February 2012   AUS$ 14.90 - NZ$ 17.90 - SAR 105.95 - NOK 102   £ 4.90

elektor

www.elektor.com

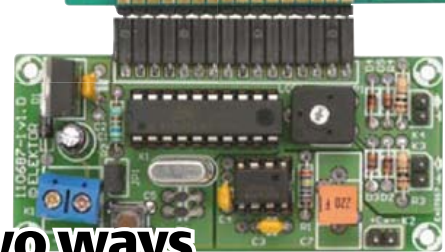## A Serial Interface for Android Smartphones and Tablets

ElektorBusBrowserForAndropod
LightSensor
Scheduler on   off
LED Node 1
LED Node 2
          ADC-Value
Ohm   Adc raw
Limit-Page
                    Settings
Test SMS   Test Data Transmission

AndroPOD

+ ## Bit-banging the FTDI-USB Module
unravelled and applied to a keyless entry control panel

Select mode - S1
Capacitance

Multiplier 100
(S1) to change

Select mode - S1
Period

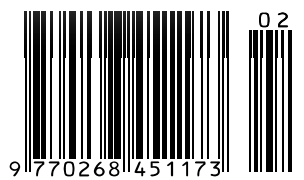Remove all Caps
Cal: C=0pF (S1)

Freq Gen
        10kHz

Pico C-Plus
& Pico C-Super

Our 'small-C' meter upgraded in two ways

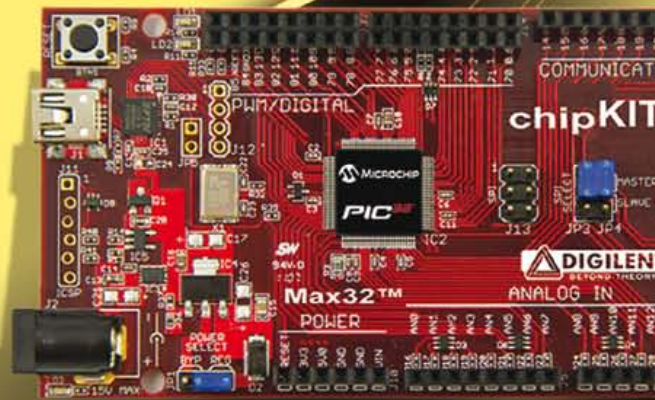**+** # Emergency Generator Load Meter
No-break AC power for your home

9 770268 451173

02

All things considered but measured first

It's been noted frequently that electronic circuits are getting increasingly complex in design and have a bad tendency to attract microprocessors for no apparent reason. It seems logical because micros enable the amount of hardware to be reduced drastically while still offering flexibility in terms of functionality of the circuit — in other words, you just program in what you think you might need. No soldering, no parts purchasing.

Great, electronics gone all digital! Just deal with ones and zeroes, no problems with analogue signals that vary in level just by pointing at a PCB track. Tough luck. Any digital circuit that somehow needs to communicate with the outside world, is again using analogue signals. It's because our real world simply isn't digital — in between all kinds of extremes like 'on' and 'off', 'all' and 'nothing', 'hot' and 'cold', 'dark' and 'light', there's a whole range of gradations (well, with a few exceptions).

So what does a digital circuit do to communicate with the real world? The analogue value measured by a sensor is first translated into a digital value (by an A/D converter) before it can be processed by digital electronics. Likewise, at the output of the circuit it is often necessary to convert digital back to analogue, usually with the help of a D/A converter or a PWM control.

These considerations were spurred by the very contents of this February 2012 edition, which contains several projects that seem to happily combine the analogue and digital realms. Fine examples are the new software for the enhanced Pico C meter, the interface for wideband lambda probe, and the dynamics processor discussed in the Audio DSP Course. The above ADC-digital-DAC method applies to all of these, and more. Never disregard the analogue bits in your digital circuit — although not MSB, they're still highly significant.

Enjoy reading this edition,
Jan Buiting, Managing Editor

CONTENTS

14 AndroPod (1)

Up to now it has been rather difficult to connect Android-based smartphones and tablets to external circuitry enabling us electronics folks to access signals for control purposes. Elektor's very own AndroPod interface board, which adds a serial TTL port and an RS485 port to the picture, changes this situation.

22 Pico C-Plus and Pico C-Super

Two new versions were developed of the software for Elektor's famous 'Pico C' capacitance meter. Version 'Pico C-Plus' includes a signal generator function as well as capacitance measurement and a simple period measurement function based on the TLC555 oscillator. The second version, 'Pico C-Super', adds a frequency counter and implements a full blown period counter.

28 .Net-MF for Electronics Engineers

The advantage of Microsoft's 'dot-net' platform is the application source code compatibility between different processors., allowing the same source code to run equally well on a module using an NXP, Renesas, Atmel, etc. microcontroller and on a Windows, Mac or Linux PC computer using Mono, the multi-platform open-source version of dot-net.

67 Bit-banging the FTDI-USB Module

This article describes the electrical design and software requirements for a keyless entry control panel comprised of a numeric entry pad, an LCD display, relay contacts for unlocking a door and a USB interface. Even though this writing will delve into the inner workings of FTDI's FT2232H and its Bit-bang Mode, understanding the technology will require neither an in-depth knowledge of USB nor the use of a microcontroller!

ELEKTOR

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Beta Layout
www.beta-layout.com 59

CS Technology, Showcase
www.cstech.co.uk/picdemo 78

DesignSpark chipKIT™ Challenge
www.chipkitchallenge.com. 2

Easysync, Showcase
www.easysync-ltd.com 78

Elnec, Showcase
www.elnec.com 78

Eurocircuits
www.elektorpcbservice.com 35

EzPCB
www.siliconray.com 65

First Technology Transfer, Showcase
www.ftt.co.uk 78

Flexipanel, Showcase
www.flexipanel.com. 78

Future Technology Devices, Showcase
www.ftdichip.com 78

Hameg, Showcase
www.hameg.com 78

HexWax, Showcase
www.hexwax.com 78

Jackaltec
www.jackaltec.com 9

Labcenter
www.labcenter.com 88

Maxbotix, Showcase
www.maxbotix.com 79

MikroElektronika
www.mikroe.com 3

Minty Geek, Showcase
www.mintygeek.com 78

Pico Technology
www.picoscopemso.com/125 31

Quasar Electronics
www.quasarelectronics.com 27

Robot Electronics, Showcase
www.robot-electronics.co.uk 79

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www.robotiq.co.uk 79

Tyder, Showcase
www.tyder.com 79

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to reserve your own space for the next edition of our members' magazine

Cost effective LF RFID IC for animal identification applications

Atmel® Corporation's low-frequency (LF) one-time programmable (OTP) transponder IC, type IDIC® ATA5575M2 is optimized for next-generation animal identification systems for pets, wildlife or livestock. Extending the broad and well-known Atmel RFID family, the new device can also be used for waste management applications according to the BDE standard.

Low-cost LF RFID IC ATA5575M2 with OTP Functionality and Unsurpassed Read Performance for Animal Identification Applications

The Atmel ATA5575M2 OTP functionality simplifies the production process and allows for increased flexibility compared to read-only devices. Before shipping, customers can program into the device any necessary information, including the specific country or the manufacturer code supplied either by the International Committee for Animal Recording (ICAR) or government authorities. This reduces lead-time and time to market down to approximately 1 to 2 weeks.

The device architecture enables better read distances with different coils and readers. The write distance is reduced as one-time programming is required, which usually takes place in close coupling to the programming device during the final tag test and customization. Large write distances are typically unfavorable due to the risks involved with multiple tag programming. These improvements help minimize both cost and chip size.

Additionally, the integration of optional trimmed 250-pF or 330-pF on-chip capacitors reduces system cost. These capacitors eliminate the need for external components because a coil is all that is needed for a complete system, thus enabling extra-small access control applications. At approximately 0.9 square millimeters, the Atmel ATA5575M2 can be used in most transponder packages, including glass transponders or plastic key housings for very small tags (such as animal tags).

The memory in the device contains a unique manufacturer-programmed ID which the user can overwrite with a specific animal ID code. The user ID (UID) can be read and archived (along with the animal code) before programming to ensure reliable traceability.

Since an LF device operates in the range of 100 kHz to 150 kHz, the Atmel ATA5575M2 can be used worldwide. It is designed for rugged environments and can also be used in conditions not typical for RFID application devices, including underwater (fish tagging), in dirt (outdoor livestock), or injected via glass or plastic transponders (under the skin of animals) for tracking purposes.

The ATA5575M2 transponder IC supports the FDX-B and FDX-A standards:

• FDX-B: ASK modulation, 128 bits, differential Biphase coding with a fixed bit rate of RF/32
• FDX-A: FSK modulation, 96 bits with a fixed bit rate of RF/50

It can replace nearly all available LF RFID read-only devices that conform to the ISO 11784/85 standard in FDX-B mode.

To support the engineer and to simplify the design of complete RFID systems, Atmel provides an evaluation kit (ATA2270-EK1) with ATA5575M2 sample tags. This kit is based on Atmel's well-known AVR® microcontrollers and is accompanied by Windows® PC software, C-source code for the AVR and PCB Gerber data for the reader board.

www.atmel.com (120031-XIV)

The road to efficient, low-cost tandem organic solar cells

Belgium based Imec and its 16 project partners announce that they have launched the European FP7 project X10D, a project aiming at developing tandem organic solar cells with an increased conversion efficiency and lifetime, and a decreased production cost. The ultimate goal of the X10D project is to bring organic photovoltaic technologies (OPV) towards introduction into the competitive thin-film PV market.

Organic solar cells hold the promise of low-cost production and high throughput, both essential parameters for the uptake of a new technology by the PV industry. How-

ever, current OPV technologies are unstable when exposed to the ambient environment, and their power conversion efficiencies are not sufficient to be viable alternatives to the current dominating silicon photovoltaic technologies. By applying new designs and architectures, materials and manufacturing technologies, the X10D project aims at increasing the power conversion efficiency to achieve at least a 12% on cell level (1 cm²), and 9% on module level (100 cm²). Moreover, the X10D project has set its goal to guarantee a minimum of 20 years lifetime for OPV modules on glass, and 10 years on foil, and to decrease the cost below 0.70 €/watt-peak.
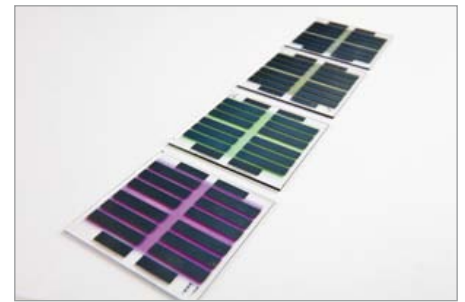
X10D gathers the available OPV knowledge and expertise from leading universities, research institutes, and companies in Europe. Furthermore, X10D brings together a complete and unique OPV research and development consortium covering both solution-processed as well as small molecule-based OPV expertise. Each segment of the value chain is represented in the project: materials development and up-scaling, device development and up-scaling, large-area deposition equipment and processes, novel transparent conductors, laser scribing equipment and processes, encapsulation technologies, energy, life-cycle, and cost analysis and finally end-users.

www.x10d-project.eu/public (120031-XI)

Three phase filter (w/o neutral line) for renewable energy sources

Renewable energies are now becoming an ever-growing alternative to generating electricity. This is the case of power generation through windmills. The power injection on the network must be done cleanly; this means that the power generating must inject it with RF noise free. The radio

frequency noise that typically range from 10 kHz to 30 MHz is unintentionally injected into the network and therefore requires the use of an appropriate filter element: this is both the desired frequency range, such as attenuation and current capacity required. Premo has developed a HCWMGF-series of filters for applications in renewable energy equipment, UPS, inverters and power inverters, with a maximum operating voltage up to 720 VAC.

Main characteristics:

- Three phase filter of three stage (high performance)
- Insertion loss above 40dB in the whole range (reaching 80 dB between 200 kHz & 1 MHz)
- Dielectric Strength above 3000 VDC
- Flammability to UL94 V2.

Premo's new HCWMGF series is available in three phase version L1, L2, L3 (without neutral) from 150A to 2500A, with power losses less than 0.02%.

All PREMO filters have been developed taking into account the specific needs of the application they are intended, in terms of attenuation levels, volume, weight, connections, mechanical shape, etc. In collaboration with Development Centers, Universities, Suppliers and Customers, PREMO has incorporated into its design innovations and new magnetic materials to provide results that fully meet customer needs and requirements.

Premo EMC, has a fixed and a mobile laboratory for EMC testing machines / facilities to its customers and EMC solution for compliance with specific regulations to be applied.

www.grupopremo.com   (120031-XV)

Hameg: CAN/LIN protocol analysis now also in the MSO entry level class

For the first time, HAMEG offers the option HOO12 which allows triggering and decoding of CAN and LIN protocols for less than €500. Combined with the options HOO10/11 for I²C, SPI, and UART/RS-232 HAMEG now offers most of the customers in the automotive, medical, aircraft, and automation industries a complete solution for the development of embedded systems. Also, a table presentation for the decoded values of all protocols was implemented which presents in one line all information of a message telegram. These lines are linked to the messages in the memory which allows easy navigating within the up to 4 MPts deep memory. Special trigger properties allow the precise isolation of single messages. Additional search and filter functions are available by a new firmware which simplifies and speeds finding of special events appreciably such as defined rise times or I2C addresses. The HMO series even decodes two CAN buses simultaneously, hence they are especially useful for system designers. For individual measuring tasks the 2/4 analog and 8/16 digital channels can be annotated which is very useful. Users who are mainly interested in the protocol level, can use the least expensive oscilloscope of the HMO series, the 70MHz HMO722, and the CAN option in order to be able to analyze this bus for less than €1,700.

www.hameg.com   (120120-I)

Sub-GHz wireless transmitter with 8-bit PIC® MCU to simplify secure remote keyless entry designs

Microchip announces the PIC12LF1840T48A which is the first in a family of single-chip devices that integrate an eXtreme Low Power (XLP), 8-bit PIC® microcontroller with a sub-GHz RF transmitter. The PIC12LF1840T48A's combination of features in a single, 14-pin TSSOP package makes it ideal for space-, power- and cost-constrained applications, such as remote keyless entry fobs for automobiles, garage doors and home security systems, as well as a broad range of other home and building automation systems. The device is also optimized to run Microchip's royalty-free KEELOQ® advanced code-hopping technology, a proven security technology used worldwide by leading manufacturers.
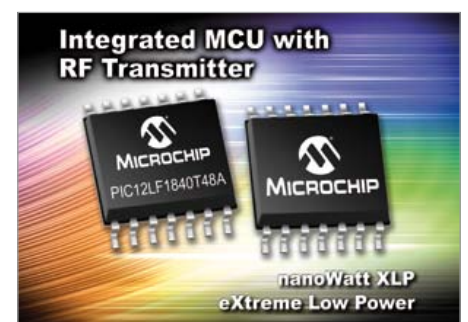
In addition to secure wireless communication,

the PIC12LF1840T48A is designed to maximize battery life via an extremely low operating voltage of 1.8V. Furthermore, the XLP microcontroller has extremely low sleep current consumption, and is efficiently integrated with the transmitter to enable fast wake-up and send functionality that takes full advantage of the MCU's 8 MIPS operation.

Application note AN1393 'Using the PIC12LF1840T48A Microcontroller with integrated sub-GHz Transmitter' is available for download, to assist engineers in developing remote-control designs.

The PIC12LF1840T48A is available in a 14-pin TSSOP package. Samples are available today, and volume production is expected in January.

http://www.microchip.com/get/K4KF

(120120-II)

Bitscope pocket analyzer

BitScope Pocket Analyzer is a unique test instrument combining a powerful Mixed Signal Oscilloscope, Protocol Analyzer, Waveform and Clock Generator, Spectrum Analyzer and Data Recorder in one tiny USB powered device.

It offers 10 capture channels (2 analog and 8 digital) with 100 MHz analog bandwidth, 40 MSps logic speed and up to 12 bits analog resolution as well several output channels for its signal generators, triggers and external control signals.

Pocket Analyzer is fast with a frame rate up to 100 Hz driving a digital phosphor display. It works just like a quality stand-alone scope. View waveforms, plots, spectra and more on its smooth flowing real-time screen. Even live capture logic data can be viewed this way.

Alternatively large buffers support high speed one-shot capture with post-capture zoom, scrolling and measurement, or it can stream direct to disk for off-line replay and analysis.

Software is included for Windows, Mac OS X or Linux. Features include mixed signal, storage and sampling oscilloscopes, logic timing, SPI, CAN, I²C and UART packet decoders, a spectrum analyzer, X-Y phase plotter and data recorder.

http://bitscope.com/us (120120-III)

Industry's first FlexRay™ transceiver designed for high temperature automotive applications

Austriamicrosystems' new AS8222 FlexRay transceiver, with an in-package maximum ambient temperature of 150°C and bare dice with a maximum temperature of 165 °C, is the first to be able to work in harsh, high temperature powertrain applications. This extended temperature range enables the use of FlexRay in every vehicle domain, especially in environments beyond the

standard automotive requirements.

FlexRay is an automotive network communications protocol designed to be faster and more reliable than CAN. These transceivers provide the interface between the digital logic and the copper cable transmission lines. With transmission rates up to 10 Mbit/s, FlexRay provides 20 times the speed of the unshielded twisted copper cable used in cars today. FlexRay is fault tolerant and

time triggered, providing dependable delivery of messages for safety applications.

The AS8222 is a single FlexRay transceiver with a battery supply connection and FlexRay bus wake-up functionality, and conforms to the FlexRay standard v2.1 rev B. austriamicrosystems' AS8222 provides various bus and failure diagnostics, making it optimal for high-speed automotive bus systems and safety-critical applications.
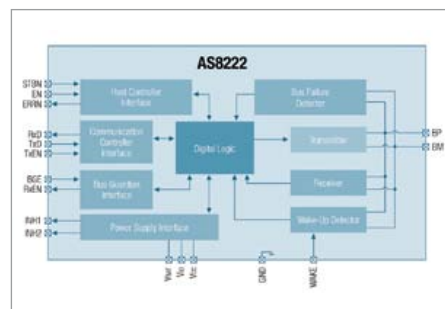
The excellent performance for electromagnetic immunity results in network designs with high robustness against external disturbances. Key safety and protection features of the AS8222 FlexRay transceiver include an optional interface for a two-wire bus-guardian or supervision circuits, auto-

matic thermal shutdown protection and short circuit protection. Designing with the AS8222 is simplified as it supports 12 and 24 V systems with very low sleep current and is compatible with a wide range of microcontrollers running at 2.5, 3, 3.3, and 5 V.

The first customer project with the AS8222 will move into mass production by the end of 2012.

www.austriamicrosystems.com/FlexRay/AS8222

(120120-IV)

Extremely rugged RS485 transceivers achieve 20Mbps

Linear Technology Corporation introduces the LTC2862-2865, a family of exceptionally rugged, high voltage tolerant RS485/RS422 transceivers for elimination of field failures without the need of costly external protection devices. In practical RS485 systems, installation cross-wiring faults, ground voltage faults or lightning induced surge volt-

ages can cause overvoltage conditions that exceed absolute maximum ratings of typical transceivers. The LTC2862-2865 feature ±60 V overvoltage fault protection on the data transmission lines, protecting bus pins during operation and power shutdown. Whether a circuit is transmitting, receiving, in standby or powered off, the LTC2862-2865 tolerate any voltage within ±60 V without damage, increasing the robustness of any typical RS485 network. The low power family supports fast 20 Mbps and low-EMI slew-rate-limited 250 kbps data rates, as well as half- and full-duplex versions.
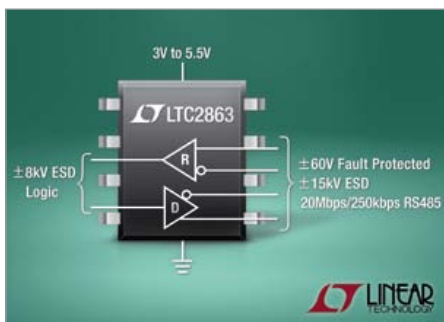
The LTC2862-2865 family provides valuable protection and reliability for a wide variety of RS485/RS422 applications, including industrial control, instrumentation networks and automotive electronics. An extended ±25 V input common-mode range and full failsafe operation improve data communications reliability in electrically noisy environments and in the presence of ground loop voltages. This extended common-mode range allows the LTC2862-2865 devices to transmit and receive under harsh conditions that would otherwise cause data errors and possible device damage. Enhanced ESD protection allows these devices to withstand ±15 kV (HBM and IEC-1000-4-2 air discharge) on the transceiver pins without latchup or damage; all other pins are protected to ±8 kV HBM. Fully symmetric receiver thresholds allow the devices to maintain good duty cycle symmetry at low signal levels and boost receiver noise immunity. The LTC2862-2865 family is offered in commercial, industrial and automotive temperature grades and available in DFN and SO packages with industry-standard pinouts. These devices provide a pin-compatible upgrade path from Linear's half-duplex LT1785 and full-duplex LT1791, 250 kbps ±60 V fault protected transceivers.

www.linear.com/product/LTC2862 (120120-VI)

Expanded Vinculum-II precompiled firmware & source code offering

USB solutions specialist Future Technology Devices International Limited (FTDI) has introduced additional elements to its family of precompiled, bridging ROM files that support its Vinculum-II (VNC2) USB host/device controller ICs. These files can be loaded directly into a VNC2 IC and utilised by its 16-bit microcontroller core in order to perform basic data transfer operations between common interfaces. Interface options include SPI, UART, USB host and USB device, with data operations such as mass storage, human interface devices, and communication device class. This provides engineers with off-the-shelf software capabilities that can be immediately implemented — enabling shorter development time and resulting in faster time to market. The new ROM files from FTDI are:

A SPI master to UART sample application ROM — which demonstrates the bridging

of a VNC2 UART to the VNC2 SPI master for controlling SPI slave devices. Data is transferrable in both directions.

- An SPI slave to USB memory bridge sample application ROM demonstrating the bridging of a USB memory (Flash drive) device present on the VNC2 USB host port to a SPI interface.

- An SPI master to USB human interface device (HID) sample application ROM demonstrating the bridging of a USB HID class device (such as a keyboard or a mouse) present on the VNC2 USB host port to a SPI interface.

- A UART to communication device class (CDC) modem sample application ROM demonstrating the bridging of a CDC device present on the VNC2 USB host port to a UART interface, with data transferrable in both directions.

- A UART to FT232 host sample application ROM demonstrating the bridging of a FT232/FTxxx class device present on the VNC2 USB host port to a UART interface.
- A UART to USB HID Class Host Sample Application ROM demonstrating the bridging of a HID class device present on the VNC2 USB host port to a UART interface.
- A UART to USB Memory Sample Application ROM demonstrating the bridging of a USB memory device present on the VNC2 USB host port to a UART interface.

Each of the precompiled ROM files is accompanied by the source code, to allow users to modify and expand upon the reference software. Complete documentation and application notes are also included, which provide engineers the context of the implementation. Further ROM files are in the process of being developed and will be released in the near future. Should a specific combination of interface and application be required, FTDI is accepting inputs for its next round of development. Designers should contact FTDI at support1@ftdichip.com to make their request.

www.ftdichip.com/Firmware/Precompiled.htm
(120120-VIII)

Infrared preheater

hand soldering and rework tools provider JBC Tools, Inc. introduces the PH Infrared Preheater. The PH Preheater is streamlined, easy-to-use and packed with features. Additionally, it perfectly complements the rest of the JBC product line.

The PH Preheater heats PCBs from below, allowing hand soldering to be completed much faster and at lower soldering tip temperatures. As a result, solder tip life is increased and there is a reduced risk of thermal stress on components and PCBs.

With a 'Teaching' function using a thermocouple for the first PCB, a profile can be learned quickly. For subsequent work on the same type of board, the use of the thermocouple is not required, greatly reducing work time.

www.jbctools.com (120120-V)

DesignSpark chipKIT™ Design Challenge

Now in its third month, DesignSpark chipKIT™ design challenge for energy-efficient applications is witnessing the development of some wild and innovative projects.

By Ian Bromley (UK)

We've been absolutely delighted by the amount of enthusiasm we've received for the DesignSpark chipKIT™ competition — and also the high quality and imagination of the ideas that have been submitted thus far. As a reminder, or for those hearing about this for the first time, the DesignSpark chipKIT challenge, which was launched in November last year at Elektor Live*!*, is about encouraging engineers, students and hobbyists to develop new and innovative energy-efficient solutions, while also maintaining an eco-friendly footprint. And what's more, total cash prizes of $10,000 can be won, including a first prize of $5000.

I think it's reasonably clear that we need to achieve a much higher level of energy sustainability on both a local and global level, and innovative energy-efficient embedded electronics can make a significant contribution in meeting this goal. As I said in last month's edition, it's not just about developing new technologies at the device level, such as ultra-low-power microcontrollers or other electronic devices; there are many possibilities and opportunities at the system or application level. For example, a more energy-efficient light bulb helps save energy, for sure, but perhaps even more valuable in terms of energy saving is a home automation control system that handles lighting around the home, turning lights off and on when we actually need them.

Back at the launch of the competition at Elektor Live*!*, we certainly enjoyed a couple of highly successful workshops with some excellent cooperation and camaraderie from all the participants. I had superb help from my competition colleagues: Jeroen Hobbelmans from Microchip and Clemens Valens from Elektor, so, my thanks go out to them. The only technical issues we experienced were with USB drivers and connecting up the chipKit boards to PCs. So a couple of tips on that which could be useful for any new entrants experiencing difficulties in getting their board up and running: firstly, within the open-source MP IDE (Multi-Platform Integrated Development Environment) tool library is a wide range of FTDI drivers, which should fix most connectivity issues; secondly, although it wasn't a widespread problem at the workshops, could be the possibility of some issues with those running Windows 7, however this can easily be fixed by running Windows XP Mode, where available. With the competition well under way, entrants are now busy developing energy-efficient and environmentally friendly applications

based on the chipKIT™ Max32™ development platform from Digilent, which features Microchip's 32-bit PIC32 microcontroller. The chipKIT™ Max32™ development platform is a 32-bit Arduino-compatible solution that enables engineers, student and hobbyists to easily and inexpensively integrate electronics into their projects. The chipKIT™ hardware is compatible with existing 3.3 V Arduino shields and applications, and can be developed using a modified version of the Arduino IDE and existing Arduino resources, such as code examples, libraries, references and tutorials.

Some of the submissions that we've seen so far include those designed for applications in home automation, energy monitoring, controllers for solar power charging and smart wind-turbine monitors. A couple of the more exotic ones include a control system for unmanned underwater glider (a type of AUV — Autonomous Underwater Vehicle), and a 'Miles per Gallon' (that's km/L for those that prefer new money) energy-consumption efficiency display for use in old or classic cars to enable more economical driving.

As a reminder, all entries must include an extension card developed using RS' free-of-charge and award-winning DesignSpark PCB software tool with code compiled using Digilent's MPIDE software. Additionally, during the competition, which finishes at the end of March 2012, entrants are being strongly encouraged to engage and interact with other members of the online DesignSpark community, available at www.designspark.com, by posting information on their projects, providing updates on progress, and sharing comments and ideas on their respective designs. Participants will automatically qualify for entry into bonus Community Choice Awards, in addition to admission into spot prize draws for the best collaboration to win vouchers exchangeable for products ordered from RS Components/Allied Electronics.

The competition entries will be judged on the level of energy efficiency and the quality of the extension card's PCB design. Entries are due on March 28, 2012 and the winners will be announced in April 2012.

(120117)

Further details and registration for the DesignSpark chipKIT™ challenge are available at: **chipkitchallenge.com**.
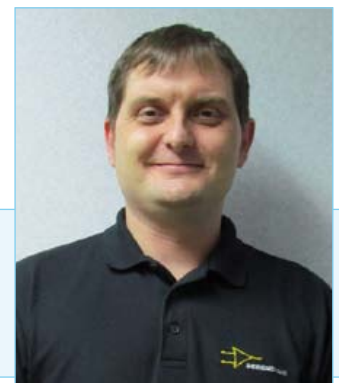
> Ian Bromley is a Technical Marketing Engineer at RS Components and the Project Manager for the DesignSpark PCB software tool. Prior to working for RS, Ian worked for many years as a design support consultant with Texas Instruments, in addition to working as a field applications engineer immediately following his graduation in 1994 with an honours degree in microelectronic engineering.

From Breadboard to PCB
Elektor PCB Service: the 'one-stop' PCB shop

You wouldn't be the first to have a project grind to halt because of the PCB design. Everything is so easy while a project 'lives' on a breadboard or as an 'aerial construction'… with a little soldering any problem is then quickly resolved. But the step to a final PCB design looks like a completely separate project! It starts with the choice of CAD software (Eagle/Cadsoft, DesignSpark or Altium to mention just a few). Then you need a library with all the right components and the question of whether it should be 'through-hole' or SMD immediately arises as well. What about the cooling of the components and the routing of signals with high frequencies? All this has to be brought together in the PCB design. Oh, and don't forget, it may also need to have a USB connector and/or a power supply connection.

No wonder then that a large number of our readers gladly leave that job to us, Elektor. And indeed — experience tells us — it is much easier for you to buy a PCB from us than for you to design it yourself and then make it or have it made. Circuit boards have been designed for many of our projects and we used to have these PCBs made in large numbers by PCB manufacturer Eurocircuits, after which you could order boards from us using the order form in the magazine, telephone or fax and later via our website. The older projects were available as special productions from the Eurocircuits PCB shop. Ah, the good old times… "sigh".

But, those old times were not all that good. There was considerable confusion with these two separate outlets and we finally decided that the best way we can be of service to you is through just one outlet — the one at Eurocircuits. From now on, here is where you can order the circuit boards designed by Elektor. But you can just as easily submit your own design for manufacturing. This means that on our website you will see links to the Elektor PCB Service which will lead you to Eurocircuits, who will handle the order.

By design, the navigation through the website automatically introduces you to the different PCB production methods (an educational journey) and ordering options. It will be clear now that the business of PCB manufacturing has a magic word: 'pooling'. Pooling means that your order will be accommodated on a larger circuit board. So your PCB will be placed next to a design from someone else on a large 'collection board'. Only in this manner is it possible to make efficient use of the production capacity.

There are a total of six products in the PCB Service;
- the 'Standard Pool' (8 layers with a choice of finishing methods),
- the 'PCB Proto' (two circuit boards, two or four layers),
- the 'Tech Pool' (based on 100 µm technology),
- the 'IMS Pool' (Insulated Metal Substrate — especially for components with high heat output, for example LEDs),
- 'On Demand' (made to measure option) and
- 'Off the shelf' (Elektor PCBs).

The **one stop PCB-shop** is open now — many thousands have already 'boarded'.

You can access this service online by going to
www.elektorpcbservice.com.
The Elektor PCBs are easily accessible there.

The Elektor Team

(120090)

AndroPod (1)
A serial interface for Android smartphones and tablets

By Bernhard Wörndl-Aichriedler and Julian Nischler (design) and Jens Nickel (editorial)

With their high-resolution touchscreens, ample computing power, WLAN support and telephone functions, Android smartphones and tablets are ideal for use as control centres in your own projects. However, up to now it has been rather difficult to connect them to external circuitry. Our AndroPod interface board, which adds a serial TTL port and an RS485 port to the picture, changes this situation.

The smartphone market has literally exploded in the last year. Now everyone can walk around with a pocket-sized computer equipped with a dual-core processor clocked at up to 1.6 GHz, which can easily hold its own against many a notebook computer. These mobile computers also feature high-resolution touchscreens, lots of sensors, WLAN capability, an SD card connector, and (lest we forget) telephone functions such as text messaging. Prices for some of these devices have now dropped as low as 100 to 200 pounds, which makes them worth considering as control centres for your own electronics projects. Potential applications include home automation systems and control units for instruments of your own design – or maybe all you need is a man-machine interface or a data logger that you can connect to your own circuitry as necessary. Other fascinating potential applications can be found in the realms of robotics and remotely controlled models. For electronics enthusiasts who enjoy developing their own hardware and software, the Android operating system is virtually the only viable option, since Google's competitors Apple and Microsoft have imposed many restrictions on DIY apps. The spectrum of Android hardware (from various manufacturers) and software is enormous, and the operating system is open source. Android is backed up by a powerful programming environment that provides access to nearly all hardware functions and enables users to develop very attractive and user-friendly applications.

Elektor products and services

- AndroPod with RS485 extension, fully assembled and tested board 110405-91
- BOB FT232 USB/TTL converter, fully assembled and tested 110553-91
- RS485/USB converter, fully assembled and tested 110258-91
- USB-A/Micro-B cable
- Power adapter for smartphones with Micro-B-USB plug
- Software download (free)

All products and downloads are available via the web page for this article: www.elektor.com/110405

The interfaces

Until recently it was virtually impossible to connect your own circuitry to an Android smartphone. Leaving aside exotic solutions such as utilising the audio input (as described in last month's edition [1]), the available interfaces consist of the USB port (for wired connections) and the WLAN and Bluetooth ports (for wireless connections). However, the wireless ports are not exactly easy to use, and you're forced to include a costly transceiver module in your own circuit to handle communication. Potential interference problems are another issue that cannot simply be ignored. Furthermore, Bluetooth has inherent latencies.

This leaves us with the USB port, which is implemented as a 'basic' USB device (slave) port in smartphones. This is because mobile phones are usually connected to a PC that provides the USB host (master) functions. If you want to communicate with an Android smartphone over USB, you therefore have to equip your own circuit with a microcontroller that can act as a USB host. There are now a few boards available from various manufacturers that are equipped with a suitable IC, and some of them are also Arduino compatible. In Android version 2.3.4 and later, Google has incorporated a software interface called Open Accessory API that can be used to control these boards over USB. However, only the very latest smartphones support this interface in the as-delivered configuration. In addition, you must incorporate a USB library in your own device.

The concept

Fortunately for us, two students of hardware and software design at the Hagenberg Campus of the Upper Austria University of Applied Sciences were given a special assignment as part of their studies: develop a low-cost, stable and fast smartphone interface that can be used to control external circuitry. While programming their first test apps, they noticed that every time they pressed the Debug button in their IDE, a status message for setting up a TCP connection flashed on the screen [2]. With their curiosity aroused by this unexpected message, they started digging into the source code of the Android operating system. They even-
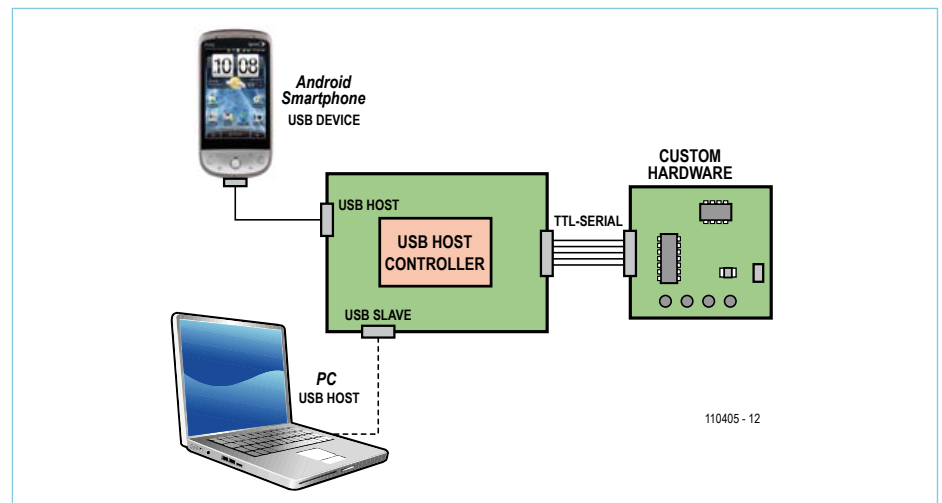
tually found the answer: every device with Android version 1.5 or later (which means virtually every Android smartphone or tablet on the market) includes a USB driver for the Android Debug Bridge (ADB) [3]. A closer examination of the capabilities of this interface revealed that it provides a simple means to establish TCP connections over USB. ADB is intended to be used for debugging Android apps, as well as the operating system itself and the boot loader. To simplify the integration of this interface, the protocol has been designed to be as simple as possible (see inset).

The interface and the USB driver hide the details of the ADB protocol and its USB packaging from programmers. At the Android app level, the only thing that is necessary for data transmission is a small TCP server. This sounds worse than it actually is, since powerful and well documented Java classes (such as *java.net.ServerSocket*) can be used for this purpose. This reduces the programming effort to a few short lines of code. We will discuss this in more detail in next month's issue.

The hardware

In the external circuitry you will need a microcontroller that is able to act as a USB host and has enough flash storage to hold the ADB protocol and the required TCP functions in program memory. The students chose a Vinculum II USB host controller from FTDI for this purpose [4]. This IC, which is also known as 'VNC2', has two USB ports that are able to act as either host or device ports. The core of the MCU is a 16-bit CPU clocked at 48 MHz, accompanied by a hefty

256 KB of flash memory and 16 KB of RAM. The Vinculum controller has enough free pins available to allow external circuitry to be connected to the device. The student designers decided to use the programmable hardware UART for the interface, with the usual serial interface lines (RXD, TXD and GND). Along with the handshake lines RTS and CTS, which are also present, it can be used to implement a full-fledged RS232 interface (with suitable level conversion).

Figure 1 shows the basic connection scheme. The two USB ports allow an Android device and a PC to connected to the interface concurrently, with the Android port configured as a USB host and the PC port configured as a USB device. The PC can provide the operating power for the interface, but it can also do more. The two Austrian students devised a way to use the ADB simultaneously for both their own 'novel' purpose and its originally intended purpose, which is debugging an Android app from a PC. This is made possible by using the Vinculum controller as an sort of intermediary, with a router implemented in the controller firmware to send the byte packets to the right destinations. Two TCP ports are used to determine which data goes where; the designers reserved port 1337 for controlling external circuitry. This capability is invaluable in the development of user-defined apps, since it allows development to be carried out with the external circuitry connected.

The board

The main components of the interface board, dubbed AndroPod by its designers

Figure 1. The USB controller has two USB ports, which can be used to connect a smartphone and a PC at the same time for debugging.
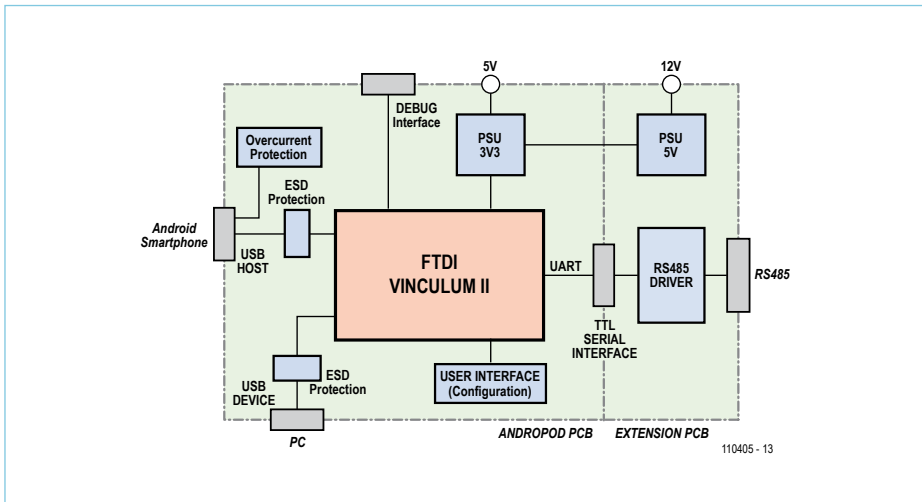
Figure 2. The board provides several ports, including a TTL UART port and an RS485 port, and offers a broad selection of power options.

Figure 4. The USB-A to Micro-B cable supplied with the smartphone can be used to connect the smartphone to the AndroPod.

(see **Figure 2**), are the Vinculum II controller, the two USB connectors and the serial interface connector. There is also a 3.3 V power supply unit (PSU) that reduces the 5 V supply voltage from the USB port to 3.3 V, which is the operating voltage of the Vinculum IC. A VNC2 debugger module can be connected to the debug port, but this is not necessary in normal operation with fully tested and debugged firmware. The user interface consists of status LEDs and two small switches used for setting configuration parameters.

To increase the versatility of the AndroPod, Elektor added an RS485 extension to the design. Antoine Authier in the Elektor lab had the idea of laying out this extension so it can be separated from the main board. If you do not need an RS485 port, you can simply saw off this part of the PCB.

The circuit
The developers used the FTDI Vinculo board as the starting point for the design for the AndroPod, but they chose a VNC2 in a 32-pin QFN package to make their design more compact. As you can see from the schematic diagram in **Figure 3**, their version does not require many external components.

The IC needs an external quartz crystal to generate a precise, stable clock signal. Decoupling capacitor should also be fitted next to the supply pins of the controller IC. In addition to the regulated 3.3 V supply voltage, the Vinculum II needs a separate supply voltage for the PLL (VREGOUT). This voltage is generated internally, but it needs an external buffer and an analogue filter for noise attenuation.

The wiring of the USB host and device ports is simple. It essentially consists of 27 Ω resistors (these values are taken from the data sheet) and suitable USB connectors. A standard USB-A connector (K2) is used for the host port for connection to the smartphone. This allows the USB-A to Micro-B cable included with the smartphone to be used for this link (**Figure 4**). You should bear in mind that whenever a smartphone is connected to a USB port, it wants to be charged. This means that the AndroPod board must be able to supply 500 mA at 5 V. The easiest way to do this is to provide power from the USB device connector (K1). A Micro B connector is used here, so that the AC adapter provided with the smartphone can be connected to this port.

If a device that draws more than 500 mA is connected to K2, the board is adequately protected by IC2. This special-purpose IC

is specifically designed for USB power management and limits the output current to 500 mA.

Immunity to external electromagnetic interference is enhanced by diodes and ferrite beads

The power source
The AndroPod board (**Figure 5**) is available from the Elektor Shop fully assembled and tested (without the optional components marked by an asterisk in the schematic diagram). There are several options for powering the board. Usually the main AndroPod board powers the RS485 extension, but it can also work the other way round. To make this foolproof, the design is implemented with two separate 5 V rails, which are labelled '+5V_CORE' and '+5V_EXT' on the schematic diagram.

As already mentioned, the AndroPod can be powered over K1, but it can also be powered over the debug port (K3). The third option is to use the +5V_EXT pin on connector K4, K5 or K6. In any case, you should always remember the 500 mA load requirement. Three-position jumper JP1 must be configured according to the selected power option. The supply voltage from the selected +5V_CORE source first passes through a fuse. IC1 reduces the supply volt-
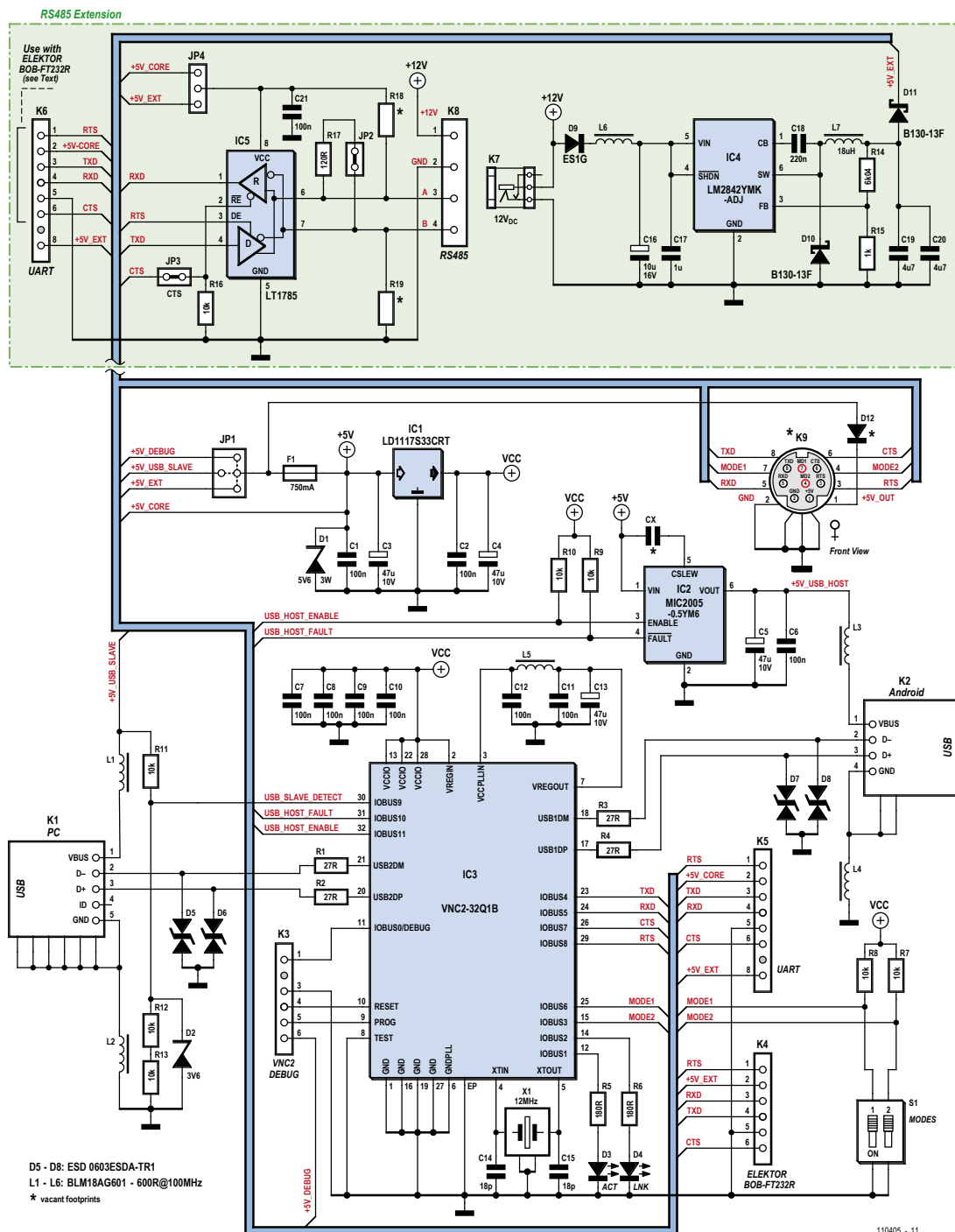
Figure 3. Schematic diagram of the AndroPod and the RS485 extension (shaded in green).
The components marked with an asterisk are optional.

COMPONENT LIST

Resistors (1%, 0603)
R1–R4 = 27Ω
R5,R6 = 180Ω
R7–R13,R16 = 10kΩ
R14 = 6.04kΩ
R15 = 1kΩ
R17 = 120Ω
R18,R19 = 680Ω (recommended value)

Capacitors
C1,C2,C6–C12,C21 = 100nF 50V (10%, X7R, ceramic multi-layer 0603)
C3,C4,C5,C13 = 47µF 10V (20%, ESR 0.7, tantalum, case B 1210)
C14,C15 = 18pF 50V (5%, C0G/NP0, ceramic multi-layer 0603)
C16 = 10µF 16V (10 %, tantalum, case B 1210)
C17 = 1µF 25V (10 %, X7R, ceramic multi-layer 0805)
C18 = 220nF / 25V (10%, X7R, ceramic multi-layer 0603)
C19,C20 = 4.7µF 10V (10%, X5R, ceramic multi-layer 0805)
Cx = not fitted

Inductors
L1-L6 = ferrite bead, 600Ω @ 100MHz, 500mA (0603)
L7 = 18µH choke (1.25A)

Semiconductors
D1 = zener diode 5.6V 3W
D2 = zener diode 3.6V 375mW
D3 = green LED (0603)
D4 = yellow LED (0603)
D5–D8 = bipolar suppressor diode (0603)
D9,D12 = ES1G diode fast recovery 1A 400V
D10,D11 = B130-13-F Schottky diode 1A 30V
IC1 = 3.3V voltage LDO regulator 1.3A (SOT-223)
IC2 = MIC2005 0.5 A current limiting power distribution switch (SOT-23-6L)
IC3 = Vinculum II USB Host Controller (QFN32)
IC4 = LM2842 600 mA step-down DC/DC regulator (TSOT-6)
IC5 = LT1785 RS485-Transceiver (SOIC8)

Miscellaneous
X1 = 12MHz quartz crystal (18pF 30ppm)
F1 = 750mA Polyfuse
S1 = 4-pin (2x2) pinheader with jumper, or 2-way DIP switch
K1 = USB Micro-B socket
K2 = USB A socket
K3 = 6-pin pinheader (2.0mm)
K4 = 6-pin pinheader (0.1'')
K5,K6 = 8-pin pinheader (0.1'')
K7 = 2.0mm power adapter plug
K8 = 4-way PCB screw terminal block (5.00mm)
K9 = 8-way mini DIN socket
JP1 = 3-pin pinheader (0.1'') + 1 pin + jumper
JP2 = 2-pin pinheader (0.1'') with jumper
JP3 = solder bridge
JP4 = 3-pin pinheader (0.1'') with jumper
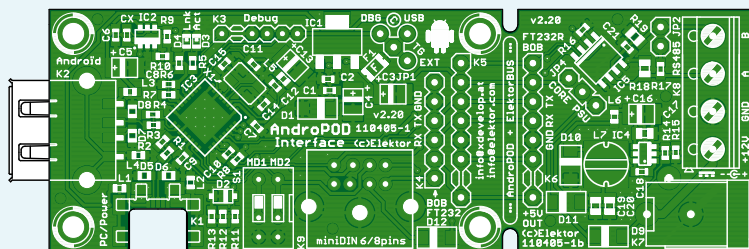
Figure 5. The compact multilayer board is available from the Elektor Shop fully assembled and tested (without the optional components).

age to 3.3 V for the Vinculum controller. The input 5 V can be also be tapped off at connector K5 or K6 (on pin 2 in each case) to power the circuitry connected to these ports. This is also possible at the optional Mini DIN connector (K9) if diode D12 is replaced by a solder bridge. Fitting the diode makes the Mini DIN port foolproof, as otherwise pin 1 can be used not only to draw 5 V power from the board, but also to feed in a 5 V supply voltage. In the latter case you must ensure that no jumper is fitted at JP1. If the diode is fitted, the voltage drop across the diode must be taken into account. In this situation the voltage available on pin 1 of K9 is lower than 5 V.

The +5V_CORE rail also extends to the extension portion of the board, where it can be used to power the RS485 driver. However, the RS485 extension can also be powered from the 5 V PSU built around IC4, which converts a 12 V input voltage from the terminal strip or the power connector to 5 V and feeds this voltage through a diode to the +5V_EXT rail. These two options can be configured with jumper JP4. As already described, the +5V_EXT rail can be used to power the AndroPod and the external circuitry.

The ports

The connection options of the AndroPod and the extension board are just as varied as the power options. UART TTL signals are available on connector K5. The pins of connectors K5 and K6 are interconnected on the board. If you separate the extension board, you can use suitable plug-
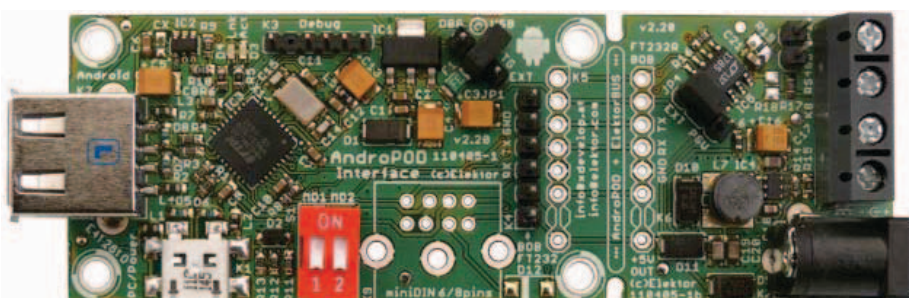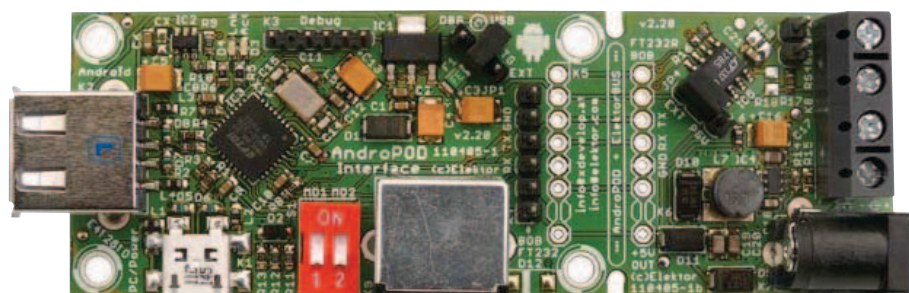
Android Debug Bridge

Each ADB packet transmitted over USB has the following structure:

Address	Length	
0x00	4 bytes	Command
0x04	4 bytes	Parameter 1
0x08	4 bytes	Parameter 2
0x0C	4 bytes	Data length
0x10	4 bytes	Data checksum
0x14	4 bytes	Magic number (command EXORed with 0xFFFFFFFF)
0x18	-	Data

Some examples of commands are 'CNXN' (connection initialisation), 'OPEN' (open connection), 'WRTE' (write date) and 'OKAY' (confirmation).

After this protocol has been implemented, it is very easy to establish a TCP connection, for example on port 1337 (PC to smartphone, smartphone to PC).

Command	Param.1/Param.2 (simplified)	Data (simplified)	Comment
CNXN	-	host:xxxx:xxxx	Establish connection with smartphone
CNXN	-	device:xxxx:xxxx	Smartphone confirmation
OPEN	PC connection ID / 0	tcp:1337	Open TCP connection on port 1337
OKAY	ADB connection ID / PC connection ID		Smartphone confirms opening of TCP port
WRTE	PC connection ID / ADB connection ID	Hello to Phone	Send data to TCP port
OKAY	ADB connection ID / PC connection ID		Smartphone confirms data reception
WRTE	ADB connection ID / PC connection ID	Hello to PC	Smartphone sends data to PC
OKAY	PC connection ID / ADB connection ID		PC confirms data

and-socked connectors to restore these connections.

The signals on pins 1 to 5 of K5 (serial interface lines and 5 V for powering external circuitry) are also routed to a set of solder pads, to which an eight-pin Mini DIN socket can be soldered. Our plans call for fitting this connector on boards supplied by Elektor at some time in the future. Among other things, it could be used for connecting sensors or instruments controlled by the smartphone or tablet. The MODE1 and MODE2 signal lines are also available on the Mini DIN connector.

If you want to load your own firmware into the Vinculum controller, you can use the debug interface, or you can use K4 if you connect the BOB-FT232 USB to TTL converter (also available from the Elektor Shop [5]) to this port as shown in **Figure 6**. Downloading firmware to flash memory with the debug module and over the serial port are both described in document [7].

Next we have the RS485 extension. The terminal strip provides connections for 12 V, GND, A and B. Among other things, it can be used to connect ElektorBus hardware
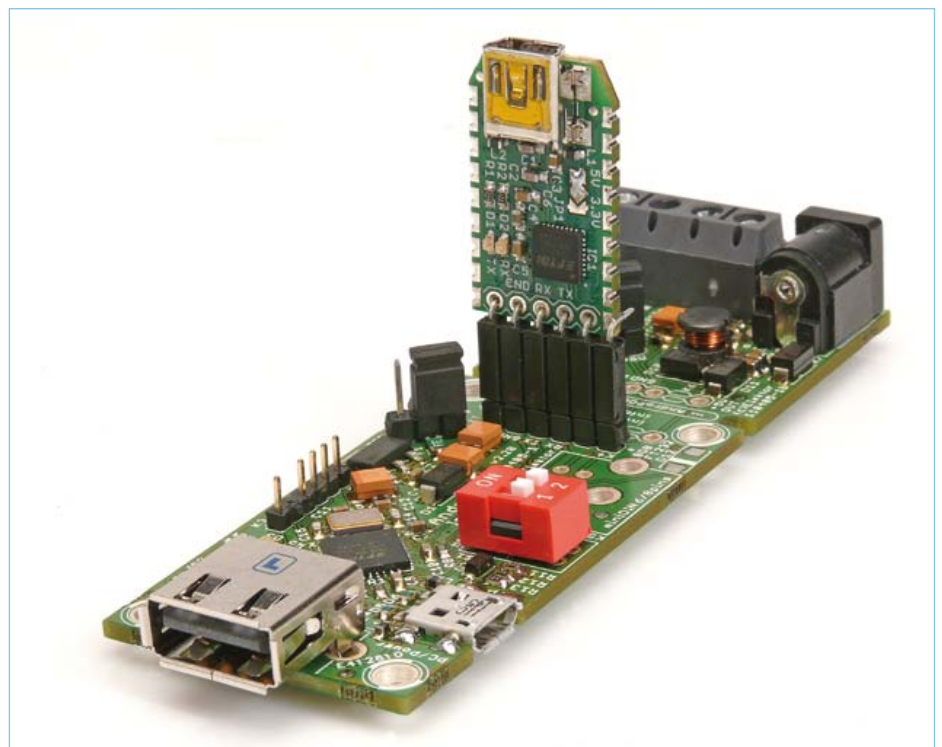

Figure 6. Firmware updates can be downloaded using a BOB FT232 adapter. This compact USB to TTL adapter is available from the Elektor Shop fully assembled and tested.

Figure 7. The free download AdifController software installs drivers, configures the AndroPod, and sends data to the smartphone.

[8]. If you already have some 'Experimental Nodes' (110258-1), please note the altered pin assignments on this connector. The RS485 bus lines can be terminated properly using JP2. The optional pull-up and pull-down resistors (R18 and R19) pull the bus lines to defined voltage levels when all of the nodes are inactive (failsafe biasing). It is recommended to fit resistors for this purpose somewhere on the bus, as otherwise the bus will be much more vulnerable to interference during inactive phases [9].

The RX, TX and RTS lines of the serial port control the LT1785 driver used in the ElektorBus project to enable half-duplex communication. Here the RTS signal is connected to the driver enable (DE) pin. In normal operation the RS485 driver receives all of the bytes it transmits (echo mode). This can be suppressed with the CTS line, although the current version of the Vinculum firmware does not support this option.

As an added bonus, the extension board can be used as a stand-alone RS485 to TTL converter, or as an RS485 to USB converter if the BOB-FT232 USB to TTL adapter is connected to port K6. However, in this case the DE pin of the LT1785 must be driven by the PC software. The current ElektorBus PC software does not support this, and here we recommend the RS485 to USB converter described in a previous issue of *Elektor* [6].

Device configuration

The Vinculum II controller on the board comes pre-programmed with the AndroPod firmware developed by the designers.

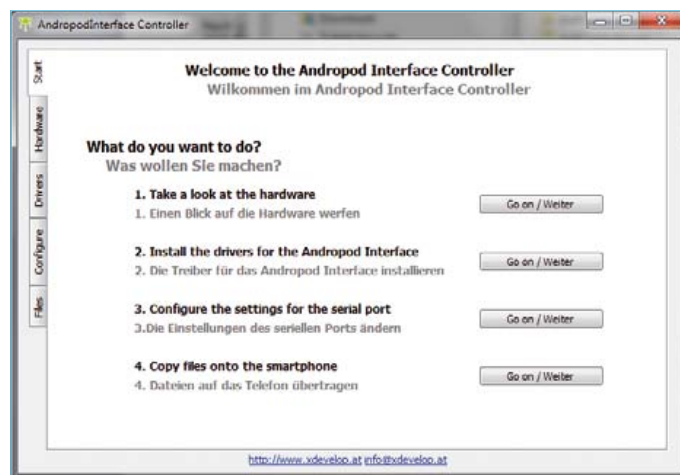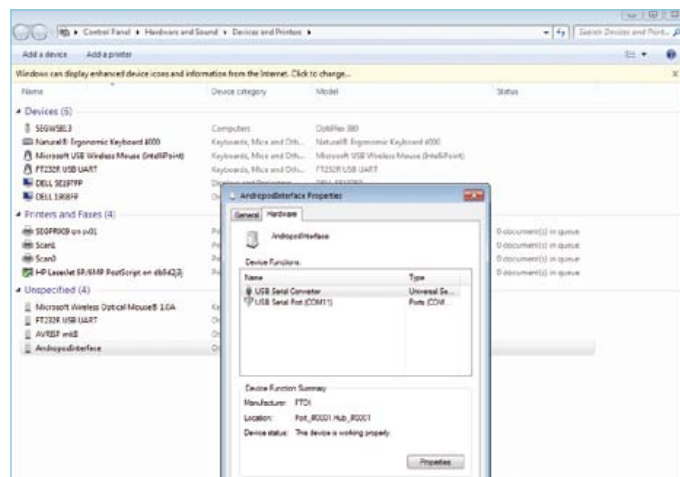The baud rate and the UART parameters can be configured

Figure 8. The AndroPod acts as a USB to serial converter during the configuration process. You can check this by double-clicking the 'AndropodInterface' entry in the Windows Device Manger window.
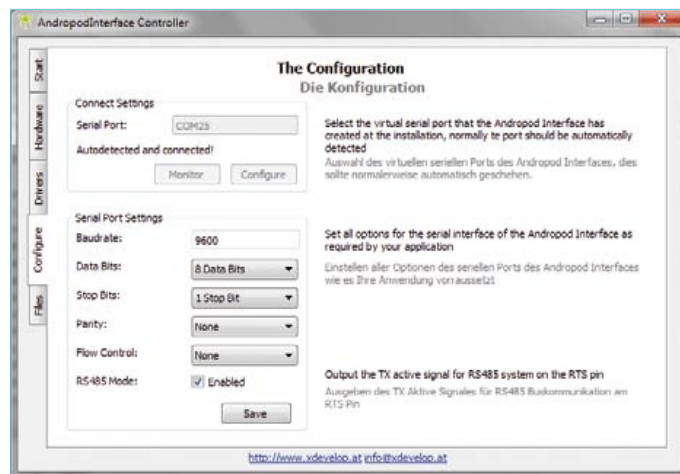
Figure 9. Serial interface configuration for connecting your own circuitry.

using the AdifController utility program on the PC. The designers developed this program specifically for the AndroPod interface, and there is no need to modify the Vinculum firmware. You can also use AdifController to specify whether the RTS line should be used to control the LT1785. As usual, the software for this project is available in a zip archive that can be downloaded free of charge from the Elektor website [6].

The right-hand switch (switch 2) of DIP switch S1 must be set to the On position (configuration mode) for device configuration. This switch should be set to the '2' (Off) position (debug mode) for debugging Android apps and normal operation. The left-hand switch (switch 1) is not used by the current firmware version.

Before connecting an Android smartphone to K2 (using a second USB-A to Micro-B cable available from Elektor [6]), you must enable ADB in the smartphone. It is disabled by default for security reasons. With the home screen displayed on the smartphone, press the bottom left menu key to open a menu with the 'Settings' option. Open the 'Settings' screen, select 'Applications', and then select 'Development'. Tick the 'USB Debugging' checkbox here.

After the smartphone is connected, the yellow LED should start blinking slowly (once per second). It blinks faster when ADB is not enabled.

Testing

Initial testing is performed in debug mode. The most convenient way to power the board is from the PC over K1 (connected to the PC by a USB-A to Micro-B cable). JP1 must be set accordingly.

Start by opening Windows Device Manager and checking whether the AndroPod is recognised correctly as 'AndroPodInterface'. It may be necessary to first disconnect the board from the PC and then reconnect it. In most cases, you will first have to install the appropriate drivers, which can be done conveniently with AdifController. To do this, first run the setup program *AndroPod-InterfaceInstaller.exe* in the download folder extracted from the zip archive. You can safely ignore the Windows warning that the program is not secure and might pose a threat to your computer.

After completing the installation, open AdifController from the 'All Programs' list. In the main window (**Figure 7**), select the 'Drivers' tab. Click 'Install driver for Debug Mode' to install the debug mode driver, and then install the configuration mode driver in the same manner. After this the AndroPod board should be shown properly in Device Manager. If not, try disconnecting and reconnecting the smartphone cable.

If everything is OK up to this point, change the board to configuration mode (set switch 2 to On) and reset the board by again disconnecting and reconnecting the cable. The board should appear again in Device Manager as 'AndroPodInterface'. Double-click the device name to display the Properties window, where you should see that the Vinculum controller is operating as a USB serial converter (see the screen shot in **Figure 8**). Now select the 'Configure' tab in the AdifController window (**Figure 9**). The default setting is 9600 baud, although significantly higher baud rates are possible (up to 1.5 Mbaud).

Now you should change back to debug mode to test data transmission. For this you naturally need a suitable Android app. The authors have put a ready-made, highly versatile app on the Android Market site, since this makes installation relatively easy. Look for 'ElektorBusBrowserForAndroPod' on the Android Market site (this app will be described in detail in the next issue). When installing the app on the smartphone, confirm that you wish to allow it to access Internet and text messaging (SMS) functions. The yellow LED on the board should light up continuously after the app is started. To test

About the designers

Julian Nischler (right) and Bernhard Wörndl-Aichriedler (left) are engineering students at the Hagenberg Campus of the Upper Austria University of Applied Sciences, majoring in hardware and software design. Julian also runs an event agency on the side, and Bernhard is active as an independent hardware developer. More information on these two designers and their projects is available at www.xdevelop.at.
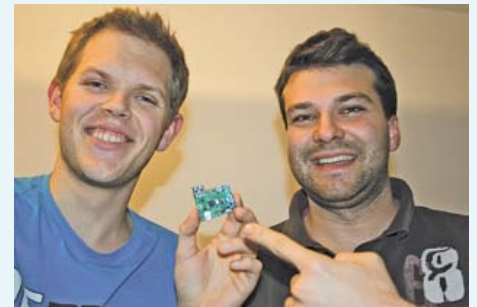
The designers were supported in their project by Michael Bogner and Thomas Müller-Wipperfürth of the Software & Hardware Design faculty (www.hardware-software-design.at), Helmut Strasser, Prof. Andreas Magauer, Prof. Peter Klotz and Nicole Miletic.

data transmission, connect a BOB-FT232R USB to TTL converter between port K5 and the PC. You can also use an FTDI USB to TTL adapter cable, but only if you modify the connector to match the pin assignments of connector K5. A third option is to use the previously mentioned Elektor RS485 to USB converter [6], which can be connected to the terminal strip on the AndroPod board with three wires. If you choose this option, you will test the RS485 extension at the same time.

Now launch your preferred terminal emulator program on the PC and configure it to communicate at 9600 baud over the COM port used for the USB converter. Press the bottom left key on the smartphone, which should bring up the app menu. After you press the 'Test Data Transmission' button, you should see a very familiar message in the terminal window.

In the next issue we will introduce the rest of the app's functions. It can display custom user interfaces and send event-driven text messages, and you don't need to be an Android expert for any of this. For those of you who want to do their own Android programming, it provides a good example of how to construct an app for controlling your own circuitry.

(110405-I)

Internet Links

[1] www.elektor.com/110690

[2] http://en.wikipedia.org/wiki/Transmission_Control_Protocol

[3] http://developer.android.com/guide/developing/tools/adb.html

[4] www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_Vinculum-II.pdf

[5] www.elektor.com/110553

[6] www.elektor.com/110405

[7] www.ftdichip.com/Support/Documents/AppNotes/AN_159%20Vinculum-II%20Firmware%20Flash%20Programming.pdf

[8] www.elektor.com/110258

[9] www.ti.com/lit/an/snla031/snla031.pdf

Pico C-Plus and Pico C-Super
Elektor's 'small-C' meter upgraded in two ways

By Jon Drury (UK)

The popularity of *All Things Test & Measurement* among Elektor readers got substantiated once again recently by Pico C, a cute DIY capacitance meter specially designed to deal with small capacitors like below 10 pF, much to the enjoyment of radio amateurs and leaving professional instruments well behind. One limitation of the instrument was noted though, its maximum value of about 2500 pF, triggering reader Jon Drury to write new software culminating in two new versions called *Pico C-Plus* and *Pico C-Super*. *C+*? No, assembly language was used to write the firmware!
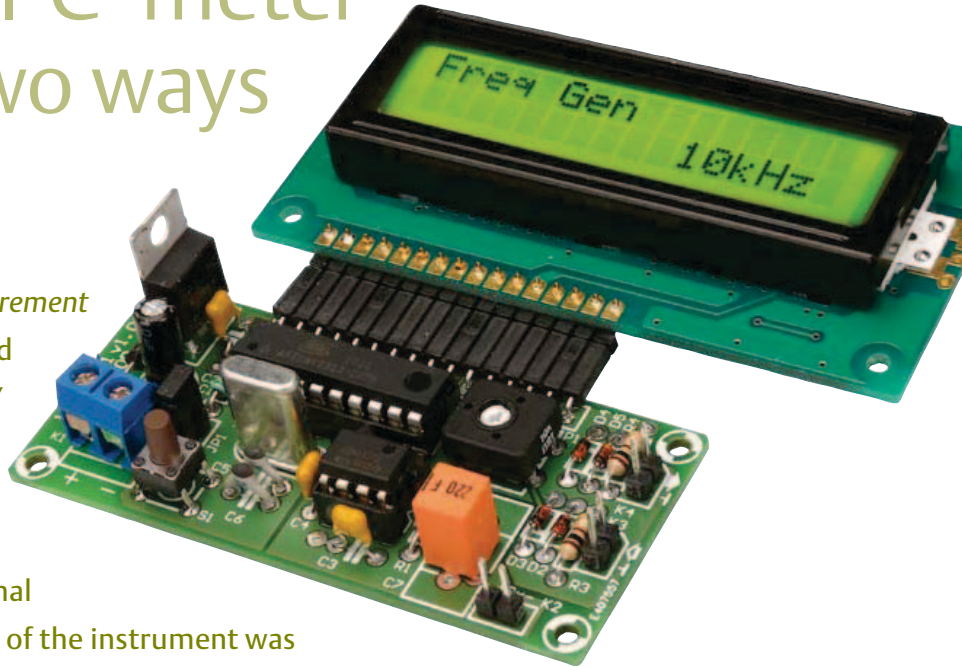
Two new versions were developed of the software for Pico C. Version **Pico C-Plus** will run on the board as published [1] and includes a signal generator function as well as capacitance measurement and a simple period measurement function based on the TLC555 oscillator. The second version, **Pico C-Super**, requires minor changes to the original PCB (two cuts and three wires) to allow an external signal to be measured. This version adds a frequency counter and implements the period counter properly. As an alternative to track cutting and wire soldering, a new board design was produced for Pico C-Super.

Pico C-Plus: look, no board modding!
When I read the original article in the April 2011 edition [1], it seemed to make little sense that a 24-bit counter should be lim-

ited to 2500 pF. The article states that a count of 680 is equivalent to 1 pF and as 24 bits gives a maximum count of 16,777,215, the range should extend to 16,777,215/680 = 24,672 pF. I decided to investigate by rewriting the software in pure assembler to keep control of the 24-bit arithmetic required and to stay close to the hardware. A later study of the source code for the published software shows that compromises were made in order to work within the constraints of the Bascom arithmetic (see **inset**). The assembler version uses a 24 x 24 bit multiply and 48 x 24 bit divide which I have derived from Atmel's application note AVR200 and this avoids having to make any compromise in the arithmetic. I have also taken a different approach with the ISR (interrupt service routine) and use just one ISR to start and stop the count as well as controlling the number of periods

that are averaged. Since Pico C is essentially a period measurement device, this was my first development target. I have retained the signal averaging of the original, but use multiples of 10 so that scaling becomes a simple matter of shifting the decimal point. Signal averaging is also of benefit in this application as there is some noise on the oscillator period. The new meter ranges and accuracies are shown in **Table 1**. As in the original software, calibration values are stored in EEPROM. When the board is used for the first time, the software will recognise that the EEPROM is blank and insist on calibration to be carried out. Calibration is then optional for further measurements, but can be performed at any time by selecting the 'Calibrate' function from the mode selection sequence. Please note that the new software carries out an 'autozero' operation automatically at the beginning of

Editor's note. The modifications and extensions described in this article are the result of reworking and do not imply corrections to the original design of Pico C (April 2011) [1], nor the associated PCB, microcontroller or kit supplied by Elektor (nos. 100823-1, 100823-41, 100823-71 respectively). The original publication and related products stand unaltered.

Pico C-Plus/Super Features

- Completely rewritten software (assembly code).

- Ready-programmed controllers available.

- Extended capacitance range:
  <1 pF to 500 nF, max. resolution 0.01 pF

- 3 capacitance ranges: 5 nF, 50 nF, 500 nF

- Pico C-Plus:
  software upgrade only; no PCB modifications required

- Pico C-Super: software upgrade & minor PCB alterations
  required. Reworked PCB available.

- Period meter ranges: 16 ms, 160 ms, 1.6 s

- Frequency meter range: 8 MHz, max resolution 1 Hz

- Signal Generator:
  - range 0.8 Hz – 10 MHz
  - resolution 0.1% up to 10 kHz, 1% across 10 kHz – 100 kHz
  - square wave 0 – 5 V

Table 1. Capacitance measurement.

Multiplier	Max. capacitance	Resolution
1	500 nF	1 pF
10	50 nF	0.1 pF
100	5 nF	0.01 pF

Table 2. Period measurement.

Multiplier	Maximum	Resolution
1	1.6 s	0.1 μs
10	160 ms	10 ns
100	16 ms	1 ns

Note: a minimum of 1.5 μs applies to all ranges

Table 3. Frequency measurement.

Gate Time	Max. frequency	Resolution
10 ms	8 MHz	100 Hz
100 ms	8 MHz	10 Hz
1 s	8 MHz	1 Hz

a measurement cycle and nothing should be connected to the input until after the autozero time.

The new software includes a separate period measurement function with options to average 1, 10 or 100 periods. The maximum multiplier of 100 allows periods to be measured with a resolution of 1 ns.

Since f = 1/P there is an opportunity to add high resolution, low frequency measurement (<100 Hz), but sadly there's no room on the 2 x 16 LCD. The period function has a minimum measurable time of 1.5 μs, since this is the execution time of the ISR.

The period measurement function was then used to implement the logic of Pico C with improved results, see **Table 2**. The multiplier feature now acts to select the measurement range. The maximum range on each scale is determined by the maximum count before overflow occurs and I have chosen to generate overflow at 24 bits to keep the maths simple(!) although the two concatenated counters can give 26 bits (by using OC1A

as well as OC0B). The other consideration is that the maximum measurement period is nearly a second (0.839 s) for 24 bits and longer times would start to feel slow. From preliminary calculations of maximum range as above, a range of about 8 nF was expected with the multiplier at 100, since this is about 3 times the figure used in the published software (the original Pico C included a multiplier of 32). However, I was only able to measure around 5.8 nF which is a bigger error than could be explained by component tolerances (5%). The published figure of 680 counts/pF may well be inconsistent with the published base frequency of 3.2 kHz (see **inset** for calculation). In this extended version with the multiplier set to 100, capacitance can be resolved down to 0.01 pF but limited to 5 nF, whereas with a multiplier of 1 resolution drops to 1 pF but the range extends up to 500 nF using the published component values. The linearity of the meter was checked on all ranges by measuring individual capacitors and then measuring them in various combinations (see results). Although some slight deviation is noted at the top end, it is less than 0.1%.

Clearly, if the value of R1 is reduced the top limit can be extended. I prefer to use 470 kΩ which extends the top limit to a convenient 1 μF with no detriment to the bottom end. However, it would be interesting to test even lower values of R1 to see whether the meter could also be used to measure low value electrolytic capacitors.

With this much code written there was still room in the 2313 memory for more code, so it seemed logical to add frequency measurement and a signal generator to get the maximum use from the hardware. The signal generator turns out to have a very wide range from 0.8 Hz right up to 10 MHz (but with reduced resolution at the top end). It uses a table of 18 spot frequencies located in EEPROM to retain as much program space as possible. Users should tailor the frequencies in the table to suit their own application. The frequency counter (**Table 3**) uses a precise software delay routine as both counters are already in use. The delay times were checked using a version of the period measurement function.
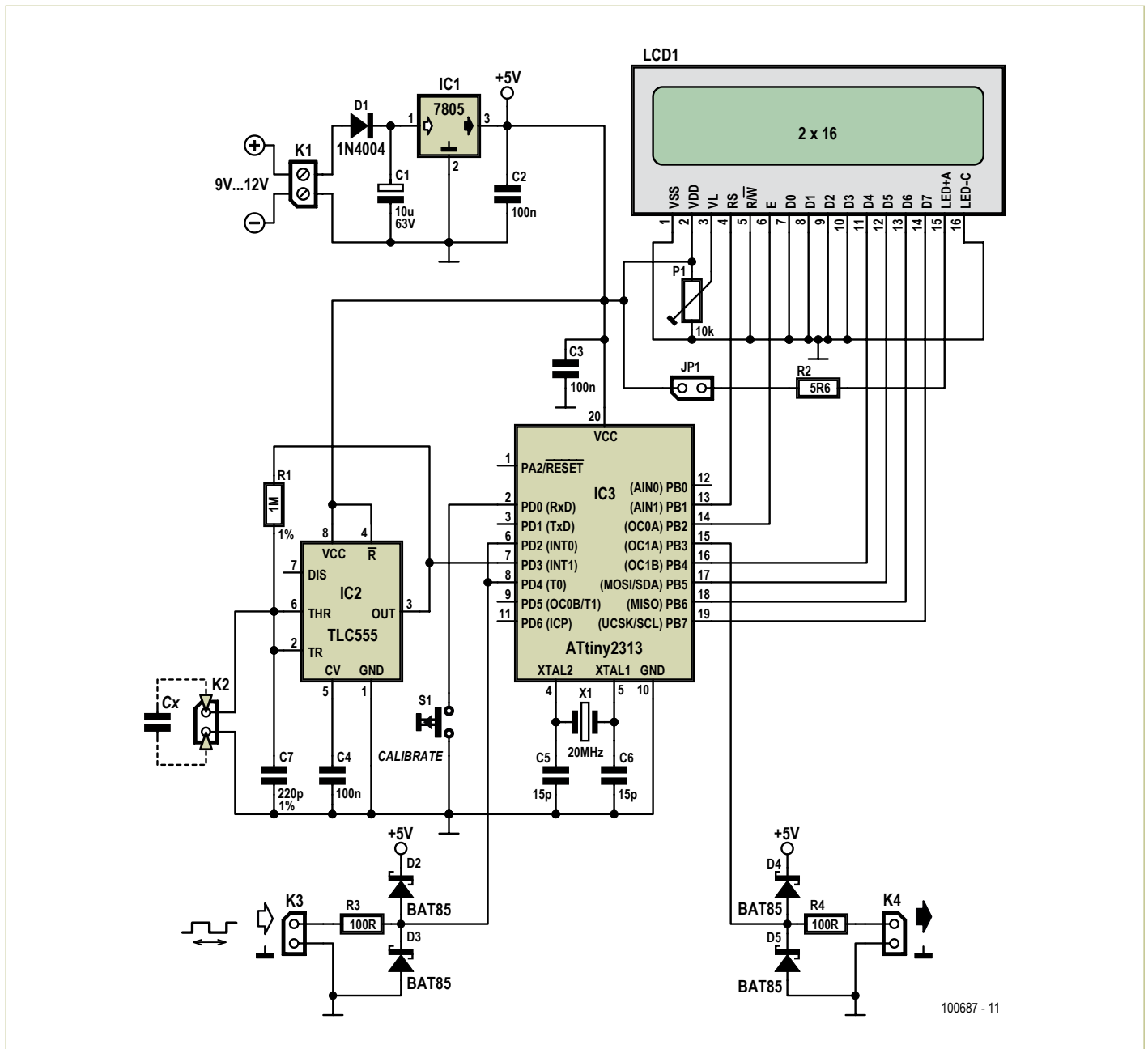
Figure 1. Circuit diagram of Pico C-Super, incorporating changes to the original design from April 2011. We now have extended capacitance range (up to 500 nF), a signal generator, a frequency counter, and a period meter — software-wise, it's all crammed into a single ATtiny2313 micro!

ToDo for Pico C-Plus

- (Re)program the ATtiny2313 with PicoC-Plus.hex and PicoC-Plus.eep (EEPROM contains basic table for signal generation), or order a ready programmed microcontroller # 110687-41 from Elektor [2].
- Use pin 15 (OC1A) of the 2313 for signal output.
- Use short presses of the switch to move through the menus and a long press (>2 sec) to accept the displayed option or to exit from any mode.

Pico C-Super:
minor surgery, or a new board

IF you want the little instrument originally called Pico C

(1) to have the extended capacitance range of Pico C-Plus;

(2) to have the signal generator of Pico C-Plus;

(3) to act as a frequency counter

(4) to act as a period meter

REM in other words, to make full use of the extended software version called Pico C-Super

THEN some pins of the pins of the 2313 need to be freed up!

ELSE stick to Pico C-Plus or even happily continue using the original Pico C!

Programming aside, this is because pin 8 of the 2313 (T0 input) is used as an output in the published version to control the TLC555. But in the extended software version Pico C-Super, this pin is used as an input for frequency measurement and the TLC555 Reset pin is connected permanently to 5 V. A change is also required to split pins 6 & 7

as the revised versions use INT1 for capacitance measurement and INT0 for external period. Without changes the period function shows the period of the 555 oscillator.

ToDo for Pico C-Super

To get the frequency counter and period measurement functions working requires two cuts and three wire links on the original Pico C board:

- cut track between IC2 pin 4 and IC3 pin 8. (Frees up T0 input)
- connect IC2 pin 4 to IC2 pin 8. (Leaves IC2 running permanently — RST tied to +5 V)
- connect IC3 pin 8 to input socket. (Input to T0)
- cut track between IC3 pins 6 & 7. (Frees up INT0 — used for external Period)
- connect IC3 pin 8 to IC3 pin 6. (External input to INT0)

The changes are reflected in the circuit diagram shown in **Figure 1**. Diodes have been added for input protection. The PCB incorporating the above changes carries item number **110687-1**. For the convenience of readers new to the Pico C Saga the PCB silk screen is shown in **Figure 2**; the PCB artwork file may be downloaded free from [2] and the ready-programmed controller for Pico C-Super is available as item # **110687-42**.

What else? The **parts list**, of course, and the actual construction but that should not present problems as only through-hole components are involved and a single-side circuit board.

One word of caution though:
check and double check the pin numbering of the LCD you are using – the schematic shows a circuit symbol only, not the physical shape or actual pin arrangement.

Some results

First, a word of caution. The reworked meter is extremely sensitive on the 100x range and the presence of a hand is detectable at a range of about 5 cms (2 in.). So for best results I have activated the switch by using a pot trimmer during calibration to avoid errors from hand capacitance.

For your amusement, a photo of my prototype with a 1.6–5.0 pF variable capacitor is shown in **Figure 3**. The capacitance will start to increase when a hand is placed about 5 cms away and rises to about 5 pF when the wire is gripped between two fingers. Note the wire is 10 cms (4 in.) long and attached to the 'live' pin of the input. Is it an

COMPONENT LIST (Pico C-Super version only)

Resistors
R1 = 1MΩ 1%
R2 = 5.6Ω 5%
R3,R4 = 100Ω 5%
P1 = 10kΩ 20%, preset

Capacitors
C1 = 10µF, 63V, lead spacing 2.5mm
C2,C3,C4 = 100nF 50V ceramic, lead spacing 0.2'' (5.08mm)
C5,C6 = 15pF 100V 5%, ceramic, lead spacing 0.2'' (5.08mm)
C7 = 220pF 63V 1%, polystyrene, lead spacing 7.18mm

Semiconductors
D1 = 1N4004
D2-D5 = BAT85
IC1= 7805
IC2= TLC555
IC3 = ATtiny2313, programmed, Elektor # 110687-42*

Miscellaneous
JP1,K2,K3,K4 = 2-pin pinheader, straight, lead pitch 0.1'' (2.54mm)
JP1 =jumper 0.1'' (2.54mm)
K1 = 2-way PCB screw terminal block, lead pitch 5mm
K2,K3,K4 = 2-way socket, straight, lead pitch 0.1'' (2.54mm)
LCD1 = LCD, 2x16 (TC1602C-01YA0_A00), Elektor # 120061-71*. Check pinout when using any other device.
LCD1 socket = 16-way SIL, lead spacing 0.1'' (2.54mm), right angled
LCD1 plug = 16-pin pinheader, lead spacing 0.1'' (2.54mm), right angled
S1 = pushbutton, SPNO, tactile feedback, 6mm
X1 = 20MHz quartz crystal, C_L = 18pF, 50ppm
PCB # 110687-1*

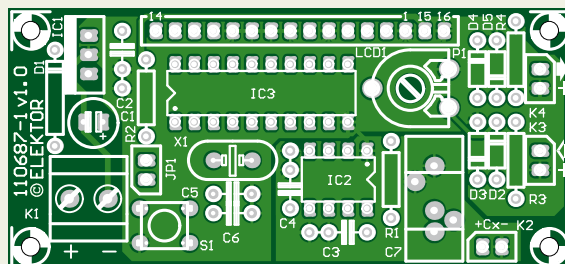* ordering details at www.elektor.com/110687

Figure 2. Component side of the reworked PCB for Pico C-Super, i.e. the version with all the bells & whistles. If you want to make the board yourself, the full artwork may be downloaded from [2].

Compromises in the original Bascom code

The published software declares the period as a long variable, which in this case is 32-bit signed — a maximum of 2.147×10^9. The critical step in the arithmetic requires the period (24 bits) to be multiplied by the value of reference capacitor in tenths of a pF, so by 10,000 which is just over 13 bits. That requires a result which is 24+13 = 37 bits, and as one bit of a long variable is the sign that only leaves Bascom with 31 bits and the critical multiplication step can cause an arithmetic overflow.

The original software deals with this problem firstly by dividing the 25 bits read from the concatenated counters by a factor of 8 in the 'Measure-ok' routine and so reducing the reading to 22 bits. A second compromise is made in the calculation by the statement:

```
If Period <=214748 Then 'do calculation'
      Else 'error'
```

This limits the period to values which won't cause the subsequent multiplication to overflow, but also puts an artificial limit on the maximum value of capacitor that can be measured.
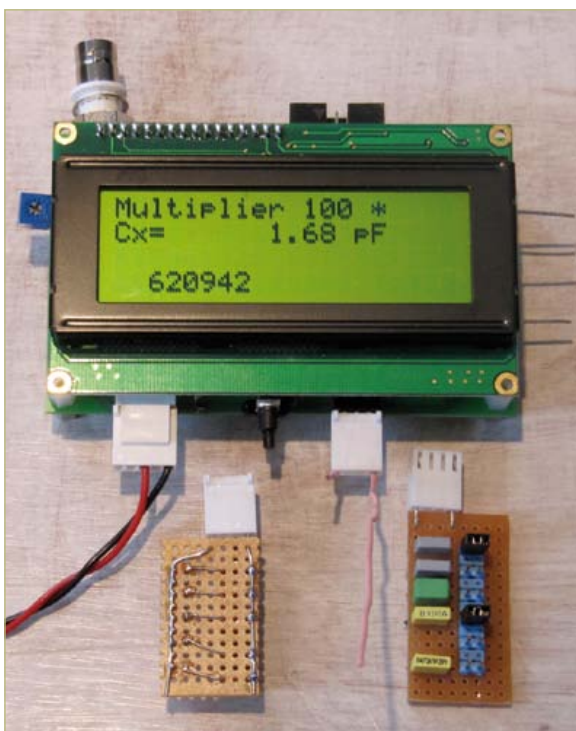

Figure 3. It is any good? The author's prototype gets 'grilled' for accuracy using an array of capacitors and test fixtures. Note the use of a 4x20 LCD, which turned out very useful for diagnostic purposes.

Counts per pF!

The base oscillator frequency of 3.2 kHz is equivalent to a count of

$$20 \text{ MHz} / 3.2 \text{ kHz} = 6250$$

and C7 is 220 pF so

$$6250 / 220 = 28.4 \text{ counts/pF}.$$

But the original software counts 32 periods, giving

$$28.4 \times 32 = 909 \text{ counts/pF}$$

which is rather different from the originally published figure of 680 counts/pF. This would explain the difference between the expected highest capacitance of around 8 nF and the actually measured limit of 5.6 nF.

aerial or a capacitor, what do you think? You will also see in the photo that a 4 x 20 LCD is being used, which has been invaluable in providing space for diagnostic messages during software development.

As mentioned above linearity checks were carried out as the TLC555 oscillator is expected to perform linearly over a 3-decade range of frequencies from 1 Hz to 3.2 kHz. The photo also shows one of the test fixtures made from a small piece of plain perforated board and a header strip. The fixture capacitance is measured as C_0 and then each individual capacitor as C_1, C_2 etc. A variety of values are fitted so that sufficient capacitance can be selected to overload the meter on a given range. A spreadsheet was used to subtract the fixture capacitance from each individual reading in order to calculate its contribution. Then when capacitors get combined the theoretical reading is calculated from the sum of the fixture and the individual capacitors. The error is calculated first in pF and then as a percentage of the theoretical value. The agreement between measured and theory was found to be normally better than 0.1%.

The results of the accuracy measurements have been summarized in a table you can find in optional archive file **110687-W** for the project (free download from [2]).

When measuring larger capacitors on x10 and x1 ranges some noise can be seen. For example, a 10 nF capacitor measured 10089.1 pF on x10, but on x1 the reading varies between 10085 and 10091 pF. Also, there appears to be a small amount of noise picked up at the input of the TLC555 where the input impedance is quite high. Much less noise is seen with measurements on x100 as a result of the signal averaging.

(110687)

References

1. Pico C, Elektor April 2011. www.elektor.com/100823

2. www.elektor.com/110687

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.Net-MF for Electronics Engineers
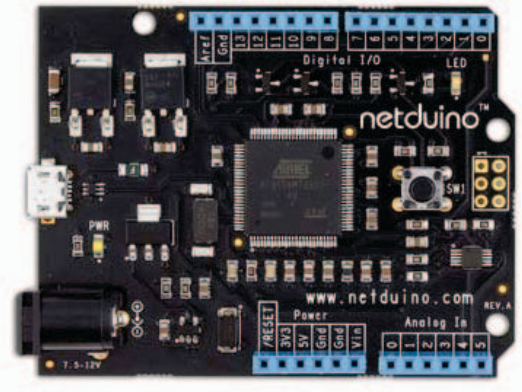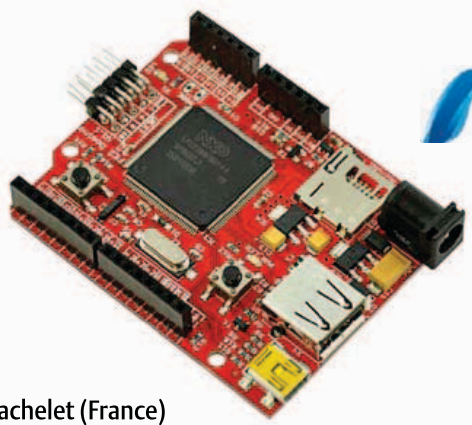
By Claude Bachelet (France)

During the course of my microcontroller projects, I got interested in an inexpensive, simple, powerful approach that was easy to implement, test, and debug, with extensions and directly usable examples, and all in a simple, powerful, up-to-date language: C#.

For us electronics engineers and enthusiasts, the trickiest bit is producing the 'computer' part of a project. Using an off-the-shelf microcontroller module avoids our having to build a circuit with components that are difficult or even impossible to solder, allowing us to concentrate on the project functions. Now the majority of these functions have to be performed in software, and this puts quite a lot of electronics engineers off. Several platforms set out to make programming easier, for example Arduino for 8-bit microcontrollers. Here, we're going to be looking at a platform for more powerful 16-, 32-, or 64-bit (or even more in the future) systems. This platform is called .Net Micro Framework, an open-source product from Microsoft, available under an Apache 2.0 licence. So as '.Net' is pronounced "dot-net", and 'Micro Framework' gets abbreviated to 'MF', we're going to be talking about

'dot-net MF'. Gadgeteer [1] is a development environment set up by Microsoft in order to roll out its .Net-MF technique in a simple and vaguely entertaining way.

The advantage of the dot-net platform is the application source code compatibility between different processors. Thus it will be very easy to change module during development. The same source code will run equally well on a module using an NXP, Renesas, Atmel, etc. microcontroller and on a Windows, Mac or Linux PC computer using Mono [2], the multi-platform open-source version of dot-net. A porting kit is also available from [3] for adapting dot-net to any module at all.

Hardware

A typical .Net-MF system is fitted with a 32-bit processor and has a minimum of 64 KB of RAM. Several manufacturers offer compatible boards, and not forgetting too the open-source and open-hardware community projects, like Netduino ('Plus', **Figure 1**) [4]. These are cheap boards inspired by Arduino, but based on an Atmel ARM7 processor (AT91SAM7X512) running at 48 MHz. The Plus version includes an Ethernet interface as standard.

GHI Electronics [5] offers a family of modules called 'FEZ', for 'Fast and Easy'. The range is available, in order of an increasing number of function, as Mini, Panda II, Domino, Rhino, Spider, and Cobra. The Cobra and Spider are based on the manufacturer's EMX microcontroller module (LPC2478, 4.5 MB Flash memory, 16 MB RAM) and are the most powerful in the range. They are especially interesting for their graphics capabilities and their memory. The other modules are also based on ARM7 processors from NXP. The Mini and Panda II have an LPC2387 pre-programmed with GHI's .Net-MF core (proprietary, hence the chip is called the USBizi100); Domino and Rhino have a pre-programmed LPC2388 (USBizi144). The main difference between the processors is the number of I/Os and the USB functions.
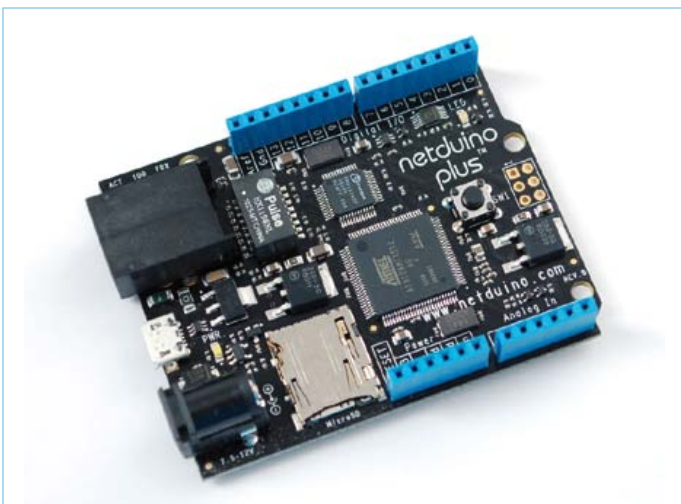

Figure 1. The open-hardware, .Net-MF platform-compatible Netduino Plus board offers an Ethernet port.

Getting started in just 10 mins
(+ download time)

The Panda II and Domino modules are in the Arduino format (standard, not Mega) and thus are compatible with a wide range of Arduino extension modules or 'shields'.

Internet access for the FEZ modules is based on the W5100 chip from WIZnet. This is not one of the most up-to-date ICs, nor the best-performing (it only supports four sockets), but it is fairly fast and will be quite adequate for most applications. Thus it's possible to use the Arduino Ethernet Shield or to use the WIZ812MJ as

described in Elektor's November 2009 issue (Elektor item # 090607-91) and the adaptor from NKC Electronics [6]. This may possibly be a little cheaper, but you will need to make a minor modification (**Figure 2**), which oughtn't to be a problem for any Elektor reader.

It's fairly easy to build your own hardware extensions, or to use display, motor, radio, infrared, GPS, etc. modules available from numerous websites. You can also find ready-made modules supplied complete with their drivers (source code in C#) [7].

| Table 1. Specifications of the individual FEZ modules				
Module	**FEZ Rhino**	**FEZ Domino**	**FEZ Mini**	**FEZ Panda II**
Format	Proprietary	Arduino	Parallax BasicStamp2	Arduino
Size [cm]	7.6 x 7.1	6.8 x 5.3	4.8 x 2.8	6.8 x 5.3
Microcontroller	LPC2388		LPC2387	
User Flash memory	Around 148 KB			
User RAM	Around 62KB			
Ethernet & TCP/IP	W5100 from WIZnet, TCP client/server, UDP, DNS, DHCP, max. 4 sockets			
I/Os	60	30	36	60
PWM	6			
Analogue inputs	8	6	6	6
Analogue output	Yes			
UART	5 TTL	3 TTL	3 TTL + 1 RS-232	4 TTL
SPI	2			
I²C	Yes			
CAN	2	1	1	2
One-wire	Yes			
USB Host	Hub, joystick, keyboard, mouse, printer, CDC, custom and serial port emulation.		No	
USB peripheral	Debugging, custom, keyboard, mouse, or CDC emulation.			
SD/MMC cards	4-bit SD bus, SDHC possible, connector available.			
Real-time clock (RTC)	Yes		No	
Battery back-up RAM	2 KB			
Watchdog	Yes			
User application protection	Yes			
Debugging interface	USB, serial			
JTAG connector	No	No	No	Yes
Operating power [W]	0.55		0.52	
Standby power [W]	0.33		0.33	
Hibernation power [W]	0.06		0.03	
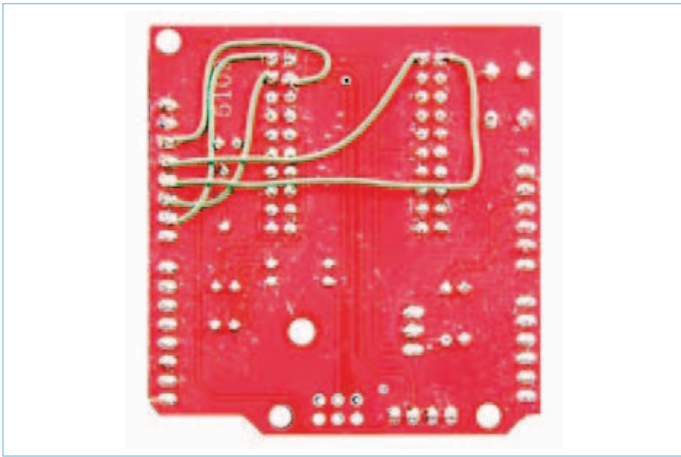
Figure 2. How to wire up your own Ethernet shield with a WIZ812MJ module and a suppporting board from NKC Electronics for use with the FEZ Domino board.
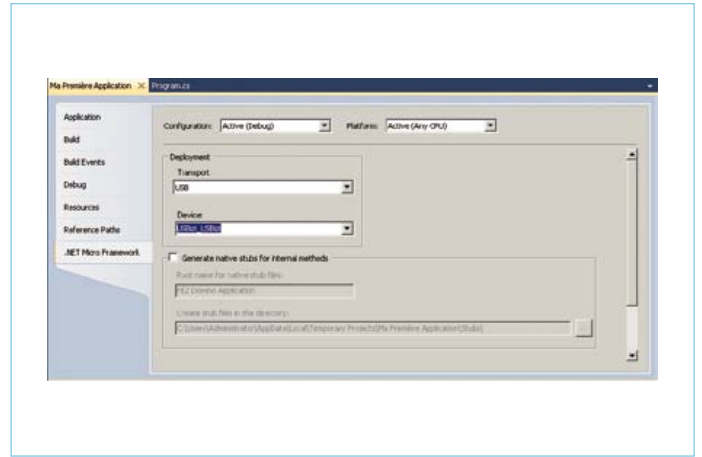

Figure 5. It's important to configure the tool correctly so that the communication with the board will work.
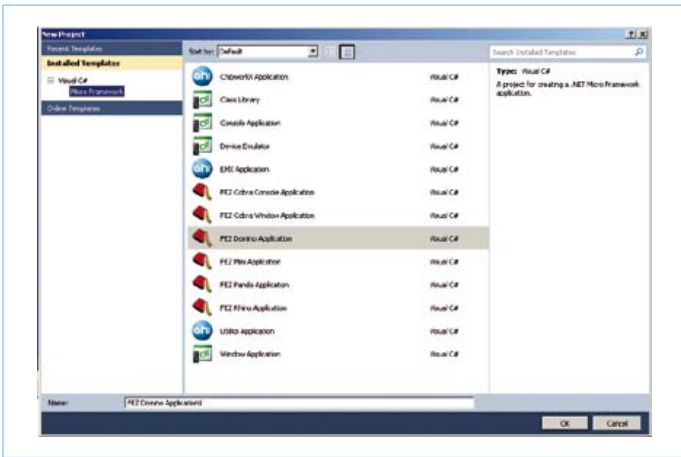

Figure 3. The window that lets you start a new .Net-MF project for the FEZ Domino board.
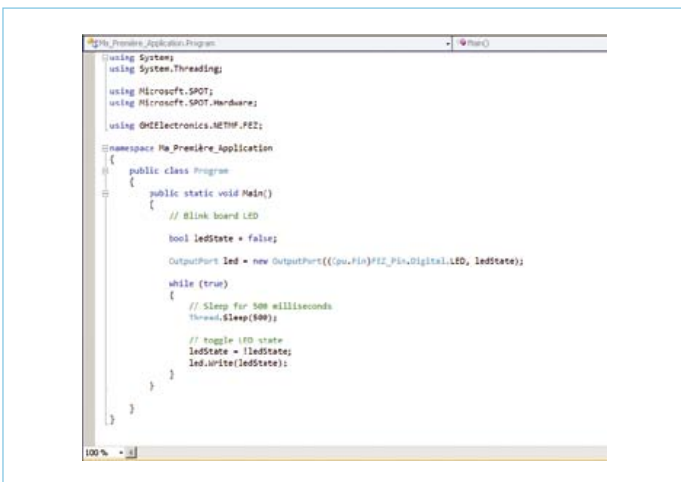

Figure 4. Not quite C, nor C++ — this is C#. Connoisseurs will note the multi-tasking nature thanks to the 'Thread' commands. Note too the 'OutputPort'-type declaration of the LED object.

Software

Even though in this article we are using an FEZ Domino module (the red board in the photo at the start of the article), all the procedures described are still valid when using the other modules. You just have to load the correct module's .Net libraries and if necessary adapt the syntax for the method for accessing the physical resource. Let's get down to business!

- Download Visual C# Express and install it onto a computer (www.microsoft.com/express/downloads/#2010-Visual-CS)
- Download and install the SDK .Net Micro Framework 4.1 (www. microsoft.com/downloads/details.aspx?displaylang=en&FamilyID=cff5a7b7-c21c-4127-ac65-5516384da3a0)
- Download and install the .Net libraries for the module used (for the FEZ family www.ghielectronics.com/downloads/NETMF/GHI%20NETMF%20v4.1%20SDK.zip)
- A free terminal may be useful for updating the firmware, for example Tera Term (http://ttssh2.sourceforge.jp/)
- If necessary, install the USB drivers for communication with the module (for the FEZ family you'll find them here: www.ghielectronics.com/downloads/NETMF/GHI%20NETMF%20USB%20Drivers%2032-Bit.zip)

Run Visual C# Express, click on File > New projects (**Figure 3**). Select the module type, give the application a name (**Figure 4**) and you're off! Now, plug in the FEZ Domino module using its USB cable, and change the Transport under Project/Properties (**Figure 5**). If USBizi appears, all is well; if not, install the USB drivers or change the cable. Close Properties and press F5 — the program is compiled, deployed into the module, the module is re-booted automatically, and... the LED flashes!

By left-clicking with your mouse in the grey column to the left of one of the program lines, you can add a breakpoint and step through the program (using F11) from this point onwards. You can then see the statuses of the variables in the Locals window and even modify them!

Last word

.Net-MF undoubtedly simplifies writing and debugging a microcontroller project, but it's down to you to learn how to program in C#.

To encourage you, remember that C# is pronounced "see sharp" – an accidental pun by Microsoft. Remember too that there are loads of examples of C# code at [7], for example, and elsewhere on the Internet.

Happy project making!

All Internet links in this article are available on the article's web page [8], which will avoid your having to copy them out by hand.

(120033)
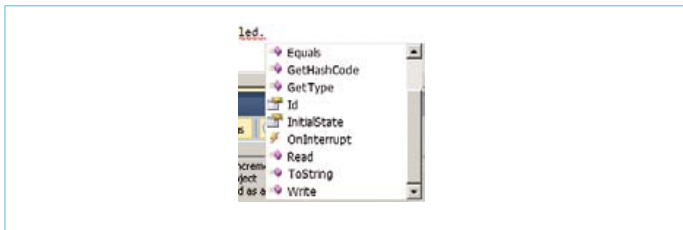
By typing the name of an object followed by "." (here we go again with 'dot'!), you can display the object's methods and properties.

When you hover the mouse over the text, the expression types can be displayed as here for OutputPort.

Internet Links

[1] Gadgeteer: www.netmf.com/gadgeteer/

[2] Mono: www.mono-project.com

[3] Porting kit: www.microsoft.com/downloads/en/details.aspx?FamilyID=CCDD5EAC-04B1-4ECB-BAD9-3AC78FB0452B&displaylang=en

[4] Netduino: www.netduino.com

[5] GHI Electronics: www.ghielectronics.com

[6] NKC Electronics: http://store.nkcelectronics.com/nkc-ethernet-shield-diy-kit-without-wiz812mj-mod812.html

[7] TinyClr: http://tinyclr.com/

[8] This article: www.elektor.com/120033

Wideband Lambda Probe Interface (2)

Measure, control and diagnose using the PC serial interface

By Sebastian Knödler (Germany)

In the last issue we described the interface board for a wideband lambda probe. This versatile board can be used in stand-alone mode or more conveniently from the comfort of a PC or laptop using its serial interface port. When used together with a computer the interface has access to the diagnostic features of the CJ125 lambda probe interface chip and allows measured values and operating conditions to be stored for analysis later on. The interface board is set-up and controlled using a simple set of commands.

Last month we took a look at the operating principle and circuit of this lambda probe interface design [1] and its operation in stand-alone mode. Included in the circuit is a TTL/RS232 interface chip giving it the capability of communication with a PC fitted with this type of serial port. The communication protocol does not use any handshake signals so only three wires are needed (TXD, RXD and GND), connecting to the three pins of X1 (see **Figure 1**). Should your PC not have an RS232 port then a standard USB/RS232 adapter cable can be used, allowing communication via one of your PC's spare USB ports.

Data

Before the serial interface can be used it will be necessary to set up the PC's COM port (or virtual COM port). The configuration data is 115,200 baud, 8 data-bits, 1 stop-bit, no parity, no handshake.

Once communication is established the lambda interface board sends data packets containing lambda measurement information at a rate of five per second. The rate can

be changed to once per second and the data can be sent in an Excel compatible '.csv' format. The data packets have the following simple format, for example:

Lambda: 250
Ref: 252
Bat: 505
Status: 32
CJ: 255

In MS Excel compatible mode the same values are output as:
250;252;505;32;255

The first line or value in each data packet **'*Lambda*'** contains the digital value produced from the 10-bit A/D conversion of the U_A voltage from the CJ125. Using this value we can determine the pump cell current to calculate the exact value of lambda:

$$I_p = \frac{Lambda \times 5}{A_p \times R_{shunt} \times 1023}$$

A_p is the pump current amplification fac-

tor (8 for rich and 17 for lean mixtures) and R_{shunt} is the 61.9 Ω shunt resistor. Plugging in some typical values (*Lambda: 250*) and A_p = 8 the pump cell current equates to:

$$I_p = \frac{250 \times 5}{8 \times 61.9 \times 1023} = 0.0025A = 2.5mA$$

The second value in the data packet **'*Ref*'** is a correction value as already mentioned in the first article, for the 5 V reference voltage used by the D/A converters. The value of *Ref* is derived from the equation:

$$Ref = \frac{1.22 \times 1023}{5}$$

1.22 V (±1 %) is a precise reference voltage on ADC3 (Pin 26) of the ATmega8. Any deviation of *Ref* from its optimal value of 250 indicates that of the 5 V reference used by the A/D converters is inaccurate.

It's probably no surprise that **'Batt'** is the digital value of the supply voltage U_{batt} or U_b. The voltage divider formed by R23/R24

reduces its value so that it can be measured by the A/D converter (ADC2, pin 25) of the ATmega8. If the value falls below 440 (=10.5 V) or rises above 670 (=16.0 V) the ATmega8 stops measurements and switches to standby mode.

Status and *CJ* are values representing the microcontroller status register and the CJ125 diagnostics register. The status register bit definition is given in **Table 1**. The 'Watchdog' bit indicates that a program failure has been detected and the program needs a clean restart. The CJ error bit indicates an error in the CJ125 which is specified in the CJ value byte.

The **CJ** byte is the binary value of the 8-bit CJ125 diagnostics register. **Table 2** indicates their bit assignments and **Table 3** interprets the detected failure codes. When no errors are detected the CJ byte has the value of 255 i.e. all bits have the value '1'.

When an error is detected the output X2/Pin2 is driven high and the probe heater turned off to prevent over heating. The probe pump current is also turned off and measurement of the Nearn cell R_i is not valid so that the values of U_R und U_A are not usable.

As the probe ages it tends to produce errors especially during the warm-up phase. The condition will generally resolve as the probe reaches operating temperature but an increasing occurrence of errors indicates that the probe is ready to be replaced.

Commands

The serial interface supports eight commands (**Table 4**) from an external PC and these are sent as a single character. The character's ASCII code is sent so it's important to make sure that only upper case characters are input. A command is terminated with a CR (carriage return, ASCII code 13) and only becomes active once the carriage return is received. A short description of each of the commands follows:

C (Calibration Mode): The CJ125 is switched to calibration mode (see paragraph below).

N (Normal Mode): The CJ125 supplies actual lambda readings (see paragraph above).
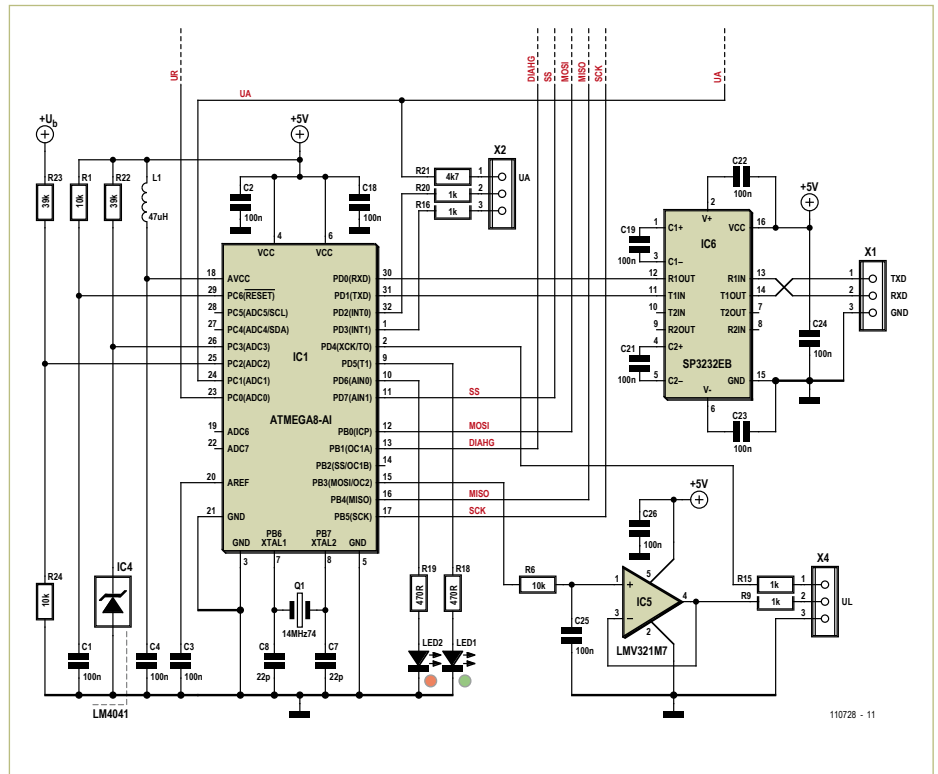

Figure 1. An external computer can send commands to the unit and receive λ measurements and probe status information via the RS232 interface.

Table 1. Status register bit definition

IntF.7							IntF.0
Calibration mode	Watchdog	System ready	SPI error	U_{batt} high	U_{batt} low	Probe over-temperature	CJ error

Table 2. CJ125 diagnostic register

CJF.7							CJF.0
DIAHG	DIAHD	I_A/I_P	I_A/I_P	U_N	U_N	V_M	V_M

Table 3. Interpretation of failure bits

Failure bits	DIAHG/DIAHD	I_A/I_P, U_N, V_M
0 0	Short circuit to ground	Short circuit to ground
0 1	Heater not connected	Low battery voltage
1 0	Short circuit to U_{Batt}	Short circuit to U_{Batt}
1 1	No error	No error

Table 4. Table of commands	
Command	**Function**
C	Calibration Mode
N	Normal Mode
H	Start measurements
D	End measurements
F	Fast transfer (5 Hz)
S	Slow transfer (1 Hz)
T	Clear text mode
E	.csv mode (Excel compatible)

Table 5. Percentage O2 concentration versus pump cell current						
O$_2$ concentration	0.0 %	3.0 %	6.0 %	8.29 %	12.0 %	20.9 %
Pump cell current	0.00 mA	0.34 mA	0.68 mA	0.95 mA	1.40 mA	2.55 mA

H (Start measurements): Turn on probe heater. The system will be ready to start measurements in approximately 30 s.

D (End measurements): Turn off probe heater.

F (Fast): Data packets sent at a rate of 5 per second.

S (Slow): Data packets sent at a rate of 1 per second (the standard setting).

T (Text): Data packets sent in text format (see paragraph above).

E (Excel): Data packets sent in Excel format (see paragraph above).

Figure 2. The relationship between oxygen concentration and pump cell current shows good linearity.

Calibration

The command 'C' puts the CJ125 in calibration mode. The has the same effect as pulling pin 1 of connector X4 to ground when the unit is used in stand-alone mode (described in the first instalment of this project). The circuit automatically performs a self calibration at switch on (when power is applied). A (re)calibration is only necessary if an extended period (> 24 h) of continuous measurement is underway.

Accuracy

The wideband lambda sensor type LSU4.2 together with the CJ125 interface chip achieve maximum accuracy when measuring lambda values close to λ = 1. At more extreme values i.e. lambda values around λ = 1.7 accuracy can be expected to be within ±0.05, drifting by ±0.15 over the probe's lifetime. At λ = 1.009 the error is much smaller quoted at ±0.006 increasing to just ±0.008 after 2000 operational hours. In order to accurately calculate the oxygen content of the exhaust gases it is necessary to establish a calibration curve (**Figure 2**) using the values given in the lambda probe data sheet (see **Table 5**). It is evident that the oxygen concentration shows a close linear relationship to the value of pump current I_p.

From this we derived in last month's article the equation giving the oxygen concentration:

$$O_2 = \frac{I_p + 0.035}{0.1221}$$

The calculation requires oxygen to be present in the exhaust which implies a lean burn i.e. when there is excess air in the mixture. Different calibration data is required for accurate measurement of combustion produced by a rich mixture and also if the LSU4.9 type lambda probe is used.

A more accurate calibration can be made by probe immersion in a specialist calibration gas (e.g. from the gas supplier BOC).
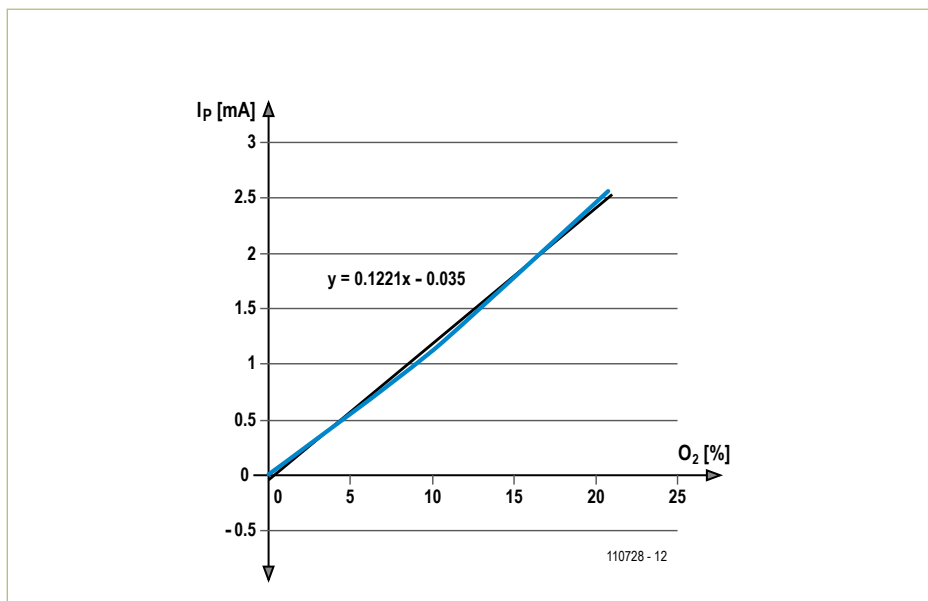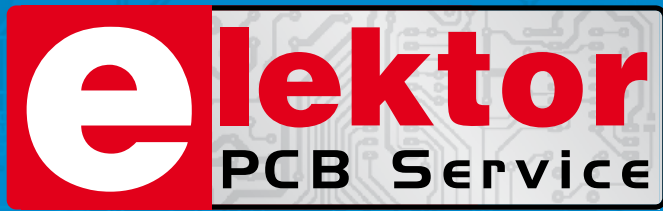
(110728)

Internet Link

[1] www.elektor.com/110363

PicoScope 2205-MSO Grilled

By Thijs Beckers and Jan Buiting (Elektor UK /US Editorial)

A mixed signal oscilloscope (MSO) combines an oscilloscope with a logic analyser, their readouts appearing on a single screen if desired. When we saw Pico Technology's [1] entry level MSO type 2205 announced as "priced under £350" (for the oscilloscope only) we thought we'd better request a sample for reviewing in and around the Elektor Labs.

We received the full kit that's advertised at £399, .i.e. comprising the instrument proper, a pair of x1/x10 passive probes, a

logic cable and test hooks. The 2205 MSO has the familiar appearance of a PicoScope: blue ABS case and two BNC connectors on the front panel. The logic analyser has 16 inputs; the associated yellow wires coming out of a pinheader connector are terminated in tiny receptacles. To these you connect as many little red wires with clip-on hooks as needed for your measurement (up to 16 supported). Also, there are four black GND wires with matching clip-on hooks.
The 2205 is conveniently powered over the PC's USB port, and will not work on a passive hub. It's compatible with the USB 1.1 standard, but 2.0 is recommended. At the rear side of the instrument is the familiar 'AWG' socket supplying the arbitrary wave generator output signal.

Software: PicoScope 6
One great thing about Pico's series of USB oscilloscopes is that they use a common piece of software — currently PicoScope 6 — that detects the actual model connected. The CD-ROM enclosed with our review model of the 2205 showed release 6.6.14 and we figured we would not need it as for sure Pico's online update service would be more up to date. So we ran our previous software installation for a Pico 3206B oscilloscope confiscated by Thijs and used the 'check for update' service, which promptly said v. 6.6.13 was available! Although hard to believe in this day and age of "Internet rulez" here was a rare occasion of a CD in a box beating the Internet for software versions.
The CD installed without a hitch (Windows XP SP2, Vista or 7 required). After connecting the scope and clicking through the 'New Hardware Found' Wizard (do not connect to Windows Update), the instrument was up and running in no time. The first time PicoScope 6 starts, it's with channel A activated and you can begin your

measurement right away. You are free to alter the setup used by the program when it launches.

All Elektor editors doing serious work have split PC screens. Being too lazy to go downstairs to the lab and fetch a working benchtop function generator, we decided to use our 3206B as an AWG and the 2205 MSO as the 'scope. This can be done with amazing ease just by launching the PicoScope software two times over and allocating the 3206B AWG to one PC screen and the 2205 MSO to the other (**Figure 1**). Unfortunately there is no easy way to determine which screen belongs to a 'scope. You have to click the Help menu and click 'About PicoScope 6' to get a popup with information on the software and the scope connected. All done.

We liked
The analogue inputs on channels A and B were found to present a very steady image on our display throughout the frequency range. All 'standard' settings are available; triggering (with lots of options, see **Figure 2**), probe selection, axis scaling, lowpass filtering, xy-mode, persistence mode... the works! The software can also be switched to Spectrum Mode, with a bandwidth of 25 MHz and the ability to zoom in freely on any part of the spectrum. For an MSO in this price range to provide an Arbitrary Wave Generator is remarkable. In fact, the presence of even a simple generator is a big plus on a budget 'scope. The frequency is freely adjustable and the generator goes up to 100 kHz. It has several waveform presets built-in like sine, square, triangle, sin(x)/x, white noise and can generate arbitrary waveforms, which means you can draw your own waveform on a grid without constraints and with a resolution of up to 16384 samples.
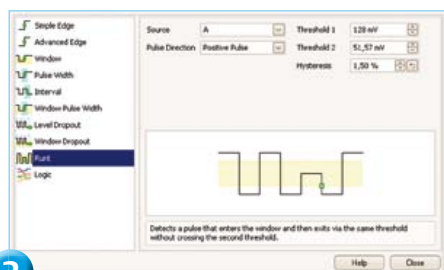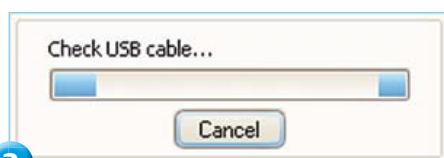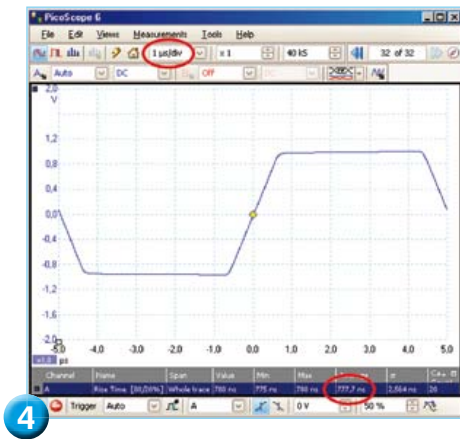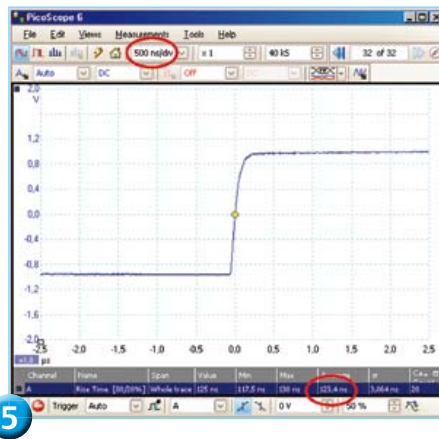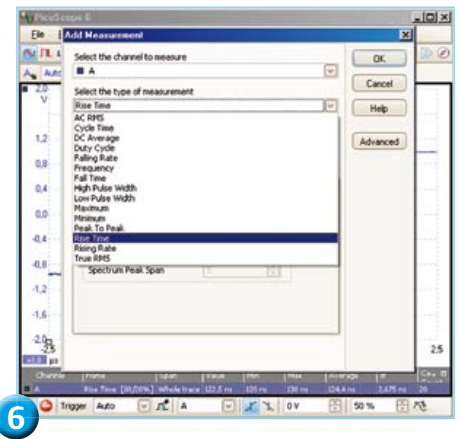
With all the analogue profusion, you'd almost forget about the 16 digital inputs. A neatly organised popup lets you select digital inputs you want to enable as well as set the threshold level (the latter per bank of eight inputs). You can also group inputs into busses. The 16 digital inputs plus the two analogue channels can all be shown together with not much more load on the CPU than when showing only one analogue channel (see below), and the display windows can be conveniently sized to accommodate all signals.

The software appears quite stable. It doesn't crash when you abruptly disconnect the USB cable to the scope. Instead it polity displays a box 'Check USB Cable' (**Figure 3**). When the instrument is reconnected, the software resumes exactly from where it was halted.

A pretty neat feature of the software is its ability to view back several waveforms (up to 10.000!) that are automatically buffered in a temporary memory. You can easily browse through them in the Buffer Overview popup.

CPU load

Displaying real-time waveforms on the computer screen requires considerable processing power. On our test system, a slightly antiquated Pentium Dual-Core E5400 @2.70 GHz and 4 GB RAM CPU usage varied, depending on the selected sample rate, from 0% in the 'off' setting (no measurement) to as much as 60% with both channels activated (capture rate set at the default 30 captures per second). Oddly but not alarming, the CPU load didn't rise linearly with the decrease of the 'Collection Time' (time scale adjustment). There was a dip at 100 ms/div with about 5% CPU usage, while at 200 ms/div and higher, CPU usage jumps to ˜55% (except for the 1000 s/div

(!) where CPU usage drops to almost 0%). In the lower Collection Time ranges (2 µs/div and below) CPU load drops again to about 20˜25% depending on the setting. In Persistence Mode CPU usage gets quite high: about 70% peaks were seen. Spectrum Mode is less exacting with about 40% peaks.

We liked slightly less

Although xy-mode is available, as with most digital scopes, it is sometimes difficult to get the image you'd expect to see on the screen. A test with a prototype of an upcoming project tested our patience as we scrolled through all the available Collection Time settings to end up at the image we expected to see. It did work, unlike our attempts with a 'budget' LeCroy WaveAce 224 DSO, but this of course means starting from the wrong direction. Ideally you should to see directly what is happening and not tweak, dial and click until you get to see what you would expect to see. This xy-mode crux seems to be more of a general problem with digital scopes and we guess users have to live with it.

A second potential weakness we came across was the performance of the AWG. Starting from 10 kHz and up we noticed significant jitter in the generated signal. The internally generated wave resulted in a wobbly image on our screen — independent of the signal amplitude and most noticeable with square waves and arbitrary waves. It looked like the triggering system had some issues, but when we fed the same channel with an equally shaped waveform generated by an external generator, the waveform was displayed rock steady. Pico Technology explained this is due to quantisation caused by the fixed clock rate, as the exact timing of edges has to be dynamically adjusted in order to keep the average frequency over several cycles to an exact figure.

Another thing we noticed during our mini test was that the rise time seemed to depend on the Collection Time setting. See for example **Figures 4** and **-5**: When set to 1 µs/div, the rising edge seemed to be about 778 ns, while set to 500 ns/div, one step further, the rise time measured about 123 ns, the latter being the correct value when double checked with the LeCroy scope. After checking with Pico Technology this matter was cleared: for a smoother waveform in the screenshots we had set the software resolution enhancement to 12 bits. Doing so effectively limits the slew rate of the signal giving the characteristic 'Straight Edge' to the normally exponential rise time capture. With the enhancement turned off (8 bits resolution), there was no difference in the rise time.

Incidentally, the tool we used to determine the rise time is a handy utility with lots of measurement types to choose from (see **Figure -6**)! Not to be sniffed at!

We think

We believe this newly presented family member has a lot to offer for money. The full kit is comprehensive containing all the probes, connectors and software needed to start right away. Even taking into account the need for a reasonably fast computer, which is on most working desks anyway, the 2205's value for money ranks among the top few instruments we had the chance to work with. But be warned: you still need to know what you're doing and how you are measuring; otherwise you could end up with the wrong conclusions.

(120091)

Internet Link

[1] www.picotech.com

Eclipse Sensor
Measuring the sky brightness during a (partial) solar eclipse

By Reinier Ott (The Netherlands)

This description shows how Flowcode and E-blocks can be helpful in the development of a standalone measuring instrument. Naturally the design and construction of the measuring instrument itself are also discussed.

A total eclipse of the sun is a fantastic experience for those who have witnessed it. Unfortunately the phenomenon is relatively rare and the duration of totality (= the period when the moon completely covers the sun) is at most a few minutes. Of course you will try to record all kinds of things with a camera, but that turns out to be not that easy: one moment we are standing in full sunlight (a light value of more than 50,000 lux), a few minutes later the landscape is plunged in the shadow of the moon when the light value of the sky is often less than 1 lux. If we want to record something of this extraordinary experience, then the enormous change in light level quickly becomes a problem. In addition it is not unlikely that we have travelled halfway around the world to experience this and it is then very unfortunate that at the supreme moment we are fiddling with our equipment while a fantastic spectacle is taking place before our eyes.

With these considerations in mind, we therefore have to solve two important aspects: our measuring equipment has to have a sufficiently large dynamic range and everything has to be automated. This, of course, quickly hints at some kind of data logging system. Since the locations for observing this phenomenon are not always in a civilised part of the world, a battery powered device that can measure for at least 4 hours is indispensable.

Compact measuring and data logging system

The purpose of the instrument that has been developed is to measure the bright-

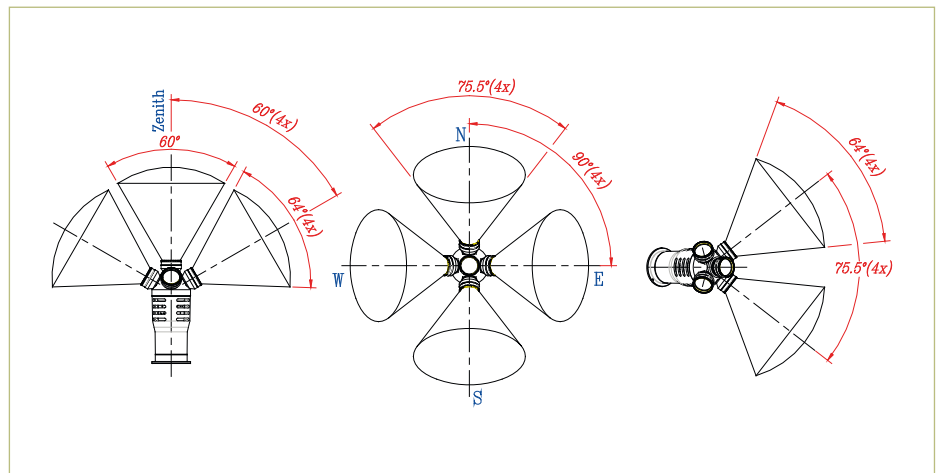Figure 1. The five measuring sensors assembled at fixed angles.

Figure 2. Light intensity measurements in 5 directions with little overlap.

Table 1. Overview of the specifications of the measuring instrument	
Measuring principle of sensors	**Frequency measurement**
Sample-frequency	Fixed : 0.5 s
Data logging frequency	1 s
Number of channels	8
Measuring interval per sensor	8 s
Sensor types	5x light (TSL 230) 1x temperature (LM35) 1x relative humidity (H1) 1x external
Max. logging time	9.1 hours[1] (32,768 measurements)
Light range per sensor	0.1 to 50.000 lux[2]
Temperature	–25 °C to +50 °C
Relative humidity	20% to 100%
External measuring input	5 Hz to 10 kHz (5 V)
External power supply	Battery or 9-V power adapter
Internal battery power supply	6 V (4x AA Alkaline)
Current consumption	80 mA (6 V)
Storage of data	SD/MMC card
Processor	PIC 18F4455
Total weight (incl. batteries)	976 g (sensor 302 g)
Tripod mount	5/8" thread

[1] Longer logging time is also possible
[2] Depending in the calibration (construction and filters)

ness of the sky during the eclipse, in five different directions. In addition, the instrument also contains a temperature sensor and a humidity sensor.

Besides the 16 x 2 LCD, the device also has three indicator LEDs, three pushbuttons and a slot for an SD card. The power supply switch is on the back. This switch also functions as the reset-switch for creating a new log file. **Table 1** summarises the most important details of the sky brightness meter.

The light sensor head consists of five identical elements, which are based on the TSL230 programmable light/frequency converter. Each sensor IC is pointed to a different part of the sky from which the light needs to be received: Zenith (= straight up), northern, eastern, southern and western parts. This is achieved by the construction and the azimuth design (= bubble level and pointed to the north) of the instrument (see **Figure 1**).

To reduce the amount of interference from artificial light (street lighting and such) and to match the spectral sensitivity of the TSL230 closer to that of sunlight, each sensor is fitted behind a blue filter (Wratten # 80A). There is also a black plastic shield underneath each sensor to prevent unwanted light influence from the other sensors.

Figure 2 shows the cones of light to which each of the sensors is sensitive. The glass filters each have an effective opening of 25.5 mm (1") and a thickness of 2 mm.

By limiting the solid angle of sensitivity for each sensor there is minimal overlap of the five sky regions.

The entire instrument itself consists of a control console and a removable sensor unit. The console contains the controller, which is centred around a PIC 18F4455. This processor takes care of the communications with the measuring sensors, the display, storage on the SD card and the push button panel with indicator LEDs.

The development of the 'Eclipse Sensor', as the instrument is called by the author, has been realised with the help of E-blocks (from Matrix Multimedia).

The schematic for the entire circuit, which is not shown here to save space, can be downloaded free from the Elektor website, shows

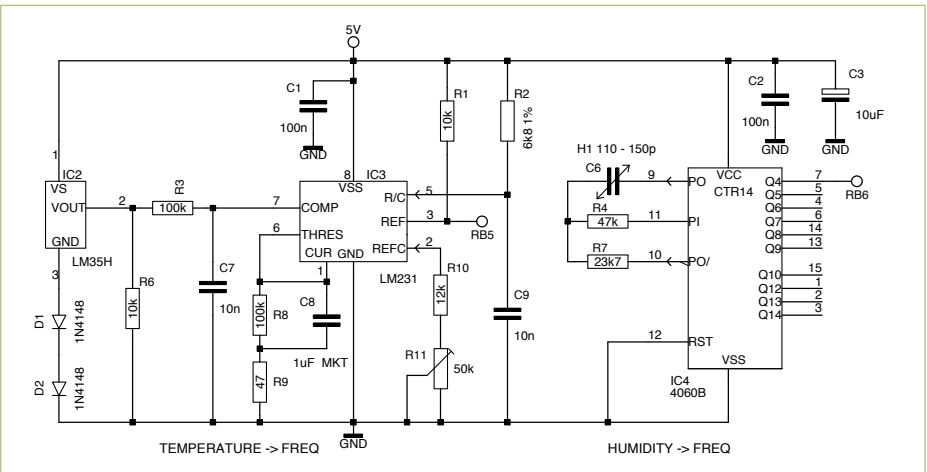Figure 3. Construction of the sensor with the filters.

Figure 4. The circuit around the temperature sensor and humidity sensor.

Listing

```
short SensorCount(unsigned char Msk , short SensorCount)
// Computing counter value of sensor
// INPUT : Msk = Mask to select number of sensor (1 to 8)
// INPUT : SensorCount = Counter value for raising pulse
// OUTPUT: SensorCount = new value after detecting raising pulse
{
        if ((FCV_SENSOR & Msk))
    {
        if ((FCV_SENSOROUD  & Msk) ==0)
        {
            SensorCount++ ;
            FCV_SENSOROUD = (FCV_SENSOROUD | Msk);
        }

    } else {
        FCV_SENSOROUD = (FCV_SENSOROUD & (0xff-Msk));

    }

        return (SensorCount);

}
```

that practically all the pins of the 40-pin PIC have been used. These include, among others, the 8 independent input channels, which also require 4 pins as outputs for the addressing of the light sensors. The display, the card-reader and the three buttons with the LED indicators use another 16 pins. The temperature sensor, an LM35, is located on a separate PCB in the sensor unit (see schematic **Figure 4**). Via an LM231 voltage to frequency converter its output signal is made into a form suitable for the PIC. The operating frequency range can be adjusted with trimpot R11. In order to obtain an acceptable resolution for the temperature recording it is sensible to choose a frequency of about 5 kHz (at 20°C). The two in series connected diodes (D1 and D2) ensure that the sensor is also able to measure temperatures below freezing. The circuit board also contains another sensor (Philips H1) for measuring the relative humidity. The variation in frequency as a result of the change in capacitance of the RC network C6/R4 is scaled with a binary counter (IC4) into a range from 6 to 8 kHz for optimal processing by the PIC.

With the PC software 'EclipseSens.exe', written by the author, the values of the sensors can be converted to °C and %RH using calibration curves.

Measuring principle

There are eight independent measuring channels. The measuring of all eight channels is based on frequency measurement. The measuring time (= sample time) amounts to exactly 0.5 s, after which 0.5 s is reserved for the processing and storing on the SD card.

Every second 1 sensor is read. These are multiplexed into a block of exactly 8 seconds. Each the of the measuring channels is sequentially selected using a bit mask (Msk) parameter. During the measuring window of 0.5 s all the rising edges of the corresponding sensor are counted.

The detection of which is defined within Flowcode as a compact routine in C (see listing).

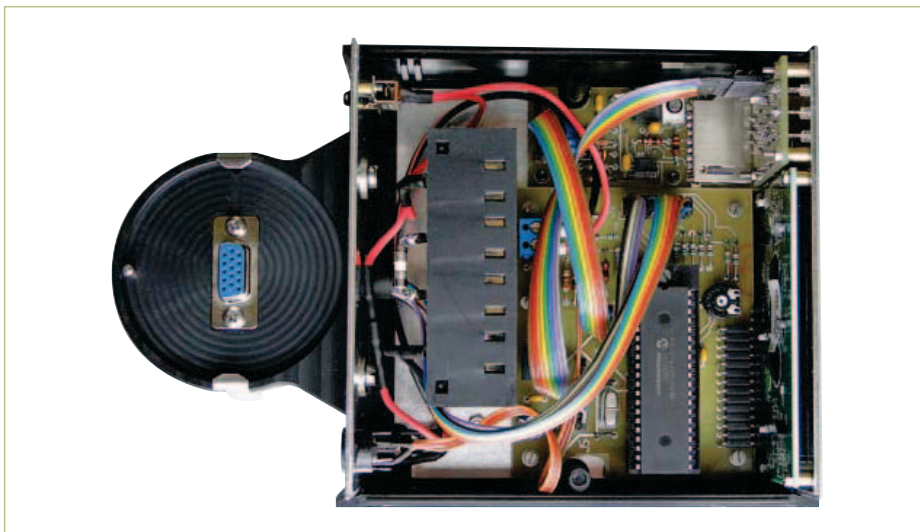See **Table 2** for the sensor characteristics and the assigned bit masks.

Figure 5. A view of the internals of the housing...

Table 2. Sensor characteristics								
MultiPlx	1	2	3	4	5	6	7	0
Sensor	Lux_Z	Lux_N	Lux_E	Lux_S	Lux_W	Temp.	Humid.	Ext.
Meaning	Light Zenith	Light North	Light East	Light South	Light West	Temperature	Relative humidity	Spare input
Auto-ranging	Yes	Yes	Yes	Yes	Yes	No	No	No
Msk (hex)	0x01	0x02	0x04	0x08	0x10	0x20	0x40	0x80
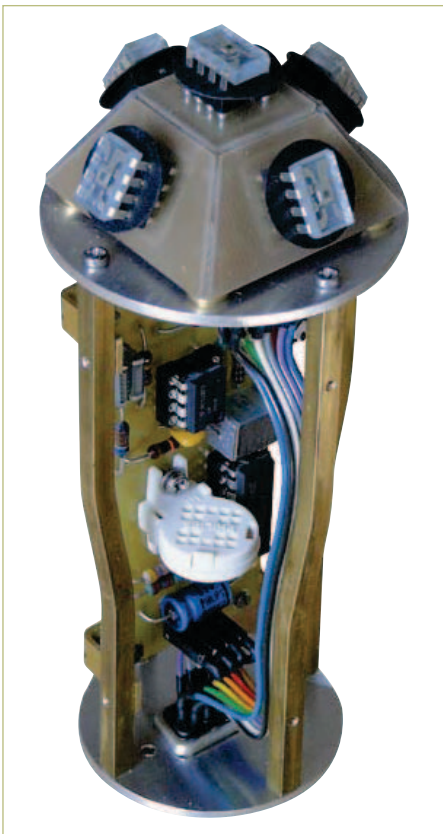
Figure 6. ...And the internals of the sensor.

Table 3. Addressing TSL 230						
S1	**S0**	**SENSITIVITY**		**S3**	**S2**	**f_o SCALING (Divide-by)**
L	L	Power Down		L	L	1
L	H	1x		L	H	2
H	L	10x		H	L	10
H	H	100x		H	H	100
Source: Datasheet TSL230, Texas Instruments						
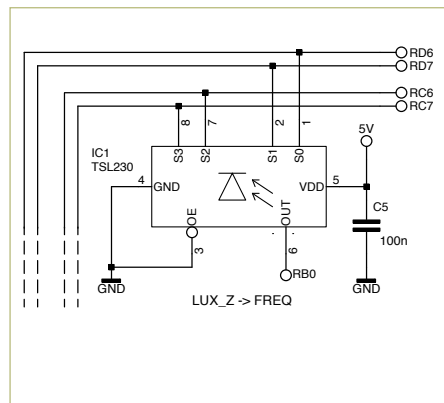
Figure 7. This shows one of the five TSL230 light sensors. The address pins of all the sensors are connected in parallel to a simplify the control.
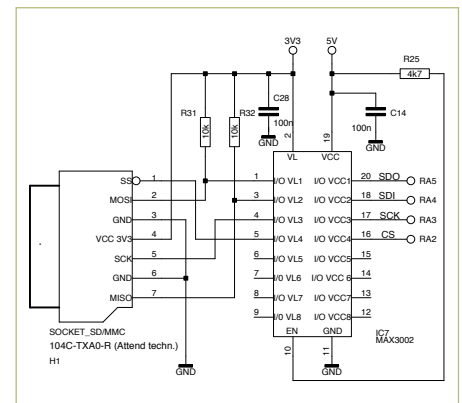
Figure 8. For the SD card there is a bidirectional voltage converter from 3.3 to 5 V.

Auto-ranging

As already mentioned, the amount of sunlight/sky brightness has to be measured with a large dynamic range. Normally a frequency measurement has a limited resolution. The processor also imposes limits on these frequencies. The programmable sensitivity scales of the TSL230 offer a solution in this case. This is also the most important reasons why this sensor IC was selected.

The datasheet for the TSL230 shows that four pins are required for addressing the sensitivity scale (**Table 3**). This allows for a lot of possibilities. In the circuit all these pins are connected in parallel (see **Figure 7**), so that all sensors react at the same time to a change in setting. This drastically reduces the number of connecting wires to the sensor unit, but even more important is that the software in the PIC can be kept relatively simple, which benefits the measuring speed and the size of the program. The only disadvantage is a relatively large rounding of the measuring values of one or more channels when there is a large difference in light level between them.

Important are the limit values for each TSL230. These are fixed and have a lower limit of 200 Hz and an upper limit of 4 kHz. If during a measuring cycle one of the sensors exceeds a limit value then the instrument will switch to a difference sensitivity scale during the dead time (after the final measurement of the five light sensors). This therefore happens for all sensors simultaneously.

Card reader

An SD-card operates at a voltage of 3.3 V. Because the instrument operates at a 5-V power supply voltage there is the necessity for a bidirectional voltage converter. For this purpose the principle of the level translator (MAX 3002) is copied from the E-block EB037 from Matrix Multimedia (see partial schematic **Figure 8**). Note that this IC is only available in a TSSOP package. Soldering the 20 pins with a pin pitch of 0.65 mm (!) does require some practice.

In this way the measurements can be directly stored on an SD card (it is important to note that the file system format is FAT16). This uses the Flowcode4 macro 'PIC_FAT16.c' (make sure that this is version 020710 or later).
SD card detection takes place when the but-ton 'INIT CARD' is pushed. If a card is present a new file name is automatically generated to log the information. The file name is '**ecl_#.txt**', where # is the sequence number that is stored in the EEPROM of the processor. This number is automatically incremented after each initialisation of the SD-card (after 255 follows 0, etc.).

Measuring protocol

The format of the data stored on the SD card is as follows. For example, after some time:

Eclipse data: 4298 1701 2429 3488 0 6.14 190 144 124 217 170 2429 3488 0 14.15 1948 1473 1296 2191 1724 2429 3488 0 22.15...

The file always begins with the key word 'Eclipse data:' (for recognition by the data processing software). Subsequently the measured values are written, separated by a space. The synchronisation of each series begins with a 'floating' point number: The value before the point is the measuring time in whole seconds. The value after the point is the code value for the autoranging. This is then followed by the eight counter values
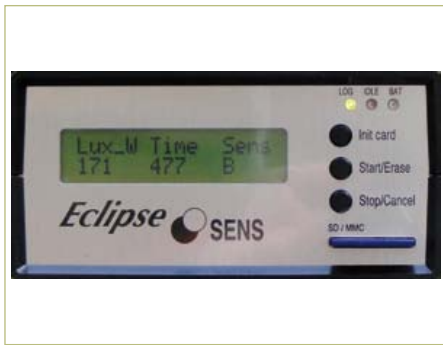
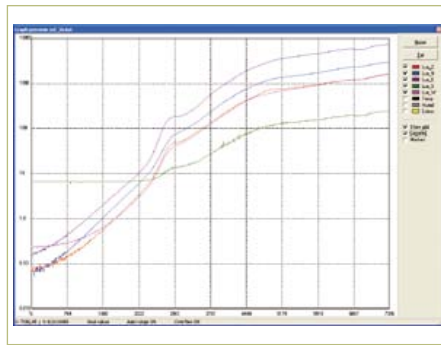Figure 9. Overview of the operation and readout at the front of the control unit.

Figure 10. Example graph during a sunrise.

from the sensors, and so on.

Operation

After the unit is switched on a short intro is displayed. This briefly shows the details of the owner (to improve the chance of recovering the unit after loss or theft). This can of course be changed by suitably modifying the Flowcode program.

After this the measurements start automatically (see **Figure 9**).

Meaning:
- Lux_W: Sensor measuring value (counter value) (in this case the western light sensor)
- Time: Number of elapsed seconds of measuring time (in this case 477 s)
- Sens: Sensitivity indicator for the light sensors
  (A = lowest sensitivity,
  E = highest sensitivity)

When the instrument is turned on and after the intro, the yellow LED ('Card Idle') will light up to indicate that the SD card has not yet been initialised. During this time the sensor is carrying out measurements, but the results are not yet stored.

With the button 'START/ERASE' the measurements will now start to be logged. The measuring timer then starts at 0 sec-

onds. The button 'STOP/CANCEL' ends the logging.

Battery condition management

For battery powered devices such as this one, it is important to know what the condition of the battery is (after all, the measurements during a total solar eclipse cannot be repeated). That is why it would be nice to know whether there is sufficient voltage to make measurements for the next few hours without any problems. There is a red LED on the front panel to indicate the battery condition.

Another aspect concerns the error free operation of the data logging system. For this it is very important that at all times the voltage is guaranteed to be correct when writing to the SD card. In this way the processor ensures that no write operation can be carried out when the battery voltage is too low. The voltage level of the battery is measured continuously with the following divisions:

U_{batt} > 5.6	LED off	Sufficient voltage
5.6 ≥ U_{batt} > 5.3	LED flashing	Sufficient, but be watchful
5.3 ≥ U_{batt} >5.1	LED on	Insufficient: Init card not possible
U_{batt} < 5.1	LED on	Insufficient: Running log stops

If the battery voltage is too low during the initialisation of the SD card, the message 'Battery too weak' appears on the display. The hardware for measuring the battery voltage is extremely simple: The battery voltage is, via a fixed voltage divider, connected directly to the RA0 pin of the 18F4455, which has been configured as an analogue input. The 5.1-V zener diode across the resistor to ground protects the input against high voltages when a mains adaptor is connected.

Processing the results

The data stored on the SD card are just raw results which are not directly interpretable. The purpose of the Windows program ECLIPSESENS.EXE is for the conversion of the measuring results.

With this Windows application the stored values can be processed further and are converted to the correct light values, temperature and humidity in lux, degrees Celcius and % relative humidity respectively. At the same time the measured curves can be displayed. **Figure 10** shows the large dynamic range of the light intensity curves (logarithmic in lux), which thanks to the auto-ranging routine in the PIC can be shown nicely. In this specific situation the sensor was positioned in the vicinity of a strongly lit building. That is why there is a different result for the curve of the south channel (green curve).

After all this effort begins the long wait for the next occurrence of a total solar eclipse (see **Table 4**).

(110647-I)

Internet Links

Software (Flowcode source- en hexcode, data processing software for WinXP/Win7, schematics and additional info are available as a free download from: www.elektor.nl/110647

Experience during the total solar eclipse in 2006: http://www.dutch.nl/rcott/eclips290306_1.htm

Table 4. Upcoming total solar eclipses	
14 November 2012	Southern part of the Pacific
3 November 2013	Central Africa
29 March 2015	N. Atlantic Ocean and Spitsbergen[1]
9 March 2016	Indonesia
21 August 2017	United States
[1] http://home.kpn.nl/nicole.franssen/SB_Eclips_Spitsbergen.htm	

Leading down to zero Ohm

By Thijs Beckers (UK/US Editorial & Elektor Labs)

Somehow it was decided we should stage a Soldering Contest at ElektorLive! event on November 26th of last year. My colleague Jan Visser was supposed to be in charge of the competition and was asked to come up with a fair & solid contest. His proposal was a skill test consisting of soldering 13 zero-ohm resistors onto a Universal Prototyping Board size 1 (UPBS-1/Elex) [1]. The soldering quality would be checked by measuring the total resistance using a four-point measurement [2], rating the visual quality of the solder points and verifying correct placement of the resistors. To make sure he had everything covered, Jan asked several colleagues to participate in a 'dry run'. Yours truly was also invited.

After several colleagues went before me with success, it was my turn. Without further ado I started putting the resistors in place, like they were in the example photograph (you didn't get to see the backside of the PCB, that would spoil it). The UPBS-1 I had to use came from a batch that didn't turn out exactly as we wanted, so I was told a couple of weeks earlier. Not knowing exactly just what had gone wrong with it (it lacked a silk screen overlay indicating the location copper pads and traces) it lead to me believing it was formatted like a 'standard' PCB prototyping board with just holes and pads and no connections between the pads (see **photo 1**).

So I bent some pins on the backside of the PCB to connect the resistors together. Then I soldered all the pins to the pads and the bent pins to the correct pins. After finishing Jan came in to check my work. While inspecting the back side of the PCB he frowned considerably upon my work. Clearly he wasn't expecting this and some hilarity spread across the lab as everyone gathered round. It turned out I overlooked the copper tracks printed on the back of the board (take a *very* close look at the photo; you *might* be able to distinguish a lighter shade of green where there's a copper trace underneath). Oops, there was no need to connect the resistors by their wires as I had done, but no harm in it either.

After the merriment had subsided a little, it was time to measure the total resistance of my 13 series resistors. And guess what: now it was my turn to revel: I won this part. My PCB, hands down, was the one with the least resistance in total. While others scored in the 36-40 mΩ range, my PCB measured only 32 mΩ. A clear winner!

Now this was a little odd. After checking again and verifying it was not a measurement error, we cut the extra connections I had made with the leads (see the photograph with the back of the PCBs) and measured again. Now my PCB measured about 39 mΩ, roughly the same as my 'competitors'. The only conclusion was that when working with resistances this close to zero, it does matter when you shunt a copper trace with a component lead. So in the real contest ahead Jan was forced to take this into account.

We also tried overheating some soldering joints up to 450 ºC (842 F) (the yellowish soldering points in photo 1), but failed to measure any difference in resistance, so for the contest we had to rely on visual inspection for this.
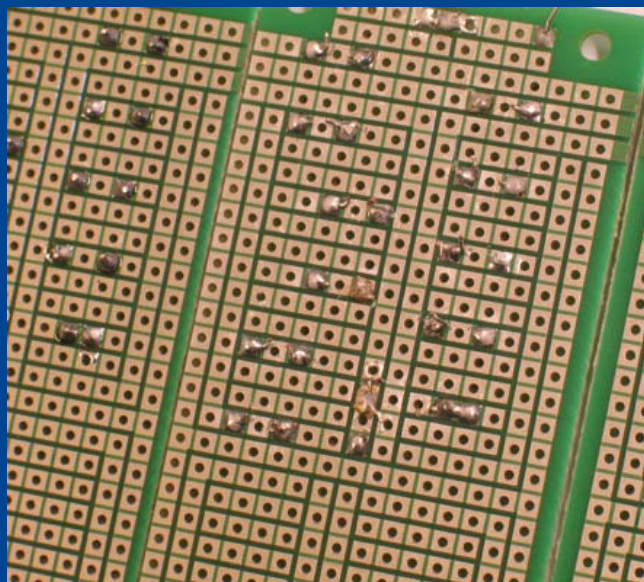
1

2

3

As a quick test, we measured the resistance of one 0 Ω resistor. It measured 4.8 mΩ. Now 13 times 4.8 mΩ equals… 62.4 mΩ, not nearly 39 to 40 mΩ. Now what? Ok, let's shorten the distance the current travels for the measurement by shortening the leads (see **photographs 2** and **3**). 1.66 mΩ, that's more like it. Seems in this range a tiny piece of wire makes a big difference!

All in all, the incident gave Jan a good chance to prepare for any quirks and deviations he could expect during the contest. At the time of writing we can congratulate the winner of the contest: Marcel van Gaalen. Congratulations (again)!

(120042)

Internet Links

[1] www.elektor.com/110446

[2] http://en.wikipedia.org/wiki/Four-terminal_sensing

E-LABS INSIDE

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Pictures taken at ElektorLive! 2011
The Netherlands

EXPLORING

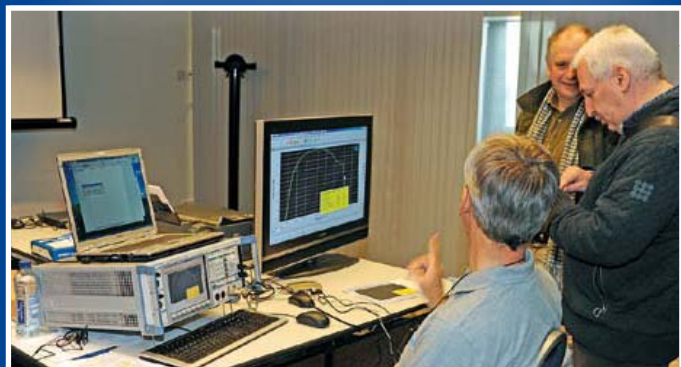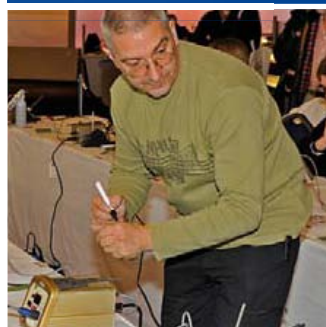PROFESSIONAL

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chipKIT Max32 homework
The right solution to the wrong problem

By Clemens Valens (Elektor France Editorial)

At the ElektorLive*!* 2011 event (Evoluon, Eindhoven, the Netherlands, November 26th 2011) two sessions were organised of a 'getting started' workshop to inform participants about DesignSpark PCB, the PIC32 and the chipKIT Max32 board. This was obviously within the context of the DesignSpark chipKIT Challenge organised jointly by Elektor, Circuit Cellar and RS Components. Ian Bromley from RS Components kindly presented DesignSpark PCB, Microchip's Jeroen Hobbelmans introduced the PIC32 processor and I talked about the chipKIT Max32 board the contestants are required to use. One of the goals of the sessions was to get potential contestants up and running with this board.

During the first session we noticed that attendees were running into problems because of missing FTDI drivers needed for talking to the board over a serial port. Most people managed

doesn't work on pin 13!
The second part of the exercise, modifying the sketch so that it would work, was left to do as homework. The participants left and I never gave it any more thoughts, having other things to do.

Imagine my surprise when the first Monday morning following ElektorLive*!* I received an email from Martin Koster, one of the participants of the workshop, with the complete solution to the exercise, and more. Martin is a thoroughly working engineer, so before doing anything else
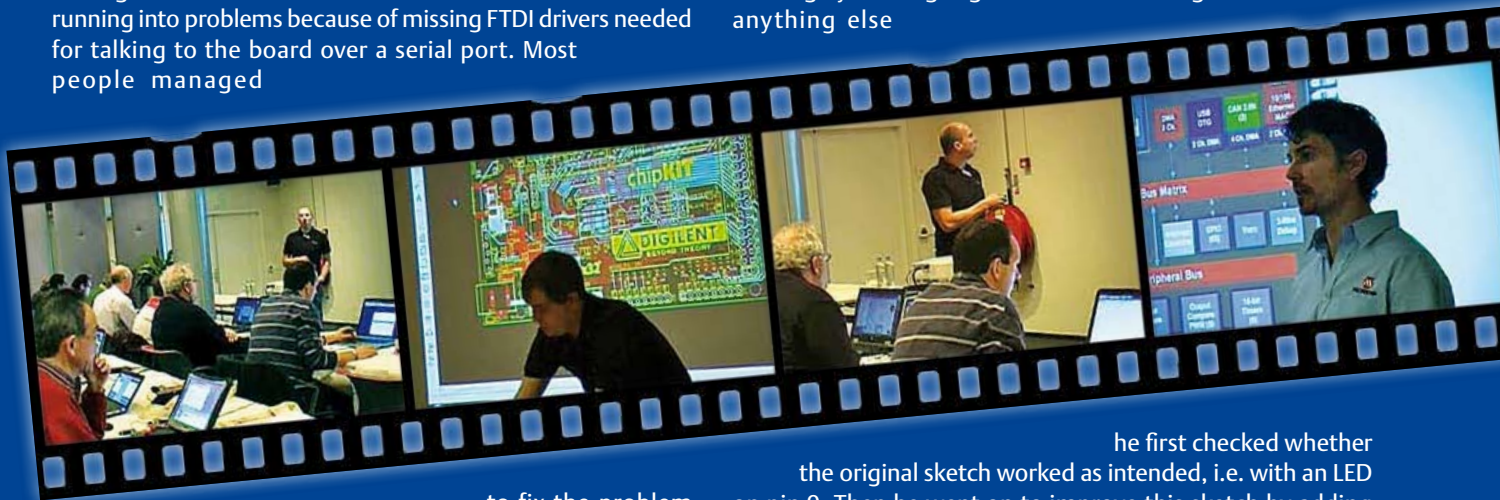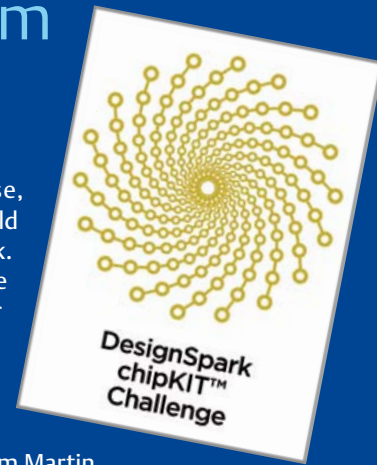
to fix the problem by themselves, but some had more serious issues and required some special attention. While we were busy trying to get those people over the initial hurdles, others were either playing around or idling, which was a bit unfortunate. Therefore, for the second session we decided to throw in an extra exercise to occupy those participants who did not run into these problems.

The exercise was to first explain why the Dimmer example sketch (File -> Examples -> 4.Communication -> Dimmer) does not work with the LED mounted on the Max32 board, and then modify the sketch so that it would work.

The answer to the first question seems easy enough: the LED is not connected to the right pin (duh!). Indeed, the example expects an LED on pin 9 whereas the LED on the Max32 board is connected to pin 13. However, when you naively change the pin number in the software it still doesn't work. The reason for this is that the sketch uses analogWrite to set the brightness of the LED and, in contrast to what you may expect from its name, this function uses PWM to emulate an analogue output. Of course the PIC32 features hardware PWM functions, but the outputs are not routed to pin 13 of the Max32, so analogWrite simply

he first checked whether the original sketch worked as intended, i.e. with an LED on pin 9. Then he went on to improve this sketch by adding support for an RGB LED, and finally he implemented a software PWM function to emulate analogWrite on pins that do not have hardware PWM capability. With this function it is possible to control the brightness of the on-board LED. Problem solved. Note that the resolution of this function is a bit crude, but the general principle will be clear.

Now I would have given Martin an A+ for his work, if only he had used the correct example. Instead, he based his work on the example 'Fading' (File -> Examples -> Analog -> Fading), which is very similar, but does not include serial port communication to manually control the brightness. But then again, since he has been the only one to actually do his homework, tell me about it and provide video proof of his work so far, he earns top marks anyway. Well done, Martin: A+ 4U! You can download Martin's code and videos from www.elektor.com/110715.

And remember: you have until March 27 2012, 18.00 GMT (13.00 EST) to submit your DesignSpark chipKIT Challenge project at chipkitchallenge.com and maybe win up to $5000 in cash!

(110715)

E-LABs INSIDE

Electronics for Starters (2)
Transistors in action

By Burkhard Kainka (Germany)

Electronic devices are becoming more and more complex, which makes it increasingly difficult for beginners to get up to speed. In this series we therefore aim to get back to basics.
In this instalment we present some interesting experiments with transistors. We also have a quiz for you, with the chance of winning a nice prize.

Transistors can easily be regarded as one of the most significant technological inventions ever. Many aspects of modern everyday live — including computers, mobile phones and the Internet — would be impossible without them. In the 1950s these small semiconductor components started displacing vacuum valves, which had played a dominant role up to then. Germanium transistors were the first to become popular, followed later by bipolar silicon transistors and even later by field-effect transistors. Technological progress in this area was accelerated by the invention of integrated circuits (ICs), which contain a large number of transistors in a single package. However, you can implement a wide variety of functions with a single discrete transistor, as we demonstrate in this instalment.

First experiments
Start by building the circuit shown in **Figure 1**, for example on an Elektor Elex board (see elektor.com/120002). This allows you to use the same board for several experiments and utilise the through tracks for power and ground rails. A 9-V battery provides a convenient source of power. It doesn't need to be fully charged – for example, a battery retired from service in a smoke detector will do nicely. A weak battery actually has the advantage that if something goes wrong, it can't supply enough current to cause anything to go up in smoke.

Now let's try a set of simple experiments:
1. When contacts A and B are not connected, the LED should remain dark.
2. Connect A and B together. The LED should light up brightly.
3. Bridge A and B with a wet finger. The LED should light up more or less dimly.
4. Leave A and B open, and see what happens when you short the emitter (E) and collector (C) leads of the transistor together. The LED should light up brightly.
5. Connect A and B again (the LED should be lit), and then short the base lead (B) to ground. The LED should go dark.
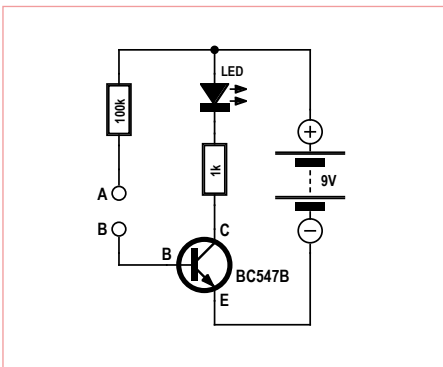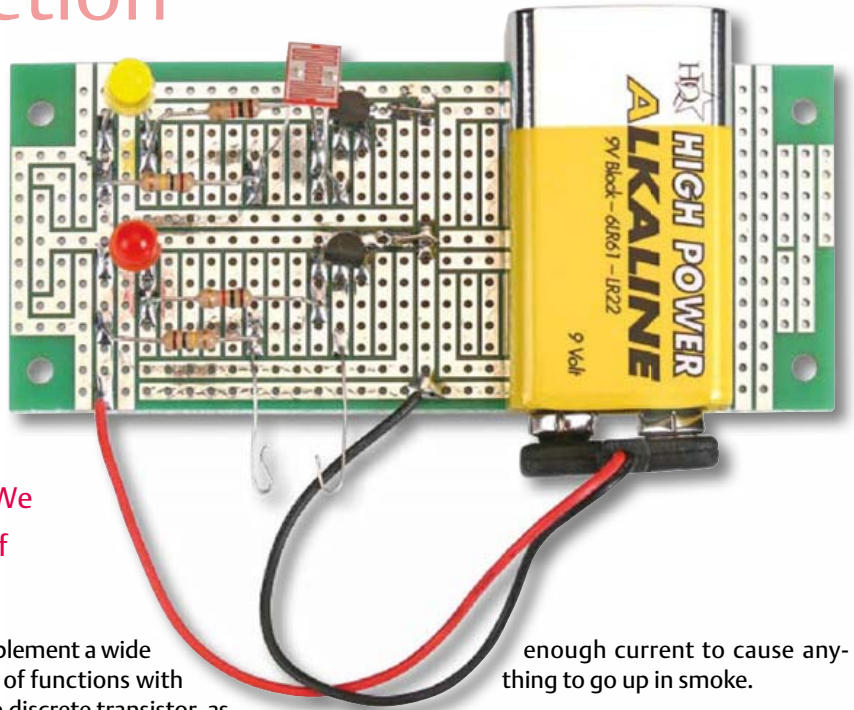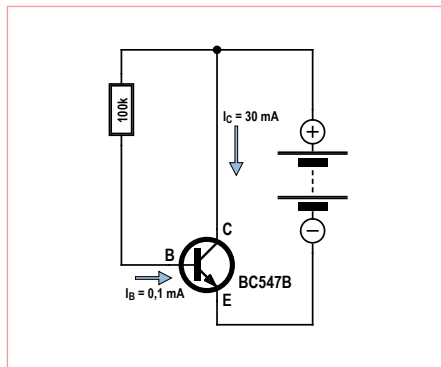

Figure 1. Our first experimental setup.
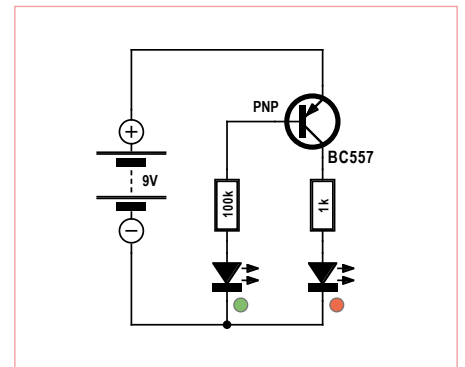

Figure 2. Basic current gain circuit.

Figure 3. A PNP transistor in a common-emitter circuit.

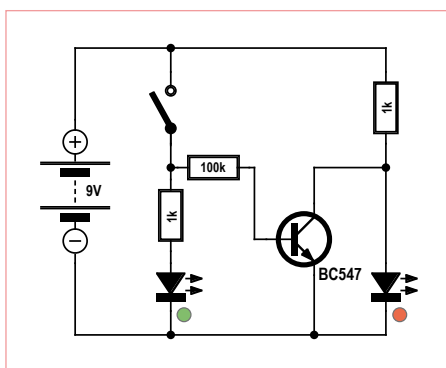Figure 4. A transistor configured as an inverter.

Figure 5. Delayed switch-off.

Glory days of TUP and TUN

There are so many different types of transistors that it can be difficult to decide which one to use. In the distant past Elektor used the designations 'TUP' (transistor universal PNP) and 'TUN' (transistor universal NPN), but in those days it was possible to buy unmarked transistors a bit cheaper than marked ones, and 'TUN' simply meant any type of general-purpose small-signal NPN transistor. Nowadays you are well advised to use the BC547B; it almost always fits and is a sort of modern TUN. You should actually have a bag of them on hand, and it won't make a big dent in your budget. For the TUP the natural choice is the BC557B.
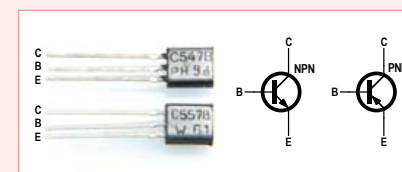
The key **BC547B** specs are:

Maximum collector voltage: 45 V

Maximum collector current: 100 mA

Current gain: 200 to 450 (290 typical)

The BC547*A* has a current gain of 110 to 220 (180 typical), and the BC547*C* has a current gain of 420 to 800 (520 typical). If you examine the current gain curves in more detail, you will see that the current gain of a transistor is fairly constant only at moderate collector currents; it drops significantly at relatively high and low current levels.

This set of experiments illustrates the basic operating principle of a transistor: a small base current (between the base and the emitter) controls a larger collector current (between the collector and the emitter). We say that the base current is amplified, and roughly speaking, we can regard the amplification factor (or gain) as constant. The widely used BC547B transistor has a gain of approximately 300, which means that the collector current is a factor of 300 greater than the base current (**Figure 2**). However, this is only true if it is not limited to a smaller value by a collector resistor (as in the circuit shown in Figure 1).

Circuit design

In order to design a transistor circuit, you first need to know exactly what you want to achieve.

a) Should the transistor operate as a switch and be either fully off (cut off) or fully on (conducting)?
b) Or should the transistor operate as an analogue gain stage and allow more or less current to flow?

You have already tried both options in the initial set of experiments. When contacts A and B are joined together, the transistor is driven fully into conduction (switched on), although it has more internal resistance in this state than a real switch with two metallic contacts. As a result, there is always a small voltage drop between the emitter and the collector. With the wet finger experiment you were in the analogue camp, and you may have noticed that the brightness of the LED depends on how hard you press your finger against the contacts. The choice of liquid also plays a role here – for example, cola yields more current than tea, due to the acids in the cola.
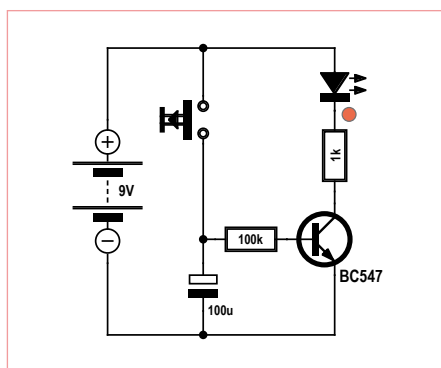
One of the difficulties in designing transistor circuits is that you do not know the exact gain of the transistor. Unlike resistors, which are readily available with a tolerance of 1%, it is very difficult to manufacture transistors to tight tolerances. The gain in particular shows a considerable range of variation. In the case of the BC547, the gains of individual devices in a new fabrication batch can lie anywhere between 110 to 800. These new devices are measured by automated equipment and sorted into the three gain groups A, B and C (see the 'TUP/TUN' inset). The range of gains in these three groups is still fairly large, which is simply a fact of life for circuit designers. They must design their circuits to work properly with every transistor in the selected group. This sometimes requires a bit of calculation; in many cases just trying it out is not enough.

Now let's have a look at the circuit shown in **Figure 3**. A PNP transistor operates in the same way as an NPN transistor, but it has the opposite polarity. This means that the emitter is connected to the positive terminal of the battery. This circuit has an additional LED in the base circuit. It is intended to show that the base current is much lower than the collector current, which is why the light from the green LED is very dim.

Inverter

From high to low, from on to off: inverters perform a very simple task in the world of computers and microcontrollers. However, a transistor can do this just as well. Up to now we have been using our transistor as a sort of controlled switch: if you switch on the base current, the transistor switches on the load current. But you can also reverse (invert) the switching function with a transistor. **Figure 4** shows a simple inverter cir-

cuit. Here the LED lights up when the switch is closed and goes dark when the switch is open. The reason for this is that when the switch is closed, the base circuit is closed through the LED and a current flows into the base. This causes the transistor to conduct, and it shorts out the voltage over the red LED. If you measure the voltage between the collector and the emitter, you will find that it is around 100 mV. At this low voltage the current through the LED is virtually nil, so it remains dark.

Delayed switch-off circuit

The current gain of a transistor can be used to extend the discharge time of a capacitor.

Microcontroller time switch

Modern time switches are built around microcontrollers. This allows them to achieve high precision without calibration. RC timing circuits have evidently had their day, but there's one thing a microcontroller cannot do: switch high currents. For this you need a transistor. A simple NPN transistor makes a suitable power driver for switching external loads. It gives the relatively lightweight microcontroller port more muscle. A popular choice for this task is the BC337, which can switch up to 800 mA. The figure shows a time clock circuit where the current that must be switched by the microcontroller is less than 5 mA. The transistor amplifies the port current enough to switch an incandescent lamp. It also provides level shifting, since the microcontroller operates at 5 V and the lamp operates at 12 V.

The small BASCOM example program implements a time switch. The timeout (1 minute) starts counting down after the button is pressed. Unlike the analogue circuit in Figure 5 of the main text, pressing the button again during the timeout interval does not prolong the timeout. How should the code be modified to enable retriggering?
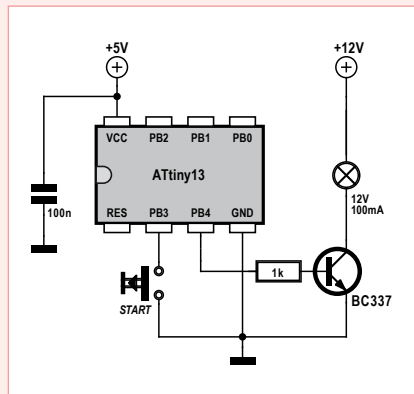

```
,Timer 60 s
$regfile = „attiny13.dat"
$crystal = 1200000
Config Portb.4 = Output
Portb.3 = 1
,Pullup

Do
  Do
  Loop Until Pinb.3 = 0
  Portb.4 = 1
  Waitms 60000
  Portb.4 = 0
Loop

End
```

The circuit shown in **Figure 5** has a 100 µF electrolytic capacitor serving as a storage capacitor. It charges quickly when you press the pushbutton, and after the button is released it supplies a base current to the transistor. The high resistance of the base resistor results in a time constant of around 10 seconds. After this interval the base current is no longer strong enough to drive the transistor into full conduction.

The time constant of an RC network is the time required for the capacitor to discharge to the point where its voltage is a factor of 1/e (1/2.718...) of the initial voltage (36.8%).

The time constant can be calculated using a simple formula:
Time constant = resistance × capacitance
$t = R \times C$
$t = 100\text{ k}\Omega \times 100\text{ µF}$
$t = 10\text{ s}$

As it happens, you can still detect a faint light after one minute. The LED actually continues to emit light for a relatively long time, but the current drops to such a low level that the light is no longer visible.
If you prefer to implement a time switch with a microcontroller, see the 'Microcontroller time switch' inset.

Twilight switch
In the circuit shown in **Figure 6** we use a light dependent resistor (LDR) as a light sensor. This component has a light-sensitive resistive layer made from cadmium sulphide (CdS). Its resistance depends on the intensity of the incident light, ranging from approximately 100 Ω in full sunlight to over 1 MΩ in the dark. The resistance at an illumination level of around 1000 lux (equivalent to a well illuminated workplace) is approximately 1 kΩ.
The combination of the variable resistance of the LDR and the fixed resistance of the 100 kΩ resistor forms a voltage divider. The transistor is cut off when the voltage between the base and the emitter (U_{BE}), which is taken from the voltage divider junction, is too low. In simplified terms, we can say that this circuit has a switching
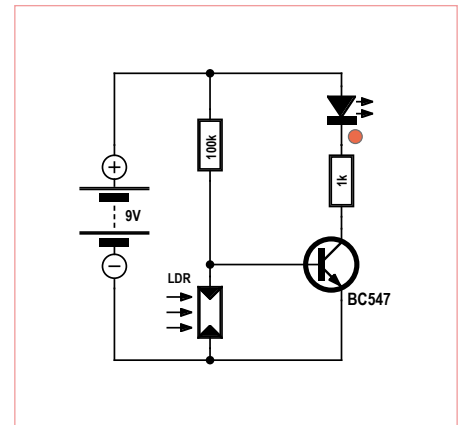

Figure 6. A twilight switch.

threshold of approximately 0.6 V. This value applies to all silicon transistors and results from the well known diode characteristic curve.
Try out this circuit with various light levels to see how it behaves. The LED is switched off when the light level at the sensor is high and switched on when the light level is low. You should see fairly abrupt switching at a certain threshold light level. The range of light levels for which the transistor is in the partially conducting state is small.

Darlington circuit
The gains of a pair of transistors can be multiplied by using the amplified current from the first transistor as the base current for the second transistor, where it is further amplified (see **Figure 7**). If each of these transistors has a gain of 300, the Darlington pair has a gain of 90,000. This circuit can be driven into full conduction with a base lead resistance of 10 MΩ, so it can be used effectively as a touch switch with two bare wires touched by two fingers. Moistening your
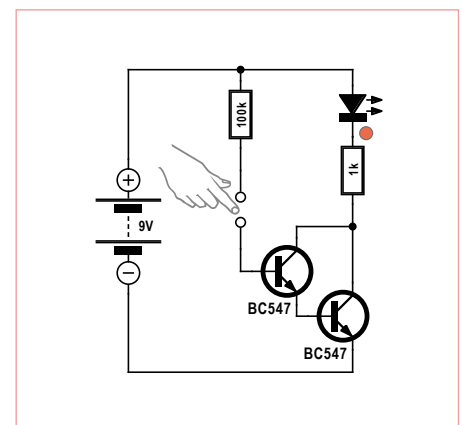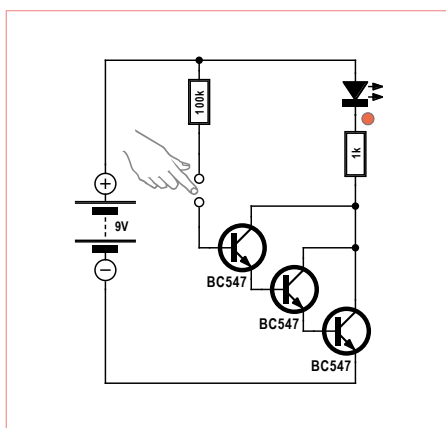

Figure 7. A Darlington pair.

Figure 8. A triple Darlington.

Quiz

The following circuit is built around a pair of transistors with opposite polarity (NPN and PNP). This is what is called a complementary Darlington circuit.

1) How would you classify the operation of this circuit?

A) A useless circuit;
   the LED will never light up

B) Touching the contact
   switches the LED off

C) A touch switch with time delay

2) What current gain can you expect?

D) Approximately 100,000

E) Approximately 5,000

F) Approximately 900

3) What are the potential advantages of a complementary Darlington circuit compared with a normal Darlington circuit with two NPN transistors?

G) Higher current gain

H) Lower input voltage

I) Lower collector–emitter voltage in the fully on state

If you send us the correct answers, you have a chance of winning a
Minty Geek Electronics 101 Kit.

Send you answer code (composed of a series of three letters corresponding to your selected answers) by e-mail to **basics@elektor.com**.

Please enter only the answer code in the Subject line of your email.

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fingers is no longer necessary; even dry skin allows enough current to flow to drive the circuit fully on. The additional 100 kΩ resistor protects the transistors against excessive base current, which would otherwise flow if the two wires were shorted together. An extension of the Darlington circuit to three transistors (**Figure 8**) can be used for interesting experiments with static charge detection. To see this, try sliding you feet on the floor while touching the base lead of this Darlington circuit with one finger. Depending on the nature of the floor and the material of your shoe soles, this will produce more or less strong charge displacements that are made visible by flickering of the LED. In many cases simply approaching the input terminal without actually touching it is enough to cause the LED to light up.

Using a LED as a photodiode

In addition to emitting light, LEDs can be used as sensors for ambient light. In principle no current flows through a diode when
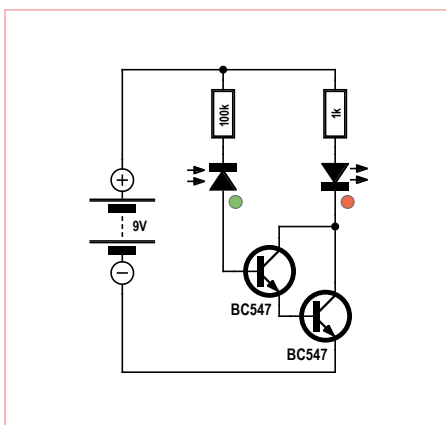

Figure 9. Amplifying the reverse current of an LED.

it is reverse biased, but in fact you can measure a very small reverse current in the range of a few nanoamperes, which is low enough to be ignored in most cases. However, the high gain of the Darlington circuit allows you to perform experiments with extremely low currents such as this. For instance, the reverse current of an LED depends on the light level, which means that an LED acts as a sort of photodiode. We can use our Darlington circuit to amplify the extremely small reverse current to the level needed to light up the second LED. In such experiments you should bear in mind that the rated reverse voltage of an LED is much less than that of a normal diode. The maximum reverse voltage of LEDs is usually specified

as 5 V on the data sheets, but the voltage on the LED in our circuit is approximately 8 V. In fact most red, yellow and green LEDs can withstand significantly higher reverse voltages before entering the breakdown region, although the reverse breakdown voltages of white and blue LEDs are very low. In any case, the 100 kΩ resistor protects the LED against serious damage.

No matter whether you are a beginner or an old hand, you should now have a look at our Quiz in the inset. If you send us the right answers by e-mail, you have a chance of winning an Elektor voucher.

(120002-I)

Audio DSP Course (8)
Part 8:
Digital dynamics processor
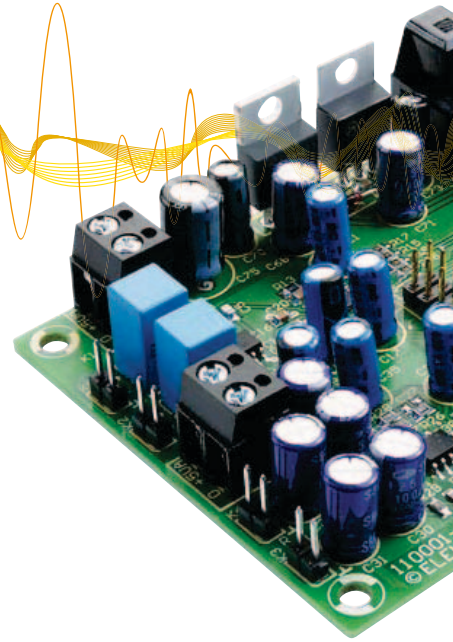
There is a big discrepancy between the dynamic range of a live performance and the dynamic range that can be reproduced by ordinary playback equipment. This is particularly the case with orchestral music, both 'big band' and classical. We can address this problem by artificially reducing the dynamic range of the signal, or, as it is picturesquely termed, 'compressing' the music. The device that does this job is called a dynamics processor, and it can be configured so that the compression characteristics are easily reproducible. The practically unlimited storage for audio signals offered by digital technology gives it a significant advantage over analogue technology in this application. In this article we look at how our DSP board can be made into a digital dynamics processor.

By Alexander Potchinkov (Germany)

The dynamic range of a live music performance that can be captured using a good-quality microphone is often greater than the rest of the signal chain can cope with. By 'dynamic range' we mean the difference between the maximum and minimum signal levels encountered within a particular period of time. In the analogue era the weakest link in the electro-acoustic signal chain was typically the recording medium, be it vinyl record or magnetic tape. An LP with a dynamic range of perhaps 40 dB can hardly be expected to preserve every nuance of an orchestral performance with a dynamic range of perhaps 70 dB or even 80 dB. Assuming that we do not want to introduce distortion in the louder passages, the quieter passages will inevitably sink below the noise inherent in the recording medium. Another example is the piped music used to entertain visitors to shopping centres or eateries. In such environments only a very narrow dynamic range can be used, considerably less than 40 dB, as the aim is gently to encourage consumption rather than to cause customers to strain their ears to hear the music or plug their ears to avoid it. In both these examples we need to reduce the dynamic range of the recording, for which we need a dynamics processor, also known in studios as an 'AGC (automatic gain control) amplifier'. Compressing the dynamic range need not necessarily lead to an undue loss in audio quality: for example, the most important aspect of a scream is not its volume but the spectral character of the voice. So a horror film on the television will not necessarily result in visits from solicitous neighbours!

## Signal processing in the dynamics processor

An AGC amplifier adjusts its gain and/or attenuation in a defined way in response to the level of its input signal. The example structure in **Figure 1** shows two signal paths: the 'signal chains' for the left and right channels ('L' and 'R'), shown in red, in which the gain can be adjusted and perhaps an adjustable delay introduced, and the 'side chain', shown in black, where the required gain is determined.

The side chain has two main elements:

- The 'level processor', a static or time-invariant system where the required gain factor is derived from the level of the input signal. It includes assessing the input level and applying a given characteristic curve that specifies the relationship between input level and applied gain.
- A time-dependent unit that determines the dynamic response of the device: in other words, how the device responds over time to a rising or falling input level. The time constants corresponding to these two situations are conventionally called the 'attack time' and the 'decay time' respectively.

The level processor is the most complex part of a dynamics processor, and typically has four characteristics that can be combined with one another:

- A 'limiter' function which limits the output level to a preset value. This can be used to help prevent overload of sensitive components such as tweeters.
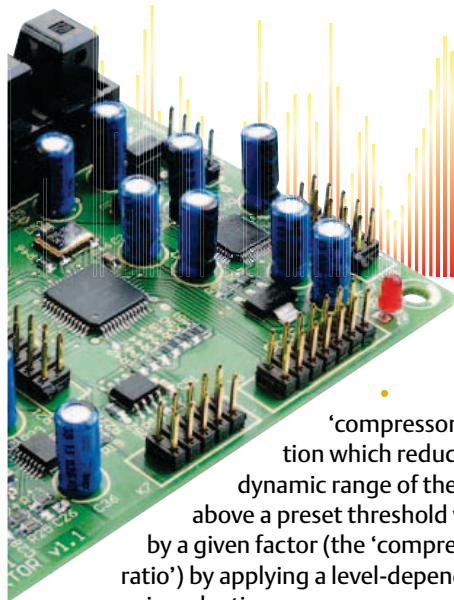
• A 'compressor' function which reduces the dynamic range of the signal above a preset threshold value by a given factor (the 'compression ratio') by applying a level-dependent gain reduction.

• An 'expander' function, which is the inverse of the compressor function.

• A 'noise gate' function which mutes signals with a level below a preset threshold. A noise gate can be used to suppress background noise, passing only the useful parts of the signal that have a sufficiently high level.
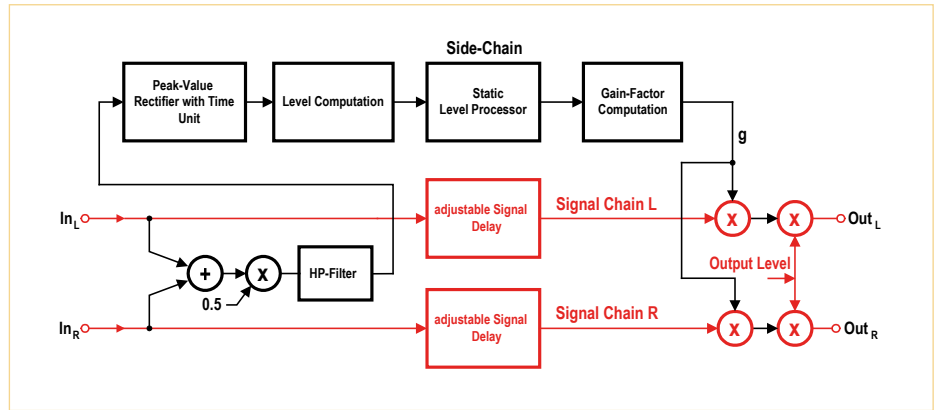
Figure 2 shows the details of the signal processing in the side chain along with the parameters involved. So as not to clutter the figure we have only shown the compressor function in the level processor and only one of the signal chains, and we have omitted the adjustment of overall output level. The first block is a peak value rectifier: readers will already be familiar with this from the article in this series describing the output level meter. The level processor includes converting the level to decibels, applying the characteristic curve, and converting back from decibels. The gain factor smoothing is shown as an exponential-decay filter, modified in this application to have hysteresis and two different time constants.

The following settings are available on the limiter, compressor and noise gate of our dynamics processor:

• T_N, the threshold of the noise gate;
• T_C, the threshold of the compressor, and R, its compression ratio;
• T_L, the threshold of the limiter;
• the attack and decay times in the time-dependent unit;
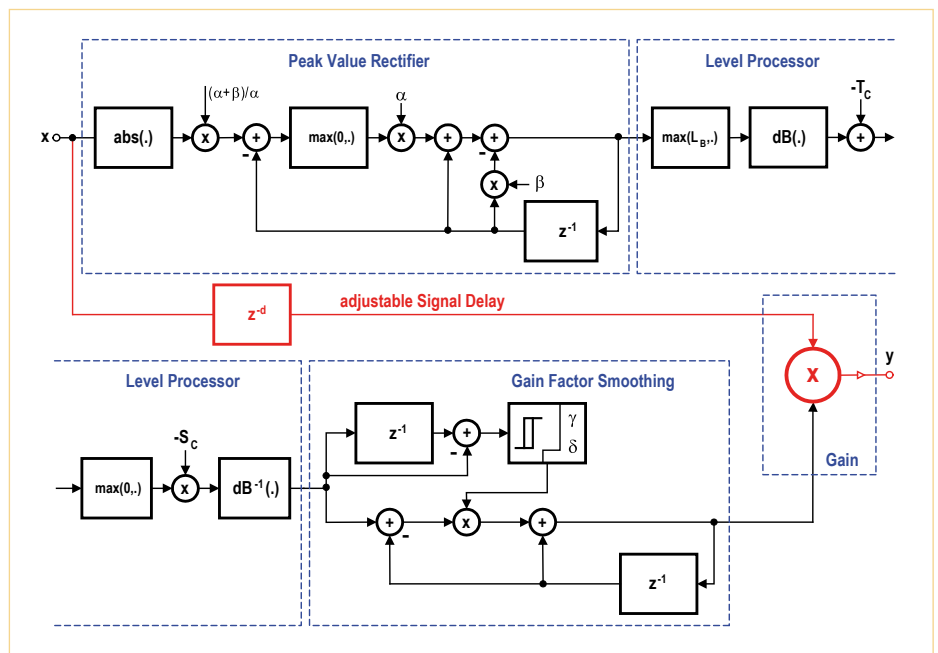• overall gain to adjust the output level.

Figure 3 shows the innards of the level processor implementing the compressor, noise gate and limiter functions. The output from the figure is the value P_g, which is the gain g expressed in decibels (that is, on a logarithmic scale). The value P_g is the minimum of the three gain values P_{gN}, P_{gC} and P_{gL}, which are independently computed by the

Figure 1. Block diagram of the signal processing inside the two-channel dynamics processor.

Figure 2. Digital processing carried out to implement the compressor function.

noise gate, the compressor and the limiter respectively.

We have also included an adjustable signal delay, which allows the unit to be used as a transient limiter. The delay allows the unit to anticipate required gain changes (at the price of adding an overall delay to the signal) and can considerably reduce the distortion introduced by the dynamics processing. Gain adjustments can be made smoothly rather than suddenly, just as an experienced sound engineer familiar with the loud and quiet passages of a piece would do at the mixing desk.

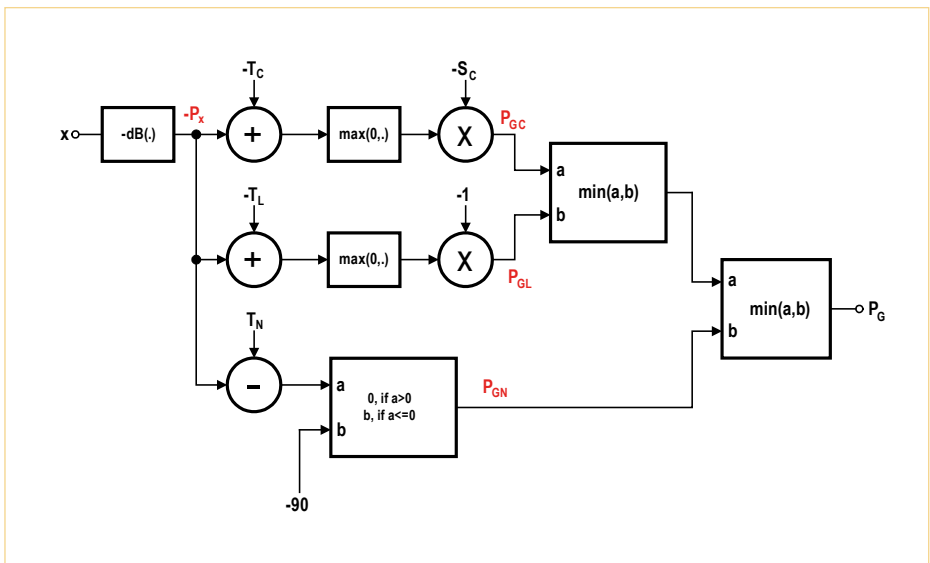The last stage in the signal processing chain is the output level unit which can compen-

Figure 3. Digital processing carried out in the level processor to implement the compressor, limiter and noise gate functions.

sate for any overall attenuation in the level processor. For example, let us suppose that the compressor threshold level T_C is set to −40 dB, the compression ratio R is 4, and the limiter is disabled by setting its threshold level T_L to 0 dB. Then as the input level varies from P_x = −40 dB to P_x = 0 dB (a range ΔP_x of 40 dB) the output level will only vary from P_y = −40 dB to P_y = −30 dB, a range ΔP_y of 10 dB (by definition $R = \Delta P_y/\Delta P_x = 4$). The maximum output level is thus P_y = −30 dB and is achieved when the input level P_x is 0 dB. This is the overall attenuation of the

level processor, which can be compensated for by the output level unit. Here we would set the gain of the output level unit to at most 30 dB if we want to ensure that the output cannot be overdriven. The example shows that the required output gain can be calculated, but more often it is set by ear. The DSP program allows output gain settings in twenty-one steps of 3 dB from 0 dB to 60 dB.

Figures 4 and 5 show two examples of the compressor in action. The middle plot in

Figure 4 shows an input signal that is zero except for two sinewaves, one with an amplitude less than the compressor threshold and one with an amplitude above that threshold. The upper plot shows the gain factor g. During the high-amplitude burst we have $g < 1$, while during the low-amplitude periods g returns to 1 as determined by the decay characteristic. An inherent problem in this kind of dynamics processing is illustrated in the lower plot. Because the gain is not reduced instantly at the beginning of the high-amplitude burst (the response time depending on the attack characteristic) there is a brief period when the output is overdriven. The best way to avoid this problem is to use the delay facility in the signal chain.

Figure 5 shows the compressor operating on a piece of music. Again the middle plot shows the uncompressed input signal and the upper plot shows the gain factor. The input amplitude is relatively high and so the gain is reduced in accordance with the compressor's settings. The lower plot shows the output signal. It is easy to see that the quieter parts of the music have been amplified (or, more precisely, that the louder parts

What goes on inside the level processor

We will look below at the calculations that the level processor carries out, using the default parameter settings as an example. These values are given elsewhere in this article. We introduce a new variable, the so-called 'compressor slope' $S = 1−1/R$, which in the default situation gives us $S = 1/2$. We write P_x for the input signal level, P_y for the output signal level and $P_g = P_y−P_x$ for the amplification in the gain stage.

In our example the characteristic curve of the dynamics processor consists of four segments. One of the dynamics processing functions is active in each of three of these segments. In the fourth of these segments the input and output levels are equal: the dynamics processor is not active.

1. $P_x < T_N$. The **noise gate** is active. In this region the input signal is suppressed and $P_y = P_{gN} = −\infty$. In practice we just choose a very high degree of attenuation for P_{gN}, say $P_{gN} = −90$ dB, which is

enough to ensure that the output is muted.

2. $T_N \leq P_x < T_C$. Dynamics processing not active. $P_y = P_x$ and hence

$$P_g = 0 \text{ dB}.$$

3. $T_C \leq P_x < T_L$. The **compressor** is active. In this region the dynamic range of the input level is compressed by the compression ratio $R = 2$. More precisely, we calculate the output level using

$$P_y = T_C + (P_x − T_C)/R$$

and the gain is given by

$$P_{gC} = P_y − P_x$$
$$= T_C + (P_x − T_C)/R − P_x$$
$$= T_C (1 − 1/R) + P_x (1/R − 1)$$
$$= S\,T_C − S\,P_x$$
$$= S\,(T_C − P_x).$$

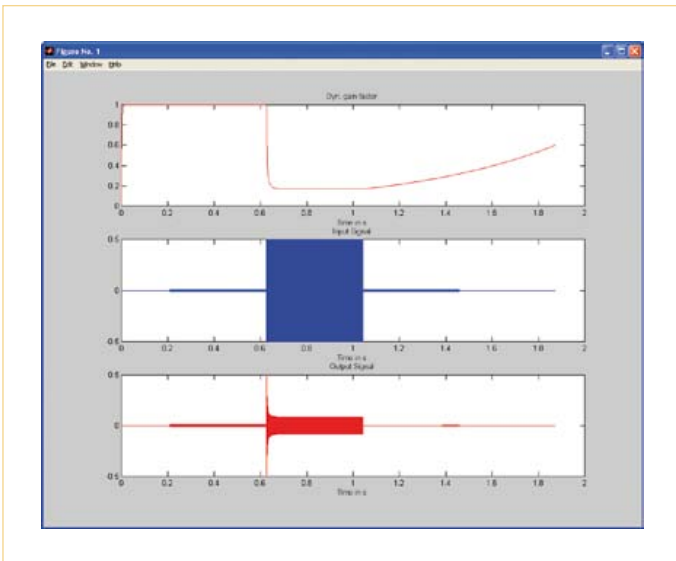4. $T_L \leq P_x$. The **limiter** is active. In this region the output level is set

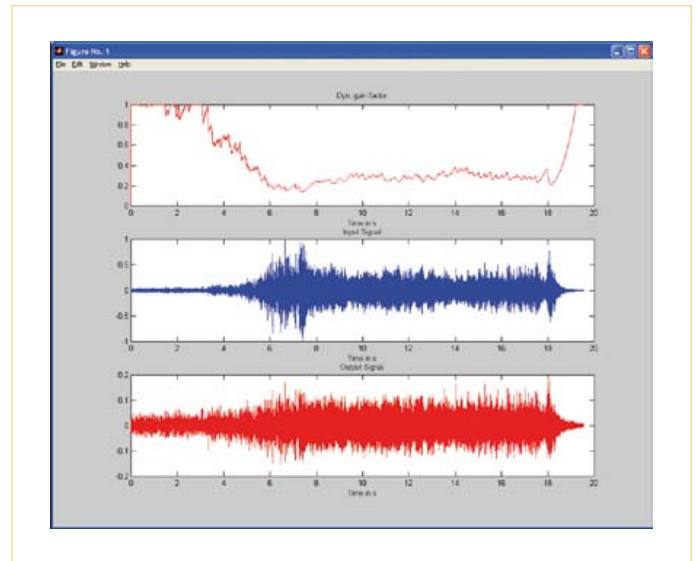Figure 4. Testing the compressor with a tone burst signal.

Figure 5. Operation of the compressor on a music signal.

have been attenuated and then overall gain has been applied to compensate) and why the device is called a 'compressor'. The effect is to increase the perceived loudness of the music: put more technically, the ratio between the peak amplitude and the RMS amplitude has been reduced and so for a given peak output level the signal contains more power. Interested readers can find out a great deal more about this by conducting an internet search for 'loudness war': you may be surprised to discover how ubiquitous dynamics processing is.

Subroutines in the audio loop

The DSP program that implements the dynamics processing functions consists of four subroutines called from the audio loop, as shown in **Figure 6**. The top four subroutines comprise the side chain, and the last subroutine comprises the two signal chains. The subroutine `SignalConditioning` prepares the input signal for the side chain. Here we need to bear in mind that a two-channel dynamics processor for use on stereo signals must have only one common side chain, in order to ensure that the com-

pressor does not disturb the balance of the signal by applying a different gain to each channel. For this reason the side chain is fed by the sum of the two channels. It is possible that doing this could lead the system to miss a peak if the two channels happened to cancel at that point. One way to avoid this would be to take the maximum over the two channels rather than their sum. It is also a good idea, especially when recording from a microphone, to add a switchable high-pass filter to exclude low-frequency signals from the side chain. This feature is called a

to the limiter threshold value: $P_y = T_L$. The required gain is thus
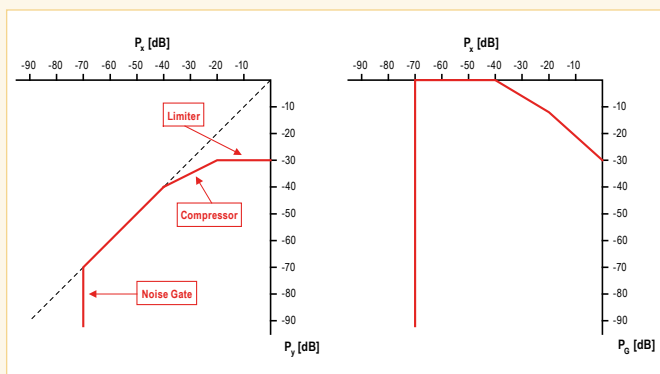
$$P_{gL} = T_L - P_x.$$

Figure 7. Input versus output level and gain with default settings applied.

The final applied gain P_g is calculated from the three gains given above using the formula $P_g = \min(P_{gN}, P_{gC}, P_{gL})$. The multiplicative factor g that is to be applied to the signal is then given by

$$g = 10^{(P_g/20)}.$$

It can be seen that the output level can only lie in the region $-70\,\text{dB} \leq P_y \leq -30\,\text{dB}$, giving an overall output dynamic range of $40\,\text{dB} = T_L - T_N$. So, for example, the dynamics processor can compress an input range of 90 dB to an output range of 40 dB with its default settings.

Figure 7 shows plots of input level P_x against output level P_y and gain P_g. The effect of the output level compensation is to raise these red curves: for example, we can see that the maximum output level $P_{ymax} = 0\,\text{dB}$ can be obtained by applying an extra output gain of 30 dB, equal to the limiter threshold value.

'de-esser' because it helps attenuate sibilant ('s'-like) sounds in speech, which are often prominent in recordings made with the microphone close to the mouth. The subroutine includes the code to sum the two input channels and halve the result, as well as a switchable high-pass filter with cutoff frequencies of 1 kHz, 2 kHz and 4 kHz. A parameter is used to enable or disable the filter and to select its cutoff frequency.

The subroutine `PeakValueRectifier` was described in the level meter article previously in this series. In this case we use the peak value rectifier and time-dependent unit on only one channel. The subroutine reads the signal `Cond` and outputs the signal `Rectified`. The parameters `Alpha`, `Beta` and `AlphaBeta` have the same meanings as in the level meter.

The subroutine `LevelProcessor` contains the main signal processing functions of the dynamics processor. It can be divided into three stages:

- extracting a logarithm to calculate the level P_x;
- applying the static characteristic curve by comparing P_x against the threshold values T_N, T_C and T_L and thence computing the decibel gain P_g;
- computing an antilogarithm to calculate the gain factor g from the decibel gain P_g.

The subroutine takes as its input the signal `Rectified` and its output is the signal `Gain`, which represents the gain factor g. There is a total of four parameters called `MinusTL`, `MinusTC`, `PlusTN` and `MinusSC`, which jointly determine the characteristics of the level processor. The first three of these correspond to the three scaled threshold values T_L, T_C and T_N, while the fourth is related to the compression ratio R by $S = 1-1/R$. The scalings used in the logarithm calculation were described in the previous article in this series.
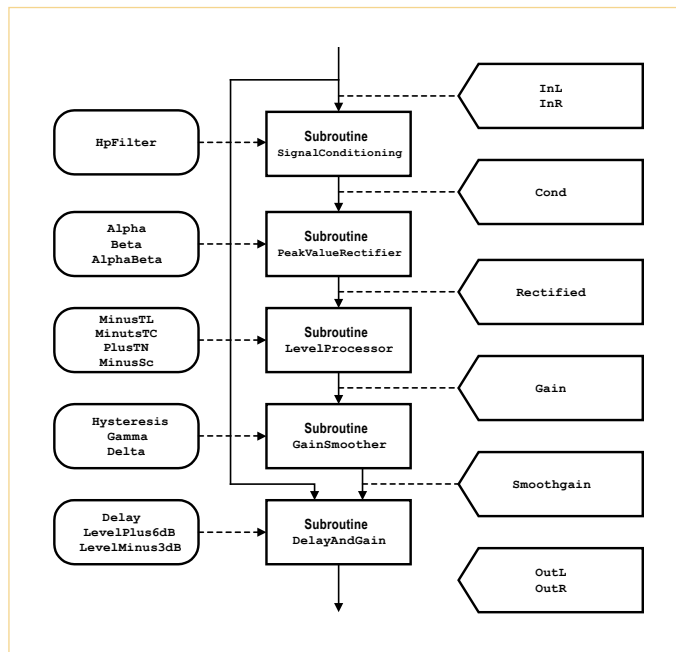
Figure 6. Subroutines and signals in the audio loop.

The logarithm calculation corresponds to that employed in the level meter, the second example DSP application in this series. The computation that implements the response curve is a little trickier. There are three conditions to evaluate first, one for each of the three threshold values that determine the operation of the unit. We will assume in what follows that the thresholds are in order $T_N < T_C < T_L$: this is how the unit will be used in practice. In other words, the threshold for the noise gate is lower than that for the compressor, which is in turn lower than that for the limiter. The incoming level P_x is compared against the three values, and three candidate gains are calculated.

- Is the input level below the noise gate threshold ($P_x < T_N$)? If so, the noise gate is active and the noise gate gain P_{gN} is set to a very high attenuation, such as −90 dB.
- Is the input level above the compressor threshold ($P_x > T_C$)? If so, the compressor is active and the compressor gain P_{gC} is computed from the threshold value, the input level and the compression ratio.
- Is the input level above the limiter threshold ($P_x > T_L$)? If so, the limiter is active and the limiter gain P_{gL} is set such that the sum of the gain and the input level is equal to the limiter threshold.

In each case, if a particular condition is not satisfied the corresponding gain value is set to zero. The last part of this process is to take the minimum of the three gain values (that is, the greatest attenuation ratio) that we have calculated. The result, which can be zero if none of the above three conditions is satisfied, determines the final output of the level processor. The last step is to convert the decibel gain value to a multiplicative value g, which entails computing an antilogarithm. Here we again use an interpolating polynomial to approximate the exponential function, in the same way as we evaluated the sine and logarithm functions in previous articles in this series.

The subroutine `GainSmoother` accepts the signal `Gain` as its input and produces the signal `SmoothGain` as its output. The routine smooths the fluctuations of the gain factor over time. As you might expect, it is not desirable to have the gain value change abruptly (a 'twitchy finger' on the mixing desk!). As well as smoothing the value, the subroutine also applies hysteresis with an adjustable threshold: this means that sufficiently minor fluctuations in gain value are ignored altogether. The subroutine has two parameters, called `Gamma` and `Delta`. These affect the attack and decay response of the smoother.

The subroutine `DelayAndGain` handles the two signal chains. It accepts the signals `InL/R` and `SmoothGain` as inputs and produces the output signals `OutL/R`. There are three stages of processing, each of which is applied to the two channels independently:

Table 1. Integer DSP program parameters and their default values				
DSP program parameter	Valid range	Word length	Alignment	Default value
`HpFilter`	[0,1,2,3]	24	right-aligned	0
`Delay`	[0,1,...,511]	24	right-aligned	128
`HubPlus6dB`	[0,1,...,10]	24	right-aligned	4
`HubMinus3dB`	[0,1]	24	right-aligned	0

Table 2. Fractional DSP program parameters and their default values			
Parameters and default values	DSP program parameters	Calculation of DSP program parameters	Default values of DSP program parameters
T_L = -30 dB, T_C = -40 dB T_N = -70 dB, R=2, t_A = 10 ms, t_R = 100 ms, n_A = 480, n_R = 4800	`MinusTL`	$-T_L/192{,}6592$	0.2076205
	`MinusTC`	$-T_C/192{,}6592$	0.1557153
	`PlusTN`	$T_N/192{,}6592$	-0.36333588
	`MinusSC`	$S=1-1/R$	0.5
	`Alpha`	$\alpha=0{,}4234^{(1/nR)}-0{,}649844^{(1/nA)}$	0.00036018
	`Beta`	$\beta=1-0{,}4234^{(1/nR)}$	0.00023982
	`AlphaBeta`	$\alpha_\beta=\beta/\alpha$	0.6658
	`Gamma`	$\gamma=1-\exp(-2.2*T/t_A)$	0.0046
	`Delta`	$\delta=1-\exp(-2.2*T/t_R)$	0.000458
	`Hysterese`	value set directly	0.001

- an adjustable signal delay in each signal chain;
- dynamic gain adjustment;
- final output level adjustment.

A circular buffer is used to implement the signal delay, with a maximum configurable delay of 512 sample times. At a sample rate of f_S = 48 kHz the minimum possible delay is $1/f_S$ = 20.83 µs and the maximum possible delay is $512/f_S$ = 10.7 ms. The dynamic gain adjustment stage multiplies the signal by the computed gain factor. The final output level adjustment stage allows any overall gain loss in the dynamics processor to be compensated for in steps of 3 dB. Two parameters control this compensation: `HubPlus6dB` allows adjustment in eleven steps of 6 dB each, and the parameter `HubMinus3dB` can be used to reduce the gain by an additional 3 dB. Using these two parameters in combination allows any compensation in 3 dB steps between 0 dB and 60 dB. For example, if we set `HubPlus6dB` to 4 and `HubMinus3dB` to 0 the total gain compensation will be 24 dB; if we set `HubPlus6dB` to 6 and `HubMinus3dB` to 1 the total gain compensation will be 33 dB.

Parameter default values

With the default values of the parameters all three parts of the dynamic response can come into play. When the input level is below the value T_N = –70dB the noise gate is active; above an input level of T_C = –40 dB the compressor comes into operation with a compression ratio of R = 2, and above an input level of T_L = –30 dB the limiter operates. To calculate the time constant parameters we go via a couple of intermediate values. We start from the sample rate f_S = 48 kHz, or the sample period T = $1/f_S$. Then for a desired attack time t_A we compute n_A = round($48000/t_A$) and likewise for the decay time t_D we compute n_D = round($48000/t_D$), so that n_A and n_D represent the times in units of the sample period. For the default values t_A = 10 ms and t_D = 100 ms we obtain n_A = 480 and n_D = 4800. From these results we can set the DSP parameters. The calculations and the default values themselves are collected in **Table 1** and **Table 2**.

Further parameters are used to set the output gain compensation and the characteristics of the high-pass filter. The default values of the output gain compensation parameters are `HubPlus6dB` being equal to 4 and `HubMinus3dB` being equal to 0, which results in an output gain compensation of 24 dB. Note that as the default value for the limiter threshold is T_L = –30 dB, the maximum output level P_y is bounded. With the output gain compensation set as above, the maximum value for P_y is –6 dBFS, which is achieved when the input is on the point of being overdriven (P_x = 0 dBFS). The default parameter setting for the high-pass filter is

Table 3. Testing the dynamics processor										
Level P_x in dBFS	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
Level P_y in dBFS, output gain 0 dB	<-90	<-90	-70	-60	-50	-40	-35	-30	-30	-30
Level P_y in dBFS, output gain 24 dB	<-90	<-90	-46	-36	-26	-16	-11	-6	-6	-6

Table 4. Program files required for the dynamics processor	
`DynaProc.asm`	**Main code**
`LogCoef.tab`	Logarithm approximation polynomial coefficients
`ExpoCoef.tab`	Exponential approximation polynomial coefficients
`Sidechain_Filter.tab`	Side chain filter coefficients
`src4392.tab`	Byte sequence for configuring the SRC
`ivt.asm`	Interrupt vector table entries, audio interrupts
`esai4r2t.asm`	Audio interrupt service routine, four input channels and two output channels
`mioequ.asm`	Handy names for the DSP I/O addresses

for `HpFilter` to be equal to 0, which disables it. The default signal delay value is for `Delay` to be equal to 128, which results in an overall delay of 128/f_S, or approximately 2.7 ms.

Because of the large number of configurable units that make up the dynamics processor there is a grand total of fourteen parameters. These include `MinusTC` and `MinusSC`, which have a considerable effect on the processing as well as parameters such as `Gamma` and `Hysterese`, which have a more subtle effect. Moderate adjustments to these latter parameters will affect the 'feel' of the sound rather than having a specific audible effect. There is plenty of room for readers to experiment here: one interesting line to pursue would be to use the FFT function in a waveform editor to investigate the relationship between the level of distortion introduced by the processor and the signal delay used (parameter `Delay`).

Testing the dynamics processor

The best way to test the dynamics processor is to apply a digital 1 kHz sinewave with an adjustable amplitude to the digital input of the DSP board. We will express the amplitude of the sinewave relative to digital full scale, that is, in dBFS. In the top row of **Table 3** we have a range of values for the

input signal level P_x from –90 dBFS to 0 dBFS in steps of 10 dBFS. The second and third rows of the table show the corresponding values of the output level P_y: to make things clearer the second row shows the results with an output gain compensation of 0 dB, while the third row gives the results with the default gain of 24 dB. The different dynamic behaviours of the unit are shown by different colours in the table: black for when the noise gate is in operation, blue for the neutral range, green for when the compressor is in action and red for when the limiter comes into play. When the output level is zero the actual audible result will depend on the next stage in the system: in some cases a small amount of dither noise is added. The time-dependent unit can be tested using tone bursts, which can be created using a waveform editor. These signals are also useful for testing the adjustable signal delay feature.

The DSP code and ideas for extending the project

Table 4 lists the software components of this project. In addition to files that we have previously used in other projects and test programs in this series, we have the main assembler code file `DynaProc.asm`, the file `LogCoef.tab` which contains the polynomial coefficients for the logarithm func-

tion approximation, the file `ExpoCoef.tab` which contains the polynomial coefficients for the exponential function approximation, and the file `Sidechain_Filter.tab` with the coefficients for the switchable high-pass filter in the side chain.

Finally, a couple of ideas for taking this project further. One simple idea would be to allow the output gain compensation to be adjusted in steps of 1 dB rather than 3 dB. Even more user-friendly would be an 'automatic gain' function that sets this parameter automatically so that whatever values were chosen for the other parameters, the maximum output level is always P_y = 0 dBFS. This can be done by driving the level processor with a full-scale test signal with P_x = 0 dBFS once during initialisation and computing the required gain compensation from the observed output level.

With that we bring our DSP course to a close. We hope that you have learned a lot on the way and that the three example applications have given you a glimpse of the range of possibilities that a DSP has to offer. All being well we will be presenting further complete projects based on this DSP board in the near future.

(120072)

A Benchmark for Microcontroller Development Kits

Putting numbers to ease of use or time wasted

Like it or not but microcontrollers, or 'embedded electronics' as some like to put it, are hotter than ever. You need a lot of fingers to count all microcontroller (MCU) manufacturers active in the market, and trying to count all their micros is unworkable. In order to get you, the end user, to actually use MCUs, their manufacturers produce all sorts of development and evaluation tools to show off their products and highlight selected features.

By Clemens Valens (Elektor France Editorial)

It's not just the chip producers who offer such boards, but also component distributors, compiler builders, independent developers and companies are doing the same. Hey, even the people at Elektor develop dev kits! The result is a huge amount of tools from which the end user is supposed to pick the one that suits his needs best — an almost impossible job.

This is where we at Elektor come in, as we feel we can help end users by reviewing some of those kits. We cannot review them all for several obvious reasons, but when we come across a kit that seems interesting to us, we will not hesitate to tell you about it. Dev kit manufacturers of course know this and sometimes they try to push their luck a bit by sending us kits that they hope we will review. Therefore, some time ago, I was not surprised when Ernst Krempelsauer, my Austrian colleague living in Germany and working in the Netherlands, asked me if I was interested in reviewing the TMS570 MCU Development Kit [1] from Texas Instruments (TI). This is a kit for playing with TI's TMS570LS20216 ARM Cortex-R4F microcontroller that's advertised as specially suited for real-time applications. When I looked at the kit as pictured on the product page on the TI web site I was interested straight away. It is an attractive large main board from Keil with a TFT display on it and many connectors lining the edges. A smaller TI microcontroller board is plugged onto the main board.

When the review sample of the kit arrived, it turned out to be not exactly what I had expected, as it was just a large USB stick [2]. The stick is so large because otherwise the MCU in its 144-pin LQFP package could not be fitted on it. It came in one of those CD/DVD boxes familiar from TI and besides the stick it contained a mini flashlight, a DVD, a USB extension cable and an installation instruction flyer. The installation instructions were simple: insert the DVD and do a full install. So I did.

I wrote down the amount of free disk space before launching the install, and the time: 9:20. More than 30 minutes and 95 (really!)

mouse clicks later the installation was complete. Looking at the free disk space left over I noticed that this demo had used a whopping 7 GB! By comparison, my Windows XP Pro folder contains 9 GB. To be totally honest, I did this installation twice. The first time I ran it while trying to do other things, but when the number of mouse clicks and the amazing number of pop-up windows started to bug me I decided to redo the installation and count and measure the

Figure 1. The TMS570 Microcontroller Development Stick kit we sadly have no use for, but maybe you do. For a chance to win it, simply enter our MCU dev kit benchmark prize draw.
(Photo: Texas Instruments)

above mentioned 'parameters'.

Naturally I now was anxious to see the demos, as well as curious to discover just what a USB stick with a handful of LEDs and a 5 cm² MCU on it supported by 7 GB of software, had to offer! Connecting the stick to my PC worked fine, it was recognized immediately,
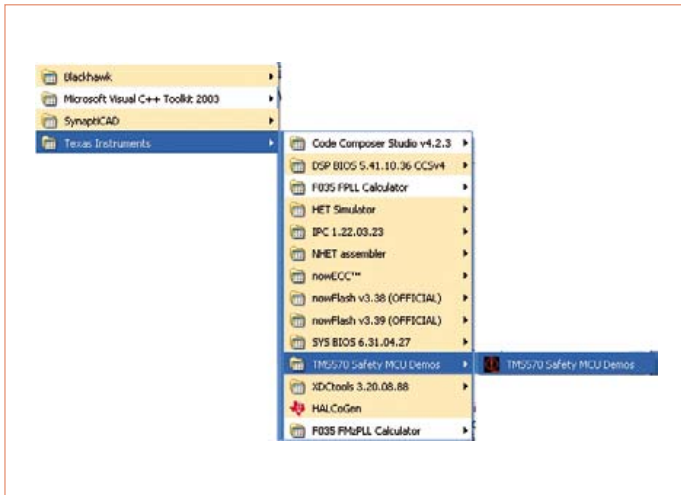
Figure 2. The pink-ish start menu items were added during the installation of the 7 GB evaluation software. Note that a version of Code Composer from another TI dev kit installation was already present on the test computer.

Figure 3. The TMS570 launchpad.
After spending quite some time reading documentation you should click the lower right button. You can safely ignore the four other buttons.

Tweak the Elektor MCU Dev Kit Benchmark and win this kit!

and I started the *Safety Demo Software* as indicated in *step 3* of the installation notes. A window with six large buttons popped up and I clicked on the upper left one labelled *Safety Features*. The tool first programmed the MCU and then showed a block diagram of the chip as well as a list of small buttons on the left that let you generate an error event in the MCU. The error is graphically illustrated in the block diagram and a little red LED lights on the board.

You will have little trouble understanding that I was deeply impressed by this very convincing demo so I quickly went on to try the others. I clicked the *Ambient Light* button and a little window with a vertical bar graph showing ambient light intensity appeared. A light sensor included on the stick makes this demo possible. If you cover the stick with your hand the bar drops to a few percent, and when you shine the flashlight on the sensor (Aha! So that's why TI included it in the kit!) you can get it up to 100 %. Wow.
So quickly on to the next demo: the *Temperature Sensor*. Clicking the button opens a small window showing a temperature graph. The demo said the temperature was over 30 °C, at least 7 °C higher than the ambient temperature, but perhaps it measured closely to the MCU or the PC? Anyway, this demo was as convincing as the others. What about the LED Light Show? Again a little window pops up and

this time you can start the pre-programmed light show or toggle the six blue LEDs manually. Not to give it away in case you want to buy this development stick yourself I will not tell you what happened but let me assure you that I was again deeply impressed.
If I remember correctly TI was the first to introduce the concept of USB development and evaluation sticks, but where the first one featured an MSP430 MCU you could break off after programming and then use in your own application, this USB stick seems to fulfil marketing purposes only. A measly 22 out of the 144 pins (called "test points") are brought out to two pin headers, although a CAN bus is available too (this MCU is said to target automotive applications). You get a compiler too, so you can write some code for the MCU but do you really need 7 GB and 95+ mouse clicks for that? I suppose some people will find a use for this kit, but not me.
While preparing this article I stumbled upon a TI booth at an electronics show and since they had this kit on display I decided to ask the staff the very reason of the existence of this kit. The answer remained vague and went along the lines of "enabling the user not wanting to spend too much money to go as far as he/she wished". I may be mistaken, but if you are willing to invest a large amount of time in evaluating such a powerful and specialized MCU, would you do it on a stick? Anyway.

Participate and win!

Assist in developing a useful and universally applicable microcontroller development kit benchmark that can be used to easily compare such kits. Send us the criteria you feel are critical to include in such a test and enter a prize draw for the the dev kit reviewed in this article. The winner will be selected at random and receive the TMS570 Microcontroller Development Stick for free. To enter the prize draw please send your suggestions to **mcubenchmark@elektor.com** and remember: no complaining afterwards; we set the rules.

In the past at Elektor we have had discussions about reviewing dev kits. How should we do this in such a way that it would be interesting and useful for the reader? Can we think of a standard approach allowing kits to be compared? This discussion never got us very far, but the above mentioned TI kit kind of revived it. In a sense it was the straw that broke the camel's back; we decided to get serious.

After some thinking we defined a benchmark for MCU development and evaluation kits to quickly compare their ease of use as well as system impact: the **helloWorld** (hW). The helloWorld rating is calculated from

$$\frac{S}{s \times (t + m + i)} [helloWorld] \qquad (1)$$

where S (note upper case) is the highest capacity hard disk space available (state of the art, in GB) in the year of release of the dev kit (according to Wikipedia [3], in 2011 $S = 4$ TB); s (lower case) stands for disk space in GB needed by the dev kit; t is the installation time in minutes; m means mouse clicks needed to get an LED flashing on the dev kit and finally i is the number of icons and shortcuts created on the desktop. The S parameter is included to introduce an element of time in the benchmark so that it will be possible to compare helloWorld ratings over time. With this benchmark an LED flashlight like the one included in the TI kit would score infinity because it does not occupy any disk space at all.

Having defined a benchmark we can now apply it to see how well it works. Let's start with the TMS570 Microcontroller Development

Stick presented earlier. Plugging the values we found during our test drive into (1) we find (with TB converted to GB):

$$\frac{4096}{7 \times (34 + 95 + 8)} = 4.27 \ hW$$

As a comparison, Arduino 1.0 consumes 232 MB of disk space, does not create any desktop icons and needs about ten mouse clicks (depending a bit on the method used to unpack the installation file) to make the default Arduino LED flash. This corresponds to a (rounded) rating of 1636 hW. **Table 1** shows some more scores for development boards including Elektor's one and only Sceptre board.

The benchmark proposed here is just an initial approach and some tweaking will probably be necessary. If you feel that a significant parameter has been left out, or that one or more parameters are not properly weighted, please let us know. Send your suggestions to mcubenchmark@elektor.com and enter the prize draw for the dev kit evaluated in this article!

(120096)

Internet Links & References

[1] www.ti.com/tool/tmdx570ls20smdk

[2] http://processors.wiki.ti.com/index.php?title=TMS570_USB_Kit

[3] http://en.wikipedia.org/wiki/History_of_hard_disk_drives

[4] Easy Sceptre Programming with Oberon-07:
     www.elektor.com/100574

| Table 1. helloWorld scores for a few kits in random order.						
Kit	**Manufacturer**	**Disk space needed**	**Installation time [min]**	**Mouse clicks**	**Desktop icons**	**helloWorld score[1]**
TMS570 Microcontroller Development Stick	Texas Instruments	7 GB	34	95	8	4.27
Arduino 1.0 with Arduino Uno	Arduino	233 MB	1	10	0	1636
EasyPIC v7 with mikroC Pro	MikroElektronika	185 MB	2	20	2	945
Sceptre with Oberon [4]	Elektor & Astrobe	4 MB	1	20	1	47663[2]
Kinetis KwikStik[3]	Freescale	3 GB	120	1500	0	1
[1] Based on a 2011 state of the art maximum hard disk size of 4 TB.						
[2] Based on values provided by Chris Burrows from Astrobe and assuming that the .NET 2.0 runtime is available on the test computer.						
[3] See http://elektorembedded.blogspot.com for the details of this low score.						
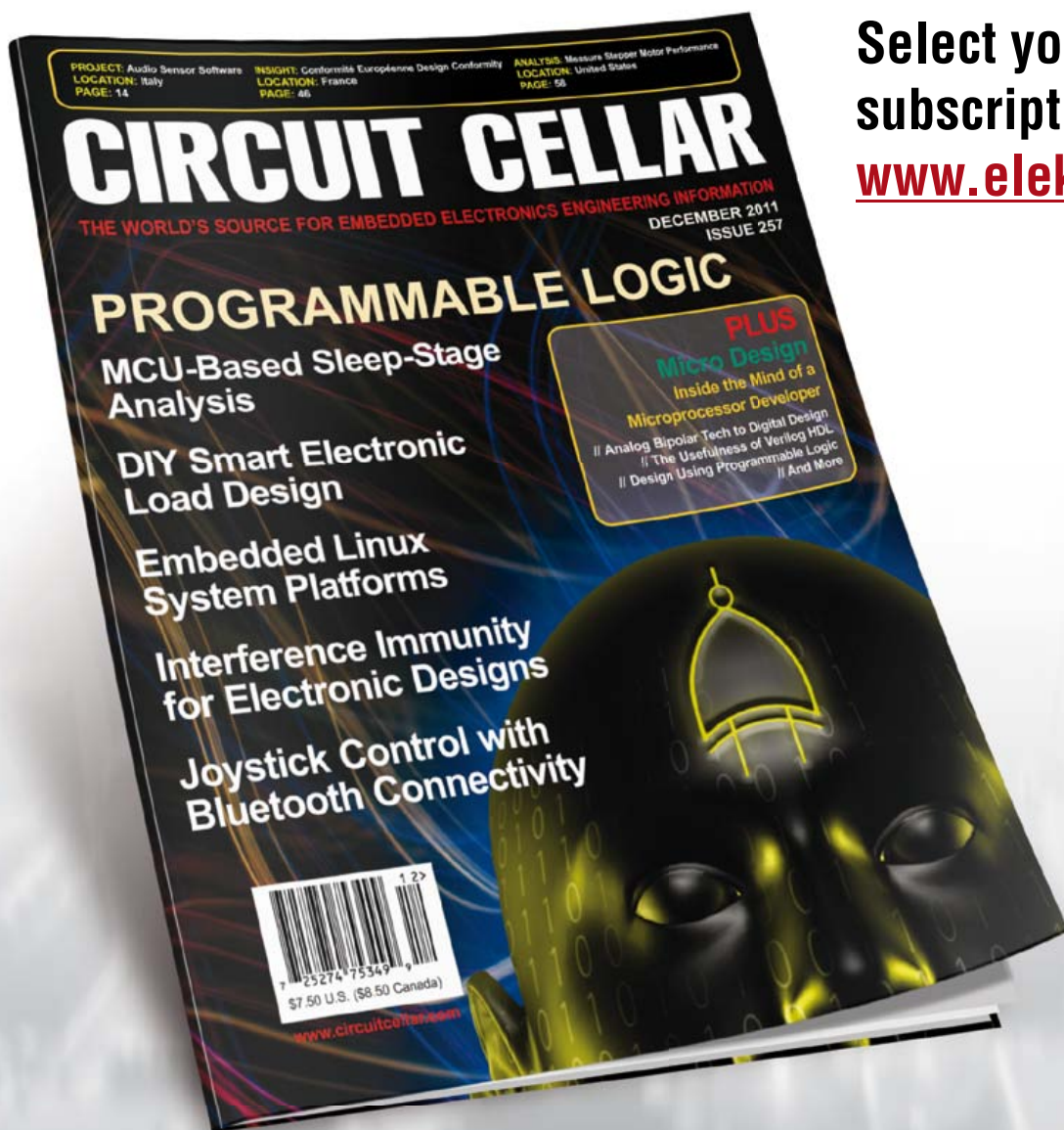
Emergency Generator Load Meter
No-break AC power for your home

Use this Load Meter to prevent overloading your emergency generator during blackouts, so that when tropical storm force winds or vicious ice storms have crippled the power grid you are reassured of your generator steadily providing power for your home.

By Chuck Hansen (USA)

After loss of power here in the northeast USA due to ice storms in winter and hurricanes in summer, I invested in a portable 2500 watt emergency AC generator with 2800 watt surge capability. It can power our furnace, refrigerator, hot water heater, and selected outlets and lights. I had our electrician install a 60 amp power transfer sub-panel that can connect the above loads to either utility power or an emergency backup AC source. The transfer sub-panel we installed has eight load circuit breakers and two 0-2500 W load meters on the front to measure the power delivered by an AC emergency power source. However, the transfer sub-panel is in the basement next to the main breaker panel, and I really need to know what the load draw is upstairs in our living space in order to best estimate the refuelling time for the generator.

How it works
The transfer panel can be wired for the split-phase 120-0-120 V_{AC} electrical service here in the US, or for our single-phase 120 V_{AC}
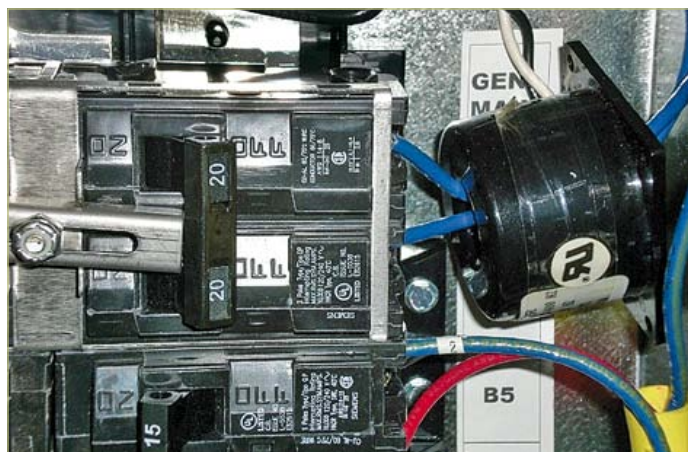
backup generator by connecting the two bus bars in parallel. The transfer panel meters are out of circuit when the transfer switch is connected to the utility main breaker panel.

The particular generator I purchased combines a high-voltage permanent magnet generator with a single phase sine-wave power inverter, to ensure compatibility with the electronic controls on our appliances. It also has an economy mode that allows it to operate at a lower fuel-saving rpm until the load demand becomes high enough to require the generator to run at high rpm.

We had a weather-proof single-phase 30 amp recreational vehicle (RV) outdoor connector installed to match the 30 amp twist-lock connector on the generator output panel and connect it to our house with a 15 foot (4.6 meter) 8-gauge (8 mm²) power cable.

I purchased a 150:1 ratio current transformer (CT) on eBay that had the appropriate UL/CE qualifications (it is very important that the CT meets all applicable local codes). My electrician routed both blue wires that feed the eight circuit breakers in the sub-panel through the centre of the CT in an additive manner **(see Figure 1)**. This is the one-turn CT primary winding. The CT secondary winding divides the primary current by the turns ratio, in this case by 150. The CT is rated for 5 VA, so in theory it can produce a secondary voltage of about 31 V_{RMS} (200 Ω load) with the maximum 23.33 amp surge load rating of our generator without saturation. This is more than enough for our remote load meter.

Schematics
The schematic for the sub-panel and load meter circuit is shown in **Figure 2**. Note that for clarity the sub-panel drawing shows only the ac power leads, not the mandatory neutral and safety ground wires that connect to the grounding block in the sub-panel. The CT is located on the emergency generator input side of the sub-panel, as described above.

Figure 1. CT installation in the sub-panel.
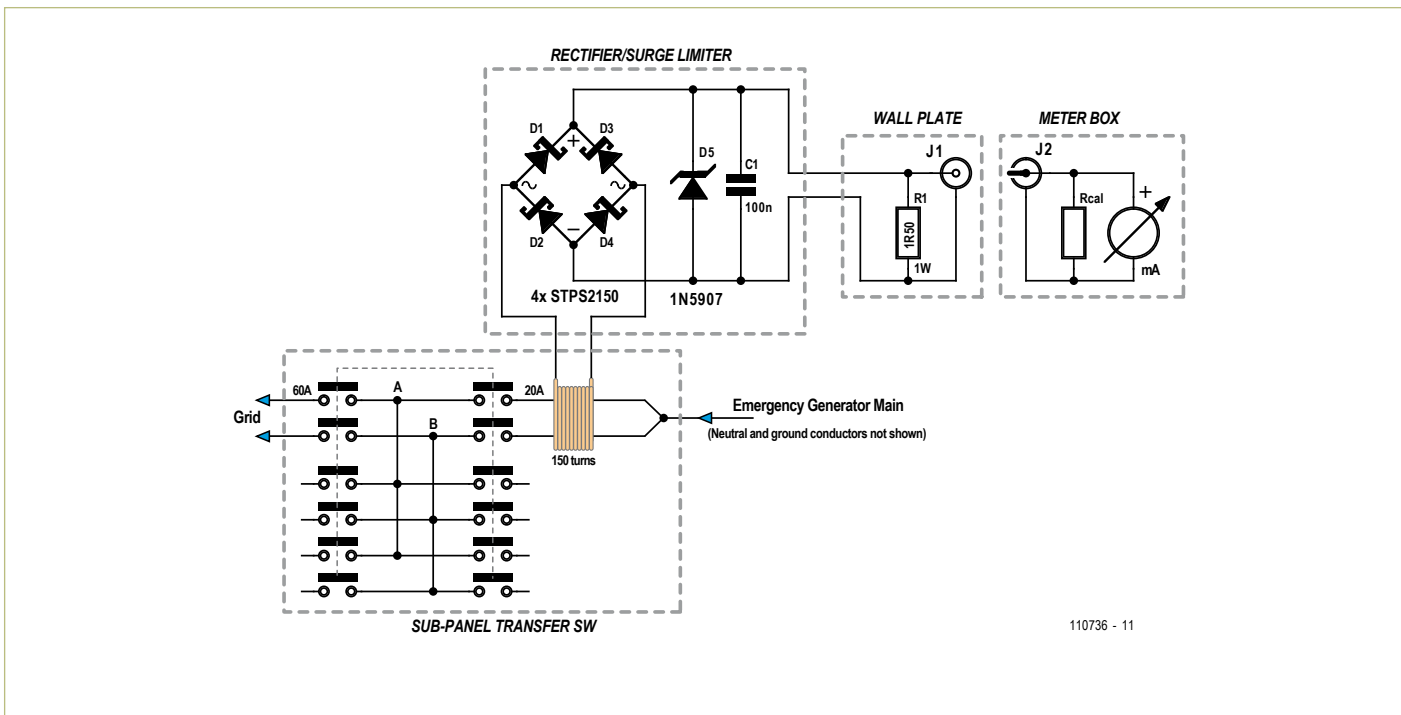
Figure 2. Schematic for the sub-panel and load meter circuit.
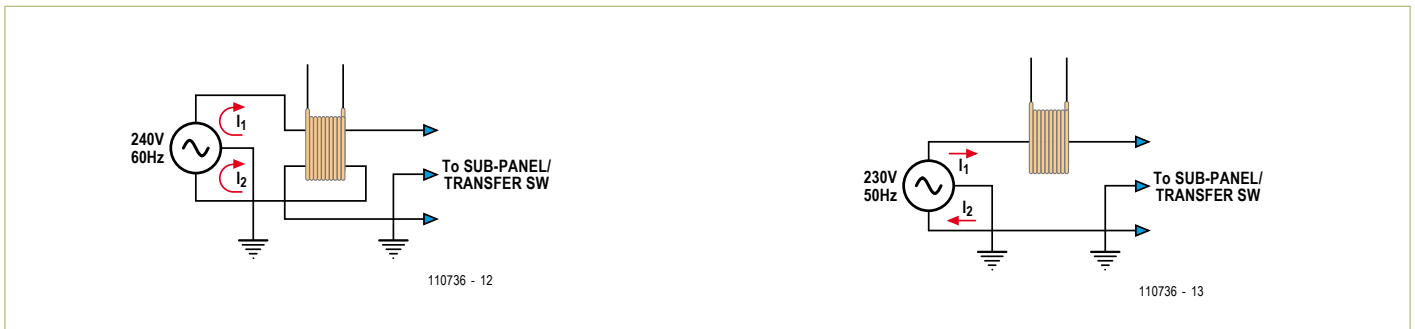
Figure 3a and b. Alternative configurations of the CT for different power systems.

The CT secondary is hard-wired to a plastic rectifier/surge limiter box I designed for this project. The CT secondary wiring is twisted to minimize stray magnetic fields. The components are mounted on a small piece of prototyping pc board. The secondary current is full-wave rectified by four Schottky diodes, D1-D4. D5, a 1N5907 transient voltage suppressor (TVS), limits the CT secondary voltage in case the two-conductor wiring to the load meter burden resistor on the main floor is accidentally opened.

The CT is a current source, so the secondary can be safely short-circuited, but it does not like to see an open circuit. The secondary voltage will be multiplied by the turns ratio times the voltage drop in the length of the primary wires inside the core aperture. Since the silicon iron core has a high magnetic permeability, the drop in the primary side is significant at higher loads and the open-circuit secondary voltage could be lethal. The 100 nF capacitor (C1) filters any voltage spikes that might occur on the CT secondary signal.
The 1.50 Ohms CT load resistor (R1) across which the load meter signal is generated is located in the main floor wall plate right at the BNC connector (I modified a standard 75 Ω F-video jack wall plate). Since this is a low voltage application, code allows us to use an open-back 'new work' electrical box inside the wall to mount the wall plate. This BNC jack will not be confused for any other common household signal connector (RCA, F-video, RJ-44 telephone, Ethernet, etc).

Measuring
I selected a 0-100 mA_{DC} analogue panel meter for our remote power indicator, which I calibrated to show 0-100% load from the generator. I used a sloped-front aluminium enclosure for this load meter (see introductory photograph). The enclosure contains a BNC input connector, the load meter and a resistor, R_{cal}, located directly across the load meter terminals. The load meter is connected to the wall plate by a short BNC cable. Since the CT is a current source, the voltage drop across the full-wave rectifiers and the wiring to the first floor wall plate will not create any error at the load meter.

R_{cal} allows for fine calibration of the load meter to be equivalent to the 2500 W full load from the generator at 100 mA full scale.

I made use of an EM-100 electronic energy meter to verify the calibration, using two toaster ovens as loads. I used 63.4 Ω for R_{cal} (this is only about a 2% correction... we engineers can get quite tweaky at times). I added red marker to the meter scale in the area above 100% to show when the generator is in its surge current-limit mode.
The voltage across the 1.50 Ω resistor in the wall plate is approximately 233 mV_{DC} at 2800 W. The fixed drop across each rectifier is 300 mV (600 mV total per half-cycle), and the voltage drop across the total of 80 feet (24 meters) AWG-16 (1.3 mm^2) interconnect wire is 50 mV. Thus the CT secondary voltage is only 883 mV, or 137 mVA at 2800 W. This is well below the 5 VA rating of the CT. The load meter can be disconnected from the wall plate at any time without any adverse effect on the CT, since load resistor R1 is located inside the wall plate.

Changes for 240 V 230 V grids
In order to make the system suitable for other power systems, I have sketched up two additional configurations, one for a North American 240 V system and one for a European 230 V system. The CT secondary connection remains as shown in Figure 2. The value of load resistor R1 as well as R_{cal} may have to be adjusted to match the different voltages.

Since the North American AC grid has split 120/240 $_{VAC}$ lines, the phase currents (shown as I_1 and I_2 in **Figure 3a**) are not only out-of-phase, but are also likely not equal. As a result, one of the phase wires must enter the CT aperture from the opposing side in order to sum rather than cancel the out-of-phase currents.

With the European 230 V_{AC} balanced centre-earth connection (**Figure 3b**) the I_1 and I_2 currents are always equal and opposite. The CT may be connected like the North American 240 V_{AC} AC power connection in Figure 3a, or alternatively only one of the two power conductors can pass through the CT aperture as shown in Figure 3b. The CT secondary current of Figure 3b will be half that of the Figure 3a connection, so load resistor R1 may have to be increased in order to reach full scale on the percent load meter.

(110736)

Bit-banging the FTDI-USB Module

Taking advantage of little-known features of FTDI's USB ICs

By Don Powrie (USA)
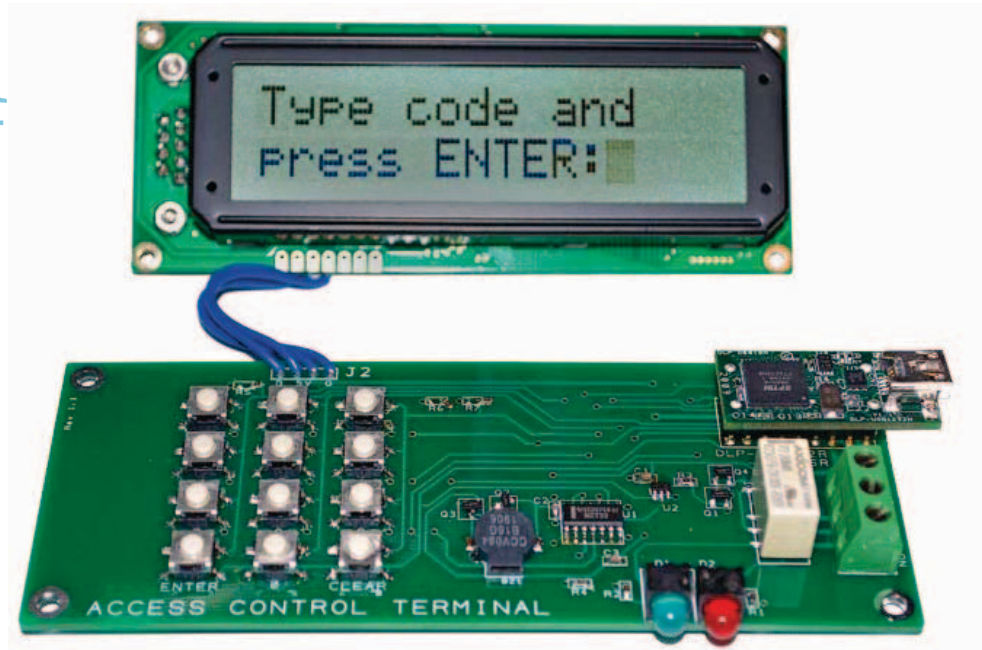
This article describes the electrical design and software requirements for a keyless entry control panel comprised of a numeric entry pad, an LCD display, relay contacts for unlocking a door and a USB interface. Even though this writing will delve into the inner workings of FTDI's FT2232H and its Bit-Bang Mode, understanding the technology will require neither an in-depth knowledge of USB nor the use of a microcontroller!

I'll begin with the assumption that the reader is already somewhat familiar with FTDI's line of easy-to-use USB ICs before diving into a couple of their lesser-known characteristics. If you haven't been exposed yet to these devices, then I might suggest boning up on their capabilities and applications by reviewing some of my earlier publications at [1].

Returning to the project, all user software will reside in a single application on the host PC, and the only ICs used in this design are the FT2232H and a couple simple logic gates. The FTDI module used is available for purchase from DigiKey, Mouser Electronics and FTDI's other distributors.

Bit-bang basics

Once the USB drivers have been loaded onto the PC and the port is open to the USB module (I used the DLP-USB1232H to make assembly easier), the Bit-Bang Mode can be enabled. The VC++ source code for this project is available for download from the project webpage [2]. The D2XX command for enabling the Bit-Bang Mode is FT_STATUS status = FT_SetBitMode(m_ftHandle, 0x01, 0x01) where the handle is returned from the call to open the port, the second parameter is used to select which of the eight data lines are inputs or outputs and the third parameter is the initial high/low state for the lines configured as outputs.

To read the high/low state of the IO lines that are configured as inputs, you would use the FT_GetBitMode(m_ftHandle, &data) function. The 'data' parameter points to the current state of the inputs. The important thing to keep in mind is that this function returns the instantaneous state of the inputs. Conversely, data that is written to the module (using the FT_Write() function) does not immediately appear on the output pins. Instead, the data appears at a preselected update rate. If the update (or baud) rate is currently set to 9600 and you send multiple bytes of data all at once, then each byte will automatically appear on the output Lines — one at a time — every 104 µs until all bytes have been issued.

FTDI's USB chips have always been able to do this. However, with the introduction of their new high-speed chips, the update rate can now be accurately controlled, and up to 8 serial streams can now be generated at precise baud rates to drive serial devices at stable baud rates. For example, the following code will set the update rate to the baud rate required by the LCD module and the TTL serial interface that I utilized in this project:

```
div = 0x8c30;//35888 decimal for 19200 baud to LCD with 0.6% error
status = FT_SetDivisor(m_ftHandle, div);
```

Note that the serial data can only be clocked **out** at a controlled rate. Unfortunately, no serial reply data can be clocked back in on an input line. You would have to use the second channel of the USB IC to receive return data; but that's OK for this project since we are only driving an LCD display (Crystalfontz America part # CFA632-YFB-KS) with TTL serial data, and we don't care about return data.

Now that we have eight controllable I/O lines that can also clock out TTL serial data at controlled baud rates, the platform is set for our project.

One 8-bit variable

The host app keeps track of all inputs and outputs, including the serial data stream to the LCD, using a single 8-bit variable. To read the high/low state of an IO line

configured as an input, you would call the FT_GetBitMode() function and mask the return variable so that you can look at a single bit. To change the high/low state of an output, you should first update the state of the bit in question in the 8-bit variable and then write out the byte.

So far so good... but what if you want to send a serial data stream of 200 bytes on
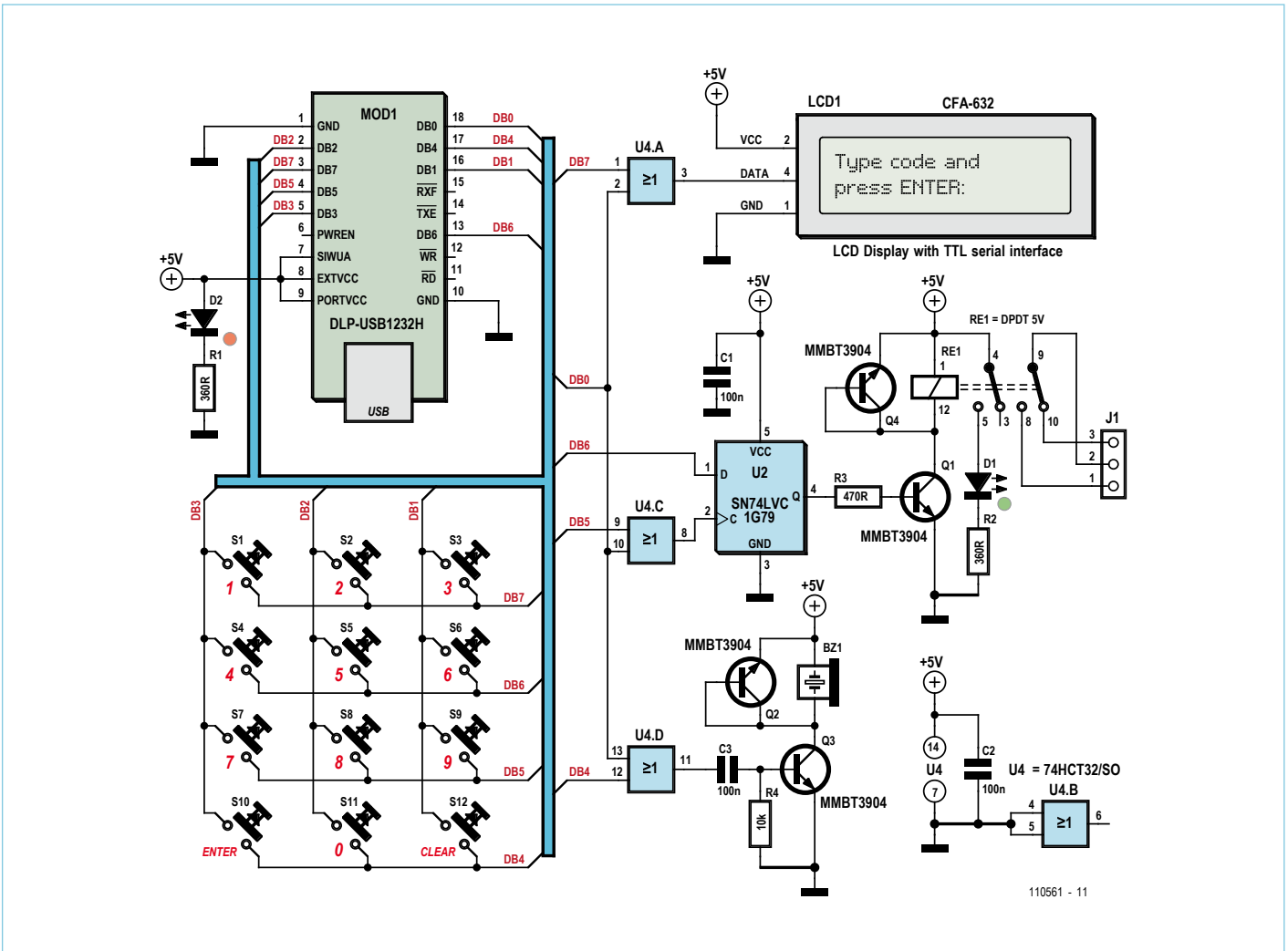
Figure 1. The DLP-USB1232H module after being suitably bit-banged acts as the controlling element of a code lock.

Figure 2. Component side layout of the circuit board designed for the code lock (here at 80% of its true size). The Gerber files may be downloaded from the Elektor website [2].

one of the eight I/O lines without affecting the other seven? That's right; you build a 1,600-byte buffer where each byte has only one bit that gets changed according to the next bit that is to be clocked out serially at the next timer tick, and then you send the entire buffer with the FT_Write() function all at once. Tedious? Yes! But computers love doing tedious tasks, and you only have to write the software once for clocking out long serial strings.

Hardware

For the following, refer to the electrical schematic shown in **Figure 1**. To scan the 12 keys in the numeric entry pad using seven of the eight available I/O lines; you just drive the DB4, DB5, DB6 or DB7 'row' lines low (one at a time) and look at the state of the three 'column' lines connected to DB1, DB2 and DB3. If a switch is pressed, then the corresponding column reports a low level on its I/O input line.

DB0 controls whether the host is reading the keyboard or driving the LCD display, relay or beeper 'devices'. When DB0 is logic High, the OR gates all block data from driving these devices.
When Low, the keyboard is ignored, and data can be written to these devices via DB4 through DB7.

By now you have probably surmised that holding a keyboard switch down will disable the host's ability to write to one or more of the devices. You can get around

this somewhat by waiting in the host app for each key press to be released before proceeding. There is almost always a way to break a design if you go looking for one, but then this system is designed to keep someone out of a locked area. If they hold a key pressed, then they're definitely not getting in.

The Gerber files for making the circuit board for the project may be downloaded free from [2]. The component mounting plan appears in **Figure 2**.

Bit-Bang++...+?

At first I was tempted to present a project in which the hardware was comprised of eight TTL serial LCD displays all connected to a host PC using just the eight I/O lines and the Bit-Bang Mode. That would have worked fine, but it really didn't present much of a challenge. It would also have been more expensive. The Bit-Bang Mode can also be used for more mundane tasks like control-

ling eight relays or simple digital I/O. More adventurous types can try controlling multiple SPI devices such as A/D and DACs. I guess the primary take-away from this article is that you don't necessarily need a microcontroller — and its associated firmware development — in order to use the USB interface to control the world around you. The Bit-Bang Mode can be a perfect low-cost solution for systems requiring only host-side software to connect to the environment outside of a PC.

(110561)

Internet Links

[1] www.dlpdesign.com/pub.shtml

[2] www.elektor.com/110561

ROBBI the Robot
A PIC animated robot head

By Walter Trojan (Germany)

The field of electronics has enormous potential to fascinate young minds and it is not always necessary to splash the cash on expensive games consoles. This project is an example of what can be achieved with very little outlay.

It was shortly before Christmas when I got a visit from my grandson. After some excitement about what Santa may be bringing it turned out that what would really please him would be a robot head that could move, blink, and make sounds. Of course if it could detect and follow a light source then so much the better. Before work had even begun his name had been chosen; meet ROBBI.

The KISS principle

No problem, I thought as I rummaged through a junk box, I can usually find enough in here to at least make a start on a new project. I found a servo salvaged from an old radio-controlled model, a few other components and a PIC12F683. This 8-pin microcontroller has a built-in PWM module which could easily be used to produce ROBBI's sounds but with just five I/O pins remaining there may not be enough for all the other necessary functions. This was going to be a challenge.

For the mechanical design of ROBBI we have stuck to the 'Keep It Simple, Stupid!' principle:

ROBBI's head is just a cardboard box fashioned to look like a robot head. Two holes are made at the front for the eyes with LEDs glued in place. Two flat washers and a couple of rubber O rings were added for effect (see photo). A small loudspeaker is installed behind the mouth with cut-outs in the cardboard to give vent to the sound. The 'ear studs' are photo transistors which detect light sources to the left and right. The servo body is fixed to a wooden board with the servo arm attached to the head. A length of 6-way ribbon cable terminated with a female header (K2) connects the head electronics to the controller board.

PIC tricks

The complete controller PCB is fitted to the rear of a four cell AAA battery holder which powers the unit. The batteries can either be alkaline primary cells or NiMH rechargeables. Four fresh alkaline cells produces a voltage just slightly too high for the PIC used in this circuit (**Figure 1**). Two series connected 1N4001 diodes introduces a voltage drop to keep supply below the suggested maximum. For use with NiMH cells (which produce a slightly lower voltage) a jumper at J1 is installed which shorts out the diodes and supplies full battery voltage to the circuit.

The PIC microcontroller is clocked from its internal 4 MHz oscillator and uses four I/O signals to control all of the robot head functions: For the majority of the time GP0 and GP1 are used as digital outputs to supply 20 mA to the two LED 'eyes'. Periodically the software reconfigures them as inputs to read the collector voltage of the two phototransistors. When there is very little or no light present the phototransistor will not be conducting so its collector voltage will be the forward voltage drop across the blue LED (2.7 V approx).

The relatively high values of resistors R8/R9 and R10/R11 limit current through the LEDs to just 0.2 mA so for this short period they will not emit any light. With increasing light levels the phototransistor begins conducting, pulling the voltage at its collector to some point between 2.7 V and 0 V. The two voltage levels are measured by pins GP0 and GP1. The voltage difference is used to control the direction that the head faces. The phototransistor recommended here for T2 and T3 is the BP103BF which has good sensitivity and with a daylight filter is ideal for detecting light from a flashlight.

GP2 is configured as a PWM output to send audible tones to the speaker. Transistor T1 is a buffer to drive the loudspeaker and resistor R3 reduces the sound volume to an acceptable level.

GP3 is the reset input with an RC network formed by R2-C2 and activated by pushbutton S2.

GP5 drives the servo control input with a pulse every 20 ms. The pulse width can vary from 1 to 2 ms and defines the position of the servo output arm.

GP4 drives the 'heartbeat' LED (LED 1) which pulses once a second to simulate ROBBI's heart.

Light and sound

ROBBI's behaviour is all programmed into firmware and took far longer to implement than it did to develop the hardware. In the situation when ROBBI has not detected a light source he enters standby mode with his head moving slowly from left to right, his eyes lighting up in different sequences and occasionally letting out a squeal. During this mode he is constantly looking for a light source and responds when one is detected by turning his head towards it.

The author tackled the software design using a conventional 'main loop' together with many sub-routines. Timer 1 is programmed to generate an interrupt every 20 ms, the interrupt service routine takes care of all the active components.

The servo arm position is proportional to the width of a pulse sent to the servo every 20 ms. A pulse width of 1.5 ms moves the servo arm to its centre position. A pulse width of 1.0 ms drives it to one end of its travel and 2.0 ms drives it to the other.

Under software control the LEDs produce five different effects: off, constantly on, slow flashing, fast flashing and sparkle. Likewise for the sound generator there are five effects: sound off, middle-pitched tone (rising quickly), high-pitched tone (falling quickly), high-pitched tone (falling slowly) and low-pitched tone (rising slowly).

The tones are produced by re-writing parameters to the PWM register to continually update the period length. The main loop checks for any light source. When light is detected ROBBI is switched to 'follow-me' mode turning his head to the light source and tracking it if it moves. When the light goes out ROBBI turns, blinks and lets out a squeal as described above.

The movement sequences are not fixed in the program code but are stored as parameters in a two-dimensional table. Each line contains a description of ROBBIs next set of actions:

< Time duration in 20 ms ticks, servo target position, speed, left LED, right LED, sound >

As an example: < 200, 100, 2, 4, 1, 3 >

The first value indicates a time period of 200 ticks which equates to 200 x 20 ms = 4 s. In this time the servo needs to travel from its current position to the leftmost position (100 x 10 µs = 1.0 ms) the next value 2 indicates that each servo pulse width will be reduced by 2 µs (this is a slow movement). The left LED is driven in sparkle mode (effect number 4) and the right LED is continuously on (effect number 1). The last parameter indicates a falling high-pitched tone. Once the last line of the action table has been completed the program loops back to point to the first line again. This movement table makes it easy to alter and experiment with ROBBI's behaviour.

The firmware has been written in Pascal and is approximately 600 lines in length. The Mikroelektronika Pascal pro compiler version 4.6 was used to generate the hex file but the newer version 5.2 should
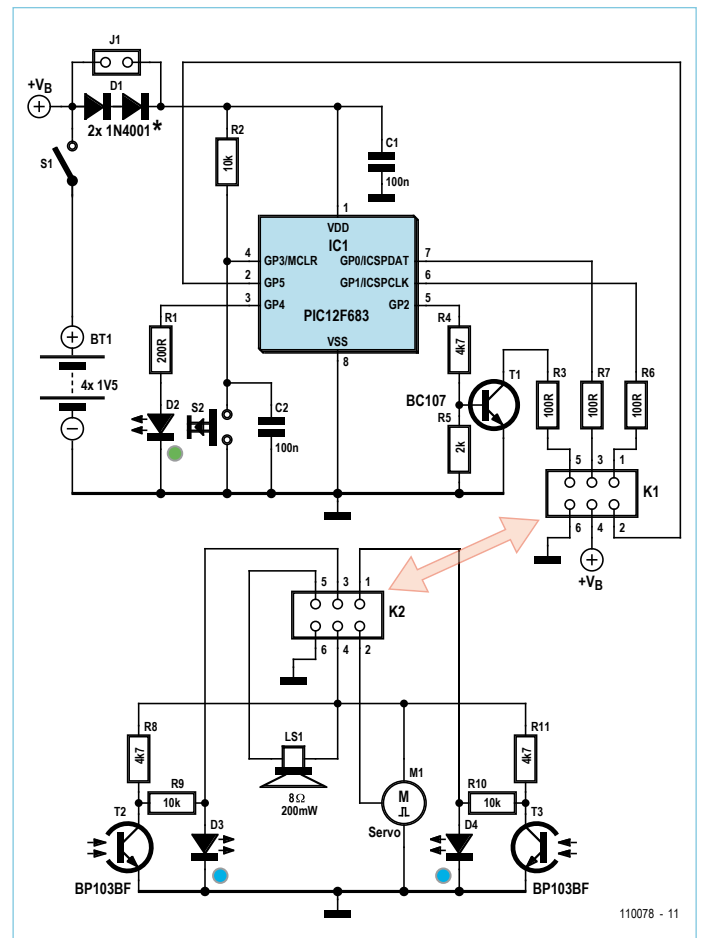
The project consists of a control circuit using a PIC microcontroller together with sensors and a model servo actuator, a loudspeaker, two LEDs and two phototransistors.

also compile the code without problems. The size of the resulting hex file is only 1.5 KB which puts it under the 2.0 KB limit for the free demo version of the compiler. This zero-cost option provides a good introduction to software development, ideal for use by school groups and computer clubs. As usual the source and hex file are available for free download from the Elektor project web page [1]. ROBBI can also be seen on the Elektor YouTube channel [2] starring in his own video.

And it came to pass...

...that the grandson was pleased with the author's work and the author was relieved that he had managed to squeeze all the functions into the tiny microcontroller. No doubt a bigger microcontroller would allow interface to more sophisticated peripheral chips like for example the ISD4002 speech chip which would then give ROBBI the power of speech. When my grandson learns of this it will be time to embark on phase 2 of ROBBI's development.

(110078)

Internet Links

[1] www.elektor.com/110078

[2] www.youtube.com/user/ElektorIM

Hexadoku
Puzzle with an electronics touch

If you don't fancy clearing snow, defrosting water pipes, chopping wood or walking the dog, Hexadoku is the perfect excuse to stay indoors. Simply enter the right numbers in the puzzle below.
Next, send the ones in the grey boxes to us and you automatically enter the prize draw for one of 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 £ 80.00 and three Elektor Shop Vouchers worth £ 40.00 each, which should encourage all Elektor readers to participate.

Participate!

Before March 1, 2012, send your solution (the numbers in the grey boxes) by email, fax or post to
Elektor Hexadoku – 1000, Great West Road – Brentford TW8 9HH United Kingdom.
Fax (+44) 208 2614447   Email: hexadoku@elektor.com

Prize winners

The solution of the December 2011 Hexadoku is: 35C24.
The Elektor £80.00 voucher has been awarded to Eugene Stemple (USA).
The Elektor £40.00 vouchers have been awarded to Reinhard Rindt (Germany),
Arno Habermann (The Netherlands) and Francisco Pérez Cortés (Spain).
Congratulations everyone!

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

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

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Webinar Programme:

The Making of an Improved Radiation Meter
Date: Thursday February 16, 2012
Time: 15:00 GMT (16:00 CET)
Presenter: Thijs Beckers (Elektor)

This webinar covers the design history and ins and outs of Elektor's highly successful Improved Radiation Meter published in the November 2011 edition. This low-cost and all do-it-yourself instrument is able to detect different types of radiation like alpha, beta and gamma using 'sensors' you never thought of as suitable for this kind of application. You can look forward to a lively and highly topical webinar on a guaranteed 'experimentalicious' circuit!

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Here comes The Elektor Bus!
Presenter: Jens Nickel (Elektor)

Many Elektor readers have actively participated in designing what's now known as the Elektor Bus. Elektor editor Jens not only tells the story of how it all came about, but also delve into protocols, bus conflicts and hardware considerations.

Let's Build a Chaos Generator
Presenters: Maarten Ambaum and R. Giles Harrison (Reading University)

Join us in this webinar to look at the making of the Chaos Generator project published in the September and October 2011 editions of Elektor. Get out your opamps, wipe your monitor and glasses and turn up the volume loud!

E-Blocks, Twitter and the Sailing Club
Presenters: Ben Rowland and John Dobson (Matrix Multimedia)

E-blocks are small circuit boards containing a block of electronics that you would typically find in an electronic or embedded system. In this webinar Ben and John demonstrate rapid prototyping of an E-Blocks configuration capable of automatically sending Twitter messages to members of a sailing club.

Platino – an ultra-versatile platform for AVR microcontroller circuits
Presenter: Clemens Valens (Elektor)

Many microcontroller applications share a common architecture: an LCD, a few pushbuttons and some interface circuitry to talk to the real world. Platino offers a flexible through-hole design for such systems based on the popular AVR microcontrollers from Atmel. Platino supports all 28 and 40 pin AVR devices, several types of LCD and has a flexible pushbutton and/or rotary encoder configuration.

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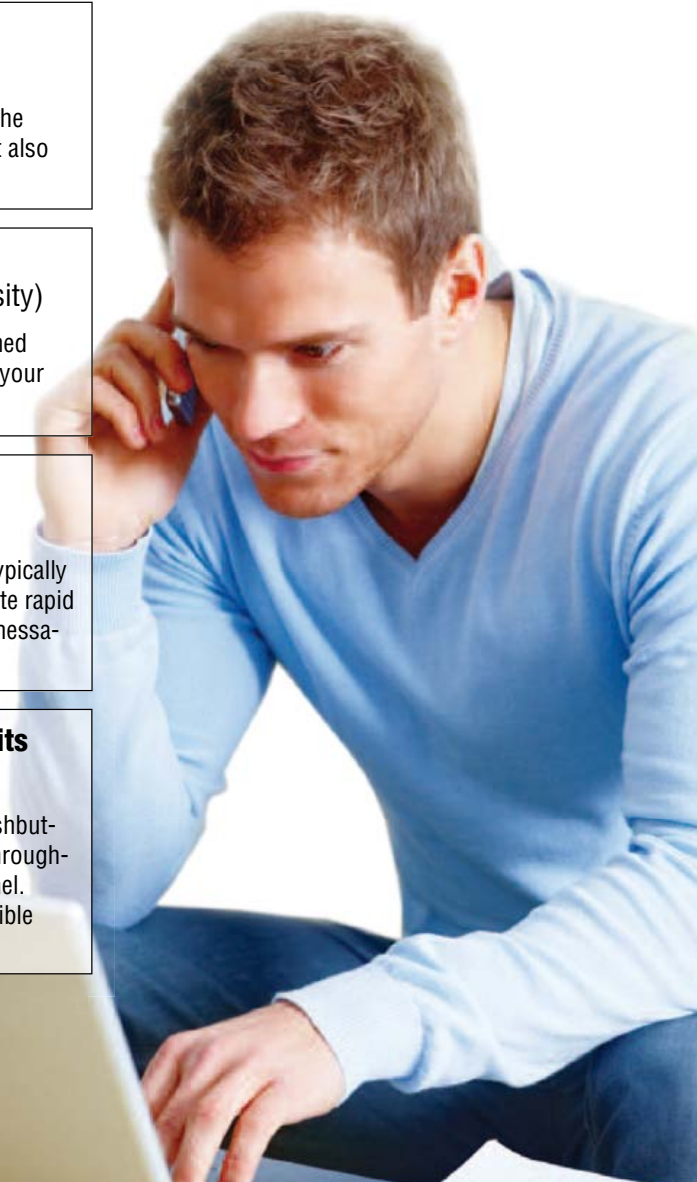
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Elektor 'Consonant' Control Preamplifier (1978)

By Jan Buiting (Elektor UK/US Editorial)

This month's story starts at *Elektor Live!* on November 26, 2011 and goes back all the way to 1978. Bear with me.

A high ranking Philips official called Henk van Houten got invited to the *Elektor Live!* event held in Eindhoven, The Netherlands. Mr van Houten, *Executive President & General Manager Philips Research* duly arrived and actually got a tour of the exhibition floors ('rings')

Elektor track record spanning a measly five years, was unable to help Henk right there and then by naming the project.

When the interview footage was up for editing, two not so high ranking editors, Harry Baggen and myself, started rummaging the Elektor magazine archives to locate the project and enable our cameraman Patrick to insert a running caption showing the proper name and date of publication in Elektor magazine. Harry was successful first — mainly triggered by the mention of a stereo width expander he was able to identify the project as the 'Consonant'
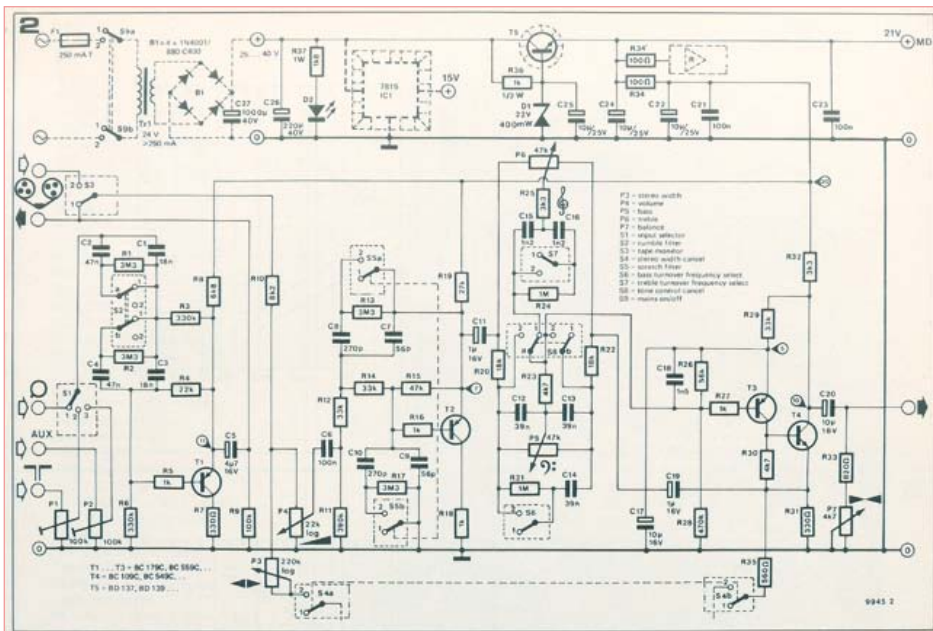
in the Evoluon building, a pinnacle of technical and architectural innovation in 1966 when Philips ruled Holland in terms of electronics. The building that looks like a flying saucer certainly merits Googling.

Slightly unnerving to the two Elektor managers showing Mr van Houten around the event, their guest started to talk real-life electronics like soldering, 2N3055's and PCB drilling, rather than high brow marketing and commercial lingo. When he got interviewed [1] by Elektor Editor in Chief Wisse Hettinga, Henk turned out to be an avid Elektor reader from the olden days, happily recalling his student days spent building audio and radio projects. At one point in the interview he could not recall the name of "an old Elektor audio project with a huge PCB like so" [moving hands approx. a foot apart] "it was something to do with stereo width expansion, can't remember the exact details but it was a great project". Wisse, normally a confident interviewer but with an

control preamplifier from 1978.

Normally, that would have concluded the matter but after a short visit to Elektor House's attic I returned to my desk with a full-blown prototype of the Consonant in my hands. The first thing I noticed was that it was indeed about a foot wide, all because of a large circuit board secured behind the front panel. The unit looked so professional, younger colleagues and passers-by said it was "something Sanyo/Kenwood/Sony from the 80s, no?"

Remarkably, the article on the Consonant was published in a Summer Circuits edition of Elektor, all 10 pages of it, cheerfully amidst much simpler projects of the "NE555 electronic doorbell" and "shoo-dog" variety typically covering half a page at the most. The name 'Consonant' follows a tradition in the 1970s at Elektor and other electronics publishing houses to give audio equipment names related to music like 'Crescendo', 'Prelude', 'Stentor', 'Fidelio' etc. Full marks to the then designers and editors it would appear, but the

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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

name 'Consonant' has unexpected deep layers! In terms of music, 'Consonant' is desirable as you don't want to hear any 'dissonance' now do you? As such, the name is highly original and perfectly in line with a fine tradition. There is a hint of a linguistic issue though, the Latin preposition 'con' meaning 'along', and the verb 'sonare', 'to sound'. Apart from English-speaking readers viewing upon 'consonant' as the direct antonym of 'vowel' and thus missing the musical context, Grammar School boys might object further that anything 'sounding along' with the original sound (like noise, hum, rattle, rumble, DeutscheWelle and what have you) is highly undesirable and a far cry from "high fidelity".

I have to say the 1978 article is boring straight from the beginning when we are told in very unmusical terms:

The principal considerations which governed the design of the Consonant were that:
1. The performance and facilities offered should be comparable with those provided by the best commercial designs.
2. The circuit should be simple to construct and should use readily available components.
3. The controls should be laid out in a clear and logical fashion for ease of operation.

On a positive note and using starched language too, you can only "*admit to all of the above requirements having been satisfied largely if not fully.*" Nowhere does Elektor sing its own praises about the project — all descriptions of the excellent performance of the preamp are factual, dryly technical, and in modest terms. Nowhere did I find those horrible woolly terms the audio fraternity have a habit of using when extolling on audio equipment.

The **circuit diagram** probably fell victim to non-technical page layout staff as it looks horizontally crushed on the page compared to the construction drawings and the performance graphs taken with a Bruel & Kjaer recorder (long since gone). The schematic of the Consonant is reproduced here for old time's sake, along with the **specifications**.

Back to the technology, the stereo width control that started all this gets activated when S4 is closed. A 'wide' stereo image was

considered desirable at the time and was also used sometimes to "further enhance" older recordings remastered from originally monaural material. Undoubtedly the effect was used at the time to make a cramped room like student's digs "sound larger". Today, the effect is popular among young rock bands like *Bloc Party* and *Editors* whose guitar riffs seem to sprawl wide from the PA towers and across the field at live gigs.
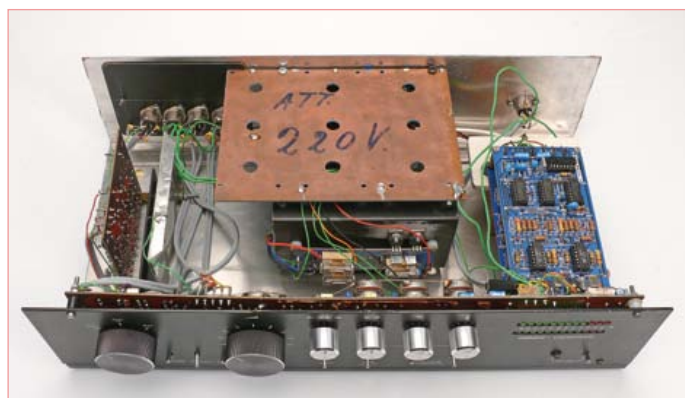
Elektor Consonant specifications

Frequency response:	20 Hz – 50 kHz (+0 dB, –3 dB)	Channel separation:	>50 dB (at 1 kHz)
Max. output voltage:	3.5 V_{rms} (10 V_{pp})	Dynamic range:	> 90 dB
Nominal output voltage:	440 mV_{rms}	Output noise level:	approx. 0.1 mV
Signal-to-Noise ratio:	>72 dB for 440 mV_{rms} out	Filters:	
Overload margin:	>15 dB above 440 mV_{rms} out	Rumble filter:	60 Hz (–3 dB), 12 dB / octave
Total harmonic distortion:	approx. 0.04% (for 440 mV out)	Scratch filter:	10 kHz (–3 dB), 12 dB / octave
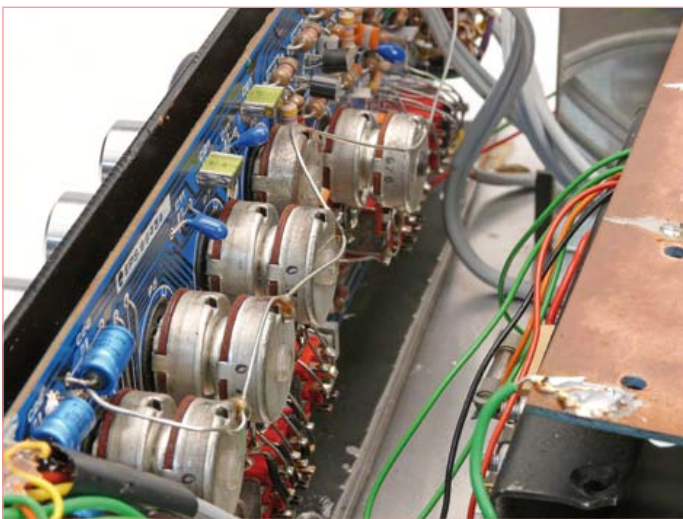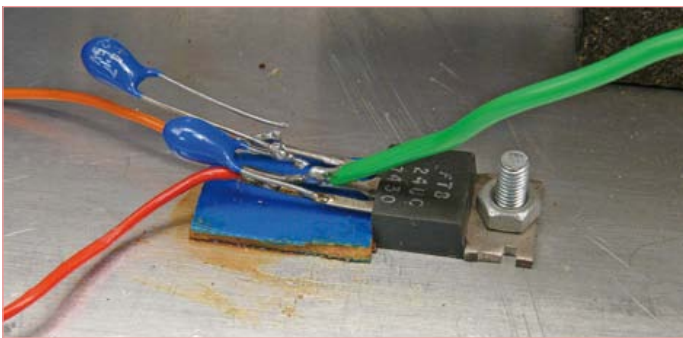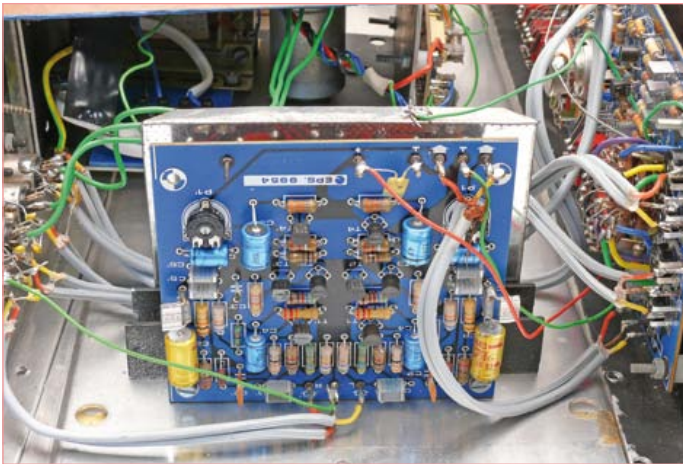
In the Consonant, the left and right channels are linked via R35 and pot P3. The fixed resistor, the article says, joins the emitters of T4 and T4' and thus effectively converts these two stages into a differential amplifier. The signal appearing at the collector of T4 now represents (L–kR), where k is a constant determined by the circuit parameters. The minus explains the antiphase contribution from the right channel. Likewise the right channel mathematically will consist of (R–kL). The upshot is that the antiphase signals make the sound from the 'opposite' channel appear even further removed in space, creating an impression of image widening so desirable at the time, if only to fool your ears or your impress your guests.

Towards the end of the 1970s it was still fashionable to build one's own audio gear at a fraction of the price of commercial units — and show it off. The terms 'nerd' and 'geek' did not exist yet, and 'hobbyist' had a positive ring. It was also contemporary to have everything on a single PCB including pots and switches, all to avoid cumbersome wires susceptible to picking up noise. One problem lurked though: the pot bodies had to be isolated from the front panel to avoid earth loops. This bit of information was shared with the readers in a lengthy *Missing Link* published in the February 1979 edition.

The artwork of the huge, single-sided printed circuit board (370 x 90 mm), i.e. the copper track layout and component mounting plan, was printed in the centrefold of the magazine to avoid any risk of vertical misalignment between facing pages not cut from the same folio sheet at the printers. Home PCB etching and drilling was a big thing at that time and many must have gone through the trouble of actually lifting the pages from their precious magazines to enable the PCB track layout to be transferred to copper clad board. The stylish black front fascia designed for the Consonant was also printed but not at full scale as it was impossible to fit even on a spread (double A4 pages).

The Consonant shown here worked after restoring two broken solder joints between tantalum caps and the legs of a voltage regulator screwed to the bottom plate. The case also contained the Preconsonant disc player preamp published in the same edition as the Consonant (AbsFab marketing!).

I will not be tempted to word the sonic qualities of the Consonant other than saying that its noise contribution is inaudible at all volume levels I consider normal for my living room. I found no need to turn the tone controls from their 'flat' positions, so no Baxandallizing for me. The stereo widener I found very artificially sounding and even turned up a little gave me a headache when playing an LP record like Mike Oldfield's *Tubular Bells*. These days I have a spacious living room— come to think of it, it's *infinitely* larger and wider than in 1978 when I had none to speak of, and no money either to afford a Consonant.

(110718)

To celebrate the resurfacing of the Consonant, a scanned copy of the original article from Elektor July & August 1978 may be downloaded free of charge [2]. Regrettably parts, circuit boards or tech support are no longer available for the project.

Internet References

[1]   video: ElektorIM (sic) channel on www.youtube.com

[2]   www.elektor.com/110718

The Money Dance

By Gerard Fonte (USA)

Competition

There are those that view commerce as a battle to win or lose. We're the good guys and they're the bad guys. If we get what we want, we win! It's just human nature to desire the most for the least. In the short term, that's good. And, if you're buying or selling a house, you aren't likely to get much repeat business (assuming you're not a builder). So, pushing for every dollar makes sense.

But if you are buying or selling lots of somethings, like parts for your product, or your product itself, this attitude is simply wrong. Commerce is a symbiotic relationship. Done properly, both parties benefit to this dance. It's not win/lose, it's win/win. You get something you need (product or money) for giving something you have (product or money). That's what free-enterprise is all about. The important thing here is to be reasonable. Both sides want a good product for a good price. Both sides benefit when there's a good product sold at a good price. This is another way of saying that there is a balance of needs. The need for a product balances the need for money. When this balance is upset, problems occur.

If you demand too high a price for your product, it won't sell. You just drive your sales to your competitors or people will make due without. This is pretty obvious.

If you negotiate too low a price for the parts you need to build your product, that's bad too. But, it's not as obvious. Suppose you shop around for a part that typically costs $5 (at volume) and you find a manufacturer that sells them for $4. You negotiate real hard and get them to lower their price to $3 for a large volume of parts. That's good for you. But it's bad for them. They now have a much lower profit margin and are at risk for financial distress. If other customers find out that they're selling parts at $3, they'll want that price, too. That's more financial stress. If the manufacturer gets into a bad financial situation, they are going to sell their parts to the people that will pay the original $4. And you'll find that they simply "can't produce" the volume you need. There's no utility in getting a great price for a product, if there is no product. And, finally, companies that sell their product too cheaply, generally go out of business. This leaves you without any parts at all. You now have to pay $5 for your components because you drove the $4 vendor out of business. (Note: this is NOT an unusual scenario. Very large volume buyers can and do force some companies to make bad financial decisions that result in bankruptcy. The lure of guaranteed high-volume sales is a difficult temptation to resist.)

Lowest Price

Of course, if you're just a buyer for a small company, you generally don't negotiate price too often, so the lowest price is always the best, isn't it? The answer is no. There are many factors to consider other than price alone. There's delivery. If you production line is stopped because you can't get a part, your company suffers and the company president gets angry. There's quality. Many times "equivalent" parts are available from different sources (like resistors and capacitors, for example). If one manufacturer has fewer failures, it may be worthwhile to pay extra for that. Improving reliability reduces product returns and may offset the higher initial part cost which saves money in the long run (And, improved reliability makes customers happy and encourages repeat sales).

Having multiple sources of parts is always useful. Placing an occasional order for a slightly more expensive part is a kind of insurance in case something happens to your main vendor. Even being an occasional customer carries some influence should a special need arise.

And there are intangible reasons to buy something at a higher cost. The manufacturer may be local. The manufacturer may be a customer, as well. There may be some name recognition associated with the particular part ("Intel Inside"). In all of these cases you are buying something for the added cost. If you are getting a good price for these extras, then it's good for you.

Negative Profit

The opposite of buying a higher-priced product is to sell one below your cost to manufacture it. Surprisingly, this is fairly common. Stores have special "loss-leader" products at ridiculous prices to get you into the store. They know a certain percentage of people will buy additional products and that will offset their negative profits. And then there are the "free" printers, or telephones, or TV converters that lock you into buying a particular accessory or service. The manufacturers make their money on the continued sales of these high-mark-up items. Over time, these "free" products can be very expensive.

The Bottom Line

All of this discussion returns back to the money dance. Every monetary transaction is a give and take — quite literally. You give something and take something in return. You give 40 hours of work to get a paycheck. You spend your paycheck to pay rent or a mortgage, to buy food and clothing and to pay taxes. Money comes in and money goes out. It circulates constantly, as you do on the dance floor. Sometimes you lead and sometimes you follow.

It is critical that the partners respect each other and balance each other's needs. It's human nature to want to take as much as you can. But it's not the smart thing to do. And, of course, the larger the scale the more important the balance is. Companies and unions are not really enemies. But when negotiating, both sides naturally want to lead. It often becomes a power struggle, and the symmetry of business is lost (Political parties are not enemies, either).

Deliberately trying to unbalance the scales of commerce is like slaying the golden goose. It's short-sighted, non-productive and ends up being very costly.

(120060)

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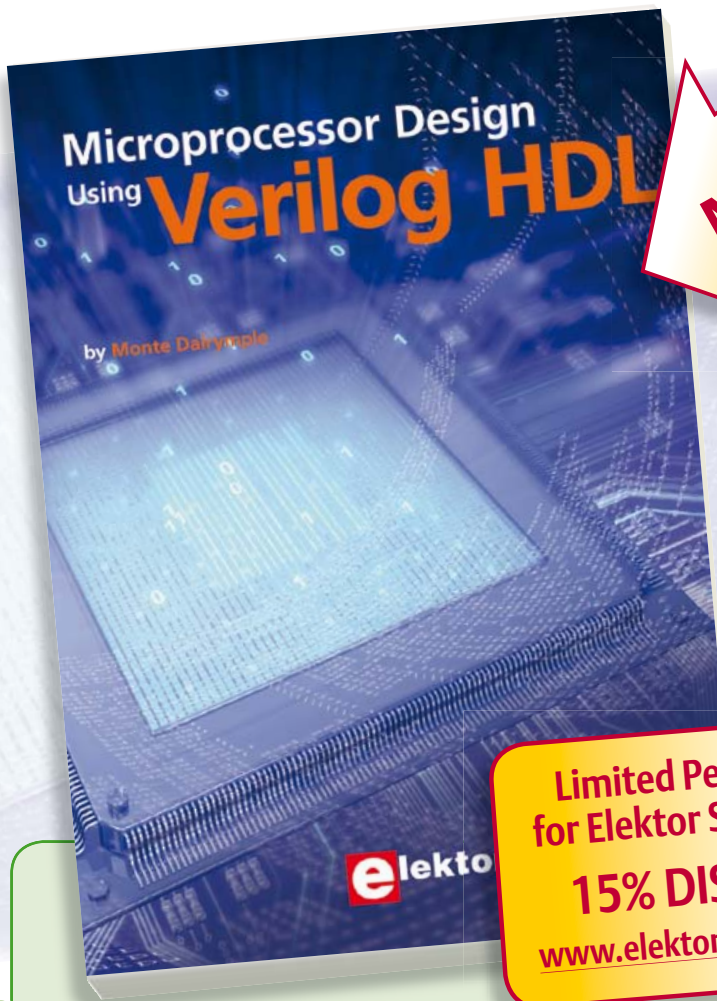
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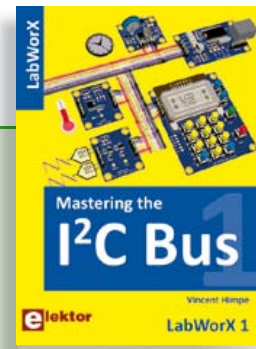
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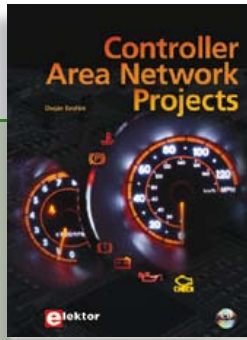
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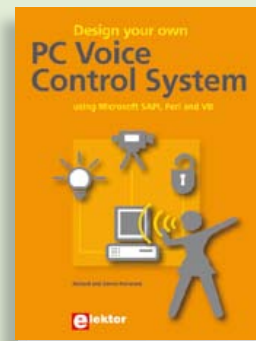
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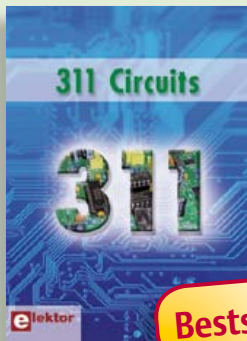
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ISBN 978-1-907920-06-6
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Bestseller!

For alpha, beta and gamma radiation

Improved Radiation Meter

(November 2011)

This device can be used with different sensors to measure gamma and alpha radiation. It is particularly suitable for long-term measurements and for examining weakly radioactive samples. The photodiode has a smaller sensitive area than a Geiger-Müller tube and so has a lower background count rate, which in turn 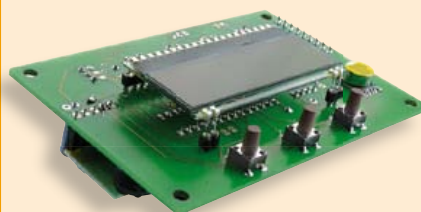means that the radiation from a small sample is easier to detect against the background. A further advantage of a semiconductor sensor is that is offers the possibility of measuring the energy of each particle. -2 regels

Kit of parts incl. display and programmed controller

Art.# 110538-71 • £35.50 • $57.30

USB Long-Term Weather Logger

(September 2011)

This stand-alone data logger displays pressure, temperature and humidity readings generated by I²C bus sensors on an LCD panel, and can run for six to eight weeks on three AA batteries. The stored readings can be read out over USB and plotted on a PC using gnuplot. Digital sensor modules keep the hardware simple and no calibration is required.

Kit of parts incl. PCB, controller, humidity sensor and air pressure sensor modules

Art.# 100888-73 • £31.10 • US $50.20

FT232R USB/ Serial Bridge/BOB

(September 2011)

You'll be surprised first and foremost by the size of this USB/serial converter – no larger than the moulded plug on a USB cable! And you're also bound to appreciate that fact that it's practical, quick to implement, reusable, and multi-platform – and yet for all that, not too expensive! Maybe you don't think much of the various commercially-available FT232R-based modules. Too expensive, too bulky, badly designed, ... That's why this project got designed in the form of a breakout board (BOB).

PCB, assembled and tested

Art.# 110553-91 • £12.90 • US $20.90
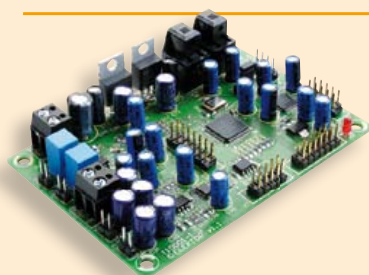
Audio DSP Course

(September 2011)

This DSP board is the platform for the applications described in our Audio DSP Course. It is also intended to enable you to develop your own initial digital audio signal processing applications. The DSP board can be used stand-alone as is, and even though it is an ideal learning platform, with its 24-bit signal processing capability for sampling rates up to 192 kHz and its high-performance interfaces, it is also suitable for applications with very stringent quality requirements for both signal to noise ratio and DSP computing power.

Populated and tested DSP board

Art.# 110001-91 • £115.70 • US $186.70

Kits & Modules

February 2012 (No. 422)   **£**   **US $**

+ + + Product Shortlist February: See www.elektor.com + + +

January 2012 (No. 421)

Wideband Lambda Probe Interface
110363-41 .... Programmed controller ATMEGA8-16AU .... 8.85 .... 14.30

Audio DSP Course (7)
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Grid Frequency Monitor
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              for 50 HZ areas (Europe) .... 8.85 .... 14.30
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110258-1C3 .. 3 pcs Experimental Node Board .... 11.50 .... 18.60
110258-91 .... USB/RS485-Converter, ready made module .... 22.20 .... 35.90

Time / Interval Meter with ATtiny
080876-41 .... Programmed ATtiny2313 .... 7.70 .... 12.60

December 2011 (No. 420)

Here comes the Bus! (10)
110258-1 ...... Experimental Node board .... 5.30 .... 8.60
110258-1C3 .. 3 pcs Experimental Node board .... 11.50 .... 18.60
110258-91 .... USB/RS485 Converter, ready made module .... 22.20 .... 35.90

USB Data Logger
110409-1 ...... Printed circuit board .... 9.75 .... 15.70
110409-41 .... Programmed controller PIC24FJ64GB002-I/sp dil-28s 13.30 .... 21.40

November 2011 (No. 419)

Improved Radiation Meter
110538-41 .... Programmed controller ATmega88PA-PU .... 9.35 .... 15.10
110538-71 .... Kit of parts incl. display and
              programmed controller .... 35.50 .... 57.30

Simple Bat Detector
110550-1 ...... PCB, bare .... 8.85 .... 14.30

OnCE/JTAG Interface
110534-91 .... Programmer board, assembled and tested .... 35.60 .... 57.30

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110258-1 ...... Experimental Node board .... 5.30 .... 8.60
110258-1C3 .. Printed circuit board 3x print Experimental Node ..... 11.50 .... 18.60
110258-91 .... USB/RS485 Converter, ready made module .... 22.20 .... 35.90

Dual Linear PSU for Model Aircraft
081064-1 ...... Printed circuit board .... 14.50 .... 23.80

October 2011 (No. 418)

Versatile Board for AVR Microcontroller Circuits
100892-1 ...... Printed circuit board .... 11.55 .... 18.70

Audio DSP Course (4)
110001-91 .... PCB, populated and tested DSP board .... 115.70 ..... 186.70
110001-92 .... Bundle DSP board (110001-92)
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September 2011 (No. 417)

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USB Long-Term Weather Logger
100888-1 ...... Printed circuit board .... 16.00 ...... 25.90
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PC Fan Control

To enable all fans inside a PC to be controlled in safe and flexible ways, a circuit was designed that provides extensive capabilities. It allows up to six PWM fans to be controlled simultaneously, with the rotation speed of each fan measured individually by reading its tacho signal. An existing fan control on the PC motherboard (like the CPU cooler) can be used as a signal source for controlling the fans connected. The circuit can operate autonomously when configured using USB, but it's also possible to control and monitor it via USB.
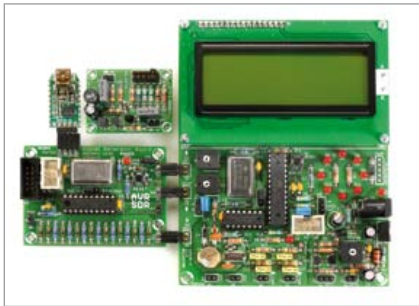
Software Defined Radio with AVRs

Next month we kick off a new series showing how Atmel AVR microprocessors can be used for digital signal processing (DSP). A total of three circuits board gets proposed. The first includes a signal generator based on an ATtiny2313, the second board contains a complete SDR receiver with display and serial interface, and the third PCB is used to construct an active antenna. In total, more than 20 experiments can be done with these boards. All software was created with the WINAVR GCC Compiler in AVR Studio, and of course it's available on the Elektor website for your own experiments.

LED Touch Panel

Today, almost every cellphone or tablet computer has a touchscreen. There are several ways to implement a touch screen, ranging from a resistor array with a plastic film using a capacitive grid etched on to the screen, right up to a camera device that tracks your finger movements. However, there are other touch screens with a configuration you wouldn't think of straight away. This article describes a touch screen for home or lab construction, with an 8 x 8 matrix of LEDs determining the presence of your finger by alternately transmitting and receiving and so determine which LED is covered by the finger.

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

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