

7 new projects

+ Solar Thermal Energy Regulator

eilektor

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Cloud Altimeter

a practical meteorological tool



+ DIY Fuel Cells

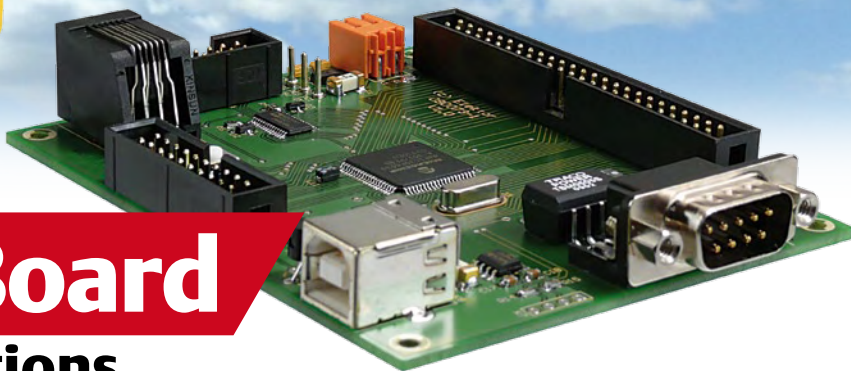
+ CO₂ Meter

+ VisiOLED

+ EV Charger

dsPIC Control Board

for major applications



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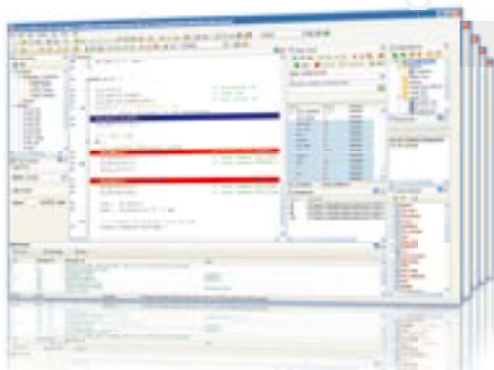
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Mikroelektronika manufactures competitive development systems suitable for programming and experimenting with different microcontroller families such as PIC®, dsPIC®30F, dsPIC®33/PIC®24, PIC32®, AVR®, PSoC®, 8051 and ARM®. They feature numerous on-board modules but also have the possibility of improving their performance by interfacing additional modules ordered separately.



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Energetic with energy

Although we are all electronics-minded people here at Elektor and this edition has a focus on sustainable energy sources and new ways of reducing energy consumption, it's curious and worrying to note that it took decades until electronics finally gets utilized to reduce the negative effects of, and created by, electronics itself. To be fair, that's the electronics at the heart of electrical equipment doing the actual amps guzzling from the wall outlet. It also underscores the powerful effect of good electronic design in high-energy consumption systems. Let's consider an industry-grade electric heater with a remote thermostat 'embedded style'. As much as the microcontroller manufacturers will like to tell you that their 32-bit XYZ product is now down to nano-amp standby current and awake in nanoseconds in response to a non-maskable interrupt or a key press, you should not care too much and get down to programming. Actually one second less of heater-on time due to smarter programming of the micro will result in a real energy saving and less carpet eating by the CFO as a result of the monthly energy bill (delivered to him/her by post). This year's Embedded World show in Nuremberg was all about 'green approaches' suitably backed by 'rapid prototyping' — see page 44. On the face of it, that's a logical combination — if you can't do the programming and prototyping in 'like' under 10 minutes including removing the kit from the plastic blister packaging you are wasting valuable energy. Interfacing microcontrollers to the real world has never been easier and the traditional gap between the pale pizza-fed programmer and the construction engineer wielding big spanners and 'doing the AC stuff' seems to vanish rapidly. The dsPIC board on page 20 and the associated solar heat collector application on page 26 are green as can be but fail miserably in terms of rapid prototyping, so don't tell anyone and optimize the system programming like a good engineer should. We're providing all the materials and design information to get you going, like a good publisher should, and it shall be our silent mutual understanding, satisfaction and enjoyment once the system operates exactly as you want it and you've experienced a steep learning curve. Agreed? We put a lot of energy in it — not all electrical I'm glad to say.

Jan Buiting, Editor



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A monthly roundup of all the latest in electronics land.

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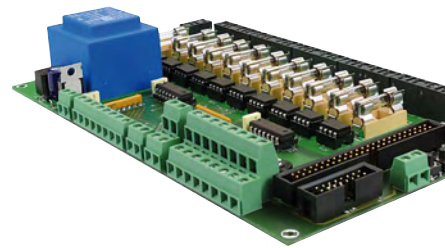
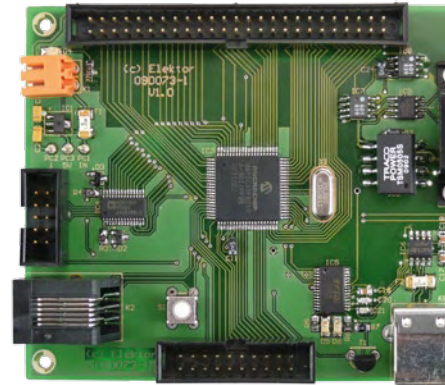
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A report on the world's largest show on microcontrollers and embedded technologies.

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The control board based on the dsPIC30F6010A microcontroller 'Plus' has been designed for incorporation into typical industrial electronics applications like controlling motors or adjustment of static up- or down-converters.



26 Solar Thermal Energy Regulator

This board is useful for regulating installations comprising several sets of solar collectors with different orientations or configurations with several hot-water storage tanks, requiring several valves and pumps to be controlled.



32 Worry-free Drilling

A pipe and wire locator (also called stud locator) can come in very handy for locating all sorts of things inside walls before you start drilling, including electrical wiring, pipes, and even joists or studs. We tested thirteen different models in the Elektor lab to see what they can (and can't) do and how deep they can find studs, joists, pipes and wiring inside walls.



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48 Cloud Altitude Meter

Here's Aircontrol, a portable instrument that will tell you the height of the cloud base straight above you.

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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. Analog and digital; practical and theoretical; software and hardware.



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Part 3 *Negative feedback*

How negative feedback can be done right, remarkable experiments in the project.

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Embedded real-time Java VM supports Java 6 Standard Edition



Aicas (Karlsruhe, Germany) has released JamaicaVM 6, which is claimed to be the only Java VM for real-time applications to support the Java 6 language and standard APIs. JamaicaVM 6 has improved graphics performance and an extended number of supported platforms. It supports graphics on QNX and Linux platforms, both with and without X-Server. In total, 14 embedded operating systems are supported. Soft real-time behavior on Linux and Windows has been improved.

JamaicaVM 6 enables the development of hard and soft real-time applications, applications for portable devices and graphic-rich applications, and the development tools help optimize applications for speed and low memory footprint. Java applications can be ported from desktop to embedded systems with no changes.

JamaicaVM is a Java Virtual Machine (JVM) that provides performance guarantees for all primitive Java operations, thus satisfying the main requirement for hard real-time performance. It also eliminates memory leaks and fragmentation, which are the cause of many serious bugs in embedded applications. JamaicaVM 6 features real-time garbage collection to bring safety, determinism and hard real-time performance to embedded systems. It also provides access to a large set of Java classes and APIs for real-time and non-real-time programming provided by the RTSJ and J2SE Java standards.

JamaicaVM is suitable for projects that require low latency for seamless graphic, industrial or financial applications and microsecond response times for hard real-time events. It support a number of security standards to enable device certification, including conformity to DO-178B. It is also scalable, with the ability to manage a large number of tasks in parallel while giving each task deterministic behavior.

www.aicas.com/jamaica.html

(100267-1)

eRecyclingCorps aims to cut mobile phone e-waste

Of the four billion wireless subscribers in the world, only one percent of them recycle their handsets. In the US alone, 130 million phones are retired each year. The global e-waste problem is substantial and growing, and it is the target of eRecyclingCorps, a new Dallas-based company that made its debut at CTIA. The company will help carriers buy back used handsets from consumers and ensure they are resold or responsibly recycled.



eRecyclingCorps deploys a web-based platform that integrates directly into the point of sale system at carrier retail stores, where 60% of all US phones are sold. It makes valuable consumer trade-in incentives, efficient in-store collection and strict privacy controls an integral part of every new phone purchase. By partnering with eRecyclingCorps, carriers can reclaim subsidies, increase customer loyalty, and significantly reduce downstream e-waste.

Sprint, the first carrier to use eRecyclingCorps, has deployed the system in 1,100 company owned Sprint stores, 1,400 Sprint preferred dealers, and through its online channels. Sprint's buyback program gives customers an instant account credit for trading in eligible wireless devices. Sprint has set its sights on the ambitious goal of achieving a wireless reuse and recycling rate of 90% of total device sales by 2017.

While estimates vary, the following data helps size the e-waste problem in the US and globally:

- Globally, only 1% of mobile phones are recycled (source: USGS)
- Of the 275 million US mobile phone users, only 10% recycle (source: EPA)
- 98% of consumers will recycle if they are given incentives (source: ABI Research)
- E-waste is fastest growing waste stream in US (source: EPA)
- Recycling 1 million mobile phones can provide 185 households with electricity for 1 year (source: EPA)
- Nationwide, 130 million cellular phones go out of use annually (source: EPA), creating an estimated 65,000 tons of electronic garbage

eRecyclingCorps was co-founded by CEO David Edmondson, previously CEO of RadioShack, and board chairman Ron LeMay, formerly President and COO of Sprint. Both of them played an important role in the growth of the wireless industry, and they are committed to addressing the unintended ecological consequences of its success.

www.erecyclingcorps.com

(100267-XV)

USB adapter links memory sticks to cellphones and PDAs

Mobidapter, newly introduced by Saelig Company, Inc., is a USB memory stick reader which plugs directly into the SD memory slot on mobile/cell phones, smart phones and PDAs, permitting — for the first time — reliable, rapid transfer of files from USB sources. Just insert Mobidapter to a phone's SD slot, connect it to a USB memory device, and you can e-mail text files, images, and PowerPoint files in a jiffy. Now files can be transferred anywhere, without a PC, with all operating systems because no drivers

are required.

USB memory sticks have become the de facto way to carry and transfer data, but until now it has been impossible to connect them to mobile phones and PDAs. Mobi-



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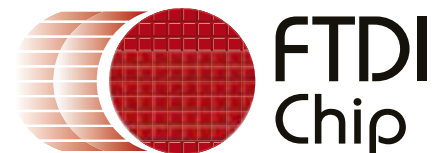
A programmable system-on-chip dual USB 2.0 host/ slave controller.

- Handles USB host interfaces and data transfer functions using the in-built 16-bit enhanced MCU with 256 kbyte Flash and 16kbyte RAM.
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- Libraries for several USB classes FAT file system support.
- Interfaces to UART, FIFO, SPI Slave, SPI Master and PWM.
- Multiple package size options including VNC1L pseudo compatible option, provide cost effective solutions for the different applications.
- Time to market can be reduced using the wide range of available development modules.



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dapter works with any make of mobile or cell phone, SmartPhone or PDA with an external SD socket. It can also be used with mini-SD sockets with the aid of a simple adapter. Both SD and SDHC hosts are supported. In effect, Mobidapter becomes a standard USB host connector, interfacing with USB memory devices to a maximum 32 GB.

Mobidapter can also be used with many other devices, such as TVs, PDAs, GPS devices and digital picture frames. It is now possible to transfer data such as pictures, MP3 files, Microsoft Office applications, or any type of file between a standard USB memory stick and a mobile device. Last-minute data sent from the head office while you are in the field, but no Internet access? No problem! Download it via your cellphone to a memory stick (and hence your laptop) using Mobidapter. Mobidapter is compatible with virtually all of the latest phones with an external SD memory slot and all standard USB memory sticks. Power is provided from the host device, so no batteries are needed. Applications include instant transfer of images, music and data between phones, PDAs, MP3/MP4 players from any location; data backups; work files, etc.

Mobidapter is available now from \$59.00 each directly from Saelig Company Inc., Pittsford, NY.

www.saelig.com

(100267-XII)

IC combines Bluetooth interface with noise-canceling audio processor

CSR claims that its new CSR7810 is the industry's first audio processor with easily integrated Bluetooth connectivity for handsets with noise cancellation capability. The CSR7810 includes voice processing technology designed to radically improve the audio quality of conversations in extremely noisy environments. By combining Bluetooth and voice processing functionality in a single chip, the device significantly reduces manufacturing costs and design integration time as well as overall PCB space. Existing handset designs that incorporate a CSR Bluetooth device can be easily upgraded to CSR7810 and benefit from noise cancellation.

The chip's noise cancellation algorithm uses signals from one or two microphones (digital or analog) to remove background noise from the transmitted voice signal. By monitoring



the caller's voice as well as ambient sound and calculating the difference between the two signals, CSR's dual-microphone noise cancellation dramatically improves audibility.

CSR's audibility enhancement algorithms improve incoming audio quality by dynamically adjusting the volume and equalization at the earpiece to compensate for background noise. CSR's Clear Voice Capture (CVC) hands-free configuration technology for voice equalization and echo cancellation in speakerphone mode is also included. This mode uses a single-microphone noise reduction and echo cancellation algorithm to improve transmitted and received audio quality, which allows handsets to support speakerphone operation while maintaining high voice quality.

The key element of the CSR7810 is the Kalimba DSP, a very power-efficient architecture optimized for low-power connectivity applications. Kalimba is the lynchpin of CSR's audio platform solutions. As audio functionality becomes an increasingly important aspect of connectivity products, CSR customers are asking for integrated Kalimba functionality in more and more devices. CSR's Kalimba DSP has shipped in over 100 million Bluetooth devices.

www.csr.com

(100267-11)

Mass flow meter for medical gases



Designed for anesthesia equipment, the Sensirion SFM4100 mass flow meter precisely measures air and other non-aggressive gases with an impressively wide dynamic

measuring range of up to 20 standard liters per minute with zero drift. The sensor utilizes Sensirion's CMOSens® technology, which enables the sensor component to be combined with the analog and digital signal processing circuitry on a tiny CMOS silicon chip, to provide a fully calibrated and temperature-compensated output signal on a digital I²C interface and operate reliably at pressures up to 7 bar (100 psi).

Its outstanding long-term stability makes the SFM4100 the first choice for products that require a high rate of deployment with long service intervals. For OEM application, calibration settings for more than one gas can be stored at the same time in an individual sensor device. Self-test features support testing of the entire signal chain from analogue signal acquisition through the digital signal processing chain A/D conversion, linearization and temperature compensation) while the mass flow meter is in use, which is a major benefit for use in safety-critical applications.

In addition to mixing carrier gases for anesthesia, the SFM4100 is well suited for integration in other medical and analytical equipment and use for process automation tasks.

www.sensirion.com

(100267-IV)

Miniature reflective object sensor targets medical applications

The Optek OPB733TR miniature reflective sensor combines a 7.6 x 4.06 mm footprint with lensed optics for an enhanced sensing range in space-constrained applications. The reflective sensor has a PC board mounted profile of just 2.89 mm and incorporates a lensed IR LED with a typical peak emission wavelength of 890 nm and phototransistor elements to collimate the light beam for enhanced resolution over a detection range of 10 to 25.4 mm.

With its enhanced sensing range and miniature size, the device is suitable for applications in tube-in-place and tube proximity hospital infusion pumps, encoders for volumetric measurement in transfusion pumps, and as a carousel or bin sensor for medicine dispensing equipment.

The OPB733TR consists of an IR LED mounted alongside a NPN silicon phototransistor, which responds to light reflected by the object being sensed. The phototransistor output (collector current in the On state) is 0.1 mA at a distance of 12. mm from



the target with an IR diode forward current of 20 mA and a V_{CE} of 5 V. The rise and fall times of the phototransistor signal are typically 15 ms. The surface mount package is reflow solder compatible up to 260 °C. The sensors are available on 16-mm tape on 7" diameter reels, with 500 pieces per reel.

www.optekinc.com

(100267-V)

Smart on/off switches enhance user convenience with battery-powered devices

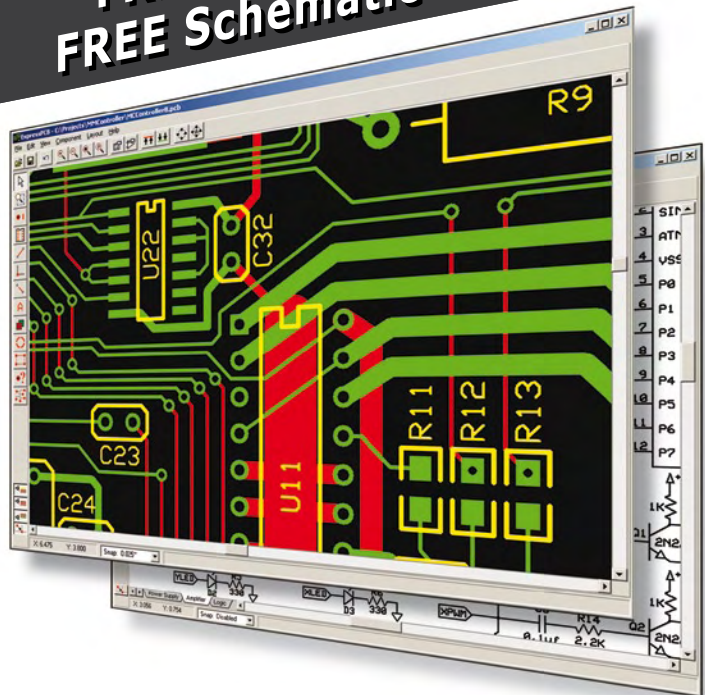
STMicroelectronics has introduced new smart pushbutton on/off controller ICs designed to improve the user experience with virtually any battery-powered portable device, including e-readers, tablets, media players, smartphones and digital cameras. These new chips will enable next-generation mobile products to offer easy-to-use power-up, power-down and unfreeze/reset functions that prevent damage to the end-user product. In addition, these single-chip turnkey solutions significantly ease the design task by eliminating the need for numerous discrete electronic components in product designs. The new STM6600 and STM6601 smart pushbutton on/off controller chips offer protection for battery-operated devices in many ways, including minimizing the risk of powering up without sufficient battery power to complete the sequence, which can damage the unit. To prevent this, the chip blocks power-up if the battery is excessively discharged. It can also prevent power-up if it detects a fault in the power supply. The IC connects directly to the power button, and another Smart Reset™ input can be connect to any other pushbutton in the system. It includes circuitry to prevent unwanted power-ups or system resets caused by external interference such as electrostatic discharge.



As the latest members of ST's family of power-path management chips, the STM660x ICs also implement Smart Reset capabilities to help users restore normal operation with products that have crashed or frozen. Smart Reset requires both pushbuttons to be held down for a minimum period (determined by an external capacitor) before a reset occurs.

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This two-action reset eliminates the need to hide the reset button behind a hole in the outer case to prevent accidental use, thereby reducing engineering costs and allowing the case to be sealed if required. The protection features integrated in the STM660x devices replace up to 30 or 40 discrete components or a complex programmable logic device with a separate voltage regulator, clock, and a voltage detector to monitor the battery condition, or the alternative solution of a microcontroller with dedicated housekeeping features along with an external crystal, voltage detector and firmware. The STM660x 2x3-mm footprint occupies less than half the PC board space of any alternative approach, freeing up valuable space for mobile products. Another plus for

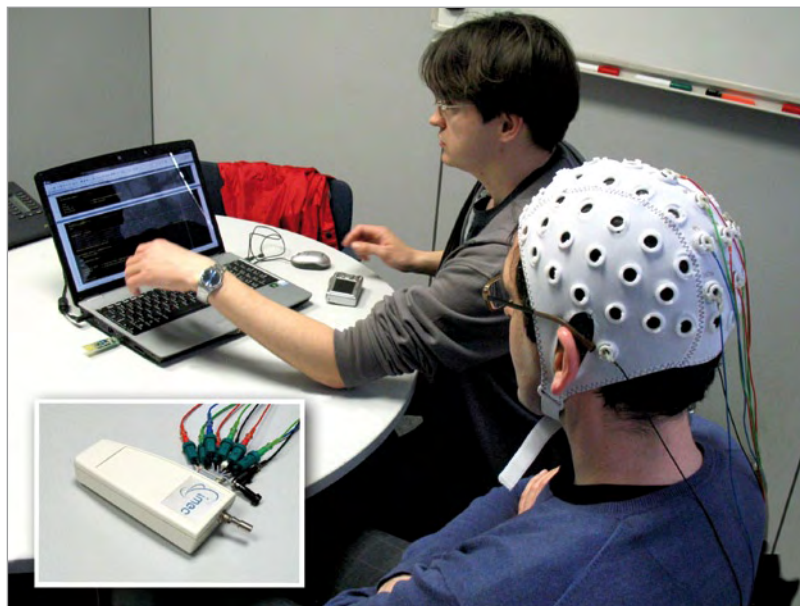
portable product designers is the device's low active current consumption (6 μ A) and a nanopower shutdown mode consuming less than 1 μ A.

www.st.com/powerpath

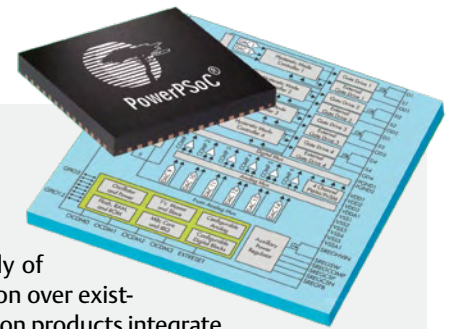
(100267-IX)

“Thinking cap” helps disabled people communicate

IMEC, the Holst Centre and the Laboratory for Neurophysiology and Psychophysiology at the Catholic University of Leuven (Belgium) have demonstrated the *Mind Speller*, described as a portable, comfortable, and intelligent textual and verbal communication prototype device that enables people with motor disabilities to communicate. A prototype version of the device was recently presented at the Medtech Conference in Stuttgart, Germany. The Mind Speller is a electroencephalogram (EEG) based device that interprets brain waves to spell words and phrases. It detects and interprets events related to P300 potentials in the EEG signals of a user who selects characters displayed in alternate rows and columns. P300 potentials are often used as a metric of cognitive function in decision processes, but currently available P300 devices are large, expensive and uncomfortable in use. The Mind Speller, by contrast, consists of a portable module no larger than a matchbox connected to a cap housing electrodes located at specific positions on the user's head to capture the relevant EEG signals. The electronics in the module were developed by IMEC and the Holst Centre and include their proprietary ultra low-power eight-channel EEG chip for processing the EEG signals, a commercial low power microcontroller to digitize the EEG signals, and a low-power 2.4 GHz wireless module that transmits the EEG signals to a nearby PC. The data is interpreted on the PC by powerful, robust signal processing algorithms developed by a research team led by Professor Marc Van Hulle.



Alternative solutions to help people communicate despite severe impairments are also available. These solutions utilize eye tracking technology or laser pointing. However, they require long, error-prone calibration processes, and they are very expensive



Programmable devices transmit data over power lines

Cypress Semiconductor has launched a family of programmable devices for data communication over existing power lines. These Powerline Communication products integrate several functions in addition to communication, including power measurement, system management and LCD drive. According to Cypress, they also offer better than 97% packet success rate without retries and 100% success rate with retries, which is supported by the integrated device firmware. They enable systems to communicate over high-voltage and low-voltage power lines to support applications such as lighting and industrial control, home automation, automatic meter reading, and smart energy management. Unlike existing products that require external microcontrollers and filters, Cypress's PLC devices integrate a frequency-shift keying (FSK) modem, network protocol and application code with the programmable analog and digital blocks and microcontroller of the PSoC architecture to provide a single hardware platform for a wide variety of applications. Cypress offers reference designs for high-voltage (110 V to 240 V AC) and low-voltage (12 V to 24 V AC/DC) coupling circuits based on boards compliant with FCC and CENELEC standards.

Additional features include support for bidirectional half-duplex communication, the option of using the full platform (PHY, protocol and application code) or only selected components (PHY and protocol or PHY only), variable baud rates up to 2400 bps, and an onboard power supply that taps operating power from the power line bus.

The Cypress PLC family includes a cost-optimized, fixed-function device with an I²C interface (CY8CPLC10), programmable PSoC-based devices (CY8CPLC20), and programmable PSoC-based devices optimized for LED support (CY8CLED16P01). All devices are currently in production.

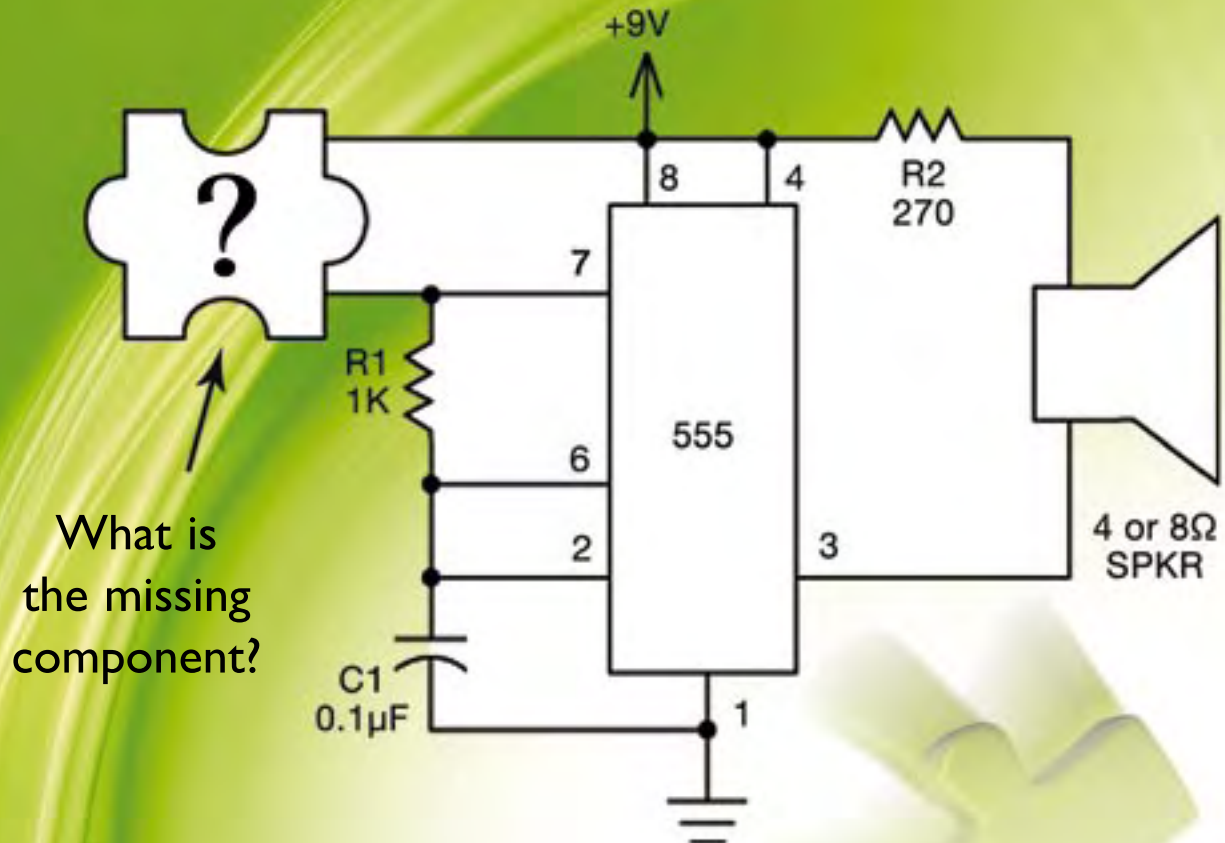
www.cypress.com

(100267-VIII)

due to the technology used and the need for custom solutions. According to Prof. Van Hulle, the Mind Speller is a generic device that can easily be adjusted to different users, which means it could be a cost-efficient communication solution for people with temporal impairments for whom existing solutions are too expensive. The Mind Speller could also help patients that do not benefit from existing devices based on motor activity, since the Mind Speller is based using P300 EEG potentials to read people's thoughts instead of interpreting motor activity.

www2.imec.be/be_en/press/imec-news/mindspeller.html
(100267-X)

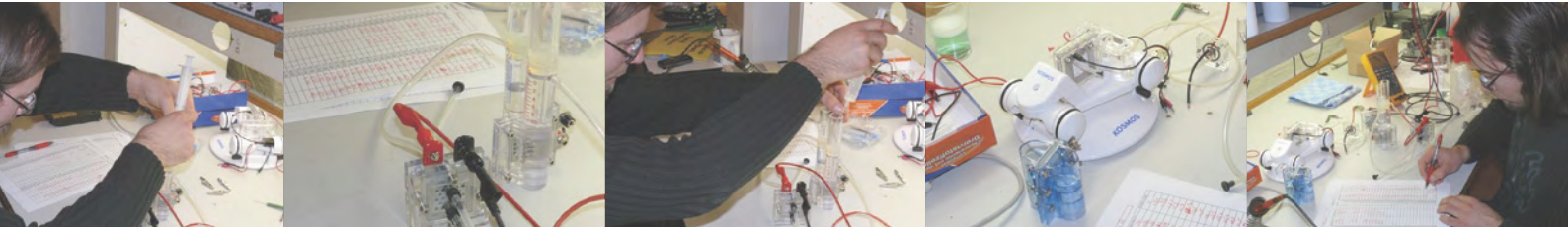
Can You Guess the Missing Component?



Amateur electronic musician Joe Rhythm is planning a one-man video concert that he plans to post on YouTube. Controlling his array of instruments requires both hands and he wants to build a pressure-sensitive tone generator that he can control with a free finger or even an elbow or foot. Joe quickly whipped up a simple tone generator using parts from his bench stock. Since there wasn't enough time to order a pressure sensor, he improvised by making one from materials he had on hand. What did he use? Go to www.jameco.com/solve6 to see if you are correct and while you are there, sign-up for our free full-color catalog.

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Clean Power from Hydrogen

Fuel cells in practice

By Thijs Beckers (Elektor Netherlands Editorial)

Sustainable energy is what everyone wants nowadays, but what's the best solution? The options include storing energy in large batteries, hydroelectric power plants with water reservoirs, and hydrogen, but there's still no clear answer to this question. Hydrogen appears to be a very promising candidate for mobile applications. Several car manufacturers already have prototype 'hydrogen cars' driving around, powered by fuel cells. Let's have a look at what you can actually do with fuel cells.

It appears that the worldwide demand for energy will continue to rise. Worldwide energy consumption in 2008 was 474 exajoules ($474 \times 10^{18} \text{ J}$) [1], which amounts to a constant daily consumption of 15 terawatts ($15 \times 10^{12} \text{ W}$). Worldwide energy consumption is expected to increase by 54% between 1995 and 2015. This results for the most part from rising consumption in Asian countries, with an anticipated increase of 129%. Of course, this is mainly due to the fact that the per capita energy consumption in countries such as India and China is among the lowest in the world and that these countries expect to achieve very strong economic growth, which goes hand in hand with a strong increase in energy demand. Per capita energy consumption in the Western countries is already very high. For instance, the USA accounts for approximately 29% of worldwide energy consumption, despite the fact that its population is only about 5% of the total world population. The industrial and transportation sectors consume enormous amounts of fuel. The majority of this (around 80 to 90%) consists of oil and gas. The rest comes from nuclear energy and sustainable energy generated from natural sources, such as wind, water and sunlight.

Fossil fuels

At the start of the Industrial Revolution in the late eighteenth century, the main sources of energy were oil and coal. We need energy in our daily lives to run our central heating systems, refrigerators, television sets, PCs and cars. All of these systems and devices need energy, which is largely provided by fossil fuels. Our central heating systems run on natural gas, our household appliances run on electricity generated by power plants that operate primarily coal or natural gas, and our cars run on petrol. Our society is almost entirely oriented toward energy from fossil fuels.

However, these energy sources will not last forever. At some point the oil wells will be pumped dry, the gas deposits will be exhausted,

and all the coal will have been mined – and what will we do then? In response to this pressing question, innumerable projects and studies for the development or exploitation of new energy sources have been launched, including cold nuclear fusion, solar energy, biofuels, wind energy, and what have you.

Alternatives

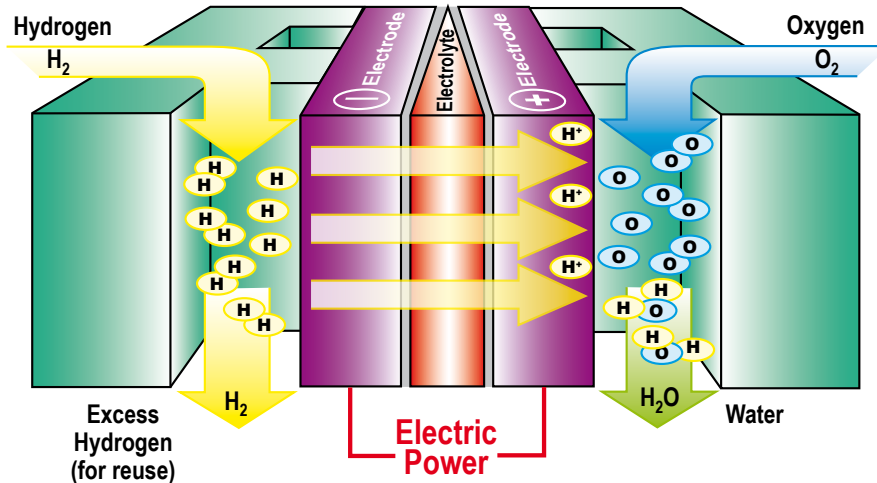
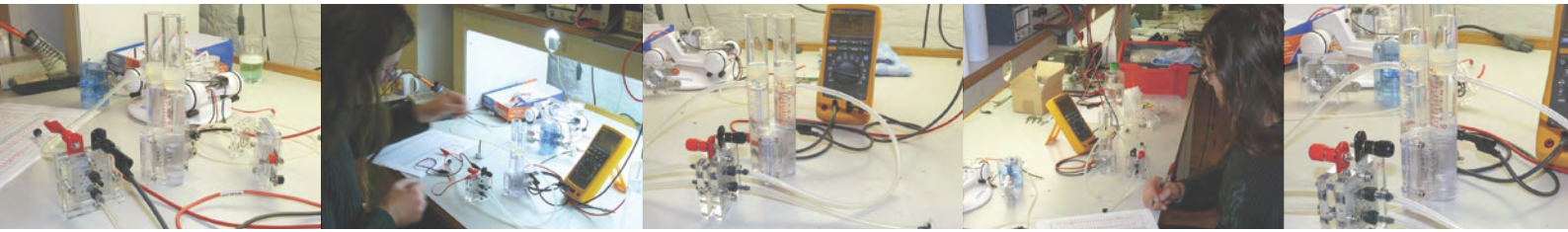
In principle, the amount of energy from the sun that 'bombards' the earth is more than adequate to meet all of our energy needs for the next hundred years. However, we have not yet developed a perfect method for converting this energy into a usable form. Although solar cells are becoming more and more efficient, it still takes a considerable amount of energy to produce them, and most of this energy still comes from fossil fuels.

There's also the question of how to store this sustainable energy. One way to do this in a 'green' manner is to store it in the form of hydrogen. There are presently a good number of tricky issues here, but considerable effort is currently being put into developing suitable storage options and a practical infrastructure for hydrogen as a fuel.

H₂

Hydrogen is a naturally occurring substance that takes the form of hydrogen molecules (H₂) consisting of two hydrogen atoms. It is a gas at room temperature and normal pressure, with a density of 0.084 grams per litre.

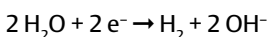
This makes it approximately 14 times lighter than air. Hydrogen is the lightest and smallest of all elements. As a result, it can easily pass through porous materials and even through metals such as platinum, which is a characteristic that requires special attention in storage systems. Hydrogen forms an explosive mixture with air and gaseous chlorine, but pure hydrogen is very stable.



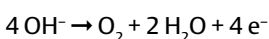
Electrolysis

Hydrogen can be produced in several ways. The most common method is to use an electric current to decompose water into hydrogen and oxygen. This process is called electrolysis, and it works as follows. Two electrodes are placed in an electrolyte: first an anode, which is connected to the positive terminal of an external voltage source, and second a cathode, which is connected to the negative terminal of the voltage source. These electrodes are made from a metal that is not altered by the electrolytic process, but instead acts as a catalyst for the process. Platinum is often used for this purpose. The surface characteristics of the electrode have a strong effect on the amount of hydrogen that is released.

A DC current is used for electrolysis. There are several options for the voltage source, such as a battery or a solar cell. An electrolyte, such as sodium sulphate (Na_2SO_4), must first be added to the water to provide ions so that a current can flow, since pure water is a very poor conductor of electricity. Oxygen (O_2) forms at the anode (which is connected to the positive voltage), while hydrogen forms at the cathode. Due to the supply of electrons to the cathode (negative voltage), the following reaction occurs at the cathode:



The hydrogen formed at the cathode rises through the liquid and can be captured. The hydroxyl ions (OH^-) formed at the cathode are used in the reaction that occurs at the anode. The following reaction occurs there due to the shortage of electrons (positive voltage):



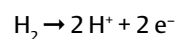
The oxygen formed at the anode also rises through the liquid and can be captured.

The reaction at the anode requires twice as many OH^- ions as are formed at the cathode. This means that two hydrogen atoms are released for every oxygen atom that is released. In other words, the process produces twice as much hydrogen as oxygen.

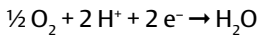
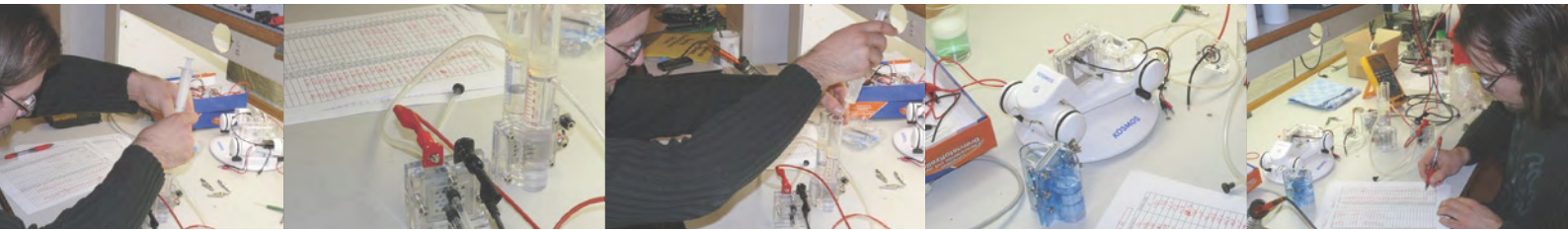
Fuel cells

The process of electrolysis is reversed in a fuel cell. The reverse reaction yields an electric current, along with pure water as a by-product. Here again an electrolyte is necessary to allow the reaction to occur. In fuel cells, the electrolyte takes the form of a special membrane. The fuel cells we examined for this article (described below) are all of the type called 'PEM fuel cells', where 'PEM' stands for 'proton exchange membrane'. The advantage of this type of fuel cell is that it can operate at room temperature. There are now many other types of fuel cells that operate under other conditions, including some that operate at much higher temperatures [2].

The membrane of a PEM fuel cell is made from Nafion. This is a polymer with a molecular structure so dense that only hydrogen ions can pass through the material; oxygen ions are held back. On each side of the membrane, there is an electrode consisting of a carbon mat with a coating of vapour-deposited platinum. The anode side receives a continuous stream of hydrogen, while the cathode side receives a continuous stream of oxygen. The platinum catalyst splits the arriving hydrogen molecules into hydrogen ions according to the following formula:



The electrons are absorbed immediately by the electrode. They pass through the connected external load and arrive at the cathode. The positively charged hydrogen ions diffuse through the membrane to the cathode, where they react with the released oxygen ions to produce water according to the following formula:



The electrons necessary for this reaction are supplied by the cathode. In this way, the membrane allows hydrogen and oxygen to combine and form water in a clever manner without any visible combustion or explosion.

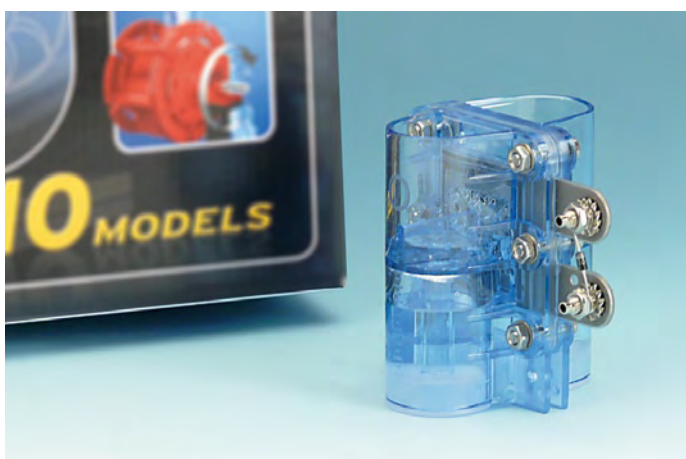
The voltage generated by this type of fuel cell is usually between 0.6 and 0.9 V, which is too low for most applications. For this reason, it is common practice to connect several fuel cells in series in order to obtain the required voltage. The required current capacity is achieved by ensuring that each cell has sufficient surface area.

Try it yourself

It's now relatively easy to perform your own experiments with fuel cells, since a number of kits are available commercially. They are primarily intended to be used for educational purposes in order to explain the concept of sustainable energy. We put several kits through their paces and examined what they could do (caution: most of the fuel cells concerned are intended to be used with the accompanying kit, but not for other experiments. Otherwise the warranty is rendered void).

Fischertechnik

We received the *Hydro Cell Kit* from Fischertechnik [3]. This kit consists of an integrated unit containing a PEM fuel cell, water tank and gas reservoir; a solar panel; and some fastening hardware. This kit is actually an accessory for the *Eco Tech* kit from Fischertechnik, in



which ten different constructions operate from solar power. With the combination of the two kits, the fuel cell can be used for electrolysis in order to buffer the solar energy by storing it in the form of hydrogen gas. When the solar panel does not receive enough light, the fuel cell can be used to generate electricity from the hydrogen gas. This combination illustrates precisely what is expected from a sustainable solution to our virtually insatiable demand for energy.

Heliocentris

We received the *Dr FuelCell Science Kit* from Heliocentris [4], a company that specialises in fuel cells. This very extensive kit comes with four books full of theory, explanations and instructions for experiments and measurements, which are clearly oriented toward educa-



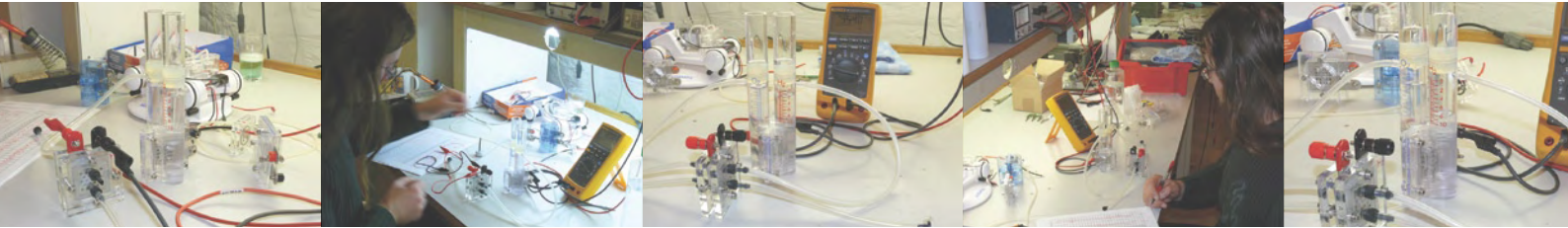
tional use. The kit has a separate unit for electrolysis and storing the hydrogen and oxygen, a solar panel to supply power for electrolysis, a PEM fuel cell for DIY assembly, and a measuring unit with several different loads. The kit also includes a methanol fuel cell, which we ignored during our tests. This kit includes everything you need for experimenting with sustainable energy solutions.

Eitech

Eitech [5] sent us their *Construction Set C30*. This kit includes instructions for building three different structures powered by a hefty PEM fuel cell. A special feature of this kit is that it comes with a small canister holding 20 litres of hydrogen gas, which can also be refilled



(but only by the manufacturer, unfortunately). This kit is not suitable for generating your own hydrogen. There is a booklet with a concise explanation of how it all works, and from the specifications alone



you can see that this fuel cell is more powerful than those in the other kits. All in all, this is an excellent choice for DIY experiments.

Kosmos

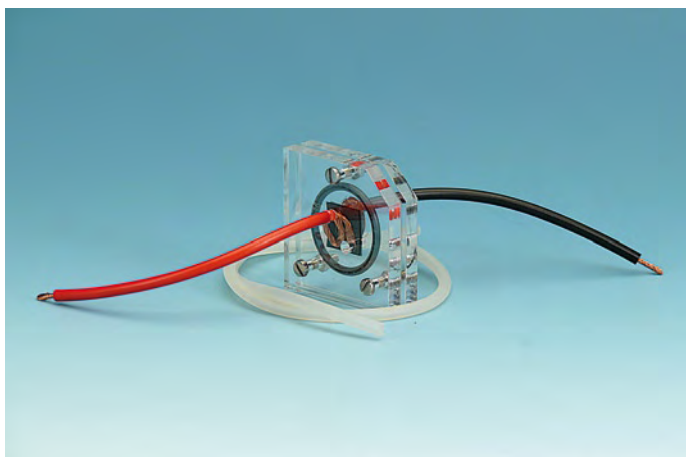
Kosmos^[6] sent us their *Brennstoffzelle Classic* ('Classic Fuel Cell'). This kit also includes a reversible PEM fuel cell, which means that it can be used to generate hydrogen or to generate electricity. Here the fuel cell is used to power a small car using hydrogen as the fuel.



Everything necessary for performing experiments, such as hoses, cables, a gas canister, a multimeter and a solar panel, are included in the kit. The extensive assembly instructions also include a detailed description of the operating principle of the fuel cell (and the solar cell). Highly educational.

Franzis

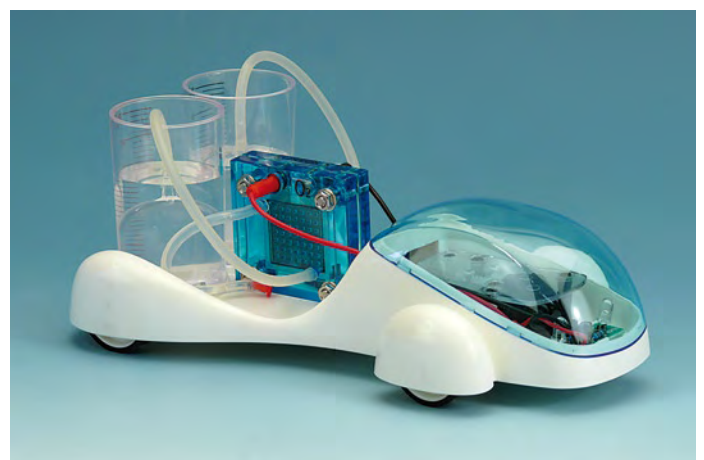
The *Lernpaket Experimente mit der Brennstoffzelle* ('Learning Kit for Fuel Cell Experiments') from Franzis^[7] contains the components necessary for making your own fuel cell. With a bit of patience, you can assemble the small cell in 15 minutes. However, you have to make the fuel (hydrogen) yourself. Along with several other experiments, this is described in the accompanying user guide. This approach is



not as user-friendly or convenient as the others, but it works. The fuel cell has the lowest power output of the lot, which is obviously due to the relatively small surface area of the membrane.

Horizon

We also included the *Hydrocar* from Horizon Fuel Cell Technologies in our test. This kit is similar to the Kosmos kit in terms of content, but the documentation is not nearly as extensive.



A few measurements

Naturally, the first thing we wanted to know about the fuel cells is how they actually performed in practice. For this reason, we made several measurements intended to clearly show the power and energy characteristics of the fuel cells at a glance. We connected the fuel cells to several different loads in order to obtain an idea of how much power they could supply.

Determining the efficiency is more difficult because it is necessary to know exactly how much energy in total is used to generate the hydrogen. However, some of the kits specify that both reservoirs (oxygen and hydrogen) must be completely full in order to obtain maximum power. This results in the generation of more hydrogen than can be held in the hydrogen reservoir, so it bubbles out of the reservoir and is lost. Consequently, the energy that is used can never be fully recovered, which makes the efficiency appear worse than it actually is.

Figures 1a and **1b** show the output power of the kits versus time (during which the amount of fuel in the reservoir gradually decreases). Due to the low voltage generated by the cells, the loads have low resistance: $4\ \Omega$ for the first measurement and $1.2\ \Omega$ for the second measurement. With such low load resistances, cable resistance and contact resistance also become important factors. For instance, the measurements with a $1.2\text{-}\Omega$ load were actually made with a $1\text{-}\Omega$ load resistor; the remaining $0.2\ \Omega$ came from the cable and contact resistances.

With most of the cells, the output power remained fairly constant until it dropped abruptly when the fuel was used up. The cells from

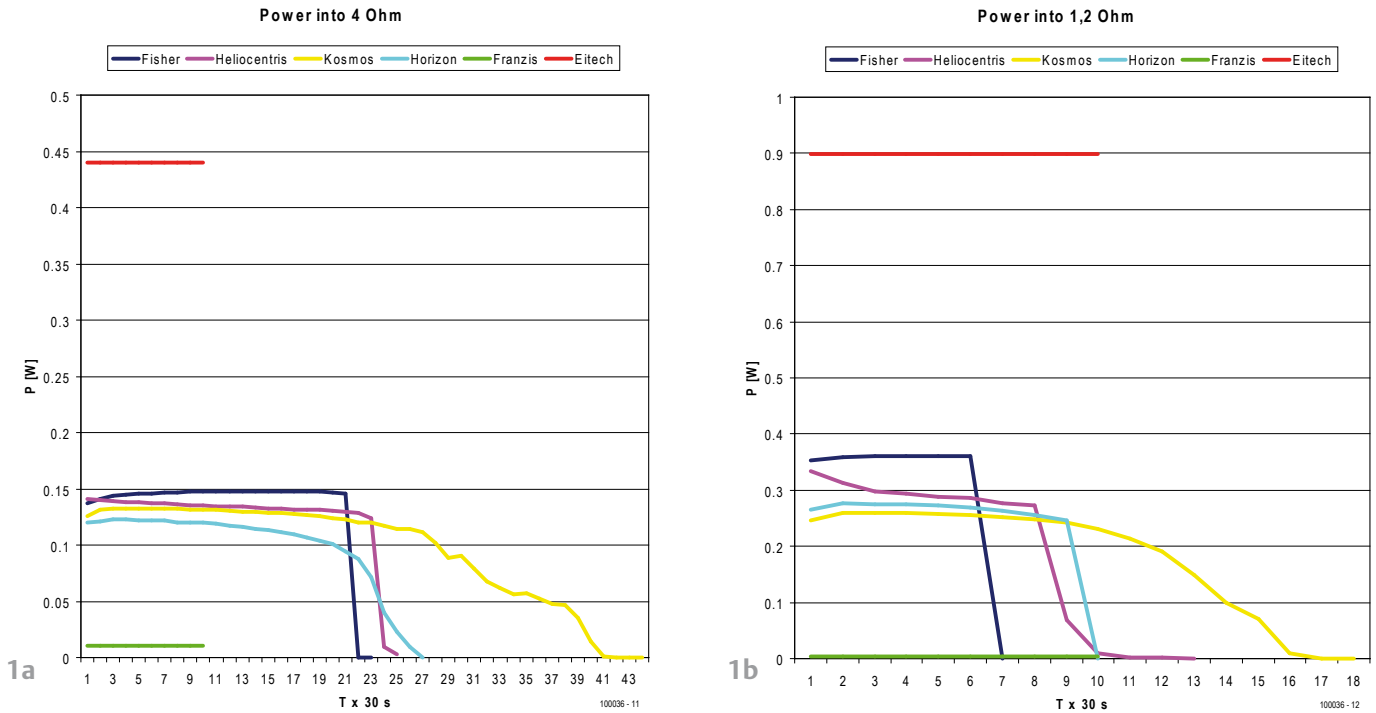
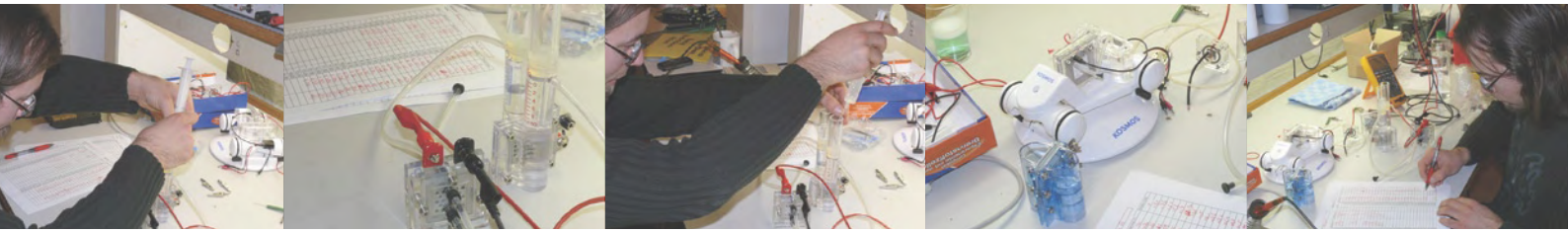


Figure 1a/1b. The output power of the fuel cells drops abruptly when the fuel supply is used up.

Eitech and Franzis were fuelled with hydrogen from the gas canister of the Eitech kit and therefore delivered a constant power level. Only the fuel cell in the Kosmos kit showed a slowly decreasing power level. This is probably related to the construction of the water reservoir and gas storage unit. The relative high power of the Eitech fuel cell is also remarkable — nearly three times as large as most of the other cells. With its two membranes, this fuel cell also has a considerably larger surface area. By contrast, the power output of the self-assembly fuel cell from Francis was rather low. Of course, this is partly due to the small surface area of the membrane, but it could also be partly due to the cell design intended for DIY assembly, which results in higher contact resistance and reduces the overall performance.

Figures 2a and 2b show the amount of energy used by the fuel cells for electrolysis (indicated as ‘U’) and the amount of energy generated by the fuel cells (indicated as ‘G’) with different loads (4 Ω and 1.2 Ω), combined in a single chart for each resistance value. Of course, this does not include the Eitech and Franzis fuel cells because they are not designed to generate hydrogen. Only the output energy is shown for these two fuel cells on the charts. The energy input was stopped when the reservoirs were full. Depending on the individual kit, the total energy input for fuel gen-

eration was 250 to 300 joules. The total energy output with a 4-ohm load ranged from 75 joules with the Horizon fuel cell to 123 joules with the Kosmos fuel cell, corresponding to an efficiency range of 27 to 40% (roughly speaking). This may not appear especially high, but it is actually not bad if you compare it with the efficiency of an internal combustion engine in a car (around 25%). The results are slightly worse with a 1.2-ohm load: 63 joules from the Heliocentris fuel cell and 90 joules from the Kosmos fuel cell, with corresponding efficiencies of 24 and 30%. These are still very acceptable figures.

Applications

The small fuel cells we tested generate enough power to meet the needs of ‘small’ applications with power consumption up to 0.5 W. The Eitech fuel cell can be used to power a respectable pocket torch (1 watt) if you use a suitable voltage converter. The gas canister is small enough to be portable and contains a reasonable amount of hydrogen. Unfortunately, a practical and commercially feasible solution to the problem of hydrogen storage is not yet available. However, Toshiba has already developed a methanol fuel cell [8] that is commercially available, so a solution for hydrogen should not be too far away. Research on hydrogen storage in special alloys that allow it to be stored at room temperature with approximately the same density as in liquid form is presently underway at full speed.

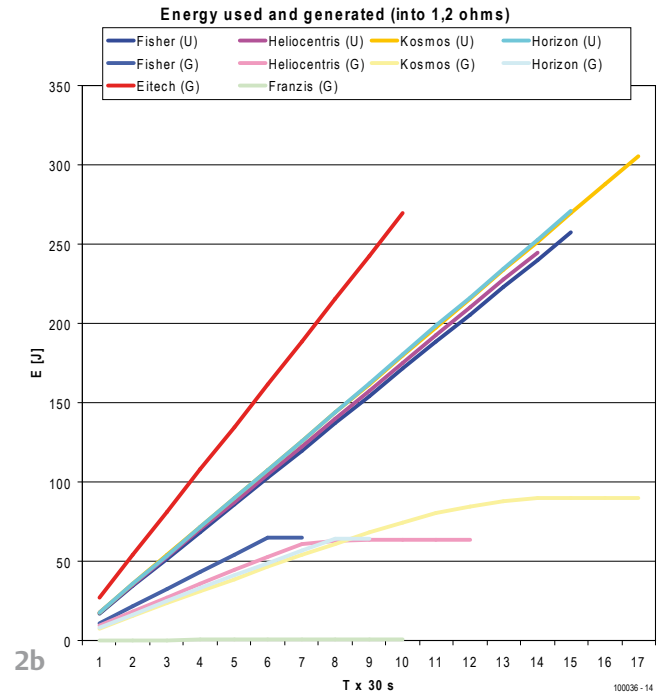
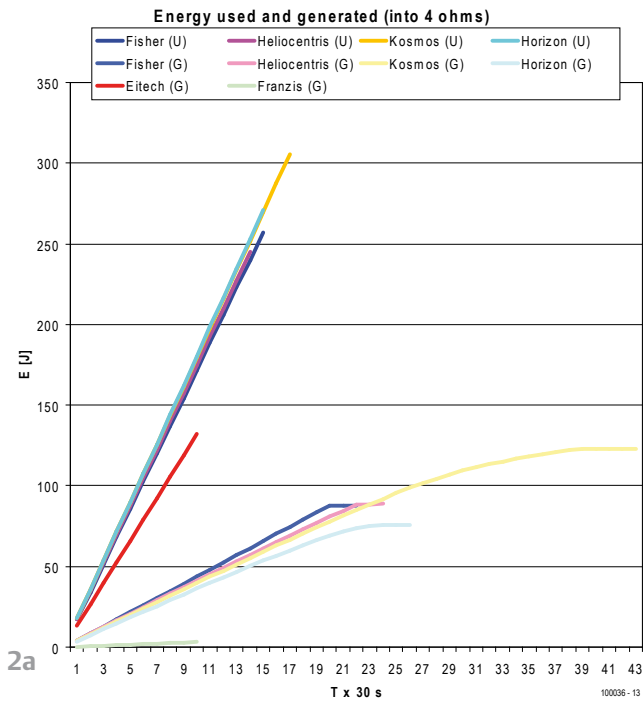
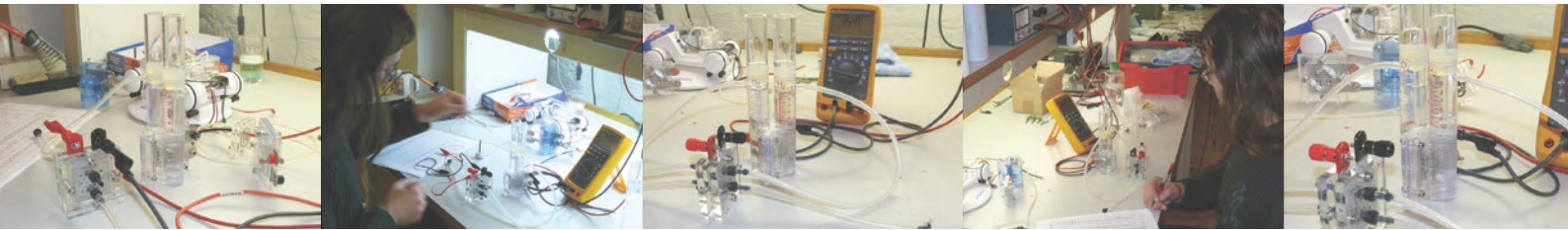


Figure 2a/2b. The total energy generated by the fuel cells is less than the amount of energy used to produce the hydrogen, but with a yield of around 30% for the overall process the efficiency of these simple cells is five percentage points better than the efficiency of a typical internal combustion engine.

Ready for the future?

Our test results show that you can achieve respectable efficiency with a relatively simple fuel cell. With the PEM fuel cells in our test, the process of converting energy (such as solar energy) into stored energy in the form of hydrogen and then generating power from the stored hydrogen yielded an overall efficiency of around 30%. This already a good deal better than the efficiency of typical internal combustion engines, even ignoring the energy necessary to produce the fossil fuel used by the internal combustion engine (the solar energy accumulated by plants millions of years ago, pumping the oil, refining the crude oil, transport and so on).

The lifetime of early fuel cells was not especially satisfactory. Nowadays this is not such a problem, although it varies considerably depending on the type of fuel cell. The lifetime of PEM fuel cells is now long enough for use in cars (including hybrid cars).

A more significant problem is hydrogen distribution (or hydrogen availability). Filling stations for conventional fuels are widely distributed, but stations where you can fill up with hydrogen and locations where hydrogen tanks can be delivered are few and far between. To give the 'society with water as a fuel' described by Jules Verne in his novel *The Secret Island* (1874) a chance to become reality, our infrastructure must be adapted to using hydrogen as a fuel. That's a tall order, but it doesn't seem impossible. The first hydrogen station for

home use is already on the market^[9].

The further course of these developments is something that only the future can tell. Nevertheless, the fact is that our fossil fuel resources are nearly exhausted and we must look for new options.

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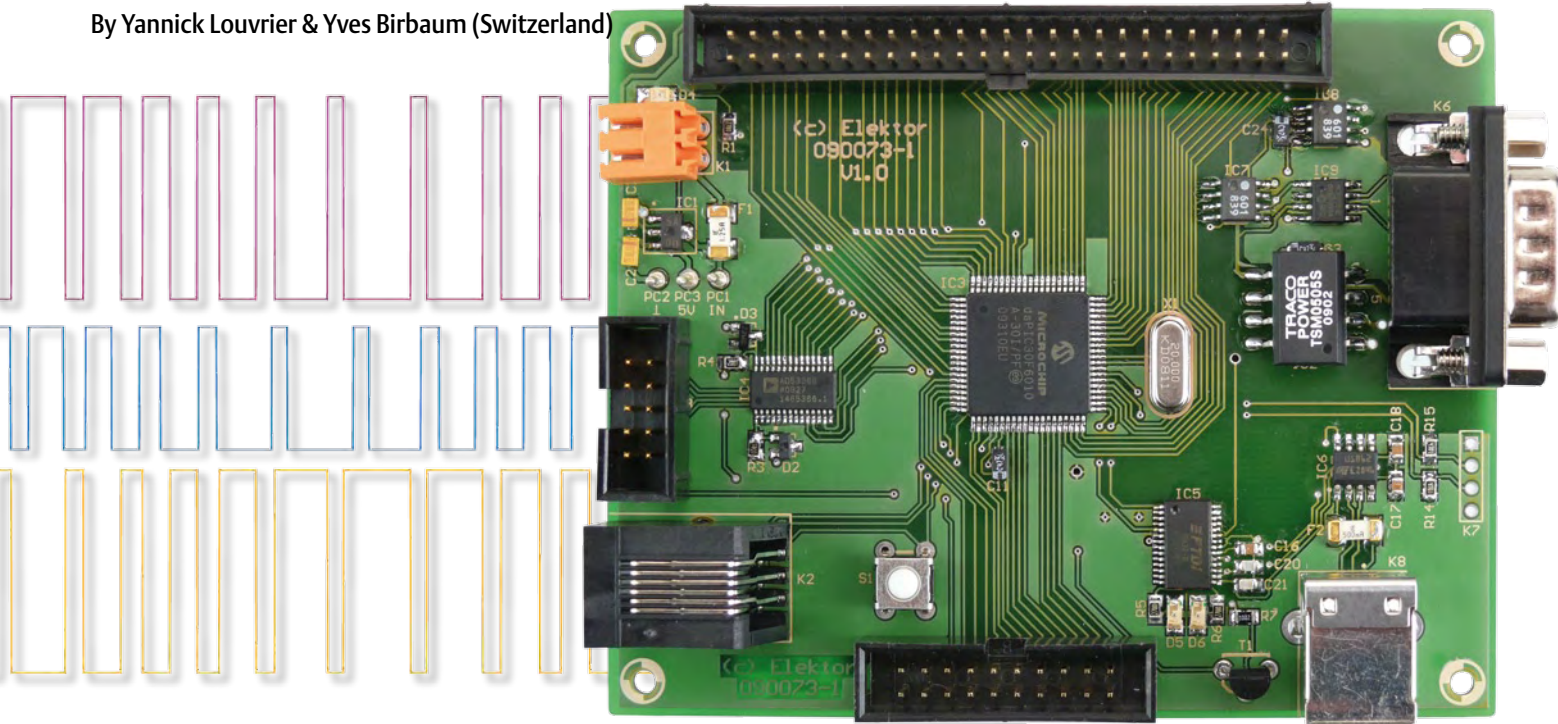
We wish to express our thanks to Eitech, Fischertechnik, Franzis, Heliocentris and Kosmos for providing the experiment kits.

Internet Links

- [1] http://en.wikipedia.org/wiki/World_energy_resources_and_consumption
- [2] http://en.wikipedia.org/wiki/Fuel_cell
- [3] www.fischertechnik.com
- [4] www.heliocentris.com
- [5] www.eitech.de
- [6] www.kosmos.de
- [7] www.franzis.de
- [8] www.toshiba.co.jp/about/press/2009_10/pr2201.htm
- [9] www.horizonfuelcell.com/store/hydrofill.htm

dsPIC Control Board for industrial applications

By Yannick Louvrier & Yves Birbaum (Switzerland)



The control board shown in this article has been designed for incorporation into typical industrial electronics applications like controlling motors or adjustment of static up- or down-converters.

Technical specifications:

- universal dsPIC30 microcontroller board
- isolated CAN bus
- serial port via USB
- 14 analog inputs
- 8 PWM outputs
- I²C bus

The objectives were to obtain a board with a large number of pulsewidth modulation (PWM) generators, which enables us to control several motors and static converters at the same time. The cost of the control board needed to be as low as possible too. In addition, it must be possible to construct the board using a soldering iron, without requiring use of a reflow oven. On this basis, it was logical for us to turn to the range of

dedicated motor control micro-controllers offered by Microchip. Out of the range of devices on offer, our attention was drawn by the dsPIC30F series. This series of 16-bit hybrid microcontroller-DSP devices is capable of performing up to 30 MIPS and has a 40-bit register, thus allowing overflow detection along with the possibility of performing 16×16 multiplications and 32×16 and 16×16 divisions, making it very interesting in adjustment applications. To take advantage of maximum flexibility in this series of devices, we picked the dsPIC30F6010A microcontroller [2]. This microcontroller has 68 input/output ports and allows up to eight PWM signals to be generated. This characteristic meets our specifications perfectly, especially since it has a 144 KB flash

memory, allowing relatively complex applications to be controlled.

In addition to all these qualities, the dsPIC30F6010A also has a 16-bit A/D converter, eight output compare outputs, eight input capture inputs, two UARTs, two SPI ports, two I²C ports, two CAN controllers, and five counters.

There is plenty of free documentation about this device, with numerous examples and applications.

Another advantage is the MPLAB programming environment, which can be downloaded free from the Microchip website [3] — but is unfortunately only available for Windows. However, even though this programming environment can be a bit laborious when applications are relatively com-

plex, it does have the merit of offering lots of features, like the possibility of simulating code and controlling the time needed to execute each instruction. Although these tools aren't really essential for expert users, they do make learning to program PIC microcontrollers more fun.

The block diagram of the control board is shown in **Figure 1**. A 50-pin connector gives access to the microcontroller's 43 configurable pins, including the PWM modules, output compare, and input capture. This connector also carries the connections for the incremental detectors, allowing direct access to one of the dsPIC's counters. This port can also be used for expansion purposes.

This board designed for controlling systems of greater or lesser complexity needs to allow us to measure the dimensions to be adjusted. So 14 analog values between 0 and 5 V can be read via a 20-pin connector. In addition to the analog and digital ports, this board has a lot of communication peripherals. It has a CAN field bus, a UART connection via USB, and an I²C connection. The board uses SMD components so as to keep it as small as possible – 80 × 100 mm on a double-sided PCB. However, the board is not difficult to build, with the help of a good soldering iron.

The board in detail

After a generic explanation of the functions implemented on this control board, we must explain in more detail the hardware used and the board's various features. It goes without saying that readers should refer back to the dsPIC30F6010A documentation available from the Microchip website. The circuit diagram of the board is shown in **Figure 2**.

The big connector K5 makes it possible to utilise lots of the microcontroller's functions. It offers access to:

- port A, which, in addition to the digital input/output functions, also lets us define the analog voltage levels for the A/D converter. It offers two external interrupt inputs (INT).
- pins RC13 and RC14 of port C, which

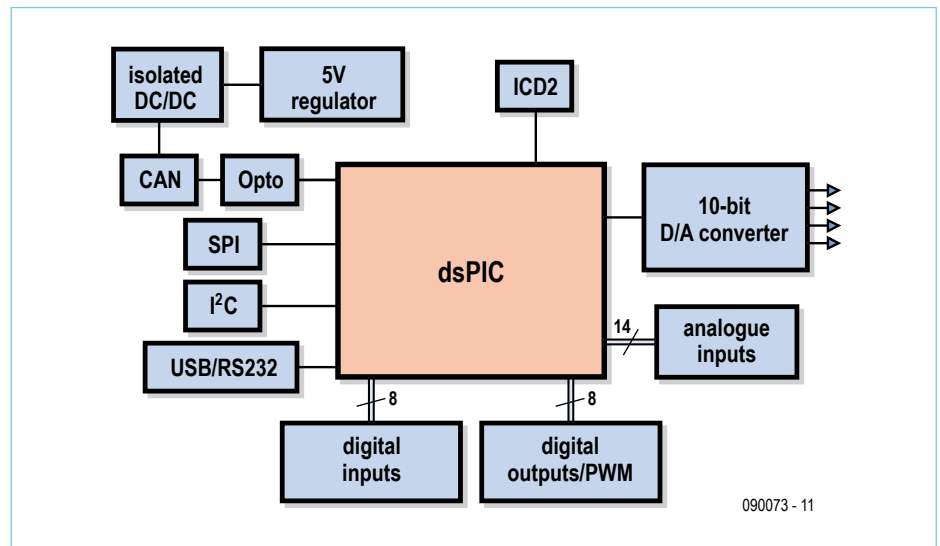


Figure 1. Block diagram of the dsPIC control board.

make it possible to configure the second channel of the ICD (In-Circuit Debugger), as well as to implement an external timebase for a real-time clock.

- port D, which has 8 input capture modules and 8 output compare modules. This register also allows programming of seven interrupts and access to the ICD's third channel.
- port E, which lets us generate 8 PWM signals. This port also offers two external interrupt inputs.
- ports RF4–RF8, which bring together the SPI1, UART2, and ICD channel 4 functions, as well as two possibilities for external interrupts.
- ports RG0, RG1, RG6–RG8 which make it possible to use the CAN2 controller, the SPI2 link, and three sources of external interrupts.
- the MCLR pin, which allows the microcontroller to be reset.

Connector K4 is assigned to measuring analog signals, and so is connected to microcontroller pins RB2–RB15, allowing 14 analog signals to be measured.

The 4-channel, 10-bit digital/analog converter used is an AD5336 (IC4). The digital value to be converted is transferred via ports RE0–RE9. For the conversion to take place, the function has to be enabled by

the microcontroller by way of pin RF4. The four analog outputs are addressed by way of microcontroller pins RC1 and RC3.

The microcontroller's built-in CAN1 controller is used for communicating with the microcontroller via the CAN field bus. In order to avoid the control board's being destroyed by possible voltage surges on the line, it was decided to equip the interface with an isolated 5 V PSU (IC2) and two optoisolators in addition to the transceiver IC9. Two pull-up resistors are all it takes to implement the I²C bus. The resistor value will change, depending on the bus speed you want to achieve. The resistor value fitted to the board is 4.7 k Ω , allowing a theoretical transmission speed of 100 kbit/s.

In order to improve the control board's connectivity and so make it easier to use, an FT232RL chip (IC5) from FTDI has been used to allow it to be connected via a computer USB port. Together with the driver [4], this IC has the effect of adding a virtual serial port when connected to the computer. This function thus allows the user to communicate via the USB port as if it was an RS-232 link.

The board is powered from a DC supply of 5–55 V, thereby affording an opportunity to recycle an old mobile telephone charger. In our case, we used a Nokia charger that provides a 5 V supply at a current of 890 mA.

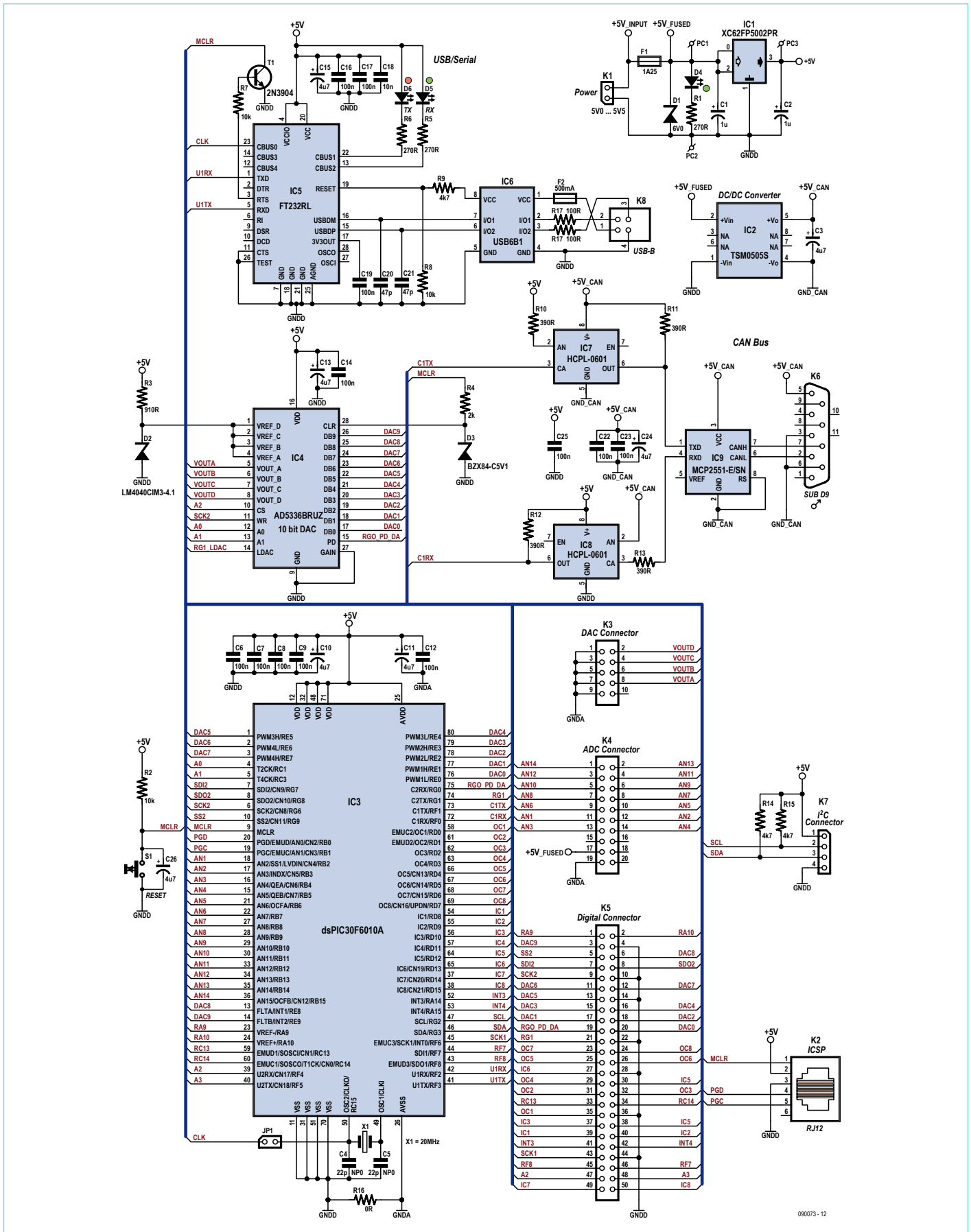


Figure 2. Circuit diagram of the dsPIC microcontroller-based board.

COMPONENT LIST

Resistors

(1%, 250 mW, SMD 0805 unless indicated otherwise)

R1,R5,R6 = 270Ω
 R2,R7,R8 = 10kΩ
 R3 = 910Ω
 R4 = 2.0kΩ
 R9,R14,R15 = 4.7kΩ
 R10–R13 = 390Ω
 R16 = 0Ω, 1%, 125mW, SMD 0805
 R17,R18 = 100Ω

Capacitors

C1,C2 = 1μF 16V, tantalum, case 'A'
 C3,C10,C11,C13,C15,C24,C26 = 4.7μF 16V, tantalum, case 'A'
 C4,C5 = 22pF, NP0, SMD 0805
 C6,C7,C8,C9,C12,C14,C16–19,C22,C23,C25 = 100nF, X7R, SMD 0805
 C20,C21 = 47pF, NP0, SMD 0805

Semiconductors

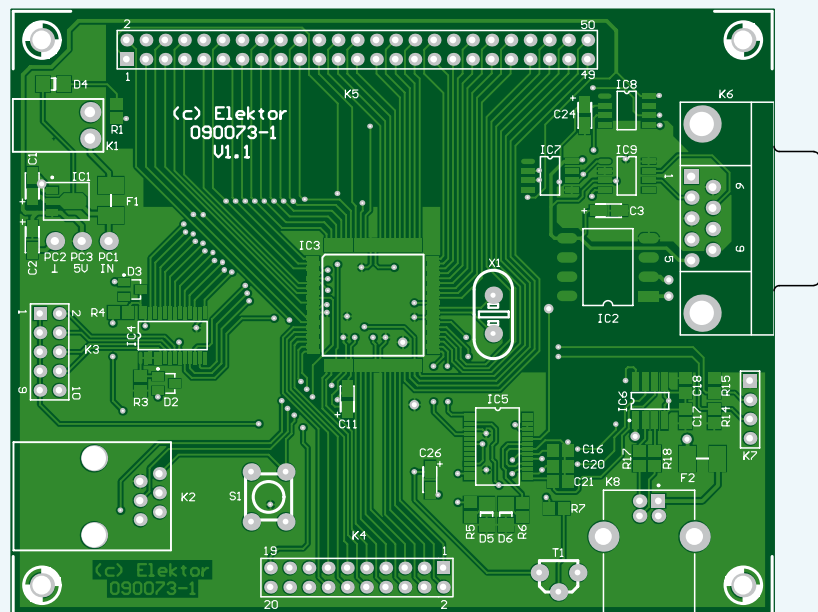
IC1 = XC62FP5002PR, SOT-89-3 (Torex)
 IC2 = TSM 05055 DC/DC converter 5V / 1W (Traco)
 IC3 = dsPIC30F6010A-30I/PF (Microchip)
 IC4 = AD5336BRUZ (Analog Devices)
 IC5 = FT232RL (FTDI)
 IC6 = USB6B1 (STMicroelectronics)
 IC7,IC8 = HCPL-0601 (Avago)
 IC9 = MCP2551-E/SN CAN (Microchip)
 D1 = Diode SMCJ6V0A (Fairchild Semiconductor)
 D2 = LM4040CIM3-4.1/NOPB (National Semiconductor)
 D3 = zener diode BZX84-C5V1 5.1V / 250mW, SOT23 (NXP)

D4, D5 = LED, green, SMD 1206 (e.g. Farnell # 1226371)
 D6 = LED, red, SMD 1206 (e.g. Farnell # 1318261)
 T1 = 2N3904BU (Fairchild Semiconductor)

Miscellaneous

K1 = 2-way boxheader, angled pins, lead pitch 3.5mm, Weidmuller type SL 3.5/2/90G with mating 2-way connector, Weidmuller type BL 3.5/2
 K2 = RJ12 socket (e.g. Farnell # 3938359)
 K3 = 10-pin (2x5) pinheader
 K4 = 20-pin (2x10) boxheader, 3M type N2520-6002-RB

K5 = 50-pin (2x25) boxheader, 3M type N2550-6002-RB
 K6 = 9-way sub-D plug (male) (e.g. Farnell # 1097063)
 K7 = 4-pin pinheader, lead pitch 2.54mm
 K8 = USB-B connector (e.g. Farnell # 1308876)
 F1 = fuse, 1.25A 125V, fast, SMD, e.g. Farnell # 1596473)
 F2 = fuse, 500mA, fast, SMD, (e.g. Farnell # 9922156)
 S1 = pushbutton, SPNO (e.g. Farnell # 1555982)
 X1 = 20.000MHz quartz crystal, HC-49US PCB # 090073-1, see [1]



Programming and start-up

The board is programmed using the MPLAB development software [3]. For the 16-bit range of microcontrollers, programming is done in ASM30 assembler directly available in MPLAB. For programming in C, the C30 compiler too can be downloaded from the Microchip website.

First-time start-up requires a compatible programmer that will let you load the bootloader into the microcontroller. In our case, programming is performed using the ICD2 programmer [5] and the MPLAB programming environment. However, you can also use another compatible programmer. If everything goes according to plan, the programmer is only required once, then the bootloader will be used for 'flashing' the microcontroller via the USB port. The Tiny PIC bootloader used has to be downloaded from the Claudiu Chiculita website [6]. A few modifications to the source file are needed to adapt it to the

dsPIC30F6010A microcontroller. The modified file has been renamed tinybld_ds6010.s and is available in the download from [1]. It's important to note that the microcontroller's configuration parameters in this file have to be adapted to suit your requirements. The bootloader is located at the end of the microcontroller's memory space, so take care not to overwrite it with an application that's too big.

The first time you use the bootloader, the driver needed for using IC5's virtual COM port must be installed on the computer. Once the drivers are installed, you still need to configure IC5 correctly, using the MPROG3.0 program provided by FTDI. Run the program and open the EEPROM-FTDI.ept file (available in the download from [1]). The parameters needed for IC5 to work correctly will be displayed (Figure 3). Program the chip with these parameters.

Once the bootloader has been programmed into the microcontroller and the FTDI IC has

been configured, the MPLAB software and programmer are no longer needed. From this point on, the microcontroller is programmed using the tinybldwin software (Figure 4 and [6]).

To put the microcontroller into bootloader mode, the reset mode has to be activated. To do this, an NPN bipolar transistor controlled by IC5's RTS signal forces the microcontroller's MCLR to zero. For this to work, the RTS command needs to be enabled in the tinybldwin program options. The transfer speed must be set to 19200 baud/s and the virtual 'comX' port must be selected. Pressing the 'Check PIC' button allows you to check the communication between the microcontroller and the computer.

To program the microcontroller, load the HEX file required and click on "Write Flash". When the microcontroller is rebooted after the reset, the bootloader is loaded. It waits 500 ms to see if there is a request

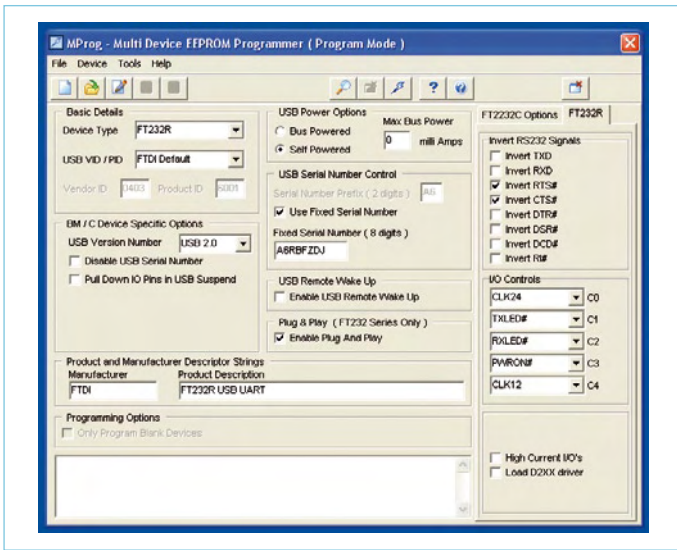


Figure 3. How to configure MPROG for programming IC5.

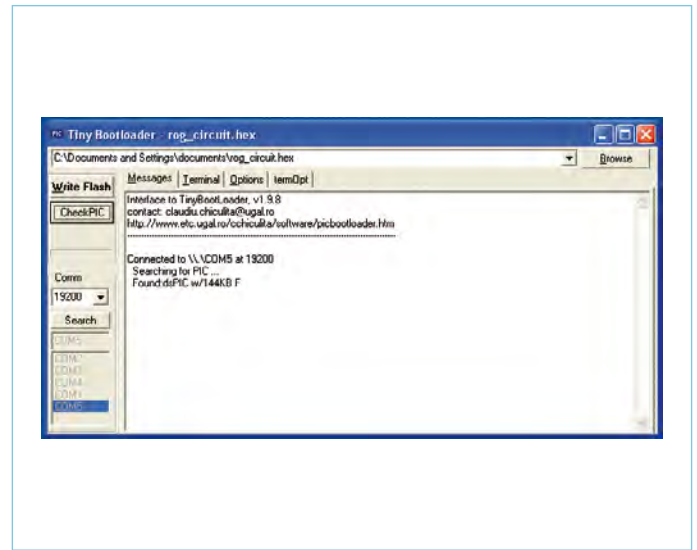


Figure 4. This program lets you load an application into a PIC microcontroller that's been pre-programmed with the Tiny PIC Bootloader program.

from the asynchronous RS-232 serial link. If yes, it goes into programming mode. If not, it runs the application stored in the microcontroller.

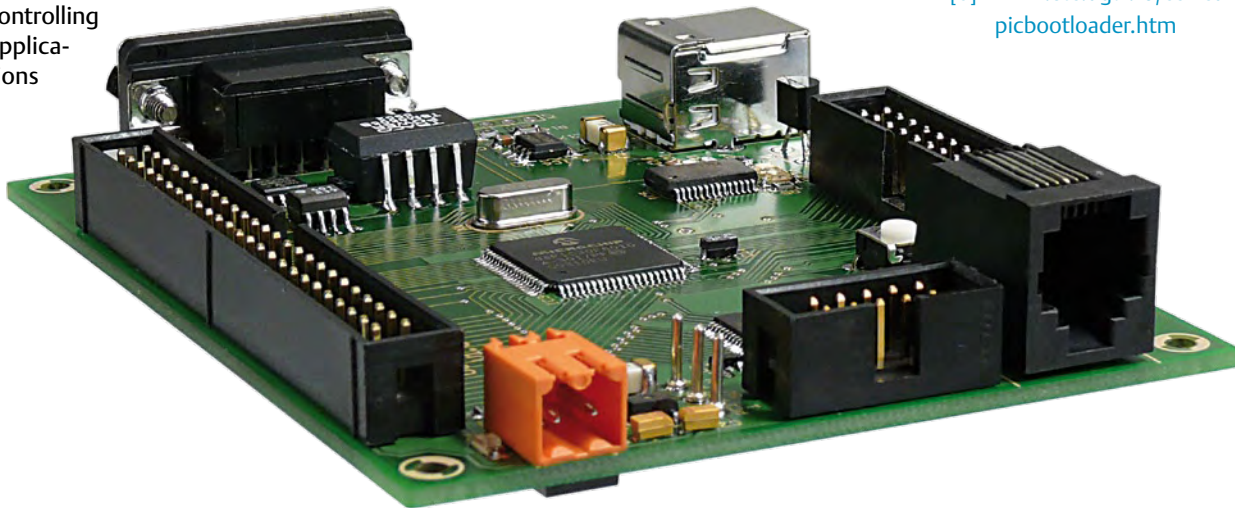
Once the board has been commissioned, you can make use of the possibilities it offers, and particularly the use of the DSP library provided by Microchip. This board dedicated to adjusting and controlling applications

needs to be able to carry out a few simple mathematical operations rapidly. To use these functions, the libdsp-coff.a library must be added to the project's other libraries (Library Files). This file can be found (probably, depending on your installation) in C:\Program Files\Microchip\MPLAB C30\lib\libdsp-coff.a

(090073-1)

Internet links

- [1] www.elektor.com/090073
- [2] ww1.microchip.com/downloads/en/DeviceDoc/70150D.pdf
- [3] www.microchip.com/mplab
- [4] www.ftdichip.com/FTDrivers.htm
- [5] www.microchip.com/icd2
- [6] www.etc.ugal.ro/cchiculita/software/picbootloader.htm



Fixed-point fractional numbers

For its library, and for the fast calculation application based on 16-bit registers, Microchip uses fixed-point fractionals coded using "1.15" notation, which makes it possible to represent numbers between -1 and $1 - 2^{-15}$ (0.999969482). Thus -1 is represented by 0xFFFF and $1 - 2^{-15}$ by 0x7FFF; hence the value 0x0001 corresponds to $2^{-15} = 1/32768$. The advantage of this coding is that it avoids overflow problems during multiplications, since the result of multiplying any numbers between -1 and $1 - 2^{-15}$ also lies between -1 and $1 - 2^{-15}$ (except for -1×-1). Two decimal fractions can be multiplied rapidly by applying the mpy function from the DSP library.

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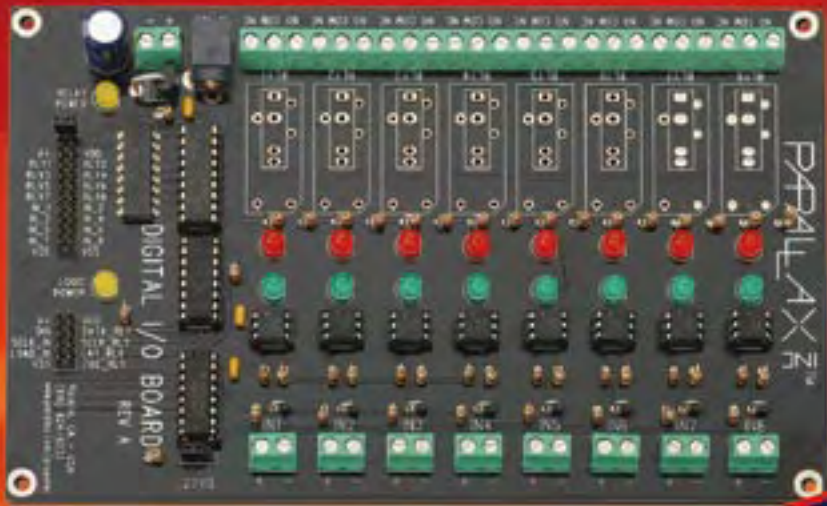
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<p>RF Modules</p>  <p>RF TX/RX Modules - simultaneously transmit composite video and stereo audio signals. 2.4 GHz ISM band. 4-ch RF, 5V operation.</p> <p>AWM630TX \$16 AWM634RX \$27</p>	<p>XP Emb Touchpanel</p>  <p>Touch-input 10.2" LCD 12V-powered Windows PC. LX800/512MB/4GB/Ethernet/3xUSB/SD.</p> <p>CUPC-80 \$849</p>	<p>Pen Scopes</p>  <p>High-perf USB 2.0 scope-in-a-probe! Up to 100MS/s, 10/25MHz 24kS buffer. +/-100mV to +/-20V. 20ns/div-50s/div C/VB/Delphi/LabView/VEE drivers.</p> <p>PS2104 / PS2105 \$193 / 280</p>	<p>RF Testing/EMI Tents</p>  <p>Economical, portable RF test enclosures, for initial compliance testing.</p> <p>Shielding Tents with external frame, instant up/down for emissions-free room.</p> <p>from \$1295 from \$3500</p>	<p>I started Saelig as an engineer - for engineers! Saelig is an olde English word means 'happy, prosperous, blessed'</p> <p>Check our website for lots of neat stuff!</p> <p>Alan Lowne • Saelig CEO</p> 

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Solar Thermal Energy Regulator

maximum power point tracking explored



By Yves Birbaum (Switzerland)

The aim of this project is to carry out regulation for thermal solar power installations. The unit shown here is useful for regulating installations comprising several sets of solar collectors with different orientations or configurations with several hot-water storage tanks, requiring several valves and pumps to be controlled.

The solar energy regulator board has been designed so it can be used as a universal control board

Commercial solar power regulators can handle one or two solar heat exchange arrays commonly known as collectors (**Figure 1**), but are not suitable for special configurations that comprise, for example, three collector arrays and two hot-water stor-

age tanks (immersion tanks) for the heating, including circulation between the two tanks. The regulation system given here is intended for solar power installations that are complex because of the number of solar collector arrays they have, or installa-

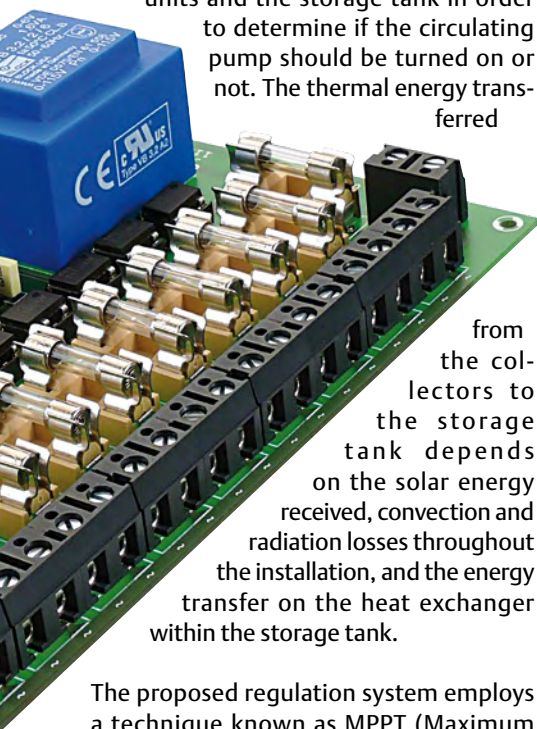
tions that have been added on to an existing system designed to provide heating and/or domestic hot water for the home. It allows energy conscious home owners to maximize use of the stored solar energy and avoids an immersion heater or heating burner turning

Technical specifications

- universal control board
- 10 outputs
230 VAC @ 1.2 A / 120 VAC @ 2.5 A
- 10 binary input/outputs (5 V),
- standard LCD display interface
- 5 pushbuttons
- digital potentiometer

on while there is still enough energy in the installation.

Regulators for solar power installations are based on the temperature difference between the roof mounted heat exchange units and the storage tank in order to determine if the circulating pump should be turned on or not. The thermal energy transferred



from the collectors to the storage tank depends on the solar energy received, convection and radiation losses throughout the installation, and the energy transfer on the heat exchanger within the storage tank.

The proposed regulation system employs a technique known as MPPT (Maximum Power Point Tracking). This enables the solar installation being controlled to always operate at the point where maximum power is being transferred to the storage tank, which is achieved by adjusting the flow rate so that the temperature at the storage tank corresponds to the best possible heat transfer through the heat exchanger. To be able to control the system in this way, we need to know the temperature of the storage tank and the solar collectors, the temperature difference of the heat transfer fluid between storage tank inlet and outlet, and the flow rate.

The energy transferred to the storage tank is the product of the fluid flow rate in kg/s, the specific heat capacity, and the heat transfer fluid temperature difference between the hot inlet and the cold outlet. The regulator will control the operating point by looking for the maximum instantaneous

power supplied to the storage tank. In the current installation, the flow rate is adjusted by diverting part of the flow directly back from the pump outlet to its inlet, using a 3-way valve.

Hardware

The heart of this regulator is a board based around a dsPIC microcontroller from Microchip, described elsewhere in this issue. A simple microcontroller would have done just as well, as this application doesn't use any calculations requiring a DSP, but as the dsPIC is very reasonably priced and the dsPIC board developed is the basic platform for several projects, we decided to use it for

controlling our solar power regulator. The solar regulation board has been designed so it can be used as a universal control board, with ten binary inputs/outputs (0 or 5 V), a display with four lines of 20 characters, five switches for choosing functions or menus, and ten AC power outputs. The circuit diagram of the board is shown in Figure 2.

The AC power outputs (230 VAC or 120 VAC) are fitted with Panasonic AQH3213 solid-state relays which incorporate an opto-isolator and a triac. These devices allow you to switch AC powered loads with a current of 1.2 A from a dsPIC board output via a 7406

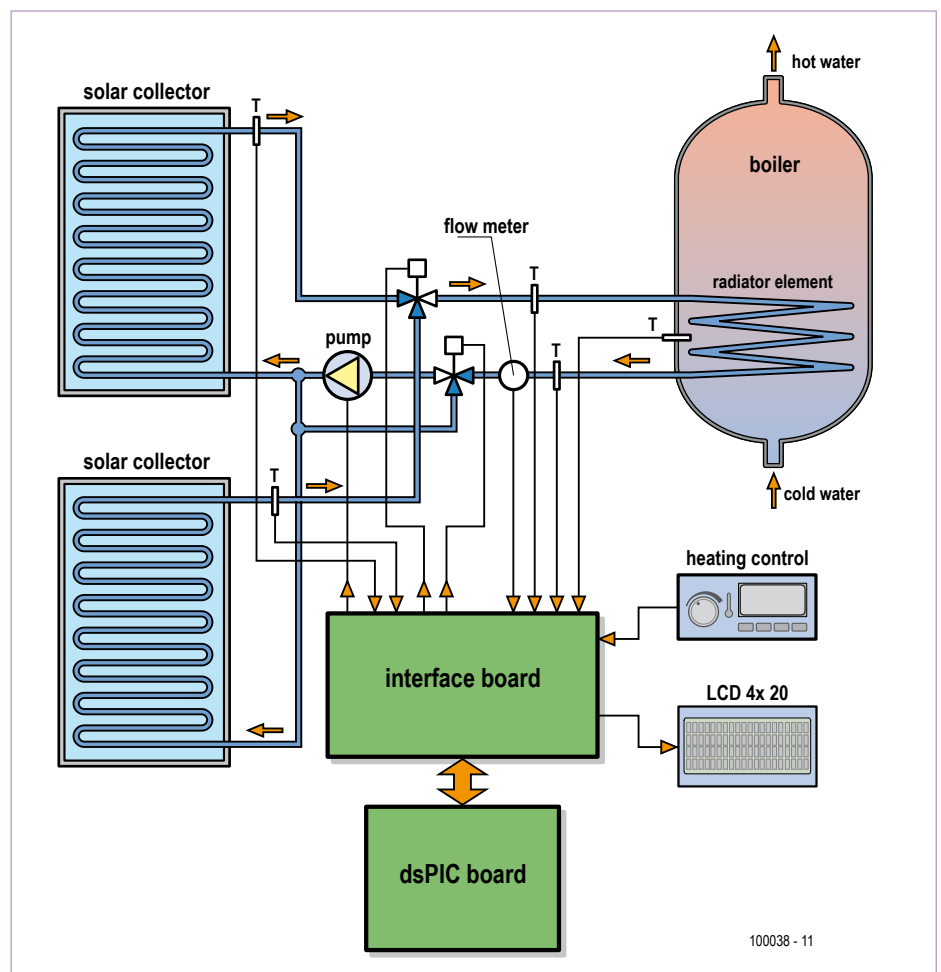


Figure 1. A thermal solar energy system using two solar collector arrays. The solar regulator has been designed for managing even more complex systems.

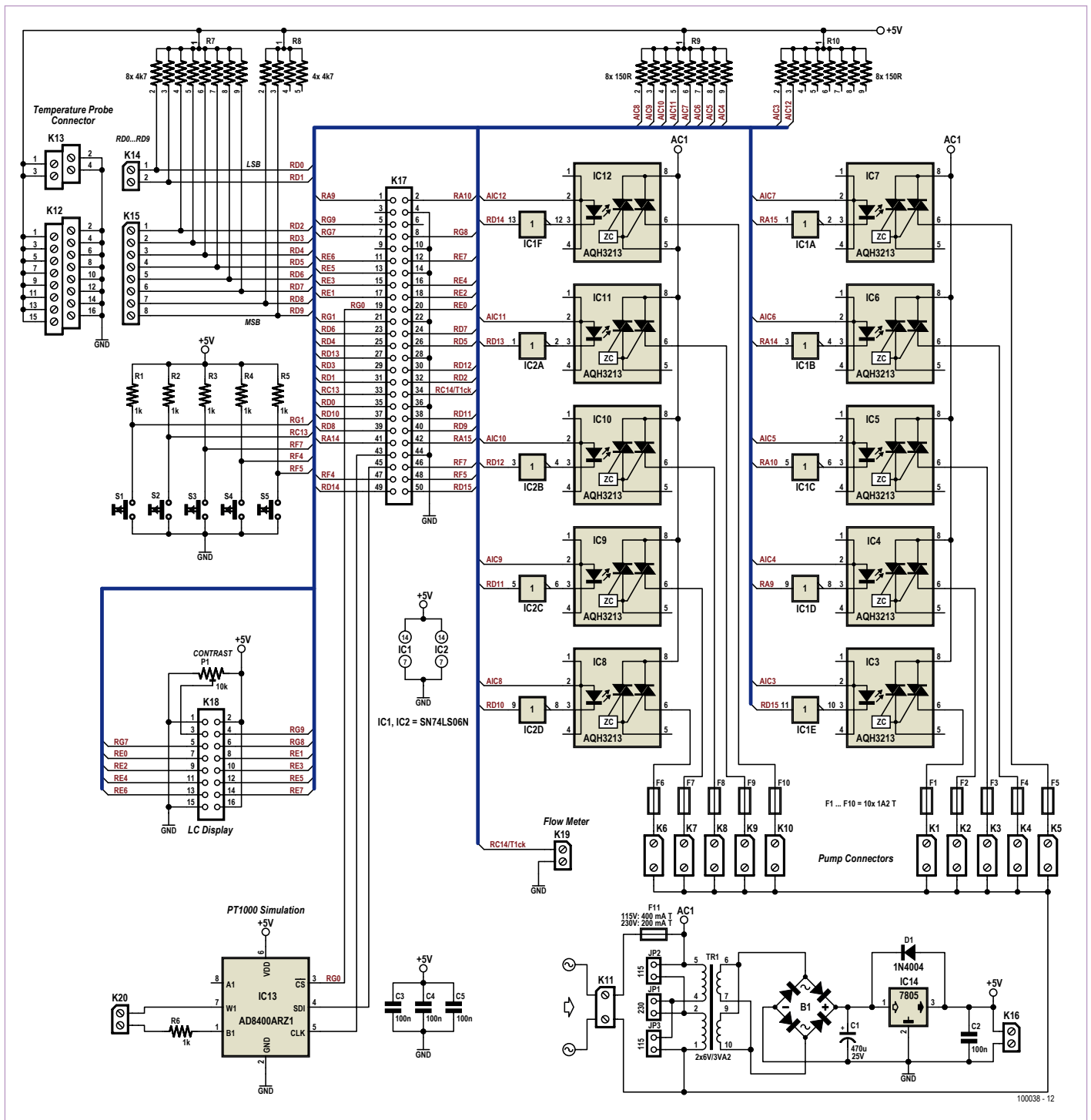


Figure 2. This project aims to be a board that can be used in many applications that require digital I/Os and controls for devices working off the AC grid. Regulating a solar energy system is only one possible application for this board.

open-collector buffer, which is able to supply the current needed to drive the optoisolator. Using the type chosen, load switching occurs at zero-crossings of the AC line voltage. All the AC power outputs are protected by 1.2 A fuses (use 2.5 A for 120 VAC grid and loads).

The flow-rate sensor chosen is a 150175 from Conrad Electronics^[2]; it provides 80 pulses per litre and can operate at flow rates from 0.5 to 50 l/min. The pulse input from the flow meter is fed to the microcontroller's RC14/T1CK digital input, allowing you to couple this input

directly to an internal counter. The temperature sensors used are type DS1821 from Maxim/Dallas. These are 1-Wire interface sensors which provide an 8-bit digital value for temperatures between -55 and +125 °C. Solid-state temperature sensors may seem an unsuitable choice for a

COMPONENT LIST

Resistors

R1-R5 = 1k Ω 1% 250mW SMD0805
 R6 = 1k Ω 5% 250mW
 R8 = 4.7k Ω 4-element SIL resistor array
 R7 = 4.7k Ω 8-element SIL resistor array
 R9, R10 = 150 Ω 8-element SIL resistor array

Capacitors

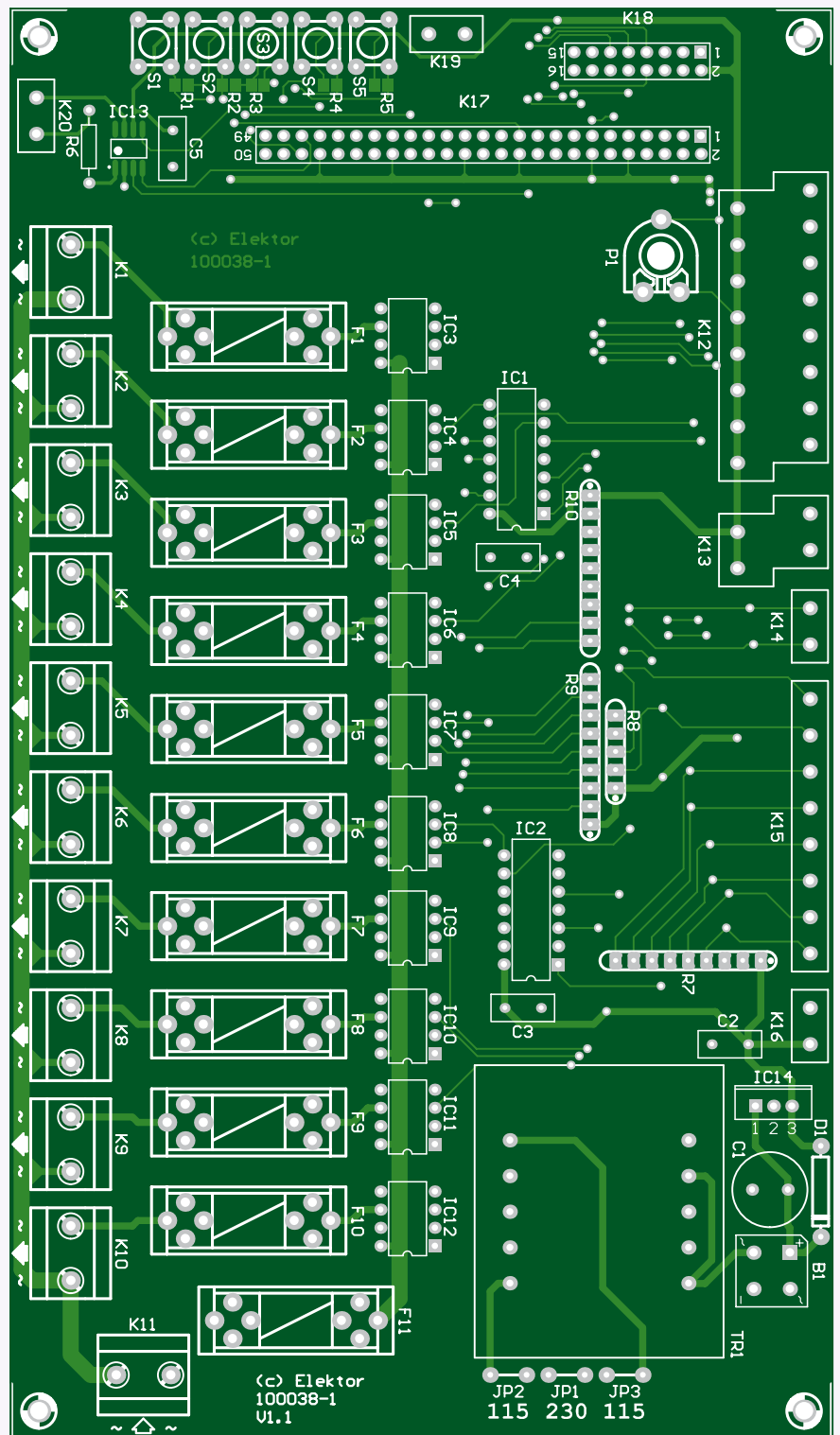
C1 = 470 μ F 25V, radial electrolytic, 10mm diam.
 C2-C5 = 100nF, 5mm lead pitch

Semiconductors

IC1, IC2 = SN74LS06N (Texas Instruments or equivalent)
 IC3-IC12 = AQH3213 solid state relay (Panasonic)
 IC13 = AD8400ARZ1 (Analog Devices)
 IC14 = 7805
 B1 = 1KAB10EPBF bridge rectifier (Vishay), 1.2A, 100Vpiv
 D1 = 1N4004

Miscellaneous

F11 = fuse, 200mA 250V (400mA, 120V), slow blow, 5x20mm
 F1-F10 = fuse, 1.2A 250V, (2.5 A, 120 V) slow blow, 5x20mm
 K1-K11 = PCB terminal block, lead pitch 7.5mm
 K12 = 4-way 2-level receptacle type MKKDSN 1,5/8-5,08 (Phoenix Contact)
 K13 = 2-way 2-level receptacle type MKKDSN 1,5/2-5,08 (Phoenix Contact)
 K14, K16, K19, K20 = 2-way PCB terminal block, lead pitch 5.08mm (e.g. Farnell # 3041440)
 K15 = 8-way PCB terminal, lead pitch 5.08mm (0.2 in.) (e.g. Farnell # 3041517)
 K17 = 50-way connector type N2550-6002-RB (3M)
 LCD1 = alphanumeric, 4 lines of 20 characters (Elektor # 050176-73)
 P1 = 10k Ω preset, horizontal
 S1-S5 = pushbutton, SPNO
 TR1 = 2x6V 3.2VA power transformer (Farnell # 1131487)
 11 holders for 5x20mm size fuses (e.g. Farnell # 146123)
 10 IC sockets type DIL-8
 2 IC sockets type DIL-14
 PCB # 100038-1, see [1]



solar power installation, as the sensor temperature may exceed 200 °C in the event of heat transfer fluid circulation stopping while the sun is shining. However, this type of sensor is suitable for installations where the circulating pump runs continuously when the sun is out. To avoid excessive domestic hot

water temperature, we need to provide a discharge radiator or to use the excess solar energy to heat a swimming pool, which is the solution usually used.

The advantage of this temperature sensor is the digital interface, which can be con-

nected directly to any microcontroller port. The 1-Wire protocol defines minimum and maximum times for holding the microcontroller output at 0 for the sensor to interpret it as a 1 or a 0. The microcontroller is in charge of the communication, it sends a temperature read request, and the sen-

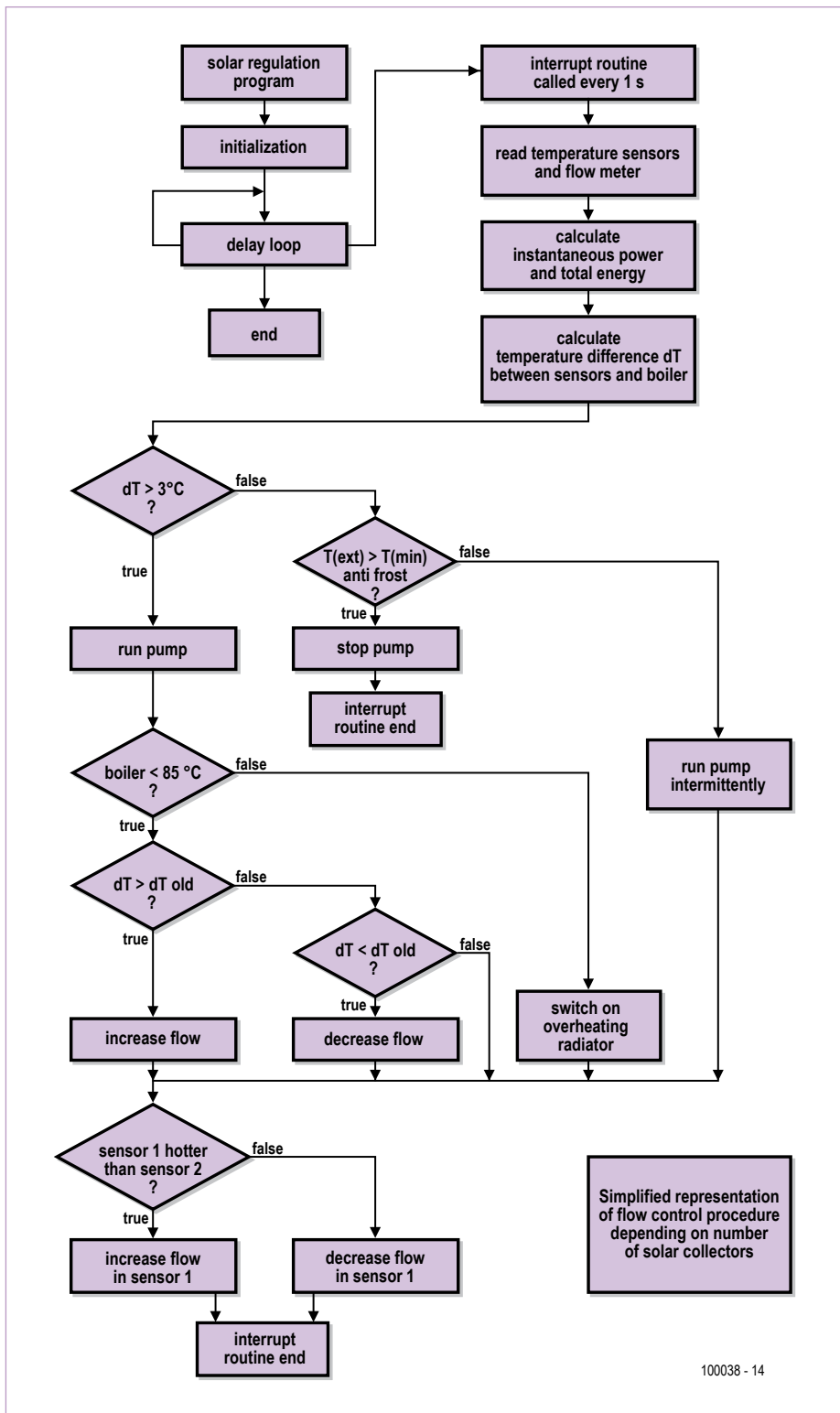


Figure 3. The flow diagram for the software that drives the solar energy regulator board.

sensor sends the serial values at the microcontroller's own pace. It takes the line briefly to 0 for each request for the next bit. 1-Wire communication lets you wire up the temperature probes easily using 3-core cable: 0 V, +5 V, and data. The sensor pull-ups are

the 4.7 kΩ resistors recommended by the manufacturer. However, for communication distances over 15 m, it may prove necessary to reduce the value of this resistor to around 2 kΩ so as to ensure a signal waveform that can be interpreted correctly.

An AD8400 digital potentiometer from Analog Devices (IC13) lets you simulate a PT1000 temperature probe. This output is used where the boiler regulator allows control of a simple solar installation but the complexity of the installation requires a separate regulator for the solar system. The AD8400 connected to the heating system regulator lets you simulate the temperature of the solar collectors and in this way avoid the boiler's starting up when the sun is out.

The dsPIC board used for controlling this solar regulator includes a 20-pin connector wired to the microcontroller's analog inputs. These inputs can be used if you want to use standard analog sensors, via a circuit for shaping the output signals from the chosen temperature probes.

The regulator measures the temperature of three solar collector arrays, the temperature of the top and bottom of the storage tank (immersion tank), the incoming hot heat transfer fluid from the collectors and the returning cold heat transfer fluid at the storage tank outlet, and the outdoor temperature. The outdoor temperature measurement enables you to avoid the heat transfer fluid's freezing in conditions of extreme cold below usual winter temperatures and there is no sun. When the temperature drops below the rated temperature for the water/antifreeze mixture, the circulating pump cycles (10 s on, 30 s off) in order to avoid the heat transfer fluid's solidifying in the piping, which would impair proper operation of the installation once the sun returns.

The 4-line, 20-character display lets you read the various temperatures of the sensors, storage tank, and heat transfer fluid, and the outdoor temperature. The flow-rate and the instantaneous energy being supplied by the solar collectors are displayed, and the total power supplied to the storage tank by the solar collectors is recorded.

The five switches let you select the operating mode for the regulator. The modes implemented are:

- automatic mode;
- discharge radiator / swimming pool mode, which operates the valve to bring

the corresponding section of the installation into operation;

- circulator mode, which runs the circulating pump for 30 s to check it is working properly.

In automatic mode, the circuit goes into swimming pool mode when the immersion tank temperature exceeds 85 °C, and the heat transfer fluid circuit is diverted via a 3-way valve to a heat-exchanger connected to the swimming pool water circuit. The swimming-pool mode enables you to heat the swimming pool even when the immersion tank temperature is below 85 °C.

Power for the system (the dsPIC board, the opto-isolators for the AC power outputs, the display, and the temperature probes) is provided by a conventional supply comprising

other is in shadow. A third probe checks the temperature of the solar collector on the west roof.

The program sequence (**Figure 3**) starts by initializing the microcontroller and variables. The main program is implemented in the interrupt generated by timer2. The initialization function has been designed in such a way as to be able to configure the microcontroller easily depending on the desired application. It lets you configure the I/Os, counters, interrupts, and analog/digital conversions. The interrupt comprising the system adjustment section is called once a second: sun exposure parameters vary quite slowly, so more rapid control is unnecessary. Temperature measurements and the main checks are carried out once per second, flow-rate adjustment and valve setting is performed once every thirty seconds. This delay allows the system to reach

Increasing the flow-rate will reduce the solar collector temperature; maintaining a temperature of 5–10 °C between the collectors and the storage tank should keep system losses close to the minimum possible. This quest for the optimum is especially worthwhile during hazy sunshine. If the flow-rate is too high, the temperature in the solar collector drops below the value that causes the pump to run, and the heated fluid is cooled in the pipes. It is necessary to find the flow-rate that lets you maintain an adequate temperature with causing frequent stopping of the pump. In strong sunshine, the flow-rate will tend towards maximum.

The program includes detection of the maximum temperature of the immersion tank. If this temperature is reached, the valve that diverts the heat transfer fluid to the swimming pool heat-exchanger or overheating

The flow-rate is adjusted to achieve maximum energy transfer to the storage tank

a small 6 volts power transformer, followed by a diode bridge, a smoothing capacitor and a linear regulator.

Software

The program developed is intended for a solar energy installation with three solar collector arrays: two located on the flat roof of a south-facing carport, the third on the west side of the main house roof.

At sunrise, the solar collectors on the carport are illuminated, but from early afternoon, they are gradually obscured by the shadow of the house. In Summer, they get the sun again partly in late afternoon, as the sun reappears in the north-west behind the house. From mid-morning till sundown, the west-facing collectors on the roof are also illuminated. The collectors on the flat roof are connected in series, but two temperature probes have been positioned according to the exposure of the collectors to the sun, in order to avoid one part of the collector overheating while the

a new state of equilibrium after a change in the flow-rate or valve settings, before being able to carry out a fresh correction if necessary.

The interrupt program goes and reads the temperature values from each sensor, it reads the flow-rate, then it calculates the instantaneous power being supplied to the installation and integrates the total energy supplied to the installation.

The temperature differences between the solar collector arrays and the storage tank are calculated. If the temperature of an array is 3 °C higher than the storage tank, the circulating pump is started.

The 3-way valve routing the heat transfer fluid between the solar collectors on the flat roof and the west roof is controlled according to the temperature differences between the various collectors. The system always seeks to balance the temperatures of the solar collectors.

The flow-rate is adjusted to achieve maximum energy transfer to the storage tank.

radiator is operated. In this event, the heat transfer fluid no longer passes through the immersion tank.

This valve is also operated when there is no sun, thereby avoiding thermo-siphon circulation between the immersion tank and the solar collectors during the night.

The minimum temperature of the heat transfer fluid is compared with the outdoor temperature. If this drops below this value, the circulating pump is run intermittently, preventing freezing of the heat transfer fluid the circuit passes via the swimming pool heat exchanger or overheating radiator, and so does not have any cooling effect on the immersion tank.

(100038-1)

Internet Links

[1] www.elektor.com/100038

[2] www.conrad.fr/debitmetre_3_4_laiton_p_18925_18937_127855_127856

Worry-free Drilling

A practical test of pipe and wire locators



By Harry Baggen (Elektor Netherlands Editorial)

All too often when you're drilling holes in a wall, you hit an electrical conduit or (perhaps even worse) a water line, with the usual unpleasant consequences. A pipe and wire locator (called stud locator in the USA) can come in very handy for locating all sorts of things inside walls before you start drilling, including electrical wiring, pipes, and even joists or studs. We tested thirteen different models in the Elektor lab to see what they can (and can't) do and how deep they can find studs, joists, pipes and wiring inside walls.

Everyone who does home improvement jobs on a regular basis, either at home or in someone else's home, sooner or later encounters the problem that holes need to be drilled in a location where there's a good chance of encountering a water pipe or an electrical conduit. If you guess wrong, you suddenly get a blast of water in your face or the earth leakage circuit breaker trips. You can avoid these problems by first using a pipe and wire locator to check whether there are any metal pipes or live conductors in the portion of the wall where you want to drill. Locators of this sort are

also very handy for determining where wooden studs are located inside a wall, such as a wall sheathed with gypsum boards. A variety of manufacturers now have pipe and wire locators in their product lines, including major brands in the power tools world such as Black & Decker and Bosch as well as companies that specialize in this area, such as Zircon. Prices range from around 40 dollars to 200 dollars, depending on the model and the features. There are also professional pipe and wire locators priced at 1500 dollars or more, but they fall outside the scope of this survey.



Naturally, the main question when you're contemplating the purchase of a pipe and wire locator is: does it really work? What can this sort of instrument find, and how deep can it detect something in the wall? We were also curious about this. For this test, we asked several companies to provide us with various models of pipe and wire locators so we could see how well they perform in practice.

Operation

Most of these devices have several electrodes arranged close together for detecting pipes or studs inside walls (see the example in **Figure 1**). These electrodes act as the plates of a capacitor forming part of an oscillator circuit. The coupling between the plates, and thus the capacitance of the capacitor, depends on the type of material near the plates. If the dielectric constant of the material in

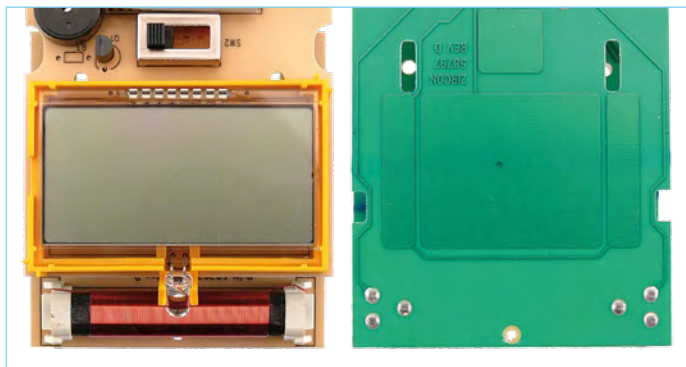


Figure 1. The sensor surfaces on the back of the PCB are readily visible in this opened-up pipe and wire locator. There is also a coil at the top for detecting metal pipes.

front of the capacitor plates changes, for example because there is a wooden stud inside the wall, the capacitance changes and with it the frequency or the signal level. This is indicated visually by a set of LEDs or an LCD screen. Some scanners use sinusoidal signals, while others emit short pulse, and there are a few instruments that utilise pulse trains. From measurements on several scanners, it appears that the measuring frequency is usually well above 10 kHz.

An additional sensor element in the form of a coil, possibly with a core, is often used for detecting metal pipes. This coil also forms part of an oscillator circuit. The coil responds to changes in the magnetic field, which in turn affect the oscillator frequency or the signal level. Most detectors operate with a measuring frequency of 100 kHz or more.

In addition, many instruments have an AC field indicator to indicate the presence of an AC line voltage. The 50-Hz or 60-Hz 'hum' emitted by power wiring can easily be picked up by a small surface antenna in the unit, which is usually already present in the form of the measuring electrodes. This signal can be amplified and used to drive an LED or a signal level meter.

Practical use

Almost all pipe and wire locators are used the same way in practice. First you hold the unit against the wall in a location where you are sure that there is nothing inside the wall, and then you switch it on. The pipe and wire locator performs a self-calibration procedure, which takes a few seconds. After this you slowly slide the unit over the wall, preferably without lifting it away from the wall, in the area where you want to drill or saw. When it approaches a stud or a pipe, an LED strip or a multi-segment display indicates that the composition of the wall has changed. Using this technique, it's perfectly possible to detect wooden joists and studs or iron and copper pipes up to a depth of several centimetres. PVC pipes are not detected unless they are relatively large, and ordinary PVC electrical conduits are almost never



Figure 2. The Bosch and Skil pipe and wire locators use a coil facing the wall for accurate detection of metal objects. The PCB tracks around the coil form the plates of a capacitive sensor for wood detection.

detected unless they have wiring inside, preferably live. Some of the pipe and wire locators we tested require you to hold a button pressed while you're scanning the wall. Although this prolongs the life of the batteries, it is sometimes not especially convenient, especially when you need to scan an area at the bottom of a wall or in a location that is not easily accessible. A more convenient solution is an instrument that switches on when you press a button and then switches off automatically a while later. This aspect is mentioned in the description of each scanner.

Another feature that can sometimes be annoying is the omnipresent beeper. Some models produce a rather irritating sound that you simply want to switch off after a while. Unfortunately, only two of the twelve instruments we tested allow this (Skil 550 and Bosch PDO Multi).

All pipe and wire locators utilise capacitive coupling between individual metal surfaces to detect wooden joists and studs. This allows the joist or stud location to be determined fairly accurately. Capacitive coupling is less suitable for detecting metal pipes, so it is not as

PIPE & WIRE LOCATORS



easy to determine exactly where they are located in the wall with the capacitive coupling method. For this reason, some scanners also have a coil that responds to changes in the magnetic field. This makes it easier to determine the exact location. With some instruments equipped with a detection coil, the user guide also states that the device is more sensitive to metal pipes if you rotate it by 90° so the coil is parallel to the pipe. The Bosch and Skil units have an especially handy design feature (see **Figure 2**): a hole at the top of the instrument that shows exactly where the measuring coil is located. This way you can accurately determine where it's safe to drill and where it isn't.

Almost all of the instruments we tested (excluding the Bosch PD06) can detect wooden studs and joists, iron and copper pipes, and wires or cables carrying AC voltage. Thin PVC conduits (for electrical wiring) are nearly impossible to detect if they do not contain any wiring. PVC pipes can only be detected if they have thick walls and a diameter of 5 cm or more. Iron, copper and steel pipes and aluminium tubes can be detected reasonably well. Uponor pipes, which are used in floor heating systems and have composite walls (including an aluminium layer), are also detected well. All of the scanners also can also detect the presence of AC voltage, which is shown by an indication on the display or a separate LED.

Some of the scanners even provide 'left' and 'right' indications on the display when you're looking for a stud or pipe, which can sometimes come in handy. The Black & Decker BDS303, Zircon Multiscanner i320 and Zircon Multiscanner i700 provide this feature.

Practical testing

In order to test the capabilities of the pipe and wire locators with various types of material at various depths, we assembled a setup in the Elektor lab with several types of pipes, wires and cables and a wooden stud behind a gypsum board, arranged such that the depth could be varied. This made it easy to determine how deep a particular type of material could still be detected.

All of the test results are listed in the table. These test results of the scanners in this test can readily be compared with each other, but you should be cautious when comparing them with the values stated in the manufacturer's specifications because we made all the measurements with the various pipes and studs located behind a single gypsum board. The results with thicker gypsum boards or solid walls containing embedded pipes or wiring may differ significantly. In any case, it's always worthwhile to first experiment a bit on the wall where you want to locate a pipe, stud or wiring.

Black & Decker BDS300



Price: around \$50

This bright orange pipe and wire locator is suitable for locating wooden joists and studs, metal pipes and live electrical wiring. The on/off button is on the side of the unit and must be held pressed while you're scanning the wall. There is a switch for selecting either wood detection or metal detection. The indicator is a LED strip with five LEDs. A separate LED lights up when a voltage (AC mains voltage) is detected. A buzzer sounds when the detected signal reaches the full-scale limit.

Black & Decker BDS303



Price: around \$70

This larger B&D model has an entirely different form than its smaller brother, with a handle that lets you grasp it firmly. It is also suitable for detecting wooden joists and studs, metal pipes and live electrical wiring. You have to hold the large power button pressed while scanning the wall, but this is fairly easy thanks to the shape of the handle. There is a slide switch for selecting either wood or metal detection. The large LCD screen with orange backlighting has three large bar scales to indicate when the unit has detected something;

it can even sense studs to the left or right of the unit. The center of a wooden joist or stud is indicated by a bull's-eye icon. A separate LED lights up when an AC voltage is detected. All of this is supported by a buzzer for acoustic signaling.

BASETech 3-in-1 detector

Price: around \$30



The least expensive instrument in the group, this unit can also detect wooden joists and studs, metal pipes and live electrical wiring. It's even smart enough that you don't have to set it to particular type of material – it indicates by itself whether it has found wood or metal. You can also use the Function button to manually set it to wood, metal, or AC voltage. The large display indicates the measured signal level with a beefy 19-segment arrow. This instrument switches off automatically after several minutes of inactivity, or you can switch it off manually. A buzzer emits an irritating noise when the maximum signal level is reached, and at the same time an indicator LED lights up. There is a separate calibration button for recalibration between measurements, so you can adjust the sensitivity as necessary.

Bosch PDO6

Price: around \$80



The PDO6 comes in the usual Bosch green and is the only instrument in the group designed solely to detect metal pipes and live electrical wiring, which is all that many users need in actual practice. You press the on/off button to switch the unit on, and it switches off when you press the button again or after it remains idle for a while. The LCD screen is small but effective, with a bar scale for the signal level. It also displays an icon when a voltage is detected. A hole at

the top of the unit indicates the exact measuring point, so you can accurately determine and mark where you can or can't drill a hole. The green illumination of this hole changes to red when the measured signal rises to a high level. In addition, the light starts blinking when a voltage is detected.

Bosch PDO Multi

Price: around \$130



The 'big brother' of the PDO6 can detect wood in addition to metal and voltage. It also has a distinctive illuminated measuring hole. This scanner has a separate on/off button, a button for wood detection, a button for metal detection, and a Zoom button. The instrument switches on when any button is pressed, and it switches off automatically after several minutes of inactivity. You can also switch it off manually with the on/off button. The display has three separate bar scales: one for voltage and two for signal level. At high signal levels, the illumination of the measuring hole changes from green to red and the buzzer beeps. Fortunately, you can disable the buzzer if you wish. When you're looking for metal objects, you can press the Zoom button to determine the precise location after initial detection. This activates an additional bar scale. The Zoom button must be pressed and held continuously when scanning for wooden objects. There is a pencil in the bottom of the unit for marking identified locations.

Brennenstuhl WMV Plus

Price: around \$25



This unit is housed in a modestly dimensioned enclosure and can detect wood, metal and AC voltage. It has a slide switch on the front that you first have to set to the desired position before you press the Scan but-

PIPE & WIRE LOCATORS

ton. Unfortunately, after this the display does not provide any indication of which function is selected, so you have to remember which position belongs to which function. There are two Scan buttons, and you can press whichever button is easier to reach in a particular situation. You must also hold it pressed while scanning. The display shows a two-digit number that indicates the signal level, along with a multi-segment bar scale as an extra indicator. Here again a buzzer provides the accompanying acoustic indication. The instrument must be rotated by 90° for more accurate detection of metal pipes.

Laserliner Starfinder

Price: around \$45



This is a small, handy scanner designed to detect studs and live electrical wiring. The user guide states that it can recognise metal studs as well as wooden studs and that no separate setting is necessary for this. Seven LEDs arranged in an arc are used to indicate the signal level as well as the selected sensitivity setting. Pressing the Mode button switches on the scanner, which switches off automatically after several minutes. You can also use the Mode button to switch between stud detection and voltage detection. Three different sensitivity levels can be selected with the Set button. There is a large Cal button for calibrating the unit. A 'calibrate' LED starts blinking when a new calibration is necessary. More LEDs light up when a stud or a voltage is detected, depending on the signal level, and a buzzer sounds when the maximum signal level is reached. A separate warning LED also lights up when an AC voltage is detected.

Laserliner Multifinder Pro

Price: around \$80



This hefty scanner with a built-in handle resembles the smaller Starfinder in terms of functionality and operation, but instead of LED indicators it has a large illuminated LCD screen with a big multi-segment bar scale that indicates the signal level. The scanner has separate buttons for power on/off, wood, metal, voltage, sensitivity, and calibration. It switches off automatically after several minutes of inactivity. The display clearly indicates what you have to do. For example, the first thing you see is a message telling you to place the scanner against the wall and then press the Cal button. A voltage indicator LED lights up when a voltage is detected. There are three manually selectable sensitivity levels, and of course there's a buzzer.

Skil 550 multi-functional detector

Price: around \$90



The sizeable scanner has a separate on/off button, a button for wood detection, a button for metal detection, and a Focus button. Like the Bosch scanners, this instrument has a hole that shows the exact measuring point. The instrument switches on when any button is pressed and switches off automatically after five minutes of inactivity, or earlier if you press the on/off button. The display has separate bar scales for voltage and wood or metal. When the indicated value rises, a LED also lights up and a buzzer sounds. When you're looking for metal objects, you can press the Focus button to determine the location more precisely after initial detection. The Focus button must be pressed and held continuously while scanning for wooden objects. Along with the Bosch PDO Multi, this is one of the few instruments that allows you to switch off the buzzer.

Stanley Fatmax Stud Sensor 400

Price: around \$55



This scanner in typical Stanley colours has only one button, which acts as an on/off switch. It must be pressed constantly while you're scanning. The unit features automatic sensitivity setting, with the sensitivity level indicated by three LEDs below the LCD screen. The large display has several arrows and a bar scale to indicate the location of a stud or pipe. A buzzer sounds at the full-scale signal level or when an AC voltage is detected. A separate LED also lights up when a voltage is detected. There is a separate 'AC tracing' mode (selected by pressing the button twice in a row) for easy detection and tracing of electrical wiring.

Zircon Multiscanner Pro SL

Price: around \$40



This model has a slide switch for selecting one of four different detection modes: wooden joists or studs, high sensitivity for deep joists or studs, metal, and voltage. The power button must be held pressed during scanning. The large LCD screen shows the selected settings, calibration mode, battery state, and – most importantly – the measured field strength with a 17-segment arrow, where the number of illuminated segments increases with increasing signal level. Here again a buzzer sounds when the maximum signal level is reached, and an LED lights up and shines on the exact measuring point on the wall, to make it easier to mark the right location.

Zircon Multiscanner i320

Price: around \$80



The i320 closely resembles the Pro SL in terms of functionality. It also has a slide switch that can be set to metal, wood, or deep wood. The AC Scan mode of the Pro SL is missing here, but the i320 can

also detect AC voltage, which is shown by a blinking 'AC' indicator on the display. The instrument is fairly slim and has an on/off button on the side that must be held pressed during scanning. The display is virtually the same as the more expensive i700 model, but without backlighting. The signal level is shown by a broad bar scale, which also indicates the location of the joist, stud, pipe or wiring. Naturally, there's also a noisy buzzer, and like the other Zircon scanners we tested, this model has an LED that indicates the centre of the detected joist, stud, pipe or wiring.

Zircon Multiscanner i700

Price: around \$110



This more expensive model from Zircon at least wins the prize for futuristic design. It consists of two sections joined by a hinge structure. This arrangement forces you to press the bottom part (the 'handle') slightly downward when the instrument is held against a wall, and this motion causes the scanner to switch on automatically. There is a slide switch for setting the scanner to wood, metal, or voltage mode. The large display has a horizontal bar scale that shows the signal level as well as left/right/centre indication. There are two LEDs that light up to indicate the precise location of the centre of the joist, stud, pipe or wiring, augmented by a beeper. The final feature of this model is an integrated marker in the form of a pencil lead that marks a line on the wall when you press the Mark button on the bottom section of the scanner.

Conclusion

After making a lot of measurements and performing various practical tests, we have good news as well as bad news for you. First the good news: all of the tested units work properly, even including the least expensive unit (approx. \$30). Now the bad news: if you want more features, more convenience or a more elaborate display, you have to spend a good deal more than 30 bucks.

It's difficult to pick a clear winner. The Black & Decker BDS303 is the best choice for wood detection, while the Bosch PDO Multi is the best for detecting metal objects and the Stanley FatMax Stud Sensor 400 is the undisputed champion in detecting AC voltage.

In terms of the price/performance ratio, the BASETech is clearly the best instrument, but detecting wood is not its strong point. However, all of its other test results are above average. Next comes the

PIPE & WIRE LOCATORS



Zircon Multiscanner Pro SL, priced slightly higher, which is a somewhat older model but nevertheless works just as well as the newer Zircon models in terms of the test results. For this money, you get an excellent all-rounder that is also suitable for detecting wood and AC voltage.

If we consider ease of use in addition to the test results, we find that the Bosch PCO Multi and the Skil 550 (which clearly come from the same factory) have the most convenient design thanks to the combination of straightforward use, a clear display, and precise location of metal objects thanks to the coil located around the measuring hole. The only minus here is that you have to hold a button pressed while scanning for wood. Unfortunately, these units are also among the most expensive in our test.

Our recommendation if you're looking for a pipe and wire locator is to first consider what you want to use it for (what do you want to find), how often you are likely to use it, and how much you're willing to pay for the convenience. Based on this information, select a model from the table that meets your needs.

Good luck with your home improvement jobs, and always watch out for hidden electrical conduits and water pipes!

(100016-I)

Black & Decker, Bosch, Brennenstuhl, Skil and Stanley scanners are available at building merchants and DIY shops.

BASETech products can be purchased from Conrad Electronics, www1.conrad-uk.com.

Zircon: www.zircon.com/buy/wheretobuy.html

Laserliner: www.umarex-laserliner.de.

Table 1. Test results: detection range (in.).

Model	Wood 1.9 x 0.7 in.	Iron	Copper	Aluminum	Uponor	PVC pipe	PVC conduit with wiring	AC voltage
BASETech 3-in-1 detector	0.8	4.0*	2.0*	2.0*	2.0*	< 0.4	0.8*	1.2
Black & Decker BDS300	1.2	3.5*	1.6*	2.0*	2.0*	1.0**	0.8	0.6
Black & Decker BDS303	2.4	2.8	1.2	1.6	2.0	1.6**	0.8	1.2
Bosch PDO 6	-	3.1	2.0	2.3	2.0	-	< 0.2	1.0
Bosch PDO Multi	1.0	4.3	2.4	2.8	3.5	0.8**	0.6	1.0
Brennenstuhl MFD WMV Plus	1.2	1.6	1.0	1.0	1.2	< 0.2	0.4	2.0
LaserLiner Starfinder	1.4	1.6	1.2	1.6	2.0	< 0.2	2.0	0.6
LaserLiner MultiFinder Pro	1.8	3.5	2.0	2.0	2.4	1.0**	1.0	1.2
Skil multi-functional detector 550	1.0	3.5	2.3	2.3	3.1	0.8**	0.8	1.0
Stanley FatMax Stud Sensor 400	1.6	2.8	2.3	1.2	2.4	< 0.2	1.4	3.1***
Zircon Multiscanner Pro SL	1.4	2.3*	1.0	1.2	1.4	0.80**	1.6	2.8
Zircon Multiscanner i320	1.6	2.3*	0.8*	1.4*	1.2*	< 0.2	0.8	0.6
Zircon Multiscanner i700	0.8	2.3*	1.0*	1.2*	1.4*	< 0.2	0.8	0.8

PVC conduit, iron pipe and Uponor pipe diameter 5/8" ; copper pipe and aluminium tubing diameter 1/2 ". All measurements made through a 15/16 inch (9.5-mm) gypsum board.

* Scanner rotated 90°

** Wood detection mode

*** AC detection LED lights up already at a distance of 6.2 inches.

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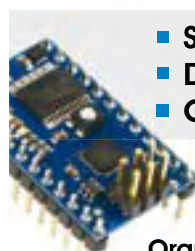
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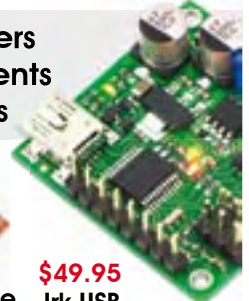
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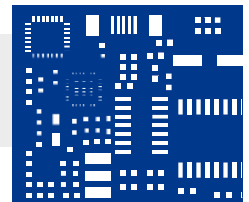
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Star LED instead of incandescent lamp

By Co Slokker (The Netherlands)

Traditional indicator lamps with a filament are often also available these days — on a one-for-one replacement basis — in versions made with LEDs. In this implementation the LED, together with a series resistor, is mounted in the traditional housing. In some applications there are wide variations in ambient light (for example day/night in the cabin of a vehicle). The lamps are dimmed at lower ambient light levels so that they are not annoyingly bright, usually using a series resistor. When you replace the incandescent signal lamp in such a circuit with an LED-lamp then the LED will be much too bright in the dimmed state. This is caused by the different characteristics between incandescent and LED-lamps.

However, by taking these characteristics into account it is certainly possible to dim the LED lamps. As an example, we will compare the characteristics of a green CML StarLED 1507145G3 with a standard 28 V/45 mA incandescent lamp. We start by determining the current drawn as a function of applied voltage for each type of lamp. Then we measure, in a dark environment, the change of relative brightness as a function of the applied voltage (see **Figure 1**). From this we conclude the following:

- At 28 V the LED is about four times as bright as the incandescent lamp at a third of the current
- The current characteristic of the incandescent lamp is strongly non-linear, while that of the LED is practically linear (after overcoming the forward voltage drop).
- The relative brightness of the incandescent lamp increases exponentially, while that of the LED is initially linear after which the slope gradually reduces.

When dimming the incandescent lamp you reduce the voltage with a series resistor. From the graph you can see that the lamp still draws about 28 mA at 12 V, while the brightness is effectively nil. The series resistor amounts to

$$(28 - 12) / 28 \times 10^{-3} = 571 \Omega$$

At 12 V the brightness of the LED hasn't even halved yet: 14.5 mS compared to 27.4 mS at 28 V.

From measurements it appears that for the LED at 12 V to appear just as bright as the incandescent lamp (6.8 μ S), a current of only about 24 μ A is required; more than 1000 times smaller than that for the incandescent lamp at 12 V! The series resistor required for this is

$$(28 - 2.5) / 24 \times 10^{-6} = 1 \text{ M}\Omega \text{ (approx.)}$$

which is obviously much more than the 571 Ω required for the incandescent lamp!

Figure 2 shows a simple circuit for the practical evaluation of the automatic brightness control for two StarLEDs. Because the LEDs that we tested are at 6 V are already just as bright as the incandescent lamp at 28 V, a 9 V battery will suffice for the power supply. With S1 you can select between automatic and manual control; the third position turns the circuit off.

The automatic control is achieved with an LDR driven double current mirror, built around T1, T2 and T3. The current through each LED is

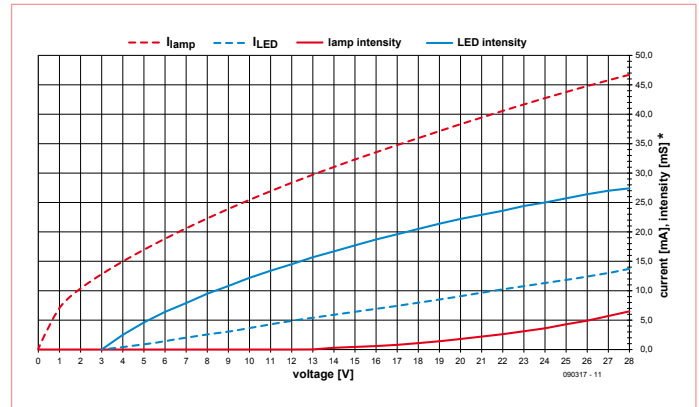


Figure 1. Brightness of the LED and incandescent lamp as a function of applied voltage.

equal to the current that flows through R1. You have to make sure that the position of the LDR is such that it is not illuminated by any of the LEDs, otherwise there is the chance of runaway feedback to maximum brightness.

With S1 in the 'manual' position you can also adjust the minimum desired brightness of the automatic control. In absolute darkness, after sufficient recovery time has elapsed, the LDR that we used here has a very high dark resistance (hundreds of M Ω) and only the current through R_v now determines the brightness. Once your eyes are sufficiently accustomed to the darkness you can set the desired brightness with potentiometer R_v. A logarithmic type is used for R_v to make the adjustment of low brightness levels easier.

Once S1 is switched back to 'automatic' there is no need for any further adjustments. The potentiometer could then be replaced with a trimpot or fixed resistor of appropriate value.

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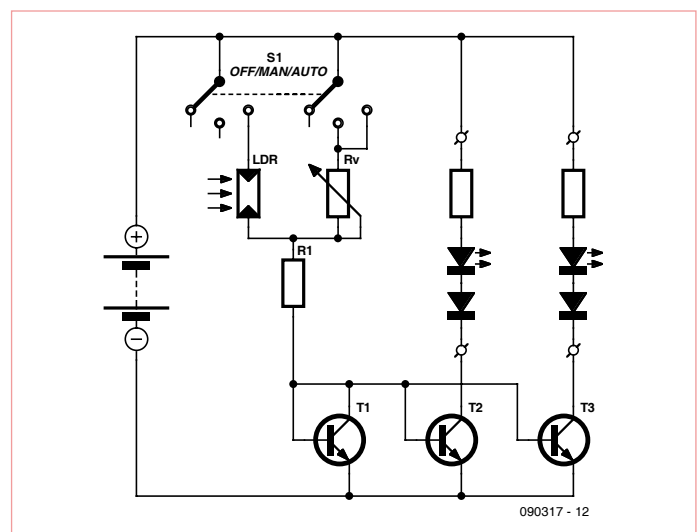


Figure 2. Circuit to evaluate the brightness of the LEDs.

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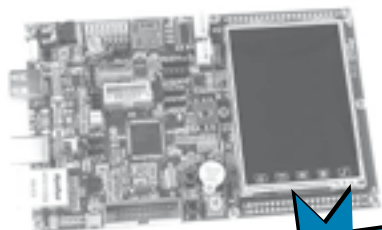
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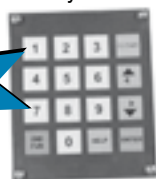
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Measured again...

By Ton Giesberts (Elektor Labs)

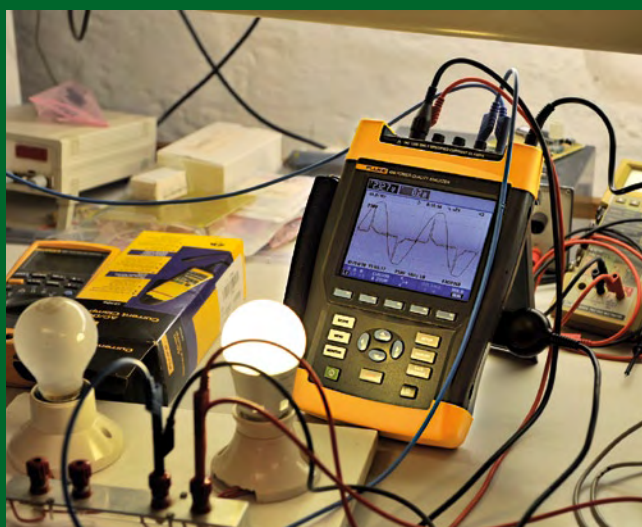
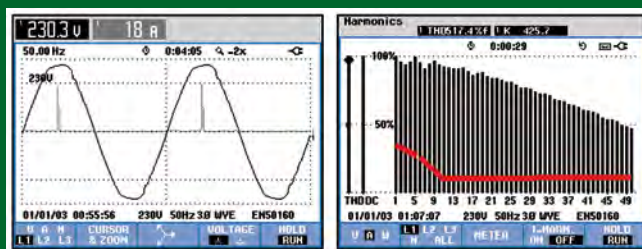
The article 'Blinded by the Light?' in the February 2010 edition showed that LED lamps didn't exactly present a clean load to the AC grid and in fact created quite a bit of pollution and disturbance. A number of readers gave us some interesting feedback to this article. One of them was Gerard Grashof, who works for Fluke Industrial and provides product support for their Scope-meter and advice on Power Quality. He wanted to point out that the behavior of such mains-powered devices could be closely monitored and analyzed with the help of some special measuring equipment made by Fluke.

We were keen to find out more about this and invited Gerard over to the Elektor Labs, obviously along with a Fluke Power analyzer!

When we previously made measurements with a 'normal' oscilloscope in the Elektor Lab on various types of lamp we already determined that, although LED lamps were very energy efficient, they presented a strange, complex load to the AC grid. The harmonics created on the AC supply lines by these devices have an effect on the size of the substations required at the end of the electricity distribution system. These harmonics are responsible for extra losses in the transformers, which means they should really be over-engineered to cope with this extra heat (larger losses). The losses in the transformers are proportional to the frequency of the harmonic multiplied by its amplitude. This is represented by the so-called k-factor, which indicates how much a transformer should be de-rated as a result of harmonics in the current. Mid and high-voltage transformers in the power AC grid can normally cope with a k-factor of 3-4. Fluke has designed an analyzer specifically for measurements on (three-phase) AC powered equipment: the 434 Power Quality Analyzer. With the help of such an analyzer we have once more made some measurements on an LED lamp. To make it easier to measure the current we used an i310s AC/DC Current Clamp. This time round we tested the Pharox lamp made by Lemnis, a 6-watt LED lamp marked by a peak value in its current consumption that's similar to that of the LED lamps we used in the original article.

In order to calibrate the equipment we first measured a 100-watt incandescent lamp. After carefully adjusting the current clamp (the Hall sensor used inside it is slightly temperature dependent) we measured a power factor of 0.98. With a pure resistive load we were really expecting exactly 1. At first we thought this might have been due to a slightly less than perfect sinusoidal waveform of the mains voltage in our Lab. However, another reason could be that due to the small current flow the current clamp did not get a large enough signal to measure accurately. In this case a simple trick is to loop the cable twice through the current clamp instead of straight through. The measured value is then too big by a factor of 3, but at least the power factor was now found to be a perfect 1. Now the time had come to take measurements on the LED lamp. The current consumption was found to be 0.067 A (*this repre-*

sents the measured value divided by 3, which also applies to all other current measurements). $\cos \phi$ was a neat 0.98, but the power factor was only 0.42. The latter is therefore a problem with energy-saving lamps, especially with LED lamps. The measured pure power consumption was 5.87 W, the apparent power was 14 VA and the reactive power was 12.7 VAR. The following day we carried out the measurements again and obtained slightly different results: 5.83 W, 11.3 VA and 9.67 VAR, $PF = 0.51$ en $\cos \phi = 0.975$. The differences could possibly be explained by the temperature dependence of the current probe and the LED lamp. The most important measurement we obtained was the k-fac-



tor for this LED lamp. This turned out to be a massive 99 (THD was 155 %)! The second measurement returned an even higher k-factor of 130, with a THD of 150 % (this changed as the lamp was on for longer). This really is an extreme value, especially when you consider that in many countries, AC power grid transformers are designed with a k-factor of 3-4 in mind...

These measurements show that big improvements have to be made in the design of LED lamps, otherwise there is a good chance that the electricity suppliers will suffer from big problems once these LED lamps start to be used on a large scale!

(100099)

Embedded World 2010 *or how to*



Vision enhancement? (source: NürnbergMesse/Frank Boxler)



Open vs. closed source: Microsoft cohabiting with a penguin.
(source: NürnbergMesse/Frank Boxler)



More than 700 students came to visit the show on Student Day.
(source: NürnbergMesse/Frank Boxler)

By Antoine Authier & Clemens Valens

In the first week of March the German city of Nuremberg once again hosted the Embedded World Exhibition & Conference. 730 exhibitors showed 18,350 visitors the full range of products for embedded technologies in 2010: hardware, software, tools, services and lots more. Elektor was among the visitors – here is our report.

Four huge halls full of booths (not booze) loaded with electronic novelties really are too much to handle, even when you have three days. At Elektor we knew this, so we came prepared with a list of exhibitors that we definitely wanted to visit. On this list was German Renesas distributor Glyn, and since they were conveniently located right in front of the main entrance, this was our first stop. Glyn staff informed us about the upcoming merger of Renesas and NEC, the companies continuing under the name ‘Renesas Electronics Corporation’ (REC). Other interesting news was the new RX MCU family positioned by Renesas as the upgrade successor to the H8SX and R32C, the latter well known to Elektor readers. This family is supposed to provide more power at less consumption, which was clearly the lead theme for this exhibition. It was green and low-power all over the place.

Being press we attended the official press conference and participated in a guided tour of the show. During this tour the green side of the show was once again emphasized with visits to (among others) Hitex, Mentor Graphics and Fraunhofer. Hitex presented a clever tool for current consumption analysis of software called PowerScale and won the Embedded World Award in the category Tools. The winner in the Hardware category was Energy Micro’s EFM32, the world’s most energy friendly 32-bit microcontroller that consumes only 180 μ A per MHz when running from 3 V.

Microchip was of course present too with their extreme low-power (XLP) microcontroller family (50 μ A per MHz). A novelty was their new MCP1640 ultra low-power boost regulator that took four years to develop. It will startup from 0.65 V and then pump from as low as 0.35 V up to 2 to 5.5 V which is obviously great to discharge batteries deeper.

Touch technology was another important theme during this exhibition. Atmel for instance won the award in the Special Merits category for their new maXTouch technology presented in the form of the chip mXT224. This IC allows for touch screens that support not just finger touch but also stylus, fingernails and even gloves for drawing or character recognition. Atmel’s touch products are supported by the free Qtouch library and Altium integrated a module in their Designer schematic/PCB drawing software for quickly designing and drawing compatible touch sensors on PCBs in any shape you like.

STMicroelectronics distributed for free (and not asking for address details!) tiny development kits for their new STM8S 8-bit microcontroller family supported by free programming tools. This kit sports one capacitive touch key that controls an

develop green tactile products quickly

LED and a USB port. When connected to a computer it becomes a “mass” storage device of 32 KB.

That brings us to the third major theme of Embedded World 2010: making microcontroller development easy. An increasing number of microcontroller manufacturers offer free or ‘mildly restricted’ tools to quickly get an application up and running. ST teamed up some years ago with the French company Raisonance to develop cheap tools for ST’s ARM products. The latest tool from Raisonance is the Open4 (business) that will be available from ST too, albeit under another. This tool, a Gameboy-ish device with a colour display, a touchscreen, a joystick, audio interface and USB debugging/programming port works with user supplied microcontroller cartridges that determine the functionality of the device. Software development for the user cartridge is done with cheap or even free programming tools and the device is supposed to sell for less than \$100.

Free tools are also available from FTDI for their brand new Vinculum II processor. The first Vinculum was a cheap solution for easily building of USB products, but FTDI went one step further with the second version that has become a full blown generic 16 bit microcontroller with lots of other peripherals and of course USB. Programming and debugging is cheap as the tools are all free. After we signed a non-disclosure agreement, FTDI showed us what will definitely be the next killer product for USB to RS-232 converters. Keep your eyes open, this product is going to change the world!

Green, cheap and easy are also the main features of the mbed ARM Cortex-M3 board. Essentially an ARM product, it was presented on the NXP stand because the currently available mbed boards have NXP processors. Software development for mbed employs a browser and a compiler farm on the internet. Write a program, compile it online and then download the executable to your mbed board. The boards are cheap and the tools are free, and many libraries are available.

Following NXP and their LPCxpresso product line with kind-a-free (up to 128 KB executable) programming tools by Code Red, compiler manufacturer Keil too presented a kind-a-free Eclipse & GCC based open source compiler for ARM processors, the DS-5. Keil (owned by ARM) made a point of telling us that they actively participate in the open source community and they contribute to the GNU C/C++ compiler. Similar statements were made by other software producing companies, which brings us to the interesting observation that the open source community seems to be slowly taken over by commercial entities that pay their employees to write free software together with their competitors.

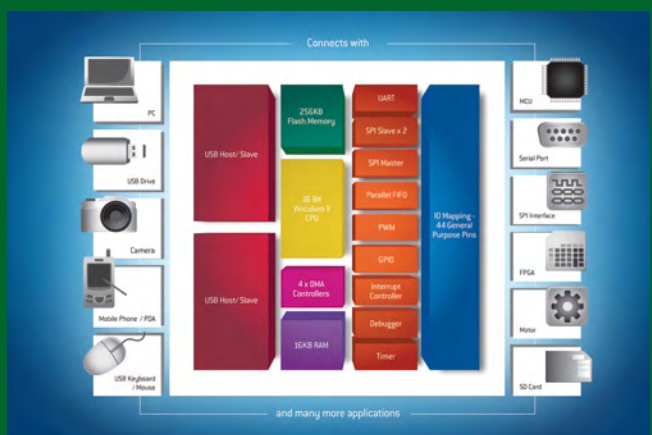
Of course there were many more interesting products and demonstrations to see, but we do not have the space to mention them all here. So why don’t you go and see for yourself next year? Nuremberg is a nice city with a well-preserved ancient centre and good food and accommodation. One warning though: try to not eat all the sweets, chocolates and cookies available on almost every booth, you need good teeth to eat your way through the information.



Clemens Valens (tall ‘n bald) at the Embedded World. (source: NürnbergMesse/Frank Boxler)



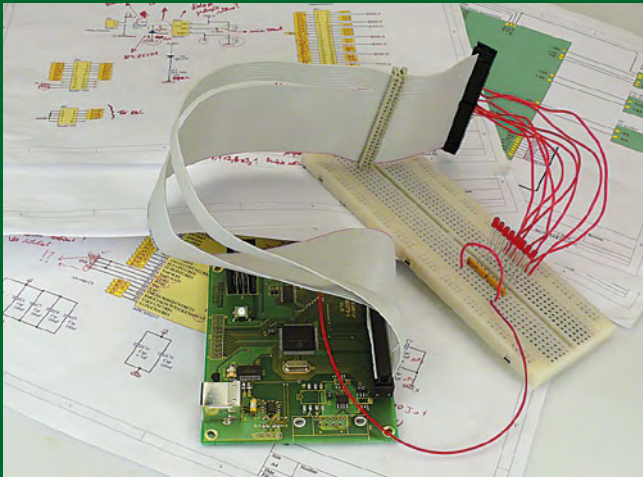
Atmel’s Qtouch suite.



The Vinculum II (VNC2) is more than just a USB host controller.

(100215-1)

The making of the dsPIC board (2)



Last month we began an insight to how we at Elektor hone a readers circuit to create a tested, reproducible design, the story continues... In the first installment [1] we reported how one of our resident engineers, Daniel Rodrigues (who hails from Portugal) redesigned the PCB and finalized the parts list. The components for this board were now on order and Daniel began work on the second set of boards for the project. This is an expansion board containing interfaces to the peripherals such as motorized valves and sensors. The two boards together form a complete control unit which manages a solar heating installation to optimize the energy harvest (see the article elsewhere in this magazine).

Once all the components for the dsPIC controller board had arrived Daniel began with the building process "I decided to use the SMD oven for one of the boards and hand-solder the other one", explained Daniel. As luck would have it we received a visit by a representative from the Dutch distributor of the 'Magnus' professional USB microscope for PCB inspection [2] (with our lab assistant Jan Visser). This was too good an opportunity to miss; Daniel rigged it up to inspect the freshly built boards. It showed up a thin solder bridge between two microcontroller pins which curiously did not measure as a short circuit. In most cases this sort of failure can be quickly identified by simple electrical tests and easily remedied.

Once he was happy with the build Daniel sent off a finished prototype controller board to the project's authors for functional testing. Here in the Elektor lab we are familiar with Murphy's Law, we know if anything can go wrong then it will. In this case Yves Birbaum had unfortunately been laid low by an illness and wouldn't be able to test the board for a few days. The uncertainty of the board's functionality was worrying Daniel. He started browsing the software folders in the solar-array controller project trying to find a routine to help in testing. Hopes were raised when he found some C files with the word 'essai' (French for 'test') in their titles; "unfortunately the functions were not much help for what I had in mind" recalled Daniel. Instead of sending characters back and forth between the con-

troller and PC using a terminal emulator program he wanted a more useful test with the controller switching a few test LEDs. He built the test hardware (see photo) and quickly modified the Main function in the C program to 'sweep' the line of LEDs. "Till now I had only worked with the standard range of PIC controllers but as you would expect there are a lot of similarities with the dsPIC instruction set and the MPLAB-IDE and C30 Compiler are really well documented" enthused Daniel. In the meantime Clemens Valens, our French editor responsible for the two articles had put the finishing touches to the original text and there was enough time for it to be sent for translation into the other languages. The Elektor test routine would likely be of interest to constructors so we have included it in with the rest of the software.

By this time we had taken delivery of two of the bare expansion boards for this project. All of the components except the relays had been ordered from Farnell, unfortunately one of them; a hex inverter was not in stock "this added another week to the process" said Daniel and by the time everything arrived it was looking doubtful we would get the finished board to the authors in time. Daniel placed all the components and cranked up the reflow oven. We were soon to witness an extension to Murphy's Law which states that the chances of anything going wrong are multiplied by the inverse of the remaining time. During board testing a DC/DC converter was found to be faulty; "when I took a closer look I could see two tiny beads of flux had apparently oozed out of the component housing". Chances are that the device had given up the ghost during the re-flow process using lead-free solder. With the component replaced he was relieved to send the boards off with a clean bill of health. The final functional test can now only really be carried out by the project's authors where both the Elektor boards will replace the author's original to control the solar installation. One practical test is worth a thousand simulations!

(100216)

[1] www.elektor.com/091079

[2] www.tagarno.dk

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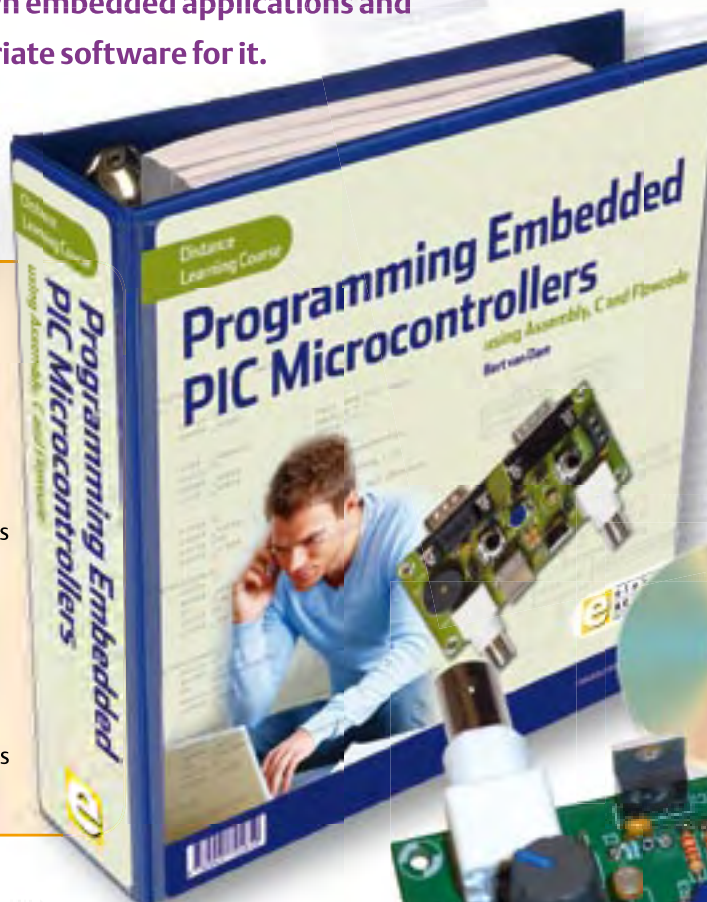
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Cloud Altitude Meter

your head in the clouds with 'AirControl'

By Antoine Authier (Elektor Labs)
from an idea by Jürgen Maiss (Germany)

This circuit was dubbed AirControl because it indicates the altitude of the clouds by measuring air temperature and humidity and then silently doing a mass of scientific calculations.

It should make an interesting meteorological tool for people who keep an eye on the sky.



When it landed (on my desk), Jürgen Maiss' 'AirControl' prototype immediately aroused my curiosity and seduced me by its originality: how could this circuit, using a simple humidity (and temperature) sensor, work out the altitude of the cloud base for cloud masses?

"A gliding enthusiast, Jürgen is also a pilot; so meteorological data are vital to him, he's bound to know his subject!" I said to myself, though still sceptical "But are the results obtained in this way reliable?"

In addition, this circuit uses a miniature digital sensor that I hadn't ever used before... that was all it took to launch me into the adventure, without a balloon or tape-measure in sight.

From a meteorological point of view

First of all, a few reminders about thermodynamics. Not being a meteorologist, I

poured over various encyclopaedias to try and understand the phenomena being exploited here. Here are some results of my research.

This circuit measures the ambient air temperature and relative humidity. In order to determine the altitude of the cloud base, it is necessary to first calculate the altitude at which the water vapor in the air condenses.

The dew point [7] or dew temperature corresponds to the saturation temperature of the air at a given pressure — in other words, the temperature at which the water vapor in the air is at a maximum. If, at constant pressure, the air temperature drops below this dew point (isobaric transformation), the excess water vapour will condense to form cloud, fog (low cloud), or dew, depending

on the altitude at which the phenomenon occurs. The warmer the air, the more moisture it can hold.

The August-Roche-Magnus formula lets us approximate this (dew) temperature T_d :

$$T_d(T, RH) = T_n \cdot \frac{\gamma(T, RH)}{m - \gamma(T, RH)}$$

$$\gamma(T, RH) = \ln\left(\frac{RH}{100}\right) + \frac{m \cdot T}{T_n \cdot T}$$

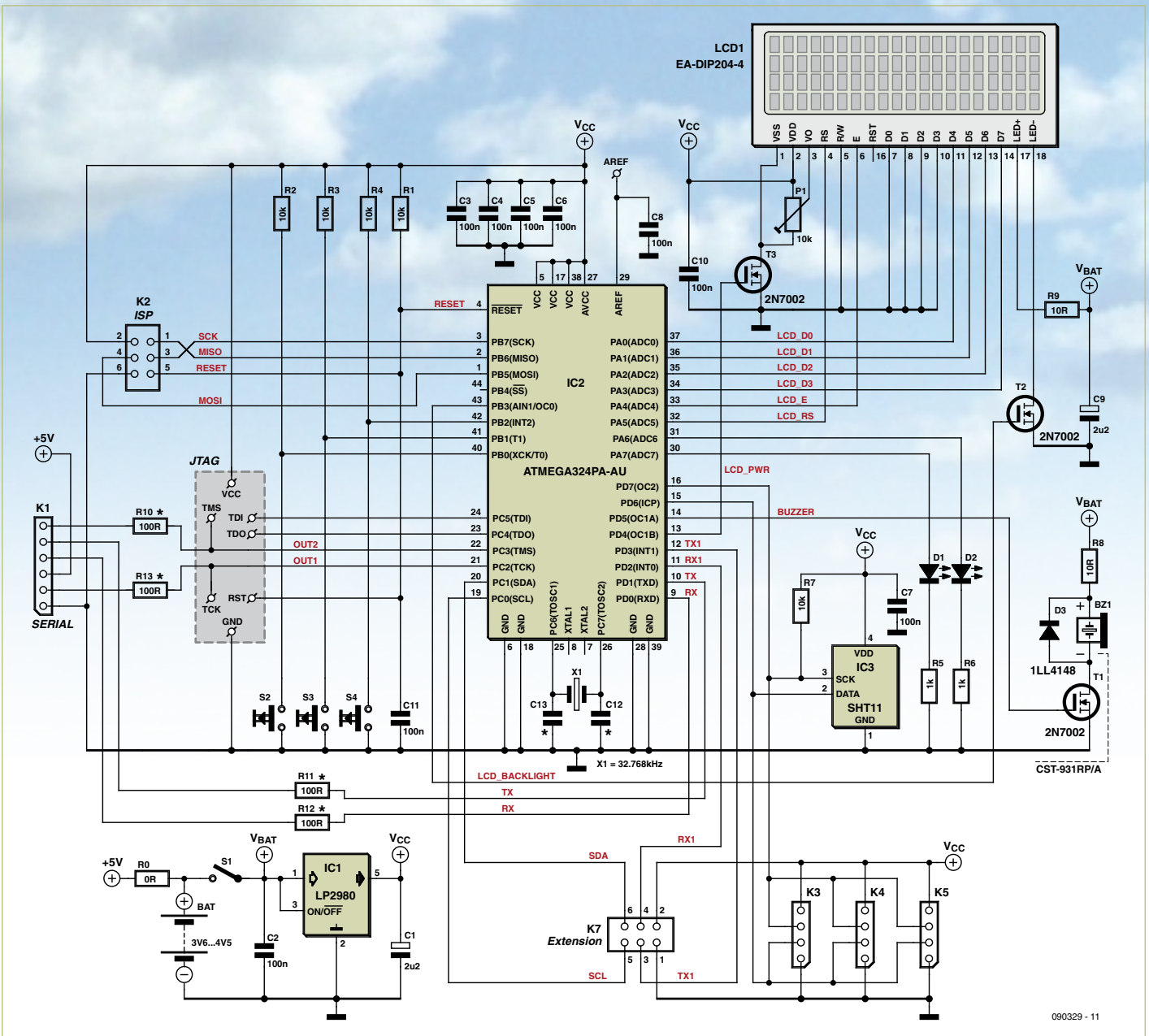
using the constants $\begin{cases} T_n = 243.12 \text{ }^\circ\text{C} \\ m = 17.62 \end{cases}$

This approximation is valid 'above water' (in the jargon), i.e. for temperatures between 0 and 60 Celsius, and relative humidity between 1 and 100 %.

In order to understand the explanations that follow, you'll probably find it helpful to read up about 'atmospheric pressure' and 'convective instability' from the link [8]. Let's now consider the standard atmosphere model as used by many meteorological offices, with a vertical temperature gradient that remains of the order of $-0.65 \text{ }^\circ\text{C}$ every 100 m (approx. 300 ft) in the lower atmosphere (also called troposphere).

Specifications:

- MCU: Atmega324PA-AU from Atmel, JTAG support
- SHT11 humidity sensor from Sensirion, 0–100 % RH, accuracy 3 %
- Powered by three AAA/R6 penlight cells
- Minimum battery life one week (with new batteries and without using the backlight)
- Works out the cloud base altitude
- 4 line × 20 character display
- Portable, sensor on detachable breakout board



090329 - 11

$$\nabla T(z) = \frac{-0.65}{100} \text{ [}^\circ\text{C/m]}$$

$$\text{i.e. } \frac{T_d - T}{z_{cloud} - z_o} = \frac{-0.65}{100}$$

z_o being measurement altitude, we finally obtain

$$z_{cloud} = (T - T_d) \cdot \frac{100}{0.65}$$

This calculation assumes that the atmosphere is standard and that the humidity is constant with altitude... All that remains is to go up in a balloon to check if this model actually works in the troposphere (up to

about 16 km; 54,000 ft.). While we're waiting for the air in our balloon to heat up, let me tell you about the hardware platform.

Hardware

To be appealing a project like this needs to be portable, compact, elegant but sturdy, and have long battery life. Its supply voltage should not be more than 3.3 V. The display should be as compact as possible, but have good resolution. Everything housed in a little case with the power source, small enough to fit into your breast pocket or even smaller bits of textile.

Three 1.5 V AAA penlight batteries or 1.2 V rechargeables, i.e. 4.5–3.6 V when connected in series, will each provide around 1000 mAh.

We'll come back later to the backlight for the display, which requires 5 V.

The supply for the various sensitive devices and modules is provided by an LP2980 [4] regulator IC from National, which can supply up to 50 mA with a very reasonable 0.12 V voltage drop. Ideal for battery-powered applications, this device supplies more than enough current for this part of the circuit, which at worst will consume 10 mA (during the measurement phase). The devices that consume more power — the backlight and resonator — will be connected to the batteries via resistors.

R8 protects the resonator [5], which is only rated for a maximum voltage of 4 V, whereas

COMPONENT LIST

Resistors (SMD 0805)

R1–R4, R7 = 10kΩ
 R5, R6 = 1kΩ
 R8, R9 = 10Ω
 P1 = 10kΩ SMD preset (Vishay TS53)

Capacitors (SMD 0805):

C1, C9 = 2.2μF 10V 10% tantalum (ESR 8Ω)
 C2–C8, C10, C11 = 100nF

Semiconductors

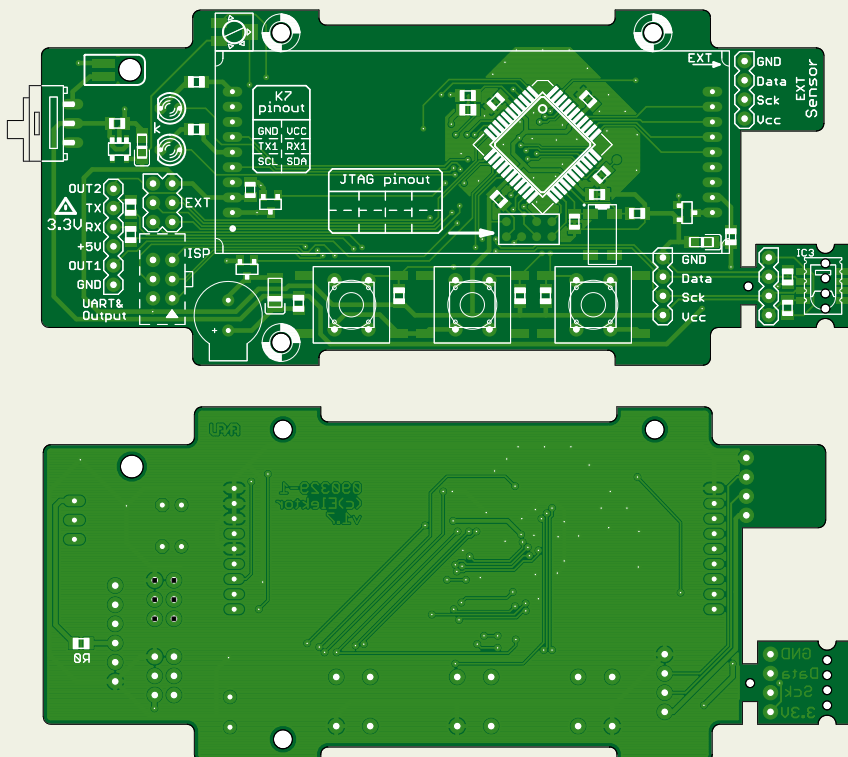
D1, D2 = LED, red, 3mm, high efficiency
 D3 = 1N4148 (SMD version: LL4148)
 T1, T2, T3 = 2N7002, n-channel MOSFET
 IC1 = LP2980AIM5-3.3, 3.3V / 50mA, regulator
 IC2 = ATmega324PA-AU, programmed
 IC3 = SHT11

Miscellaneous

X1 = 32.768kHz oscillator module, CL = 6pF (Epson Toyocom MC-306)
 LCD1 = 4x20 characters (Electronic Assembly EA DIP204-4NLED)
 BZ1 = miniature resonator (CUI CST-931RP/A)
 S1 = micro slide switch (EAO 09-10290-01)
 S2–S4 = pushbutton, SPNO, 12V / 50mA, 6x6 mm – 13 mm, Tyco Electronics FSM14JH
 K1 = 6-pin SIL pinheader, lead pitch 0.1 in. (2.54mm)
 K2, K6 = 6-pin pinheader, double row, angled pins, lead pitch 0.1 in. (2.54mm)
 K3, K4 = 4-way pin receptacle, lead pitch 0.1 in. (2.54mm)
 K5 = 6-pin SIL pinheader, lead pitch 0.1 in. (2.54mm)
 Enclosure, Bopla type BOS400 Streamline with battery compartment for 3 AAA cells (Bopla # BS 401 F-7024) and decorative fixing (Bopla # BS 400 DI-D-7024)
 PCB # 090329-1 [11]
 Front panel design, to print and cover with plastic foil, # 090329-F [11]

Complete kit (with SMD parts soldered on board)

If you're interested in a kit version of this project, please let us know by e-mailing: editor@elektor.com, subject: AirControl Kit.



three new high-grade alkalines will supply over 4.7 V. The frequency of the sound emitted (around 2.7 kHz) is pulsewidth modulation (PWM) controlled by the microcontroller via FET T1. This also allows the power consumed by the resonator to be limited. Tests have shown that PWM with a duty cycle of 40 % makes it possible to obtain a good sound volume.

The LC display is the well-known EA DIP204-4 [3] from Electronic Assembly. This module is not cheap, but there's nothing to compete with it either. Compact and connector-mounted, it provides four lines of 20 characters and a table of characters and symbols that is more suited to our languages than the usual Oriental symbols. The main reason for my choice of this display is the fact that it can be powered from 3.3 V, and doesn't need a negative voltage on its contrast pin: just a preset is enough! It's being driven here in 4-bit mode, but it's also compatible with the SPI bus (see the data sheet for the Samsung KS4073), which I would have liked to have used. Unfortunately, I didn't have the time to experiment with that this time.

The display can be turned off completely thanks to T3, which lets us save around 5–6 mA when the user doesn't need it. The complete initialisation of the LCD controller takes a little time each time the unit is turned on.

The LED backlight requires powering at 5 V, with resistor R9 to limit the current. The backlight is also connected to a microcontroller pin that can supply a PWM signal, which through FET T2 controls its brightness, and hence its power consumption. If the unit is powered from rechargeables rather than alkaline cells, the voltage to the backlight will only be 3.6 V (with fully charged batteries); in this event, the backlight brightness will be reduced, though that doesn't affect the readability of the display.

The circuit is based around an ATmega324PA processor [2] with numerous handy peripherals and very low power consumption. The ATmega88 originally used soon proved inadequate in program memory capacity, and in the number of input/output pins. What's more, the ATmega324 also contains a real-

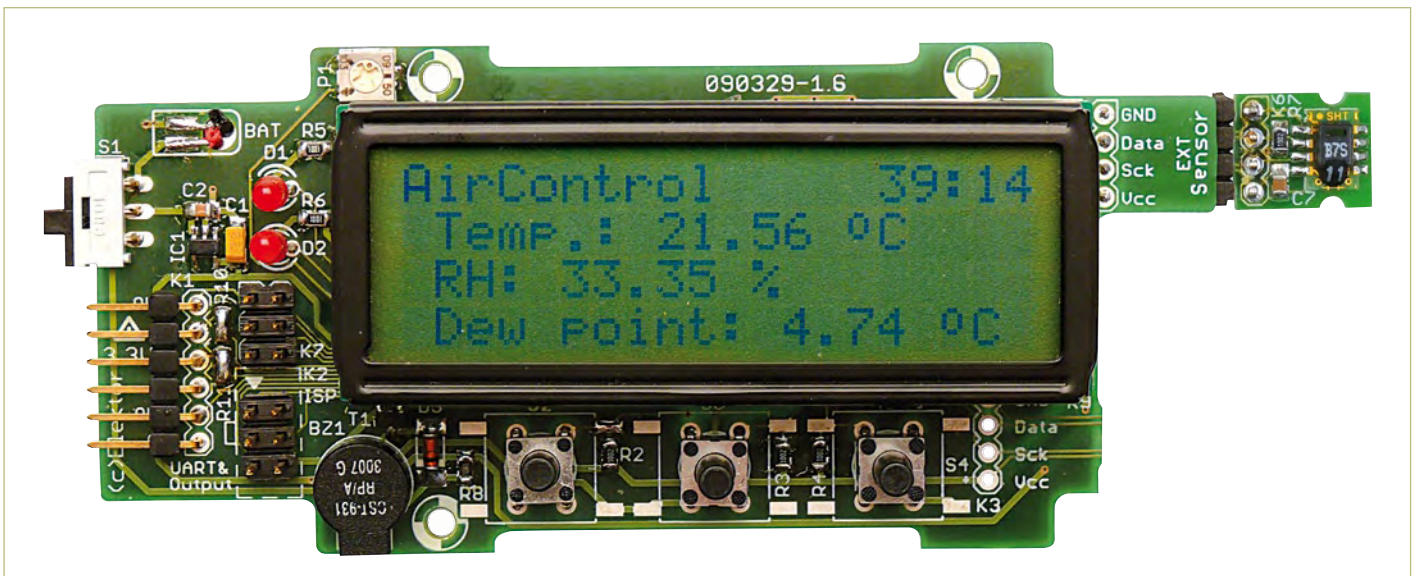


Figure 1. The PCB and main components. The great shy microcontroller is hiding under the display. Spelling error corrected.

time counter, which will let us measure the time. Watch out! Atmel provides here an `RTCCounter` which, even though it isn't a true `RTClock`, does prove jolly handy for developing a real-time clock in just a few minutes. This function will use a timer, a little bit of space in flash memory, an interrupt vector, and a few clock cycles.

It's important to connect to pins `TOSC1` and `TOSC2` of the microcontroller a crystal oscillator that presents a load of 6 pF. In this event, capacitors `C12` and `C13` are not fitted. If the capacitive loading of the crystal is different, it must be corrected using capacitors `C12` and `C13`, the values for which can be determined with the help of the oscillator and ATmega data sheets.

The user interface consists of the display already described, three push-buttons, two LEDs, and a resonator.

The temperature and relative humidity measurements are performed using a `SHT11` [1] from Sensirion, fitted onto a small breakout board, which will make it possible to fit it outside the case to improve measurement accuracy, as well as to use of for other projects (its size is small size, but not its price).

On the circuit diagram, you'll note three expansion ports:

`K1` is a serial port compatible with the `USB-TTL232` cable available in the Elektor shop as ref. 080213-71, which is very handy for hassle-free development. This cable also lets you power the board from the USB bus 5 V rail, provided you make a solder bridge across `R0` on the back of the board. In this

case, it's vital to remove the batteries, as they'll be connected directly to the 5 V rail, which risks damaging them, or even causing them to explode!

Resistors `R10` to `R13` provide basic protection for the external connector, 100 Ω is fine.

`K2` is an ISP connector for programming the

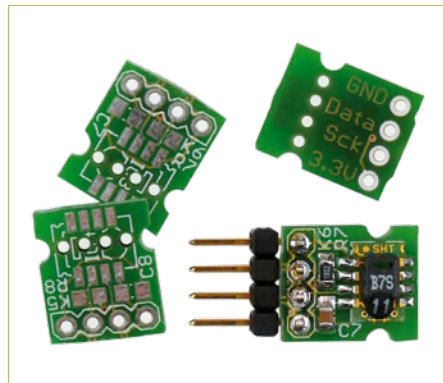


Figure 2. The breakout PCB before / after.

microcontroller *in situ*, i.e. the pins of the SPI bus

`K7` offers a second serial port and the pins of the hardware I²C module. Both may come in useful later on.

Onboard software

The source code files for the onboard software, written in C, are available as a free download on the project page on the Elek-

tor website [11]; they can be compiled using the WinAVR software suite under Windows, or using `avr-gcc + avr-binutils` under Linux (see the `readme.txt` file to find out about the versions used).

I've tried to make everything as simple and easy to understand as possible. The program is structured in three layers. The hardware driver files have the prefix `dr` and contain the explicit name of the peripheral (e.g. `drSHT1x.c/h` for the Sensirion sensor). Only the driver layer can/needs to both access the hardware and provide a simple, but I hope effective, API (Application Programming Interface). The main file containing the 'main' function, which is nothing but the program's entry point (a sort of starting point) is `AirControl.c`, the files containing the tools have the prefix `tlk` and the user interface `ui`.

The sensor uses a synchronous serial link and a proprietary protocol for communicating with the microprocessor. This protocol is similar to the I²C bus one, but is sufficiently different to prevent us from using the ATmega's built-in hardware I²C module. No worries, Sensirion provides good explanations and I've written you a driver for reading the temperature and relative humidity of the air by simply calling the `drSHT1x_measure` function. This circuit returns the values for the air temperature or relative humidity. These values are linearized and compensated.

The real-time clock is available in the file `tlkTime.c/h`. It contains the code for the date structure update interrupt vector

every second, along with two functions for reading and setting the time.

You'll also find special drivers for the LEDs, the keypad, the resonator, and the display. There is also a driver for the serial port `drUART.c`, very handy for debugging the application.

The `tblkRH.c` file contains the dew point and cloud base altitude calculation routines. It requires use of the `math(ematics)` library supplied with the `libc` for AVR, as I've implemented the calculations using floating point operators and variables to make the development faster... the downside is that the library takes up just over 2 KB of the flash memory, the code still runs fast, but I invite our readers to take up the challenge and re-program the whole thing using integers.

The dew point is calculated using the Magnus formula, the mathematical library provides the logarithm to base 10, knowing that

$$\ln\left(\frac{a}{b}\right) = \ln(a) - \ln(b)$$

and

$$\log_{10}(a) = \frac{\ln(a)}{\ln(10)}$$

and that

$$\gamma(T, RH) = \ln(10) \cdot (\log_{10}(RH) - 2.0) + \frac{m \cdot T}{T_n \cdot T}$$

with

$$\ln(10) = 2.302585$$

i.e. the C code:

```
H = (log10(RH) - 2.0) * 2.302585 +
(m*T) / (Tn + T);
Tdp = Tn * H / (m - H);
```

The application is fairly simple and displays all the values available alternately. Pressing the third push-button lets you set

the time. All that remains is to program more economical power management, a turn-off delay time for the display, and configuration for the time interval between two measurements.

Construction

The circuit fits very snugly into the elegant *BOS Streamline 400* case from Bopla with its decorative sealing gasket, as long as you solder the display module directly onto the PCB. It will be flush with the front panel. Before soldering in the display, check the basic functioning of the device. Once the display is fitted, it hinders access to the microcontroller and the JTAG port.

Start by cutting off the part of the PCB intended for the SHT11, unless you really do want to use it inside the case — in which event, remember to provide good ventilation.

Don't try to snap it off; you must saw it off, using for example a little circular saw (and a vacuum cleaner). Avoid exposing the components to fine dust particles, and take care as well to protect your eyes and respiratory tract during this operation.

Connectors K3, K4, and K5 let you connect the humidity sensor inside or outside the case, depending on how you want to use it. For use outside, solder connector K4 **on the back** of the board. In this way, you'll find it easy to cut an opening in the case opposite the sensor PCB, without falling foul of the sealing gasket.

I recommend soldering the SHT11 onto its piece of PCB with a very fine-pointed iron, and avoid taking too long over it. You need to avoid drying out the sensor (refer to the documentation provided by Sensirion where applicable).

Then solder the SMS devices in the oven, then the through-hole components, finishing off with the connectors (only the ones you're going to be using) and the LEDs, which you'll need to fit under the front panel in the holes designed for this purpose.

For the switch and the serial link, it's best to start by milling out vertically within the thickness of the lid so as to reduce it to

around 1 mm. Then make the cut-out for the slide switch. The serial link is optional. If you're using neither it, nor the OUT1 / OUT2 signals, you don't need to make a hole in the case.

All that remains for you to do is to fix the PCB using two or three 2 mm self-tapping screws above the battery compartment. Print the front panel, laminate it with self-adhesive plastic film, for example, and stick it into the recess in the lid.

Conclusion

Many readers will be wondering what use it is to measure cloud base altitude. It will be of interest to pilots, modeling enthusiasts, and people who are simply curious about meteorology. But this project also forms a good base from which to develop a weather station or a climate-measuring device. We'll certainly be coming back to this later in these pages.

(090329-1)

Internet Links

Note that, for easier reading, links in the printed magazine are truncated. For the full links, please go to the project page at [11].

- [1] www.sensirion.com
- [2] www.atmel.com
- [3] www.lcd-module.de
- [4] www.national.com
- [5] www.cui.com
- [6] www.winavr.com
- [7] en.wikipedia.org/wiki/Dew_point
- [8] comprendre.meteofrance.com
- [9] www.astrosurf.com/luxorion/meteo-nuages.htm
- [10] http://en.wikipedia.org/wiki/Standard_temperature_and_pressure
http://en.wikipedia.org/wiki/International_Standard_Atmosphere
http://en.wikipedia.org/wiki/U.S._Standard_Atmosphere
- [11] www.elektor.com/090329

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In-vehicle CO₂ Meter

Safe(r) behind the wheel

Chris Vossen (Elektor Labs) &
Thijs Beckers (Elektor Netherlands Editorial)

CO₂ itself is not really that dangerous, but it can lead to poor concentration relatively quickly. Under certain circumstances dangerous situations may arise from this, for example while driving a closed vehicle. To warn you of this a fast responding CO₂ meter was developed specifically for in-vehicle use.



Specifications

- 12 V operation (via cigarette lighter socket)
- Instantly ready for use
- Warns with indicator LEDs when CO₂ concentration is too high
- Suitable for measurements of up to 3000 ppm of CO₂

The CO₂ Meter published in the January 2008 edition continues to operate very well, so why bother to do a new design? The answer is both simple and obvious. In the previous article, we mentioned that too high a concentration of CO₂ negatively affects the ability to concentrate. And in which daily activity does the ability to concentrate play an important role? Exactly! While driving a car (excluding convertibles). We therefore wanted a CO₂ meter that was suitable for in-car use.

The 'old' CO₂ meter perfectly satisfied the requirements when it comes to its physical dimensions, but the long warming-up period and calibration phase of two hours

are of course not practical for use in a car, when you just want to start the engine and drive off.

Measuring principle

Since the long warming-up time was a requirement of the sensor that was used, there was no other option than searching for another (faster) sensor. And we found one! The ZG01C made by Taiwanese manufacturer ZyAura^[1] (see **Figure 1**).

This sensor uses the NDIR measuring principle. NDIR stands for Non-Dispersive InfraRed absorption (see also ^[2]). This measures the concentration of CO₂ in a gas by using the fact that the CO₂ in the air absorbs infrared light with a specific wavelength of 4.27 μm. By taking a 'tunnel' of known dimensions and filling it with the gas to be measured, and using a suitable sensor and light source, the concentration of CO₂ in the gas sample can be determined quite accurately.

Since the concentration of CO₂ is (or should be) normally quite low in our intended application environment (the car), a relatively long optical path is required to obtain a suf-

ficiently accurate measurement. As a consequence, any suitable sensors are generally quite large and because of the high quality optics they contain, are also quite expensive. However, ZyAura have succeeded in manufacturing a relatively compact and affordable NDIR CO₂ sensor, which is perfectly suited for our intended use.

Intelligent sensor

The sensor is suitable for CO₂ concentrations ranging from 0 to 3000 ppm (refer to specifications), which is sufficient for the application we have in mind. The average CO₂ concentration outdoors amounts to about 400 ppm (parts per million). Values above 3000 are, certainly in a car, very undesirable and can lead the dangerous situations (see table 'CO₂ concentration and effects').

The electronics integrated on the PCB of the sensor module takes much of the work out of our hands. The chip covered with resin (presumably an ASIC) already does all the measuring and interface work and makes the measured data available via an SPI interface. In addition to the CO₂ sensor itself, the module also has a temperature sensor for

ZG01C specifications

- Measuring range : 0–3000 ppm / 0.3%
- Temperature range : 0–50 °C
- Humidity range : 0–95%
- Warming-up time CO₂ : <60 s
- Measuring interval : 7 s
- Accuracy : ±50 ppm or
5% of the measured value

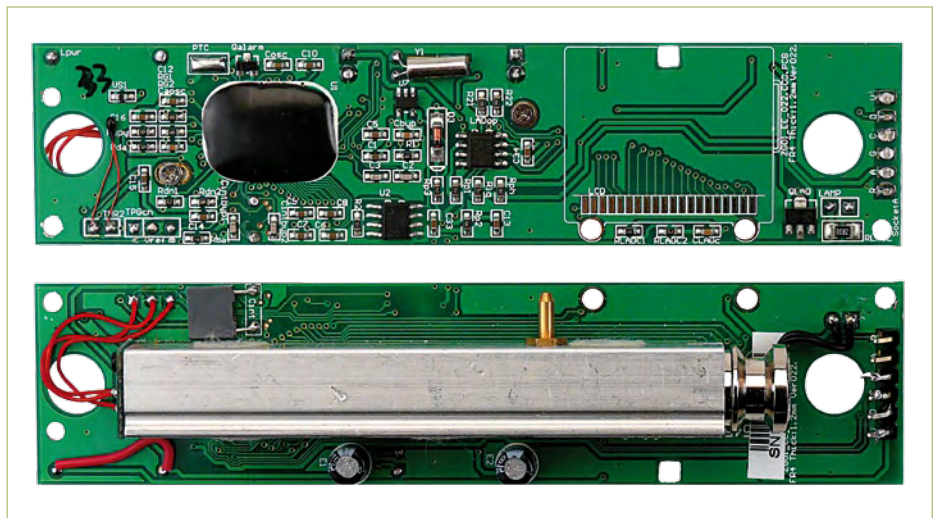


Figure 1. The sensor PCB is already fitted with all the electronics for interpreting the measurement data.

calibration purposes, the measuring result of which is also available via the SPI bus. In fact, all we have to do is show the data from the SPI interface on a display. To do this we use a microcontroller, an ATmega88 from Atmel. Its function is to indicate the measured CO₂ concentration and temperature on a display.

Schematic and PCB layout

Largely aware of what's required for the hardware, we can take a look at the schematic (see Figure 2). Since most of the work is already carried out by the electronics integrated in the sensor module, the schematic is a simple matter.

The SPI data from the module goes via K2 and directly to the microcontroller, which subsequently shows it (via K1) on the display, and depending on the CO₂ value it will turn on one of the LEDs D1, D2 or D3. The microcontroller can be programmed in-circuit via K3. However, you have to disconnect the sensor module first, because both use the same (SPI) bus.

For the display we chose a 2-line by 8-character LCD display module with an HD44780-compatible controller, so that for driving this display you can pick a 'standard' software library off the internet. The display contrast can be set with P1.

For the power supply we started with the battery voltage from the car. The sensor electronics requires a voltage of 6 volts, which is derived from a 7806 powered from the battery voltage. The microcontroller requires a regulated voltage of 5 volts, which is generated using a low-drop voltage regulator type LP2950-50. The power

supply for the LEDs also comes from this 5 V. Diode D4 was added to protect against reversed polarity.

When designing the PCB layout the sensor PCB and LED were taken into account. Both

can be mounted on the PCB with stand-offs. (see Figure 3).

Software

The software for the microcontroller is quite

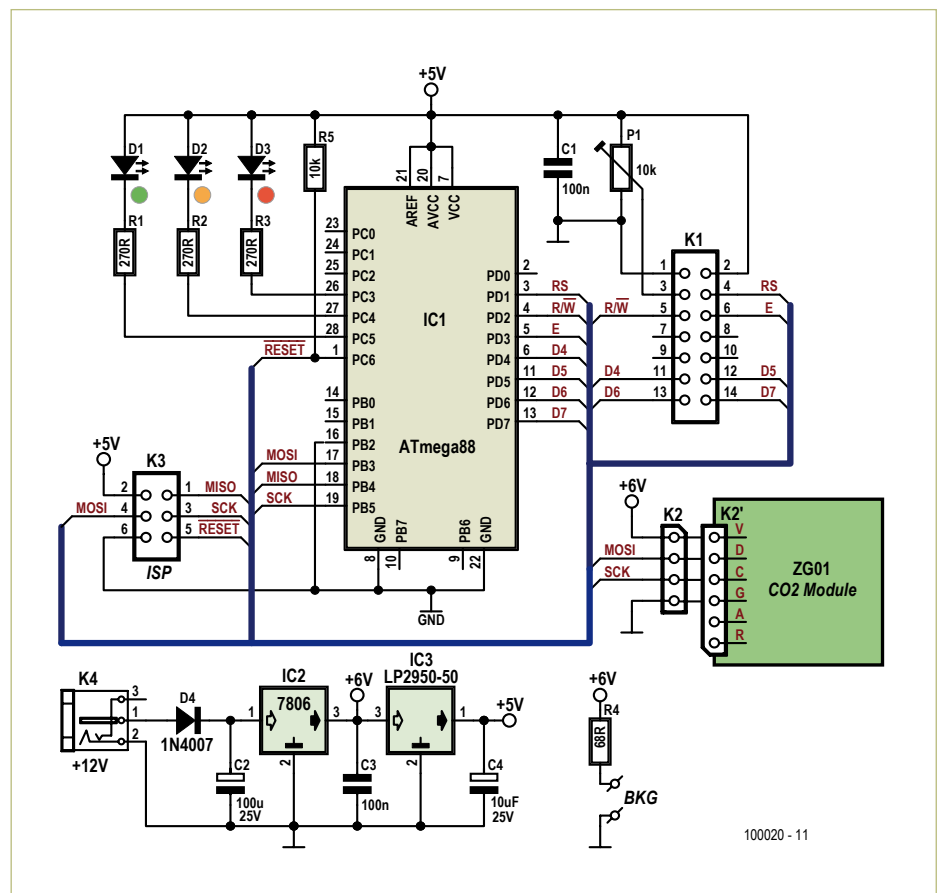


Figure 2. The schematic is very modest thanks to the integrated electronics on the sensor PCB.

CO₂ facts

CO₂ or carbon dioxide is a colourless and odourless gas which is heavier than air. The average concentration in outdoor air is about 380 ppm (= 0.0380% by volume). In cities this value is higher, typically around 700 ppm. In enclosed spaces and when there are (many) people, these values can easily be much higher. An example: exhaled air contains about 4–5% by volume of CO₂, or expressed differently, about 30 cc. When breathing about 16 times per minute that amounts to just under 30 litres per hour. In a completely sealed space of 2 m³ or 70 c.ft (small car) the concentration of CO₂ increases within 15 minutes from 0.05% (500 ppm) to 0.425% (4250 ppm). With four people in this same space this same value will be reached in only a few minutes! In the table you can see a brief overview of the number of CO₂ values and their effects.

The ‘toxicity’ of CO₂ is not really due to the gas proper. At high concentrations (over 2%) it dissolves easily in blood, which raises the acidity level; think of club soda or fizzy lemonade which has carbon dioxide dissolved in it to give it a ‘refreshing taste’. The result is that the blood (or actually the red haemoglobin) can only absorb a limited amount of oxygen, which results in shortness of breath. The same effect is also observed during intense muscular effort and is known as acid build-up.

The concentration of CO₂ does not have to be that high to start to have a detrimental effect. Above about 800 ppm (0.08%) the sense of smell increases, which means that ‘bad smells’ can be noticed earlier and better. This contributes to the feeling that you find yourself in ‘bad air’. Think about when entering an intensively used meeting room or a class room with poor ventilation after an exam.

CO₂-concentration by volume and effects

CO ₂ volume		Description
%	ppm	
0.038	380	World mean value (= 380 ppm)
0.07	700	Urban air, outdoors
0.08	800	Increased olfactory sensitivity
0.14	1,400	Urban air (indoors)
0.4	4,000	Max. value in classrooms
0,5	5,000	Long-term workplace exposure limit
2	20,000	Short-term workplace exposure limit
2.5	25,000	Intoxication-like effects on divers
3	30,000	Increased difficulty breathing
4 – 5.2	40,000 – 52,000	Exhaled air
5	50,000	(Onset of) dizziness and unconsciousness
6 – 8	60,000 – 80,000	Signs of paralysis
8 – 10	80,000 – 100,000	Lethal level

straightforward because of the high degree of integration of the sensor. A software library was downloaded from the internet for controlling the display. After initializing the hardware and configuring the controller as an SPI slave device, the display is cleared and the main loop waits for until it receives a frame. When the checksum of this frame is correct, the temperature and CO₂ value are shown on the display. Additionally, which LED should be turned on is also decided. If the checksum is incorrect, then the entire frame is ignored.

The sensor electronics, on its own accord, sends a data frame every seven seconds via the SPI bus to the controller, so that every seven seconds the displayed value is updated; more than fast enough for our application.

Construction and use

The assembly of the PCB is not likely to cause any problems. As usual, start by soldering the smallest (lowest) components (resistors, diodes, etc.) and finish with the largest (tallest). You can see the component placement in **Figure 4**. Using hook-up wire, solder a 4-pole connector to the sensor PCB, which will then be connected to K2. The schematic of **Figure 2** shows how this connector should be wired.

The PCB copper track layout can be downloaded from the web page for this project [3]. A kit is also available for this project, which has all the parts collected for you (see [3]). After assembly, the PCB can obviously be fitted in the enclosure which we offer with the kit in the Elektor online shop, but you are of course free to choose a housing of your own preference. Note that the enclosure is not supplied with pre-machined openings, so keep in mind when mounting the board in the housing that you need to make a few openings for the ambient air to pass.

The electronics will come to life as soon as the power supply is connected. The measured temperature appears on the display immediately. The CO₂ value requires 10 to 20 seconds of patience: the sensor needs a short warm-up period.

As will be obvious by now, the display shows the measured CO₂ concentration in ppm (and the temperature in °C). To make the readout slightly more noticeable in a car, three LEDs

were added. The green LED (D1) is on when the CO₂ concentration is less than 1000 ppm and is 'normal'. The orange LED (D2) is on when the CO₂ concentration is between 1000 and 1400 ppm (elevated value) and the red LED (D3) will be on when the value is above 1400 ppm, at which point it is time to take action. Particularly when there are several people in the car, this value is reached quite quickly and easily exceeded (see also our 'test report' in last month's E-LABS INSIDE section 'CO₂ meter under test', where values in excess of 1700 ppm were no exception). Particularly during long road trips, both for holidays and business, your concentration is likely to suffer after a while as a consequence of the in-vehicle CO₂ level. While this circuit does not actively keep you awake, it will in any case monitor a potentially dangerous environment and warns you that it is time to open a window or turn up the ventilation a notch.

(100020)

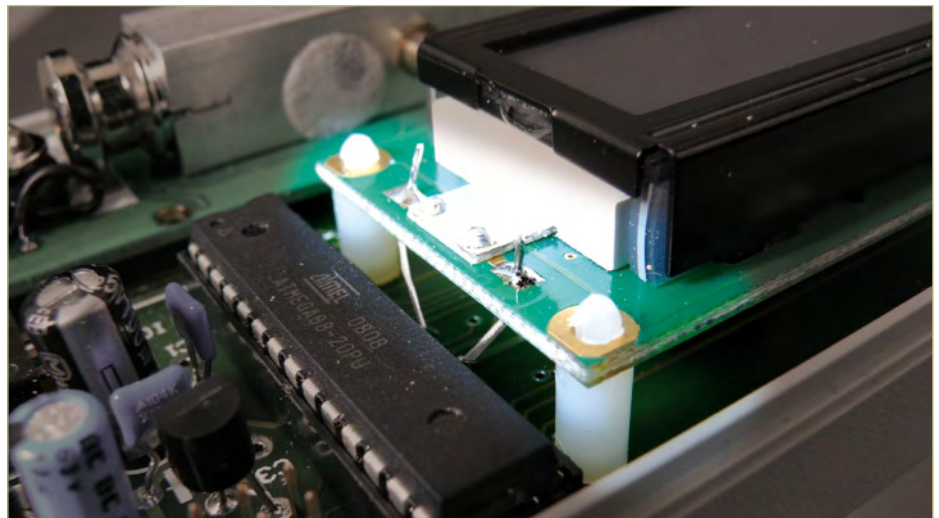


Figure 3. Spacers are used to mount the sensor and display on the PCB. For connecting the display backlight ('A' and 'K') you can use a couple of leads trimmed from the resistors.

Internet Links

[1] www.zyaura.com

[2] http://nl.wikipedia.org/wiki/Nondispersive_infrared_sensor

[3] www.elektor.com/100020

[4] www.elektor.com/090981

COMPONENT LIST

Resistors

- R1,R2,R3 = 270Ω
- R4 = 68Ω
- R5 = 10kΩ
- P1 = 10kΩ

Capacitors

- C1,C3 = 100nF
- C2 = 100μF 25V
- C3 = 10μF 25V

Semiconductors

- D1 = LED, 5mm green
- D2 = LED, 5mm, amber
- D3 = LED, 5mm, red
- D4 = 1N4007
- IC1 = Atmega88-20pu, programmed
- IC2 = 7806
- IC3 = LP2950-50

Miscellaneous

- K1 = 14-pin pinheader (14mm lead length)
- K2 = 4-way header 4-way socket for K2
- K3 = 6-pin (2x3) pinheader
- K4 = DC adapter socket, PCB mount
- LCD type PC0802LRS-AWA-B-Q
- IR module type ZG01
- Hookup wire
- PCB # 100020-1, see [3]
- Kit of parts, including sensor and LCD, Elektor order code 100020-71, see [3]
- Enclosure, Elektor order code 100020-72, see [3]

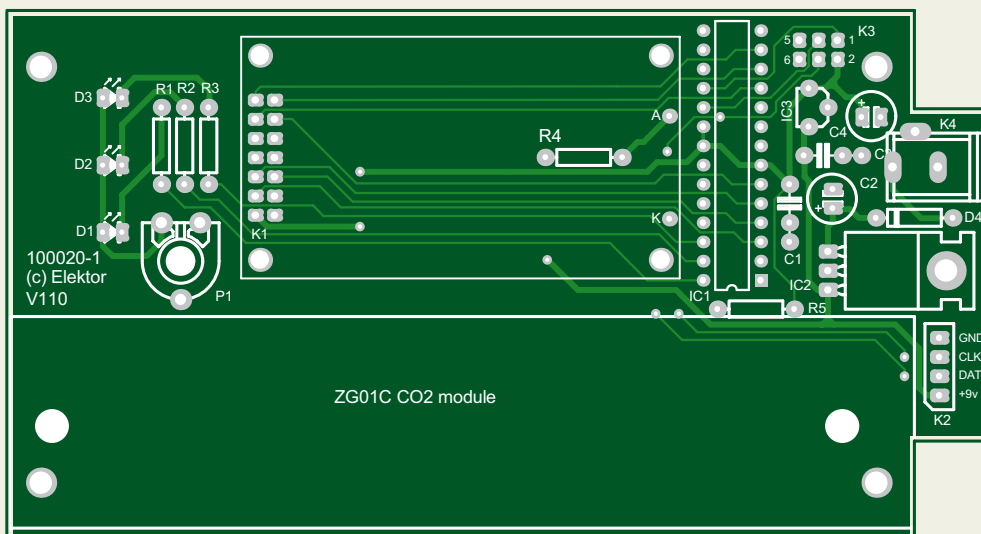
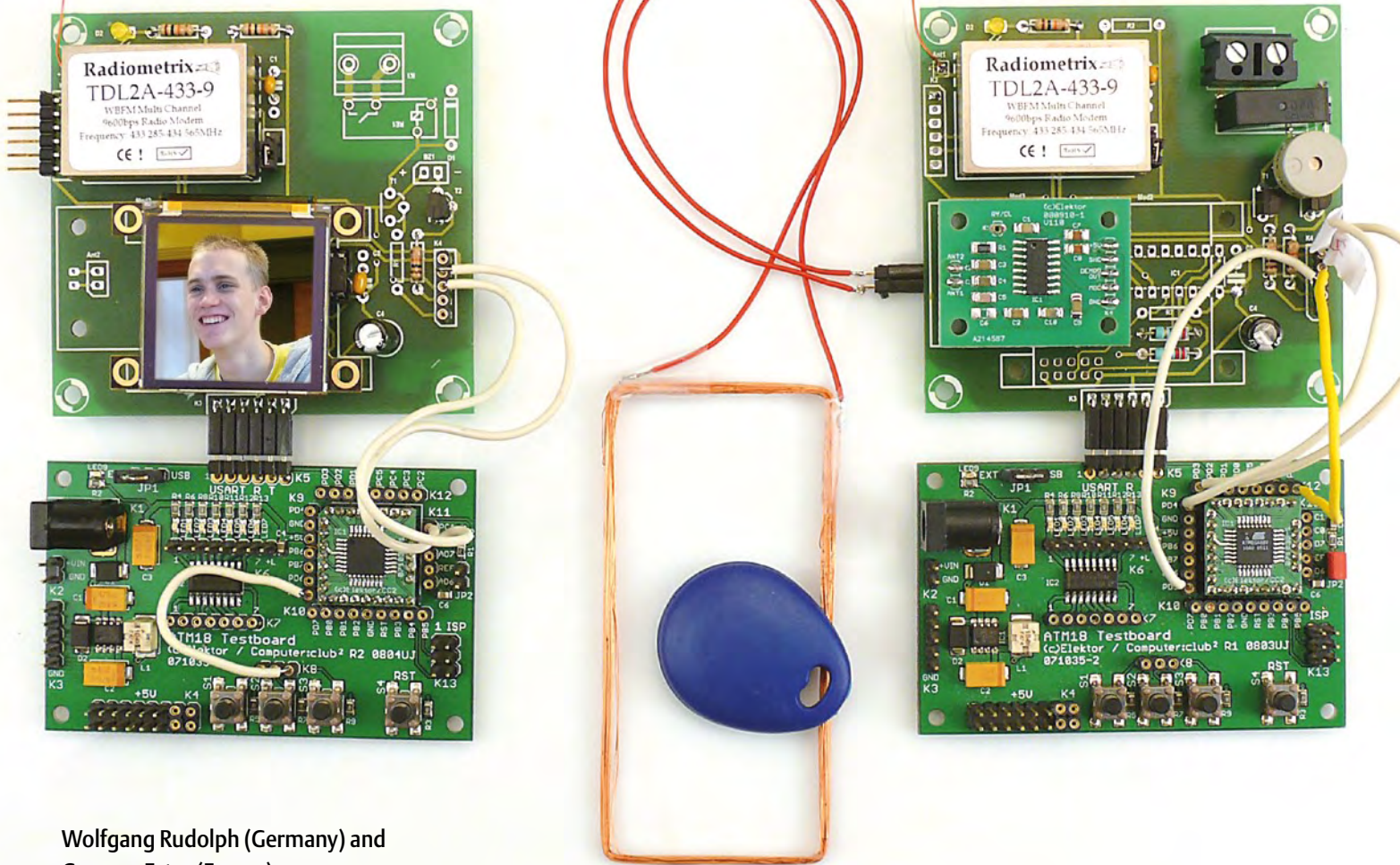


Figure 4. In the component overlay you can clearly recognize the space reserved for the sensor and LCD. Also keep in mind the contrast adjustment using P1.

VisiOLED

ATM18 with color OLED display, wireless link and RFID



Wolfgang Rudolph (Germany) and Gregory Ester (France)

It's a fascinating hardware combination, but what can we do with it? VisiOLED is a wireless door-opener featuring RFID cards for visitor identification, and visualization using an OLED display. The whole thing is based around the ATM18 board.

For a slightly more detailed overview, take a look at the block diagram in **Figure 1**. The outdoor part of the system (situated near to the front door or front gate) and the indoor part, inside the house, employ the same printed circuit boards: the VisiOLED transceiver board and the ATM18 test board. The only difference is in how they are connected up: the outdoor transceiver board is equipped with an RFID reader and an electrically-operated door latch, while the indoor board is connected to an OLED display. The indoor and outdoor stations communicate using a 433 MHz (or equivalent ISM band) wireless link.

ally-operated door latch, while the indoor board is connected to an OLED display. The indoor and outdoor stations communicate using a 433 MHz (or equivalent ISM band) wireless link.

This is VisiOLED, your doorman

The following functions are provided by the software running on the ATM18 boards. Visitors can announce their arrival at the

door using a low-cost RFID card. The RFID data are sent to the indoor unit over the wireless link. If the visitor's RFID card is recognized, an image of the visitor appears on the OLED display for confirmation. The door can now be opened remotely by pressing a button on the indoor unit. In communications between the two units the indoor unit acts as the master and the outdoor unit as the slave. The source code for the project is,

as always, made freely available and so can be used as the basis for other applications involving similar peripherals.

The RFID reader comes from the same stable as the ATM18 board, and was described in the article ‘ATM18 = RFID Savvy’ published in the June 2009 issue of *Elektor*^[1]. A TDL2A 433-9 transceiver (see text box) is used to send the RFID code from the outdoor unit to the indoor unit, where it is compared against a stored list of codes. If a code matches a buzzer sounds and the corresponding image is fetched from the memory card and shown on the OLED display.

Printed circuit boards

Each of the two stations requires an ATM18 test board and a transceiver board (Figure 2). The boards are populated differently in the two stations, which is why we have given two separate parts lists.

The circuit diagram of the transceiver board is shown in Figure 3. It provides all the connections between the ATM18 test board and the other components of the system. The wireless transceiver module (Mod1), the buzzer circuit (T2 and Bz1) and the FTDI cable interface (K2) are fitted in both indoor and outdoor stations. The relay for the door latch (T1 and Re1) and the RFID reader board, plus its antenna coil Ant2, are fitted only in the outdoor station. The following items are only fitted in the indoor station: the OLED module, connected at Mod2 (see separate text box); the 74HC4053 multiplexer (IC1), used to switch the ATM18’s serial port signals (TXD and RXD) between the transceiver and the display module; R2 and R7, pull-up resistors that provide defined logic levels on otherwise open-circuit inputs to the display and transceiver module; and R5 and R6, which protect the 74HC4053 when an FTDI interface cable is connected at K2 to program the unit.

Construction

Populate the two transceiver boards according to their respective parts lists, and check over the boards carefully. In the outdoor unit, don’t forget the wire links that run from R5 and R6 to pins 5 and 4 of K3. These are shown as white lines in the component mounting overlay on the circuit board (Fig-

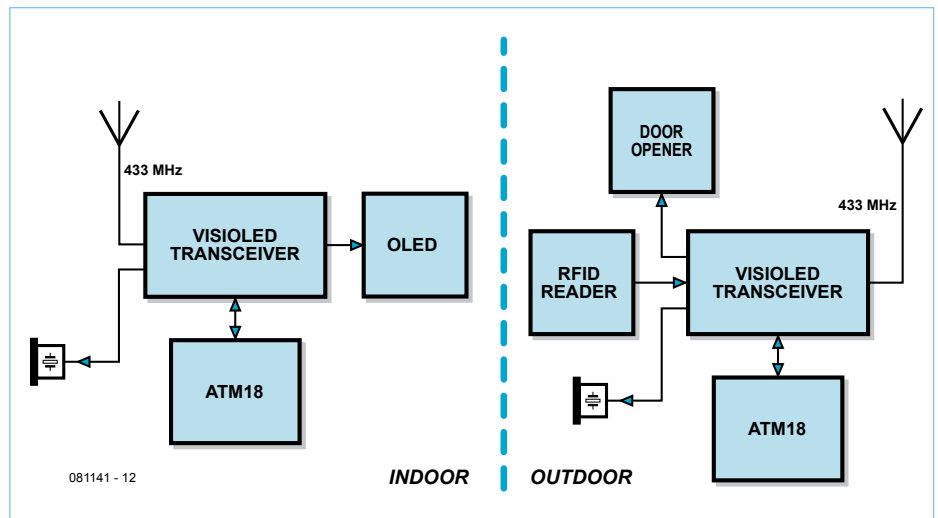


Figure 1. Block diagram of a VisiOLED installation. The outdoor unit is located at the front door, while the indoor unit can be located in any convenient position inside the house.

ure 2) and as dotted lines in the circuit diagram (Figure 3).

The ATM18 board is simply plugged into the transceiver board, mating K5 on the ATM18 board with K3 on the transceiver board. Since the transceiver board receives its 5 V supply from the ATM18 board over this connection, all three pins of JP1 on the ATM18 board must be linked together. The ATM18 board itself is powered from a mains adaptor via K1. A complete list of the necessary connections is given in Table 1.

Before use, the ATmega88 microcontrollers on the ATM18 boards must be programmed with the relevant software. As usual, the software is available as a free download^[2] from the web pages accompanying this article. Within the software the outdoor unit is referred to as the ‘slave’ and the indoor unit as the ‘master’. The program for the slave is written using BASCOM and the program for the master in C.

The software in the master unit must be configured with the codes of the RFID cards

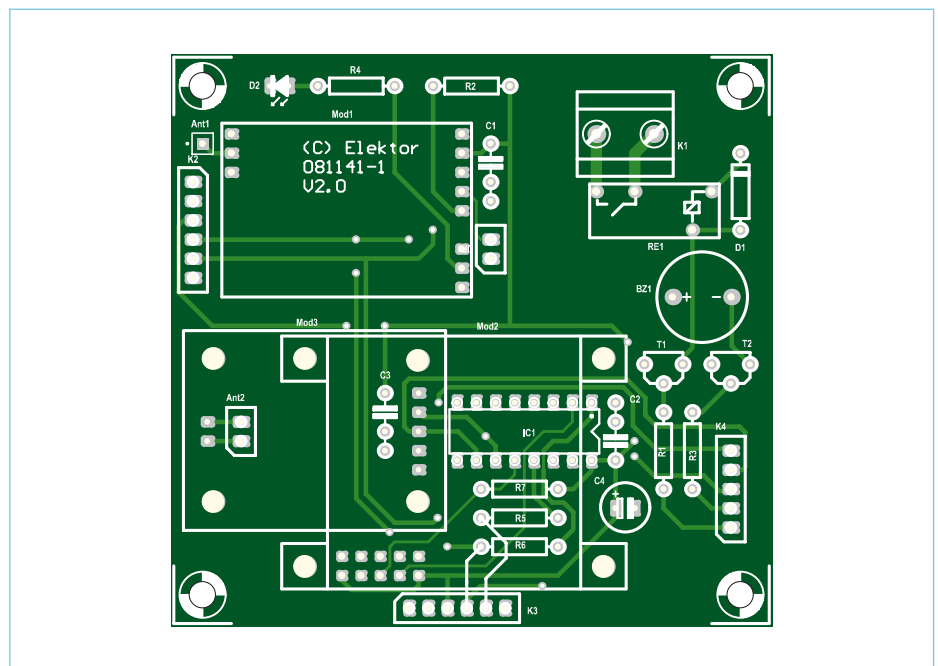


Figure 2. Both indoor and outdoor units consist of a transceiver board and an ATM18 test board. However, different subsets of the components are fitted in the two cases.

Required for:	Connection
Outdoor and indoor unit	JP1: pin 1 to pins 2 and 3 (on ATM18 board)
Outdoor and indoor unit	12 V mains adaptor to K1 (on ATM18 board)
Outdoor and indoor unit	K5 (on ATM18 board) to K3 (on transceiver board)
Outdoor and indoor unit	17 cm whip antenna to Ant1 (on transceiver board)
Outdoor unit / RFID antenna	Antenna coil to Ant2 (on transceiver board)
Outdoor unit / relay (RE)	K4 pin 1 (on transceiver board) to PC2 (ATM18 board)
Outdoor unit / buzzer (BUZ)	K4 pin 2 (on transceiver board) to PC1 (ATM18 board)
Outdoor unit / RFID (SHD)	K4 pin 3 (on transceiver board) to PD5 (ATM18 board)
Outdoor unit / RFID (DEMOD OUT)	K4 pin 4 (on transceiver board) to PD3 (ATM18 board)
Outdoor unit / RFID (MOD)	K4 pin 5 (on transceiver board) to PD4 (ATM18 board)
Outdoor unit / TXD	Wire link from R5 to K3 pin 5 (on transceiver board)
Outdoor unit / RXD	Wire link from R6 to K3 pin 4 (on transceiver board)
Indoor unit / IC1 (S1)	K4 pin3 (on transceiver board) to PC0 (ATM18 board)
Indoor unit / IC1 (S2)	K4 pin4 (on transceiver board) to PC1 (ATM18 board)
Indoor unit / button S3	K8 pin3 (on ATM18 board) to PD5 (ATM18 board)
Indoor-unit / Zoemer BZ1	K4/pen22 (transceiver-print) met PC2 (ATM18)

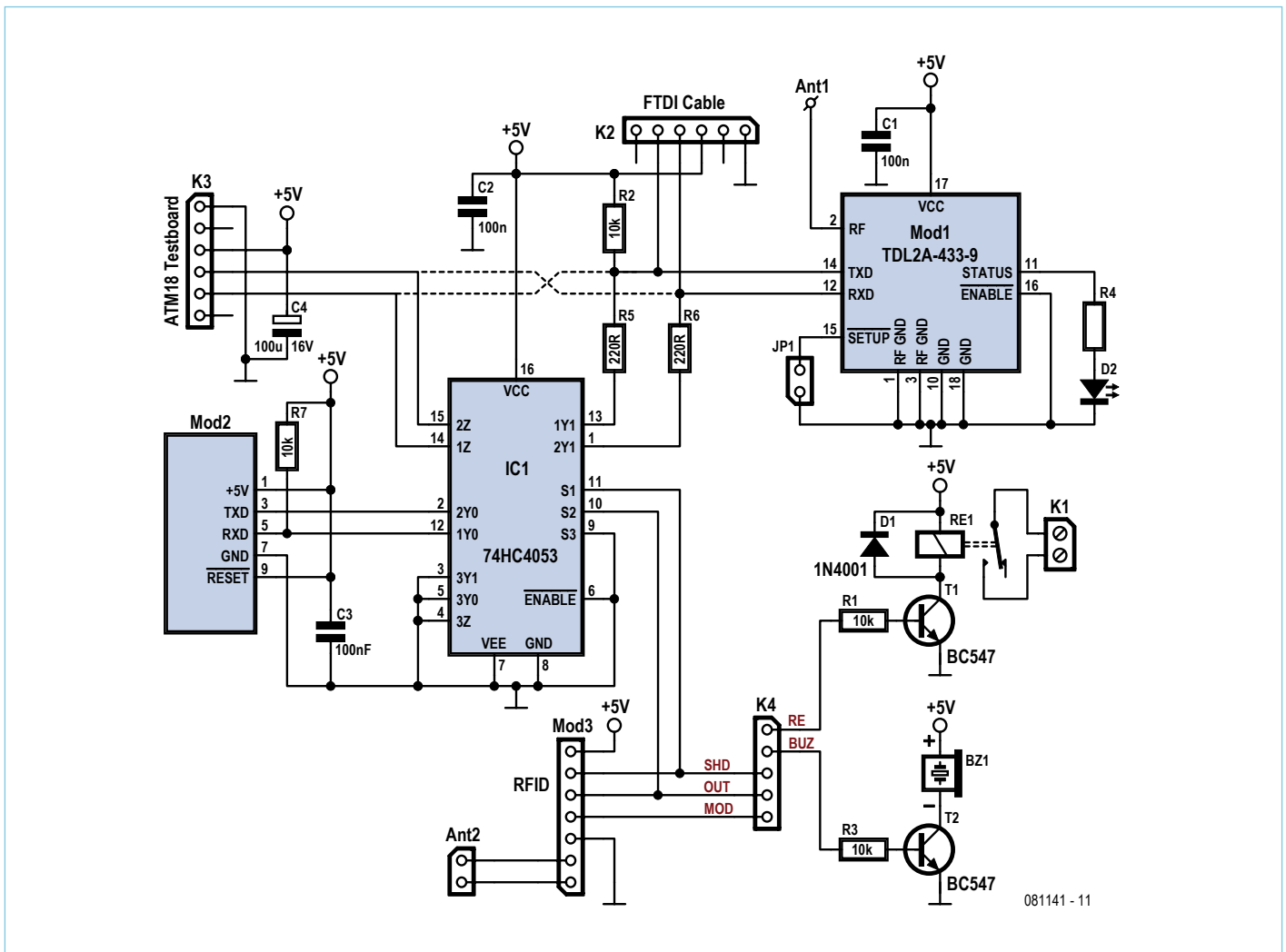


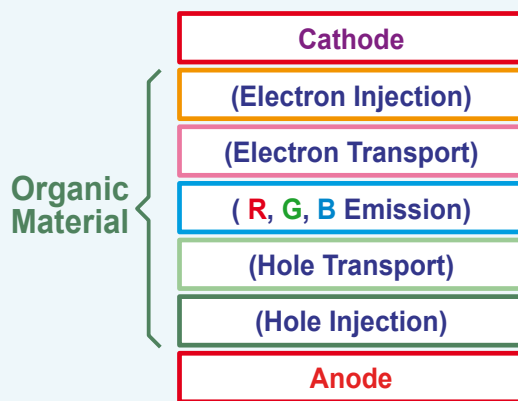
Figure 3. The main job of the transceiver board is to connect the various modules (wireless link, RFID and OLED) to the ATM18 board.

OLED: the future of light production

There are many examples of luminescence in nature. One well-known example is the glow-worm (actually a kind of beetle), which can turn its yellowish light on and off just like an (O)LED. The principle of operation of the glow-worm is biochemical rather than electrical, of course, and it can reach an energy efficiency as high as 95 %!

The first discoveries of electroluminescence in organic materials date back to 1953. Once it had been determined that certain natural polymers exhibit semiconductor properties, processes were developed to synthesise these materials, called conjugated polymers, artificially. The road was now open to manufacture semiconductors and other electronic components from plastics rather than based on a crystalline substrate.

The principle behind light-production in conjugated polymers has parallels to that behind our old friend the light-emitting diode. However, the practical development of electroluminescent displays only began in earnest in 1987, when Kodak, and shortly afterwards Pioneer, started to invest in the technology. Now OLED technology stands on the threshold of wide commercial application. According to DisplaySearch, an American market research company, turnover in OLED displays will grow from US\$500m in 2004 to US\$7bn by 2016.



081141 - 14

OLED manufacture

OLED displays have a simple structure built from one or more organic layers sandwiched between two electrodes. Typically the thick-

ness of the layers is around 100 nm to 200 nm. Two types of organic material are used: long-chain polymers, prepared in solution, and smaller molecules that are deposited using thermal chemical vapour deposition in a vacuum.

For so-called passive matrix displays the layers of molecules prepared in solution are deposited using spin coating, an inkjet process, or similar technique. The light emission principle of these 'polymer OLEDs' is mainly based on fluorescence. OLEDs that employ the smaller molecules ('small molecule OLEDs') also rely on phosphorescence. At voltages of between 3 V and 10 V electrons are injected into the active layer from the cathode. The material of the cathode is chosen to have a low work function (the energy required to liberate electrons from its surface). Suitable choices are metals such as barium or calcium, as well as certain fluorides. Simultaneously holes (positive charges) are injected into the organic material from the anode, which is made from a transparent material such as indium tin oxide (ITO) with a higher work function.

LCD versus OLED

The advantages of OLEDs compared to LCDs arise directly from their principle of operation. The liquid crystal material inside the LCD works like a Venetian blind, either blocking or passing the light generated by the backlight to the observer. OLED displays have no backlight: the light is produced directly in the panel. To display a dark pixel, an LCD has to block its backlight; in an OLED display, the pixel is simply turned off and then draws no power. OLEDs are therefore much more energy efficient than a fully backlit LCD, especially if (as is often the case for video material) the images to be displayed are largely dark. OLEDs have better contrast, some reaching ratios as high as 1 000 000 to 1. Since there is no backlight, an OLED module can be very thin. The low power consumption and economy in materials make them environmentally friendly, and the wafer-thin polymer layers do not contain any harmful substances.

Disadvantages, however

The materials used in OLED panels are extremely sensitive to moisture and oxygen and must therefore be protected behind a glass cover. Also, not all colours of light are produced with the same efficiency: this means higher current consumption and shorter lifetime, and is an obstacle to the widespread use of large full-colour panels. The lifetime of today's OLED panels is no match for that of an ordinary LED: to put this in perspective, however, Sony claims that its first OLED television has an operating life of 30 000 hours before the panel reaches half its original brightness, which corresponds to four hours of viewing every day for some twenty years.

to be accepted along with the address of the image corresponding to each one: the software download includes instructions on how to do this, along with screenshots. The datasheet for the OLED panel includes the necessary information on how to store images on the SD card in the module. All that is needed is an SD card adaptor for

your PC or laptop and a program that you can download for free: see the OLED module manufacturer's website^[3] for further details as well as the datasheet itself.

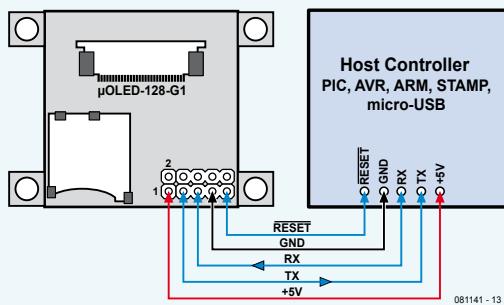
It is possible to configure the Radiometrix transceiver module before use with the help of a serial-to-USB adaptor cable (or 'FTDI

cable') 080213-71^[4] connected at K2. Configuration is essential if, for example, several transceivers are to be used in close proximity to one another. Normally this will not be the case, and the default configuration of the module will be perfectly satisfactory and no programming is necessary. On the other hand, if you do wish to program the trans-

μOLED-128-G1

This compact low-cost OLED display module uses passive matrix technology. The module includes an embedded graphics controller to provide 'stand-alone' functionality. Two software platforms are available: the serial command platform (SGC) and the 4D Graphics Language (4DGL) platform.

The SGC module that we have chosen for this project can be used



as a slave device connected to a suitable host (see accompanying figure).

The protocol used on the serial interface is very simple, with each command consisting of one or more bytes.

μOLED-128-G1 features

- 128 by 128 pixel resolution
- 256 or 65k colors
- 1.5 inch diagonal, module size 45.5 mm by 33.5 mm by 6.3 mm
- Active screen area: 27 mm by 27 mm
- Viewing angle: almost 180 °
- Simple five-pin interface
- Operating voltage 3.6 V to 6.0 V
- Current consumption typically 40 mA at 5 V
- RS-232-like interface (0 V/3.3 V levels) with automatic baud rate selection (300 baud to 256 kbaud)
- Two software versions: serial command platform or 4D Graphics Language

COMPONENT LIST

Transceiver board # 081141-1 with RFID (outdoor)

Resistors

R1, R3 = 10kΩ
R4 = 1kΩ

Capacitors

C1, C3 = 100nF
C4 = 100μF 25V radial

Semiconductors

D1 = 1N4001
T1, T2 = BC547B
D2 = LED, red, low current, 3mm

Miscellaneous

Re1 = 5V relay with 250VAC/5A contacts (e.g. Omron type G6D-1A-ASI 5DC)
Bz1 = 5V piezo buzzer (e.g. Megacera type CPM121A0A)
Mod1 = 433MHz data transceiver, Radiometrix type TDL2A-433-9 or equivalent
Mod3 = RFID module # 080910-91 from Elektor Shop or www.elektor.com/080910

tor Shop or www.elektor.com/080910
Ant1 = wire antenna, length = 170mm (6.7 in.)
Ant2 = RFID antenna coil (160 turns 0.2mm / AWG#31 ecw, 23mm diam., L = 780μH)
JP1 = 2-pin pinheader with jumper
K1 = 2-way PCB terminal block, lead pitch 7.5mm (0.3 in.)
K2, K3 = 6-pin pinheader
K4 = 5-pin pinheader
PCB # 081141-1 from Elektor Shop or www.elektor.com/081141
ATM18 Test Board # 071035-92 with controller module -91 (Elektor Shop or www.elektor.com/071035)

Transceiver board 081141-1 with OLED (indoor)

Resistors

R2, R3, R7 = 10kΩ
R4 = 1kΩ 5%
R5, R6 = 220Ω

Capacitors

C1, C2, C3 = 100nF
C4 = 100μF 25V

Semiconductors

T2 = BC547B
D2 = LED red, low current, 3mm
IC1 = 74HC4053

Miscellaneous

Bz1 = 5V piezo buzzer, e.g. Megacera type CPM121A0A
Mod1 = 433MHz data transceiver, Radiometrix type TDL2A-433-9 or equivalent
Mod2 = OLED display module, 4D Systems type μOLED-128-G1(SGC)
Ant1 = wire antenna, length = 170mm
JP1 = 2-pin pinheader with jumper
K2, K3 = 6-pin pinheader
K4 = 5-pin pinheader
PCB # 081141-1 from Elektor Shop or www.elektor.com/081141
ATM18 Test Board # 071035-92 with controller module -91 (Elektor Shop or www.elektor.com/071035)

TDL2A 433-9 transceiver module

The TDL2A from Radiometrix is a 9600 baud half duplex multichannel wireless module for use in the 433 MHz ISM (license-free) band. It is designed to emulate a simple serial cable wirelessly, offering automatic synchronisation, bit balancing and error detection, as well as automatic noise squelch in the absence of an RF signal.

The TDL2A can be set to one of eight different addresses, and can be programmed to operate on one of five preset frequencies within the 433 MHz band. The channels used are non-overlapping, and so several TDL2A wireless links can be used simultaneously.

TDL2A 433-9 features

- Default operating frequency: 433.925 MHz (ISM)
- Modulation: 16 kbps bi-phase FSK
- Power supply: 5 V at 28 mA (transmitting), 22 mA (receiving)
- Transmit power: +10 dBm (10 mW)
- Sensitivity: -107 dBm (for 1 % BER)
- Adjacent channel rejection: 65 dB at ±320 kHz
- Receiver blocking: 84 dB
- 32 byte data buffer

ceiver module, you will find a description of the various available settings for ID codes and channels on page 6 of the Radiometrix datasheet [5]. Support from Lextronic [6], the French distributor of both the 4D Systems OLED module and the Radiometrix wireless module, has been very helpful in the development of this project.

Operation

The functions provided by the VisiOLED system were described in the introduction to this article. Communication between slave and master to implement these functions uses a very simple protocol.

When the slave reads an RFID card it sends the ID code to the master and then switches its transceiver to receive (or 'listen') mode. The master receives the ID code and looks through its stored ID code list. If the received code matches an entry on the list it displays the corresponding stored image on the OLED panel and sounds the buzzer (the 'doorbell'). Simultaneously it sends the ASCII character capital 'A' to the slave, which in turn sounds its buzzer, indicating to the visitor that the RFID card has been recognised.

If button S3 on the ATM18 board in the master unit is now pressed, it will send the ASCII character capital 'B' to the slave. When this character is received the slave software sounds the buzzer and activates the door latch relay Re1 for 20 seconds. The slave then returns to listen mode.

And that is essentially all there is to it. The software has deliberately been kept simple with space for you to make your own extensions and modifications. Devious readers will have spotted immediately that it is possible to build a master unit based on the design in this article that allows unauthorised opening of any door controlled by a slave unit. This can be prevented by modifying the software to use a more intelligent protocol than just the character 'B' to control the opening of the door. Also, the slave can be protected from casual hacker attack by switching it off when leaving the house. Furthermore, since identification is based solely on possession of an RFID card, the

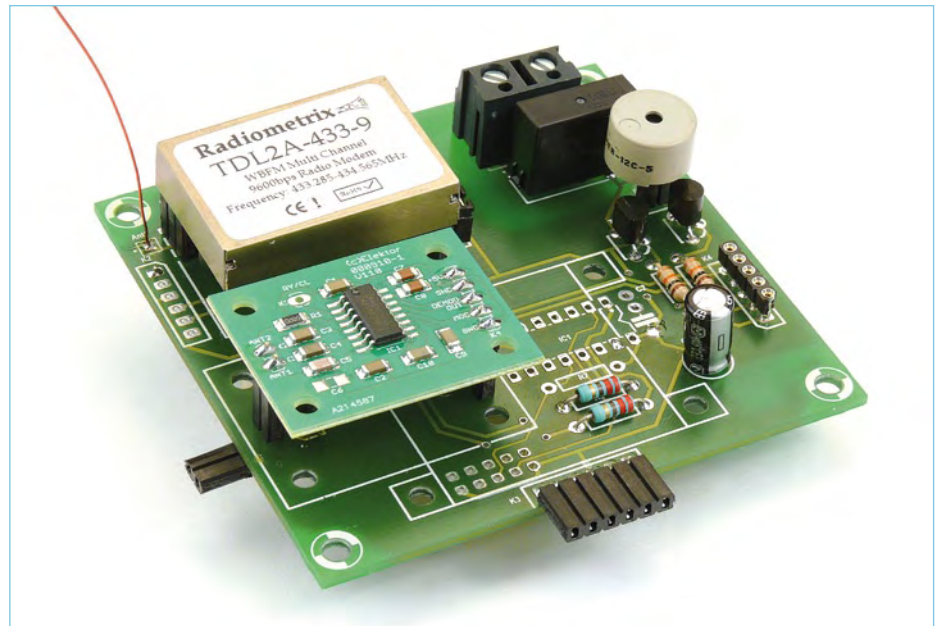


Figure 4. The board for the outdoor unit, fitted with wireless link and RFID modules.

system offers no protection against the use of stolen or cloned cards.

An advantage of the wireless connection is that it is possible to use one slave with more than one master, allowing the front door to be opened from several different places within the house.

(o81141)

Internet Links

- [1] www.elektor.com/080910
- [2] www.elektor.com/081141
- [3] www.4dsystems.com.au/prod.php?id=78
- [4] www.elektor.com/080213
- [5] www.radiometrix.co.uk/dsheets/tdl2a.pdf
- [6] www.lextronic.fr

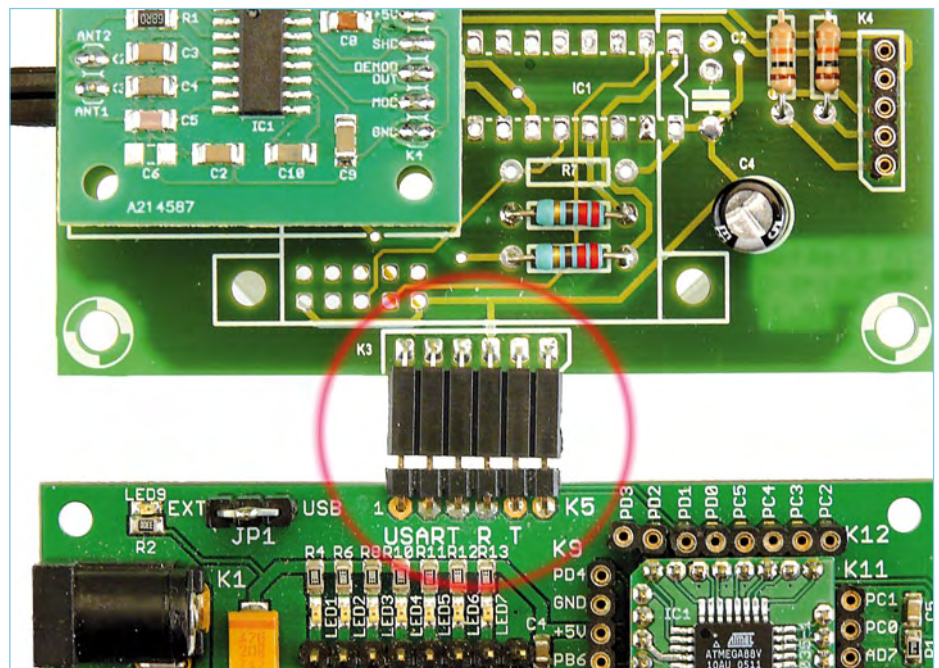
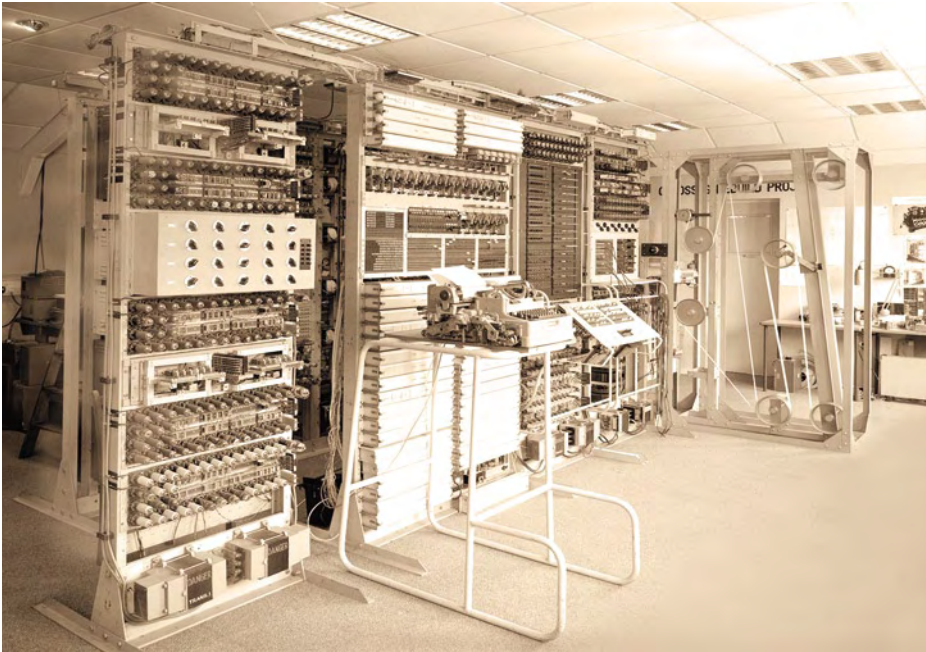


Figure 5. The transceiver board is connected as an extension to the ATM18 board.

Colossus — the Rebuild

A giant digital computer that uses tubes as its main logic elements



By Charles Coultas (UK)

Colossus was a digital computer that contained 2400 tubes and ran its programs as fast as a modern computer. It was designed in 1943 and made a significant contribution to ending World War 2. This is the story of that machine and the rebuilt version that you can visit at Bletchley Park (UK). How did Colossus come about, and how were tubes made into computing elements?

During World War 2 Enigma provided a high level of security for battlefield messaging but Hitler wanted something much more secure, an encryption method that couldn't be broken by clever cryptanalysts. (High Command never knew that Enigma had been broken, they were convinced it was secure.) The machine they chose was called the Lorenz SZ42. It had 12 code wheels (see **Figure 1**), similar to Enigma's three but each wheel had a number of tabs that could be folded in or out. The total number of tabs was 501. In very simplified form, each message character was scrambled by these tabs, then the wheels moved on exposing the next set of tabs. The wheels didn't all move together. This scrambling process was actually the Exclusive-Or function (see later). It was the job of Colossus to find the starting position of these 12 wheels. The message was now effectively randomized and unintelligible — and sure, it was transmitted by radio.

As an aside, at Elektor Live! 2009, Messrs Marc Simons and Paul Reuvers demonstrated their Enigma-E kit based on PIC microcontroller technology — the legend lives on!

Secure — in theory

At the receiving station the process was reversed: each scrambled character was exclusive-or'ed (XOR'ed) with an identical set of 12 wheels with the same tab settings. The resulting unscrambled text was the original message (if you exclusive-OR twice, you finish up

with the original). The receiving station had to know the tab settings in advance of course; these were distributed by highly secure manual means.

This was pretty secure because it was virtually impossible to guess the settings of the wheels. There were strict operating procedures which limited the length of each message, and several other things to make decryption virtually impossible. You might be thinking that letter frequency analysis could lead to a solution but letters were not converted to the same corresponding code letter each time. The method was almost a One Time Pad which is unbreakable (Google it: Wiki One Time Pad).

But on the 30th of August 1941 a German operator sent a long message to a High Command Post, probably in Vienna or Athens. The messages all began with a 12 character identifier (technically known as The Identifier), something like MESSAGE NO 4. He sent his 4000 character message via his Lorenz machine. But the reply came back over the air "Didn't get that, send it again". Of course, all messages were in German.

Breaking a very important rule, both parties reset their machines to the same initial state and the sender retyped his message. He was obviously fed up by this process because he abbreviated some words and made a few mistakes. This nullifies the One Time Pad aspect, allowing analysts to break into the code and possibly solve it.

A British listening post at Knockholt (in Kent) received both messages and the astute operator realised that it was probably the

same message (nearly) again. The results were rushed to Bletchley Park where analysts set to work on it. To have two essentially different messages encoded with the same key was a fantastic gift and Bill Tutte worked out the logical structure of the machine that had encrypted the message.

From this the first Colossus machine was designed and built. It got its name from its high level of complexity. The Mk1 version had 1500 tubes and numerous relays and uniselectors. Its sole purpose was to help work out the wheel tab settings — Colossus didn't decode the encrypted messages, that was done on another machine called Tunny pictured in **Figure 2**. A full description of Colossus and the theory of this type of encryption would take up this whole magazine, so please refer to the references at the end, they will point you to full and interesting descriptions. The rest of this article will concentrate on using tubes as computing elements.

Into technology

The main reason for starting work on Colossus was to store a possible key, all 501 bits of it, electronically. Previous methods used two paper tapes running side by side in a machine nicknamed Heath Robinson due to its weird appearance and complexity. One tape contained the encrypted message, the other contained a tentative key. These two tapes ran at high speed and tube/relay logic did statistical analysis on the resulting data stream. The problem was speed. To run the tapes fast enough to make code-breaking possible in a reasonable time, high speeds were needed, in excess of 1000 characters per second. The results were not good. Tapes broke and keeping the two tapes synchronised was a real problem.

A brilliant engineer at the Post Office had a bright idea. Tommy Flowers had been experimenting with tubes (as part of the telephone network) and he saw a way of storing the possible key electronically, in a form of memory. Only one paper tape (the message) would then run and the electronically stored key would be accessed using tubes. This promised to give enough speed to make the whole task feasible (Colossus runs at 5000 characters per second). The whole project was highly secret of course. Churchill was so impressed that he made unlimited resources available.

Critics of Flowers warned that tube failure would be so great that the machine would never work. But Flowers knew otherwise, by never switching the filaments (heaters) off, very high levels of reliability could be achieved.

Heater energy worries

The rebuild of the Colossus was started in 1994 by Tony Sale. In 1943 the engineers working on Colossus kept the tube heaters on as long as possible, 24 hours a day, 7 days a week. Tony Sale knew this but the thought of several kilowatts day and night was a worry. His solution was to use a large rotary transformer driven by a motor (Google: Variac). This applies the heater voltages (4 and 6.3 volts) very slowly, over a period of a couple of minutes. Similarly, the heaters are powered down by a reverse process. This technique has stood the test of time with very few tube failures over several years. It is the sudden heating that causes heater failure in tubes.



Figure 1. The coding wheels in a Lorenz machine were a wonder of precision metalworking.

The 12 wheels with their 501 tabs are simulated by 501 tubes called thyratrons. These are gas filled and once conducting they will stay in that state until triggered off by pulling the anode Low and extinguishing the conduction ('quenching'). They are like a single tube flip-flop. Unfortunately the heaters of these need 4 V at 1.4 A. This gives 2.8 kilowatts just for the heaters of the thyratrons! These 501 thyratrons are arranged in 12 loops to simulate the 12 wheels of the Lorenz machine. Complicated circuits drive these in exactly the same way as the Lorenz wheels; see **Figure 3** for 1 of 12 controllers — 1 for each wheel. And this is where some of the programmability of Colossus comes in: the starting point of each wheel simulation can be changed, either by hand or automatically by Colossus itself. In effect the machine will automatically search for wheel start positions that seem to give a better match to the key being tried. But how did tubes become logic elements?

From amplifier to logic element

Tubes were always intended to be analogue amplifying devices. With just a cathode and an anode, we have a thermionic diode. If the anode is more positive than the cathode, current will flow. But if the cathode is more positive than the anode, no current will flow. Add a fine grid of wires between the anode and cathode (called the control grid) and we have the triode. This grid controls the current flow between cathode and anode. Apply a varying voltage to the grid and an amplified version of this flows as a current in the triode. Now comes the clever bit. Tommy Flowers was a dab hand with tubes and he knew all about tubes with more electrodes than just cathode, grid and anode. I would guess that he woke up one morning and realised that you didn't have to use the grids for the purpose they were designed for. A pentode has two extra grids between the cathode and the anode: it has a control grid, a screen grid and a suppressor grid. The latter two grids are to improve the amplify-



Figure 2. Little known, this machine called Tunny did the actual decoding of Enigma-encrypted messages.

ing characteristics of the tube but Flowers used them all as control grids. If you keep any one of these grids negative with respect to the cathode, it doesn't matter what you do to the other grids, no current will flow. It is rather like a NAND gate – all three grids have to be positive to cause the anode to pass current. In other words, any grid being Low (negative) will cause the tube to cut off. We have a logic element. (I have simplified this process somewhat.) One circuit that is used very many times in Colossus is the Exclusive-Or circuit (XOR). Remember that the function of Colossus was to detect the subtle key settings on the 12 wheels of the Lorenz machine and this involved making many comparisons. “Does the current character on the input tape match this part of the key” for example. The XOR function produces no output if its two inputs are

the same. You might like to try to design such a circuit. Let's say that a '1' input is a positive voltage and a '0' input is a zero voltage. If both inputs are '1' then the output is '0'. If both inputs are '0' then the output is '0'. But if either input differs from the other, the output is '1' – a true XOR function.

Figure 4 shows one of the XOR circuits from Colossus. The actual XOR function is done by V1 and V2. V3 and V4 are an output buffer. It works as follows: each input is made up of two signals, A and B as shown in the drawing. A and B are always opposite in polarity. If A is positive, then B is negative. The actual voltage levels are plus and minus 80 volts, a hangover from the days of telegraphs and teleprinters. They are a differential pair, and remember, this is only one input. To simplify your understanding how the XOR works assume that if any grid of the tube in question is negative with respect to its cathode, then that tube will not conduct, it will be cut off and its anode voltage will rise. If all grids are positive with respect to the cathode, that tube will conduct and its anode voltage will fall.

Look at V1. One of its grids is driven by I/P1 A line. Another of its grids is driven by I/P2, A line. Thus for V1 to conduct, I/P1 A must be a high voltage, as must the A line of I/P2. Now what does this mean about inputs 1 and 2? Well, it means that both A's of inputs 1 and 2 are High. In other words both inputs 1 and 2 are in the same state, A=80 V and B=-80 V, and V1 will turn on. If either A of I/P1 or I/P2 is Low, at -80 V, V1 will not conduct and V1's anode will rise. Now look at V2. Exactly the same situation exists but this time with the B inputs of I/P1 and I/P2. If both B lines are High, it means that both inputs 1 and 2 are in the same state, with A=-80 V and B=+80 V. If both B lines are at +80 V then V2 will turn on and its anode voltage will fall. If this seems complicated then just keep going over the various states, it is really quite logical.

Notice that the anodes of V1 and V2 are tied together. If they are both off (not conducting) then their anodes rise, pulled towards +200 V by the 68 kΩ resistor, causing the control grid of V3 to rise above its cathode voltage, and V3 conducts, pulling its anode Low. But if the anode of V3 goes Low, the control grid of V4 also goes Low, causing V4 to stop conducting, and its anode goes High.

To summarise: if I/P1 and I/P2 both have their A lines High at +80 V (and this automatically means that their B lines will be Low at -80 V) then V1 will turn on. If the situation is reversed and both B lines are High, then V2 will turn on. If either V1 or V2 turns on, then the anodes of both V1 and V2 will go Low. V3 will turn off allowing the B output line to go High (+80 V), V3 going off will force V4 on and output line A will swing Low. So if both inputs 1 and 2 are the same, output line A will be Low (-80 V) and output line B will be High (+80 V). If the two inputs are different, output line A will be High and B will be Low. Exclusive-OR using just two tubes! V3 and V4 are simply to buffer the output. These signals can be used in many different ways inside Colossus.

The resistors are potential dividers to ensure that the tubes are comfortably on or off, well away from any doubt about what logic

level is being represented. A simple yet elegant solution to quite a complicated problem. You might like to try designing this using transistors.

This explanation is simplified somewhat, you can't make each grid act as a control grid without careful biasing. But this circuit diagram is a real part of Colossus. Notice that the screen grids of V1 and V2 are at +100 V, which ensures that they don't hold the tube off. In some other parts of Colossus the screen grids are also used for logic purposes. You might notice that the screen grids of V3 and V4 are near zero volts and this would suggest that the tubes could not be turned on. But look at the cathodes of V3 and V4, they are tied to -100 V and this means that the screen is in fact 100 volts above the cathode voltage so the screen grid will not stop the tube being turned on.

You will see a three pole jack socket on the diagram. Several such sockets are mounted on a patch panel, they allow an operator to interconnect signals using flexible patch cords (as were used in telephone exchanges in those days). V1 and V2 are EF37A, V3 and V4 are 6V6 (later to become very popular in guitar amplifiers).

The tube with most electrodes used in Colossus is the 6K8G, it is a double tube with one cathode, two anodes and five grids. It is used in the control circuit for each ring of thyratrons (in the front row, middle of Figure 3) — a very complicated circuit. You can Google on '6K8G datasheet'. A good description of pentode tubes can be found at [1]. Other tubes used in Colossus included types EF36, EF37, EF37A, 6J5, 6V6, 6K8, 807 and GT1C.

At the end of the war ten Colossi were operating at Bletchley Park with two more nearing completion. Churchill had them dismantled (although another two about to be delivered went to GCHQ).

Famous last words

Tony Sale masterminded and initially funded the Colossus rebuild. Some twenty other retired or part-retired engineers helped him with the rebuild. Tony's website [2] contains interesting information. Tony who had the idea of rebuilding this magnificent British computer in the first place must have the last word: "I feel very privileged to have met Tommy Flowers before he died in 1998 and to have had the opportunity to recreate his wartime masterpiece, the Colossus computer. The rebuild was started in 1994 and phase one was completed in 1996, the 50th anniversary of the American ENIAC computer. It just made the point that Colossus was the first in 1944 and was British. Because Colossus was kept secret until the 1970s the Americans had got away for far too long with the myth that ENIAC was the first. Now computer history has rightfully been corrected."

Thanks to Bob Alexander (on the rebuild team) for his help with the XOR circuit diagram. You can see Colossus at The National Museum of Computing [3]. Much more detailed information on Colossus and Lorenz can be found at [4].

(100130)

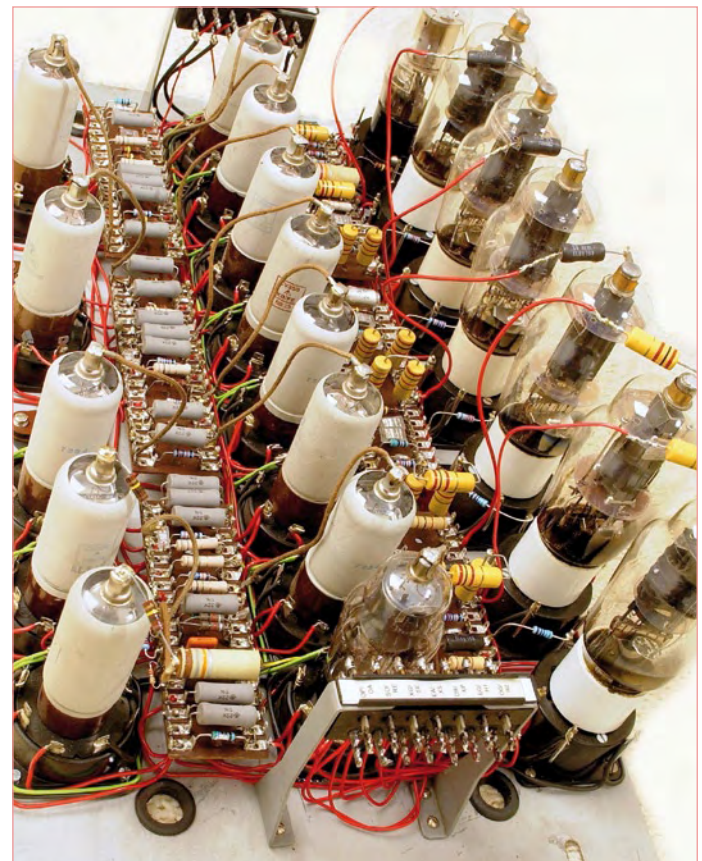


Figure 3. The valve equivalent of a single Lorenz wheel.

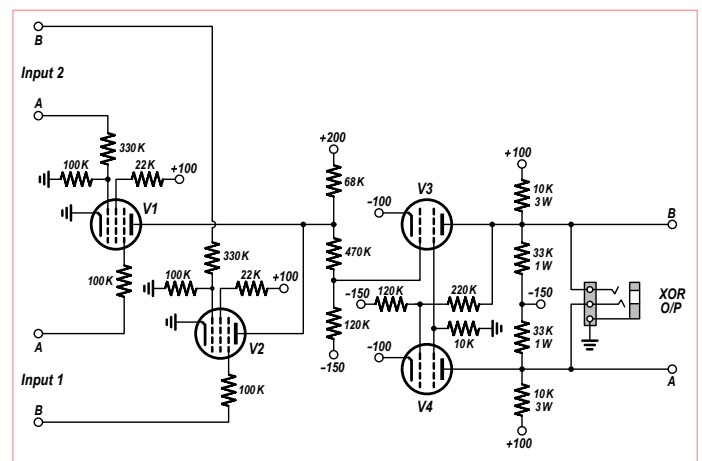


Figure 4. Typical Colossus XOR circuit based on panel J11.

Internet Links

- [1] <http://en.wikipedia.org/wiki/Pentode>
- [2] http://www.vectorsite.net/ttcode_09.html#m3
- [3] <http://www.tnmoc.org>
- [4] <http://www.codesandciphers.org.uk/lorenz/fish.htm>

Low-cost Electric Vehicle Charge Station

A coin operated kWh vending machine

By Miguel Martín Ballbé (Spain)

The acceptance of electric cars seems to be hindered by a general lack of stations where you can charge your battery just as you would 'fill up' at a fuel station, but taking some more time, of course. Here's a design for an electrical energy vending machine that's operated with coins. It's PIC based and the software was developed with Flowcode.



Until recently, the widespread introduction of the Electric Vehicles (EV) as a mainstream option ran into two major obstacles. First, there's the higher price (Tesla Roadster: 100 k\$; Mini-e: 50 k\$; Reva Microcar: 12 k€) which does not yet balance the lower running cost compared to an ICE (internal combustion engine) vehicle.

The other problem is related to EV's limited range (typ. 100 km / 60 miles) compared to the ICE cars, and the need for an AC power outlet to charge the batteries.

The latter is serious — nobody wants to be stuck with empty batteries during the daily commute. However there are some things to consider:

1. the daily to commute distance (home to work), is typically less than 60 km (40 miles);
2. there are AC power outlets (almost everywhere, far more than gas stations);
3. the cost per kilometre/mile is about one third compared to ICE, because the performance of an electric motor is about

85% while ICE performance is about 30%, where most of the energy is dissipated as heat by the exhaust, radiator, clutch, gearbox and brakes.

Installing public AC power outlets close to, or on, parking places is relatively simple, and seems to require only a small investment. EV charging stations can be installed in or near places like restaurants, shopping malls, motorway service areas, municipality parking areas, train stations and so on. For example, there are big shopping malls

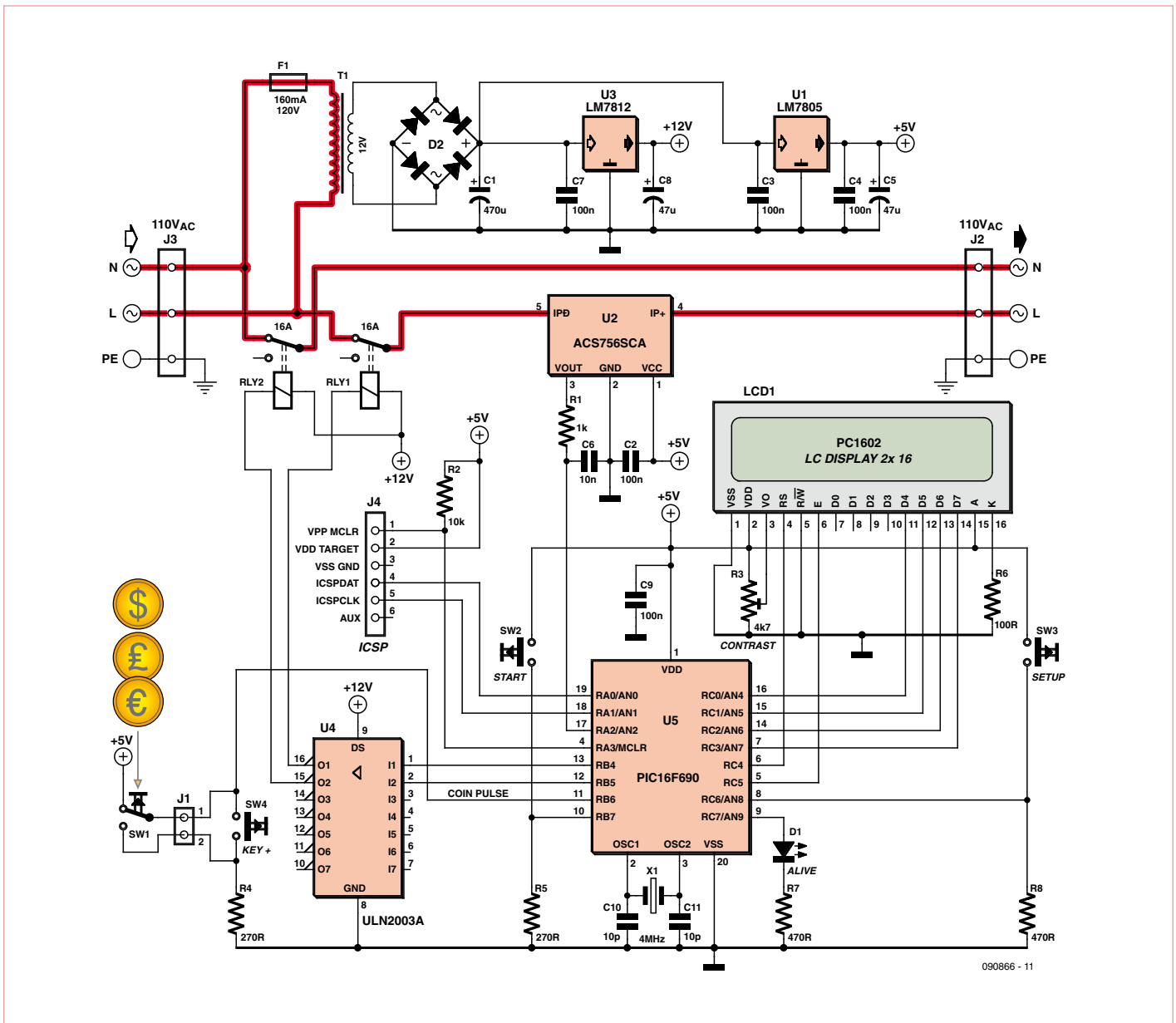


Figure 1. The EV Charge Station schematic.
Be careful with all lines, components and connections carrying live AC — they are highlighted in red.

with underground parkings. The proprietors' interest in installing EV charging stations should be not the immediate revenue, but the time the EV owners could spend there while charging ("shop till you drop"). Basically the same example applies to restaurants, roadside diners and cinemas with their own parking areas. But the energy has to be paid for, and that's where a cost effective EV Charge Station can be useful. To set up a coin operated EV Charge Station, all that's needed is a simple little coin unit in which a switch closes briefly with every (dollar) coin accepted. Next, a circuit should start to measure the

current flow, calculate the energy 'sold' in kWh, and cut off the supply according to the rate set (by you).

Design requirements

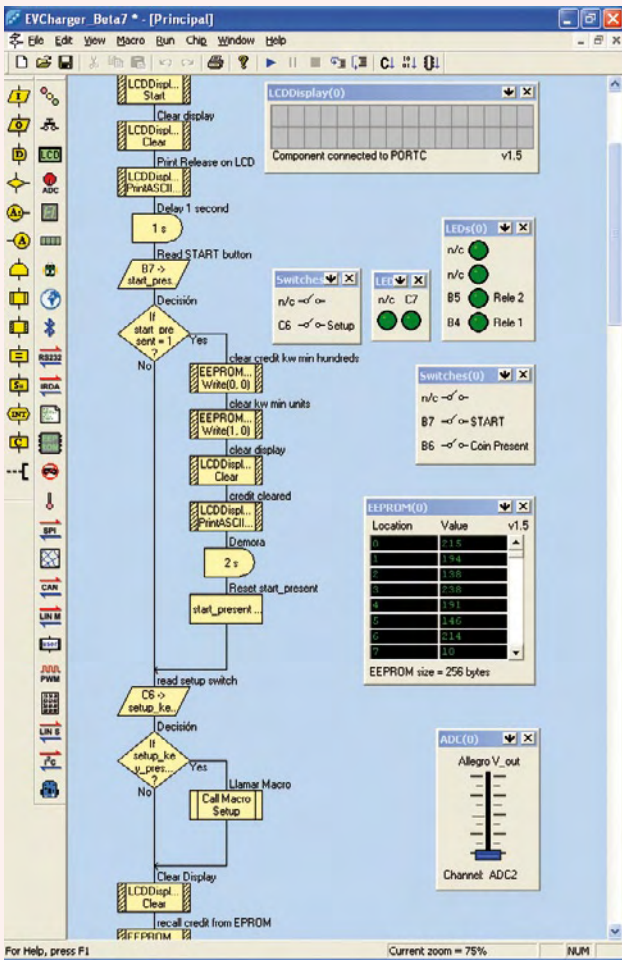
To allow the use of a standard coin-operated vending unit the system has to be able to measure the AC current flow when an EV is being charged. The system will turn the charger on after at least one coin is inserted, and count the total number of coins to compute the equivalent energy in kWh to be supplied to the customer. Measuring the average current flow per second, the system can calculate the amount of energy (in kWh) delivered

to the EV (kWh is the standard unit for billing electricity). The system turns the charger off when the energy supplied equals the amount paid for by coin insertion.

Circuit description

Let's have a look at the schematic in **Figure 1**. When AC power is present, a classic power supply based on 7812 and 7805 regulators delivers 12 V and 5 V DC. The 12V supply is used to energise the coils of relays RL1 and RL2. As the 5 V DC ramps up, the PIC MCU starts running its firmware. There is a small delay provided by the PWRUP-TiMeR set in the config BITS.

The Flowcode macros



Assuming an EV is charging at 10 A_{rms} and the current is sine shaped (largely depending on the load!) then $I_{max} = 10\sqrt{2} = 14.14$ A.

The Allegro device's $V_{out} = 2.5\text{ V} \pm (40\text{ mV} \times 14.14\text{ A}) = 3.0656\text{ V}$ max. (≈ 627 ADC) and 1.934 V min. (≈ 396 ADC) (due to alternating direction of current flow).

Peak_V_out_ADC: $ADC(V_{max}) - ADC(V_{min}) = 627 - 396 = 231$ ADC, this gives the amplitude of AC component in V_{out}.

Scale multiply x10 for better resolution: (8-bit PIC: limited maths!)
 Peak_V_{out}_ADC = Peak_V_{out}_ADC x 10 = 231 ADC x 10 = 2310 (integer).

Peak V_{out}_mV = $(\text{Peak_Vout_ADC} / 1024) \times 500 = (23100 / 1024) \times 50 = 1127$

231 ADC = 1.127V = 1127 mV

Peak_current_A: $\text{Peak_Vout_mV} / 40$. Peak_current = 1127 mV / 40 mV = 28 A (= 14 + 14 A)

Peak_current_A = Peak_current_A/2, i.e. 28/2 = 14 A

Scale multiply x 100 for better resolution:

Peak_current_A: $\text{Peak_current_A} \times 1000 = 14000$

RMS_current = $\text{Peak_current_A} / 1.41 = 14000 / 1.41 = 99$ (9.9 A)

14/1.41 = 9.9 A_{rms} = I_{rms}

This yields the RMS current multiplied by 10 for better accuracy.

The 'second' macro

Calculate the RMS current and produce kW/min:

- Peak_current: $ADC(V_{max}) - ADC(V_{min})$

Once the client inserts coins and pushes the START button, SW2, The PIC sets RB4 and RB5 high, causing the two driver stages in the ULN2003 to pull their open-collector outputs ground, which causes the relays to activate. The Allegro ACS756SCA (U2) measures the current flowing to the EV, and generates a V_{out} signal that's proportional to the instantaneous current passing effectively from the AC power outlet into the EV. The MCU, a PIC16F690 (U5) keeps track of the energy passed to the EV, and updates the display to show to the user how much energy he or she has 'pumped' into the EV. When the energy supplied reaches the value paid for, the PIC de-activates the relay and returns to its initial state. The resistor in series with the backlight LED in the LCD module keeps the standby current low, at the cost of reducing the light output somewhat. Current consumption of the circuit proper is about 30 mA at 12 V input in standby, and 150 mA when charging.

Once the client inserts coins and pushes the START button, SW2, The PIC sets RB4 and RB5 high, causing the two driver stages in the ULN2003 to pull their open-collector outputs ground, which causes the relays to activate. The Allegro ACS756SCA (U2) measures the current flowing to the EV, and generates a V_{out} signal that's proportional to the instantaneous current passing effectively from the AC power outlet into the EV. The MCU, a PIC16F690 (U5) keeps track of the energy passed to the EV, and updates the display to show to the user how much energy he or she has 'pumped' into the EV. When the energy supplied reaches the value paid for, the PIC de-activates the relay and returns to its initial state. The resistor in series with the backlight LED in the LCD module keeps the standby current low, at the cost of reducing the light output somewhat. Current consumption of the circuit proper is about 30 mA at 12 V input in standby, and 150 mA when charging.

Software and calculations

Flowcode V3 for PIC Micros was used to develop, simulate and compile the program. The .fcf file is available free from the Elektor website.

The Macro 'Main' is summarized below. Print release on LCD. If the START button is pressed, reset the credit value stored in EEPROM (this allows the owner to clear remaining credits). Copy credit value stored in eeprom. This makes possible to resume charging in the event of a power failure, recalling the credit data. Display 'enter coins and press START'. Read input switch Coin from the coin validator.

Customer credit is increased with every coin. When the customer has inserted the coins and plugged the EV, he/she can push



```

- Peak_Vout: (convert from ADC to mV)
- Delta_current: Peak_mV/40
- RMS_current: Delta_current/2
- Reset min. max. values to 512 (prepare for next measurement
cycle)
Calculate W/s:
- W/s: RMS_current(Amps) x 230 V (or AC grid voltage defined in
'setup' macro)
- instead W/s= RMS_current x 23 = 99 x 23 = 2277 W/s (RMS_cur-
rent was multiplied x10)
Show in LCD RMS_current (divided by 10) and remaining credit in
kW/min.
(Aside) counting in kW/min gives the charger a 'fuel pump' feel so
you can see the initial credit decreasing slowly. Remember, 1 kWh =
3.6x106 Ws = 60 kWmin.
Calculate W/s
- Carry_W/s= W/s + Carry_W/s
- if carry_W/s >60000 then kWmin= kWmin+1; and carry_W/s=
carry_W/s - 60000
- if kWmin >= 6 then subtract 1100 Wh from credit and set kWmin
= 0
- Credit= credit - 1
- then go to macro 'update LCD'
- return
Compare credit, IF credit <=0 then switch relay off and goto init.
return

```

Let's suppose an EV draws 10 A, and the user has paid effectively for

6 kWh i.e. 360 kWmin)
power= 10 A x 230 V = 2.3 kW
time= 1/2.3 kWh = 0.434 hours = 26 minutes. (i.e. 1 kWh is trans-
ferred every 26 minutes)

The system measures I_{rms} every second. $I_{rms} = 10$ A
Power = $I_{rms} \times 230$ V = 2300 Ws
carry_W/s will reach the value 60000 every 26 seconds (60000 Ws /
2300 Ws = 26)
60000 Ws = 1 kWmin and 60 kWmin = 1 kWh
Every 26 seconds kWmin will decrease one unit, from 360
downwards.
After 360 x 26 seconds = 9360 seconds = 156 minutes (shopping
done ☺), the relays will switch off.

The 'set-up' macro

A setup facility is provided to allow the owner to adjust the system to
the voltage present in the installation, to calibrate the accounting of
energy, and to change the kWh vending price.
Set-up is entered when the system boots while switch 'setup' is
pressed.
The Coin switch doubles as '+'; Setup doubles as '-'; Start doubles as
'confirm'.
The AC grid voltage, price and calibration are stored in EEPROM for
use in the macro 'main'.

The 'finish' macro

This clears the LCD and switches off the relays.



the START button and the relays close. Even Top Gear's Captain Slow should be able to do this.
Credit = coin credit x 6 x 60. i.e. 6 kWh; however the internal unit is kWmin (1 kWh = 60 kWmin).
If credit > 0, START charging after 30 seconds, even without the user pressing START. This is to resume charging in the event of a power failure.
The program has a loop to take 2000 (or 'calibration number') measurements of the V_{out} signal from the current sensor. The actual value will be compared and max. and min. values will be saved. The output of the ACS756SCA is linear, depending on the current flow, so knowing V_{out}, implies knowing the instantaneous current value (IP).
The Allegro's V_{out} is V_{cc}/2 when I_p = 0. In terms of the ADC (10-bit) this equals 1024/2 = 512 ADC, since V_{cc} = 5 V =

1024 ADC. The current is AC and sensitivity is 40 mV/A.
The current I_{rms} is measured and calculated from: $I_{rms} = I_{peak} / 2\sqrt{2}$.
A discussion of the rest of 'main' and other macros, including several calculations performed by the system may be found the **inset**. You may want to refer to the Flow-code program in archive file **090866-11.zip** to be able to follow the use of some labels.
"Let's we forget", the PIC config bits: XT, WDT-OFF, POWUPTMR-ON, MCLR-External. Fail-Safe clock enabled. A 4 MHz quartz crystal is used.
First start-up
The first time the system is powered up, the data in the EEPROM is inconsistent, showing abnormally high credit values. To solve this, simply switch the system ON with the



START button pressed. The display will show 'credit cleared'.

Next, run the SETUP macro, this will load correct values into several variables. This is done by switching the system ON but this time keeping 'SETUP' pressed. Some instructions are displayed about the COIN switch acting as the '+' key, likewise 'SETUP' doubling as '-' and 'START' to confirm your selection.

First the system asks for the voltage setting. You can press keys to increase or decrease AC grid voltage. The initial value is 230 VAC. Set the actual value in your area, not the nominal value.

Second, the calibration value — lowering it makes the system calculate faster.

Finally the selling price is adjusted by setting the number of kWhs credited by one coin.

Example!

Test conditions: Velleman Power Monitor, input 230 VAC but only 220 VAC out when loaded with a 1400-watts heater. Credit equal to 6 kWh, shows 360 kWmin on display. Power monitor showing 0.0 kWh. Calibration value default: 2000. Connected load (1400 W heater), 6 A detected both in Velleman and EV charger. After approx. 46 minutes, the Velleman Power Monitor reading changed from 0.9 to 1.0 kWh. The credit on the EV Charger was 302 kWmin. End of test.

So the EV Charger accounted for 58 kW/min, instead of 60 kWmin. Recalling that 1 kWh = 3,600,000 Ws, we have 58 kWmin = 3,480,000 Ws and consequently a difference

of 120,000 Ws to account for. The upshot is that the macro 'second' was called in a too large period. With $3,600,000/3,480,000 = 1.034$ you get an approximation only, but the period of calling macro 'second' appears to be 34 ms too long. Now, if 1.034 s is achieved with calibration '2000' then 1 second is achieved with $2000/1.034 = 1933$, which will be the required calibration value.

Closing considerations and ideas

Looking at different kinds of EV, a typical electrical scooter charge in kWh is: 48 V x 60 Ah = 2.88 kWh. An electric car charge in is much larger at up to 30 kWh, say, for the BMW Mini-e AC Propulsion, or the Tesla Roadster. The ElektorWheeler, then: 24 V x 9 Ah = 216 Wh which in the author's country cost 3 euros to recharge (assuming 1 € gives 33 recharge units). An electric scooter takes only one hour to recharge, while a car can take up to eight hours.

The use of an Allegro current sensor was inspired by the *ElektorWheeler* article. The 756ACS device being bidirectional, it's better suited for AC applications. The device comes factory calibrated and a comparison of readings against a high-end Fluke current clamp gave identical results.

Future enhancements include improving the disconnecting of the relays when the credit is zero. First check for I_{RMS} , and if the current is still large, say larger than 4 A, switch the relays when the current passes the zero crossing. This involves delays in the relay, the driver and the MCU to be accounted for.

Lastly, I'd like to see an AC line voltage measurement included to ensure energy calculations are fair to both vendor and customer.

(ogo866)

Some interesting websites

<http://evworld.com/index.cfm>

http://fadel.com/vending-cebek/coins-selector_P_325.aspx

www.abberfield.com.au/a/60.html

Electrical safety

The hardware is connected to an AC power outlet and does not constitute an isolating device between the AC grid and the load. Consequently, **all relevant electrical safety precautions for equipment carrying and routing live AC power must be observed when building and using this project.** This should not be taken lightly and some help is provided by the red lines in the circuit diagram; these indicate connections carrying live AC and requiring suitable isolation. Constructors should also observe 'safety guidelines for charging' supplied by the manufacturer of any EV connected up.

It is mandatory to install proper earthing for outdoor use, as well as an external current limiter. The *Campsite AC Monitor* from Elektor June 2009 is an ideal complement for ad hoc grids with 10 A or less available.

All plugs, cables, wiring and sockets used on, or in conjunction with, the EV Charger must be rated and approved for outdoor use. The unit should be mounted in a rugged enclosure complying with your national or local electrical safety regulations and the same goes for the coin validator.

Finally, beginners should seek the assistance of a qualified electrician when building this project.

Hexadoku

Puzzle with an electronics touch

High time for some puzzle fun with this new May 2010 Hexadoku. Leave the lawn mower in the shed, the solder iron in the stand and get cracking with this month's challenge.

Send the hexadecimal numbers in the grey boxes to us and you automatically enter the prize draw for four Elektor Shop vouchers. Have fun!

The instructions for this puzzle are straightforward. Fully geared to electronics fans and programmers, the Hexadoku puzzle employs the hexadecimal range 0 through F. In the diagram composed of 16 × 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 4×4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation. Correct entries received enter a draw for a main prize and three lesser prizes. All you need to do is send us the numbers in the grey boxes.

Solve Hexadoku and win!

Correct solutions received from the entire Elektor readership automatically enter a prize draw for one Elektor Shop voucher worth \$140.00* and three Elektor Shop Vouchers worth \$70.00* each, which should encourage all Elektor USA readers to participate.

* subject to €/\$ exchange rate

Participate!

Before June 1, 2010, send your solution (the numbers in the grey boxes) by email, fax or post to

Elektor Hexadoku – 4 Park Road – Vernon CT 06066
USA.

Fax 860-8751-0411

Email: hexadoku@elektor.com

Prize winners

The solution of the March 2010 Hexadoku is: 51E7A.

The \$140.00* voucher has been awarded to: Jan Schoubo (Denmark).

The \$70.00* vouchers have been awarded to: Paul Kirsch (Luxembourg), Laurence Hamelin (France) and Maarten Koppe (The Netherlands).

Congratulations everybody!

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

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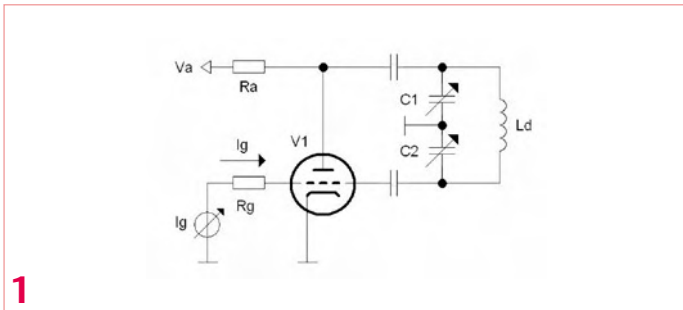
1	9	C	F	3	7	8	D	A	4	E	B	2	0	6	5
5	2	7	4	6	E	0	B	F	C	D	3	9	A	8	1
3	D	6	0	C	2	A	9	5	1	7	8	F	E	4	B
8	E	B	A	1	5	4	F	0	2	9	6	C	D	3	7
7	1	E	9	4	0	2	6	3	8	B	F	D	C	5	A
6	8	5	D	B	C	7	A	4	9	1	0	3	F	2	E
2	0	F	3	8	D	5	1	E	7	A	C	4	6	B	9
4	C	A	B	F	9	3	E	6	D	5	2	7	1	0	8
A	4	2	6	0	8	1	7	B	3	C	5	E	9	F	D
B	7	0	5	9	6	E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

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

Grid Dipper

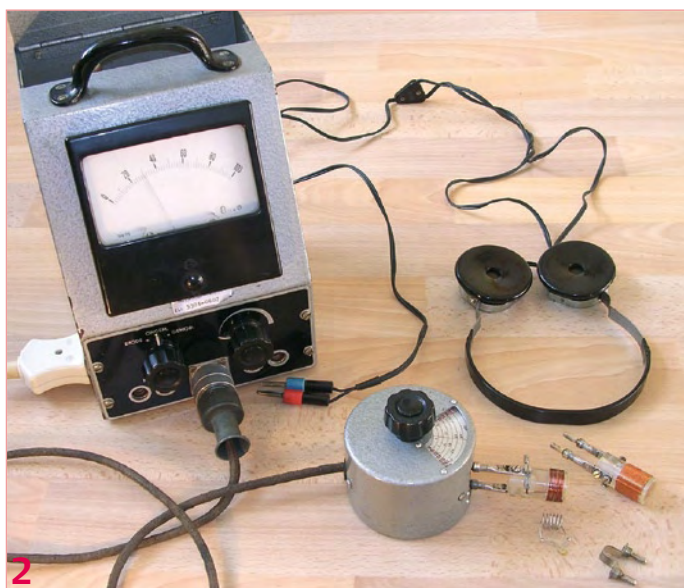
By Ronald Dekker (The Netherlands)

For a long time, the grid dip meter was the 'HF multimeter' of every RF engineer or technician. Like an ordinary multimeter, it is a simple instrument that can be used for a wide variety of quick and useful measurements on high frequency circuits, such as determining the resonant frequency of an LC circuit, determining the values of unmarked coils or capacitors, and checking the signal paths of RF stages.



1

A grid dip meter essentially consists of nothing more than an LC oscillator with a moving-coil meter that provides an indication of the amount of power drawn by the oscillator. The oscillator coil is mounted outside of the grid dipper enclosure so that it can be brought close to the LC circuit to be measured. The operating principle is very simple in practice. The frequency of the oscillator is varied slowly by adjusting a variable capacitor. When the oscillator frequency matches the resonant frequency of the circuit being measured, the circuit will start to resonate. The circuit thus draws power from the oscillator, which is indicated by a 'dip' on the meter. The resonant frequency of the circuit being measured can be deter-

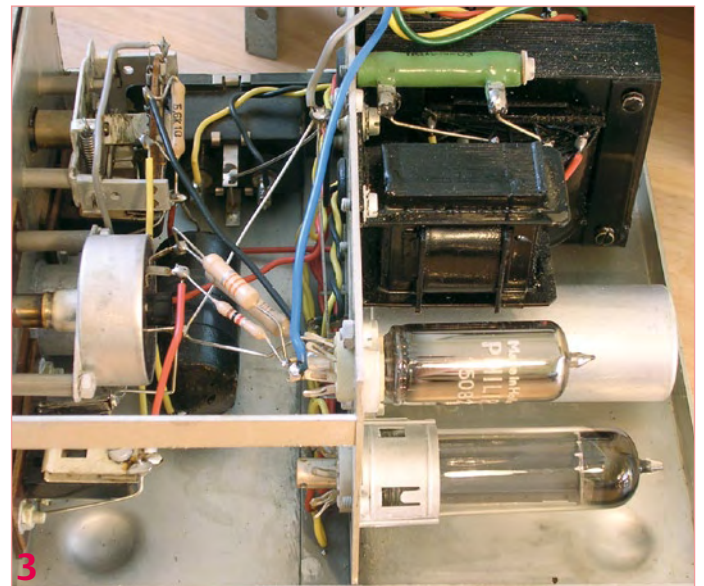


2

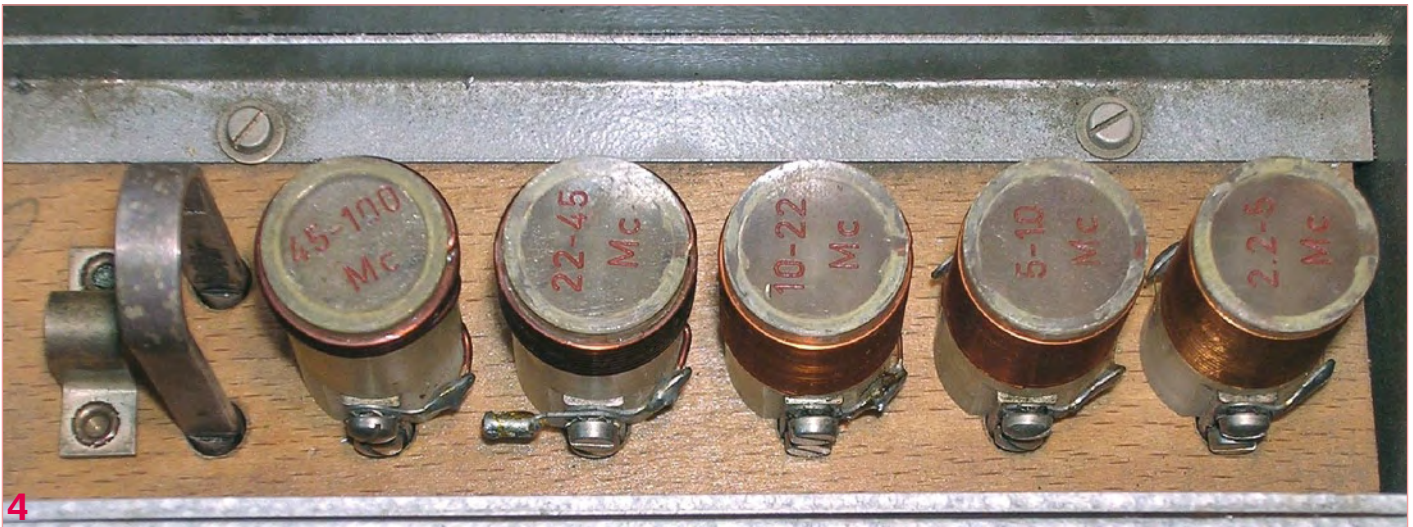
mined by reading the oscillator frequency from a calibrated scale attached to the tuning knob. Grid dip meters usually have plug-in coils to make it easy to connect different coils. This allows the meter to be used over a wide range of frequencies.

The name 'grid dip meter' originates from the time when these instruments were built using tubes. In these instruments, the grid current drops when the oscillator draws more power. This may sound a bit strange at first glance, since increased power consumption is ordinarily associated with increased current. To understand what's happening here, let's first examine the circuit of a grid dip meter in its most rudimentary form. **Figure 1** shows a Colpitts oscillator built around an RF triode. The advantage of a Colpitts oscillator is that it has a single simple coil without any taps, which makes it easy to exchange coils using a plug-and-socket connector. The drawback of this arrangement is that the circuit requires a two-gang variable capacitor.

Immediately after the oscillator is switched on, the grid voltage will be nearly zero and the tube current will be high. At first this current will be a noise signal resulting from the noise generated by the grid resistor or other noise sources. As the anode load consists of a tuned circuit, only one frequency component of this noise signal will be present on the anode. In addition, the LC circuit is designed to feed back part of the amplified signal to the grid in phase, which causes the circuit to start oscillating with gradually increasing signal amplitude at the oscillating frequency. Of course, the amplitude cannot increase indefinitely. After a few cycles, the signal amplitude on the grid increases to the point that the grid goes positive on the positive half-cycles of the signal, which causes a grid current to flow. This grid current imposes a negative DC component on the grid voltage, which acts to cut off the tube and reduce the gain. This control mechanism stabilizes the oscillator at a constant signal amplitude. If



3



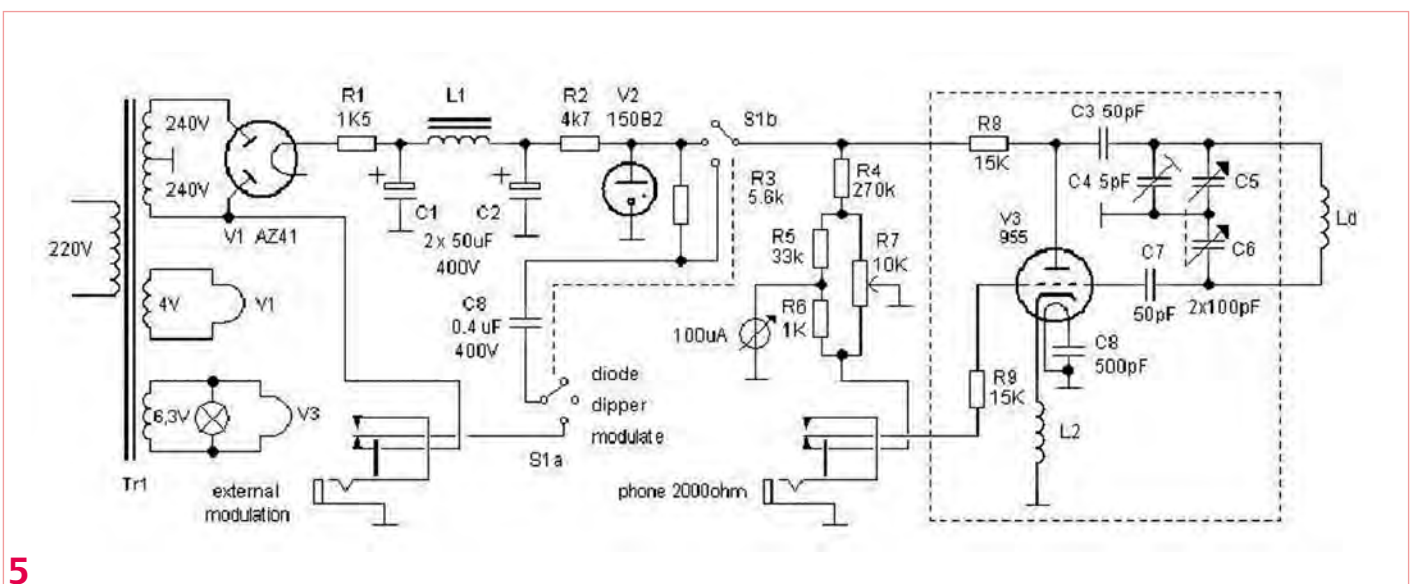
a second circuit tuned to the same frequency is now brought close to the oscillator, it will draw power from the oscillator. This power loss is offset by a slight reduction in the negative DC component of the grid voltage, which increases the gain. Naturally, this causes the grid current to drop, which produces the 'grid dip'.

The Philips Research laboratory, originally established as the 'Naturkundig Laboratorium' (physics laboratory) or NatLab for short, will celebrate its 100th anniversary in 2014. Despite what the name may suggest, during the past 100 years it has carried out research not only in the field of physics, but also in many other fields such as chemistry, mathematics, semiconductor fabrication and (of course) electrical engineering and electronics. Especially at the time when you couldn't simply order or purchase everything you needed, the NatLab had extensive workshops for the fabrication of mechanical and electronic devices and glassware, where highly skilled craftsmen produced outstanding instruments to order for the researchers. It's hardly surprising that very intriguing items can occasionally be found in the nooks and crannies of a laboratory with such a rich history.

For example, the grid dipper shown in **Figure 2** turned up during a housecleaning operation in the instrumentation section – the

group within NatLab that is responsible for purchasing and renting test equipment. This splendid instrument, which was produced exclusively in the service shops, bears a strong resemblance to the famous Model 59 grid dip meter from Measurements Corporation [1]. It consists of a probe head housing a high-frequency oscillator and a small enclosure housing the power supply (**Figure 3**) and the moving-coil meter, along with a compartment holding a set of coils for frequency ranges extending from 2.2 MHz to 400 MHz (**Figure 4**). Sadly, the documentation for this instrument was no longer available, but the point-to-point wiring makes it easy to trace the circuit diagram (**Figure 5**). This instrument had probably not been used for 30 years or so, so it was certainly a good idea to first carefully reform the electrolytic capacitors in the power supply [3]. After we treated the selector switch with a little bit of contact spray, the dipper worked perfectly – practically as good as new!

The Colpitts oscillator is built around a type 955 acorn triode tube (**Figure 6**). This type of miniature tube, which is called an 'acorn' on account of its shape, was developed by RCA in 1935 [2]. The special method used to fabricate the contacts minimizes the parasitic capacitance and inductance of the lead wires, so the tubes can be



5

Winding data for L_d (all coils wound on 19-mm plastic coil forms unless otherwise specified)		
Frequency range [MHz]	Number of turns	Wire diameter [mm]
2.2 – 5	113	0.15
5 – 10	52	0.5
10 – 22	21	0.7
22 – 45	7	1.0
45 – 100	3	1.0
100 – 220	1 turn, length 45 mm, width 18 mm	
220 – 400	1 turn, length 11 mm, width 8 mm	

used to build oscillators operating into the gigahertz range. The oscillator of the grid dipper is built entirely in accordance with the rules of high-frequency engineering, with the leads kept as short as possible by connecting the grid and the anode directly to the tuning capacitor via tubular capacitors C3 and C7. As the gain of the 955 varies considerably over the full frequency range, P1 is provided to allow the operating point of the tube to be adjusted over a wide range.

The grid dip meter is easy to use. First you select a coil according to the estimated resonant frequency of the circuit to be measured and plug it in to the probe head. With S1 in the Dipper position, you then adjust P1 until the pointer is somewhere to the right of the midrange position. Next you place the sense coil close to the coil to be measured (Figure 7). The strongest magnetic coupling is obtained when the windings of the two coils are parallel. Now you rotate the tuning knob until you see a clear dip in the grid current. The oscillator frequency is affected to a certain extent by the presence of the circuit to be measured (frequency pulling), so the next step is to reduce the coupling by increasing the distance between the coils and then repeat the measurement.

When S1 is in the Modulate position, the oscillator is AM modulated at 50 Hz and the grid dip meter can be used as a signal generator. When S1 is in the Diode position, the anode voltage of the oscillator is switched off and the instrument can be used to detect the presence of a high-frequency signal, either visually by the motion of the meter pointer or audibly using headphones.

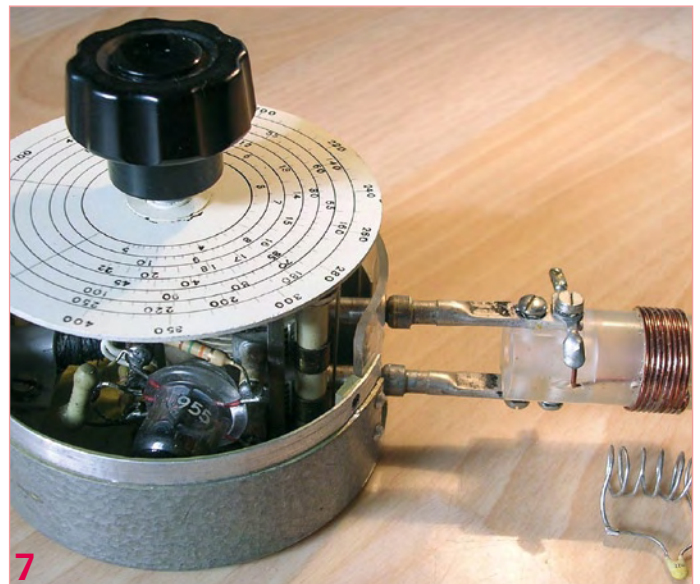
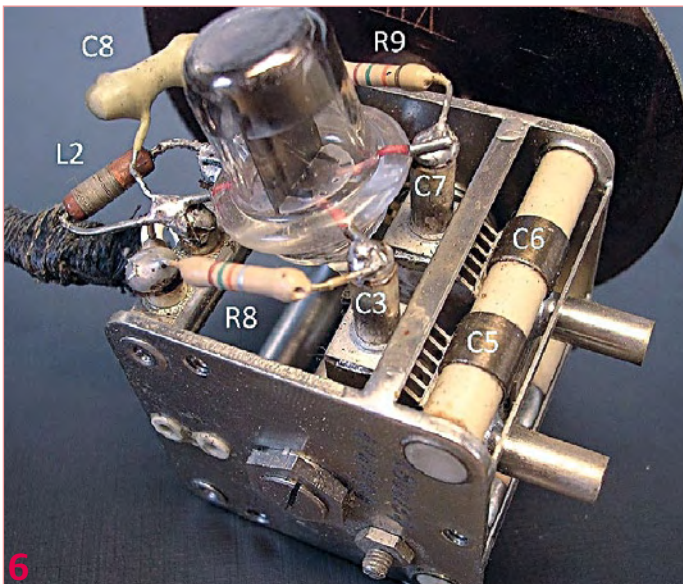
If you aren't afraid of a bit of precision mechanical construction, this circuit is an excellent choice for building a DIY copy of the instrument. You can use a Philips type 4761 (E1C) tube in place of the 955, or you can try using a normal RF triode such as an EC92 (6AB4), although this will considerably reduce the maximum frequency range. Be sure to use only one common ground point for the oscillator. Naturally, the tubes in the power supply can be replaced by semiconductor diodes or Zener diodes. Coil L2 consists of a 10-k Ω resistor wound with 30 turns of 0.15-mm (AWG 34) copper wire (Figure 6). The winding data for coil L_d is given in the table. Finally, for those of you who regard messing about with tubes and high voltages as a waste of time, lots of schematic diagrams for dip meters using transistors can be found on the Web [4].

(100101-1)

Links and Reference documents

- [1] http://oak.cats.ohiou.edu/~postr/bapix/Dip_59.htm
- [2] www.antiquewireless.org/otb/acorn tube.htm
- [3] 'Reforming Old Capacitors', Elektor May 2006
- [4] www.qsl.net/iz7ath/web/02_brew/15_lab/02_dipper/pag01_eng.htm

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



Experimentation

By Gerard Fonte (USA)

I distinctly remember my very first electrical experiment. I was about 6 at the time and was playing with a toy motor and a couple of batteries. I noticed that with two batteries, the motor went faster. I figured that a much larger voltage would make the motor run a lot faster. And with the encouragement of my slightly older brother, I shoved the motor leads into the electrical outlet. There was a flash, a pop, some smoke and a dead motor. I was lucky I didn't get zapped or burn the house down. From this experiment I learned that I should: "Never put anything in the outlet that doesn't have a plug on it." Parents are infallible.

Experimentation for learning

Fundamentally, experimentation is learning by experience. It's a good way to learn because you remember about 75% this way. Compare that to 5% for a class lecture (reference the National Training Laboratories). Unfortunately, undirected and random experimentation generally teaches you what won't work, because there are many more ways to fail than to succeed. Although, sometimes knowing what won't work can be very important. (And that's not something that they teach in school.) However, continuously failing offers little incentive to continue.

Hobbyists and engineers enjoy learning, which is a fairly rare trait. We like to solve problems and build things that work. Experimentation can be a key tool in making spectacular projects. But like any tool, you have to use it properly.

The most important thing is to take small steps. Unfortunately, this is exactly the opposite of human nature. Human beings are naturally competitive. Everyone wants to build the biggest and best of anything. This "go-for-broke" approach does not work well.

Instead, start with something that does work and modify it to your needs. For example, suppose you need an amplifier that works at 20 MHz. Find a circuit that works at 10 MHz (or 40 MHz) and try to modify it for 20 MHz. You are much more likely to succeed than if you start from scratch. True, it is not as satisfying or exciting as full-blown creation. But, do you want success or fun? Because after a while, spectacular failure is no longer fun.

If you are new to the hobby, get one of the many 'Electronic Lab Kits'. These provide parts and instructions so you can succeed right from the start. Once you get something that works, then you can start experimenting so see what different things do. This is much more effective than reading books and trying to copy circuits. (Books are more useful when you have some grasp of the topic.) Some of these kits can build up to 300 circuits and all are designed for novices. In terms of cost/learning, these labs can't be beat.

Experimentation for exploration

Another use for experimentation is in exploration. For example, I remember experimenting with magnets and coils. This situation is different from above. Moving coils around magnets and vice versa would usually produce some results. And if they didn't, that was interesting, too. I couldn't always predict what the results would be, but normally something happened. I explored magnet shape,

coil shape, voltage in, voltage out, etc. All of these had some effects on the results. So, this type of experimentation was very productive.

Unfortunately, I never took the time to write down my results. Without recording the outcomes and without proceeding in a logical and orderly fashion, I didn't discover as much as I could have. I probably could have seen patterns and trends and understood much more. Nevertheless, I did have fun. I did succeed. And I did learn something. These are certainly useful things in themselves even though it was not optimized. At a more professional level, this type of exploration is fairly common. For example, suppose you have designed and built a new receiver. You explore its performance by subjecting it to temperature variations, vibration, noise, etc. Another name for this is "Test and Measurement". T&M is arguably the most important subset of engineering. Because if you can understand and design test instruments, you can understand and design anything they test.

At this level record-keeping and completeness is important. Generally, there are a defined series of tests/experiments that you have to perform to verify that your design works as intended. Once this is confirmed, a subset of these tests is used to be sure the production units work properly. And there is a name for that, too. It's called 'Quality Control'. In essence, every test is an experiment.

Hypothesis testing

So far, the forms of experimentation we've looked at are not like the definition we learned in high-school. We were taught a much more formal approach which is usually called 'Academic Research'. In this type of experiment you first write out a hypothesis, design a particular experiment that can identify the aspect you are interested in, run the experiment, analyze the results and come to a conclusion (with the conclusion criteria defined before the experiment is started). This approach is most often used when applying for grant money. Obviously, the people who are giving money away want to know precisely how it's going to be used.

It's clear that this formal approach is not the typical one used in engineering. Nevertheless, all the elements are still there. For example, 'Define a Hypothesis' might be: 'The receiver works at 50 degrees Celsius'. The experimental design: put the receiver in a temperature chamber at 50 degrees for 30 minutes. You run the experiment by turning on the receiver in the chamber. The analysis part is if it picks up a station. If it does, your conclusion is that the hypothesis is supported.

Experience

Now we can see why experience is important in engineering. The experienced engineer has run a lot of experiments that are not taught in school. This practical knowledge is incredibly valuable. It's the difference between college and real life. As a hobbyist, you get this experience every time you build, design or just fool around with electronics. You probably didn't realize that your playing was actually scientific experimentation in disguise.

(100273)



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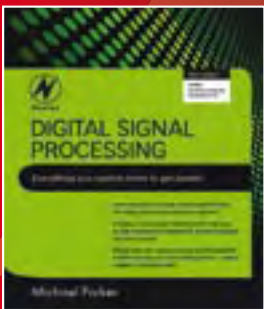
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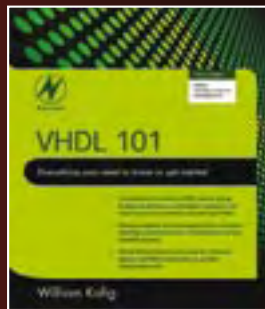
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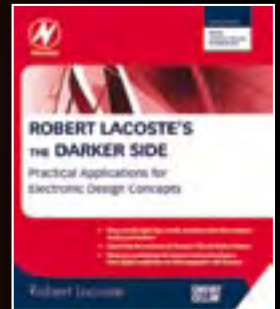
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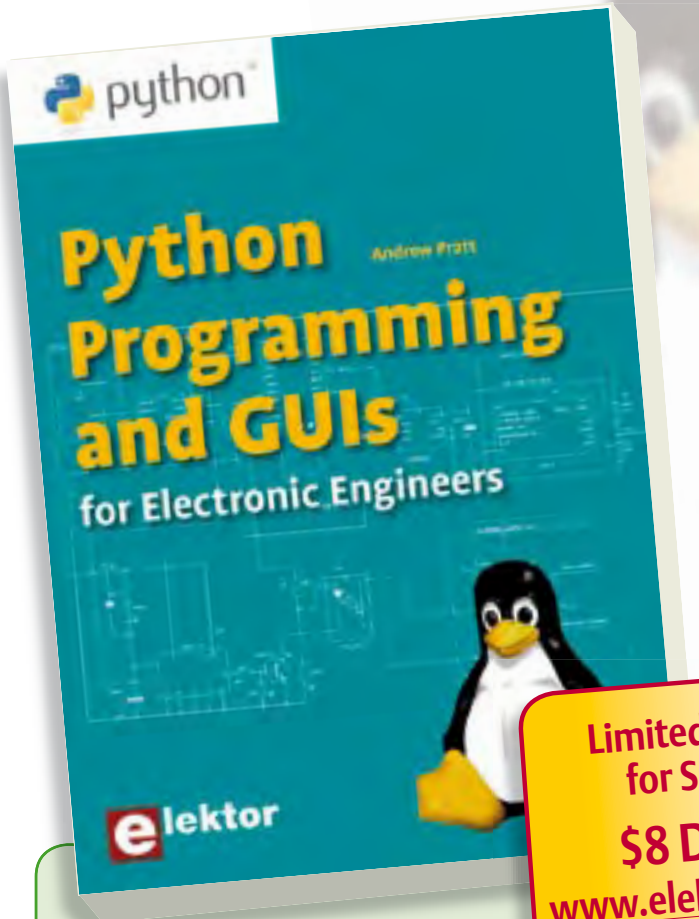
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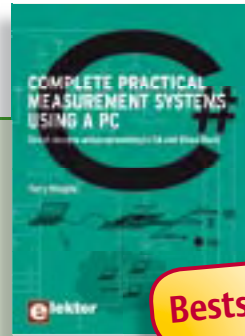
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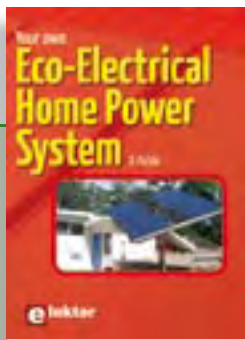
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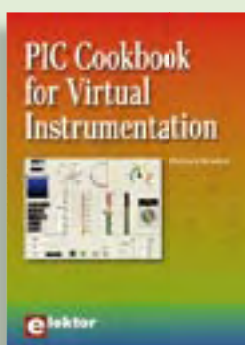


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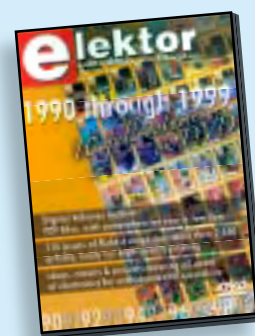
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(April 2010)

A power supply with adjustable output voltage and current limiting is part of the basic equipment of every electronics lab. However, the increased complexity of a switch-mode design scares away many potential builders, even though it actually isn't all that complicated if you use a suitable combination of well-known technologies. This circuit is suitable for building a single or dual power supply.

PCB and all components, less power transformer

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Reign with the Sceptre
(March 2010)

This open-source & open-hardware project aims to be more than just a little board with a big microcontroller and a few useful peripherals — it seeks to be a fast prototyping system. To justify this title, in addition to a very useful little board, we also need user-friendly development tools and libraries that allow fast implementation of the board's peripherals. Ambitious? Maybe, but nothing should deter you from becoming Master of Embedded Systems Universe with the help of the Elektor Sceptre.

PCB, populated and tested, test software loaded

Art.# 090559-91 • \$212.90



Modulo D
(March 2010)

The external appearance of this small module with an LC display almost belies what it has inside: a complete stereo preamplifier and final amplifier with IR remote control, adjustable tone, volume and signal levels, and an output power of 2 × 20 W (Class D), all with a single 12-V supply voltage. This makes it perfect for use in a car, boat or motor home.

PCBs, SMD-populated, and all other components

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Preselector for Elektor SDR
(December 2009)

Elektor's Software Defined Radio (SDR) is deservedly popular. The performance of a receiver depends to a large extent on its input filters. A selective input circuit improves antenna matching and immunity to interference from other strong signals. This preselector allows the use of up to four filters, tuned under software control using varicap diodes. A tuned loop antenna is also described that lets you use our SDR without an outdoor antenna.

Kit of parts, contains partly populated board, coil formers, ferrite rod with coils

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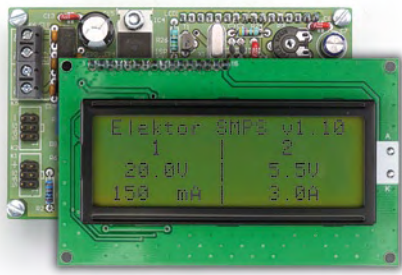
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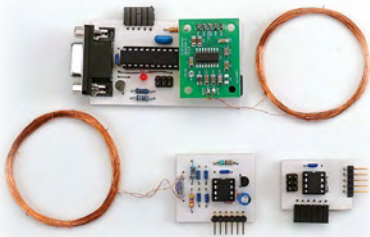
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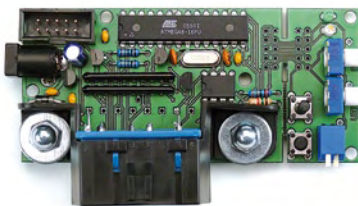
Unilab V/I/Temp. Readout

The lab power supply published in the April 2010 edition now gets a dedicated measurement circuit showing not just voltage and current on a 4 x 20 character LCD, but also temperature inside the case. The A-D conversion and calculations are handled by an Atmega 168 processor. A special circuit configuration is used to measure the current in the negative supply rail.



Program your Own RFIDs

RFID devices type EM4102 are widely available and a suitable reader was described in Elektor some months ago, based on an EM4095 reader chip on a small circuit board. The same board is now used to implement an RFID reader based on an ATtiny2313 micro. As part of the project, you'll be making your own sensor RFIDs for wireless transmitting of measured sensor data to the reader.



OBD2 Mini Simulator

Those of you keen on writing or developing utilities for vehicle diagnosis will soon discover that a real car is bit of a problem to have around in the electronics lab. In cases where a professional OBD-2 analyzer is not available or affordable, our mini simulator for OBD signals may prove useful. The circuit supports four OBD-2 protocols and is likely to become indispensable to everyone working with OBD hardware and software.

We regret that 'Auto Balancer for LiPo Battery Packs' could not be accommodated in the May 2010 issue as planned.

*Article titles and magazine contents subject to change; please check the Magazine tab on www.elektor.com
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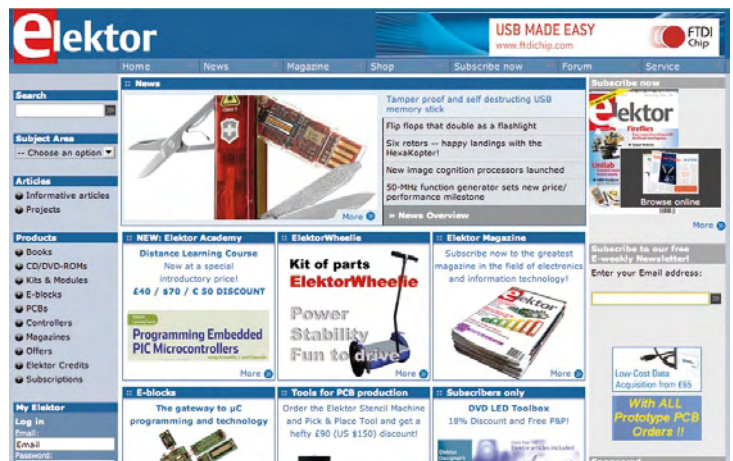
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