

**32x NE5532 = top-notch amp**

October 2010

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**+ S-FSK Powerline Communication**

**+ Quartus/Altera FPGA Design Simulation**

**+ 80 Candles for the Pentode**

**+ Satnav with Propeller**

**5532 Power Amplifier**



**20 AC/DC clamp meters on the test bench**



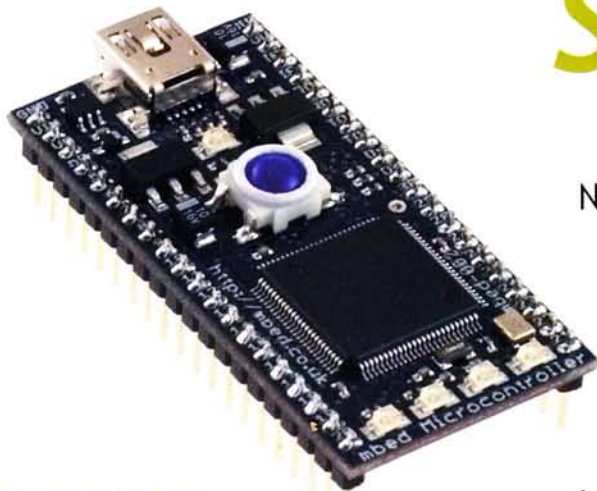
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# NXP mbed DESIGN CHALLENGE



## What TECHNOLOGY can you *SET FREE?*



The mbed Microcontroller, based on the NXP LPC1768, lets you work with an ARM Cortex-M3 in a 0.1" DIP form-factor. Combined with the <http://mbed.org> website, featuring the mbed "Cloud" Compiler, it is an ideal platform for rapid prototyping with microcontrollers.

NXP and ARM/mbed challenge you to revolutionize the way people build prototypes! Build a reusable library, component interface, reference design or product prototype that can be shared on <http://mbed.org> to help others build their prototypes even faster, and you could be walking away with part of a prize pool worth \$10,000!

**Deadline for entries is February 28, 2011.**

Join the Challenge by registering at  
[www.circuitcellar.com/nxpmbeddesignchallenge!](http://www.circuitcellar.com/nxpmbeddesignchallenge)

Apply for a free NXP sponsored mbed Microcontroller kit while supplies last.\*

NXP mbed Design Challenge empowered by:



\*No purchase necessary. See website for details.



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Memory

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- High noise immunity and low emissions
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#### • mTouch Inductive Sensing technology

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- Deploy Braille-friendly interfaces

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- Order a development tool



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## The reader/advertiser promise

If you are not in the electronics industry, or without a formal qualification in the field, it may be good to realise that electronics as a pastime would be non-existent without the wide diversity of manufacturers, distributors and suppliers of equipment, tools, components and CAD software — the friendly ones of course.

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

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

I am happy to say that Elektor is attracting an increasing number of companies, big and small, advertiser or not, wishing to run projects with us. Recently, 'projects' has taken on a wider meaning in also covering reader offers and contests. Together with our American colleagues at Circuit Cellar, we're officially launching the *NXP mbed Design Challenge* at Embedded Systems Conference in Boston, USA on September 20–23. Invariably, reader offers and contests take a lot of time and effort to arrange exclusively for you — or should I say "for your pleasure". More is in the pipeline.

Jan Buiting, Editor

(and celebrating 25 years with Elektor this month)

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A monthly roundup of all the latest in electronics land.

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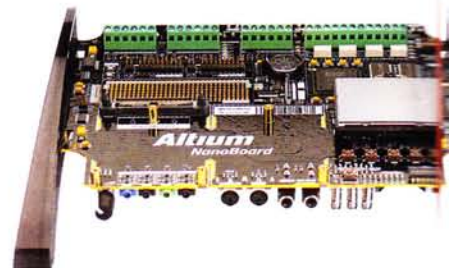
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J. Clarkson: "The (NE)5532 is audio's most popular dual opamp *in the world*". J. May: "An interesting power amplifier can be made by connecting enough 5532s in parallel, how about 32 for a start?" R. Hammond: "This may sound like a radical course of action, but it actually results in a very simple amplifier with high-end performance."

## 22 Measure that Current!

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

The main image shows the cover of the October 2010 issue of Elektor magazine. The cover features the title 'elektor' in a large, stylized font. Key headlines include '32x NE5532 = top-notch amp', '+ S-FSK Powerline Communication', '+ Quartus/Altera FPGA Design Simulation', '+ 80 Candles for the Pentode', '+ Satnav with Propeller', '5532 Power Amplifier', and '20 AC/DC clamp meters on the test bench'. Below the main cover are three smaller covers: 'Digital Effects Unit', 'Project Generator Edition', and 'Programmable DIY MP3'. To the right of the magazine cover is a globe with a horizontal strip of flags representing the United Kingdom, Netherlands, Germany, France, USA, and Spain.

**ANALOGUE • DIGITAL  
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Volume 36, Number 406, October 2010 ISSN 1757-0875

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

**Publishers:** Elektor International Media, Regus Brentford, 1000 Great West Road, Brentford TW8 9HH, England. Tel. (+44) 208 261 4509, fax: (+44) 208 261 4447 [www.elektor.com](http://www.elektor.com)

The magazine is available from newsagents, bookshops and electronics retail outlets, or on subscription. Elektor is published 11 times a year with a double issue for July & August.

Elektor is also published in French, Spanish, American English, German and Dutch. Together with franchised editions the magazine is on circulation in more than 50 countries.

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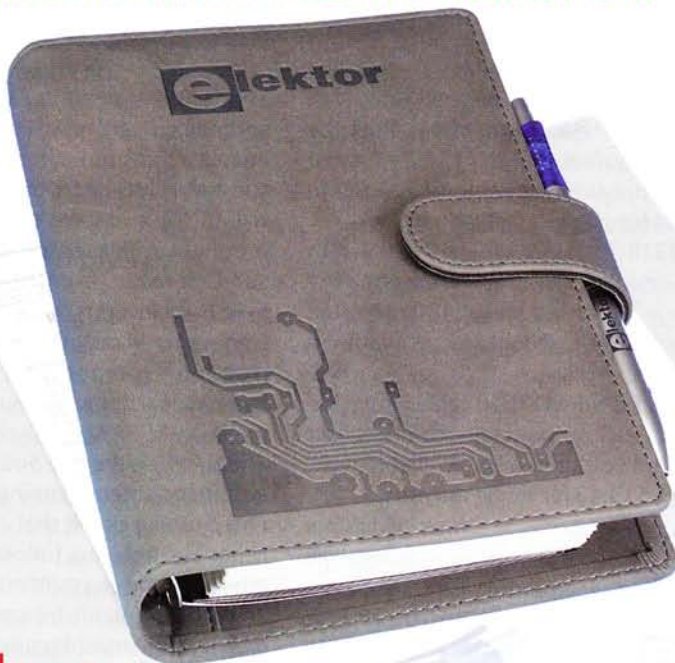


# Elektor Personal Organizer 2011

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#### The Organizer 2011 at a glance:

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- 60 pages of technical information on electronics
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- Handy monthly planner
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Distribution:  
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Telephone: +44 207 429 4073

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## Enhanced range of USB 2.0 to serial UART converter cables

Future Technology Devices International Limited (FTDI) have announced the availability of their TTL-232RG family of USB to TTL serial UART converter cables. The TTL-232RG cables build upon the existing FTDI family of USB to TTL cables, by offering new versions to support an extended variety of voltage I/O levels. The cables feature a USB to serial converter PCB encapsulated within a standard type 'A' USB connector with a wire-ended asynchronous UART output. The cables are aimed at providing USB connectivity within applications with serial UART ports. The cables provide a fast and simple method for enabling USB connectivity in such applications, with minimal changes to existing user software.



A range of cables are available for a variety of voltage I/O levels including +1.8 V, +3.3 V, +5.0 V or at user specified levels, to provide UART interfacing to devices such as MCUs, CPUs or FPGAs at a range of voltage levels. The cables derive power from the USB interface and have integrated voltage regulators removing the need for designers to provide external power or have voltage level shifters on their boards. Further, the cables can be used to provide an optional power output ranging between +1.8 V and +5.0 V for powering external circuitry. The TTL-232RG cables feature the FTDI FT232R USB 2.0 to UART converter IC with associated circuitry integrated within the cable USB connector. The FT232R manages the complete USB protocol within the device — meaning that no user knowledge of USB is required. The UART interface supports data transfers at up to 3 Mbps. Using the FTDI's Virtual COM Port (VCP) drivers, users can easily access the UART interface as a (virtual) COM port with existing software applications, removing the need for any redesign. The FTDI D2XX drivers are also

available to support application development using high-level software languages. FTDI's royalty free drivers include Microsoft WHQL certified drivers for Windows based operating systems, as well as drivers for Linux and Mac OS operating systems. All drivers are freely available for download from [www.ftdichip.com/FTDrivers.htm](http://www.ftdichip.com/FTDrivers.htm). All cables are FCC/CE compliant. The range of USB to UART cables includes:

- **TTL-232RG-VSW3V3-WE:** USB cable with wire-ended UART connections at +3.3V voltage levels and +3.3 V / 50 mA rated power output. Available now. Pricing \$21.07 for single quantity.
- **TTL-232RG-VREG3V3-WE:** USB cable with wire-ended UART connections at +3.3V voltage levels and +3.3 V / 250mA rated power output. Available now. Pricing \$24.64 for single quantity.
- **TTL-232RG-VREG1V8-WE:** USB cable with wire-ended UART connections at +1.8 V voltage levels and +1.8 V / 100 mA rated power output. Available now. Pricing \$24.64 for single quantity.
- **TTL-232RG-VSW5V-WE:** USB cable with wire-ended UART connections at +5 V voltage levels and +5 V / 450 mA rated power output. Quantities available in August.
- **TTL-232RG-VIP-WE:** USB cable with wire-ended UART output connections at user supplied voltage levels. Available now. Pricing \$19.45 for single quantity.

[www.ftdichip.com](http://www.ftdichip.com)  
(100554-VIII)

## Silabs: wireless remote control on a chip

Silicon Laboratories Inc. have introduced an EZRadio® wireless IC solution designed to reduce the cost and complexity of one-way wireless links used in a wide range of consumer, industrial and automotive systems. The new Si4010 system-on-chip (SoC) RF transmitter enables developers to optimize remote keyless entry (RKE), garage door opener, remote control, building automation and security device designs for the lowest system cost and highest performance while ensuring one-way link integrity. The Si4010 RF transmitter is the industry's first single-chip remote control IC requiring only one external bypass capacitor, a printed circuit board, battery and external case with pushbuttons to create a complete

wireless remote control. Based on a patented crystal-less architecture, the Si4010 achieves  $\pm 150$  ppm carrier frequency accuracy over the commercial temperature range and  $\pm 250$  ppm over the industrial temperature range — twice the accuracy of traditional surface acoustical wave (SAW)-based transmitters — without using an external crystal.



The Si4010 transmitter SoC is best paired with Silicon Labs' new Si431x RF receivers to enable a transmitter/receiver solution that substantially reduces the total bill of materials (BOM) and saves valuable board space for one-way link systems operating in the sub-GHz range (from 27 to 960 MHz). The Si431x receivers' state-of-the-art integration requires only two external antenna-matching components, a crystal and a bypass capacitor while eliminating the need for costly RF SAW and IF ceramic filters. The Si4010 is the first SoC transmitter with automatic antenna tuning, featuring a patented tuning circuit that automatically fine tunes the antenna for optimum transmit efficiency and constant output power. Variations in transmit frequency due to PCB loop antenna manufacturing tolerances and environmental variations can lead to significant antenna inefficiencies and wasted power. The Si4010's antenna tuning circuit continuously maximizes antenna efficiency by adjusting an on-chip variable capacitor to resonate with the antenna's inductance. The Si4010 supports programmable edge rate control for on-off keying (OOK) mode to reduce harmonic emissions and comply with governmental RF regulations. It also outperforms competing discrete solutions, offering +10 dBm output power, exceptional range and robust links. The Si4010 contains an embedded 8051-compatible MCU core with 4 kB of RAM, 8 kB of one-time programmable (OTP) non-volatile memory, a 128-bit EEPROM and 12 kB of ROM for library functions. These ROM-based functions enable developers to easily implement complex



features such as security encryption into their remote controls by using proven code to reduce risk and development time. The MCU's on-chip digital peripherals include wake-on-touch general-purpose I/Os (GPIOs), a patented 20-bit EEPROM counter providing one million cycles of read/write endurance, an LED driver, sleep timers, a debugger and a high-speed 128-bit Advanced Encryption Standard (AES) accelerator for secure one-way links.

To accelerate the development of one-way link products, Silicon Labs offers a rich set of hardware and software tools including the 4010-DASKF\_434 evaluation kit to demonstrate RKE fob functionality, the 4010-DAAKF\_434 evaluation kit to demonstrate AES encryption functionality in RKE fobs, and the 4010-DKKF\_434 development kit providing a comprehensive Si4010 software development environment.

[www.silabs.com/pr/wireless.100554-XII](http://www.silabs.com/pr/wireless.100554-XII)

## Well kitted amplifier

Piccolo is a new 50 watt amplifier kitset from Italian kitset specialist APPSI using the famous LM3886 amplifier chip to create a great sounding, easy to build amplifier. Features that make the piccolo great sounding and easy to build include low negative feedback; most of the existing 'gainclone' kitsets "borrow" from the design of the almost mythical Japanese '47 Lab' amplifiers which used the LM3875. While using roughly the same circuit, the Piccolo uses less negative feedback which makes it unconditionally stable. This contributes to its sound having a great sense of 'ease'. Yet retaining low distortion (0.03%) and generous bandwidth. The Piccolo's power supply is integrated in each 90x90mm (approx. 4" sq) mono-block module. As the power supply of any amplifier is actually part of the circuit, integrating it can have large benefits in keeping the circuit short and noise to a minimum. Small power supply capacitors are paralleled to give better performance than single large ones.

While these modules can be built in to the dedicated ezPower™ chassis to form a stereo amplifier, they are ideal for active loudspeakers and their small size is great for quality multi channel systems.

The amplifier design cuts down on the wiring and possibility for mistakes. Piccolo manages to provide excellent performance

## Xbee SIP adapter

Parallax's new XBee SIP Adapter (#32402; \$24.99) is a fully-assembled, small-footprint solution for interfacing the most commonly-used XBee module features with your 3.3 V or 5 V microcontrollers. With many XBee adapters on the market, Parallax gave this design very careful consideration to the specification to customize the product for educational and hobby uses.

The 2 x 5 dual SIP header makes a sturdy connection to your breadboard or through-hole board, and brings the basic connections to your prototyping area without taking up a lot of space. The more advanced XBee features are still accessible, through additional headers on the module.

Features:

- Onboard 3.3 V regulator
- 5 V to 3.3 V logic translator buffers common I/O pins
- Six status indicator LEDs for Power, Tx, Rx, RSSI, Associate and mode (Sleep/ON)
- Small footprint dual SIP header provides support and allows easy interfacing to DOUT (TX), DIN (RX), RTS, 5 V supply and ground
- 5-pin female header connections provides interfacing to other XBee pins such as sleep, reset and associate
- A row of 10 plated through-holes with 0.1" spacing allows the option of soldering jumper wires or a header (not included) for access to the remaining XBee pins in advanced applications
- An additional plated through-hole gives access to 3.3 V output for ADC reference (VREF) when required
- Adapter board is pre-assembled — no soldering required for using most common XBee features
- Compatible with all Parallax microcontrollers, including the 5 V BASIC Stamp modules and 3.3 V Propeller P8X32A

[www.parallax.com](http://www.parallax.com)  
(100639-1)

with remarkably few components. The only extra electrical component you need is a transformer.

The build is made even easier as the PCB slots straight into the 50 mm high ezPower™ heatsink chassis from New Zea-

land company Design Build Listen who also distribute the kits, meaning no metal working is needed.

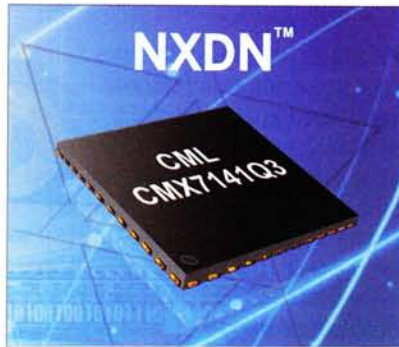
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(100639-11)





## New function image supports NXDN design

CML Microcircuits has announced the release of a new Function Image for the CMX7131 and CMX7141 ICs supporting the development of NXDN compatible digital voice radio equipment.



Called NXDN, its common air interface (CAI) is a result of a joint development between Kenwood Corporation and ICOM Incorporated. NXDN digital radio equipment supports commercial Private Land Mobile Radio (PLMR/LMR) to serve light commercial, more demanding business and industry, and public safety applications, even on 6.25 kHz channels. The technology satisfies the US Federal Communications Commission (FCC) Part 90 'narrowbanding' requirements; as of December 2009, 70,000 RF channel licenses were approved for NXDN operation. CML is committed to the promotion, support and development of this exciting new radio technology.

The CMX7131 and CMX7141 are digital PMR processors built on CML's proprietary FirmASIC technology and are suitable for use in a number of digital radio systems now including NXDN. FirmASIC component technology enables on-chip sub-systems to be configured by a Function Image, a data file that is uploaded during device initialisation that defines the device's function and feature set. This technology provides the flexibility for the CMX7131 and CMX7141 to support dPMR, DCR and NXDN radios as well as analogue two-way radios.

The new Function Image developed by CML provides a number of features very important to NXDN design, including: a high performance 4FSK data pump supporting soft-decision coding mode (which improves the reliability of the data link) and integrated RRC filters; a high performance, autonomous AFSD that greatly simplifies host microcontroller development and risk, differentiating between frame sync cases, which can also reduce an NXDN receiver's average Rx power consumption; a voice codec (ADC and DAC) for microphone/speaker paths to complement an external AMBE-3000 vocoder device and integrated auxiliary functions that reduce total BOM cost and size.

As an aside, the Chairman of the NXDN Forum recently announced that the NXDN Forum and the dPMR MoU have agreed to collaborate on issues of common interest in the promotion of 6.25 kHz FDMA technology. CML has made available, on its website, a downloadable brochure describing ETSI's role in Digital Private Mobile Radio (dPMR) available in English, French, Italian and Spanish.

[www.cmlmicro.com](http://www.cmlmicro.com) [www.nxdn-forum.com](http://www.nxdn-forum.com) (100639-IV)

## Mobile lighting controller

The AS3676 from austriamicrosystems is a highly Integrated Lighting Management Unit (LMU) with Ambient Light Sensing (ALS) and Dynamic Luminance Scaling (DLS). The chip integrates 13 current sinks, a high-efficiency step-up DC-DC converter and high-power

Advertisement

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# XGAMESTATION

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charge-pump, an analog-to-digital converter (ADC) and a programmable low drop-out regulator (LDO), all incorporated with advanced algorithms for high-efficiency display and keypad backlight, funlight, smartlight and other advanced portable illumination and indication effects.

The integration of the main illumination features facilitates controlling all mobile lighting with a single chip. This simplifies hardware and software development time and shortens time to market. The features and flexibility of the AS3676 make it well suited for a number of portable consumer electronic products, including mobile phones, mobile TV's, mobile DVD players, mobile GPS devices, and MP3 players.

With both ALS and DLS supported by the AS3676, power conservation through automatic adjustment of backlighting and other LED functions is greatly simplified. In addition, built-in features like automatic dimming, pattern

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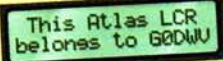
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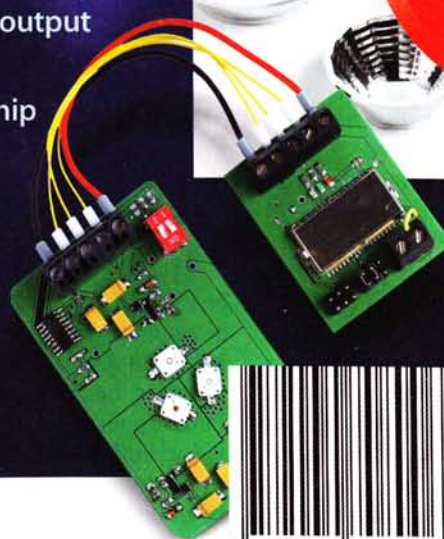
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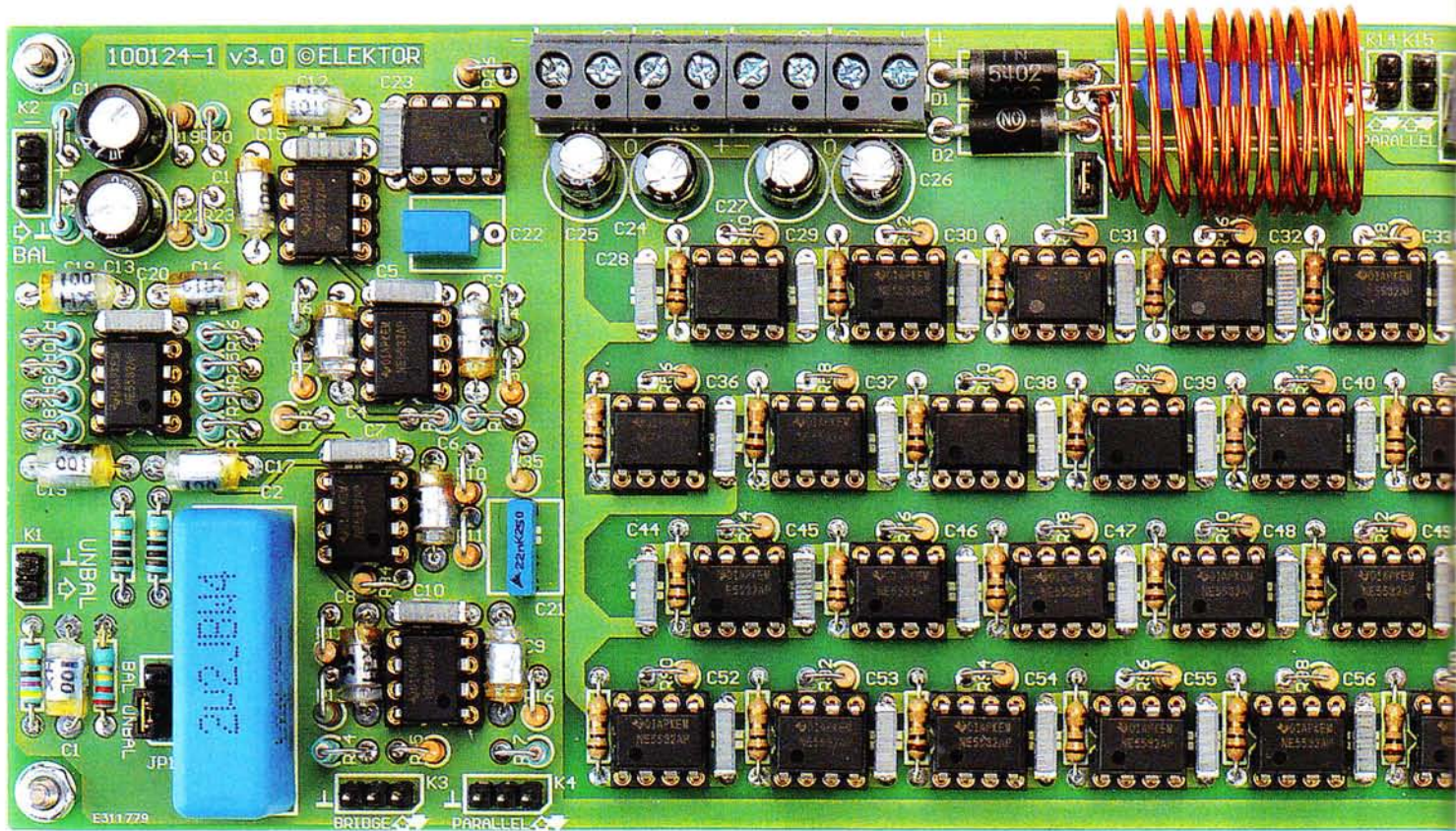


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# The 5532 OpAmp

## Part 1: design philosophy and schematics



By Douglas Self (UK)

The most popular dual opamp in the world of audio is the (NE)5532. An interesting power amplifier can be made by connecting enough 5532s in parallel, how about 32 for a start? This may sound like a radical course of action, but it actually works very well, making it possible to build a very simple amplifier that retains not only the excellent linearity but also the power-supply rejection and the inbuilt overload protection of the 5532, which reduces the external circuitry required to a minimum.

While not exactly a brand-new design, the type (NE)5532 dual operational amplifier (opamp) is a very capable device giving low distortion with good load-driving capabilities, and a remarkably good noise performance. It is only quite recently that better opamps for audio work have become available. While these can give truly outstanding results, the cheapest of them costs ten times more than the 5532, which is available at a remarkably

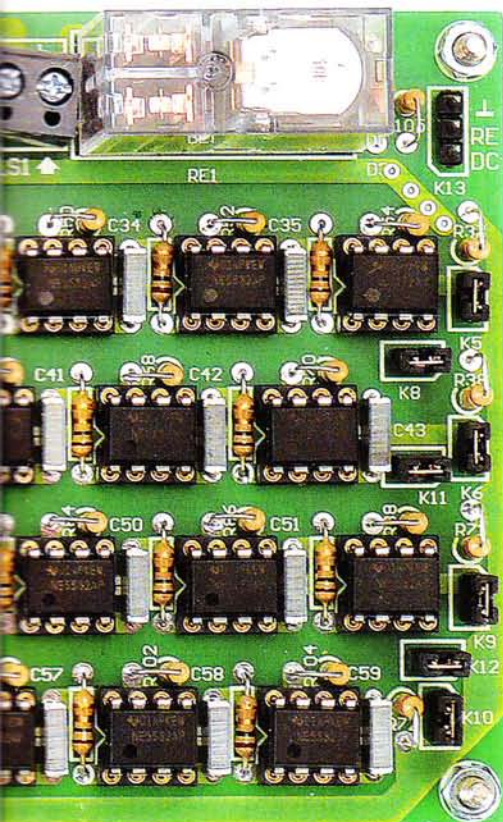
low price — in fact it is one of the cheapest opamps, because it is so widely used in audio applications.

It should be mentioned at once that the obvious limitation with using opamps to drive loudspeakers is that the output voltage swing is limited compared with a conventional power amplifier, and using a single-ended array of 5532s will give about  $15 W_{rms}$  into  $8 \Omega$ . This output can be greatly extended by using two such amplifiers in

bridge mode; one amplifier is driven with an inverted input signal so the voltage difference between the two amplifier outputs will be doubled, and the power output is quadrupled to about  $60 W_{rms}$  into  $8 \Omega$ . This should be enough for most domestic hifi situations.

The other unalterable limit set by the opamps is the maximum output current, set by the internal overload protection. A single 5532 section (one half of the dual package)





## Specification — per channel, 8 ohm load

Supply voltage	±18.3 V	
Input sensitivity	- unbalanced	840 mV (16 W, 1 % THD)
	- balanced	833 mV (16 W, 1 % THD)
Input impedance	- unbalanced	38.8 kΩ
	- balanced	93.6 kΩ
Output power, sinewave	- 0.1 % THD	16 W
	- 1 % THD	16.8 W
Output power bandwidth	1.5 Hz – 275 kHz	
Slew rate	- 5 V/μs	
Rise time	4 μs	
Signal/noise ratio	(1 W ref.)	110 dBa
	- 108 dB (B = 22 Hz – 22 kHz linear/unweighted)	
Harmonic distortion + noise	- 0.0005% (B = 22 kHz, 1 kHz, 1 W)	
	- 0.0009% (B = 80 kHz, 1 kHz, 1 W)	
	- 0.0004% (B = 22 kHz, 1 kHz, 8 W)	
	- 0.0005% (B = 80 kHz, 1 kHz, 8 W)	
	- 0.003 % (B = 80 kHz, 20 kHz, 8 W)	
Intermodulation distortion	- 0.0012% (1 W)	
	- (50 Hz : 7 kHz = 4 : 1) 0.0015% (8 W)	
Dynamic IM distortion	- 0.0011% (1 W)	
	- (3.15 kHz square wave + 15 kHz sine wave)	0.0035% (8 W)
Damping factor	- 194 (1 kHz)	
	- 111 (20 kHz)	
DC-protection	±1.5 V	
Quiescent current	300 mA	

will drive 500 Ω to the full voltage output, though it is advisable to keep the loading lighter than this to maintain low distortion at high levels. If 4 Ω operation is required, twice as many opamps must be used to supply the doubled current demand. This also applies to bridged operation into 8 Ω. The system is designed so that either single-ended or bridged operation can be used; the basic design described here gives a working stereo amplifier with just three PCBs. The amplifier cards can be paralleled without problems, and facilities are provided to connect more PCBs in parallel for driving low-impedance speakers.

Overload protection is inherent in the opamps, but output relays are used for on/off muting and to protect loudspeakers against a DC fault.

### A tour of the design

The schematic in **Figure 1** shows one channel of the complete amplifier, which consists of

unbalanced and balanced line inputs, and the power amplifier itself, which is divided into a +22.7 dB gain stage and an array of paralleled output opamps configured as voltage-followers, giving the maximum amount of negative feedback around them to minimise distortion. Let's have a look at the various sections of the circuit.

#### The unbalanced input

This consists simply of RF filter R1, C1 and DC-drain R2, which are directly connected to the gain stage when JP1 is in the 'unbalanced' position.

#### The balanced input

This amplifier is an innovative design that gives very low noise. The conventional balanced input stage built with four 10 kΩ resistors and a 5532 opamp has a far worse noise performance than a simple unbalanced input, and is also much noisier than most power amplifiers; output noise is approximately -104 dBu. This balanced

amplifier here solves this problem partly by the use of a dual balanced stage (IC5A, IC5B) amplifier that partially cancels the uncorrelated noise from each amplifier, giving a 3 dB noise reduction, and in a similar way improves the CMRR; it also uses much lower resistor values than usual (820 Ω instead of 10 kΩ) which produces less Johnson noise in the first place. This is only possible because it is driven by unity-gain buffers IC4A, IC4B, which also allow the input impedances to be much higher than usual, preventing loading of external equipment and further improving the CMRR. The noise output is less than -112 dBu, an 8 dB improvement over conventional technology.

#### The gain stage

The main input amplifier is another innovative design that achieves very low distortion by spreading the gain required over three stages. +22.7 dB could easily be obtained with one opamp but 5532s are not



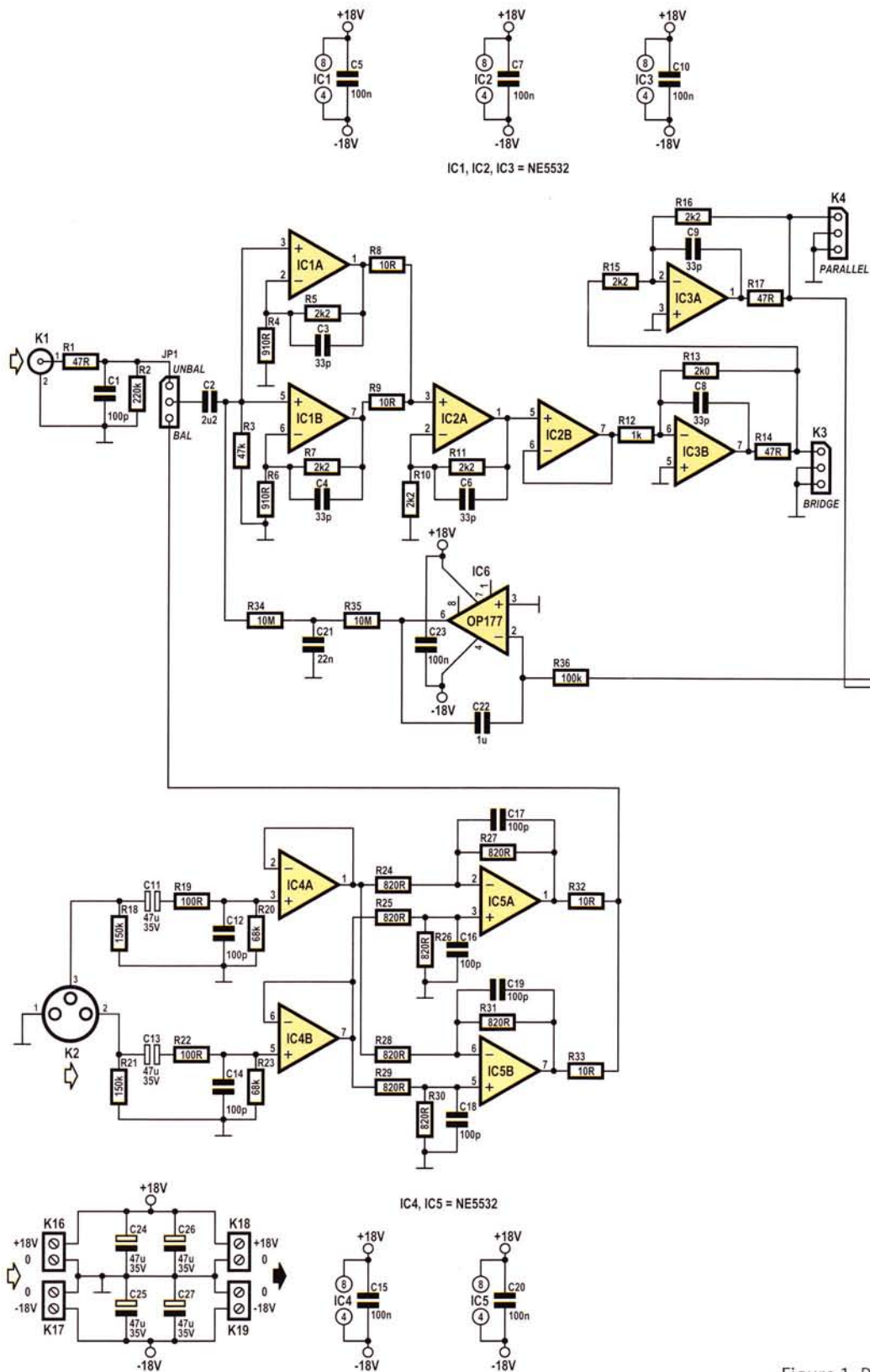
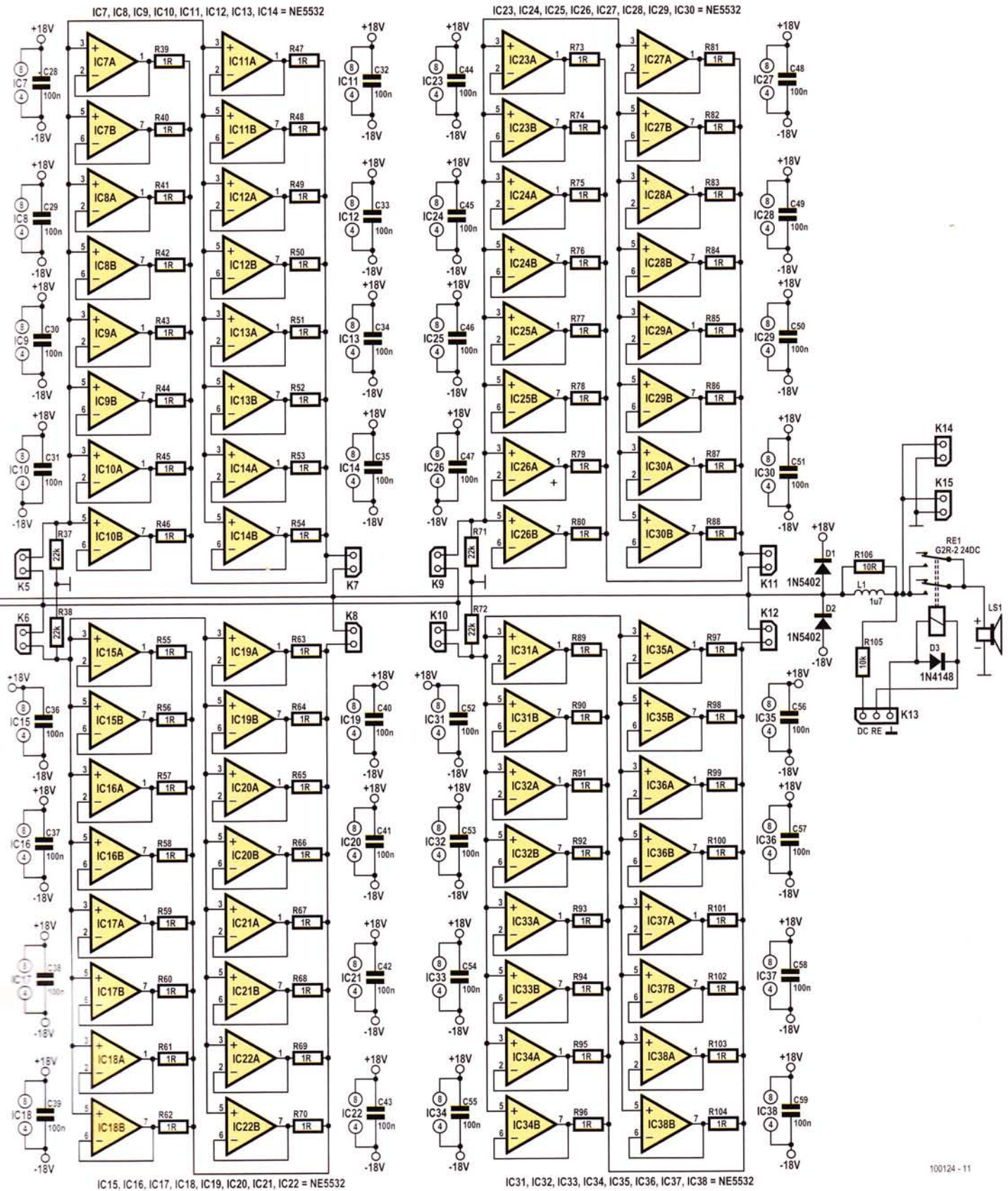


Figure 1. Power is indeed in numbers: circuit diagram of the basic NE5532 audio amplifier (one channel shown).







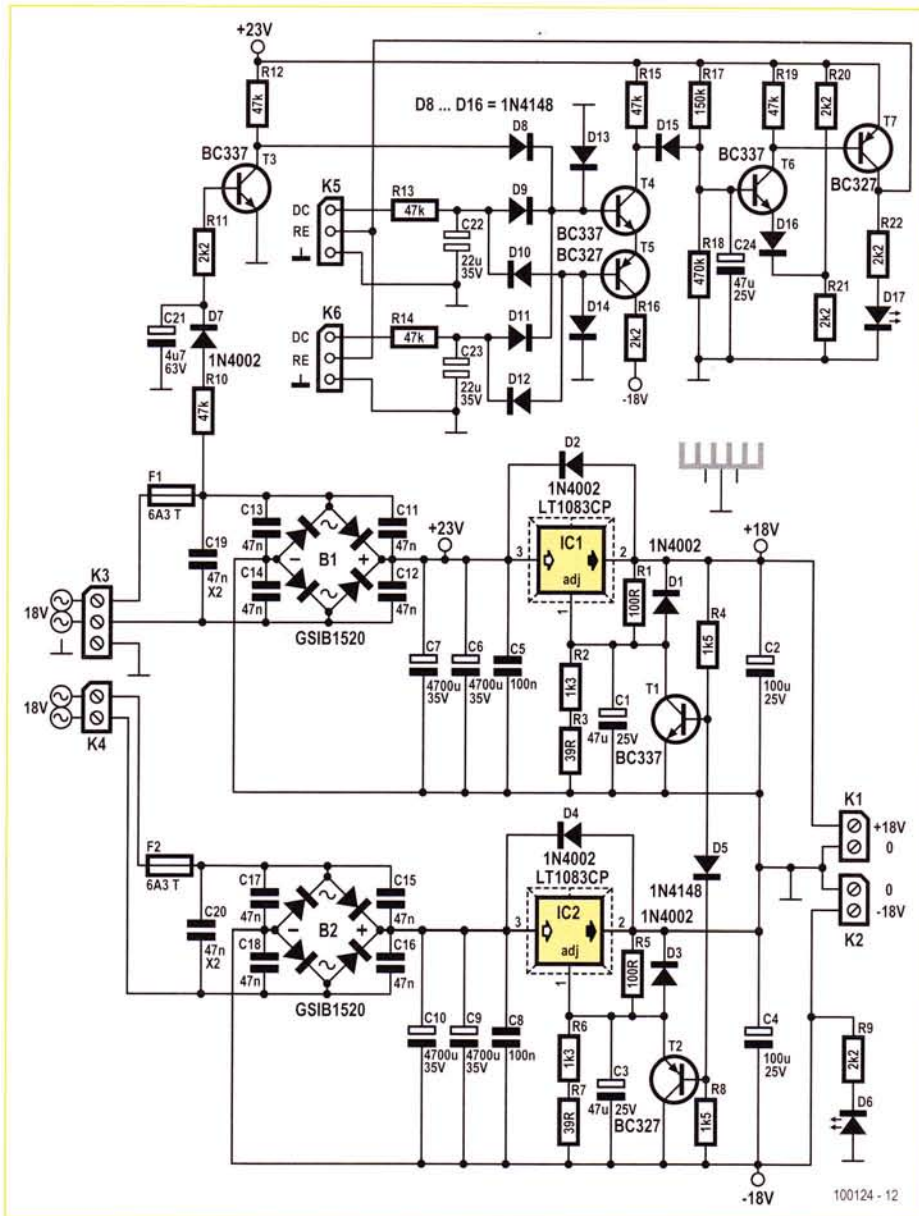


Figure 2. The symmetrical power supply is dimensioned for the 2x15-watt, 8 ohm basic version of the amplifier.

completely distortion-free, and the THD would be significant. The first stage (IC1A, IC1B) gives +10.7 dB of gain; the two outputs are combined by R8, R9 to give a 3 dB noise advantage, as in the balanced amplifier. The second stage IC2A gives +6 dB of gain. The gain is less to maximise negative feedback because the signal level is now higher. IC2B is a unity-gain buffer which prevents the 1 kΩ input impedance of final gain stage IC3B from loading the output of IC2A and causing distortion. IC2B is less vulnerable to loading because it has maximal negative-feedback. IC3B gives the final +6 dB of gain; it is used in shunt-feedback mode to avoid the

common-mode distortion which would otherwise result from the high signal levels here. It has a 'zero-impedance' output, with HF feedback via C8 but LF feedback via R13, so crosstalk is kept to a minimum while maintaining stability with load capacitance. The output at K3 is phase-inverted and can be used for bridging. IC3A is a unity-gain inverting stage which corrects the signal phase. The output is also of the 'zero-impedance' type.

**The power amplifier**

The power amplifier consists of thirty-two 5532 dual opamps (i.e. 64 opamp sections) working as voltage-followers, with their

outputs joined by 1 Ω current-sharing resistors. These combining resistors are outside the 5532 negative-feedback loops, and you might wonder what effect they will have on the output impedance of the amplifier. A low output impedance is always a good thing, but not because of the so-called 'damping factor' which is largely meaningless as the speaker coil resistance always dominates the circuit resistance. 'Damping factor' is defined as load impedance divided by output impedance; we have 64 times 1 Ω resistors in parallel, giving an overall output impedance of 0.0156 Ω. This gives a theoretical damping factor of 8 / 0.0156 = 512, very good by any standards. The wiring to the loudspeaker sockets will have more resistance than this!

The output opamps may be directly soldered into the board to save cost and give better conduction of heat from the opamp package to the copper tracks. However, on the prototype built in the Elektor labs, high quality sockets were used. Having a lot of opamps in parallel could make fault-finding difficult – if there is one bad opamp out of 32 then you are likely to have to do a lot of unsoldering (or IC unplugging) to find it. The opamp array is therefore split up into four sections of eight opamps, which are joined together by jumpers K5–K12, so on average you would only need to unsolder (or pull out) four opamps to find a defective one. In my many years of experience with it the 5532 has proven a very reliable opamp, and I think such failures will be very rare indeed. There is an output choke L1 for stability into capacitive loads, and catching diodes D1–D2 to prevent damage from voltage transients when current-limiting into reactive loads.

**The output relay and its control**

The output mute relay RE1 protects the loudspeakers against a DC offset fault and gives a slow-on, fast-off action so no transients are passed to the loudspeakers at power-up or power-down. The relay is controlled from the power supply board. With reference to **Figure 2**, at power-up R17 charges C24 slowly to give a turn-on delay. In operation C21 is charged and



T3 is on; when the AC power is removed C21 discharges rapidly, T3 turns off, and D8 turns on T4–T5, which discharge C24 and cause the output relay contacts to be opened immediately. Even a brief AC power interruption gives the full turn-on delay. Normally T4 and T5 are off and D15 non-conducting, but if a DC offset fault applies either a positive or negative voltage via R13 or R14, T4–T5 turn on and the relays are opened at once to protect the loudspeakers.

**Power supply**

Again referring to the circuit diagram of the power supply unit in Figure 2, the  $\pm 18\text{ V}$  symmetrical supply is regulated by two type LT1083 TO3-P positive regulators. When a 5532 sees one supply rail disappear, this opamp can get into an abnormal state in

which it draws excessive current. This could obviously be catastrophic with this design, so the PSU incorporates a mutual-shutdown facility which shuts off each supply rail if the other has collapsed due to short-circuiting or any other cause. If the positive rail collapses, T2 turns on and disables the negative supply. If the negative rail collapses, T1 turns on and disables the positive supply.

**Cost**

This project uses quite a lot of 5532s; 37 in each channel, but that does not mean the cost is excessive. In Great Britain, 5532s can be had from Rapid [1] for 24 p each at 100-off (Rapid are prepared to deal with anyone who has a credit card) This means that the cost of all the opamps would be about £18.00.

**To be continued**

Next month's closing instalment will cover approaches to constructing the amplifier on circuit boards, some performance figures obtained from our high-end test equipment, and an outline of challenges to those of you wishing to modify the amplifier for higher output powers and/or lower output impedance. Meanwhile this month's *E-Labs Inside* section has a page or so on issues with electrolytic capacitors encountered while the first prototype of the amplifier was tested.

(100124)

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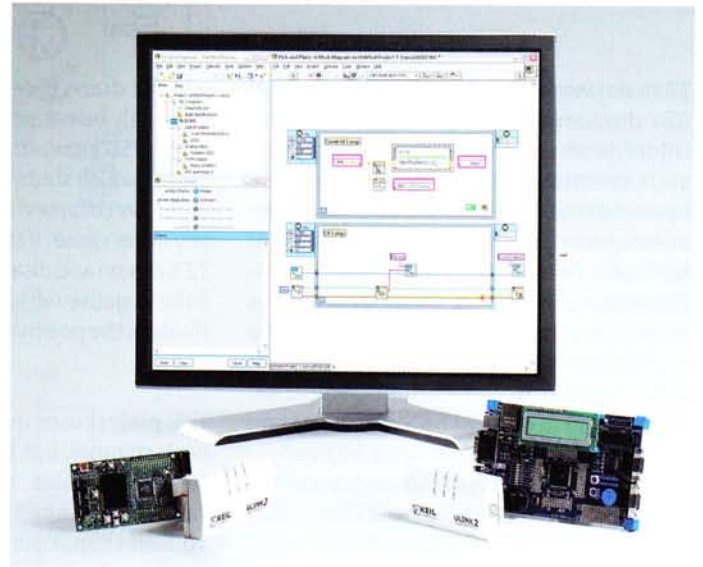
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# LabVIEW Embedded for ARM $\mu$ Cs

Clemens Valens (Elektor France)

If you think LabVIEW can only be used for producing attractive man/machine interfaces for esoteric applications, then this article is for you. If you are interested in easy programming for powerful microcontrollers, then you should read on too. And even if you haven't the least idea what LabVIEW is, don't just turn the page, for it's well worth taking a look at this tool.



LabVIEW is flagship product from National Instruments. Originally designed as a tool for driving measuring benches and displaying data, LabVIEW has evolved a great deal in twenty-odd years and has become a powerful, unique graphic programming language. It's the only tool on the market that makes it possible to develop an application on a computer, FPGA, or microcontroller using the same language and the same programming methods. It's what is known as a multiplatform language.

A program 'written' in LabVIEW Embedded for ARM looks just like any other application written in LabVIEW, with a user interface and a diagram. In the case of an embedded application, the front panel may represent the board's peripherals, like a switch or an LED, but also debugging elements like variables. In LabVIEW Embedded, the user interface is only used for simulating and debugging the application.

To give you an idea just what a LabVIEW for ARM program looks like, take a look at the screen snapshots illustrating this article. It's a very simple application that compares twice the voltage (com-

ing from the potentiometer on the board) with a threshold value. If the value is above this threshold, an LED lights up. The doubled voltage is also sent to the analogue output (don't forget to remove the loudspeaker jumper).

The magenta blocks (**Figure 1**) are the elementary I/Os corresponding to one pin of the microcontroller. LabVIEW offers a number of predefined ones, like the LEDs, but you can add your own — for example, for a relay. The green LED in the diagram is an element that appears on the front panel (**Figure 2**). It mirrors LED1 on the board. On the front panel there are also the 'threshold' and 'output' boxes. These are program variables that are not accessible on the board, but which can be modified or displayed during debugging. The '2' and '100' boxes are constants, and the triangles are mathematical or logic operations.

The large grey rectangle represents a loop (note the arrow at the bottom right-hand corner). Everything within the rectangle is

## What's in the kit?

- DVD-ROM with LabVIEW and the LabVIEW Embedded for ARM module: these are NI tools that let you program an ARM microcontroller board in a graphical fashion.
- Keil  $\mu$ Vision RealView microcontroller development kit: this is a standard integrated development environment (IDE) for programming a microcontroller in C/C++, assembler, etc. The IDE is called  $\mu$ Vision, the toolchain is RealView.
- ULINK2 USB-JTAG adaptor for programming the microcontroller and debugging the application.
- ARM microcontroller evaluation board. There are two models:

the MCB2370U from Keil based on the LPC2378 (ARM7TDMI-S) from NXP, and the EK-LM3S8962 (Cortex-M3), a Texas Instruments thoroughbred.

- Instructions and two USB cables.

Price of the kit as shown: € 8,949

For more details: [www.ni.com/arm](http://www.ni.com/arm)

LabVIEW Embedded also exists for PSD and for 32-bit microprocessors.



## LabVIEW, $\mu$ Vision & RTM

$\mu$ Vision RealView can be implemented without LabVIEW and makes it possible to develop applications for other boards or your own hardware using an ARM  $\mu$ C in the 'traditional' way. At the time of writing, RealView supported over 260 processors with ARM7, ARM9, or Cortex-M3 cores. The kit includes a time-unlimited licence with one year's technical support from Keil (renewable).

LabVIEW Embedded for ARM, on the other hand, requires use of  $\mu$ Vision (supplied with the kit), except in simulation mode. The link

between LabVIEW for ARM and  $\mu$ Vision is RTM from Keil, a real-time operating system for microcontrollers. The program in LabVIEW is translated into a program in C which relies heavily on RTM. This is the program that is compiled by RealView into an executable for the microcontroller. Without the RTM libraries (or compatible ones, all you have to do is write them...), it won't work. Note that the source codes for your LabVIEW program translated into C are accessible for inspection.

repeated until the loop is ended. Here the loop never ends, since the stop condition (the red hexagon) is closed by the green box containing the value 'False', where a value of 'True' is needed to exit the loop. The loop is clocked by the little metronome, which operates in such a way that it is run every 100 ms.

LabVIEW is multitasking, which explains why the real-time operat-

tool (part of the GNU toolchain for ARM, not LabVIEW) gives a size of just over 34 KB. An application consisting of just an empty infinite loop produces a 14 KB executable and the compilation time is just as long.

Of course, LabVIEW Embedded's real interest is for more com-

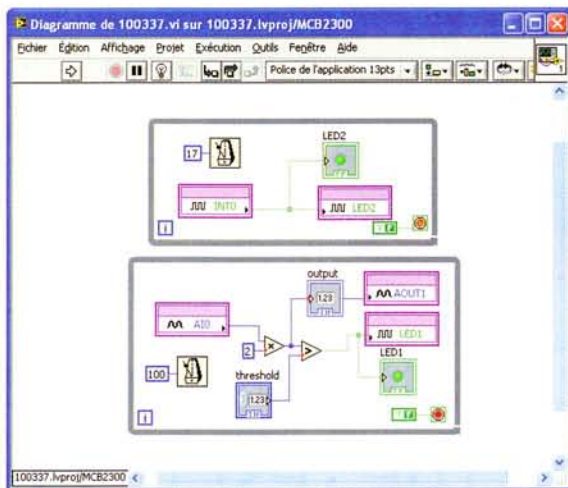


Figure 1. Diagram for the test application.



Figure 2. The test application user interface during debugging.

ing system from Keil (see box) is needed to produce the executable for the microcontroller. To illustrate this multitasking aspect, a second loop has been added which continually interrogates the board's push-button and which lights LED2 when the button is pressed. The two loops run independently of each other. Compiling this simple application takes an astonishingly long time – over a minute on the test computer (even though it's a fairly recent laptop: Intel Pentium T4200 @ 2 GHz, 4 GB RAM, Windows XP Pro SP3). This is due to the C compiler, which has a large number of files to process. The executable produced is in ELF format. The 'arm-elf-size'

### Remember the right-click!

The fact that LabVIEW is a graphical programming language doesn't mean it is child's play, even though NI has gone to great lengths to explain everything properly. So do make sure you read the short instructions supplied in the kit, and don't forget that a right-click can be helpful at all times.

plex applications. A large number of functions (PSD, TCP/IP, serial port, maths, etc.) are available and ready to use. If you're short of a function, you can create it yourself or import it via a third-party DLL (your own, for example). LabVIEW Embedded can be adapted to your hardware; the evaluation board included in the kit is just one example. Once you've mastered LabVIEW Embedded, you have an extremely powerful tool at your disposal. However, do make sure you use a powerful computer, otherwise the time you've saved in programming will be wasted waiting for it to compile.

(100337)



# Measure That Current!



## Twenty AC/DC clamp meters on the test bench

By Harry Baggen (Elektor Netherlands Editorial)

Everyone who has anything to do with electronics has at least a multimeter at home and on the work table. But what about a clamp meter? These instruments are often just as versatile as multimeters, and they aren't limited to currents of a few amperes. They also don't need to cost much more than a multimeter. Here we examine the features of twenty clamp meters suitable for measuring AC and DC current, in price classes from a few dozen pounds to several hundred pounds.

If you ask an electronics enthusiast whether he or she has a clamp meter, the usual response is that they're more suitable for electrical installers and service technicians. Nevertheless, in many cases a clamp meter can be just as useful as a multimeter — and often even more useful. The current measuring range of most multimeters is limited

to 10 A, which means you need to be careful that you don't exceed the maximum current rating and blow the fuse for the 10-A range or burn out the sense resistor. At the same time, we see more and more circuits that draw hefty currents, and this involves more than just measuring the input currents of household appliances or other

devices connected to the AC grid. Modern clamp meters, which are also able to measure DC currents, open up a wealth of new possibilities. For example, you can measure the starter motor current in a car, measure how much current an electric motor in a model aeroplane draws from the battery, or measure how much current the CPU on the



motherboard of your computer guzzles. A multimeter is not really designed to handle any of these tasks, but a clamp meter simply takes them in stride.

### Available products

While looking through the catalogues of instrument suppliers, we quickly noticed that an enormous variety of clamp meters is available. Some manufacturers have more clamp meters than multimeters in their catalogues. This suggests that there is a large demand for these meters, the majority of which are most likely used in the electrical industry. However, as we already mentioned, modern clamp meters are so versatile that they are also very attractive for all sorts of electronics applications. For instance, many modern clamp meters can measure DC current in addition to AC current, and most of them can also make many other types of measurements. For example, the group of meters we examined includes models that can measure capacitance, frequency and temperature as well as voltage and resistance. This makes them full-fledged substitutes for a multimeter. The main advantage is that they allow you to measure much larger currents, ranging from 100 to 1000 A, so you don't have to be constantly afraid of blowing a fuse or burning out a resistor in your meter.

We did our best to select meters in various price classes from the enormous variety of available instruments. All of the selected meters can measure AC and DC current, and they are also suitable for measuring relatively small currents in the low ampere range. We also included a few clamp-on current probes (also with combined AC/DC capability), which do not have their own display but can be connected to an existing multimeter or to an oscilloscope.

### Operation

The mechanical construction of a clamp meter is very similar to that of a power transformer. The jaws or yoke of the meter usually consist of a laminated metal core with a circular or elliptical shape, which is divided into two parts so the jaws can be opened and the conductor to be measured

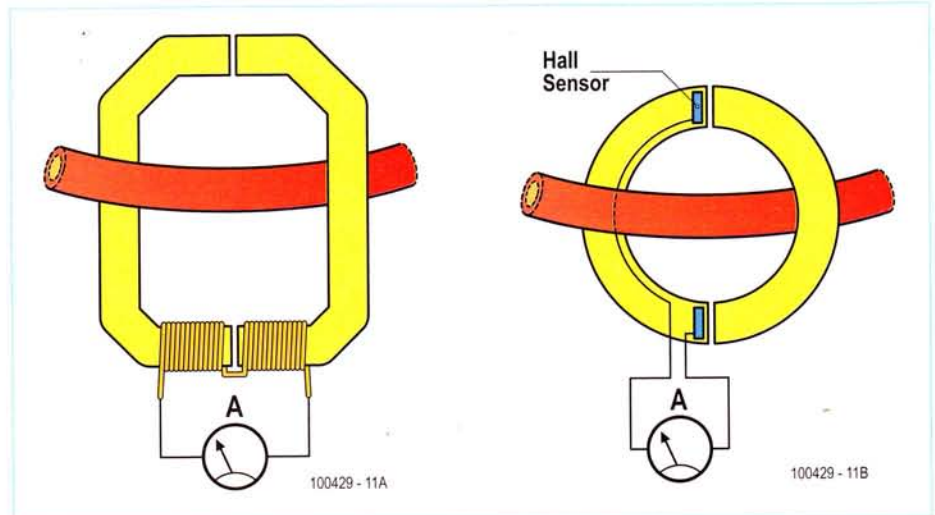


Figure 1. Operating principle of a clamp meter: a transformer with primary and secondary windings (a). In most modern meters, the secondary winding is replaced by one or two Hall sensors (b).

can be positioned inside the core. When a current flows through the conductor, it induces a magnetic field, and the laminated core conveys this field to a small measuring coil (with several turns) that is wound on the core (see Figure 1a). The strength of the current flowing through this secondary winding can be read from a meter connected to the measuring coil. The amount of current flowing through the primary conductor can be determined from the winding ratio of the two coils.

In most modern clamp meters, the measuring coil is replaced by a Hall sensor (a semiconductor device that is sensitive to mag-

netic fields). Depending on the design and the accuracy of the meter, one or two Hall sensors are placed in the air gaps between the two parts of the laminated core (Figure 1b). The voltage generated by the Hall sensor is directly proportional to the strength of the magnetic field produced by the current in the measured conductor.

In this way, clamp meters provide a simple and safe means to measure relatively large currents. Furthermore, meters that use Hall sensors are able to measure both AC and DC currents, and the latter capability is especially interesting for electronics enthusiasts.



Figure 2. A pair of Hall sensors are clearly visible in the air gaps between the jaws of this Fluke clamp meter.



Figure 4. Clamp meters are complex instruments with many adjustment points. We counted around 15 trimpots in this model.



## CLAMP METERS

### Agilent U1213A

A large, professional clamp meter with jaws big enough for 2-inch cables. Many extra features, including frequency and duty cycle measurement, as well as simultaneous read-out of AC and DC current or voltage on the dual display, which also has a bar scale. Many basic settings can be configured in a separate menu. Includes case and probes.



### Appa 30R

Handy, robustly built small clamp meter with all the basic functions but no extras. Suitable for conductors up to around 20 mm. The Peak/Hold button function must be selected before switch-on, which isn't very convenient. The 'True RMS' designation on the device does not match the description in the user guide. Includes carrying case and probes.



### Benning CM2

Dark red, handy, robustly built small clamp meter with all the basic functions, but no extra functions other than voltage and resistance. The Peak/ Hold button function must be selected before switch-on, which isn't very convenient. Clearly written multi-lingual user guide. Supplied with carrying case and probes.



### ELV ST-9700T

Small clamp meter with relatively large jaws. With regard to the mechanical construction, we noticed that the display window can be pressed in quite easily. The only clamp meter in the group without autoranging or auto shut-off. Separate on/off switch. Supplied with a temperature sensor, carrying case and probes.



### Extech EX613

Hefty, bright orange meter with capped inputs. Many extra features, including capacitance measurement, frequency measurement up to 100 MHz, and separate inputs for two type K thermocouples (included). Built-in voltage detector for AC power voltage. Probes and carrying case included.



### Fluke 355

This heavy-duty clamp meter, suitable for currents up to 2000 A, is the benchmark device for this survey. The large dual display can show the frequency of the measured signal at the same time as the measured value. Built-in low-pass filter to eliminate HF interference. Extensive calibration report, case and probes included.





**HT9021**

Hefty, robustly built clamp meter with large jaws, from the Italian make HT. Clear display with a supplementary bar scale for monitoring voltage trends. Many measuring options plus a built-in contactless voltage detector. Suitable for voltages up to 1000 V. Temperature sensor, carrying case and probes included.

**Kyoritsu 2300R**

Handy, small clamp meter designed exclusively for measuring currents up to 100 A. A special feature of this clamp meter is the open jaws, which allow it to be easily fitted over a conductor (up to 1 cm diameter). Built-in contactless voltage detector for locating live power grid wiring. With carrying case.

**Kyoritsu 2046R**

Sturdy professional clamp meter with large jaws and many functions, including voltage, resistance, capacitance, frequency and duty cycle. Large, clear display with a bar scale. Built-in contactless voltage detector for AC grid voltage. Supplied with carrying case and probes.

**Mastech MS2102**

Handy meter with fairly large jaws fitted to a well finished and sturdy housing (relative to the low price). The display is fairly small but easy to read, and it has a bar scale for monitoring voltage trends. Pity that it doesn't have a Peak button. Carrying case and probes included.

**Megger DCM340**

Sturdy meter with large jaws, fits nicely in the hand. Clear display with digital indicator and analogue scale. Unlike most of the other meters, this one has separate buttons for the extra functions, which is particularly convenient. Very succinct user guide. Supplied with case and probes.

**Metrix MX675**

Hefty, robust professional meter with large jaws, suitable for thick conductors. Large dual display, which can show current and voltage, frequency and voltage, or current and frequency at the same time. Simultaneous temperature display in °C and °F. Temperature sensor, carrying case and probes included.





## CLAMP METERS

### Multimetrix CM 605

Simple, handy meter with fairly small jaws (1.2 cm maximum), suitable for measuring relatively low currents up to 100 A. The lowest range is 10 A, so even low currents can be measured reasonably well. Analogue voltage output for displaying AC and DC current signals on an oscilloscope. Probes and carrying case included.



### Peaktech 1615

Hefty clamp meter with large display and substantial jaws with enough room for relatively large conductors. Many extra functions, including frequency, duty cycle and capacitance measurement. Autoranging can be disabled. Unfortunately, there is no button for peak readings. Temperature sensor, carrying case and probes included.



### Peaktech 1645

Handy, small clamp meter with reasonably large jaws for conductors up to approximately 1.5 cm. Operation somewhat clumsy with rotary knob and button. Supplementary bar scale on display for monitoring signal variations. Built-in pocket torch and voltage detector for AC power voltages. Supplied with probes and carrying case.



### Velleman DCM268N

Hefty clamp meter with large display and substantial jaws suitable for conductors up to 30 mm. Various extra functions, including frequency and capacitance measurement. Clear display with a supplementary bar scale for monitoring voltage trends. Plastic case, temperature sensor and probes included.



### Velleman DCM270

Small, simple clamp meter limited to measuring DC and AC currents up to 80 A; no autoranging. Cannot measure voltage or resistance. Built-in pocket torch and contactless AC power voltage detector. Supplied with carrying case.



### Voltcraft VC-521

Small, handy instrument for hobby use; rotary switch does not feel especially sturdy. The least expensive clamp meter in this survey, with a large number of measuring functions including frequency, duty cycle and capacitance. Built-in voltage detector for AC power voltage. Carrying case, probes and temperature sensor included.





**Practical test and lab test**

We tested all of the meters in a number of practical situations, such as measuring the current draw by an electric motor in a model aeroplane and the starter current of a car. These tests revealed that a peak function is especially handy (see tables). We also compared the clamp meters with each other in a test setup that generated reference currents of 10 A and 40 A. All clamp meters are suitable for use with these current levels.

The resolution of the meters at these current levels is 10 or 100 mA, whereby we must immediately mention that residual magnetism in the measuring circuit can easily cause errors of the same order of magnitude with DC currents. For this reason, it is important to zero the meter immediately before making each DC current measurement. Naturally, this problem does not arise with AC currents.

For both DC and AC, the accuracy of all of the clamp meters at the current levels used in the tests (or the maximum current if the measuring range was smaller) was within the tolerance specified by the manufacturer (1 to 3%). We expected nothing less from the more expensive meters, such as the Agilent U1213A, Fluke 355 and Metrix M675, and they were in fact well within their stated specs, but we were pleasantly surprised

Features	Agilent U1213A	Appa 30R	Benning CM2	ELV ST-9700T	Extech EX613	Fluke 355	HT 9021	Kyoritsu 2300R	Kyoritsu 2046R
Price	£270 +VAT	£175	£117	£82	£137	£535 +VAT	£ 290 +VAT	£120 +VAT	£220 +VAT
AC A	1000 A	300 A	300 A	600 A	400 A	2000 A	1000 A	100 A	600 A
Basic accuracy	±2%+5dgt	±1%+3dgt	±1%+3dgt	±3%+4dgt	±1.5%+5dgt	±1.5%+5dgt	±2.2%+8dgt	±2%+5dgt	±2%+5dgt
DCA	1000 A	300 A	300 A	600 A	400 A	2000 A	1000 A	100 A	600 A
Basic accuracy	±1.5%+3dgt	±1%+2dgt	±1%+2dgt	±3%+6dgt	±1.5%+5dgt	±1.5%+5dgt	±2%+8dgt	±2%+5dgt	±1.5%+5dgt
AC V	1000 V	600 V	600 V	600 V	600 V	1000 V	1000 V	-	600 V
Basic accuracy	±1%+5dgt	±1.5%+5dgt	±1.5%+5dgt	±1.5%+3dgt	±2%+5dgt	±1%+5dgt	±1%+4dgt	-	±1.5%+5dgt
DC V	1000 V	600 V	600 V	200 V	600 V	1000 V	1000 V	-	600 V
Basic accuracy	±1%+2dgt	±0.5%+2dgt	±0.5%+2dgt	±1%+2dgt	±0.1%+2dgt	±1%+5dgt	±1%+3dgt	-	±1%+5dgt
Resistance range	40 MΩ	40 MΩ	40 MΩ	2 kΩ	40 MΩ	400 kΩ	60 MΩ	-	60 MΩ
Continuity tester	< 10 Ω	< 50 Ω	< 50 Ω	< 25 Ω	< 50 Ω	< 30 Ω	< 50 Ω	-	< 100 Ω
Max. conductor dia.	48 mm	22 mm	22 mm	30 mm	33 mm	60 mm	42 mm	10 mm	33 mm
True RMS	X	-	-	X	X	X	X	X	X
Autoranging	X (selectable)	X	X	-	X (selectable)	X (selectable)	X (selectable)	-	X
Auto shut-off	15 min./X	30 min./-	30 min./-	30 min./-	30 min./X	20 min./X	15 min./X	10 min./-	15 min./-
Peak/Δ Zero	X/X	X/X	X/X	-/X	X/X	X/X	X/X	-/X	X/X
Min/Max/Hold	X/X/X	-/-/X	-/-/X	-/-/X	X/X/X	X/X/X	X/X/X	-/-/X	X/X/X
Display/backlight	3-3/4 digits/X	3-3/4 digits/-	3-3/4 digits/-	3-1/2 digits/-	4-3/4 digits/X	3-3/4 digits/X	3-3/4 digits/X	3-1/2 digits/-	3-5/6 digits/-
Freq. measurement	X (1 MHz)	-	-	-	X (100 MHz)	X (1 kHz)	X (60 kHz)	-	X
Temp. measurement	X	-	-	X	X (dual)	-	X	-	X
Extras	Dual display Bar scale Duty cycle Capacitance measurement				Dual display Duty cycle Capacitance measurement µA range	Dual display Internal low-pass filter	Bar scale Duty cycle Capacitance measurement	Open jaws	Bar scale Duty cycle Capacitance measurement



# CLAMP METERS

Features	Mastech MS2102	Megger DCM340	Metrix MX675	Multimetrix CM605	PeakTech 1615	PeakTech 1645	Velleman DCM268N	Velleman DCM270	Voltcraft VC-521
Price	£50	£155 +VAT	£250 +VAT	£135 +VAT	£73	£76	£105	£66	£47
AC A	400 A	600 A	1000 A	100 A	1000 A	200 A	1000 A	80 A	400 A
Basic accuracy	±2%+5dgt	±1.5%+5dgt	±1.5%+5dgt	±2%+10dgt	±3%+5dgt	±2.5%+8dgt	±2.8%+8dgt	±2.8%+8dgt	±2.5%+10dgt
DC A	400 A	600 A	1400 A	100 A	1000 A	200 A	1000 A	800 A	400 A
Basic accuracy	±2.5%+5dgt	±1.2%+5dgt	±1.2%+5dgt	±2.5%+10dgt	±2.8%+5dgt	±2%+5dgt	±2.8%+8dgt	±2.8%+8dgt	±2.5%+10dgt
AC V	600 V	600 V	1000 V	600 V	600 V	600 V	600 V	-	600 V
Basic accuracy	±1.5%+5dgt	±1%+5dgt	±1%+5dgt	±1.5%+5dgt	±1.8%+5dgt	±1.5%+8dgt	±1.5%+8dgt	-	±2%+8dgt
DC V	600 V	600 V	1400 V	600 V	600 V	600 V	600 V	-	600 V
Basic accuracy	±1%+5dgt	±0.7%+2dgt	±1%+2dgt	±1%+5dgt	±1.5%+3dgt	±1%+2dgt	±0.8%+2dgt	-	±1.5%+5dgt
Resistance range	400 Ω	400 Ω	10 kΩ	10 kΩ	40 MΩ	1 kΩ	40 MΩ	-	40 MΩ
Continuity tester	< 40 Ω	< 30 Ω	< 35 Ω	< 100 Ω	< 100 Ω	< 30 Ω	< 35 Ω	-	< 100 Ω
Max. conductor dia.	28 mm	36 mm	40 mm	12 mm	30 mm	16 mm	30 mm	16 mm	30 mm
True RMS	-	-	X	-	-	X	X	-	-
Autoranging	X (selectable)	X	X	X	X (selectable)	X	X	-	X
Auto shut-off	30 min./X	30 min./X	10 min./X	30 min./X	35 min./-	10 min./-	20 min./-	7 min./-	30 min./-
Peak/Δ Zero	-/X	X/X	X/X	X/X	-/X	X/X	X/X	-/X	-/X
Min/Max/Hold	-/-/X	X/X/X	X/X/X	-/-/X	-/-/X	X/X/X	X/X/X	-/-/X	-/-/X
Display/backlight	3-3/4 digits/X	3-3/4 digits/X	4 digits/X	4 digits/-	3-3/4 digits/X	3-5/6 digits/X	3-3/4 digits/X	3-2/3 digits/-	3-3/4 digits/-
Freq. measurement	-	X (400 Hz)	X (10 kHz)	-	X (100 kHz)	-	X (4 kHz)	-	X (10 kHz)
Temp. measurement	-	-	X (in °C and °F)	-	X	-	X	-	X
Extras	Bar scale	Bar scale	Dual display	Analogue output for AC/DC A	Capacitance measurement Duty cycle	Bar scale	Bar scale Capacitance measurement		Capacitance measurement Duty cycle

by the accuracy of the inexpensive models, such as Mastech and Voltcraft.

All clamp meters are suitable for AC measurements at 50 or 60 Hz (AC power). Most clamp meters can also measure currents at somewhat higher frequencies, extending as far as a few hundred hertz. Accuracy degrades quickly at even higher frequencies. Only a few expensive clamp meters can do better. For example, the Fluke i30 is specified for AC current measurement up to more than 20 kHz.

If you need to measure AC currents with highly non-sinusoidal waveforms, such as currents in phase-control devices, it's a good idea to select a clamp meter with true RMS capability, since it will deliver more accurate readings.

## The choice is yours

A large variety of products are available; the prices of the clamp meters described here range from around 50 pounds to 750 pounds. Which one should you choose? Just as with multimeters, the prices of clamp meters are not determined by the manufacturing cost alone, but also depend on the guaranteed accuracy, whether they have been formally calibrated, and the level of technical support. These are all matters that are primarily significant for professional use, and for hobby use you should primarily look for an affordable instrument with many features. Absolute accuracy and



formal calibration are of secondary importance for hobby use.

Among the selected meters, we noticed striking similarities between clamp meters of different makes, which were most likely purchased from the same manufacturer in Asia. This similarity is especially clear with the Appa 30R and the Benning CM2, which are simply the same clamp meter with different colours. The specifications are also identical.

With the clamp meters priced under 100 pounds, we noticed that the mechanical finishing sometimes leaves something to be desired, and in some cases we wondered how long the rotary or slide switches would last. If we assume that hobbyists won't make especially intensive use of a clamp meter, the Voltcraft VC-521 and the Mastech MS2102 provide all the basic features at a low price, and the latter in particular has fairly good construction. Unfortunately, they both lack a peak function, which is a very handy feature with a clamp meter.

If you want a somewhat sturdier and more reliable clamp meter, you need to spend a bit more. The Extech EX613 is the most versatile instrument in the moderate price range, and it can do practically anything a normal multimeter can do. The HT 9021, Kyoritsu 2046R and Megger DCM340 are accurate, good and sound instruments, but somewhat less versatile. If you really want to have a properly calibrated instrument you can rely on, your only real choice is the Metrix MX675 or the Agilent U1213A, with the latter offering a lot of features for its price. We intentionally left the Fluke 355 out of the picture, since it is in a class by itself and serves here as a benchmark for all the other meters we examined.

(100429-I)

## Clamp-on current probes



If you only occasionally need to make current measurements or observe current waveforms, a good alternative is a clamp-on current probe, which can be connected to a multimeter or an oscilloscope. The CA60 from ELV Germany is an affordable model, priced at about 60 pounds. It has two measuring ranges, so sufficient output voltage is available even with relatively low currents. The Fluke i30 is clearly intended for professional users. This device is also well suited to measuring relatively low currents, with a measuring range extending to 20 A. The i30 is supplied with a calibration report.

	ELV CA60	Fluke i30
Price	£59	£280 VAT
AC/DC A	60 A	20 A
Basic accuracy	$\pm 1.5\% \pm 5\text{mA}$ (DC) $\pm 2\% \pm 5\text{mA}$ (AC)	$\pm 1\% \pm 2\text{mA}$
Load resistance	> 10 k $\Omega$	> 10 k $\Omega$
Max. conductor dia.	9 mm	19 mm
Output sensitivity	100 mV/A 10 mV/A	100 mV/A
Special features	2 measuring ranges	Available with banana plugs or BNC connector (S version)

### The following suppliers and/or manufacturers kindly made products available for this article:

Agilent: [www.agilent.com](http://www.agilent.com), [www.bfiptilas.com](http://www.bfiptilas.com)

Appa: [www.appatech.com](http://www.appatech.com), Velleman: [www.velleman.be](http://www.velleman.be)

Benning: [www.benning.de](http://www.benning.de), Peaktech: [www.peaktech.de](http://www.peaktech.de)

ELV: [www.elv.de](http://www.elv.de)

Extech: [www.extech.com](http://www.extech.com), Voltcraft: [www.conrad.nl](http://www.conrad.nl)

Fluke: [www.fluke.com](http://www.fluke.com)

HT: [www.htitalia.it](http://www.htitalia.it), Megger: [www.megger.com](http://www.megger.com)

Kyoritsu (Kewtech): [www.kew-ltd.co.jp/en/](http://www.kew-ltd.co.jp/en/)

Mastech: [www.p-mastech.com](http://www.p-mastech.com)

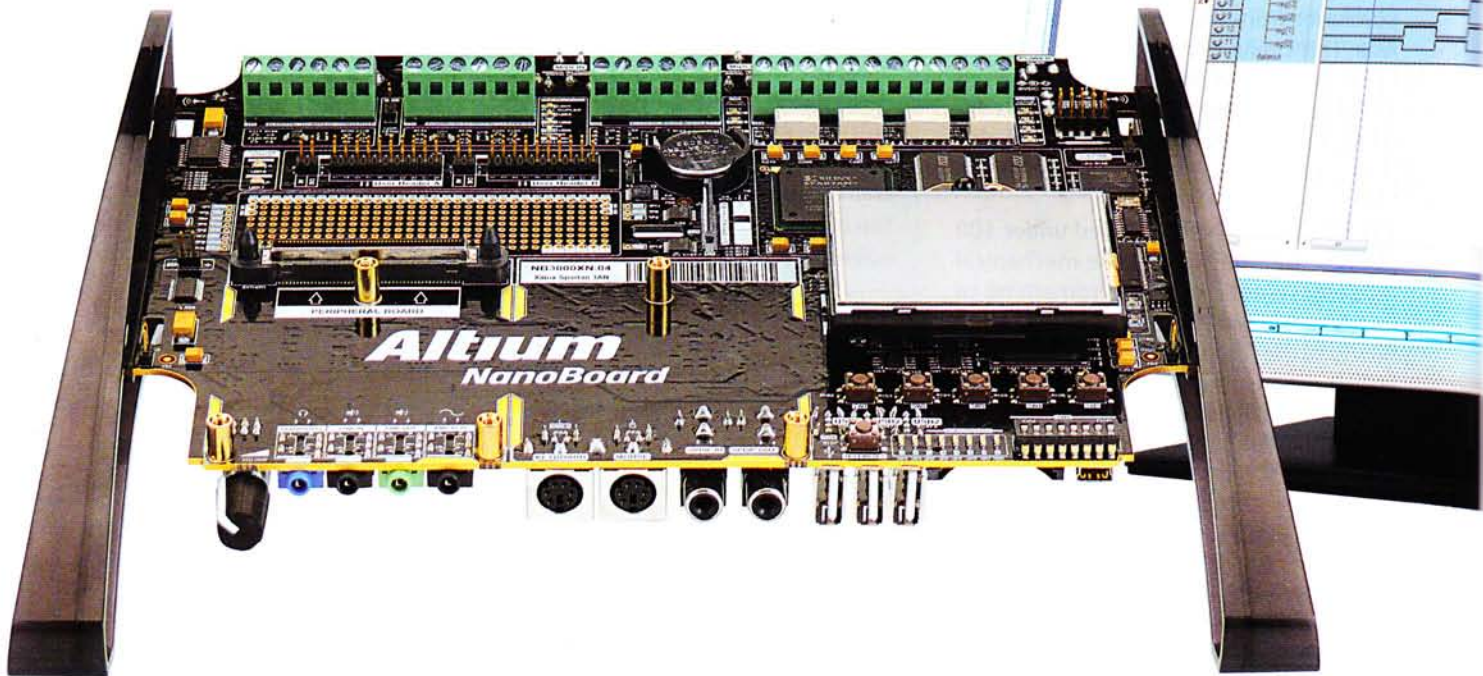
Metrix, Multimetrix ([www.chauvin-arnoux.com](http://www.chauvin-arnoux.com))



# FPGA Design Simulation

## With Quartus Web Edition and ModelSim Altera Edition

By Paul Goossens (The Netherlands)



Simulations are an important part of circuit design. Circuits built with 'ordinary' components can be simulated quite well with conventional simulation packages, but as soon as you add complex digital logic to give your circuit a bit of intelligence, most conventional simulators are no longer up to the task. In such cases, it's necessary to use an emulator to mimic the behaviour of the logic system.

Whenever you use an FPGA in a design, you're dealing with more than just hardware. An FPGA needs an internal design in order to do something useful. In a manner of speaking, you personally assemble the hardware inside the FPGA. You need special software to generate the FPGA design; this software is usually provided by the FPGA manufacturer. Special software is also available for simulating the internal design.

Many FPGA manufacturers offer a free version of their professional simulation program, which has certain minor limitations compared to the full version. For instance, there may be a limit on the maximum number of lines of code you can use, and in many cases the simulation is slower than usual. The simulation software discussed in this article has a built-in limit of 10,000 lines of code. However, a design

with more than 10,000 lines of code is a rather large design. Even with this restriction, you can still use the software if you split your design into several smaller parts. You can then test these parts one at a time.

### Software

For the examples described in this article, we used software that is available free of charge on the Altera website: Quartus Web Edition and ModelSim Altera Edition. First we'll look at what you can do with Quartus. In addition to generating designs, this package allows you to simulate designs on a small scale. Incidentally, there are also other FPGA manufacturers that offer free simulation packages for their devices. For the truly demanding user, there is a broad selection of VHDL, Verilog and mixed HDL simulators available.





### Basic aspects

A basic consideration with FPGA design simulation is that you are limited to digital simulation. With digital simulation, you have to connect your design to test code that provides the test signals for the design. You can view the output signals from the design under test in a window that strongly resembles a software logic analyser, but first you need to generate suitable input signals. With the simulator included in the Quartus package, you can use a graphic interface to draw the waveforms of these signals. After all the signals have been defined, you can start the simulation, which causes the signals you just defined to be applied to the inputs of the design.

You can choose from two options for running a simulation. The first option is a functional simulation, which ignores the propagation delays inside the FPGA. This yields clearly defined results with ideal signal behaviour. The major advantage of this type of simulation is that it only requires compilation of the design, so you can ignore the place and route, optimisation and timing closure functions. This saves a lot of time with relatively large designs. Figure 1 shows the results of a functional simulation, based on a design for a simple shift register with only one output. You can see that the signal level on the output and the state of the internal register both change on the rising edge of the clock signal. This contrasts with Figure 2, which shows the results of simulating the same circuit

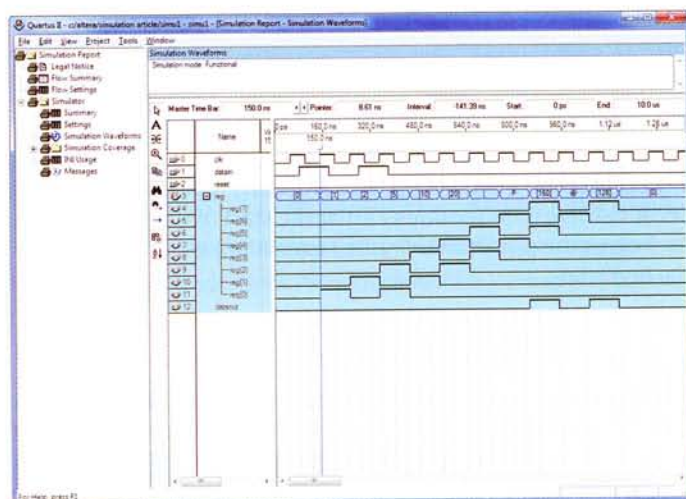


Figure 1. Results of a functional simulation of a simple shift register design with one output.

with the second option: timing simulation. This type of simulation additionally takes the internal propagation delays of the FPGA into account. You have to zoom in to a high magnification factor in order to see the difference. Then you can see that the delay between the rising edge of the clock signal and the time when the output signal changes state is 6.006 nanoseconds. Is this fast or slow? The answer depends on how fast your design needs to be.

### Optimisation

One of the first pitfalls you encounter with a timing simulation is that sometimes one or more signals are not visible in the simulation, even though they are visible in the functional simulation. Why do these signals disappear? This usually results from design optimisation by the software. Remember that the design only needs to be compiled for a functional simulation, but several additional steps are performed with a timing simulation, with a large number of design optimisations being made in the process. One of the consequences may be that a particular signal is no longer present in the FPGA.

If you need this signal for your analysis, you can connect it to an additional output of your design. When you do this, the software will think that this signal must be physically present at an output pin, so the optimisation process will not eliminate the signal. However, this may significantly alter the timing of the end result.

It's nice to know that the optimisations never change the functionality of the design, so the design will not suddenly exhibit errors due to optimisation. However, it will take up less space in the FPGA, and it will most likely run a good deal faster.

### More oomph

As already mentioned, the built-in simulator of Quartus is very easy to use. The downside of this is that it has only limited capabilities. If you need something more powerful, you can use ModelSim. The

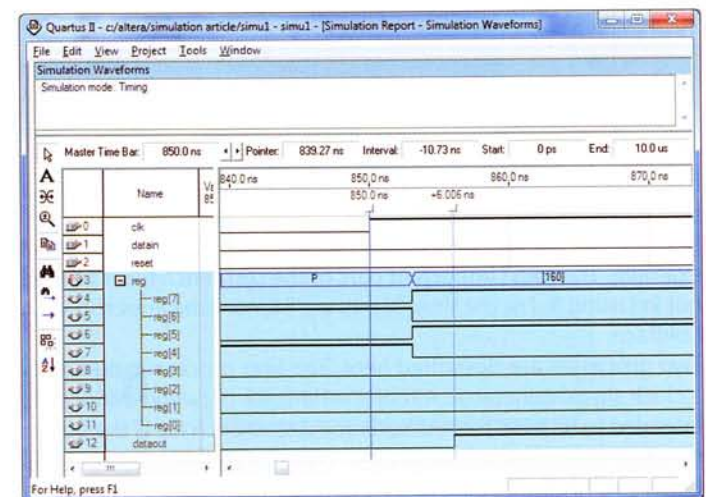


Figure 2. Results of a functional simulation of the same design as Figure 1.



## Listing 1

```

Library IEEE;
Use      IEEE.std_logic_1164.all;
Use      IEEE.std_logic_textio.all;
Use      STD.textio.all;

entity test_simu2_file is
end test_simu2_file;

architecture stimulus of test_simu2_file is

    file RESULTS: TEXT open WRITE_MODE is "results.txt";
    procedure WRITE_RESULTS(
        clk: std_logic;
        reset : std_logic;
        datain : std_logic;
        dataout : std_logic
    ) is
        variable l_out : line;
    begin
        write(l_out, now, right, 15);
        write(l_out, clk, right, 2);
        write(l_out, reset, right, 2);
        write(l_out, datain , right, 2);
        write(l_out, dataout, right, 2);
        writeline(RESULTS, l_out);
    end procedure;

    component simu2
    port (
        clk      : in STD_LOGIC;
        reset    : in STD_LOGIC;
        datain   : in STD_LOGIC;
        dataout  : out STD_LOGIC
    );
end component;

signal clk : std_logic;
signal reset : std_logic;
signal datain : std_logic;
signal dataout : std_logic;

begin

    DUT:simu2 port map (
        clk => clk,
        reset => reset,
        datain => datain,
        dataout => dataout
    );

    CLOCK_PROC : process
    begin
        clk <= '1';
        wait for 10nS;
        clk <= '0';
        wait for 10nS;
    end process;

    STIM : process
    begin
        wait until (clk'event and clk='0');
        -- wait for falling edge of clk
        reset<= '0';
        datain <='0';
        wait until (dataout='0');
        -- wait for falling edge of clk
        wait until (clk'event and clk='0');
        -- wait for falling edge of clk
        datain <='1';
        wait;
    end process;

    WRITE_RESULTS(
        clk,
        reset,
        datain,
        dataout
    );

end architecture;

```

free version of ModelSim can run simulations based on VHDL testbench files, which offer you the full range of VHDL functions.

Here we can use the shift register design mentioned above as an example. The most important part of the testbench file is printed out in Listing 1. For the time being, we'll ignore the lines shown in boldface.

Two processes are described here. The first process implements a clock signal generator. A major difference between a VHDL file intended to be used for synthesis and a testbench file is the option of using 'wait' statements. The line 'wait for 10nS' causes process execution to pause for 10 nanoseconds. This sort of statement in a design ultimately intended to be executed in an FPGA will cause an error during synthesis. FPGAs do not have any components that can be used to implement this statement directly, but it does not cause

any problems in a simulation. This process is repeated indefinitely because there is no sensitivity list at the start of the process code. As soon as the process has finished executing, it starts again from the beginning.

### Interactive

The biggest advantage of a testbench file is that it allows one or more of the outputs of the design under test to influence the input signals. In the STIM process, which is responsible for generating the 'reset' and 'datain' signals, we use an internal signal together with an output signal from the design under test to modify the input signals.

The line 'wait until (clk'event and clk='0');' causes process execution



to pause until the 'clk' signal changes state and the new state is '0'. In other words, it waits until the next falling edge of the clock signal. The 'reset' and 'datain' signals are set to '0' only after this falling edge occurs. The initial state of all internal signals is 'U', which stands for 'unknown'.

In the next line, the process waits until the 'dataout' output of the design under test goes to '0'. The 'datain' signal is set to '1' after the next falling edge.

The final statement of this process is 'wait' without any time specified. What is the purpose of this line? Without it, the process would normally repeat itself immediately after completing execution, since it does not have a sensitivity list. The 'wait' statement without any time specified causes an infinite delay and thus prevents the process from repeating.

Figure 3 shows the results of this simulation. All testbench signals and all internal signals of the design under test (DUT) are visible here. All of these signals start with the state 'U', since the simulator cannot determine what the actual state should be. In reality, all

of these signals must assume either the '1' state or the '0' state. From the simulation, you can see whether the design ensures that this happens, or whether the state of a signal is arbitrary. The initial state of a signal may change as a consequence of a different optimisation, so you should check that all signals have defined states after a certain point in time, such as after a reset.

### Testbench format

A testbench file differs from a normal VHDL file in several respects. Taking Listing 1 as an example, you can see that entities are declared in the usual manner. However, a remarkable feature of these declarations is that these entities do not have any input or output signals. A design usually has at least one input and one output, so that it can do something useful. After all, your design must be able to respond interactively to its surroundings. From this, we can conclude that a VHDL testbench file is not a design that can be programmed in an FPGA.

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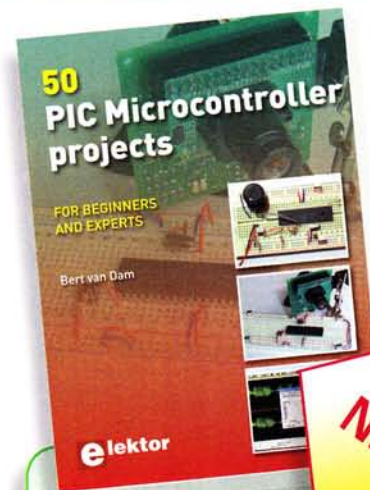
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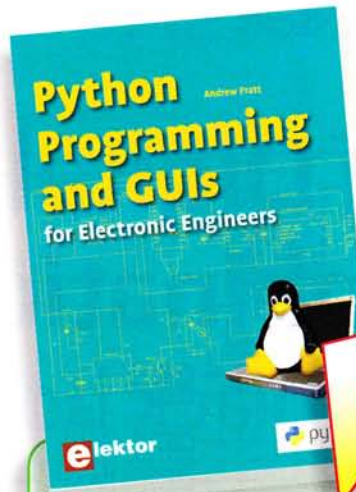




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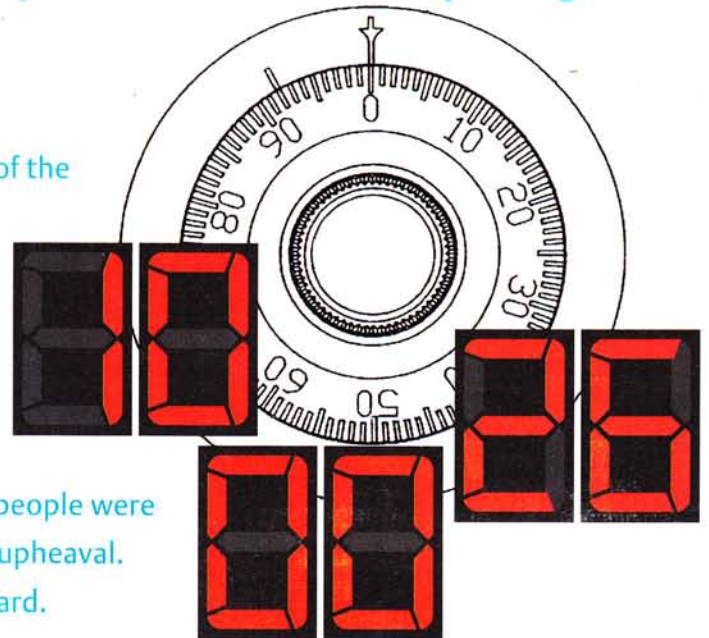


# CL-3 Digital Rotary Combination Lock

## From black box to open-source project

By Dale Wheat (USA)

The CL-3 got designed and built way back at the end of the 20<sup>th</sup> century. It used an Atmel AVR AT90S1200 flash microcontroller with a rotary encoder to emulate a mechanical combination lock, triggering a relay when the correct combination was dialed. Back in those days, it was considered prudent to keep project development and design documents a closely guarded secret. Tin-lead solder was king and people were stockpiling food and weapons for the upcoming Y2K upheaval. Today we know better – open source is the way forward.



The CL-3 was a delight to design and build but very disappointing in the marketplace. I attribute this to my complete lack of marketing skills and not on the merits of the project itself. Phillip Torrone of Adafruit Industries encouraged me to have another go at it, this time as an open source project. So here we go, but not before mentioning that a story on the design history of CL-3 is available as a free download from the Elektor website at [1].

### From the concept...

As shown in **Figure 1** the minimal CL-3 implementation uses a rotary encoder as input, emulating a mechanical combination lock dial as used on vaults. The user gets feedback via a dual seven-segment LED display, indicating the current dial position. The final output is a logic level pin that represents the 'locked' or 'unlocked' state. This level controls a relay that governs the opening of the 'vault' door.

There is also another pushbutton input that is used in conjunction with the dial to program the combination in the field. This pushbutton needs to be located in the

secure region of the circuit, where the general public does not have access. In the normal mode of operation, the rotary encoder is the primary input. A quadrature output indicates movement as well as direction. You could also determine the

speed at which the dial is being turned, if you wanted to get fancy, by measuring the period between changes in the input.

A state machine is used to keep track of the current quadrature input. Note that this is not the same as the virtual dial position. Once movement is detected, i.e., the input has changed, two of the possible remaining three states are checked to determine if the motion is clockwise or anticlockwise. The information is used to update the virtual dial position in the range of 00 to 99. Just like a mechanical dial, the value should roll over from 99 back to zero as well as go from 00 to 99 in the opposite direction.

### To the schematic

In terms of user interface, the CL-3 circuit has two outputs, which are also apparent from the circuit diagram in **Figure 2**. The first is the LED display LD1–LD2 and the second is the lock relay RE1. Everything runs under the tight control of microcontroller IC1. The current dial position is displayed on the multiplexed LED display, which is a separate unit connected to the microcontroller via connector K2–K6. A lookup

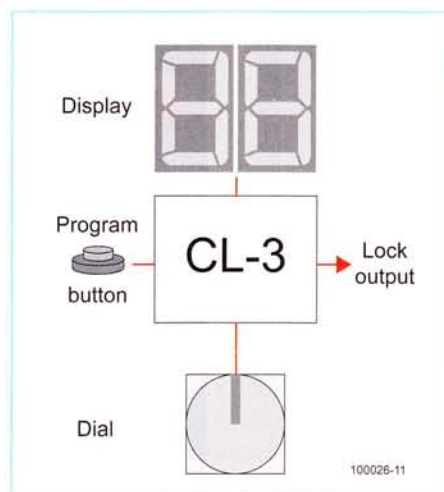


Figure 1. Functional diagram of the CL-3 electronic code lock.



## Features

- 6 digit operation (three 2-digit numbers in CW-CCW-CW sequence)
- ATtiny2313 microcontroller
- Optical or mechanical rotary encoder
- Hidden/secure programming button
- Free C code

table in the controller's memory is copied to the lower registers and used to translate the decimal value to the appropriate segment values. Those segment values are written to the ATtiny's output port, which is in turn connected to the LED segment leads via current limiting resistors R1-R9. Once a short period of time has elapsed, the tens digit is blanked and the same process is repeated for the units digit. Rapidly alternating between the two digits gives the visual impression that both digits are illuminated at the same time, due to the persistence of vision effect in the human brain. Your eye isn't fooled but your brain is.

The Atmel-recommended ATtiny2313 is a good choice for this type of project and is even pin-compatible with the AT90S1200 in the original version of the CL-3. More on-board peripherals, memory, clocks and power-saving features are just begging to be used!

The original AT90S1200 had only one external interrupt and it was used for the programming pushbutton input. I moved one of the encoder inputs to INT0 (PD2, pin 6). In the interrupt routine, the other encoder input is examined to determine the direction of dial motion.

The original CL-3 kit used a Panasonic mechanical rotary encoder that has also been discontinued. There is no direct replacement available from Panasonic, but any quadrature encoder should work. Mechanical encoders are much less expensive than optical devices, and for these in particular two small capacitors C1-C2 are provided on each of the outputs to prevent contact noise.

The relay driver is just one pnp transistor with a current limiter resistor in its base line. The power supply is dead conventional based around the 7805 voltage regulator with its usual flock of decoupling capacitors, solid (C5 and C7) and electrolytic (C4 and C6). Diode D2 affords protection against power supply reversal.

## The CL-3 software

I have corrected what could possibly have been a security issue in the original CL-3

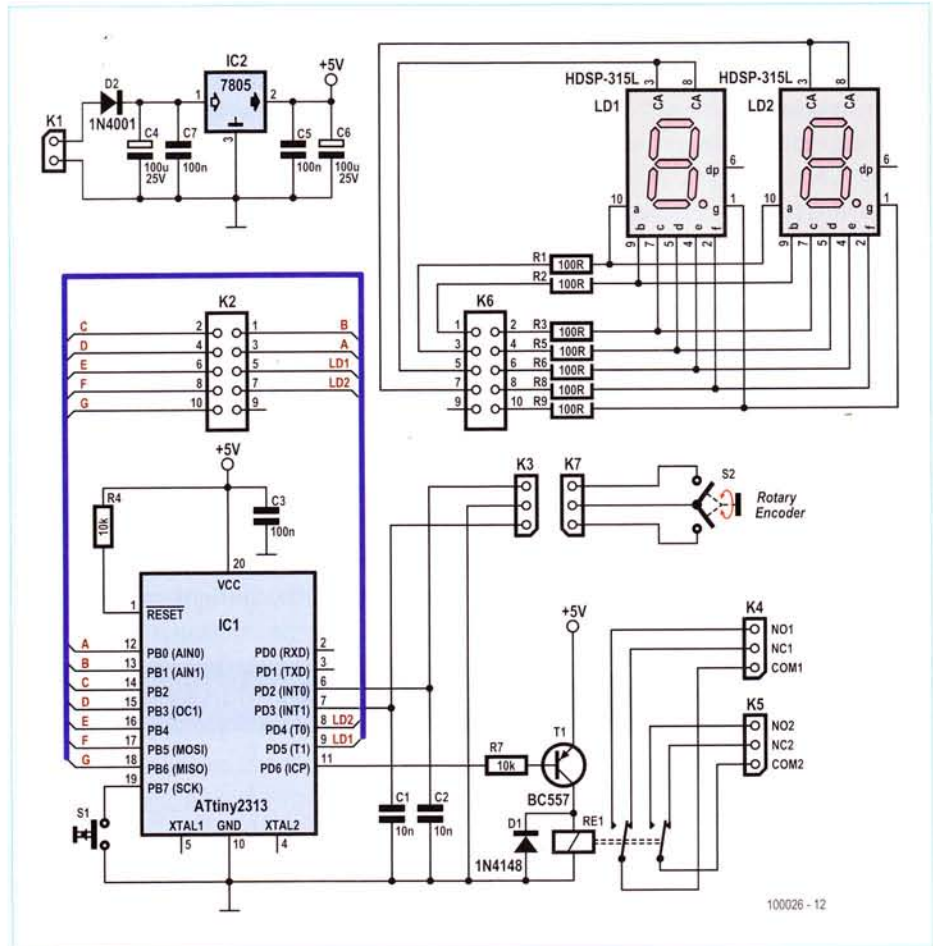


Figure 2. Schematic of the new CL-3. The project consists of a controller section and a display/encoder section.

firmware. On power up, if the unit was unlocked, the display revealed the last number of the combination for a few seconds. The new firmware corrects this, only a decade later. That's some kind of response time, eh?

The source code file written for the new CL-3 is called 'CL-3.c' and contains the C

language version of the firmware. It can be downloaded free from [1]. For your amusement the same archive file also contains the AT90S1200 assembly code for the old CL-3.

## Building it (them)

The circuit board designs for the new CL-3 are shown in Figure 3. The artwork for

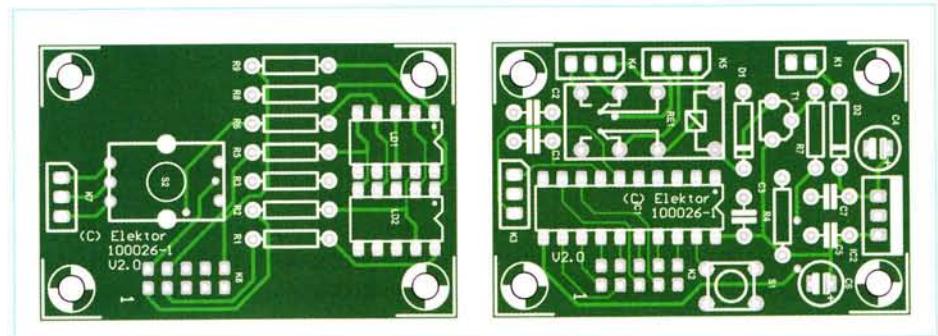


Figure 3. Component mounting plans of controller board and display/encoder board. Either connect them via cables/wires or stack the display/encoder board on top of the controller board. Copper track layout files available free from our website.



## Quadrature decoding

A *quadrature* output consists of two alternating signals that are 90° out of phase. These two signals are traditionally referred to as A and B. The two signals don't have to be exactly 90° out of phase with each other, but it is important that they do not change state at the same time.

Imagine a compass that only has a 'north or south' output and an 'east or west' output. It will only tell you the approximate orientation of the compass. At any given moment, it can only report the ordinal (or intercardinal) direction (i.e., NE, NW, SE or SW). By periodically noting the reported direction, an external device can tell when the orientation changes by comparing the present reading with the previous reading. By analysing these changes over time, the absolute position, direction of motion and angular velocity can be determined.

An *incremental shaft encoder* uses the same technique to report changes in the position of a rotating shaft or instrumentation dial. An *absolute* position is derived from the succession of changes reported by the sensor. The direction and velocity of the shaft (or dial) can also be derived.

Expanding on the compass example, the two outputs A and B correspond to the "North/South" and "East/West" outputs, respectively. Arbitrarily assigning the North and East conditions as "high", we get the following table:

Ordinal direction	North/South	East/West	Phase A	Phase B	Binary value
Southwest	Low	Low	0	0	0
Southeast	Low	High	0	1	1
Northwest	High	Low	1	0	2
Northeast	High	High	1	1	3

There are four possible combinations for any given reading. It follows that there are four possible transitions between one reading and the next for each of the possible original combinations. For example, the four transitions from the "Southwest" state are:

New reading	Transition	Value
Southwest	None	0
Southeast	Anti-clockwise	-1
Northwest	Clockwise	+1
Northeast	Error	Unknown

Note that the unexpected transition from "Southwest" to "Northeast" implies either a faulty reading or a missing transition through one of the other, expected readings. Your response to this condition depends entirely on your application. For trivial or noncritical applications (e.g., a combination lock), these events can safely be ignored.

The 'Value' column, except for errors, can then be added to a running accumulation of similar values to provide a virtual absolute position.

these small boards is available free at [1] in the form of pdf files.

The project should be simple to build as no SMD parts or special assembly techniques are required. Two boards are installed at a distance from each other, to ensure the 'vulnerable' section is not easily accessible. The same goes for the relay contacts (which are subject to tampering). If you can afford to keep the circuitry in one piece, the dis-

play/encoder board can be stacked on top of the controller board by means of pin-header/socket pairs K6/K2 and K3/K7. Still, for security reasons, pushbutton S1 should be mounted at the copper side of the controller board.

Figure 4 provides a close look at the prototype boards built by Elektor labs.

### Setting the combination

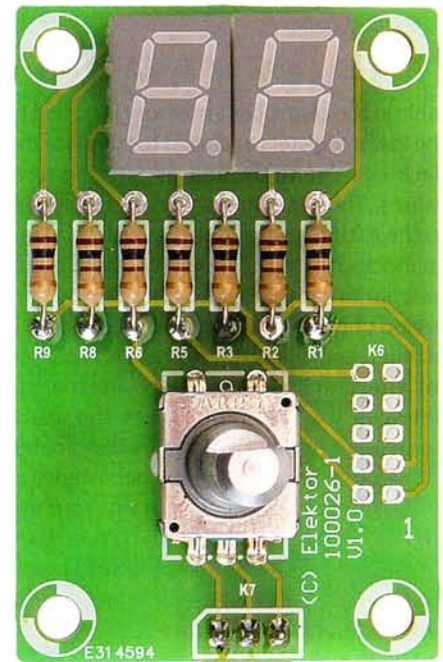


Figure 4. Prototype boards

The 3-number (6-digit) code that opens the lock is field-programmed using the physically-secured programming pushbutton, S1. All opening and programming commences when the encoder is turned clockwise (CW). To program a new combination, dial in the first number and then press the programming button. The display blanks once to confirm the new number is stored in EEPROM. Dial the second number in counter-clockwise (CCW) direction and press the button again. The display blinks twice. Repeat CW for the third number, with the predictable result. Only once all three numbers have been entered does the firmware write the new combination to the non-volatile EEPROM memory. I encourage users to write down the combination first, then enter it into the device, then confirm the combination works.

If you disallow subsequent identical numbers (e.g., 1-1-1 is not allowed), there are 100 × 99 × 99 = 980,100 possible combinations.

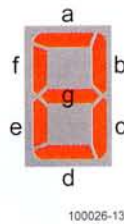
### Opening the lock

This is done just like programming the lock, i.e. CW-CCW-CW but obviously without



## Multiplexed 7-segment display logic

A single numeric digit, based loosely on the Arabic numerals popular in Western languages, can be represented with as few as seven independent 'segments', traditionally labelled 'a' through 'g'. See below. LEDs prearranged in this pattern have been available for decades



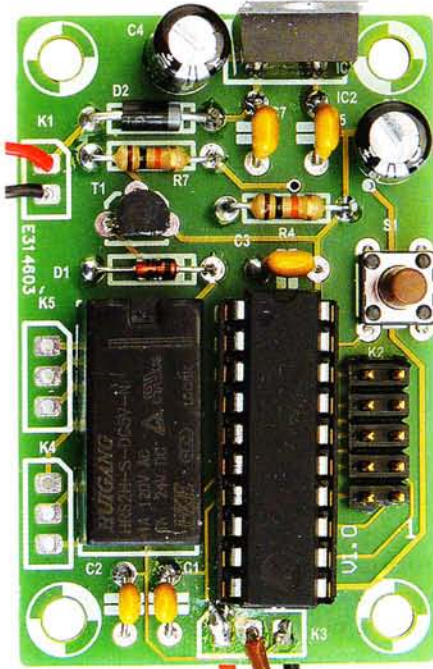
in various colours and sizes. To save pins, either the anodes or the cathodes are connected together and the other terminals brought out separately, thus the characterization 'common cathode' or 'common anode'.

To directly drive the LED segments from a microcontroller, connect seven output lines (via current limiting resistors) to the LED display module. Connect the LED common pin to either V+ for common anode displays or ground for common cathode displays.

If you have lots and lots of extra output pins available, you can connect a single output line to each LED segment for as many digits as your application requires. If not, you can *multiplex* the outputs. This reduces the number of dedicated output lines. Generally speaking, you then give up the ability to illuminate all of the LED segments simultaneously.

One way to multiplex the LED display is to arrange them in a row and column array, where the rows correspond to segments and the columns to digits. All of the 'a' segments would be connected together, as would the 'b' segments, etc. Instead of connecting the common line from each display to either V+ or ground, the common lines are individually selected (or *strobed*) by more dedicated output lines. These 'digit select lines' are almost always buffered using some sort of current-amplifying circuit, such as a common-emitter amplifier, consisting of a transistor and a resistor.

Each digit is displayed for a very brief period of time, then the next one, etc. If this happens fast enough, the display appears to be uniformly illuminating all the digits at once.



built for the project.

actuating S1 and with no blinking of the display. The lock opens when the 5<sup>th</sup> and 6<sup>th</sup> digit also match the programmed code. The relay remains actuated until the encoder is turned again either CW or CCW. The state of the lock is also stored in EEPROM, meaning that the relay is immediately actuated when the lock was open and the supply voltage gets switched off and on again.

### Using an Arduino

Attaching the user interface panel to an Arduino is very simple. The firmware is contained in CL\_3.pde, which is also found in the software archive for this project [1]. I used a polling technique instead of interrupts to make it simpler to understand. The same basic functionality is there. The logic lights up the built-in LED on the Arduino when the lock is unlocked. You could easily change the code to send a message via the serial port or take other appropriate action.

### Unlock the potential

I really enjoyed working on this project, which allowed me to see ten years of progress in microcontroller technology and programming. If you can, take a moment

## COMPONENT LIST

### Resistors

R1,R2,R3,R5,R6,R8,R9 = 100Ω  
R4,R7 = 10kΩ

### Capacitors

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

### Semiconductors

D1 = 1N4148  
D2 = 1N4001  
LD1,LD2 = 7-segment LED display, common anode (CA), h=10mm, Avago type HDSP-315L  
T1 = BC557

IC1 = Atmel ATTINY2313-20PU, programmed, Elektor # 100026-41  
IC2 = 7805

### Miscellaneous

S1 = Tactile switch, 6mm, Multicomp type MC32830  
S2 = rotary encoder, Alps type EC11E15204aE  
K1 = 2-pin pinheader, 0.1 inch lead pitch.  
K2,K6 = 10-pin (2x5) pinheader 0.1 inch lead pitch  
K3,K4,K5,K7 = 3-pin pinheader, 0.1 inch lead pitch  
RE1 = PCB mount relay, DPCO, 5VDC, Multicomp type HRS2H-SDCV5  
PCB, see [www.elektor.com/100026](http://www.elektor.com/100026)

and let me know what you think about it. I'd really like to know.

Now it's time to turn it loose on the world. While the copyrights of this article remain the property of the Publishers (because writers gotta eat!), the CL-3 software and PCB design are hereby placed in the public domain with no restrictions other than "commercial use prohibited". Go nuts!

(100026)

[1] [www.elektor.com/100026](http://www.elektor.com/100026)



# One-Button Data Entry

## Drop-in BascomAVR routines

By Vladimir Mitrovic (Croatia)

In microcontroller based projects you often need to set a bunch of parameters or initial values. If the project already has an alphanumeric or some other kind of display, even complex multiple-digit values can be effectively set with just one pushbutton that can serve for other purposes as well.

Based on an ATtiny2313, the test circuit in **Figure 1** is 'general purpose' and could be part of just about any project requiring a user interface. Pushbutton S1, together with an LC alphanumeric display, enables a form of interactive data entry. The trick is, of course, in the program, which is written in BascomAVR. The program will run on all similar circuits based on AVR microcontrollers as well as on 8051 micros if you do the necessary family-related adaptations.

The idea is to monitor not only if, but also how long, S1 is pressed. Two different cases can be distinguished:

- the button is pressed briefly (shorter than 1 s);
- the button is pressed for a long time (longer than 1 s).

When the button is pressed for longer than one second for the first



time, the program will enter data-entry mode. In this mode, the initial parameter value is displayed and the cursor is placed under the first digit (see **Figure 2**). Every short press on the S1 will toggle the sign and/or increment the selected digit by 1. Pressing the button longer than one second again will move the cursor under the following digit, which can now be edited by short presses on the button. Pressing the button longer than one second while the cursor is under the last digit will terminate data-entry mode and the program will continue to execute code in the main loop.

### Examples

In order to explain how data-entry routines can be implemented in the real program, two example programs were written: EE\_1\_button\_HEX.bas and EE\_1\_button\_DEC.bas. Both programs can be downloaded free of charge from the Elektor website [1]. They perform a simple main task: increment a counter ('Cntnr' variable) approximately ten times per second and display every new value.

The programs differ visibly in the way the counter is displayed: the first program shows the counter value as a hexadecimal number, whereas the other one shows it as a signed decimal number. The real difference between the programs is in the way hexadecimal or decimal values are edited when the programs enter data-entry mode. After the counter value has been changed and the program control is returned to the main loop, both programs will continue to count from the value that has just been set.

If you extract the counting/displaying part of example programs, the remaining code contains the structure and the routines that enable 1-button data entry, which should be easy to 'port' or 'migrate' to other similar projects.

### Program concept

The heart of any program that alters its behaviour depending on duration of some event is the time-measuring routine. In our programs, in the 'Check\_t1' subroutine we check if, and how long, the

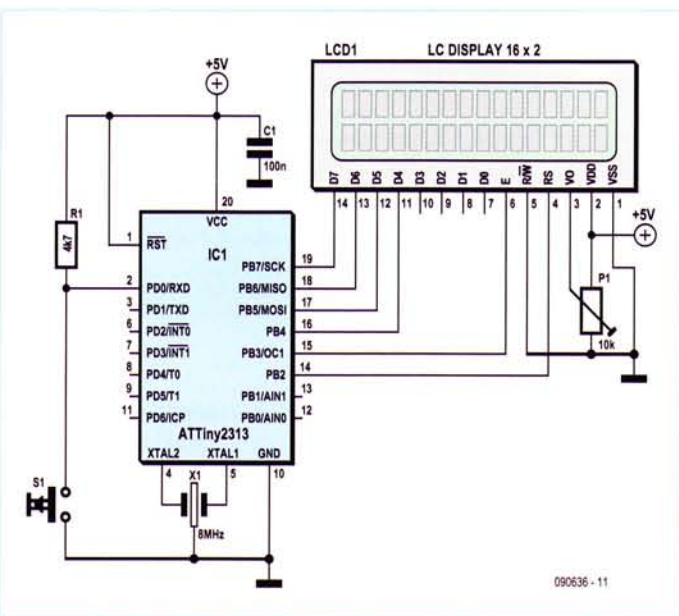


Figure. 1. One button is all you need for an elegant and effective data/parameter entry (test circuit shown).



button is pressed. Note that although the switch is labelled S1 in the diagram, it's invariably 'T1' in the software.

```
T1 Alias Pind.0      'T1 input pin
```

```
Check_t1:
  T1_time = 0
  Debounce T1 , 0 , T1_on
Return
```

```
T1_on:
  T1_time = 1
  While T1 = 0
    Waitms 10
    Incr T1_time
    If T1_time > 100 Then
      Exit While
    End If
  Wend
Return
```

The 'Debounce' statement checks if the pushbutton is pressed at all. If the check fails, program control returns to the main loop with 'T1\_time' variable set to 0. If the 'Debounce' statement establishes that the button is pressed (T1=0), the program branches to the 'T1\_on' routine and waits in While-Wend loop until the button is released or 1 second passes (whichever comes first) and then returns to the main program. If the button is released before 1 s passes, the 'T1\_time' variable will have any value from 1 to 100 (for time periods from approx. 10 ms to 1 s). If the 1-second period lapses, the program will stop monitoring the button and will return to the main loop with T1\_time = 101.

To enter the data-entry mode, you should periodically check in the main loop if the switch is pressed for longer than 1 s and if it is, call the data-entry subroutine:

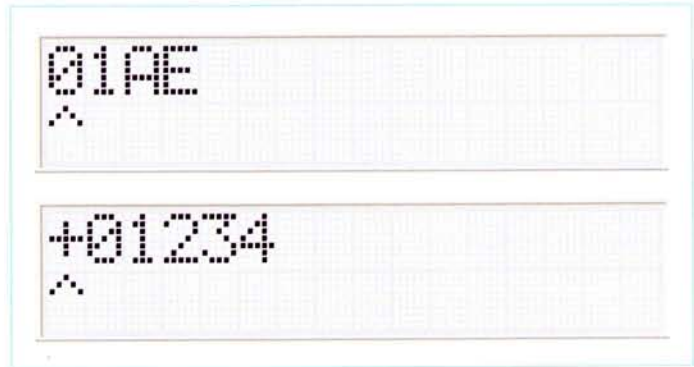


Figure 2. Display in data-entry mode: hexadecimal and signed decimal input is possible.

```
Do
  Gosub Check_t1      'check if T1 is pressed >1s
  If T1_time > 100 Then
    Gosub Edit_cntr  'if yes,
                    'enter editing mode

  End If
  ...                'else, do whatever
Loop
```

The data-entry subroutine consists of three parts:

1. initialization, in which the initial value is converted to the appropriate format for display;
2. loop, in which S1 (T1) is periodically checked and the displayed value is edited as explained before and
3. finishing, in which the edited value is saved to become the new initial value.

It is obvious that the program will not be able to execute the commands from the main loop while the data-entry subroutine is executed. Interrupt routines, if there are any, will be executed normally. It is the programmer's responsibility to ensure that such a condition does not affect the hardware controlled by the microcontroller in a destructive manner.

We will not explain the data-entry subroutine in detail. However, several notes might be helpful in order to enable you to adjust it to your own needs.

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### EE\_1\_button\_HEX description

The initial value is stored in the 'Cntr' variable (the name comes from its use in example programs and you may edit it as you please). The variable type can be Byte, Word, Integer or Long. To enable manipulation of individual digits, the variable is converted to the string 'Edit\_string' which should be properly dimensioned to accept the 'Cntr' variable (2B for Byte, 4B for Word/Integer and 8B for Long).

```
Edit_cntr:
  Edit_string = Hex(cntr)
  Cls
  Lcd Edit_string
```

The editing loop that extracts hexadecimal digits from the string is limited by the string length:

```
For I = 1 To Len(edit_string)
  Edit_x = Mid(edit_string , I , 1)
  ...
```

Since BascomAVR has no function to increment the hexadecimal digit in the 'Edit\_x' variable, a simple assembler routine 'Incr\_hex' is written and called when a short press on the button is detected. Every edited digit is merged into the initial string and displayed before the next digit is selected:

```
If T1_time > 0 Then
  Gosub Incr_hex
  Mid(edit_string , I , 1) = Edit_x
  Lcd Edit_string
End If
Next
```

Near the end, after the last digit has been edited, the new value is converted back from the string into the numeric value and saved in the 'Cntr' variable:

```
Cntr = Hexval(edit_string)
Return
```

### EE\_1\_button\_DEC description

The initial value is stored in the 'Cntr' variable (again, rename it as you please). The variable type can be Byte, Word, Integer (signed) or Long (signed). To enable manipulation of individual digits, the variable is converted to the string 'Edit\_string' which should be properly dimensioned to accept the largest possible value in the 'Cntr' variable. Allow for an extra byte for signed variables.

```
Edit_cntr:
  Edit_string = Str(cntr)
  Edit_string = Format(edit_string , "+00000")
  Cls
  Lcd Edit_string
```

Note that 'Edit\_string' is formatted with the Format() function. This is necessary if you want to display the + sign and leading zeroes; only displayed digits can be edited! The + character at the beginning of

the mask is necessary only for signed variables and should be omitted otherwise. The editing loop that extracts digits from the string is limited by the string length:

```
For I = 1 To Len(edit_string)
  Edit_x = Mid(edit_string , I , 1)
  Edit_9 = Val(edit_x)
  ...
```

Every digit is extracted as a hexadecimal character ('Edit\_x') and a decimal number ('Edit\_9'). This is necessary as you have to manipulate string (sign) and numeric (digits) values.

What will happen if the short press on the button is detected depends on the character that is extracted. If it is a sign, it will toggle:

```
If T1_time > 0 Then
  If Edit_x = "+" Then
    Edit_x = "-"
  ElseIf Edit_x = "-" Then
    Edit_x = "+"
```

This part of the program may be deleted if the initial value is unsigned (i.e. if it is stored in the Byte or Word variable). If the extracted character is a number, it will be increased:

```
Else
  Incr Edit_9
  If Edit_9 > 9 Then Edit_9 = 0
  Edit_x = Str(edit_9)
End If
```

Every edited digit is merged into the initial string and displayed before the next digit is selected:

```
Mid(edit_string , I , 1) = Edit_x
Lcd Edit_string
End If
Next
```

Finally, after the last digit has been edited, the new value is converted back from the string into to the numeric value and saved in the 'Cntr' variable:

```
Cntr = Val(edit_string)
Return
```

The data-entry routines are explained in a somewhat simplified manner; check the example programs in the free download [1] for the complete routines!

(090636)

### Internet Link

1. [www.elektor.com/090636](http://www.elektor.com/090636)



# Discover the STM32!

By Jens Nickel (Elektor Germany Editorial)

Microcontroller evaluation kits are a wonderful resource. Those supplied by chip manufacturers are usually reasonably priced as development costs can be recouped in chip sales. For the engineer/student it's a good opportunity to work hands-on with the devices and the software tools. From the manufacturers viewpoint the more people who become proficient with their devices the more chips they will sell.

STMicroelectronics has already had a positive response to their low-cost 8-bit STM8S Discovery Kit. At the last Embedded World exhibition in Nuremberg they handed out 5,000 of these 8-bit evaluation boards free to visitors. The company is also about to introduce a similar kit for their 32-bit family of microcontrollers (STM32F). The controller chosen for the STM32VL-Discovery kit is the STM32F100RBT6B, one of their low-cost 'Value line', based on an ARM Cortex-M3 architecture with 128 KB Flash memory and 8 KB RAM [1]. The kit is due to be shipped mid September 2010 and will be stocked by a number of suppliers. Farnell already have plenty on back-order, not surprising considering the retail price of the kit is just £6.80 or \$9.90 in the US.

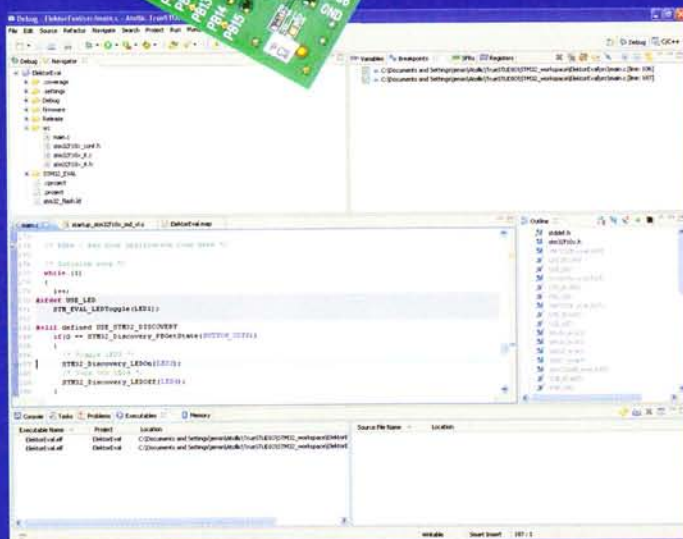
STMicroelectronics also supply a range of STM32xxx-EVAL evaluation platforms but the STM32-Discovery is a much more economical introduction to the Value Line family. All software is available for download from the Internet and a USB cable will be needed to connect the kit to a computer. Unlike many other manufacturers whose evaluation boards are designed in the form of a large USB stick and are quite densely populated the STM32 Value Line Discovery has more board space and uses a rectangular board. Single rows of pin headers are fitted along the long side and at the lower end through which the processor pins have direct access to the outside world. Many other evaluation boards provide just a few solder pads for connecting external circuitry but the Discovery board is more versatile and can be used as a processor board with peripherals wired in the prototyping area or linked to an additional circuit board.

The hardware is divided into two areas; the main part contains the target controller together with a reset button, a 'user' button and two LEDs. These allow you to run and interact with simple demo programs without the need for any additional hardware.

The somewhat smaller upper area of the PCB is fitted with a USB socket. Power for the board is derived from the external computer via the USB cable. Underneath there is a second (more powerful) STM32 controller which takes care of programming and debugging the target processor. The functions of this debugger are compatible with the ST-LINK programmer/debugger tool. This means that free ST-LINK software such as the 'ST-LINK utility' [2] also runs on the board to allow the STM32F100 memory contents to be read. A nice feature also is that the programmer/debugger functions are not restricted to the on-board target controller; it can be hooked up to an external STM32 controller using the 4-pin SWD (Serial Wire Debug) connector.

There is a choice of three tool chains available from IAR, Keil or Atollic to deal with the job of writing and debugging firmware for the STM32. We chose the 'TrueSTUDIO for STM32' from Atollic AB as the development environment. The Lite version can be downloaded for free [3] and is neither time nor code size limited but has fewer functions than the professional version. This powerful IDE based on ECLIPSE is simple to install and includes a good selection of project templates for different hardware platforms so for example it is not necessary to concern yourself with generating your own make-files (the first steps of creating a new project are described in the 'quick start guide' of

the development environment). Selecting 'STM32\_Discovery' as the evaluation board will load a small demo project to control the two LEDs in response to user button presses. Although the newcomer may find the development environment a little daunting at first, they will soon get to know how the individual project files hang together, what information is shown in the windows and where the most important debugger control panel is. To run your own programs in the 'lite' version it is necessary to activate the debug process, the run procedure and





generation of binaries is only possible in the professional version. In the 'Build Configurations' menu (accessible from the main menu under 'Project') make sure that 'Set Active' has been selected in 'Debug'. Otherwise new or modified programs will not be transferred to the controller for debugging.

Now there's no reason why you can't start thinking up your own applications for this powerful system. A good starting point for those new to the environment is the examples posted on the STM32-Discovery website [4]. Running through these will quickly boost your confidence with the system. The download-

able data describes the board in detail (circuit diagram, pinouts and jumpers). STMicroelectronics have indicated that the website will be active by the 15<sup>th</sup> September at the latest.

(100454)

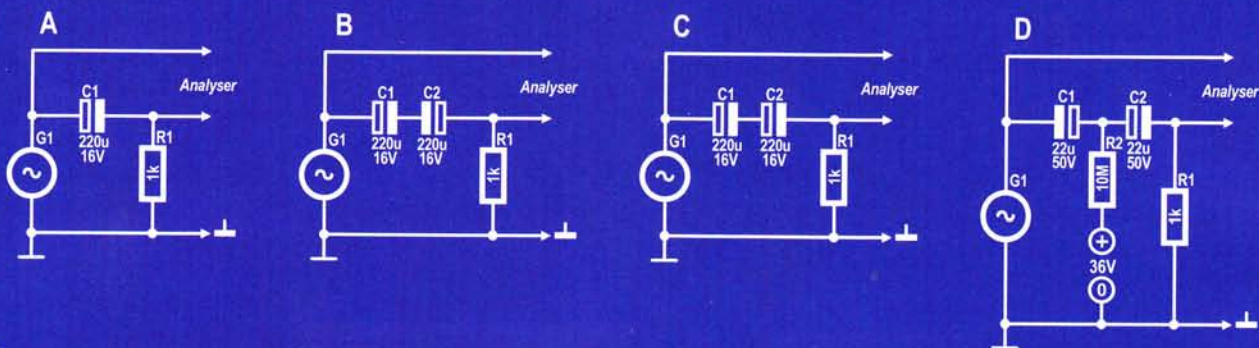
[1] [www.st.com/mcu/inhtml-pages-stm32.html](http://www.st.com/mcu/inhtml-pages-stm32.html)

[2] [www.st.com/mcu/familiesdocs-110.html](http://www.st.com/mcu/familiesdocs-110.html)  
(the last one in the list)

[3] [www.atollic.com/index.php/download/downloadstm32](http://www.atollic.com/index.php/download/downloadstm32)

[4] [www.st.com/stm32-discovery](http://www.st.com/stm32-discovery)

# Electrolytic capacitors in audio circuits



1

100452 - 11

By Ton Giesberts (Elektor Labs)

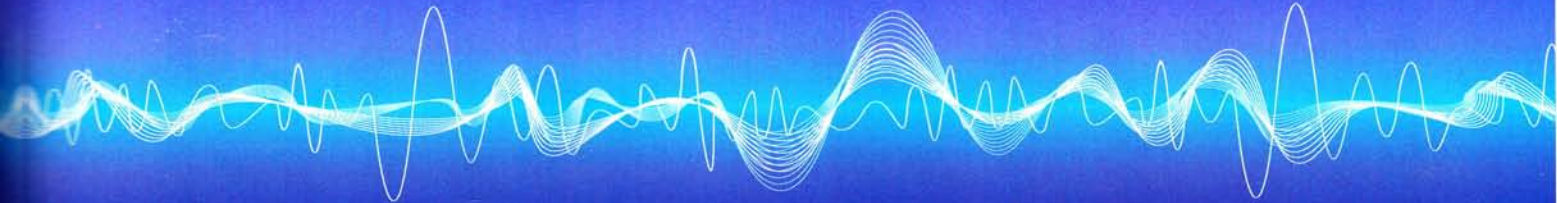
Here at Elektor, for more than 20 years we've held the opinion that electrolytic capacitors have the worst properties for audio signal paths, possibly with the exception of ceramic capacitors. Our dielectric of preference is plastic film, with polyester/terephthalate as a minimum. Even better are polypropylene and polystyrene versions. Of course, there are 'ultimate' capacitors like Teflon or silver-mica devices, but we're talking about electrolytic caps here.

Electrolytic capacitors are commonly used as coupling devices in valve amplifiers, but we also frequently find them in solid-state amplifiers. The advantage of electrolytic capacitors is their large capacitance to volume ratio. In the original design of the '5532 Power Amplifier' (first part of this edition), two electrolytic capacitors were used, which we eliminated in the final design; a DC control is added instead to compensate for any offset. In this way any discussion as to whether electrolytic capacitors have an audible effect on the sound, in whatever way, can be avoided. Nevertheless we were curious what the effect of the electrolytic capacitors would have been if we had left them in the signal path. We will show the results of the THD measurements, tests with MLS and standard IMD signals did

not result in any clear differences between input and output of the test configuration. The various test configurations are shown in **Figure 1**.

We started with the simplest measurement of a high-pass filter (**Figure 1a**). **Figure 2** shows the FFT analysis of the generator and the output of the network. The generator generates a sine wave at 20 Hz with an amplitude of 5 V<sub>rms</sub>. The graph shows the signal from the generator (cyan) and the voltage across R1 (green). There is therefore an increase in distortion, but the harmonics are below -120 dB! In reality they are even lower, because they are only a little stronger than the harmonics from the generator, which are at -130 dB (2<sup>nd</sup> and 3<sup>rd</sup> harmonics). Expressed as a percentage the distortion increased from about 0.00017 % to 0.00023 %. The measurement was repeated for other types of 220-μF electrolytic capacitors. Next was a non-polarised electrolytic. It came as a surprise that the comparison with the generator signal shows practically no difference. This was followed by the two different types of electrolytic cap from the first measurement, this time connected in series in a bipolar manner (**Figure 1b**). There still was practically no difference to be seen between input and output. To find out whether the polarity made a difference, we turned the second electrolytic around (**Figure 1c**); the measurement across R1 now showed two harmonics which were a few dB larger than the measure-





ment with one electrolytic. We can therefore conclude that a bipolar configuration, with respect to distortion, is preferable over a single electrolytic. We assume that the non-linearities are cancelling each other. We followed this with measurements using other electrolytics (different manufacturers and rated voltages). The results gave different pictures, but always an increase in distortion. In all these situations a bipolar connection had a positive effect.

After this we did tests with electrolytic capacitors that were 10 times smaller. The corner frequency is now at 7 Hz instead of 0.7 Hz with the 220  $\mu\text{F}$  device. There is now a greater voltage drop across the capacitor. The result of a measurement using the configuration of **Figure 1a** at 20 Hz ( $5 V_{\text{rms}}$ ) can be seen in **Figure 3**. There is now considerably more distortion (about 0.005 %), and that is only due to the electrolytic! We also tried a bipolar connection, which gave a chart with a second harmonic that was about 17 dB lower, but the third was a little bigger. The rounded distortion figure remains the same.

We had one remaining question. Does the DC voltage across an electrolytic capacitor have an effect on the distortion? That is why we carried out a measurement according to **Figure 1d**. We don't have to show the result, because the two curves (with and without DC voltage) are practically on top of each other.

To get a feel for the quality of standard plastic film capacitors (Siemens/Philips 'MKT') we did two more tests with two versions of the high-pass filter with a corner frequency of 20 Hz. The first version was a large 4.7  $\mu\text{F}/250 \text{ V}$  capacitor and a 1.69-k $\Omega$  resistor. The second version was a cheap 2.2  $\mu\text{F}/100 \text{ V}$  capacitor (type without plastic case) and a 3.65-k $\Omega$  resistor. The results of the measurements are shown in **Figure 4**. Both versions gave pretty much the same result. Only the 2<sup>nd</sup> harmonic increased by 12 dB and the third remained practically identical.

From these tests we can conclude that when using electrolytic capacitors in the audio signal path it is desirable to locate the corner frequency well below the desired audio range. In cases where the impedances are low (kilo-ohms) there is no real alternative to electrolytics for blocking potential DC voltages. The disadvantage of the large capacitance is that a change in DC voltage will still be partially allowed to pass, because of the long time constants involved. Switch-on phenomena also last longer. A consideration can be to increase the impedance (results in more noise), so that it is still possible to use a polyester (MKT) device. The advantage is then that the polyester cap can be dimensioned for the desired corner frequency.

From this we can conclude that when using electrolytic capacitors as coupling capacitors there is practically no measurable effect on the audio signal provided that the capacitor is considerably over-dimensioned. With these 'too large' electrolytics it is also beneficial to use them in a bipolar connection.

We have looked here at only one aspect (harmonic distortion). There are obviously many more characteristics of electrolytic capacitors that could have an 'audible' influence on the sound quality.

Here is an overview of interesting publications if you would like more information about capacitors.

## Literature and Internet links

Capacitors in A.F. Circuits, Elektor February 1992

A real-time signal test for capacitor quality,

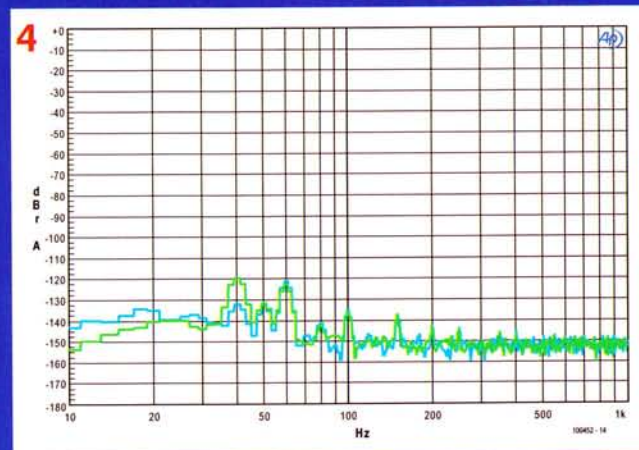
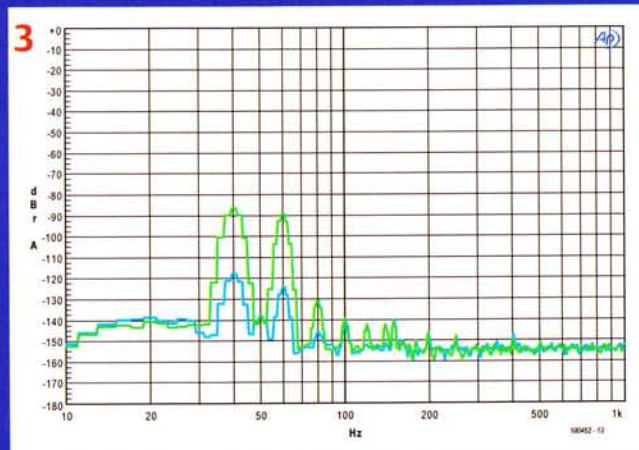
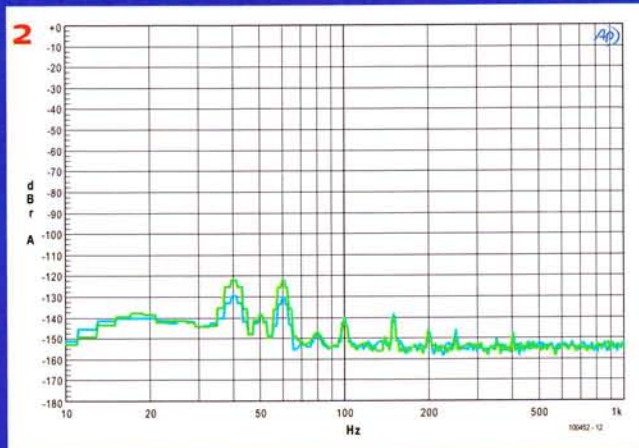
The Audio Amateur, April 1985

Capacitor Sounds, Electronics World, July 2002 – January 2003

Picking Capacitors, Audio Magazine, February 1980

<http://sound.westhost.com/articles/capacitors.htm>

<http://www.national.com/rap/Application/0,1570,28,00.html>



(100452-1)



# A Pocket Projector

By Jens Nickel (Elektor Germany Editorial)

Advances in high power LED technology has made it possible to shrink the size and price of LCD projectors. Makers of so-called pico-projectors boast that their devices will fit into your pocket and are ideal for projecting stills and videos from flash memory video players, camcorders and portable DVD players onto a wall for everyone to see. Serious bit of kit or just a toy? With Conrad Electronic [1] offering the 'Aiptek Pocket Cinema T15' for 99 euros (some 80 pounds) we thought it was time for us to find out.

Our first impression was that the term 'pocket projector' is in no way an exaggeration. The device sits in the hand and looks well built. Included in the kit are a rechargeable battery, an AC power charger, a small tripod and an AV cable (3 x RCA sockets). The only video input on this unit is the AV connector for stereo sound and video signal. An S-Video signal provided by some laptops (or mobile phones) will also be suitable but you will need to buy an adapter cable. For our test we took the signal from an old DVD player.

In the first test we projected an A4-sized image (35 cm diagonal). Our initial subjective impression of the image was surprisingly favourable with colour saturation better than expected. The 640 x 360 resolution is less than a PAL signal, so the image is understandably a little soft and the picture shows some evidence of video processing. The biggest limitation however is poor image brightness (8 Lumen compared with 2000 to 15000 Lumen for a standard metal halide LCD projector). Attempts at viewing a bigger image (it can focus images with a diagonal of up to 127 cm) required an absolutely dark room.

At this point curiosity got the better of us; brandishing a set of screwdrivers we went in search of screws to undo. With the bottom half of the case removed we could see the main PCB and at the front, the projector lens extending from a black box which presumably contained the complete optical arrangement and the light source. To go any further we needed to lift the lid but it looked like it was glued to the middle section. Luckily lab assistant Jan Visser had come over to see what we were doing and he volunteered to lend a hand. He seems to have a sixth sense, able to identify the position of concealed screw heads, plastic clips and double-sided tape.

A couple of minutes later the unit was dismantled. Inside we found the power LED fitted to a PCB with an aluminium plate to aid heat dissipation. A finned heat sink is also fixed to the plate. At the opposite side of this optical box we can see a thumbnail sized display screen. The operating principle is now fairly clear; light for the white LED (from Cree) passes through a series of lenses to produce a parallel beam of light. The beam passes through a half-silvered mirror set at 45° in the optical path and strikes the reflective display. The image on the display is reflected back and then out through the lens via the half-silvered mirror.

Identification marks on the LED PCB shows that the unit originated from the Hong Kong based company iView. Their web-



site indicates it is possible to order the optical module type IPL-512DG which was specially developed for the Pico projector [2]. The site News pages report that this module has also been integrated into a mobile phone to become the first phone with this feature.

We also discovered that the mini display unit in the projector is a LCoS (Liquid Crystal on Silicon) unit. This type of display similar to an LCD is based on liquid crystal technology but works in a reflective rather than transmissive mode. The liquid crystals are applied to a mirrored substrate, as a liquid crystal pixel flips between on and off, light is either reflected from the mirror or blocked. This technology can produce high resolution images and is compact. We couldn't find an English website with information on the HX7009 chip which is supplied by Himax in Taiwan [3]. The same company are also responsible for the HX8852 display driver chip which accepts digital video conforming to the ITU656 protocol [4]. Next to it is the TVP5150AM1 chip from TI [5], this converts PAL input signals into ITU656 digital signals. The largest chip on the board is an 8-bit microcontroller type HT46R23 from Holtek [6].

(100450)

[1] [www.conrad.de](http://www.conrad.de) (Part No 346313)

[2] [http://iiview.apaci.com.hk/en/products/products\\_details.php?pageNo=1&pid=11](http://iiview.apaci.com.hk/en/products/products_details.php?pageNo=1&pid=11)

[3] [www.himaxdisplay.com](http://www.himaxdisplay.com)

[4] [www.himaxdisplay.com/en/product/HX8852.asp](http://www.himaxdisplay.com/en/product/HX8852.asp)

[5] <http://focus.ti.com/docs/prod/folders/print/tvp5150am1.html>

[6] [www.holtek.com/english/news/products/022701.htm](http://www.holtek.com/english/news/products/022701.htm)



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# GPS ft. Propeller

## Parallax multiprocessor enhances satnav functionality



By Steffen Möriz (Germany)

A more versatile GPS receiver for in-car use and radio-control model applications was the spur to designing this project, with capturing motion speed and presenting this in both digital and analogue form a primary requirement. With eight CPUs onboard working in parallel, the Propeller microcontroller from Parallax manages these demanding graphic applications with ease.

For quite some time now there have been a number of approaches to capturing the speed of moving objects extremely accurately by means of GPS. Despite this, off-the-shelf gadgets produced for in-car route navigation generally do not have a built-in speed capture function. Maybe the manufacturers do not want complaints from customers when their tacho reading (which intentionally shows higher than actual speed) doesn't correspond with the GPS display. An additional hand-held satnav device doesn't make much sense in this situation, particularly as the speed display is very small. Squinting at tiny figures is not necessary with the GPS receiver described

here, which shows the GPS speed with clarity in both analogue and digital form. Furthermore it can track your progress and speed changes during the last 90 minutes. The device can be used out on the road and equally well in model sports such as radio control (RC) cars.

### Hardware

It was back in May 2006 when the Californians at Parallax launched their remarkable Propeller microcontroller. Truly exceptional was the provision of eight integrated CPUs that operated practically in parallel. Parallax calls these CPUs 'Cogs'. The system speed is 80 MHz, producing a maximum perfor-

mance of 160 MIPS.

The architecture of the Propeller makes it hard to compare with traditional microcontrollers. Because the eight Cogs can share tasks among themselves, interrupts are no longer required and the programmer has full control over the use of the Cogs. Reading in serial data, processing this data and output to the graphical LCD (GLCD for short) all take place in parallel.

The system speed of the Propeller is shown in the schematic (Figure 1), using a 5 MHz crystal that is multiplied internally by a factor of 16.

The KS107/108-compatible GLCD equipped



## Features

- Automatic baud rate recognition (4800 or 9600 baud) of the GPS mouse
- Designed for GPS mouse models with 3.3 V or 5 V supplies
- Graphical presentation of speed values for the last 90 minutes
- Speed and direction of movement analogue and digital
- Position- and time display (UTC time)
- Switchable between metric (m) and imperial (miles/feet) units
- Two buttons for selecting image and function within an image

with 128 x 64 pixels is controlled by an 8-bit wide data bus.

A 24LC256-I/P EEPROM (IC2) is used for storing an application-specific program (the firmware).

The MAX3232CPE (IC3) serves to adapt the levels between the Propeller and the GPS mouse used as GPS sensor. The latter can use either a 3.3 V or 5 V supply and must provide an RS-232 interface (4800 or 9600 baud). Serial GPS mouse units of this kind generally have a sub-D connection and it's

worth checking this and the supply voltage before purchase.

### Propeller firmware

Software for the Parallax Propeller is programmed with SPIN. On the Parallax homepage the necessary objects are already waiting for you:

- "FullDuplexSerial"
- "Propeller Eeprom"
- "Ks0108V1.6" (revised by the author)

With these objects we can create an EEPROM, a RS-232 interface for hooking up to a GPS mouse and the controls for a KS107/108-compatible GLCD.

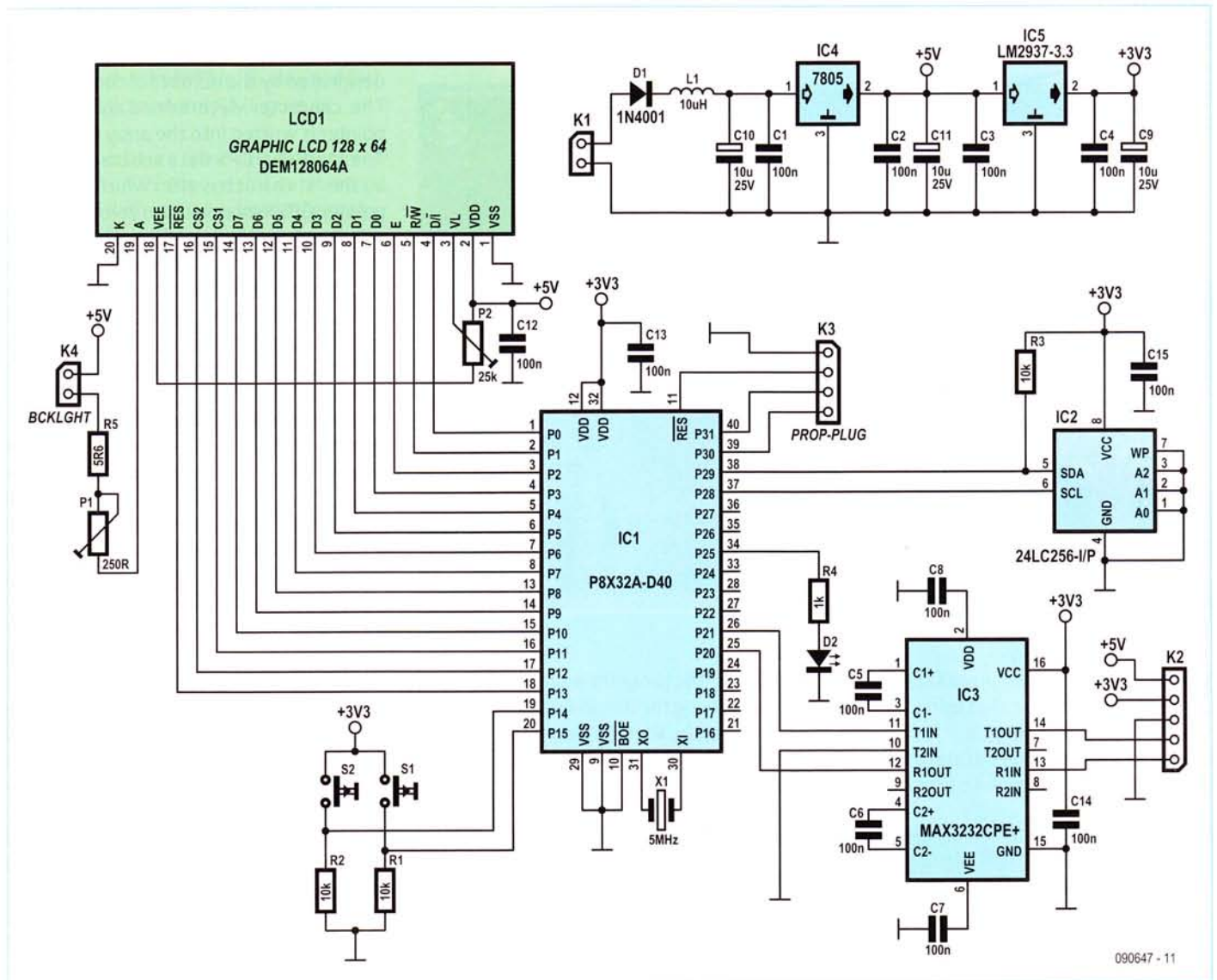


Figure 1. The circuit comprises basically just a single Propeller chip (IC1) and an LCD for the graphics. K2 is for connecting a serial GPS mouse.



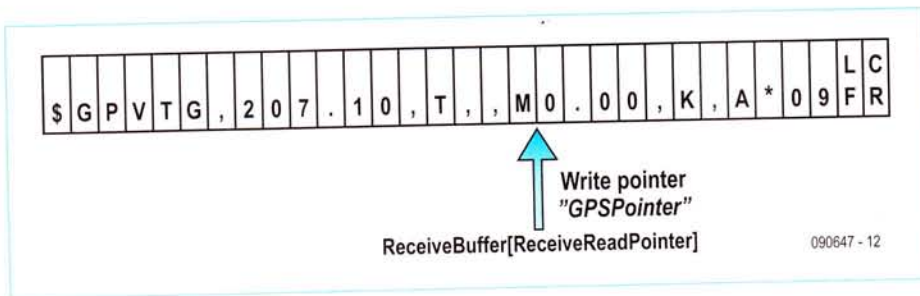


Figure 2. Format of a GPS data set.

The parallel processes of the Cogs make interrupts superfluous, which as already mentioned is a significant advantage of the Parallax Propeller.

In this GPS project you'll have the pleasure of programming five Cogs:  
 1. The main program GPS.Start requires one

screen. As they require a relatively long processing time a dedicated Cog is provided.

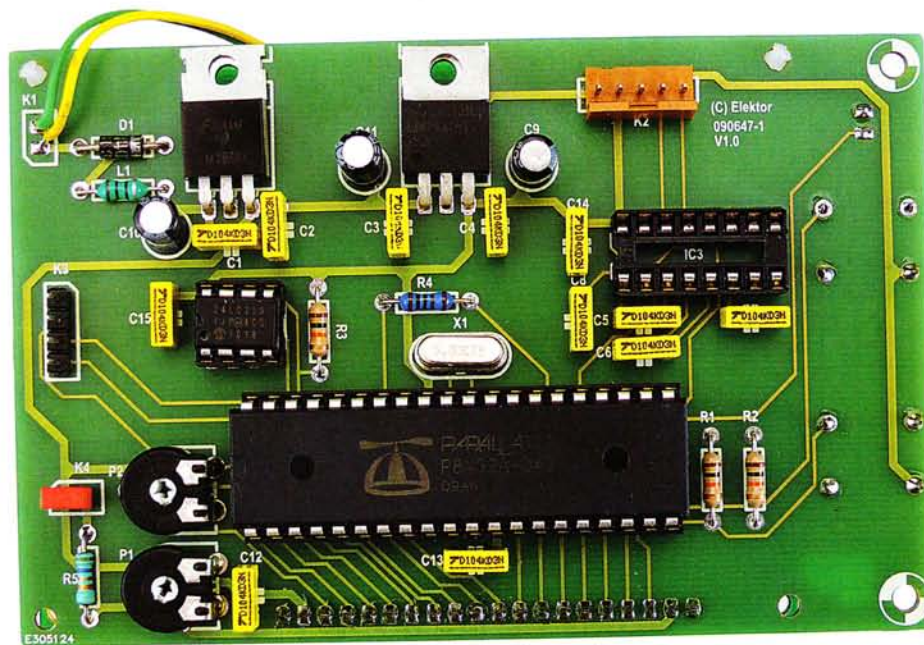
Let's now investigate the ReceiveData function of the fourth Cog in detail. With the library function FullDuplexSerial spin a character from the serial interface

compared with the write pointer ReceiveWritePointer. If the pointers are unequal, then the Variable ReceiveBuffer[ReceiveWritePointer] is read out and the read pointer is incremented by 1. This process is repeated until the write pointer is the same as the read pointer.

The GPS mouse delivers data using the NMEA-0183 protocol into ASCII format. Each set of data begins with the character '\$', followed by a two-character long transmit indicator and a three-character data label. After this come the data sets, separated by commas. Finally the set is closed with an optional checksum and CR/LF. A set can contain up to 82 characters, in a format designated by the number of commas.

The character determined by the read pointer is written into the array GPSBuffer. The start of a GPS data set is recognised by the '\$' character, after which the write pointer GPSPointer is set to zero. The character LineFeed (decimal 10) enables the end of a GPS string to be recognised. A GPS data set written to the GPSBuffer has the sample structure seen in Figure 2. In this example we are reading the GPS data sets \$GPGGA, \$GPVTG and \$GPRMC containing the following GPS data:

- \$GPGGA includes Latitude, Longitude, Quality of the signal received, number of satellites received and height above sea level.
- \$GPVTG includes the speed.
- \$GPRMC includes clock time, date and direction of movement (effectively compass direction).



**Practical matters**

To simplify construction a printed circuit board (Figure 3) has been designed, on which all components (apart from the GLCD) are mounted on the top side. The GLCD is attached to the other side.

The power supply voltage is connected to the multipin connector K1; a range between about 8 V and 18 V DC is permissible.

The GPS mouse is plugged in at multipin connector K2. Power for the mouse is applied either to pin 5 (5 V) or pin 4 (3.3 V) and Pin 3 (supply return). Pin 1 is commoned with the transmit line (TxD) of the GPS mouse and pin 2 with the receive line (RxD).

- Cog. From this main program the Cogs described next are called using the command COGNEW(entry,...).
2. Cog for FullDuplexSerial.start. Reads in data from the GPS mouse over the serial interface.
  3. Cog for KS0108V106.start. Drives GLCD with 128 x 64 pixels with KS107B/ KS108B-Controller. Preparation for text and graphic functions.
  4. Cog for ReceiveData. Writes data from the RS-232 interface into a ring buffer (circular buffer).
  5. Cog for Picture\_Page\_4\_Cog. Graphical functions are programmed on this

is read in. The program waits in this line of programming for the period that the character is read in. For this reason it is both logical and necessary to start a dedicated process (Cog) (cognew ReceiveData). Every new character received is written into the ring buffer ReceiveBuffer (array[0..50]) by means of the write pointer ReceiveWritePointer. The write pointer is incremented by 1 for each new character received. When the write pointer reaches a value of 51, it is reset to zero. To generate a GPS string, the function ReadBuffer is read out from the ring buffer in the main program. To this end the read pointer ReceiveReadPointer is



A jumper on K4 switches on the background lighting of the GLCD. Brightness is preset with P1 and contrast with P2.

LED D2 indicates the state of the data received as follows:

- Steady light = Checksum and quality of received data in order
- Rapid flashing = Checksum error
- Slow flashing = Quality error

The Parallax Propeller chip is programmed in-circuit using the SPIN programming language, which can be downloaded free at the Parallax homepage and the 'Prop Plug' programming adapter from Parallax. Connection to the PC is by USB cable. On the GPS board the 'Prog Plug' is plugged into the multipin connector K3 (Figure 4).

Before operation you need to check whether the GPS mouse still needs to be configured with software that either came with it or else can be downloaded from the manufacturer's website. The serial interface of the GPS Mouse should be configured as follows: 9600,N,8,1.

After powering up the GPS Propeller board the Receiver searches for the GPS mouse, first at 4800 baud. If a 9600 baud receiver is used, then the display will indicate only random characters initially. Afterwards the correct presentation of received data at 9600 baud will appear (Figure 5).

If after one second the data from a GPS mouse cannot be interpreted correctly the error message 'no GPS signal' is shown. A correct signal will produce an image with digital and analogue speed display (Figure 6).

At lower left the maximum speed achieved previously is shown.

Press button S2 can now switch between metric and imperial units (statute miles and feet). This setting is now valid for all subsequent displays and remains stored in the EEPROM even when power has been removed.

Operating S1 allows the following functional displays to be called up sequentially:

Direction of movement display (Figure 7) similar to a compass (digital and analogue). History display (Figure 8) with graphical

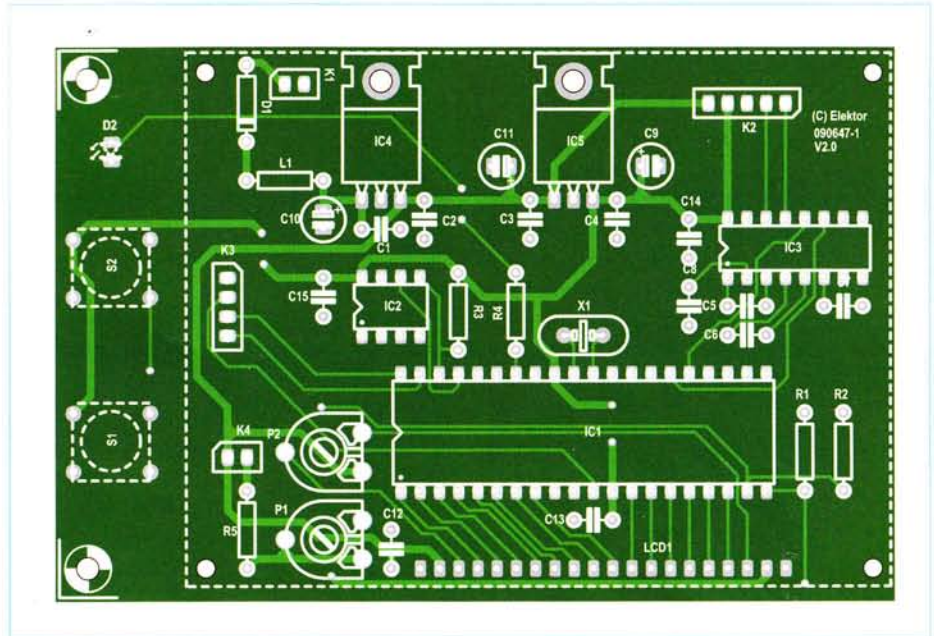


Figure 3. Inserting the components of the PCB developed for the GPS-Propeller.

## COMPONENT LIST

### Resistors

- R1,R2,R3 = 10kΩ
- R4 = 1kΩ
- R5 = 5.6Ω
- P1 = 250kΩ trimpot
- P2 = 25kΩ trimpot

### Capacitors

- C1-C9,C12-C15 = 100nF
- C9,C10,C11 = 10µF 16V

### Inductor

- L1 = 10µH

### Semiconductors

- D1 = 1N4007

D2 = LED (3mm)

IC1 = P8X32A-D40 (Propeller chip; Parallax)

IC2 = 24LC256-I/P

IC3 = MAX3232CPE+

IC4 = 7805

IC5 = LM2937ET-3.3

### Miscellaneous

X1 = 5MHz quartz crystal

LCD1 = graphic LCD 128 x 64, DEM128064

K1,K4 = 2-pin pinheader

K2 = 5-pin pinheader

K3,K5 = 4-pin pinheader

PCB # 090647-1 ([www.elektor.com/090647](http://www.elektor.com/090647))

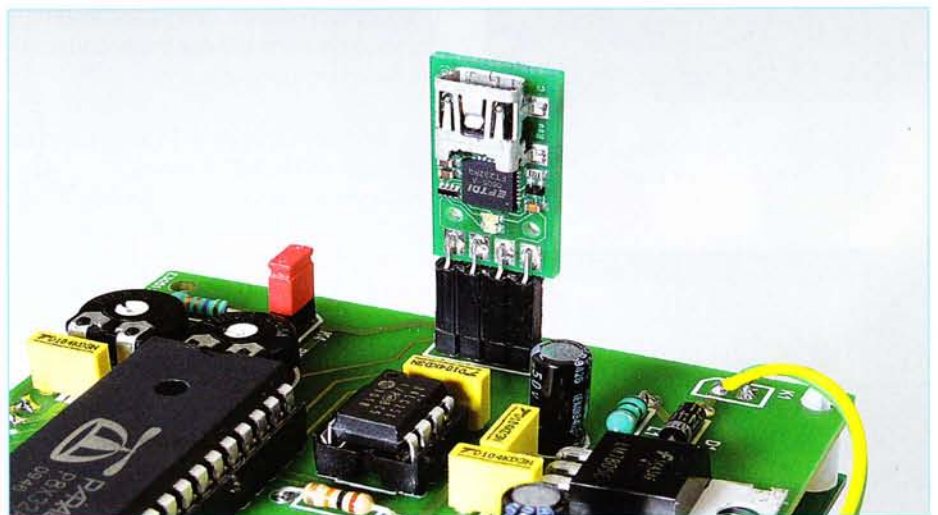


Figure 4. Programming uses the USB programming adapter 'Prog-Plug', which is plugged into the PCB.





Figure 5. Switching on the unit displays the GPS Search Image based on data received at 9600 baud.



Figure 9. Display of raw GPS data. Data blocks can be called up individually.



Figure 10. The group display combines data from all three GPS data blocks.



Figure 6. If the data is correct a speed display appears in km/h. Pressing S2 will switch to miles per hour (mph) which is the norm around Rocklin, CA.

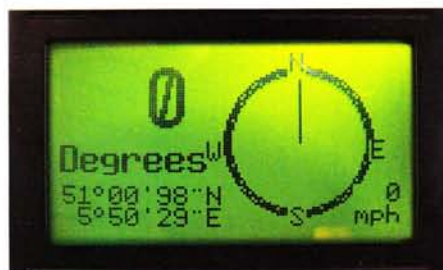


Figure 7. The compass-like display of motion direction.



Figure 8. History readout with graphical display of the speed progression.

progress readout through 90 minutes in 1 minute steps and additional display of current speed. At power-up the History function is first disabled. The word 'OFF' is displayed (on the right, next to 'History') indicates there is no data recorded. Operating switch S2 initiates recording and 'ON' appears. If switch S2 is held down for longer than 5 seconds in 'OFF' mode, the data is wiped. The legend 'Erase Data' alerts this. Another brief push of S2 from 'ON' to 'OFF' saves the current data into the EEPROM. At lower left (at '#60' on the display) a countdown mechanism is included. This decrements from 60 to 0, one second at a time, then the last minute is shown. Next the countdown starts again from the beginning. This makes it easy to spot when the next display refresh is coming up. The countdown display is static when no GPS data is being received. Every minute a line is displayed showing the minimum and maximal speed limiting values.

Raw data display (Figure 9) with the data received from the GPS mouse. Press button pages through the data blocks \$GPGGA, \$GPVTG and \$GPRMC.

Group data display (Figure 10) with the display of all the data blocks: Speed in large characters, height above sea level, direction of movement, signal quality (0/1), total number of satellites, clock time and date (UTC time), position and maximum speed. The maximum speed achieved previously, which is also stored in the EEPROM, can be recalled by pressing S2. According to the module that was preselected for display on the analogue and digital speed display

(Figure 6), the screen can show kilometres per hour (km/h) and metres (m) or miles per hour (mph) and feet (ft).

(090647)

### Internet Links

- [1] [www.parallax.com](http://www.parallax.com)
- [2] [www.spinvent.co.uk/](http://www.spinvent.co.uk/)
- [3] [http://en.wikipedia.org/wiki/NMEA\\_0183](http://en.wikipedia.org/wiki/NMEA_0183)  
(Wikipedia, NMEA data format)
- [4] [www.kowoma.de/gps/zusatzerklaerungen/NMEA.htm](http://www.kowoma.de/gps/zusatzerklaerungen/NMEA.htm)  
(detailed information on NMEA in German, use Google search engine or Google Chrome to translate)
- [5] [www.elektor.com/090647](http://www.elektor.com/090647)  
(project page with software download and ordering details for PCB)

### About the author

Following Communication Technology studies at University of Applied Sciences (UAS) in Bingen, Germany, Steffen Möritz has been employed for more than 20 years in the industrial automation field in the automotive industry. His spare time is occupied designing microcontroller circuits for automotive and model applications, primarily using Parallax Propeller and PIC microchips. Steffen can be reached at [steffen@moeritz.com](mailto:steffen@moeritz.com).





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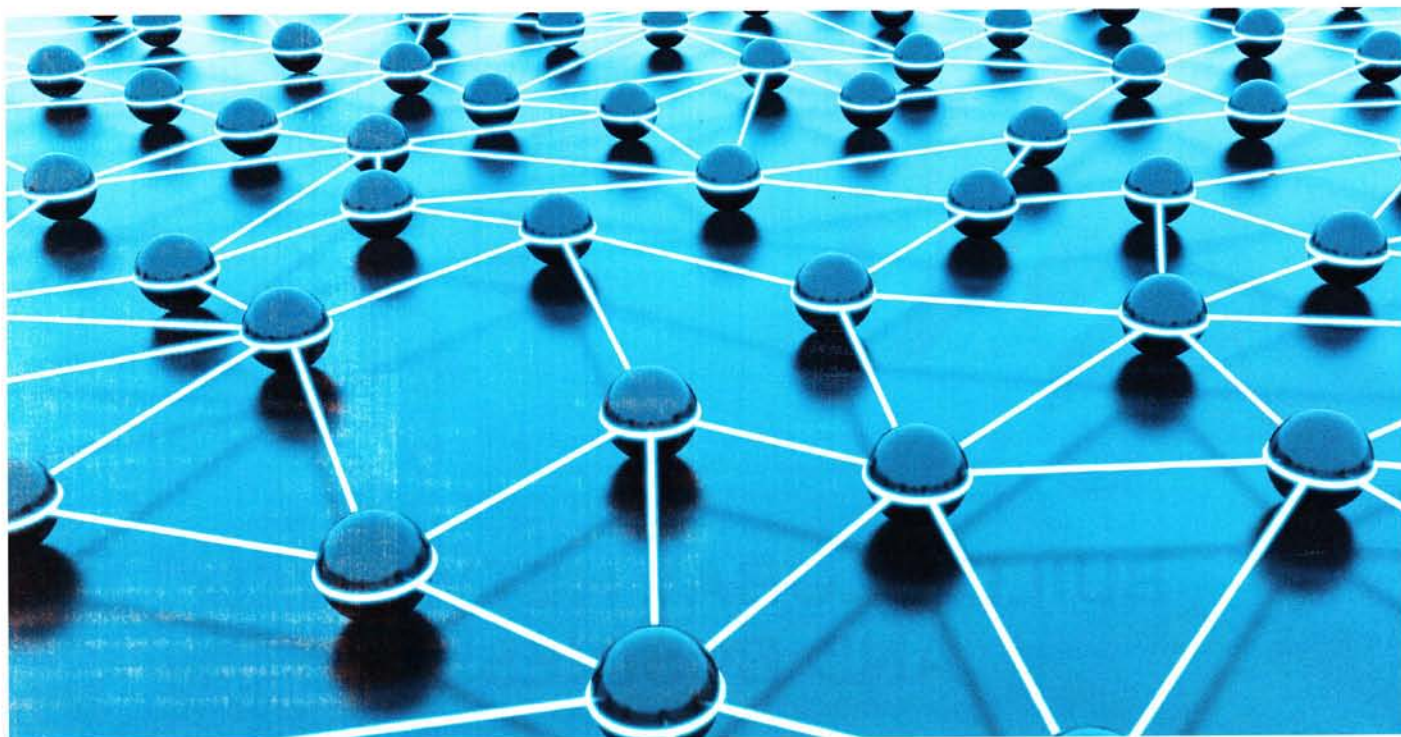
THE GLOBAL STAGE FOR INNOVATION





# ZigBee Today & Tomorrow

## Technology and applications



By Joe Lomako (TRaC) (UK)

When it comes to applying ZigBee technology, the ideas people are coming up with are proving to be more and more elaborate and inventive. It is no surprise then that many (if not all) of the biggest names in wireless and microprocessor technology have shown considerable interest if not direct involvement. What's humming out there?

ZigBee is a specification which defines a high level communication protocol using low power digital radios using the IEEE 802.15.4 standard. The idea behind ZigBee is that it offers an infrastructure for a Wireless Personal Area Network (WPAN) which is highly adaptive, simpler, less expensive and consumes less power than other WPANs.

There are essentially three flavours of ZigBee: ZigBee, ZigBee PRO and ZigBee RF4CE which is a similar technology that is used for RF control of consumer electronics.

The differences between the various technologies can be defined using a combination of the Network topologies, the security employed and the method of Network addressing. This can be shown in contrast in **Table 1**.

### Let's start networking...

Each ZigBee network is essentially made up of a 'coordinator', 'router' and an 'end device'. They can all be fully functioning devices

with an intrinsic function but will also perform ZigBee functionality. The coordinator forms and manages the network; the router can route messages as well as allow other devices to join the PAN router and the end device is just that. It can join a network but has no routing capability. These devices are defined in **Figure 1**. In essence the ZigBee network can be made up of two topologies: Tree/Star (**Figure 2**) or Mesh (**Figure 3**).

**Table 1. Zigbee basic versions and their capabilities**

	ZigBee	ZigBee PRO	RF4CE
Topology	Star / Tree	Mesh	Tree
Security	Normal	High	Normal
Network Addressing	Distributed	Stochastic	Pairing



One of the strengths of ZigBee PRO is the meshing network topology which means that the networks can be extended over considerable geographical areas, such as in a large buildings or even an industrial pipeline. It has a 'self healing' mechanism which means that if one of the components of a multihop route from one device to another leaves the network for any reason an alternative route using alternative adjacent devices will be identified and implemented.

As for the end products, in simple terms, a ZigBee device is constructed of a ZigBee compliant platform (a radio part and a ZigBee part) with the appropriate application (profile) sitting on top. The radio is based around the 802.15.4 standard (and comprises of a PHY and MAC layer) and the ZigBee 'stack' sits on top. The abstract layer models in Figures 4 and 5 illustrates this.

.. and then profiling

The ZigBee platform becomes a so called functioning 'ZigBee device' when it has a 'profile' placed on the top of it. A profile is a set of commands and attributes which are used to send specific messages over a ZigBee network.

There are two types of profile; a Public Profile, which has been developed by the ZigBee Alliance members and has specific command attributes. Anybody employing a Public Profile must adhere to the rules of that particular profile. Presently there are several Public Profiles, which we will touch on later. There is also another type of profile, the Manufacturer Specific Profile (MSP). These are proprietary profiles which a manufacturer may develop because he wishes to use the ZigBee technology but not the Public Profiles.

Public ZigBee profiles

There are several profiles at present. These include

- ZSE, also known as Smart Energy;
- ZHA, also known as Home Automation;
- ZTS, also known as Telecoms Applications;
- ZHC, also known as Personal Healthcare;
- ZBA, also known as Construction and Building;
- ZRC, also known as Consumer Electronics.

Each is discussed briefly below.

**Smart Energy Profile (ZSE)** has been designed to be used in smart home area networks (HANs), to manage and improve the efficiency of energy consumption. There are many devices presently on the market from utility meters (gas, water and electric) to in-home displays, which can provide historical and real-time data indicating energy usage. Smart energy devices (Figure 6) are being enabled across the entire world from small households to entire governments.

**Home Automation (ZHA)** — was one of the first profiles to reach maturity and has developed to become a very robust and ubiquitous tool in the ZigBee box. It enables the user to simplify the house-

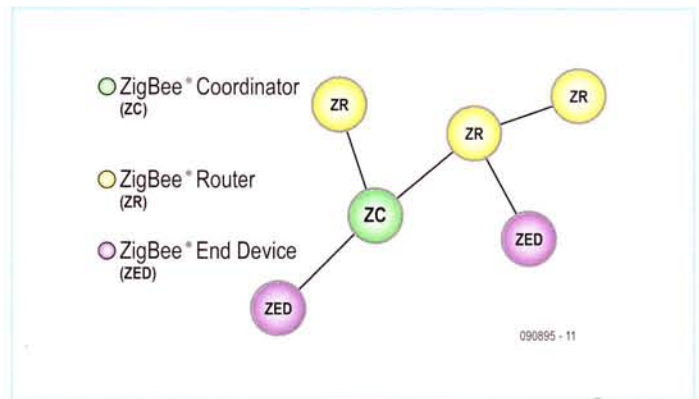


Figure 1. The message routing within a Zigbee network is largely governed by the Zigbee Coordinator (ZC).

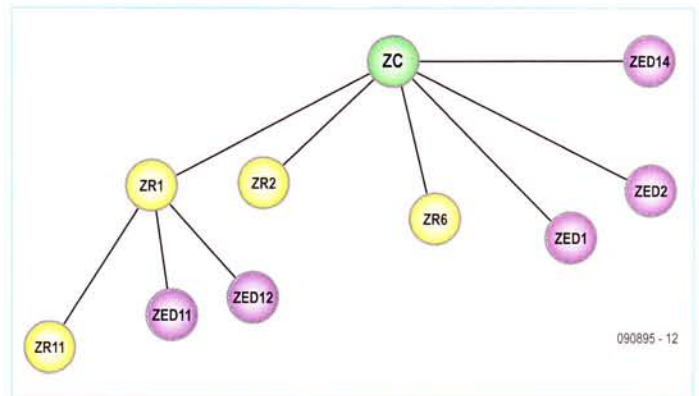


Figure 2. Zigbee network with tree structure.

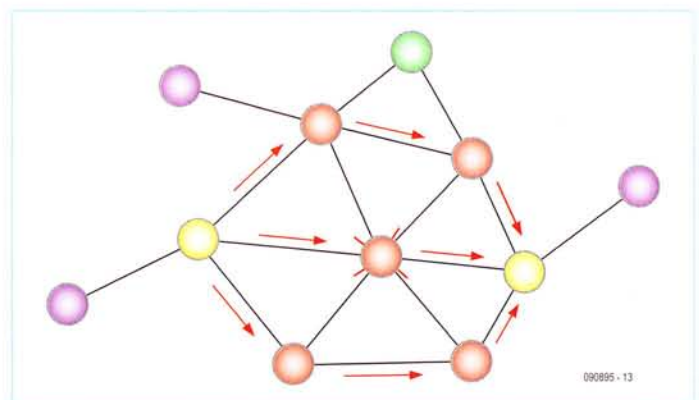


Figure 3. Zigbee network with mesh structure.

hold tasks and create a unique experience within the household. There are many products on the market which are very diverse in their applications; these include simple lighting control such as on/off and dimmer switches and lights. When used in connection with other types of technology the whole home automation system can be enhanced. For example, the light mood settings on one's home can be set from a smartphone, or if arrival at home is going to be late the drapes could be closed remotely. The possibilities are end-



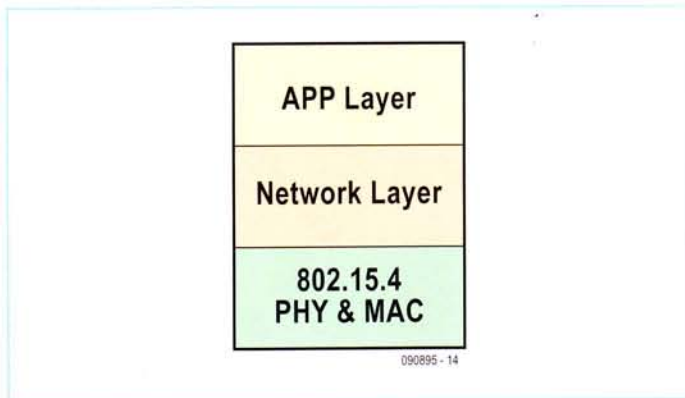


Figure 4. The compliant platform.

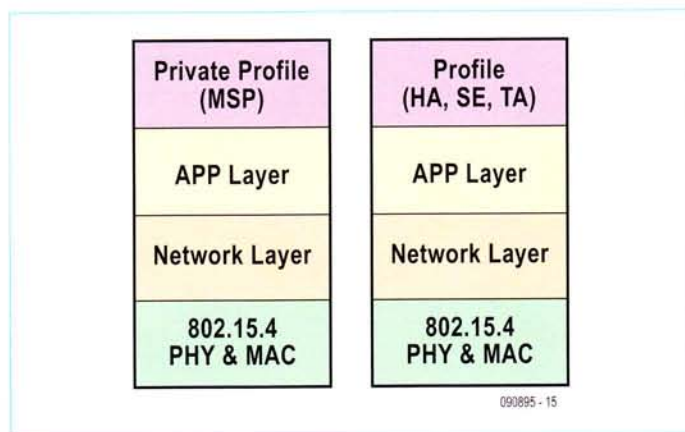


Figure 5. Examples of Public and Private Profiles.

less and applications are becoming more and more versatile.

**Telecoms Profile (ZTS)** – is designed to enable information delivery to mobile-enabled devices. Imagine a visitor walking round a museum viewing the exhibits and when a particular exhibit is reached further information is required on this. Quite often it would mean reading the programme or typing in a number on a cumber-



Figure 6. A ZigBee'd Smart Energy meter.

some audio handset supplied by the museum to play the specific audio. With ZigBee telecoms applications, the ZigBee enabled mobile device will automatically detect the location and send the appropriate information for that exhibit creating a more enhanced user experience.

**Healthcare (ZHC)** – is one of the newest profiles to be developed and is probably one of the most important profiles available. The world's population is ageing, therefore greater demands are being placed on the healthcare infrastructure. ZigBee technology is being used to support the ageing population maintain their independence by providing assisted living support. There are devices which can be installed in an elderly user's home which can monitor if they have a fall or can go further and monitor if a bath is overflowing or a gas cooker has been left on. In the instance that an 'alert' is issued a central monitoring station can pick up the message and provide assistance if needed.

In addition to this there is an increase in chronic medical conditions such as obesity, diabetes, chronic pulmonary disorders and high blood pressure. A ZigBee'd blood pressure meter is shown in **Figure 7**. As a result of this there are many organisations which have been formed with the objective of developing solutions and infrastructure to support the medical professions in meeting the demands of their patients needs. ZigBee technology is playing a very important role in healthcare and is increasingly being employed in medical devices or aids. This type of remote monitoring has attracted considerable interest over the last few years and some studies have suggested it could provide considerable savings for the world's health services or enable doctors and health professionals to increase the number of patients they can attend to, in some cases doubling them!

Take for instance a diabetic who has to monitor their blood sugar 2-3 times per day. In the traditional system, they would take their reading on their handheld system and then usually record the results in a journal. They would take this to the doctor at their next appointment, which could be days or weeks away. The doctor would analyse the data and act upon it by which time the information recorded may have no bearing on how the patient is today. However, by using a ZigBee-enabled blood sugar monitor which is connected to a remote monitoring system (which could be a specialist centre staffed by qualified nurses or health professionals). The patient would use a device which would be connected to the remote monitoring station via a cradle. The patient would make their measurement which would be displayed on the meter, when the meter was replaced on the cradle the recorded data would be automatically sent to the remote monitor. This takes a few seconds compared to several days on the traditional system. Now the remote centre would assess the data and determine if any immediate action need be taken. A real life case in a trial of a similar system showed that a diabetic patient was not adhering to a strict diet and via the remote monitoring system a doctor was able to intervene before any serious condition occurred. So clearly the healthcare industry is one which can really benefit from ZigBee technology.



**Construction and Building Automation (ZBA)** — is designed to provide an adaptable system of management of complex buildings. It provides a means of economically centralising lighting, HVAC and security. This also allows remote monitoring of the efficiency of many of the systems. In addition to this, in new constructs where lighting and/or security systems need to be adaptable; this ZigBee profile provides an excellent way of achieving this adaptability.

**RF4CE (ZRC)** — This profile is built on the ZigBee RF4CE platform and will allow an advanced functionality and user experience in the control of home entertainment equipment and domestic products. Although at the time of writing this profile is in its infancy, the market requirement is constantly changing and the applications in which we will see the RF4CE profile are potentially endless.

**Conclusion**

Clearly ZigBee is incredibly versatile and in some respects it is only limited by the imagination of the designer to come up with inno-



Figure 7. This blood pressure monitor can be read out remotely over a Zigbee link.

vative and fantastic new ideas for applications in which to employ the technology.

Yes ZigBee does have its critics, and always will, which is embraced, as criticism is the fuel of innovation. So in the greater perspective ZigBee has a lot to offer and is clearly here to stay; as can be seen from the various examples above ZigBee can (and will) be used in many different product types and applications and who knows what's next?

(090895)

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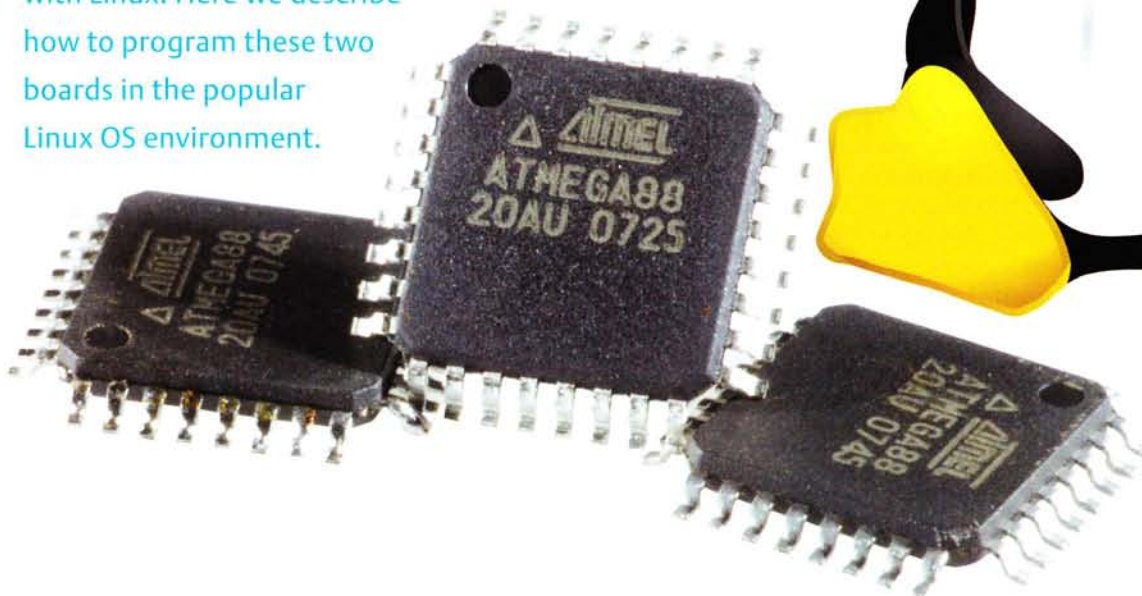


# Tux and ATmega

## Programming ATM18 boards under Linux

By Wolfgang Rudolph (Germany)

Many electronics enthusiasts and professionals use the open-source operating system Linux because they appreciate the technological elegance of this proven and continually upgraded operating system. The Elektor ATM18 AVR board and the Minimod18 can also be used with Linux. Here we describe how to program these two boards in the popular Linux OS environment.



Windows users have it easy. If you have a suitable USB programmer, you can program the microcontroller module of the ATmega board directly in the AVR Studio development environment [1]. Linux users, by contrast, are faced with an initial problem because AVR Studio is only available for Windows. Unfortunately, it does not run properly inside the Windows API wrapper Wine [2], which is able to simulate the Windows OS environment for many Windows programs.

But where there's a will, there's a way. With the command-line program AVRdude, you can use the ATM18 AVR board under Linux. Of course, this also works with Minimod18, although 'direct' microcontroller programming is usually not necessary with this especially compact module because Minimod18 has a boot loader that can receive hex files via USB and store them in memory. If you 'overhaul' the Minimod18 with a programmer, the boot loader will be overwritten and one of the key features of the module will be lost. In this case, the boot loader must be downloaded into flash memory again to restore normal operation.

The following instructions apply to a programmer compatible with AVRISP Mk II, such as the Elektor AVRprog USB programmer

designed by Benedikt Sauter [3]. If you use a different type of programmer, see the inset for more information. The instructions are based on a Debian distribution of Linux.

### Installation

Here we assume that you have a good basic understanding of how to install and use programs on a Linux system. In order to program the microcontroller of the Elektor ATM18 AVR board, you first need some software. As usual, you can use apt-get to meet this requirement fairly simply (assuming the computer has a connection to the Internet). However, you must first log in as the root user by typing `sudo` (depending on the distribution) and your password immediately ahead of the apt-get command.

Next, enter the following command after the prompt:

```
apt-get install avrdude avr gcc-avr avr-libc
gdb-avr avra make udev
```

Answer the question 'Do you want to continue?' with 'Yes'.



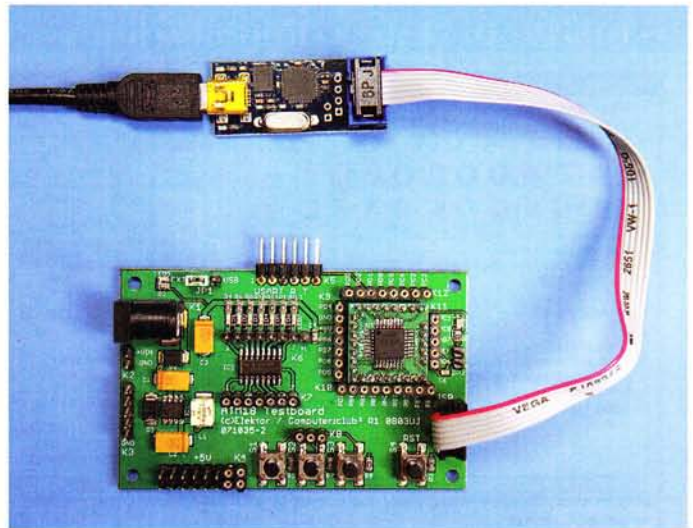


Figure 1. Hey, it works under Linux too: microcontroller programming with the Elektor AVRproG USB programmer [3].

The necessary packages will now be loaded and preconfigured. A few older packages may be de-installed and replaced by other packages or newer versions. If you see a message reporting that the kernel does not support udev, you must update the kernel before udev (or a new version of udev) can be loaded. Although it is possible to continue with the installation in this situation, you should not do so, since there is a risk of a system crash. A reliable kernel update is always the preferred solution. However, you can rest assured that Linux does not make it easy for foolhardy users to make mistakes of this sort. A particular file must be altered before Linux actually comes into danger.

Before you update the kernel, it's a good idea to quickly check whether the installation can actually run with the udev version already present. As the saying goes: nothing ventured, nothing gained!

After the installation process has completed, you can connect the USB programmer to the USB port and use the `lsusb` command to determine the device ID:

```
pole1:/home/wolf# lsusb
Bus 005 Device 003: ID 090c:6300 Feiya
  Technology Corp.
Bus 005 Device 001: ID 1d6b:0002 Linux
  Foundation 2.0 root hub
Bus 004 Device 002: ID 046d:c517 Logitech, Inc.
  LX710 Cordless Desktop Laser
Bus 004 Device 001: ID 1d6b:0001 Linux
  Foundation 1.1 root hub
Bus 003 Device 001: ID 1d6b:0001 Linux
  Foundation 1.1 root hub
Bus 002 Device 001: ID 1d6b:0001 Linux
  Foundation 1.1 root hub
Bus 001 Device 004: ID 0a12:0001 Cambridge
  Silicon Radio, Ltd Bluetooth Dongle (HCI
  mode)
Bus 001 Device 001: ID 1d6b:0001 Linux
  Foundation 1.1 root hub
Bus 001 Device 005: ID 03eb:2104 Elektor
wolf@pole1:~$
```

The ID of our programmer is 03eb:2104. If you can't read the ID with `lsusb` (sometimes new devices are not shown), you can use `dmesg` instead:

```
[ 5145.834284] usb 5-7.4.4: new full speed USB
  device using ehci_hcd and address 10
[ 5146.150088] usb 5-7.4.4: config 1 descriptor
  has 1 excess byte, ignoring
[ 5146.150088] usb 5-7.4.4: configuration #1
  chosen from 1 choice
[ 5146.154083] usb 5-7.4.4: New USB device
  found, idVendor=03eb, idProduct=2104
```

```
[ 5146.154083] usb 5-7.4.4: New USB device
  strings: Mfr=1, Product=2, SerialNumber=3
[ 5146.154083] usb 5-7.4.4: Product: AVRISP mk2
  (CC2)
[ 5146.154083] usb 5-7.4.4: Manufacturer:
  Elektor
[ 5146.154083] usb 5-7.4.4: SerialNumber:
  0000A00128255
wolf@pole1:~$
```

The most recently recognised device appears at the end of the (long) output list. With the Elektor programmer, you will see `idVendor=03eb`, `idProduct=2104`. This gives you the assurance that the programmer has been recognised properly. If you don't like wading through the full `dmesg` output list, you can type `dmesg | tail` to display only the tail of the list. Incidentally, the number in square brackets at the start of each line in the list is not significant; it is simply the elapsed operating time of the computer, and it is not displayed by all versions of Linux.

If you use a different programmer, it will of course be reported with a different ID. If you can't find it in the device list, disconnect the programmer from the USB hub and enter the `lsusb` or `dmesg` command again. Now you should be able to see what has changed in the command output (which device is missing or has been added).

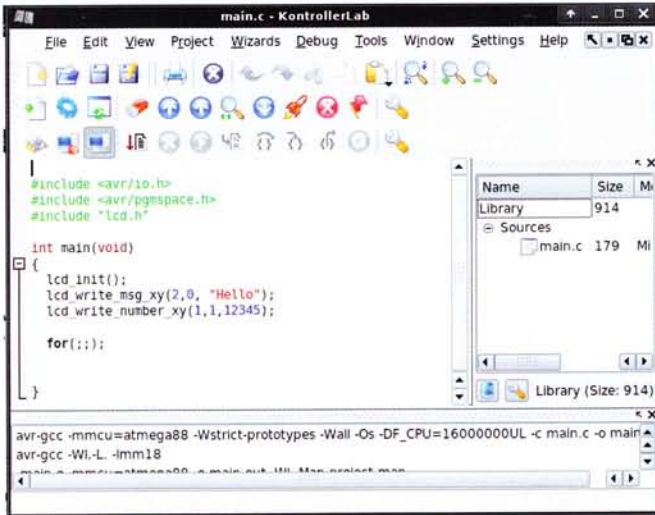
To avoid having to log in as the root user every time you use the programmer, you can edit the `permissions.rules` file, which is accessed via path `/etc/udev/rules.d/020`. Near the end of this file, just before `LABEL="permissions_end"`, there is an entry containing the device ID you found above. You can use the `vi` editor (or any other suitable editor) to make the desired changes:

```
vi /etc/udev/rules.d/020_permissions.rules

# AVR ISP mkII Atmega Programmer
SUBSYSTEM=="usb_device",
  SYSFS{idVendor}=="03eb",
  SYSFS{idProduct}=="2104", GROUP="plugdev",
```



## A matter of taste: command lines



Graphic front ends for AVRdude (which has a command line user interface) are available on the Web, although we haven't tested any of them. The fact that we restrict ourselves to the command line interface here should not be regarded as a value judgement; it simply reflects the notorious difference between Linux users and Windows users.

If your distaste for command line interfaces is sufficiently large, you can try alternatives such as a Java GUI [6] or a KDE program called Kontrollerlab [7], although it appears that the later program is no longer being maintained. With the exception of the simulator, Kontrollerlab is certainly usable as a substitute for AVR Studio under Linux. Unlike AVR Studio, it supports AVRdude without plugins, so you can download program code to the ATmega directly from the IDE.

### Other programmers

The AVRdude program has a large number of options. For example,

```
MODE="0660", SYMLINK+="foo"
LABEL="permissions_end"
```

If you enter "plugdev" for GROUP=, users without root privileges will also be able to use the programmer.

If vi (the grandfather of all editors) isn't your cup of tea, you can make the changes with any other editor that has root privileges. A good choice here is Midnight Commander, which is something of a Swiss army knife for Linux.

The changes take effect only after the udev configuration has been reloaded as follows:

```
udevcontrol reload_rules
```

Now you can query the programmer with the following command:

```
avrdude -c avrispv2 -P usb -p m88
It replies:
```

you can use the -c option to select a different programmer. If you only have a programmer with a parallel (printer) port interface available, you can use it this way. You can also ask AVRdude whether it recognises the connected programmer:

```
avrdude -vvv -c help
```

If it doesn't recognise the connected programmer, it responds:

```
avrdude: Can't find programmer id „help“
```

Valid programmers are:

```
dasa3 = serial port banging, reset=!dtr
sck=rts mosi=txd miso=cts [/etc/avrdude.conf:693]
dasa = serial port banging, reset=rts
sck=dtr mosi=txd miso=cts [/etc/avrdude.conf:680]
siprog = Lancos SI-Prog <http://www.lancos.com/siprogsch.html> [/etc/avrdude.conf:667]
```

If you have a programmer of a completely unknown type or use a homemade programmer, you can view the AVRdude main page to see how to configure the pin assignments for the parallel port:

Default Parallel port pin connections  
(these can be changed, see the -c option)

Pin number	Function
2-5	Vcc (optional power supply to MCU)
7	/RESET (to MCU)
8	SCK (to MCU)
9	MOSI (to MCU)
10	MISO (from MCU)
18-25	GND

```
avrdude: AVR device initialized and ready to accept instructions
```

```
Reading | #####
##### | 100% 0.01s
```

```
avrdude: Device signature = 0x1e930a
```

```
avrdude: safemode: Fuses OK
```

```
avrdude done. Thank you.
```

All of the above applies equally well to the Minimod18. Its boot loader simulates a programmer (more specifically, a USBasp programmer) and can also communicate with AVRdude. In this case, you must enter the parameter -c USBasp instead of -c avrispv2 -P usb.

You also have to enter -p m328p for the microcontroller, as other-



wise AVRdude will complain that the signature is wrong.

**A hot topic: fuses**

This is not the place for playing around, since you can easily mess things up with the wrong fuse settings, or even make the microcontroller unusable. Whenever you need to change fuse settings, always engage your brain first and think things through twice before you do anything.

Enter the following command to read the fuse settings:

```
avrdude -p m88 -c avrispv2 -P usb -F -v -B 10
-U hfuse:r:high.txt:i -U lfuse:r:low.txt:i
```

AVRdude responds with:

```
avrdude: Version 5.10, compiled on Jan 19 2010
at 18:01:15
Copyright (c) 2000-2005 Brian Dean,
http://www.bdmicro.com/
Copyright (c) 2007-2009 Joerg Wunsch
```

...

```
avrdude: AVR device initialized and ready to
accept instructions
```

```
Reading | #####
##### | 100% 0.02s
```

```
avrdude: Device signature = 0xff00ff
avrdude: Expected signature for ATMEGA88 is 1E
93 0A
avrdude: safemode: lfuse reads as 62
avrdude: safemode: hfuse reads as DF
avrdude: safemode: efuse reads as 7
avrdude: reading hfuse memory:
```

```
Reading | #####
##### | 100% 0.00s
```

```
avrdude: writing output file "high.txt"
avrdude: reading lfuse memory:
```

```
Reading | #####
##### | 100% 0.00s
```

```
avrdude: writing output file "low.txt"
```

```
avrdude done. Thank you.
```

```
pole1:/home/wolf#
```

There's not enough space here to print the full response (AVRdude

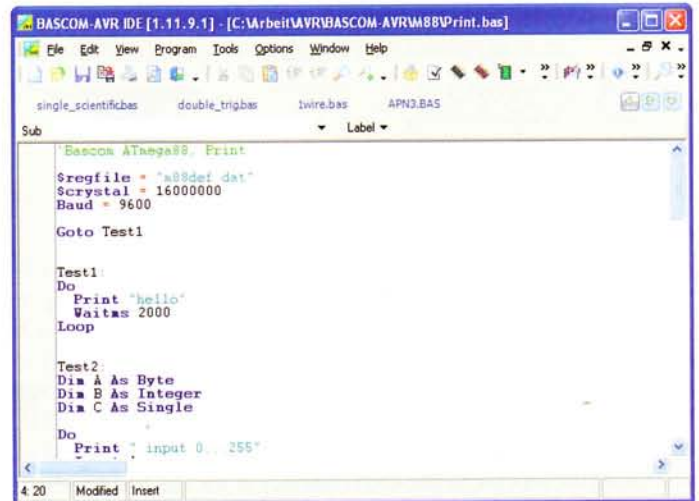


Figure 2. Whipping up a test program: BASCOM feels perfectly at home under Linux with the Windows API wrapper Wine.

is a real blabbermouth). The two lines you're interested in at this point are:

```
avrdude: safemode: lfuse reads as 62
avrdude: safemode: hfuse reads as DF
```

This gives you the fuse settings you need to know. At the same time, they are written to the files low.txt and high.txt as specified in the command. You can view the file contents with:

```
cat low.txt.orig
:01000000629D
:00000001FF
```

and

```
cat high.txt.orig
:01000000DF20
:00000001FF
```

If it's necessary to change the fuse settings, there is a handy tool available for calculating the hex values: Fusecalc [4]. Of course, you can also calculate them by hand with the aid of the data sheet. However, remember what we said: a single mistake could be fatal for the microcontroller.

You can use AVRdude to write the fuse settings to the microcontroller in the same way as you read them:

```
avrdude -c avrispv2 -P usb -p m88 -U
lfuse:w:0x62:m -U hfuse:w:0xDF:m
```

Here we omit the response from AVRdude, which gets a bit boring after a while. The main thing to check is that there aren't any error messages. If there are, first check the connecting cables and the supply voltage. If errors are indicated but you cannot find the cause, you can use the -f option to force AVRdude to try to write the settings to the microcontroller despite the error message(s).



**Knuckle down, ATmega!**

The next thing you need is a program for the ATmega. You can write your own with gcc or BASCOM (which runs nicely under Wine), or you can use any desired program you already have available, such as the LED running-light display program from the first article in the ATM18 AVR board series (which can be downloaded free of charge from the Elektor website [5]). In any case, you only need the hex file, which is designated main.hex here. Use the following command to download the hex file to the flash memory of the microcontroller:

```
avrdude -p m88 -c avrispv2 -P usb -F -v -B 10
-F -U flash:w:main.hex
```

The response from AVRdude (only the final part is printed here) is:

```
...
avrdude: AVR device initialized and ready to
accept instructions

Reading | #####
##### | 100% 0.01s

avrdude: Device signature = 0x1e930a
avrdude: safemode: lfuse reads as FF
avrdude: safemode: hfuse reads as DF
avrdude: safemode: efuse reads as 1
avrdude: NOTE: FLASH memory has been specified,
an erase cycle will be performed
To disable this feature, specify the
-D option.
avrdude: erasing chip
avrdude: reading input file "main.hex"
avrdude: input file main.hex auto detected as
Intel Hex
avrdude: writing flash (146 bytes):

Writing | #####
##### | 100% 0.14s

avrdude: 146 bytes of flash written
avrdude: verifying flash memory against main.
hex:
avrdude: load data flash data from input file
main.hex:
avrdude: input file main.hex auto detected as
Intel Hex
avrdude: input file main.hex contains 146 bytes
avrdude: reading on-chip flash data:

Reading | #####
##### | 100% 0.07s
```

```
avrdude: verifying ...
avrdude: 146 bytes of flash verified

avrdude: safemode: lfuse reads as 62
avrdude: safemode: hfuse reads as DF
avrdude: safemode: efuse reads as 1
avrdude: safemode: Fuses OK

avrdude done. Thank you.
```

Now the microcontroller has the new program code in its flash memory, and you can use the program. Don't forget to connect the appropriate I/O pins of the microcontroller to the inputs of the ULN2003 on the ATM18 AVR board [5], so you can see the running-light pattern on the LEDs.

You need a different program for the Minimod18, since it doesn't have any LEDs on board (but it does have a display module). A program that outputs a simple message is adequate for testing.

As you can see, it's not that difficult to use the ATM18 AVR board or Minimod18 module with a Debian Linux distribution. If you use a different distribution, you will need to modify these instructions appropriately because program installation is slightly different and there are a few other differences in how things are done.

We conclude our instructions in the friendly spirit of AVRdude:

```
Elektor/cc2 done. Thank you!
```

Now you can start having fun with the ATM18 AVR board or Minimod18 in your Linux environment!

(100177-1)

**Internet links**

- [1] [www.atmel.com/dyn/products/tools\\_card\\_mcu.asp?tool\\_id=2725](http://www.atmel.com/dyn/products/tools_card_mcu.asp?tool_id=2725)
- [2] [www.winehq.org](http://www.winehq.org)
- [3] [www.elektor.com/080083](http://www.elektor.com/080083)
- [4] <http://frank.circleofcurrent.com/fusecalc/fusecalc.php>
- [5] [www.elektor.com/071035](http://www.elektor.com/071035)
- [6] <http://avr8-burn-o-mat.aaabbb.de/>
- [7] <http://sourceforge.net/projects/konrollerlab/>



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# Power Line Communication & the Chip Issue

## Will S-FSK win the 'format war'?

By Giacomo Cesari (Future Electronics, Italy)

If spread-spectrum frequency shift keying (S-FSK) becomes the dominant standard for smart meters, components implementing it will become commercially attractive to OEMs for any kind of PLC with a low data-rate requirement, for applications such as building automation and street lighting control. Here's a guide to implementing S-FSK technology in new modem designs, describing how System-on-Chip (SoC) devices address the challenges of the application. Chip hunters — enjoy!

While technology for implementing Power Line Communication (PLC) has been in existence for decades, it has not yet succeeded in becoming a mainstream application. This is not least because of the technical difficulty of transmitting data reliably over a medium that also carries high alternating currents.

Governments are responding to the threat of climate change by investing billions in the installation of smart energy meters, which promise to reduce power consumption and to improve the regulation of demand. The vision for smart meters, however, requires a means of communicating to and from a control centre, and the power line would appear to be a convenient medium for this. And so meter manufacturers and their utility company customers are now witnessing something like the 1980s' Betamax vs. VHS 'format war', as competing semiconductor suppliers push rival technologies for implementing meter networks, not only via PLC but also short-range radio, cellular radio and so on.

### What makes S-FSK so popular?

Frequency band allocations across power lines differ from region to region of the world. In Europe, EN 50065-1 (published by CENELEC) specifies the frequency allocations from 3 kHz to 148.5 kHz, see **Table 1**.

In North America, FCC Part 15 defines a wider and less rigid spectrum allocation, across a range greater than 500 kHz.

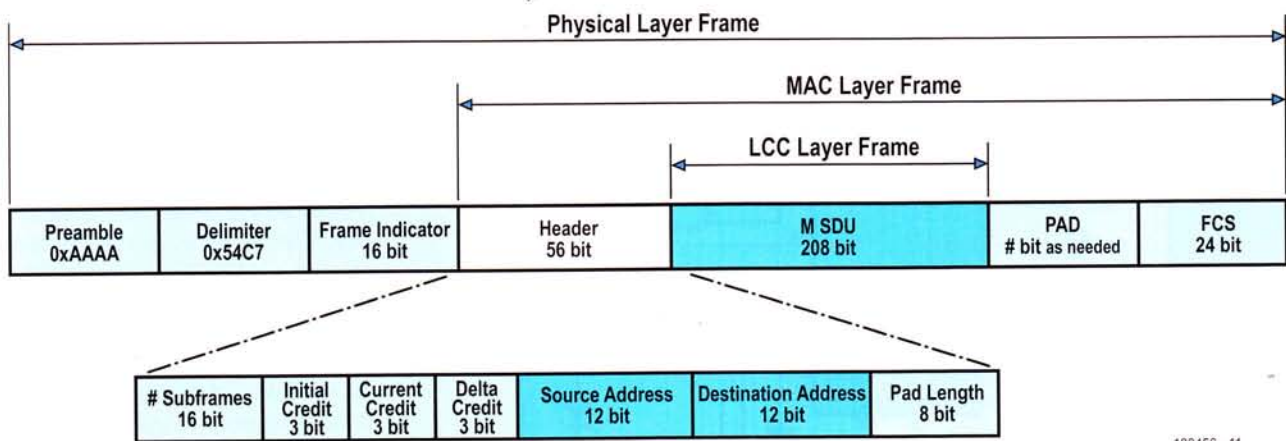
In FSK modulation schemes, information is transferred to the Power Line in the form of two frequencies:  $f_s$  and  $f_m$  (where the index 's'

(space) means 0, and 'm' (mark) means 1). FSK modulation has been used for many years, and in the past, when it was implemented in the analogue domain, it was neither cost-effective nor easy to set these two frequencies more than around 2 kHz apart. Consequently these systems were very vulnerable to noise: any other device connected to the power line that generated noise at the frequency of the signal — this could be as simple as a vacuum cleaner — could cause the communication channel between nodes to be dropped. S-FSK is much less vulnerable to noise: this is because, in S-FSK,  $f_s$  and  $f_m$  are set typically 10 kHz apart. This development was possible because, in the digital domain, it is easy to generate these frequencies inside an IC. Because  $f_s$  and  $f_m$  are far apart, it is extremely unlikely that noise will swamp both frequencies simultaneously. The latest S-FSK ICs from ON Semiconductor and STMicroelectronics are also able to switch back to amplitude modulation to keep the channel open in case extremely high noise levels make frequency modulation impossible.

So noise at one of the frequencies might reduce the effective data rate, but the communication channel stays alive. This means that the S-FSK modulation scheme offers very high reliability — a vital characteristic for smart meter applications, which transmit mission-critical usage data.

The S-FSK technique is supported by industry collectively: IEC 61334 is a set of standards, aimed primarily at Smart Meter applications, which implements S-FSK. Large-scale deployments are now start-





100456 - 11

Figure 1. Standard power line data frame structure (IEC61334-5-1).

ing to happen: France, for instance, has begun a very large smart meter deployment that uses S-FSK. But other countries are waiting for regulatory bodies to define other standards before they make a decision on which technology to implement.

Indeed, while S-FSK provides a low data rate (up to 2400 bits/s), other modulation schemes promise higher rates. Some of these (for instance OFDM and DSSS), are being tested or even, in the case of the Differential Code Shift Keying (DCSK) technique developed by IC manufacturer Yitran, being deployed (in Spain).

But for smart meters, S-FSK is definitely the front runner because of its proven reliability in the field. This means that integrated devices supporting the technique are becoming available in volume and at competitive prices. This in turn could spur a wider range of applications to adopt S-FSK.

What, then, are the main challenges facing the designer of a PLC modem that implements S-FSK? And to what extent do today's SoCs deliver a complete solution? Let's begin by understanding the principal functions of a power line modem.

### Basic architecture of a power line modem

A PLC modem's architecture typically consists of three blocks:

- Analogue Front End (AFE), comprising a coupling device, filters and a power stage
- Physical layer (PHY)
- Protocol

The physical layer incorporates a system for FSK modulation, filters and an amplifier.

The protocol layer is the means by which communication between multiple nodes is managed. The protocol is responsible for safely transferring information between two or more nodes, managing the payload by encrypting it (if needed — this is not required in all cases), and generating the correct formatting for the frame to transmit properly. **Figure 1** shows a standard PLC frame format, as defined by IEC 61334-5-1.

Whatever the frame format used, the protocol layer provides the following functions:

- Acknowledgement-based signalling, with the capability to retransmit lost packets
- CRC error detection to test the integrity of received data

- Carrier Sense Multiple Access (CSMA) capability using the BIU (Band In Use) detector to check if the line is in use — a means of collision-avoidance.
- Addressing
- Encrypting of data for transmission
- Full control over the following transmission parameters:
  - Acknowledged
  - Unacknowledged
  - Repeated transmit
  - Sequence numbering

### Extent of integration in today's modem ICs

Early moves by semiconductor manufacturers to satisfy demand for S-FSK devices failed to provide completely integrated solutions, or left a significant amount of software implementation to the OEM designer. A popular reference design for S-FSK modems, DRM035, was released by the then Motorola Semiconductor in 2003, based on the 56F801 digital signal controller. Still marketed by Freescale Semiconductor today, the reference design can be used as a blueprint for the design engineer to develop their own solution.

But this approach of implementing modulation and protocol layer functions in software left the design engineer to implement the AFE discretely — a tricky task. PLC systems connected to the AC grid must, at least in Europe, comply with the following standards:

- Powerline signalling (EN50065-1:2001, FCC Part 15)
- Powerline immunity (EN50065-2-1:2003, EN61000-3-2/3)
- Safety (EN60950)

### How to couple a PLC system to the grid

Generally speaking, a coupling network (capacitor and transformer) is the means by which signals are injected (or received) onto (or from) the AC power line ('mains'). One side of the transformer is driven by the output stage of the PLC modem's amplifier.

The role of the capacitor is to reject the grid's 50 Hz (60 Hz) voltage; it also provides impedance to make the connection of the two voltage sources (AC grid and power line signalling) in parallel.

The power amplifier driving the transformer can be implemented in two ways: with discrete transistors integrated inside an S-FSK IC (as in the ST7570); or in the form of a dedicated IC (such as the



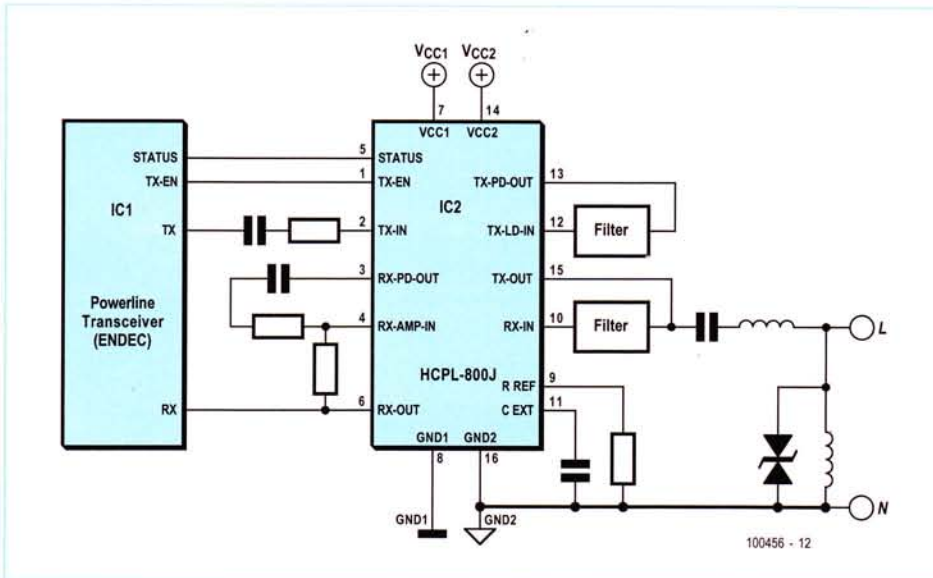


Figure 2. Block diagram of PLC modem AFE using the Avago HCPL-800J.

tioned above — in fact, they are best described as S-FSK modem systems-on-chip. The AMIS-49587 from ON Semiconductor, released in its latest version in December 2009, implements the physical interface (PHY) in mixed-signal hardware blocks and the Media Access Control (MAC) and protocol layer on an embedded firmware ROM. The firmware runs on an embedded ARM7 core. The device can communicate with an applications processor via Serial Communications Interface (SCI).

By eliminating the need for the system designer to develop the protocol layer, ON

AMIS-49587). An integrated power amplifier offers a very compact design, but it might in some instances restrict range, and be limited in its temperature tolerance. This could occur, for example, if the impedance at the power amplifier is very low.

For applications that require galvanic isolation, Avago Technologies has introduced the HCPL-800J coupling IC. As shown in Figure 2, the isolated output stage can directly drive a coupling network made of a capacitor and inductor.

Coupling to the power line is not the only problematic area of the AFE — the band pass filter is also important. Before designing a suitable filter, it is necessary to consider in which region of the world the modem is to be operated. In Europe, the EN50065 spurious emission limit curve governs the maximum level of all harmonics for all frequencies in the range from 10 kHz to 148 kHz. For example, if a modem transmits on a carrier frequency of 120 kHz, it is necessary to ensure that the second and third harmonics are at a level below 62 dBµV and 58 dBµV respectively.

The situation in the US is different: here, regulations do not specifically limit all harmonics, but rather limit only the harmonic levels at frequencies greater than 500 kHz. This means that if the same 120 kHz modem is to be used in the US, only out-of-band harmonics greater than the fourth order are of concern. Also there is a limit in the amplitude of the output signal of 122 dBµV.

### Today's integrated solutions

The latest semiconductor product introductions for S-FSK modems are far more integrated than the Freescale reference design men-

Semiconductor greatly accelerates the end product development process — at an applications level, the system just needs to feed raw data to the AMIS-49587 over the SCI, and the SoC handles all the processing and transmission of the data.

The intention of STMicroelectronics' S-FSK SoC, the ST7570, is similar. It is a complete implementation of an S-FSK modem, including the whole AFE. Its architecture is slightly different from the AMIS-49587: the ST7570 performs modulation through turnkey firmware running on a DSP core; it uses an embedded 8051 controller core to implement the protocol layer's PHY and MAC.

These new devices — the ST7570 is about to come out of the 'sampling' phase — illustrate the level of integration that has just become available to designers of S-FSK modems. The main challenge in designing PLC networking gear has therefore now shifted from implementing the communications — this job is now done by SoCs — to value-added functions, such as the user interface, and appliance monitoring and control capabilities.

Perhaps this availability of turnkey IC designs, from multiple IC manufacturers that are big enough to support high-volume production, will do more than anything to drive the market towards the S-FSK as the modulation technique of choice for power line communications. The decisive blow in the PLC modulation 'format wars' might already have been landed.

(100456)

Table 1. Frequency band allocations under EN 50065-1.		
Band name	Frequency range	Usage
Band A	3 kHz – 95 kHz	For utility companies only
Band B	95 kHz – 125 kHz	Applications without an access protocol
Band C	125 kHz – 140 kHz	Applications with an access protocol
Band D	140 kHz – 148 kHz	Alarm and security applications with no access protocol



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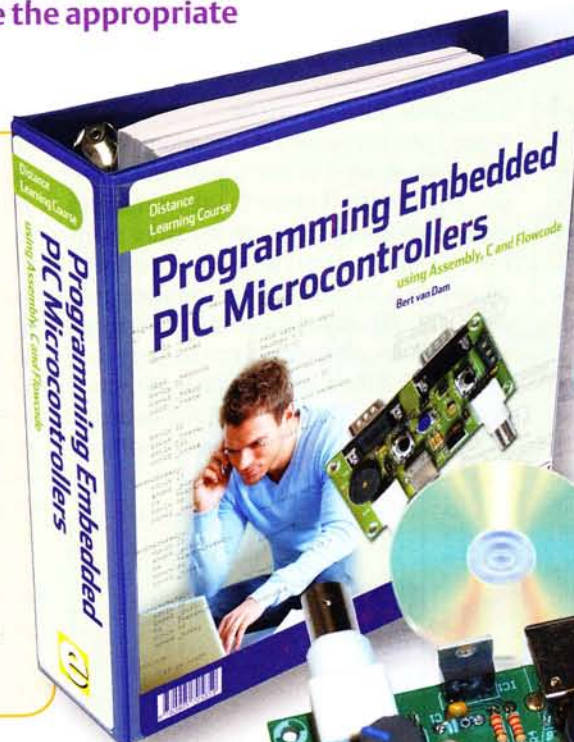
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# Wheelie GT

## Gear tooth sensing improves handling

By Günter Gerold and Uwe Hofmann (Germany)

It's been over a year since we introduced the Elektor Wheelie (a self balancing single axle vehicle). Now the GT modification described here senses the speed of each road wheel to give better stability and improved performance over uneven terrain.



Up until now the Elektor Wheelie control system used an accelerometer and a tilt sensor to sense movement of the vehicle's footplate. The tilt angle and the rate of change of the tilt angle are used in a control system which drives two motors to keep the vehicle stable. Leaning forwards tilts the plate forwards and produces an acceleration response from the control system; leaning backwards has the opposite effect. The regulation is applied to both motors equally. A pot sensing left/right tilting of the control lever adjusts the current to the drive motors thereby allowing the Wheelie to turn corners.

The control system does not have any information on the rotational speed of the wheels so it cannot compensate for any load variation on individual wheels. When a wheel hits an obstacle the control system reacts by increasing drive to the free wheel, producing an unwanted turn. Off-road capabilities of the original Wheelie are therefore somewhat limited.

To solve this problem we have added rotation sensors to each of the two wheels. Now the control system can sense the wheel speed and adjust power to the individual motor, helping it to overcome obstacles.

### The gear tooth sensor

A good way to measure the rotational speed of a gear wheel is to use a gear tooth sensor. This device (Figure 1) uses a magnet and a Hall-Effect sensor to measure magnetic field strength. When the device is placed close to the teeth of a rotating gear wheel the disturbance caused by each tooth moving through the field can be detected by the Hall-Effect sensor which outputs a sawtooth waveform. The ATS665 detector from Allegro includes a signal condition-

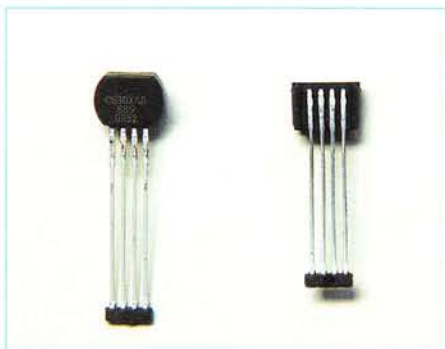


Figure 1. The gear tooth sensor consists of a permanent magnet and a Hall-Effect element to sense the magnetic field.

ing circuit with an amplifier and comparator (Figure 2); this generates a more useful square wave output signal. These sensors were originally developed for use in vehicular ABS systems and drive control.

The Elektor Wheelie uses a direct drive system with the final drive gear wheel connected directly to the road wheel. This configuration makes it simple to fit this type of sensor to the gearbox. This non-contact form of revolution sensing is very reliable, is not subject to wear and can be completely sealed from the environment. A small PCB (Figure 3) has been designed for mounting the sensor together with the other three components shown in the circuit in Figure 4. The board greatly simplifies the job of fitting the sensor to the gearbox. The newer ATS667 from Allegro can be substituted for the ATS665 shown in the circuit diagram.

### Evaluating the data

The ATmega8 in Figure 5 evaluates the speed impulses received from the two sensors connected to K3 and K4. Connector K1 provides an I<sup>2</sup>C interface between the ATmega8 evaluation board and the existing ATmega32 (pins 22 and 23) on the Wheelie main board.



The sensors output 60 impulses for each revolution of the road wheel. A method of measuring speed by counting the number of impulses in a given time window does not give sufficient resolution especially when the Wheelie is travelling at low speeds. It is better to measure the time between impulses i.e. the time it takes for two gear teeth to pass the sensor. A free running timer is used to measure this period, the firmware keeps track of the timer overflows to calculate the time interval. The evaluation board configures itself as an I<sup>2</sup>C slave. When a request is received from the ATmega32 main board the evaluation board responds by returning the values. The values sent are the reciprocal of the wheel speed. The ATmega32 first calculates the speed in km/h then the individual wheel speeds are summed and the value used to scale the control lever sensitivity. The speed reading could also be used in the development of a speedometer for the Wheelie or as one of the operating parameters transferred over a telemetry link.

**Fitting the components**

The complete additional parts required to implement the GT modifications consists of a evaluation PCB to take the ATmega8 microcontroller and two small PCBs on which the sensors are mounted. The evaluation board (Figure 6) contains no SMDs and is not at all difficult to assemble. The sensor PCBs however have two SMD components (R1 and C1) which need to be soldered on the track side of the board. The Hall-effect

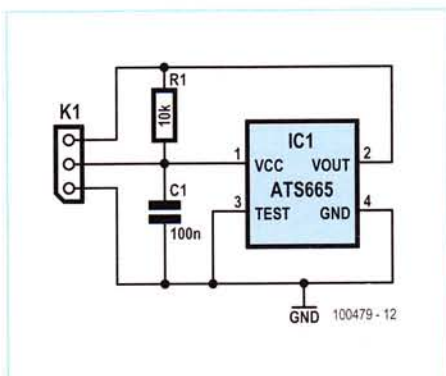


Figure 4. Circuit diagram of the sensor PCB.

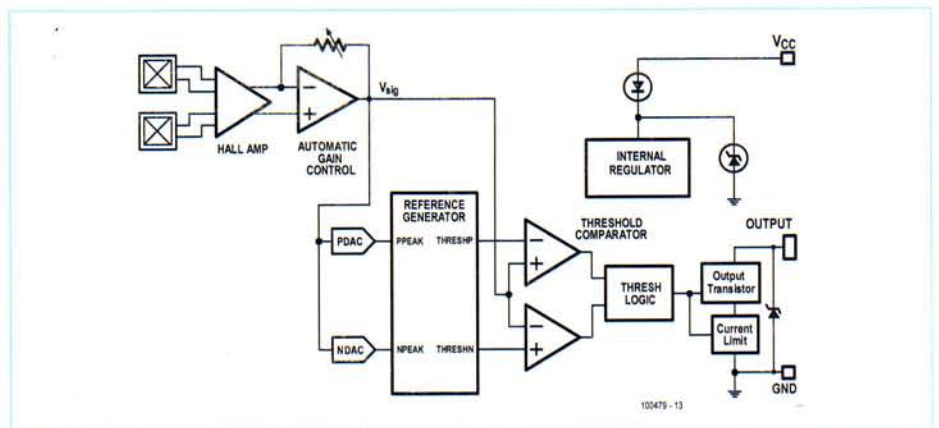


Figure 2. The AT5665 sensor contains an integrated amplifier and comparator.

**COMPONENT LIST**

**Sensor board**

**Resistors**  
R1 = 10kΩ

**Capacitors**  
C1 = 100nF

**Semiconductors**  
IC1 = AT5665 (or AT5667, see text)

**Miscellaneous**  
K1 = 3-pin pinheader  
PCB no. 100479-2\*

\*A kit of parts containing signal processing board (100479-1), two sensor boards (100479-2) and all components is available from the Elektor Shop, order code 100479-71.

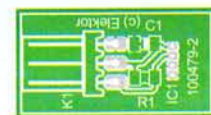


Figure 3. A small PCB simplifies the job of fitting the sensor to the gearbox.

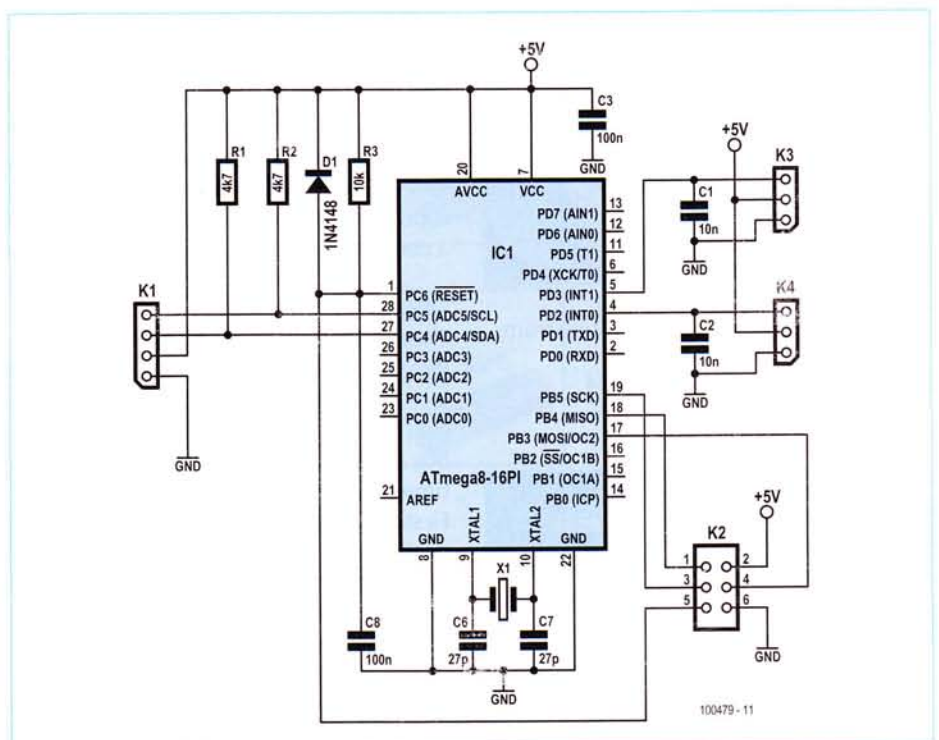


Figure 5. The evaluation board ATmega8 processes both gear tooth sensor signals.





Figure 7. Mounting the sensor on the small PCB.

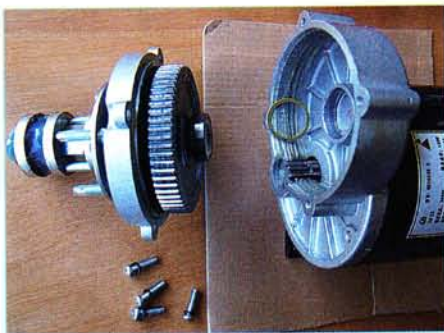


Figure 8. Release the four bolts and carefully remove the casing which holds the stub axle and the final drive gear wheel.



Figure 9. The correct hole position from the casing edge.

**Table 1.**  
Connections between the ATmega8 PCB and the Wheelie main board

ATmega8 signal processing board	Connection to the Wheelie main board
K1/Pin 1 (GND)	K3/Pin 5 (GND)
K1/Pin 2 (+5 V)	K2/Pin 2 (+5 V)
K1/Pin 3 (SDA)	IC7/Pin 23 (SDA)
K1/Pin 4 (SCL)	IC7/Pin 22 (SCL)

## COMPONENT LIST

### Signal processor board with ATmega8

#### Resistors

R1,R2 = 4.7kΩ  
R3 = 10kΩ

#### Capacitors

C1,C2 = 10nF  
C6,C7 = 27pF (or 22pF)  
C3,C8 = 100nF

#### Semiconductors

D1 = 1N4148  
IC1 = ATmega8-16PI, (programmed)\*

#### Miscellaneous

X1 = 16MHz quartz crystal  
K1 = 4-pin pinheader  
K3,K4 = 3-pin pinheader  
K2 = 6-pin (2x3) pinheader  
PCB no. 100479-1\*

\* A kit of parts containing signal processing board (100479-1), two sensor boards (100479-2) and all components is available from the Elektor Shop, order code 100479-71.

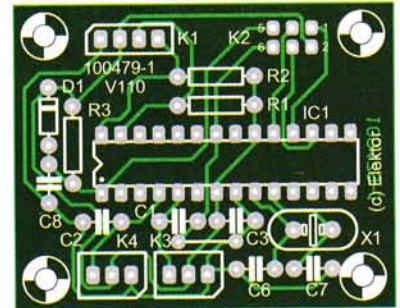


Figure 6. The evaluation board is wired to both sensors and the Wheelie main board.

sensor is mounted from the other side of the board and soldered on the track side. The legs are first bent flat along the body of the sensor (Figure 1) and then pushed through the board and soldered to the pads on the track side. Note that a small gap should be left between the sensor and PCB (Figure 7). This allows the sensor to be fixed to the PCB using epoxy adhesive. The lead ends can now be cropped close to the solder joints on the PCB. Finally a short length of heat shrink sleeving over the sensor will prevent any possibility of the leads shorting to the gearbox casing. Connections to the board can be made by soldering the three wires directly to the pads of K1. This is more robust and removes any reliability issues of a connector at K1.

### Construction

The most time-consuming part of this modification will be fitting the rotation sensors into the two motor gearboxes. The greatest challenge is drilling one hole in the gearbox aluminium casing — and get it right first time round!

Firstly undo the four screws holding the gearbox cover in position then pull the cover off complete with the stub axle and large gearwheel (Figure 8). The housing will be filled with grease. The ball race housing contains a spring washer which will most likely adhere to the ball race as you pull it out of the housing. Keep this washer safe, you will need it later during reassembly.

The position of the hole to take the sensor can now be marked on the casing, it is

11.5 mm (0.45 inch) away from the edge of the casing (Figure 9 and Figure 10). Use a centre punch to mark the point; it will prevent the drill from wandering. Before drilling it will be necessary to clean the grease away from the area where the hole will be drilled. Lay some paper kitchen towels or clean rags on the bench to catch any swarf. Debris which does find its way into the casing can be removed with a pair of tweezers (the more meticulous types out there will no doubt remove all the grease, flush out the housing after drilling and re-pack with grease).

Once the position has been marked and double checked make a pilot hole through the casing using a 3 mm (1/8 inch) drill. Check the position of the hole again before drilling through with a 9 mm (3/8 inch) drill. The sensor PCB (with its cables attached) can now be permanently fixed to the casing using two-pack epoxy glue (with the sensor chip positioned into the hole). Be sure to degrease and abrade this area of the case before gluing. Once the glue has set the hole (Figure 11) will be completely sealed by the PCB (Figure 12) and the sensor will be close enough to the gear teeth to generate impulses when the cog turns. Any debris remaining in the gearbox housing must be carefully removed before re-greasing the gear wheels and reassembling the housing (don't forget the spring washer).

### Wiring

Three-core cables are used to connect the sensor PCBs to the ATmega8 PCB.



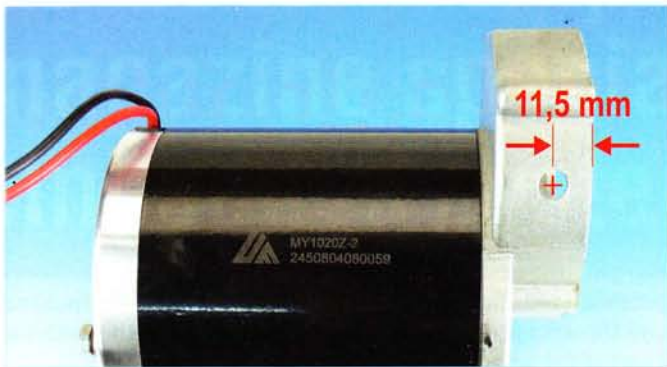


Figure 10. The motor before...

A four-way flat band cable connects to K1 of the ATmega8 PCB and to the points specified in **Table 1** on the existing main board in the Wheelie.

### Software and Updates

The firmware for the ATmega8 fitted to the evaluation board can be downloaded for free from the Elektor Website. The direct link is: [www.elektor.com/100479](http://www.elektor.com/100479).

A commented source file is included in the download folder for this article along with the Hexfile.

The Elektor shop stocks the complete kit to convert the standard Wheelie to the Wheelie GT including a pre-programmed ATmega8.

It will also be necessary to upgrade the existing ATmega32 main board firmware in the Wheelie so that it can handle data from the evaluation board. The new firmware (hex and source code) is available for free download from [www.elektor.com/100479](http://www.elektor.com/100479).

Some hardware modifications will also be necessary to the main board for Wheelies using the GT sensors:

1. Replace the three 470  $\mu$ F capacitors C1, C2 and C3 with better spec 1000  $\mu$ F capacitors (use low ESR types e.g. the Panasonic FM series).
2. Change R14 to 47 k $\Omega$  and add a 100 nF capacitor between IC7/ Pin34 (ADC6) and ground (solder it between the correct leg of R14 and ground)

The improvement in stability of the Wheelie GT version (especially in off-road situations) can be seen on one of the author's YouTube videos; search for guenter1604.

(100479)

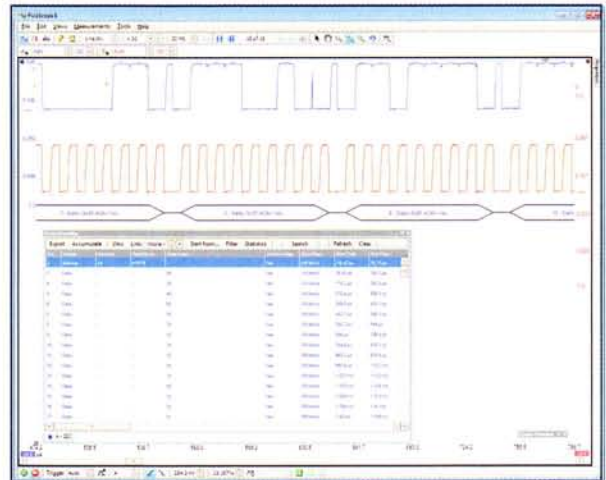


Figure 11. ...and after fixing the sensor PCB

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# From Microphone to Line Input

By A.J. Ribbink (The Netherlands)

The requirements a microphone preamplifier is expected to meet are very different from those formulated for a line amplifier. For the first, a large gain and a low noise contribution are very important, while a line amplifier has to be able to handle a much larger signal without generating distortion. A microphone input has a sensitivity of a few millivolts; a line input must be able to cope with several volts.

In most cases a different type of circuit is used for each of these different types of input. With the circuit described here it is however possible to meet both requirements at the same time. Using only a single potentiometer, both the gain and the volume can be adjusted.

A dead common (audio) amplifier is shown in **Figure 1**. In this circuit the amplification (gain)  $A$  is determined by the ratio of the feedback resistor  $R$  to  $R_1$  as follows:

$$A = (R+R_1)/R_1.$$

Volume control  $R_p$  is really nothing more than a voltage divider comprising  $R_3$  and  $R_2$ , where  $R_2 + R_3 = R_p$ . Drawing it in a different way

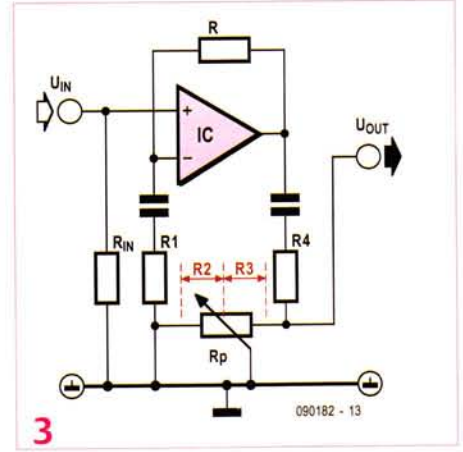
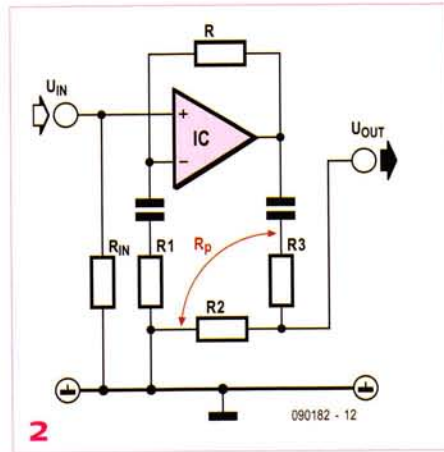
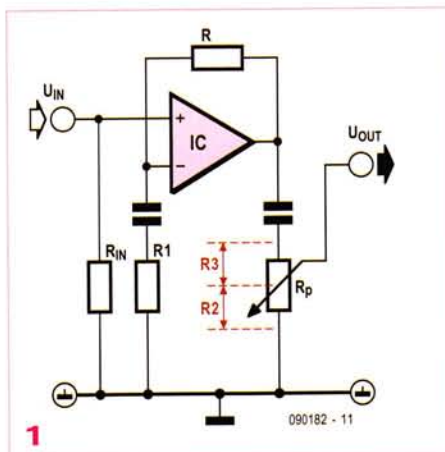
eter, both gain and volume can be controlled.

$R_1$  is still present in **Figure 3**, where its function is to limit the maximum gain. The additional resistor  $R_4$  has two purposes: it prevents a potential (and undesired) short circuit of the amplifier output and forms the voltage divider for the volume control, together with the  $R_3$  part of the potentiometer.

The circuit can be used with ICs as well as amplifiers built from discrete components. The value of  $R_4$  can be changed to the desired output impedance and the volume control curve. If control all that way down to zero volts at  $U_{out}$  is not required, then  $U_{out}$  can also be taken directly from the output of the amplifier circuit.

A bad contact in the wiper of the potentiometer will not result in too much of a cracking noise, because  $R_1+R_p+R_4$  are connected in parallel with feedback resistor  $R$ . The gain is reduced in the event of poor wiper contact, which means that cracking noise remains limited.

In most circuits  $R_1$  has a much smaller value than  $R_2$ . For a smooth control,  $R_1$  should therefore change value much slower than  $R_2$ . A (reverse) logarithmic potentiometer is therefore recommended. With a normal logarithmic potentiometer the volume will reduce



results in the schematic of **Figure 2**. The operation of the voltage divider can be expressed as:

$$D = R_2/(R_2+R_3).$$

Gain factor  $A$  and division ratio  $D$  together determine the amplification of the overall circuit as in

$$U_{out} = A \times D \times U_{in}.$$

The output voltage is therefore adjustable by changing  $R_1$  and/or  $R_2$ .

Because of the opposite actions of  $R_1$  and  $R_2$  — a larger value of  $R_1$  results in a smaller output voltage, while a larger value of  $R_2$  increases the output voltage — these two resistors can be combined as illustrated in **Figure 3**. In this way, using only a single potentiom-

eter when the potentiometer is turned clockwise! A reverse-log potentiometer or a logarithmic slide potentiometer mounted 'upside down' gives a normal, familiar control.

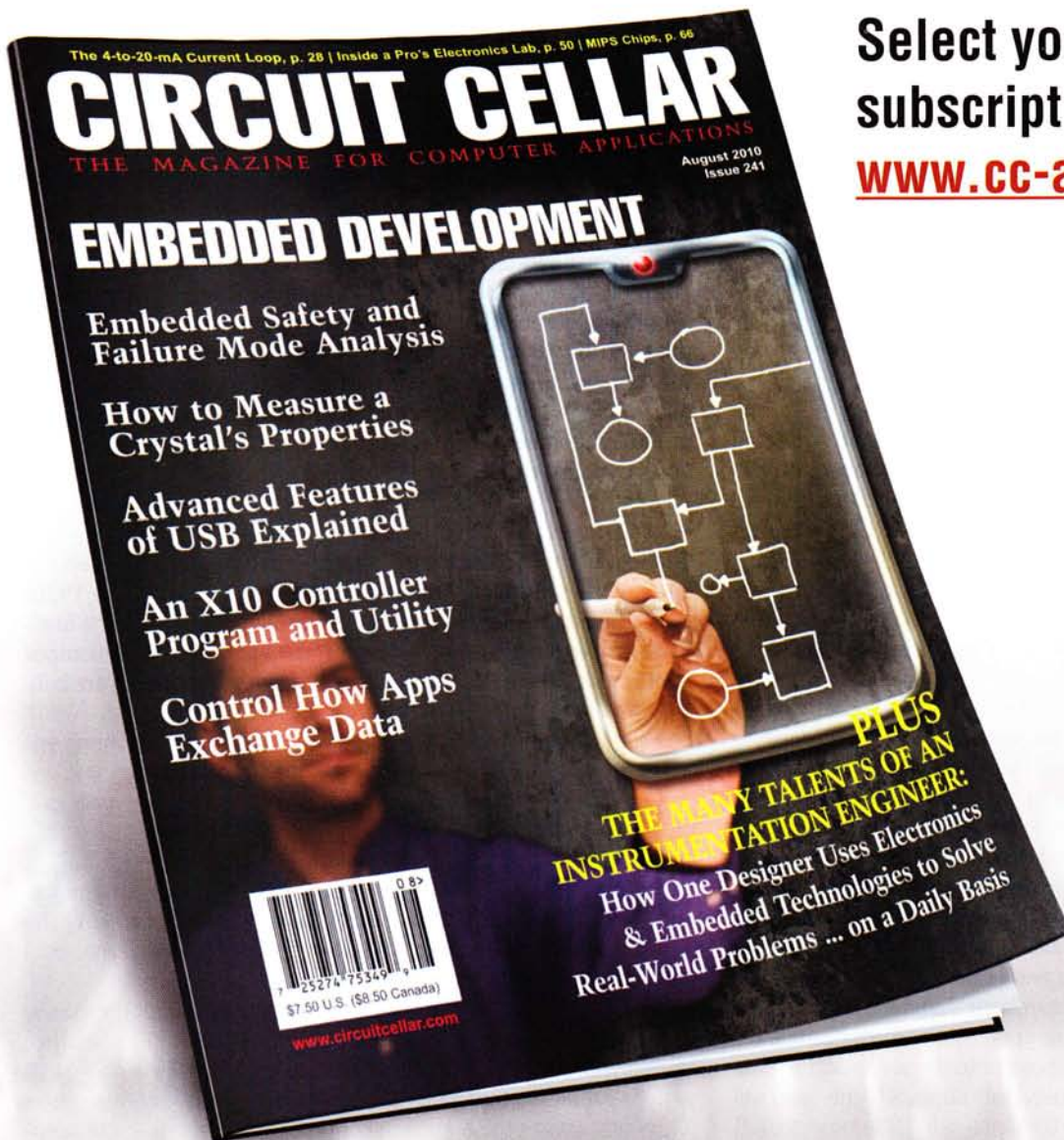
Suitable resistance values are, for example, 50 k $\Omega$  for  $R_p$ , 22 k $\Omega$  for  $R$ , 56  $\Omega$  for  $R_1$  and 220  $\Omega$  for  $R_4$ . Using these values the maximum and minimum amplification are about 360 and 1.5, respectively.

At the lowest operating frequency the capacitors need to have a (much) smaller impedance than  $R_1$  and  $R_4$ . The input impedance of the circuit is mostly determined by resistor  $R_{in}$  and can be adjusted to suit whatever signal sources are likely to be connected. Noise suppression filters and/or frequency dependent networks can be connected in front of this. Frequency dependent feedback is not recommended for this circuit, because the the RC filter characteristic will change when the gain and volume are adjusted.

(090182-1)



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# 80 Candles for the Pentode



Figure 1. Eighty years back in time. Left to right: tubes type RES164, 34, EF97 and 1j18b.

By Andre Adrian, DL1ADR (Germany)

The first transistor radio was called Regency TR-1 and appeared on the market in 1954, at a time when radios with vacuum tubes had been around for decades. One of the most successful tubes is the pentode, a vacuum electron tube with five (Greek: pente) electrodes. A famous early pentode was the 'RCA-34' (UX-234), it reached commercial use in the early 1930s and was announced as a 'Super-Control R-F Amplifier Pentode'.

To celebrate the Pentode's 80<sup>th</sup> birthday this article in the Retronics series describes the construction of a shortwave radio for the 49 m

supply rail and the suppressor grid is tied to the negative terminal of the anode battery.

The '34' pentode has a barium oxide coated filament. The filament requires 2 V at about 60 mA. The resulting 120 milliwatts cause the filament to heat up to 800 °C and to glow nearly invisibly. The Russian subminiature pentode type 1Ж18Б (1j18b) requires even less heating power: 1.2 V at 24 mA.

In **Figure 1** you see pictured, left to right: type RES164 pentode (ca. 1928), type 34 pentode (ca. 1930), miniature pentode type EF97 (1957), and a subminiature pentode type 1Ж18Б. The (spectacularly) low-voltage type EF97 can work with just 6 volts on its 'plate'.

## Basic operation of the Audion

An Audion consists of an LC resonant circuit for setting the reception frequency, and an amplifier. To enable very high gain to be achieved, part of the amplified RF signal is fed back to the input. Consequently the Audion operates as an amplifier on the verge of self-oscillation. The radio frequency is amplified and demodulated simultaneously. Amplitude demodulation is achieved by the different response of the control grid to negative and positive voltages. The rectifier in the tube between control grid and filament is conductive for positive voltages, but not for negative voltages. A 'grid leak' network of 1 MΩ in parallel with a capacitor of 68 pF at the control grid supports the grid rectifier.

## A simplified Audion radio

Changes in the feedback cause changes in frequency. To keep this effect within limits, a radio ham called F.H. Schnell in the 1920s added an adjustable attenuator element in parallel with the feedback winding. In the simple circuit shown in **Figure 2**, all components determining the receiving frequency and feedback are con-

## build a shortwave radio based on the '34' pentode

and 41 m broadcast bands, based on the '34' pentode or later types. With only one tube and a 1.5 m (5 ft.) wire antenna, reasonable reception at headphone volume levels is within reach. Depending on the tube used, the anode voltage is a safe 6 to 45 volts supplied by batteries. The radio can be built in 'classic' fashion using a flat coil and variable capacitor, or in modern guise using a ferrite core and a variable capacitance diode. The successor to the pentode, the field effect transistor (FET), can also be used, although its higher gain will make tuning the radio a real achievement.

### In the beginning: tungsten

The hot tungsten filament of an incandescent lamp emits electrons. This was observed by Thomas Alva Edison in 1883 as he installed an electrode next to a filament in the bulb. In vacuum, a current flows between filament and anode. In the course of the years more electrodes were 'inserted' between filament and anode. Beside the cathode and anode, the pentode has a control grid, a screen grid and a suppressor grid. The control grid can be said to correspond to the gate of a FET. The screen grid is usually connected to the positive

connected to ground (earth) at a single point. The LC resonant circuit consists of variable capacitor C1 and a section of coil L1. The antenna and the control grid are connected to a tap on the resonant circuit.

Coils L1A and L1B work as an autotransformer and adapt the low AC resistance of the antenna and control grid to the high-impedance resonant circuit. The feedback is via C2 onto feedback winding L1C with its parallel connected attenuator in the form of potentiometer R1, which acts as the feedback control. L1C forms a second autotransformer with the rest of L1. With the centre of L1 grounded, a phase shift of 180 degrees is established between the feedback winding and the resonant circuit. The desired positive feedback is obtained in conjunction with the phase shift of the amplifier.

High-frequency choke L2 separates the RF part of the Audion from the AF part. Every inductor has stray parallel capacitance — invisible but always present! For the RF choke we have about 10 pF. The stray capacitance of the primary winding of output transformer Tr1 is much higher. Without L2, it would effectively short-circuit the high frequency signal.



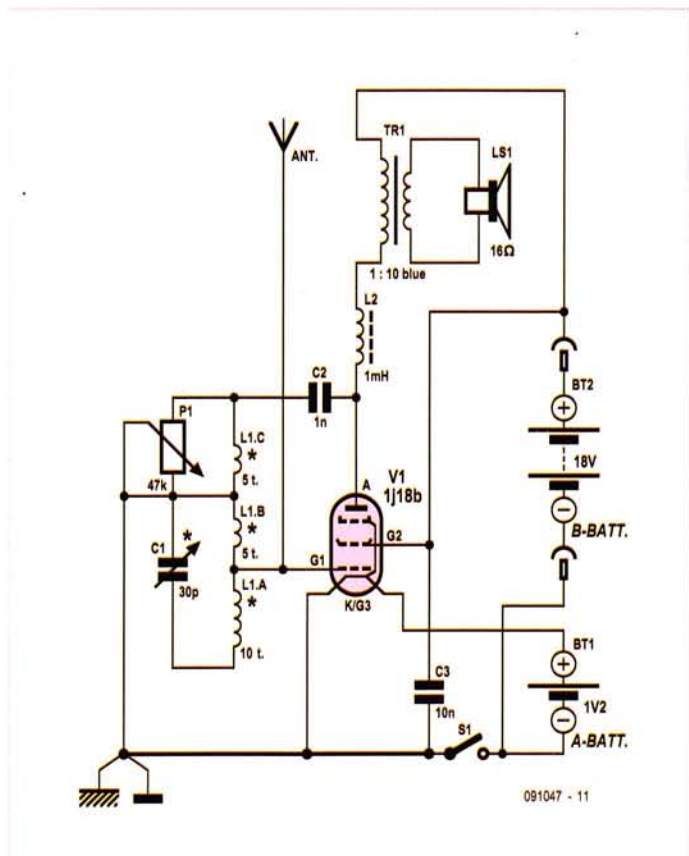


Figure 2. Schematic of the simplified Audion '2010 style'.

Output transformer Tr1 matches the high AC resistance of the tube to the low impedance of the Walkman-style headphones. The two 32 Ω earpieces are connected in parallel. The 'A' battery supplies heater power to the tube, the 'B' battery, the anode (plate) voltage. An AA size NiMH battery is just fine as a

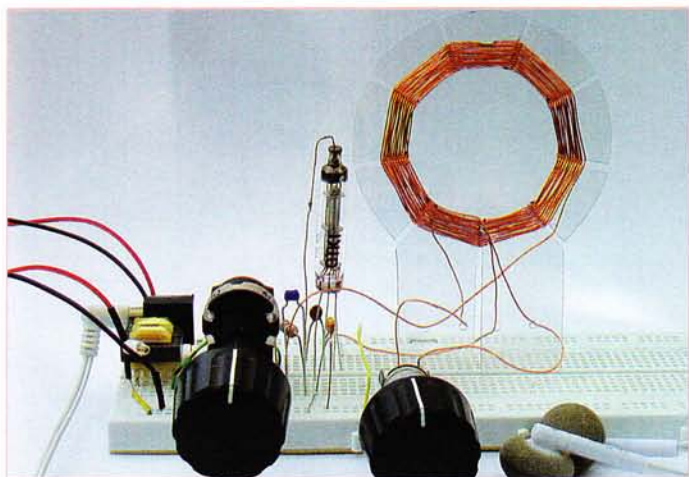


Figure 3. The author's simplified Audion constructed on breadboard.

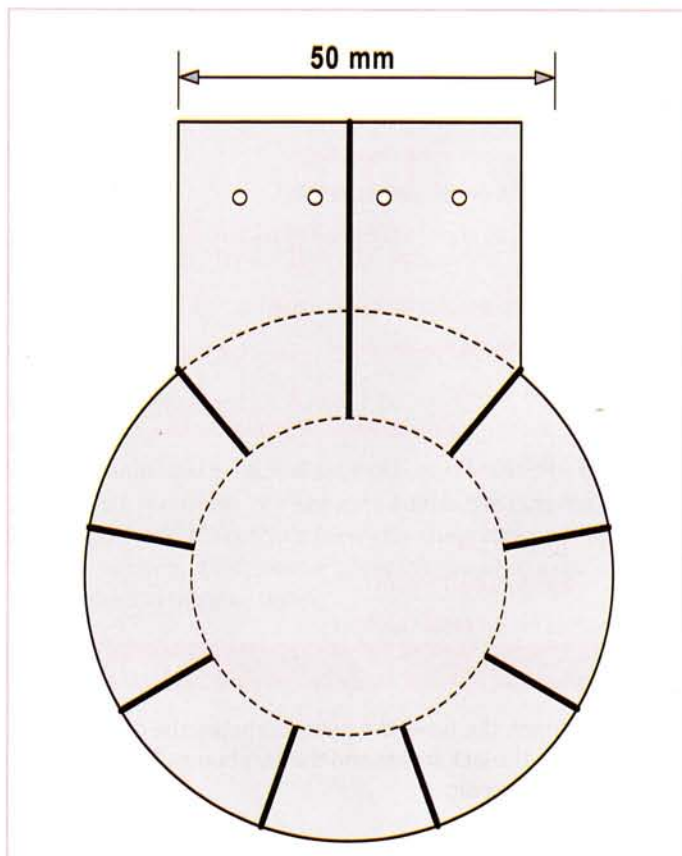


Figure 4. Use this template to make your own 41-mm holder for the spider web coil in the radio.

filament power source. The anode battery consists of two series-connected 9 V batteries. Current consumption amounts to 24 mA from the A battery, and 2 mA from the B battery. Capacitor C3 short circuits any RF signal at the screen grid. The secondary of Tr1 is intentionally not grounded. The front panel should consist of a grounded metal plate, or at least have some kind of metal foil (grounded, of course) on the inside. The antenna connector should be located at the rear of the enclosure. All these measures reduce the sensitivity of the circuit against the dreaded 'hand effect' — if the radio operator's hand is in the vicinity of the radio, the resonant circuit is detuned.

The length of the antenna should be limited to 1.5 m (5 ft.). A longer antenna is possible and allows you to pick up more stations but only if connected via a small capacitor of 4.7 pF to 33 pF. A proper antenna earth connection is essential to good reception. The GND connection of the circuit should be connected to conductive heating pipe.

Potentiometer R1 also adjusts the volume. If you turn it up too far you will hear a howling sound. Your Audion then works as a transmitter and may cause interference on other receivers. Remember, the Audion is a **regenerative** radio!

### Practicalities

The parts list of the proposed receiver is given in the **inset**. The picture of the breadboarded prototype in **Figure 3** shows the



**Audion Parts List**

- C1 = 35pF tuning capacitor with reduction gear (vernier), or Philips 'beehive' style (Opperman Electronic, Germany)
- C2 = 1nF ceramic multilayer capacitor
- C3 = 10nF ceramic multilayer capacitor
- L1 = spider web coil 10+5+5 turns 0.3 mm (AWG #28) enamelled copper wire.
- L2 = 1mH choke (Fastron SMCC)
- R1 = 47kΩ potentiometer, linear
- S1 = SPST on/of switch
- Tr1 = 1:10 miniature AF transformer, colour code: blue (Reinhöfer Electronic, Germany)
- V1 = 1j18b tube (NOS on Ebay)
- 3.5mm stereo jack socket
- Battery holder for one 1.5V AA cell
- Clip-on leads for 9 V 6LR22 batteries

The spider web coil support consists of 0.4 mm thick transparent PE plastic which is sold as sheets in the stationery trade (anyone remember late afternoon Powerpoint presentations using overhead projectors?). The template shown in **Figure 4** is placed under the film and its outline is copied onto the sheet with a CD marker pen. The shape can be cut out using heavy duty paper scissors. To allow the slots to be cut easily 3 mm (1/8 in.) holes are drilled at the ends. For the complete winding you'll need 3.2 m (approx. 11 ft.) of 0.3 mm (AWG #28) enamelled copper wire, plus two pieces of about 10 cm (4 in.) for the taps. The wire should be wound tightly onto the former. After 10 turns, a wire loop is bent. Before you continue winding, solder the wire loop to the connection wire. The second tap is after another five turns.

For more on tube radios, visit the author's website <sup>[1]</sup>.

(091047)

beehive trimmer, the tube, the potentiometer, the output transformer next to the jack socket and the earphones. The spider web coil is visible in the rear.

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# Hexadoku

## Puzzle with an electronics touch

In this the Northern hemisphere leaves are starting to fall and temperatures have gradually dropped to levels where you might want to stay indoors. Ideal conditions we say for a new release of Elektor's famed & famous Hexadoku puzzle. Enter the right numbers in the puzzle, send the ones in the grey boxes to us and you automatically enter the prize draw for four Elektor Shop vouchers. Have fun!

The instructions for this puzzle are straightforward. Fully geared to electronics fans and programmers, the Hexadoku puzzle employs the hexadecimal range 0 through F. In the diagram composed of 16 x 16 boxes, enter numbers such that all hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once

in each column and in each of the 4x4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation. 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 November 1, 2010, send your solution (the numbers in the grey boxes) by email, fax or post to

Elektor Hexadoku – 1000, Great West Road – Brentford TW8 9HH  
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Fax (+44) 208 2614447 Email: hexadoku@elektor.com

### Prize winners

The solution of the July/August 2010 Hexadocube is: 2975EF.

The Sceptre/Intersceptre kit worth £236 was won by: Simon Lehmayr (Germany).

The £40.00 vouchers have been awarded to: Andy Wood (Australia), Per Troelsen (Denmark) and Jean-Claude Carré (France).

Congratulations everyone!

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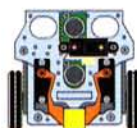
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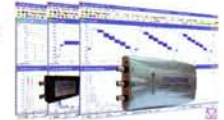
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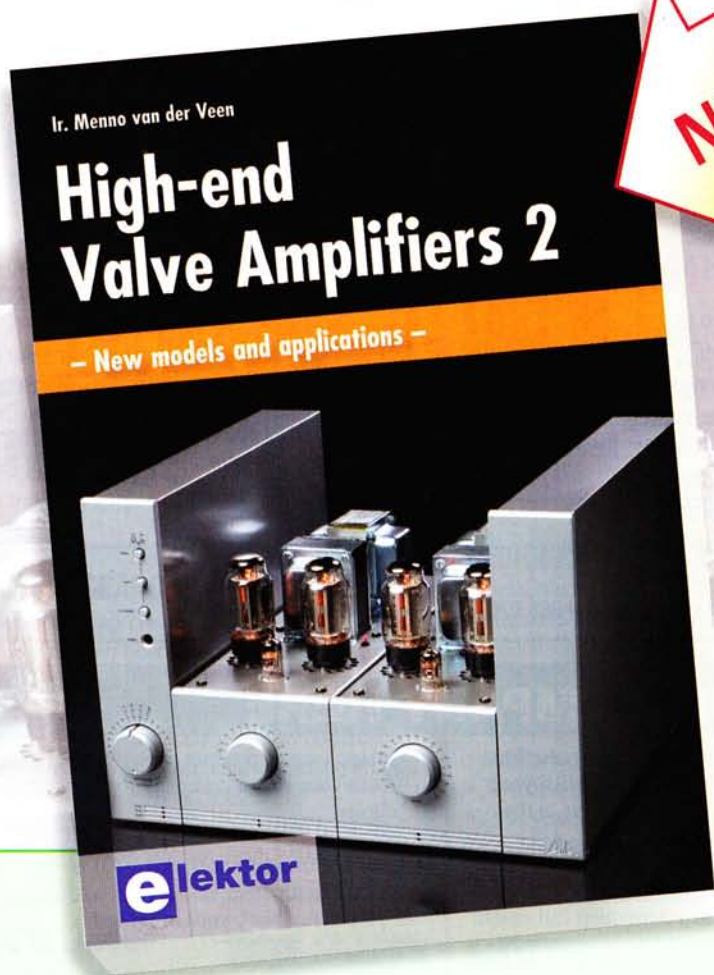
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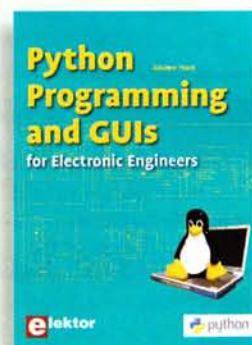


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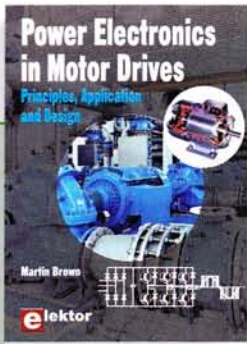
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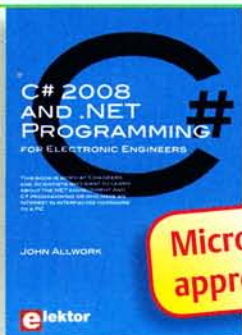


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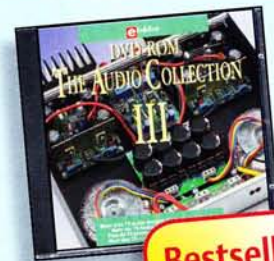


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(July/August 2010)

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### InterSceptre

(June 2010)

In our March issue, we introduced Sceptre, a fast prototyping system fitted with a 32-bit microcontroller. Even on its own, this board will let you produce some great results, but if we add an extension board to make it easier to access all its peripherals, the Sceptre platform becomes downright powerful. What's more, if you fit this extension board into a suitable case, you'll be able right from the start to develop a prototype that you can use 'properly' in a installation, with no trailing wires or bits of sticky tape holding everything together. Now that's what you call fast, convenient prototyping!

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### dsPIC Control Board

(May 2010)

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### Reign with the Sceptre

(March 2010)

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

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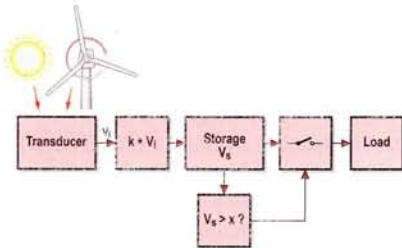
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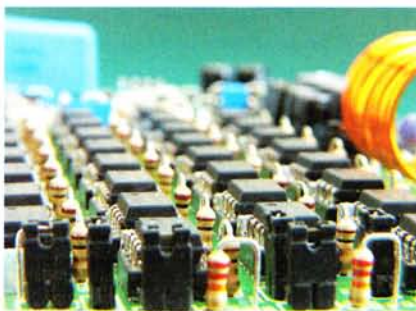
### Mobile O<sub>2</sub> Meter with Minimod18

Nicely complementing the CO<sub>2</sub> Meter and Mobile CO<sub>2</sub> Meter projects recently published in Elektor we now present an O<sub>2</sub> (oxygen) Meter. For divers and cave explorers it is absolutely essential to instantly know the current oxygen concentration in their air supply (from the cylinder) or in the ambient air (deep underground). In this article we present suitable sensors for oxygen-level measurements, the way sensor signals are processed and, best of all, an oxygen meter based on the renowned Minimod18 board described in the January 2010 edition.



### Energy Harvesting

Alternative energy sources are all the rage lately. In this article we present a number of ideas for powering circuits from solar energy, even under poor sunlight conditions. However, the less than constant and dramatically low voltages supplied by solar panels can be processed with the help of clever circuits, enabling voltages down to 200 mV to be used, and constant supply power to be guaranteed.



### The 5532 OpAmplifier (2)

Have you ordered your NE5532's yet? They're cheaper by the hundred! In this the second and concluding instalment on what's already known as "a remarkable audio amplifier" we'll be discussing the OpAmplifier's construction and performance, the latter to confirm (with graphs from our Audio Precision analyser) that a top-notch design is on the table. For purists and other advanced audio boffins we also have guidance on configuring the amp for bridged operation and higher output powers.

Article titles and magazine contents subject to change; please check the Magazine tab on [www.elektor.com](http://www.elektor.com)  
 Elektor UK/European edition: on sale September 23, 2010. Elektor USA edition: published September 10, 2010.

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