£248.55**

and three **Elektor SHOP Vouchers** worth £35.00 each.

We believe these prizes should encourage all our readers to participate!

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

PARTICIPATE!

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

editor@elektor.com - Subject: hexadoku 1-2008.

Alternatively, by fax or post to: **Elektor Hexadoku**
Regus Brentford - 1000 Great West Road - Brentford TW8 9HH
United Kingdom - Fax (+44) 208 2614447

The closing date is **1 February 2008.**

PRIZE WINNERS

The solution of the November 2007 puzzle is: **41EBA**.
The **E-blocks Starter Kit Professional** goes to:
Terry Stallard (UK).
An **Elektor SHOP voucher worth £35.00** goes to:
Michael Murphy (IRL); Henning Björgo (N);
Srdjan Bogdanovic (SRB).
Congratulations everybody!

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

Filmnet Decoder (1989)

Jan Buiting

Although I have never forgotten this blockbuster from the old days I was delighted to find, in a storage locker at the former Elektor premises, the Elektor Filmnet decoder from 1989. The unit was in good nick and instantly took me back to an extremely exciting time at Elektor when reception of satellite TV channels and decoding of pay-TV and other scrambled signals created massive response from our readership. According to a Swedish journalist who called me in the summer of 1989, in Scandinavia an estimated 20,000 units were in use of the Elektor Filmnet Decoder. All for private and experimental use, of course.

The publication itself was a non-standard affair in three ways. First, the project could not be published in the Dutch edition of Elektor for fear of legal ramifications (Filmnet being owned by a Dutch/Belgian consortium). Secondly, for basically the same reasons (lawyers on the phone), the PCB designed for the project was not offered for sale through Elektor's Readers Services. Thirdly, the designer published under the name P.N.P. Wintergreen, slightly adapted from a character in *Catch-22* for reasons that should be obvious by now.

Well it did not stop masses of Dutch hobbyists from building the decoder. The word soon spread that Filmnet had been hacked big time by Elektor and a fairly cheeky electronics retailer/advertiser in The Hague soon had a pile of illegal copies of the English-language article under his counter, having sold out his stock of several hundred English language magazines ordered from… Elektor!

The Elektor Filmnet Decoder is a wonder of ingenuity as the designer successfully stuck to his intention to use cheap, commonly available components only, with a quaint preference for pnp transistors. The result was an ugly single-sided PCB but few cared — the project was dirt cheap and easy to build from BC5xx trannies and 40xx ICs — mission accomplished.

The crux of decoding the Filmnet channel on the Eutelsat satellite was the composite TV sync signal hidden in a subcarrier at 7.56 MHz in the transponder's baseband signal. Once you had found the missing syncs, a PLL and some really clever circuitry would happily restore the video signal to its original format. Next, you could start watching (and recording) 'certain' movies aired late on Saturday nights.

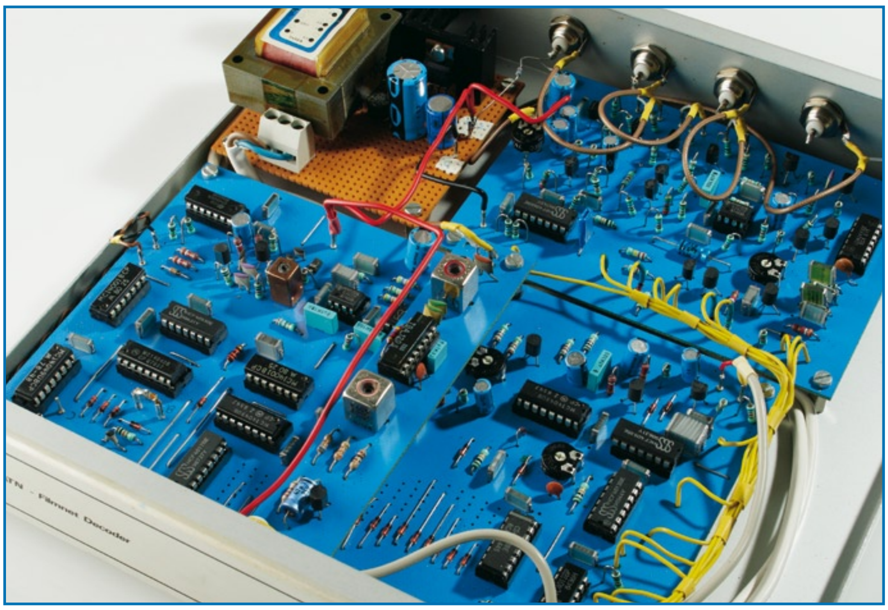
Filmnet changed their scrambling format several times but were defeated time and again by updates to the Elektor decoder published in *From the Satellite TV Desk*, a short running series of articles in the magazine. After three updates, P.N.P. Wintergreen had enough of it and devised a little circuit that adapted automatically to changes in Filmnet's scrambling system. From then on, owners of a fully updated Elektor Filmnet Decoder did not even notice 'mode changes'. After the 'autoadapt' update several Dutch and Belgian readers started to adapt the circuit for compatibility with cable TV.

I also remember a parcel and a non appreciative letter from a lecturer at a German Fachhochschule (Polytechnic) who claimed that the Elektor design was 'no good' because neither he nor any of his 20 "advanced" students could get the decoder to work. He threatened to end his school's subscription to Elektor if we failed to prove him wrong. So we pulled the neatly built decoder from the box — a quick glance at the board by the experts and yep, there's two presets interchanged and a BC547 for a BC557! After three minutes of soldering by a trainee in our lab the unit worked spot on without any need for adjustment. It was returned to the sender with a short accompanying note that unfortunately got lost.

Our Filmnet decoder got good coverage in the electronics press, and the relevant articles in Elektor magazine were also prominently mentioned in several editions of John McCormac's illustrious *Black Book* on video hacking.

I am happy to think that the project gave so many of our readers a sense of great achievement when the red 'scrambled' LED on the decoder front panel went out and the wild tearing and other gobbledygook on the TV screen changed to a normal picture.

(070790-I)



Scanned pages of the original March 1989 articles on the Filmnet decoder are available as a free pdf download from the Elektor website.

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

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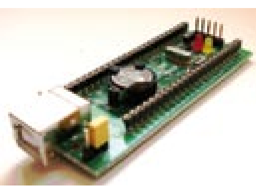

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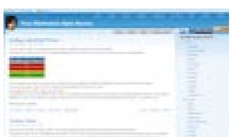

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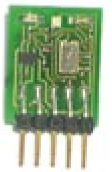

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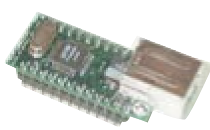

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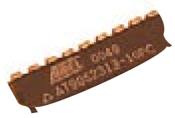

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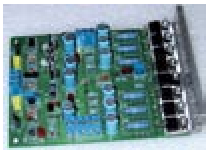

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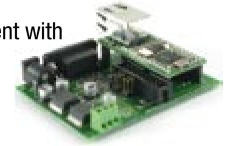

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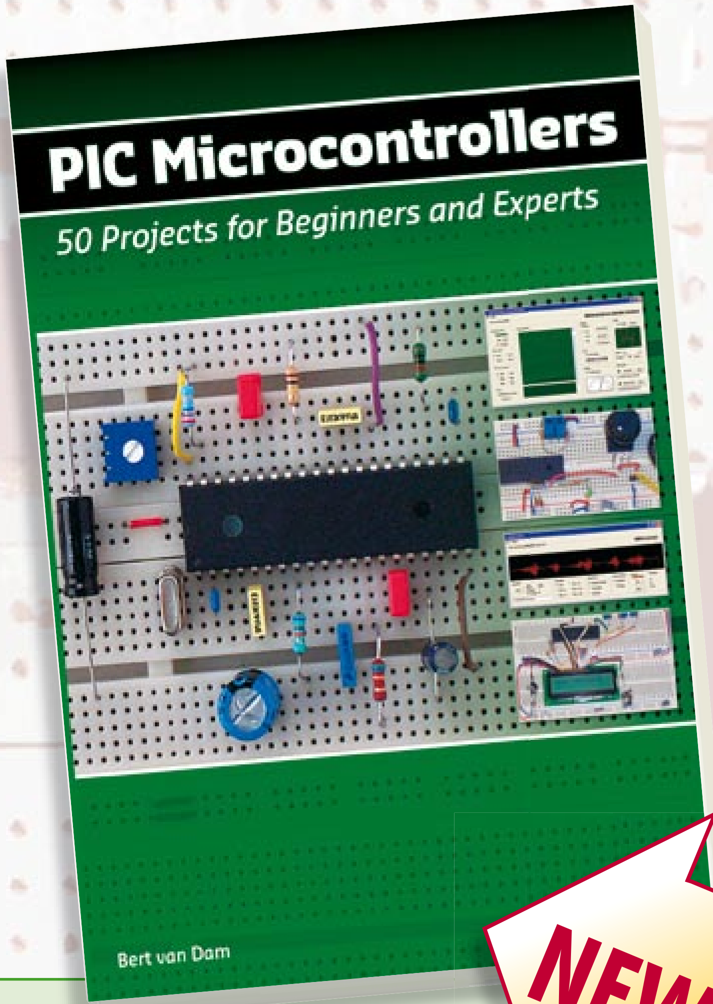

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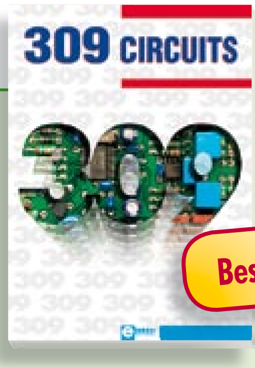

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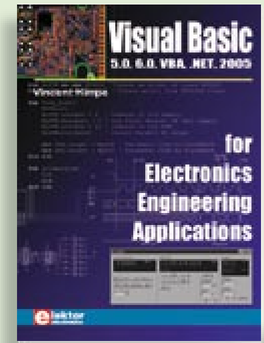

5.0, 6.0, VBA, .NET, 2005

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Reflow Solder Controller

(December 2007)

The Elektor lab needs to solder SMDs more often these days, something that undoubtedly also applies to many of our readers. In the January 2006 issue we described in some detail how you could build your own reflow oven using an inexpensive electric oven. That article resulted in many enthusiastic comments from our readers, which confirmed to us that there was a lot of interest in such a project. We now present a completely new version of the control electronics for a DIY SMD oven.

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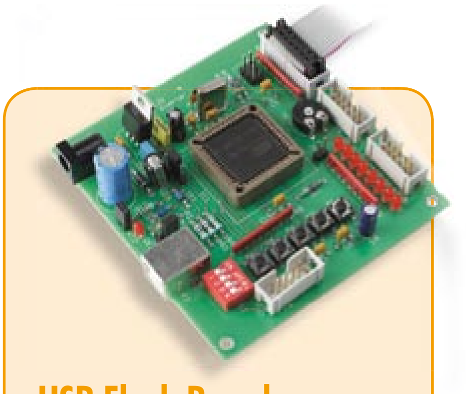

USB Flash Board

(November 2007)

Flash microcontrollers are easy to program. In the past, program code was usually downloaded via a serial interface, but nowadays many PCs (especially laptops) only have USB ports. This versatile Flash Board provides a solution to this problem. It is built around an AT89C5131A, which is an extended 8051-family microcontroller with an 80C52 core and a Full Speed USB port. As a sort of bonus, the IC has a complete update interface for downloading new fi rmware. Atmel also provides suitable software in the form of its FLIP program, which is available free of charge.

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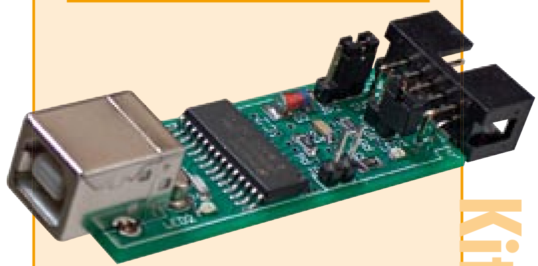

USBprog

(October 2007)

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070802-81	Software on CD-ROM	5.20	10.40
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Reflow Solder Controller			
060234-91	Populated PCB with enclosure	171,80	343,60
AVR Web Server			
060257-1	Printed circuit board	9,60	19,20
060257-41	ATmega644, programmed	13,80	27,60
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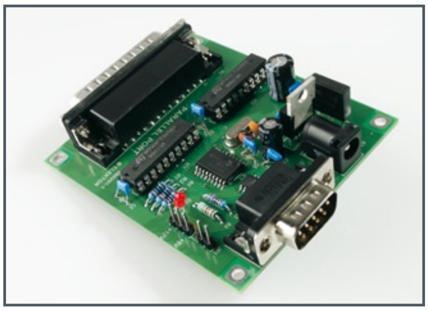
Surround light

Philips equip some of the latest flat screen monster TVs with a coloured background light system that responds to the picture contents. Unfortunately this system is not available with other TV brands, let alone computer displays. In the February 2008 issue Elektor presents two systems for home construction that allow similar effects to be achieved. One circuit is a completely analogue design, the other first digitizes the input signals and then does all further processing in digital fashion. The projects allow you to retrofit an image-controlled background light to your TV or PC display.

LED Ring Flasher

A ring flasher is what you need for macro photography using a digital camera. The device allows uniform lighting to be achieved of the object to be photographed so you don't have these nasty shadows and halos. Professional ring flash units are expensive so Elektor developed one based on LEDs and an associated driver.



CAN Explorer

A CAN bus is not just for vehicles and industrial automation systems but also for things in and around the home. Unfortunately the configuration of a CAN bus is not a simple affair and that's where our controller comes in by establishing a link between CAN-ed devices and the trusty PC. The resultant setup, in combination with free software, allows you to get control of a CAN bus and test the operation of CAN devices connected.

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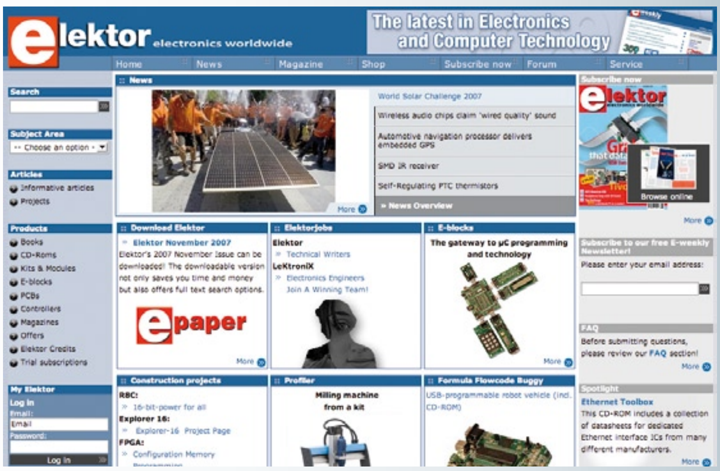

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September 2007

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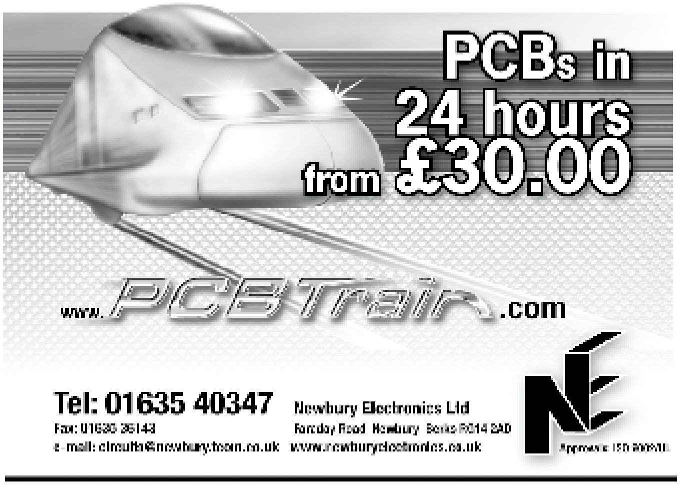
January 2008



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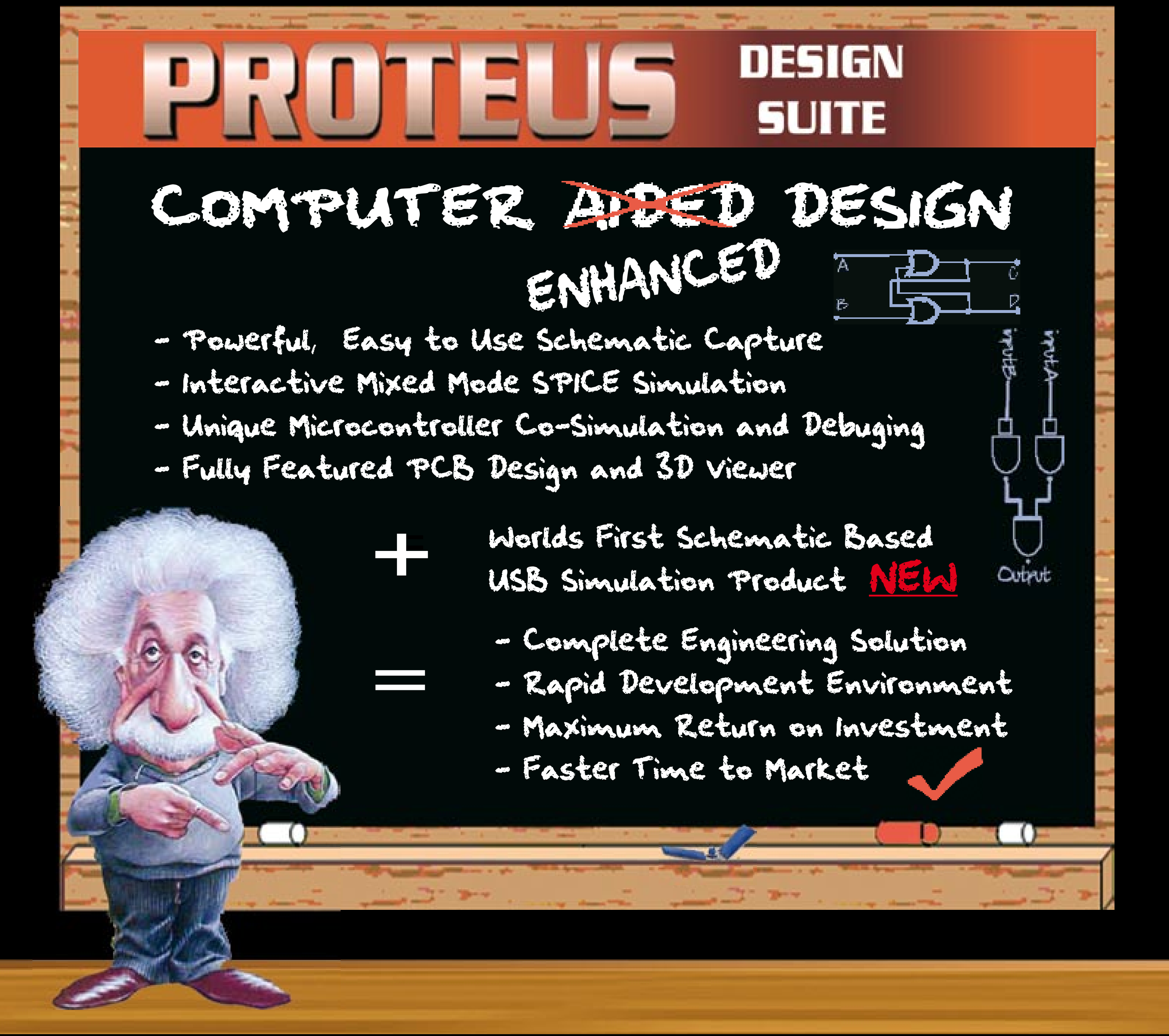
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