M16C Display Computer
GRAPHIC TALENT

DigiButler — assembly, test & software
paX — voltage amp & input buffer
USB Programmer — AVR Prog for ATM18

THE PC TAKES CONTROL
Measurement Software
**Theremin Synthesiser Kit**

**KC-5295 £14.75 + postage & packing**

The Theremin is a strange musical instrument that was invented early last century but is still used today. The Beach Boys' classic hit "Good Vibrations" featured a Theremin. By moving your hand between the antenna and the metal plate, you can create unusual sound effects. Kit includes a machined, silkscreened, and pre-drilled case, circuit board, all electronic components with clear English instructions.

- Required 9VDC wall adapter (Maplin #GS74R £6.99)

**IR Remote Extender MKII Kit**

**KC-5402 £7.25 + postage & packing**

Operate your DVD player or digital decoder using its remote control from another room. It picks up the signal from the remote control and sends it via a 2-wire cable to an infrared LED located close to the device. This improved model features fast data transfer, capable of transmitting pay TV digital remote control signals using the Pace 400 series decoder. Kit supplied with case, screen printed front panel, PCB with overlay and all electronic components.

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**Battery Zapper Kit MK II**

**KC-5427 £29.00 + postage & packing**

This kit attacks a common cause of failure in wet lead acid cell batteries: sulphation. The circuit produces short bursts of high-level energy to reverse the damaging sulphation effect. This improved unit features a battery health checker with LED indicator, new circuit protection against badly sulphated batteries, test points for a DMM and connection for a battery charger. Kit includes case with screen-printed lid, PCB with overlay and all electronic components with clear English instructions.

- Suitable for 6, 12 and 24V batteries

**LED Water Level Indicator MKII Kit**

**KC-5449 £10.25 + postage & packing**

This simple circuit illuminates a string of LEDs to quickly indicate the water level in a rainwater tank. The more LEDs that illuminate, the higher the water level. The input signal is provided by ten sensors located in the water tank and connected to the indicator unit via-light duty figure-8 cable. Kit supplied with PCB with overlay, machined case with screen printed lid and all electronic components.

- Requires 12-18V AC or DC, 500mA plugpack

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**QM-1500 £2.25 + postage & packing**

This full featured Digital Multimeter is perfect for the home handyman or young experimenter and will give years of reliable service. It features a huge 10A DC current range as well as diode and transistor testing functions. Also measures AC & DC volts and resistance. At this price you should buy two!

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**Short Circuits Book and Parts**

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Precision, slim line long nose pliers that are ideal for working in confined areas. They have serrated jaws so you can get a firm grip on the item you're holding.

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For those who want to write:

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BitScope DSO Software for Windows and Linux

BitScope DSO is fast and intuitive multi-channel test and measurement software for your PC or notebook. Whether it’s a digital scope, spectrum analyzer, mixed signal scope, logic analyzer, waveform generator or data recorder, BitScope DSO supports them all.

Capture deep buffer one-shots or display waveforms live just like an analog scope. Comprehensive test instrument integration means you can view the same data in different ways simultaneously at the click of a button.

DSO may even be used stand-alone to share data with colleagues, students or customers. Waveforms may be exported as portable image files or live captures replayed on other PCs as if a BitScope was locally connected.

BitScope DSO supports all current BitScope models, auto-configures when it connects and can manage multiple BitScopes concurrently. No manual setup is normally required. Data export is available for use with third party software tools and BitScope’s networked data acquisition capabilities are fully supported.

www.bitscope.com
Programming a graphic display is distinctly more difficult than programming a text display. Our mini microcontroller board features a new display-on-glass module and a high-performance Renesas M16C microcontroller. The board is available fully assembled, and the microcontroller is pre-loaded with a TinyBasic interpreter to simplify the development of graphics applications – even for novices.

Two events triggered the conception of this AVR programmer: the feedback received on USBprog from Elektor, October 2007 and a series of articles started last month around our ATM18 project. The outcome is a plug-and-play AVRISP mk2-compatible USB programmer for AVR controllers!
In addition to its audio uses, the soundcard can also be used for measuring purposes. But which software is the most appropriate? In this article, we help you get oriented by giving you an overview of what can be found out there.

The tiny frequency counter module described here consists essentially of just an ATtiny2313 microcontroller and an LCD panel. The microcontroller is clocked at 20 MHz, and so the counter module can be used at frequencies of up to 5 MHz without the need for a prescaler.
Elektor International Media provides a multimedia and interactive platform for everyone interested in electronics. From professionals passionate about their work to enthusiasts with professional ambitions. From beginner to diehard, from student to lecturer. Information, education, inspiration and entertainment. Analogue and digital; practical and theoretical; software and hardware.
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FPGAs have established a firm position in the modern electronics designer’s toolkit. Until recently, these ‘super components’ were practically reserved for specialists in high-tech companies. That’s all changed now, also because of the Elektor FPGA module. The combination of the module and the prototyping board is the perfect introduction to FPGAs. The nine lessons on the courseware CD-ROM are a step by step guide to the world of Field Programmable Gate Array technology. Subjects covered include not just digital logic and bus systems but also building an FPGA webserver, a 4-channel multimeter and a USB controller. The CD also contains PCB layout files in pdf format, a Quartus manual, project software and various supplementary instructions.

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5/2008 - elektor
Compact Fluorescent lamps

Dear Editor — I liked the article on CF lamps in the January 2008 issue. It gives an insight into the requirements for operation of these miniature fluorescent lamps, but despite the attempts of various governments to inflicts these units on the populous, there is still some resistance to their general use. There are many reasons for this. In Britain at least, the cost is relatively high compared to the humble incandescent lamp, although prices have dropped in the last few years. One issue with all CFLs is to know the colour emitted by them. The warm-up time can be a problem in some applications, especially in outdoor units having a short on time such as in IR detector controlled fittings at doorways. In cold weather these can take a few minutes to give a useful light, and by then, the detector is ready to switch off again.

I have used the standard BC fitting replacements for several years now, but current building regulations in the UK demand at least a certain number of low energy fittings in every new build or extension. These must be of a type that cannot accept a standard incandescent bulb as a replacement, effectively ruling out the GLS replacement lamps now becoming widely available here. We are therefore faced with fluorescent fittings, Bi-pin types or square 4D fittings. Unfortunately, the lamp unit manufacturers have been slow to provide suitable units that are acceptable to the home user. Most of the fittings available that will only accept a none-incandescent type lamp tend to have a somewhat industrial look to them, necessitated by the requirement of providing a ballast of some kind and a place to keep said ballast away from danger. That has to include dissipation of heat in a safe manner, isolation from prying fingers and safety in failure either of lamp or ballast.

There are pendant drops made that will only accept a bi-pin lamp, but they do not readily take a standard shade as the fitting is larger than the old bayonet holder. Then there is the lamp equivalent problem. How does one relate 18 W = 100 W and pictures of several light bulbs on the website under the original article (look for item number 070559-11 under DIN shunts). The new firmware is available on the website under the new version makes it possible to use the meter with 60-mV digital shunts.

I recently installed some new lamps in my garage, the tubes were, although perhaps efficiency has been sacrificed for colour temperature. I modified a fitting to take a 16 W 4D lamp from 2×60 W golf ball bulbs, and for some reason ordered a cool white lamp. It is very bright, but using a 2700° lamp in the same place gives a dismal, gloomy light. It is still 16 watts, but how many incandescent lamps should it have on the pack? It is all a matter of perception.

No-one seems to quote lumen output from GLS lamps (standard household bulbs). These vary enormously dependant on the construction of the filament and the coatings on the lamp in any case. A 60 W rough service lamp has a tough relatively cold filament that gives a yellow light, whilst the mushroom lamps so popular in the 1960s were fragile beyond belief and burned at a high temperature with a coiled coil filament. This gave a very white light compared to its predecessors.

Comparing wattage ratings between GLS, quartz-halogen, CFL, ‘normal’ fluorescent and other discharge lamps is a bit like comparing fruit, vegetables and bread. It is meaningless without colour temperature and total light output being compared. It would be far more helpful to insist on comparison of lumens per circuit watt, which would also include losses in the ballast. One almost unknown loss outside of the electrical fraternity is that suffered in standard iron cored ballasts used for standard fluorescent lamps with switch starters. These can add 15% or more to the tube rating, thus a traditional 40 W 4-foot (1200 mm) fitting actually used a total circuit power of nearer 50 watts, and whilst the efficiency was far above that of a tungsten lamp, only recently have HF ballasts become the norm in traditional ‘long’ fittings.

I recently installed some new lamps in my garage, the tubes being rated at 58 W and the whole fittings claiming to be 59 W. The power factor is also close to 1 and so these are suitable for use with the new meter.
The ‘Dekatron’ decimal counter valve (1)

Dear Sir — your magazine used to be good, unfortunately it swerves time and again to high-tech subjects. What good are FPGAs and microcontrollers to me when I can’t get any use from them? To be able to follow your construction projects you need an academic degree and vast amounts of ‘pocket money’ to buy special parts and programming tools. That used to be different, and better, in the past.

For example, in your March 2008 issue you present the Dekatron counter valve with a schematic. Where, please, should normal people go to obtain, at a reasonable price, such parts declared obsolete decades ago? Kind of utopian, no? I am not so affluent as to spend my hard earned cash of working logic gates but in goat form — you can see a Youtube video of them in action here: www.youtube.com/watch?v=vu3o6JNclRQ

Best wishes

Rob Ives (Flying Pig)

In a word, brilliant! Everyone, put down your soldering irons and get out your scissors and cardboard.

The great efficiency associated with standard fluorescent lamps came from the fact that the light was emitted over an exceptionally large surface compared to a filament lamp. This gave softer shadows, less glare and a greater distribution of light over a given area. The humble tungsten filament lamp, like its predecessor the candle, was effectively a point source. With the CFL we are back to a point source (relatively speaking) so it has to be intensely bright to give a reasonable light output, as do HID lamps. Similar reasoning applies to LEDs as well. Unfortunately this tends to give them a characteristic starkness and glare. Here we go again!

The energy debate will continue no doubt, but what is the environmental effect of the CFL now poised to replace the incandescent lamp? Disposal of large quantities of dead units may be an issue, as they all contain mercury and some exotic phosphors, typically rare earth and metallic phosphor salts.

The cathodes (the heater bit that glows in a switch-start fitting) are made from tungsten wire coated with barium, strontium and calcium salts, and are similar in design to an electronic valve (tube) cathode, being designed for optimum thermionic emission at low temperatures. If these things ever do replace the simple GLS lamp, even at five times the life span there will be a lot of undesirable rubbish being dumped into the ground, and no doubt even more regulation will be needed to ensure that the lamps are re-cycled in a safe manner. This cost could be inflicted on the retailer or the manufacturer, putting up the price and making their use less attractive.

There is also the question of energy required to actually make, package and distribute these lamps. They may use one fifth of the energy in their life time, but how much energy is expended making each one in comparison to its more humble cousin? The glass envelope is far more complex than a single bulb, and the electronics for the CFL ballast inevitably has to be made and built. Despite the maker’s claims, the life of the CFL can be depressingly short, especially in the very compact designs that have a cooking hot ballast in the centre of the spiral fitting.

Are we in danger of moving the energy consumption and pollution generation from the end user to the manufacturing and disposal process, or like the electric car, from our cities to the power stations?

Andrew Denham (UK)

of working logic gates but in goat form — you can see a Youtube video of them in action here: www.youtube.com/watch?v=vu3o6JNclRQ

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on this grot. Not my cup of tea and I am cancelling my subscription.

G. Kratzin (Germany)

A bemusing response indicating that Mr Kratzin has missed the point about our Retronics articles entirely, see the footer printed with every instalment.

Anti-Standby Switch — a sequel on safety

Dear Editor — on your green standby switch project (January 2008, Ed.), a current transformer MUST always work into a very low impedance load. It is extremely dangerous to not have a low-value load resistor across the secondary, across which a small ac voltage is developed. So dangerous that some commercial current transformer manufacturers install the load resistor within the transformer module. Without such a load, under transient and high current events several thousand volts can be developed across the secondary as it tries to drive its secondary current into a non-existent load.

Without a load a CT looks like a voltage step-up transformer multiplying the 240VAC mains input being pushed through it. Only the saturation of the core limits the energy. The secondary winding, load resistor and PCB must be rated for the divided down primary load current. For example if the primary is rated for 13 Amps and there is a 1:10 turns ratio then the secondary must be designed for a steady state current of 1.3 Amps and a peak current of say 5 Amps (typical domestic 0.2 second fault current is 50 Amps). Obviously with a low impedance load and suitable conductors the power dissipation is very small.

(name withheld at request of correspondent)

The designer, Thomas Scherer, replies

Dear Jan — I thank the correspondent for being so concerned about safety issues. But in my eyes he is too concerned about this and misses the point in some way. Specifically, the rule he mentions is no law of nature. In fact this is pure theory which doesn’t match the real circumstances. Especially transients may happen with every inductive load, with coils and ordinary transformers too. This is nothing special. But they do not occur at the high energy levels he mentions. Therefore this never is as dangerous as you believe — otherwise a big part of commercially produced electronic devices would be dangerous. What he has not considered really is the amount of energy a pulse can have which is provided by this little current transformer. Like you said: this energy is limited by the core of this transformer and therefore is not insignificant. Second, there is no “no load” condition. Connected to the secondary coil of the current transformer is found a 10-k ohm resistor in series with a 100-nF capacitor which has nearly zero ohms for transients. A transient pulse of 1 kV peak should produce a current of 0.1 A which equals a peak power of about 100 W (for some µs). This little transformer is never able to produce such a peak power. And if you still believe in your theory: I measured the voltages which occur at the secondary windings of the current transformer during shutting off currents of 10 A on the primary side. The result is that the maximum measured pulse peaks do not reach 20 V. Is this dangerous? Not even for the following opamp, I believe, because the voltage at the 100-nF capacitor never exceeds 1 V. Lastly the correspondent is completely wrong in thinking that the parts at the secondary winding of the current transformer need to withstand 5 A peaks. This really never will happen. This is a practical case of impossibility ;-) So I am really sure the PCB is totally safe and nobody can be killed but your theory of unsafety....

Dr. Thomas Scherer

The original correspondent replies

Dear Jan — as your contributor Thomas points out it is all a matter of coupling. The CTs I was working with were designed to accurately measure (to within a percent or so) the primary current (typically 300 A) and in that application had many thousands of secondary turns to scale the primary current down to an electronics-friendly few milliamps using a substantial core. I have seen capacitors and ICs explode off the board when a load of 1 ohm was inadvertently omitted and in one case a senior engineer was thrown the length of the test bay when a technician...

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A selection from the contents
• Elektor RFID Reader
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• USB Flash Board
## EasyPIC5 Starter Packs—everything needed to learn about and develop with PIC microcontrollers from only £99

Four starter packs available, all of which include the EasyPIC5 development board, USB power/programming lead, blue backlit 16x2 character and 128x64 graphic LCDs, touch-screen overlay for GLCD, RS-232 lead, PIC16F877A 40-pin microcontroller and DS18B20 temperature sensor plus manuals and software.

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Our EasyPIC5 Starter Pack is ideal for those wishing to learn about and program using assembly language or other makes of compiler. The pack contains all required leads, character and graphic LCDs, touch-screen, PIC16F877A MCU and DS18B20 temperature sensor. Exclusive to Paltronix, the pack also includes a getting started guide, tutorials and example programs—ideal for newcomers to microcontrollers.

### EasyPIC5 BASIC Starter Pack - £114
EasyPIC5 C Starter Pack - £189
EasyPIC5 Pascal Starter Pack - £149

Get off to the best start with the EasyPIC5 and save money with one of our compiler starter packs, which include the contents of the above EasyPIC5 Starter Pack plus a full version of MikroElektronika’s mikroBASIC, mikroC or mikroPascal PIC compilers. These user-friendly compilers feature in-circuit debugging when used with the EasyPIC5 and also provide library routines to support all the EasyPIC5’s built-in I/O devices and optional add-on boards.

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### UNI-DS3 Universal Development System

**Description**
Work with various MCUs using one development board with the UNI-DS3. Currently supporting PIC, dsPIC, AVR, 8051, ARM and Psoc devices, the UNI-DS3 has a wide range of I/O features from £109 including main board and one plug-in MCU card.

**Features**
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**Options**
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The new dsPICPRO3 is a development system for the dsPIC with advanced I/O and communications devices including RS-232, RS-485, CAN, Ethernet, real-time clock, SD card reader and displays. Starter packs priced from £149.

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### PoScope Multi-Function Instrument

**Description**
The PoScope features a 16-channel logic analyser with I2C, SPI, 1-wire and UART serial bus decoding, dual-channel oscilloscope, pattern generator, spectrum analyser, chart recorder and square-wave/PWM generator in one low-cost instrument for £79.

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### LAP-16128U Logic Analyser

**Description**
The LAP-16128U from ZeroPlus is a powerful 16-channel 200MHz logic analyser with UART, I2C and SPI protocol decoding priced from £195. Further protocol decoding options available including 1-wire, Microwire, CAN, LIN, I2C/2 and USB.

**Features**
- We can supply all ZeroPlus logic analysers and advanced protocol decoding options.

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### Leaper-48 Universal Device Programmer

**Description**
The Leaper-48 is a USB-based universal device pro-grammer supporting an extensive range of memories, programmable logic devices, microcontrollers and digital signal processors at a low price of £295. Please see our website for full list of supported devices.

**Features**
- We also stock Leap device programmers for EPROM/ EEPROM/Flash EPROM, 8051 and PIC.

**Options**
- Starter packs priced from £149.

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### Robo-PICA Robot Experiment Pack

**Description**
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- Similar robot kits stocked based on 68HC11, 8051, AVR and BASIC Stamp plus large range of accessories.

**Options**
- Starter packs priced from £149.

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### NX-51 V2 Microcontroller Trainer

**Description**
Designed specifically for teaching 8051 microcon-troller interfacing and programming, the NX-51 V2 incorporates a useful range of I/O devices and comes complete with detailed example programs for £99.

**Features**
- Other training systems available for microcontroller and electronics teaching.

**Options**
- Starter packs priced from £149.

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### IDL Series Circuit Labs

**Description**
The IDL-400 Logic Trainer, IDL-600 Analogue Lab and IDL-800 Digital Lab all feature a large solderless breadboard, built-in DC power supplies, switches, displays and useful logic gates or test features and are priced from just £179.

**Features**
- We have a large range of prototyping products from breadboards to advanced digital and analogue circuit labs.

**Options**
- Starter packs priced from £149.
USB Digitisers & Digital Multimeter

National Instruments has announced the release of the NI USB-5132/5133 digitisers and the NI USB-4065 6½-digit digital multimeter (DMM). These small, lightweight instruments feature bus-powered and plug-and-play operation, which makes them ideal for portable, benchtop and OEM applications. They are also shipped with NI LabVIEW SignalExpress LE, an interactive measurement workbench for quickly acquiring, analysing and presenting data, with no programming required.

The USB-5132/5133 50 MS/s and 100 MS/s digitisers offer two simultaneously sampled channels with 8-bit resolution. These USB digitisers feature 10 input ranges from 40 mV to 40 V and programmable DC offset, and come standard with 4 MB/8 MB of onboard memory for measurements requiring extended data captures. The USB-4065 DMM offers 6½ digits of resolution at up to 10 readings per second and up to 4 MB/8 MB of onboard memory for measurements requiring extended data captures. The USB-4065 DMM offers 6½ digits of resolution at up to 10 readings per second and up to 3,000 readings per second at lower resolutions. With ±300 V of isolation, current measurements up to 3 A and 2- or 4-wire resistance measurements, the USB-4065 offers a complete multimeter solution for portable 6½-digit measurement needs.

Each of these instruments includes its own soft front panel, which provides an interactive, familiar interface to get up and running quickly. For data logging applications, engineers can easily combine the USB-5132/5133 digitisers or the USB-4065 6½-digit DMM with LabVIEW SignalExpress measurement software. Together, this intuitive software and the bus-powered architecture of these new instruments are extending the ease-of-use and performance of portable measurements.

www.ni.com/modularinstruments/usb

(080075-V3)

Verotec strengthens direct sales route and technical support

Verotec, the successor company to Vera Electronics and APW, announce that a new online shop will be launched on March 1st 2008. Well-known APW / VERO products such as KM68 Subracks & Front Panels, Diplomat, LBX & Verotec Cases, Fan Trays, 19” rack cases and many others can now be purchased either directly or through the new on-line shop. Selected sizes from all ranges are also available from the leading pan-European catalogue distributors Farnell and RS Components. Verotec standard products are available direct on short lead times with many popular items being available ex-stock. Customisation is a very common requirement for all types of sub rack and enclosure; Verotec’s experienced technical support team are available to advise on the best product for any particular application and to provide quotations for custom builds. The intrinsic experience, knowledge base, tooling and production equipment availability normally means that Verotec is able to offer the most competitive price and lowest time to market for any standard enclosure configured to meet the project needs.

For 50 years, the name VERO has been synonymous with high quality electronics packaging. The majority of Verotec employees are ex VERO and APW; they have extensive knowledge and experience of the design, engineering, manufacturing and customisation of all the products. The traditionally high quality, fit and finish associated with the VERO name is being maintained and bettered; in-house technical and commercial departments provide support on all aspects of the product range.

www.verotecshop.co.uk

(080087-30)

PS-900 soldering system

OK International has introduced the PS-900 Soldering System. Controlled and powered by SmartHeat® Technology, the PS-900 provides users with exceptional capability to solder high thermal demand applications including lead-free solders, multi-layer boards, and large mass components. The PS-900 is a fixed temperature system that varies power to match the thermal demand of the device being soldered. SmartHeat® Technology provides an exceptionally fast response when under load while eliminating the potential for thermal overshoot. The result is a high quality solder joint formed at safe, controlled temperatures. The PS-900 has a compact footprint power supply in a rugged, lightweight cast aluminum housing. The system includes an ergonomic soldering handpiece, an Auto-sleep Workstand for the soldering iron, and a temperature resistant tip removal pad.

Over 30 tip geometries are available in dimensions as small as 0.4 mm (.016”) to 5 mm (.197”). This range of tips allows users to perform a wide variety of applications including single point soldering of through-hole and SMD leads, drag soldering SMD leads, touch-up and pad clean-up. All PS-900 tips employ the use of high plating thickness. This feature protects the tip from flux attack, therefore, prolonging tip life and lowering operating costs.

The Auto-Sleep workstand, which is unique to OK International, automatically reduces the tip temperature during idle periods, providing increased tip life. Moreover, with SmartHeat® Technology, the PS-900 does not require calibration. This eliminates costly down-time typically associated with conventional soldering systems.

http://www.okinternational.com

(080073-X)
USB Connected High Speed
PC Oscilloscopes

PicoScope 5000 Series
The No Compromise PC Oscilloscopes

With class-leading bandwidth, sampling rate, memory depth and an array of advanced high-end features, the PicoScope 5000 PC Oscilloscopes give you the features and performance you need without any compromise.

250 MHz bandwidth
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In addition to the standard triggers the PicoScope 5000 series comes as standard with pulse width, window, dropout, delay, and logic level triggering.

250 MHz Spectrum Analyser
High-speed USB 2.0 Connection
Automatic Measurements
Arbitrary Waveform Generator

Define your own waveforms or select from 8 predefined signals with the 12 bit, 125 MS/s arbitrary waveform generator.

Waveform Playback Tool
PicoScope software now allows you to go back, review, and analyse up to 1000 captures within its waveform playback tool.

5000 SERIES
The PicoScope 3000 Series of oscilloscopes from Pico Technology includes general purpose and high resolution models: With 12 bit resolution and 1% accuracy, the 10MHz PicoScope 3424 is able to detect changes as small as 0.024% (24ppm) -- making it the ideal 4-channel oscilloscope for analog design and analysis. The higher speed 8 bit models in the PicoScope 3000 series feature sampling rates up to 200MS/s and up to 1 MS/s record lengths for general purpose and portable applications.

2000 SERIES
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Remembering Sir Arthur C. Clarke

Science fiction writer and visionary Sir Arthur C. Clarke died on 19 March 2008 in Colombo, Sri Lanka, at the age of 90. He was born on 16 December 1917 in Minehead, Somerset in the United Kingdom and moved to Sri Lanka; then called Ceylon, in 1956.

The international telecommunication community will remember Sir Arthur for making popular the concept of using the geostationary orbit for communications. In October 1945, Clarke published in the British magazine Wireless World a technical paper entitled „Extra-terrestrial Relays — Can Rocket Stations Give World-wide Radio Coverage?“ The paper established the feasibility of artificial satellites as relay stations for Earth-based communications. Clarke predicted that one day communications around the world would be possible via a network of three geostationary satellites spaced at equal intervals around the Earth’s equator.

Nearly two decades later, in 1964, Syncom 3 became the first geostationary satellite to finally fulfill Clarke’s prediction. Later that year, Syncom 3 was used to relay television coverage of the Summer Olympic Games in Tokyo to the United States — the first television transmission over the Pacific Ocean. Now, there are hundreds of satellites in orbit and providing communications to millions of people around the globe. In 1954, Clarke had also proposed using satellites in meteorology. Today, we cannot imagine predicting the weather without using dedicated meteorological satellites.

Looking back on these developments, in his book How the World Was One — Beyond the Global Village, published in 1992, Clarke wrote: „Sometimes I’m afraid that you people down on Earth take the space stations for granted, forgetting the skill and science and courage that went to make them. How, often do you stop to think that all your long-distance phone calls, and most of your TV programmes are routed through one or the other of the satellites? And how often do you give any credit to the meteorologists for the fact that weather forecasts are no longer the joke they were to our grandfathers, but are dead accurate ninety-nine percent of the time?“

Clarke wrote more than 80 books involving science, and science fiction. His short story The Sentinel served as the basis for Stanley Kubrick’s 1968 film 2001: A Space Odyssey. His other famous works include The Exploration of Space, The Promise of Space, The Fountains of Paradise, his semi-autobiographical novel Glide Path, and Childhood’s End. Before his death, Clarke had just reviewed the manuscript of his latest novel, The Last Theorem.

Alterna & Bitec: next-generation video system development

Altera and Bitec Ltd. jointly announced the availability of a video development kit that enables designers to rapidly develop and prototype high-performance, cost-sensitive video applications. At the heart of the kit are Altera’s Cyclone® III FPGAs, which are an ideal video processing platform given the device’s large parallel processing capabilities with up to 288 multipliers, 4-Mbit embedded memory blocks, and low power consumption. The kit supports multiple video I/O formats, allowing video application developers to quickly develop, debug, and prototype designs using their lab video signals and displays.

The video development kit features a Cyclone III development board with two high-speed Mezzanine Connector (HSMC)-based video interface daughtercards developed by Bitec. The kit supports composite, S-video, DVI and RGB video and contains:

- Cyclone III EP3C120F780 development board
- Quad-Video HSMC daughter-card (8 composite or 4 S-Video inputs)
- DVI HSMC daughtercard and DVI cable
- Quartus® II Web Edition software
- Access to Alterna® OpenCore Plus evaluation intellectual property (IP) megafunctions including the Video and Image Processing (VIP) Suite
- A CD-ROM with a video mosaic reference design developed by Bitec

The Cyclone III FPGA-based video development kit is currently available exclusively through Bitec. Interested customers can find additional information about the kit and general technology at the websites below:

www.bitec.ltd.uk/call_video_dev_kit.html
www.altera.com/devkits
www.altera.com/products/ip/dsp/image_video_processing/m-alt-vipsuite.html
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Visit www.microchip.com/DSCMotor today
The prices of graphic displays are dropping, which makes them increasingly attractive for many applications. However, programming a graphic display is distinctly more difficult than programming a text display. Our mini microcontroller board features a new display-on-glass module and a high-performance Renesas M16C microcontroller. The board is available fully assembled, and the microcontroller is pre-loaded with a TinyBasic interpreter to simplify the development of graphics applications – even for novices.

Dr Uwe Altenburg

There are countless applications for a stand-alone microcontroller board with a graphic display – everything from model railways or regulating the temperature in your home or conservatory to robotics.

However, driving the display and programming the associated microcontroller are tasks that exceed the skills of quite a few beginners. For this reason, in this article we present a ready-made board equipped with a display, a high-performance 16-bit microcontroller, and even a Basic interpreter [1].

The powerful M16C – the big brother of the R8C, which is well known to many of our readers – can also be programmed in C just like any other microcontroller, so advanced users have plenty of opportunity to develop their own applications. In any case, you can take advantage of features such as 128 kB of flash memory, a 10-bit ADC, PWM signal generation and much more, which make this mini board a truly versatile module.

Display

Electronic Assembly has released a novel ‘display on glass’ module with the part number EA-DOGM128, which is driven via an SPI interface [2]. This interface can be clocked at up to 20 MHz, so data transmission is not a significant bottleneck. Data is only transmitted in one direction here (from the microcon-
controller to the display), so only two signal lines are necessary. All in all, only five microcontroller I/O pins are needed – two for the data lines and three for the control lines (RESET, /CS and DATA). The display also features a very low profile of only 5.8 mm. The integrated LED backlight and automatic contrast adjustment ensure good legibility under all conditions, combined with low current consumption. Thanks to its pinheader contacts spaced at 2.54 mm, the module is easy to fit on a PCB. And on top of all this, it is available in several colour combinations (e.g. from Reichelt Germany [3]).

**Microcontroller**

Our search for a suitable microcontroller led us to choose the Renesas M16C28/29 [4]. This 16-bit machine has an impressive array of features. With 128 kB of flash program memory, 4 kB of flash data memory and 12 kB of RAM, it is generously endowed with storage capacity. Although the display has its own graphic memory, the data for the display must still be assembled in the microcontroller. A monochrome display with a resolution of 128 × 64 pixels requires an image memory of 1 kB in the microcontroller for this purpose (128 × 64 ÷ 8). The M16C28/29 has two DMA channels, so data can be copied directly from the image memory to the display without imposing any significant load on the microcontroller.

![Figure 1. The circuitry around the M16C is relatively uncomplicated.](image)
Naturally, this little powerhouse in its 64-lead P-LOPFP package also has a lot more to offer. Along with a 10-bit ADC with 16 input channels, it has several timer units, one of which can generate up to eight PWM signals with a resolution of 16 bits. There is an SPI interface for the display (of course), as well as two UARTs available for user-defined functions. A third UART is used for the ISP/debug interface.

Without wishing to revive the old debate on the relative merits of RISC and CISC architectures, we can simply mention here that the instruction set of this CISC processor is extremely efficient. The instruction execution time is only 50 ns with a 20 MHz clock. Several registers can be saved on the stack at the same time with a single assembly-language instruction when an interrupt routine is called. This results in extremely short interrupt response times. For information on other features, such as clock generation using a PLL, we suggest that you consult the datasheet.

Circuit

The schematic diagram of the circuit (Figure 1) is relatively uncomplicated. It is built around an M16C29 microcontroller (IC1) with a minimum of peripheral components. The Reset input manages nicely with a simple RC network (R12/C2). The primary clock signal is generated using an 18.432-MHz crystal (Q1). The microcontroller has a specified maximum clock frequency of 20 MHz. Given the capabilities of the internal dividers and the requirement to have the serial interfaces support all standard baud rates from 300 to 115,200 baud, the maximum clock frequency that can be used is 18.432 MHz. However, the SMD crystal used here is a standard component.

In the interest of maintaining a low profile, the display is soldered flush against the surface of the circuit board. All other components are mounted on the solder side. This means that SMD components must be used (with a few exceptions). This applies to the second crystal as well (Q2), which operates at 32.768 MHz to provide a secondary clock signal. There are essentially two situations in which the secondary clock can play a role. The first is when a timer is programmed to act as a real-time clock, for instance in order to trigger a low-priority interrupt once per second. Alternatively, the secondary clock can be used in place of the primary clock in order to operate the microcontroller with the lowest possible power consumption.

A 10-way MicroMatch connector is used for programming and debugging the microcontroller. The signals available on this connector correspond to the signals needed by the Renesas E8 emulator for this type of microcontroller. The Renesas emulator is available from Reichelt [3], among other sources, but it can also be obtained from Rutronik or Glyn along with an evaluation board. The emulator is accompanied by a very good C compiler, which...
can handle a code size of up to 64 kB in the free version. But that’s not all: for the C fans among our readers, the next issue of *Elektor* will have an article describing a small circuit that lets you program the microcontroller without using purchased hardware. All you actually need to flash into the M16C is a serial interface and a few freely downloadable tools (for example, from Renesas), and many readers are probably already familiar with them from the R8C ‘Tom Thumb’ project.

### Display power

The display (LCD1) requires only a single supply voltage of 3.3 V. The microcontroller can be operated at 3.3 V or 5 V. As the display module is intended to be used in other circuits, we decided on a supply voltage of 5 V.

A supplementary low-drop 3.3-V voltage regulator (IC2) generates the supply voltage for the display. Simple voltage dividers (R1–R10) are used to adjust the levels of the signals from the microcontroller to the levels required by the display. Here the fact that the display is driven by only five lines, and only in one direction, is a distinct advantage. It keeps the amount of hardware necessary for level adjustment within reasonable limits.

The display microcontroller (an ST7565) needs higher internal voltages to drive the LCD segments. For this purpose, a set of external capacitors (C14–C21) must be connected to its integrated charge pump circuit.

The LEDs for the display backlight are driven via series resistors R19, R20 and R21 and a simple transistor stage (Q3). The display illumination is always on unless it is programmed otherwise. In the simplest case, the illumination can be switched on and off under software control. However, the I/O pin used for this purpose (P7.4) can also be programmed as a PWM output to provide a conveniently adjustable brightness level under software control.

One of the two free serial interfaces is connected to one of the 14-way headers via an RS232 level converter (IC3, a MAX202). This interface can be used for connection to a PC or a modem. The TinyBasic interpreter, which is described later on in this article, also uses this interface for downloading program code. (Note: if you’re not afraid of a bit of soldering work, you can tap off another V24 signal from the T2OUT pin of the MAX202 – see the schematic diagram.)

The second serial interface can be connected to the header either directly or indirectly via an RS485 level converter by suitable configuration of jumpers SW1, SW2 and SW3. This means that the module can also be connected to a network and share a bus with other microcontrollers.

### Drive logic

Now let’s turn our attention to the graphic display. The SPI interface is

### Listing 1. Display initialisation

(Data types used: BYTE = 8 bits unsigned, WORD = 16 bits unsigned, INT8 = 8 bits with sign, INT = 16 bits with sign, LONG = 32 bits with sign)

```c
// --- Init sequence ---
const BYTE InitList[] = {
    0x40, // start line
    0xA1, // normal layout
    0xC0, // normal COM0..63
    0xA6, // normal display
    0xA2, // set bias 1/9
    0x2F, // booster regulator on
    0xF8,0x00, // booster to 4x
    0x27,0x81,0x16, // set contrast
    0xAC,0x00, // no indicator
    0xAF // display on
};
// --- Init display ---
void InitDisplay()
{
    BYTE nCmd;
    LCD_CS = 1; // no chip select
    LCD_RES = 0;
    Sleep(50); // 50ms reset delay
    LCD_RES = 1;
    Sleep(50); // 50ms power-up delay
    LCD_MODE = 0; // command mode
    for (nCmd = 0; nCmd < sizeof(InitList); nCmd++)
    {
        SPISend(InitList[nCmd]); // send cmd
        Sleep(1); // wait 1ms
    }
}
```

### Listing 2. Page copying

```c
// --- Copy a single page ---
void CopyPage(BYTE nPage)
{
    BYTE nPos;
    LCD_MODE = 0; // command mode
    SPISend(0x40); // memory base
    SPISend(0xB0 + nPage); // select page
    SPISend(0x00); // col low
    SPISend(0x10); // col high
    LCD_MODE = 1; // data mode
    for (nPos = 0; nPos < 128; nPos++)
    {
        SPISend(Pixels[nPage][nPos]); // copy page
        SPISend(0x00); // send byte
    }
    LCD_MODE = 0; // command mode
    SPISend(0x81); // send nop
```
operated in Mode 0, which means that the data is clocked into the display on the rising edge of the clock. The timing diagram for this is shown in Figure 2. The individual data bytes are transferred to the display sequentially using this clocking scheme. In the code examples, the SPISend() routine is called for this purpose (see Listing 1).

The display must be initialised before any image data is sent to it. The routine that does this is called InitDisplay(). This routine sends several commands after the Reset pulse and a short startup time delay. The A0 line of the display must be held low while the commands are being transferred. Consult the data sheet for the display microcontroller (ST7565) for the specific functions of the individual commands. The sequence of commands shown in Listing 1 is designed to initialise the display to an operational state.

The next question is how to send image data to the display. To answer this question, you first have to understand how the image memory of the display is organised. The EA-DOGM128 is divided into eight sections called ‘pages’. Each page consists of a 128 × 8 array of pixels. This means that each page needs 128 bytes. The top left pixel corresponds to bit 0 of the first byte of the top page.

The display has a write pointer in addition to the image memory (see Figure 3). The write pointer can be set to a specific position in a page by sending commands to the display. All data bytes sent after this are written to the image memory starting from this position. The write pointer is incremented automatically during this process. Naturally, each data byte modifies eight pixels at the same time. Modifying a single pixel is thus not possible, and it would anyhow not be especially efficient. Instead, a copy of the image memory is maintained in the microcontroller, and it is also organised in pages. This can be achieved by declaring a suitable variable: BYTE Pixels[8][128]. All drawing operations are performed directly on this internal image memory. This simplifies the graphics routines, and it is significantly faster.

Of course, the internal image memory must be copied periodically to the display. In the simplest case, this can be done by an interrupt routine that copies only one page at a time to the display. The CopyPage() routine first sends several commands to the display to set the write pointer to the start of the page to be copied. After this, the page data is sent to the display, and the process is terminated by a NOP command (see Listing 2). At a data rate of 1 Mbit/s, the copy process takes approximately 1.1 ms.

--- Listing 3. Pixel setting ---

```c
// --- Set a single pixel ---
void SetPixel(BYTE x, BYTE y)
{
    if (x < 128 && y < 64) // clip
    {
        BYTE nPage = y / 8; // calc page
        BYTE nMask = 1 << y % 8; // calc mask
        Pixels[nPage][x] |= nMask; // set pixel
    }
}
```

Figure 4. The Bresenham algorithm constructs lines as sequences of adjacent pixels. Here three steps in a straight line are followed by a diagonal step (see Listing 4).
If the interrupt routine is called every 10 ms, it takes around 80 ms to transfer a full image. Naturally, it is only necessary to copy the pages where changes have actually occurred. For this purpose, a ‘Dirty’ flag is maintained for each page. It is set by the graphics routines. The alternative ‘high-end’ solution is to use a DMA channel for the page data.

Graphics programming

Now that you know how to connect and program the EA-DOGM128, you might think that you’re all set – but in fact you’re just getting started. Here we want to talk about drawing line and circles, which is not as simple as it seems.

Of course, the first thing you need is a routine for setting the values of individual pixels, which goes by the name SetPixel(x,y) – see Listing 3. As the image memory is virtually located in the RAM of the microcontroller, the routine only has to set the right bit. One of the most important tasks in this connection is range checking, as otherwise it would easily be possible to set bits that have nothing at all to do with the image.

Avoiding the need for floating-point arithmetic another is another factor that makes revisiting the ‘stone age’ of computer technology worthwhile. At that time, clever approaches were often devised to compensate for low processing power – something that seems to neglected more and more these days. In the 1960s, Jack Bresenham was working at IBM on graphic output for plotters, and around 1962 he developed an algorithm that bears his name: the Bresenham algorithm – see Figure 4 and Listing 4. Even now, 40 years later, this algorithm is just as important as ever.

Lines and circles

The Bresenham algorithm first considers only straight lines with slope $0 < a < 1$ (first octant). The line is drawn by processing the x coordinates incrementally starting from the initial point and deciding for each point.

### Listing 4. Line from point A(ax,ay) to point B(bx,by)

```c
// --- Draw a line ---
void DrawLine(BYTE ax,BYTE ay,BYTE bx,BYTE by)
{
    INT x = (INT)ax;       // start
    INT y = (INT)ay;
    INT dx = (INT)bx - ax;  // distance
    INT dy = (INT)by - ay;
    INT8 sx = 1;
    INT8 sy = 1;

    if (dx < 0)            // x orientation
    {                      
        sx = -1;
        dx = -dx;
    }

    if (dy < 0)            // y orientation
    {                      
        sy = -1;
        dy = -dy;
    }

    if (dy <= dx)          // select direction
    {
        INT c = 2 * dx;
        INT m = 2 * dy;
        INT d = 0;

        while (x != bx)    // draw in x direction
        {
            SetPixel(x,y);  // set pixel
            x += sx;
            d += m;
            if (d > dx)
            {
                y += sy;
                d -= c;
            }
        }
    }
    else
    {
        INT c = 2 * dy;
        INT m = 2 * dx;
        INT d = 0;

        while (y != by)    // draw in y direction
        {
            SetPixel(x,y);  // set pixel
            y += sy;
            d += m;
            if (d > dy)
            {
                x += sx;
                d -= c;
            }
        }
    }
}
```

whether the y coordinate should be increased. The y coordinate is increased if the error relative to the straight line is greater than half a pixel. The error is calculated for each step in a manner that only requires an integer comparison. Finally, the algorithm can be applied to the other seven octants by mirroring or by reversing the direction of drawing. This yields a very fast and exact line-drawing algorithm. The Bresenham algorithm can also be used to draw circles and ellipses, which avoids the need to calculate sine and cosine values. A suitable listing can be downloaded from the Elektor website [6].

TinyBasic interpreter

As mentioned above, the microcontroller used here has enormous potential, including a relatively large memory capacity, analogue inputs, and a variety of interfaces. It would be a sin to use this potential for nothing more than driving the display. To make it even easier for novice programmers to create their own graphic applications, the author has developed a Basic interpreter.

Programs can be generated using a convenient PC-based text editor that highlights keywords in colour (Figure 5). The program code can then be downloaded directly to the flash memory of the microcontroller, where it will be launched immediately when the module is switched on.

An overview of the language and the available commands is available online [1]. Naturally, it supports conditional branching and loop commands, as well as mathematical functions such as SIN(), COS(), EXP() and LOG(). There are also commands for graphic output (PLOT, MOVE, DRAW, COLOR, FRAME, CIRCLE, PICTURE, BARGRAPH) and for accessing the hardware (POKE, PAUSE, SOUND, SETCOM, SETPWM, SETPORT, SET_CLOCK, SET_DISPLAY, SET_NETWORK, SET_COUNTER, SEND, REC, I2CIN, I2COUT, and SPI_SHIFT).

As an example, up to eight R/C servos could be connected to the module, which is enough for a small walking robot with facial expressions and gestures.

A sample application…

As a sample application to get you started, here we describe how to use

Listing 5. Analogue clock in TinyBasic (excerpt)

```plaintext
' --- Definitions ---
define BTN1_PRESSED (port0.5 = 0) ' Button 1
define BTN2_PRESSED (port0.6 = 0) ' Button 2
define BTN3_PRESSED (port0.7 = 0) ' Button 3
define BACKLIGHT port7.4 ' LCD backlight
#define T20SEC 20000 ' Backlight time

' --- Hardware ---
setdisplay LCD_DOGM128x64 ' Display type
setclock REAL_CLOCK ' Real-time clock
setport 7,$10 ' Backlight output
setport 0,0,$E0 ' PB switch pull-ups

' --- Variables ---
float w,t0,t1
byte ho,mi,se,da,mo,ye,x,y
byte Icon[18]

' --- Init ---
BACKLIGHT = 1 ' Backlight on
Timer0 = T20SEC ' Start timer
gosub Scale ' Draw clock face

' --- Main loop ---
do
if BTN1_PRESSED or BTN2_PRESSED or BTN3_PRESSED then
  Timer0 = T20SEC ' Start timer
  BACKLIGHT = 1 ' Backlight on
elsif Timer0 = 0 then
  BACKLIGHT = 0 ' Backlight off
endif

if Time.Second <> se then
  gosub UpdateTime ' New second
  gosub UpdateTemp ' Update time
endif
```

Figure 5. The PC-based text editor provides a convenient development environment for Basic programs.
the module to make an analogue clock with an integrated display of the indoor and outdoor temperature. This requires a small amount of additional circuitry for measuring the temperature in a suitable manner.

A temperature-dependent current source, such as the AD592, can be used as the temperature sensor. The advantage of this sensor is that it has a linear characteristic. You only have to connect a 10-kΩ resistor in series with the sensor in order to covert the current into a temperature-dependent voltage with a scale factor of 10 mV/K (see Figure 6). Unfortunately, this sensor is relatively expensive. As an alternative, you could construct a similar circuit using the more economical LM344 sensor.

The AD592 supplies a current of 273 µA at a temperature of 0 °C. This results in a voltage of 2.73 V across the resistor. The analogue inputs (in this case P0.0 and P0.1) have a resolution of 10 bits, which means they supply values in the range of 0 to 1023. The currently measured temperature can be calculated using the simple formula 'temp = (analogue_value – 559) ÷ 2.04'.

Naturally, the previously described routines for lines and circles can be used for the analogue clock display. The sin() and cos() functions must be used to calculate the positions of the hands. TinyBasic provides these trigonometric functions (and others) – see Listing 5. As this is supposed to be an analogue clock, the hands should of course move smoothly. For this reason, the positions of the hour and minute hands are interpolated. This gives the impression of continuous motion. The second hand is represented by a small circle, which is more a question of design than necessity.

...and your own applications

If you buy the display board from the Elektor Shop, you receive a fully assembled and tested module. The TinyBasic interpreter is already installed in the microcontroller. The Basic development environment can be downloaded from the Elektor website [6] free of charge, along with additional examples and listings.

For beginners, we have also put together a step-by-step guide that describes how to install the necessary software on the PC and how to download your own application.

Web Links
[1] www.tinybasic.de/
[3] www.reichelt.de/ [in German]
[4] www.m16c.de/

Component availability notice
Ready assembled and tested board including display and pre-programmed microcontroller (bootloader and Basic Interpreter) available from the Elektor Shop, order code 070827-91.
Bare PCB, ref. 070827-1 available from www.thepcbshop.com.
assembly, test and software

DigiButler (2)

Richard Sumka & Eric Gregory (Freescale Semiconductor Inc.), Luc Lemmens & Jan Buiting (Elektor)

Continuing on from the April 2008 issue, in this the second and final part of the article we go about assembling the kit and connecting up the hardware and software to get DigiButler active on the web and in control of an electrical appliance in your home or office.

Assembly and test

All components used in this project are contained in a kit that is available through the Elektor Shop as #071102-71 (Figure 1). The PCB contained in the kit comes with all but six SMD components ready-soldered and the Coldfire micro ready programmed with the DigiButler firmware. This makes building the project a matter of soldering three dozen or so through-hole components and six relatively large SMD parts including the Ethernet transformer T1.

The component mounting plan of the DigiButler board is shown at true size in Figure 2. The associated parts list clearly indicates which parts are prestuffed on the board you get, and which ones have to be soldered.

Assembly of the board should be straightforward using the parts from the kit. Solder the SMD components first and follow with the through-hole components. The SMD parts you have to solder yourself are:

- capacitors C20, C21 (both 4.7μF solid) located at the underside of the board;
- capacitor C15 (4μF7 solid) located between J11 and J12 located at the top side of the board;
- transformer T1 (H1102NL) located at the top side of the board. Triangle marker on the PCB overlay to register with the white dot printed on the device;
- quartz crystal Y1 (25 MHz) located at the top side of the board;
- voltage regulator U2 (LD29080DT33R) located at the top side of the board.

If you use a fine-tipped solder iron and the usual care and precision then mounting these parts should not cause problems. Give the mounting of T1 a thorough visual inspection to make sure no adjacent pins are short-
circuit by solder blobs. Now, on with the soldering of the lead-
end parts from the kit. Voltage regulator U2 has a thermal pad on the un-
der side of the device, the tip of which should be soldered to the nearby copper square on the PCB. The centre pin is not used — the metal pad establishes the ground connection.
The connectors, fuseholder and relay should be assembled last. Pay special attention to J14 and RE1 which should be placed on the board together before being soldered.
The ‘pin-1’ marker printed on resistor networks RN1, RN2 and RN3 should register with the respective little circles on the PCB overlay. Watch the polarity of radial electrolytics C22 and C25, LEDs D2 and D4, diodes D1 and D3, and finally U4, the MAX3232ECPE. When placing the assembled PCB directly onto a hard surface, take care to avoid damage to the passive surface mount components at the underside of the PCB. Four 5 mm high PCB pillars secured with M3 nuts will take care of the problem.
The base of RS232 socket J13 may be secured to the board using two M3 screws and bolts. RJ45 socket J2 has two plastic studs that snap secure into the 3 mm holes on the board. Do not install jumper JP2 (BDM_ENABLE) and set JP1 (BDM_SEL0) the right-hand position (2-3).
Check the board carefully before applying power. Ensure that all solder joints are good and that there are no shorts. Connect power to the board using either an unregulated or a regulated DC supply with an output voltage of 5-8 V. LED D2 should light up.

**I can do it cheaper**

Be our guest, although you’ll find the price of the DigiButler kit hard to beat. Especially for those among you who insist on sourcing their components locally and doing the microcontroller programming all by themselves we also supply the same SMD-prestuffed PCB with an empty microcontroller as Elektor Shop # 071102-1. ‘Empty’ means no firmware in the MCF52231, so you will also need the TBLCF hardware and software, or a professional equivalent from Freescale or a third party.

**TBLCF hardware**

For completeness’ sake we recall that the PCB design and construction notes for Daniel Malik’s Turbo BDM Light Coldfire Interface (TBLCF) may be found at [7] referenced in Part 1 of this article (April 2008). PCBs for the TBLCF are supplied through the Elektor Shop as # 071102-2. The bare board is shown in **Figure 3**. You will need TBLCF if you want to make changes to the DigiBut-

ler firmware, or use the hardware as a Coldfire development system.
Remember the ‘free samples’ trick we showed in last year’s 3-Axis Accelerometer article? Use the Freescale website again to get a free MC908JB16JDWE chip for the TBLCF programmer. For the project name, enter: ‘Elektor DigiButler’. Caution: the supply of free samples is strictly at the discretion of Freescale Semiconductors Inc. Look in Elektor’s forum topics on exercise extreme caution if using this board to switch power to an AC mains powered load as dangerous voltages will exist on the pins of J14 and RE1. The maximum current switched by the relay contacts is 2 A. If in doubt consult an experienced professional.

**Figure 2. DigiButler board layout. The board comes with all but six SMD parts premounted**
COMPONENTS LIST

1. Components pre-fitted on board

**Resistors**
- R3 = 12kΩ, SMD 0805
- R4 = 390kΩ, SMD 0805
- R5 = 10MΩ, SMD 0805
- R6, R7, R8, R9 = 51Ω, SMD 1206

**Capacitors**
- C2, C3, C4, C12, C13, C14 = 220nF ceramic, SMD 0805
- C9, C10, C11 = 100nF ceramic, SMD 0805
- C15 = 10nF ceramic, SMD 1206

**Inductors**
- FB1, FB2 = BLM31PG601SN1 ferrite bead, 2.7mm, SMD 1206

**Semiconductors**
- U1 = MCF52231CAF6 (Freescale)*
- U2 = LD29080DT33R (STMicro)
- Q1 = BC546B
- D2 = LED, 3mm, green
- D3 = 1N4148
- D4 = LED, yellow, 3mm
- C25 = 220μF 6.3V, electrolytic, radial

2. Components to fit on board

**Resistors**
- R1 = 22Ω SFR165
- R2, R7, R176 = 10kΩ SFR16s
- R15 = 470Ω
- R10, R13 = 75Ω SFR165
- R14 = 270Ω
- R16 = 1kΩ SFR16S
- RN1 = 7-way 4x0.7 SIL
- RN2 = 5-way 10kΩ SIL
- RN3 = 7-way 10kΩ SIL

**Capacitors**
- C1, C23, C24, C26, C143, C144, C147 = 100nF ceramic, lead pitch 5mm
- C15, C20, C21 = 4μF, solid, SMD 1206
- C16 = 100nF ceramic, lead pitch 5mm
- C17 = 120nF ceramic, SMD 0805
- C18 = 220μF 6.3V, electrolytic, radial
- C20, C21 = 4μF, solid, SMD 1206
- C22 = 330μF 16V, electrolytic, radial
- C25 = 220μF 6.3V, electrolytic, radial
- C26 = 22μF ceramic, SMD 0805
- C27 = 1nF ceramic, SMD 0805
- C28 = 100nF ceramic, SMD 1206
- C29 = 10nF ceramic, SMD 0805
- C30, C31 = 100nF ceramic, SMD 0805
- C32 = 220nF ceramic, SMD 0805
- C33 = 220nF ceramic, SMD 0805
- C34 = 22nF ceramic, SMD 0805
- C35 = 2nF ceramic, SMD 0805
- C36 = 22μF ceramic, SMD 1206
- C37 = 22μF ceramic, SMD 1206
- C38 = 22μF ceramic, SMD 1206
- C39 = 10μF ceramic, SMD 0805
- C40 = 10μF ceramic, SMD 0805
- C41 = 10μF ceramic, SMD 0805

Compilation and programming

Code (re)compilation and device (re)programming is only necessary if you
- 1. have an unprogrammed board # 071102-1 and/or
- 2. want to make changes to the existing firmware.

The project software including the full C source code is available from the Elektor website as a free download — you’ll find it as archive file # 071102-11.zip. Unpack it into an appropriate directory.

Compilation and (re)flashing the MCF52231 requires CodeWarrior Development Studio for ColdFire Architectures, v. 6.3. CodeWarrior is an integrated development environment which includes a project manager, editor, compiler and debugger. Version 6.3 is a free download. At ref. [1] it’s marked as “Updates and Patches” but Elektor has ‘inside information’ that it’s actually a full install version! The download is about 140 MB. Type ‘Elektor DigiButler’ when you are asked for the project name.

At the time of writing, the ‘Special Edition: CodeWarrior for ColdFire Architectures’ (v. 7.0) revealed some issues with the MCF52231 micro we’re using. An update/patch or service pack for 7.0 has been announced by Freescale. It should be well worth the wait considering that the suite can compile up to 128 k of code in ‘C’ and unlimited assembly code. The Special Edition can be downloaded at [1] too — sit back & relax for 270 MB or so.

Programming and debugging also needs a background debug pod such as TBLCF or the USB-ML-CFE [2] from P&E Micro. A detailed procedure to do the firmware flashing is given in the ‘(re-)Flashing your board’ inset.

Network connection

The most important part of the project is connecting DigiButler to a network, and for this we need an IP address for the board. An IP address is similar to a telephone number and allows the board to be identified by other devices on the network. By default, the board software is configured to request an IP address from a DHCP server, although it can be reconfigured to have a fixed, or static, IP address. Most home cable or DSL modem routers have built-in DHCP server functionality and are able to provide local IP addresses.

To link to your network, connect the DigiButler board to your router using a standard RJ45 cable. Next, connect the

Figure 3. TBLCF board, unstuffed.
board to a PC’s COM port using a regular RS232 cable. USB-to-RS232 adapters are often problematic so an (older) machine with a real serial port (COM) is preferred. If necessary, borrow the kiddies PC.

Start up a terminal session such as Minicom for Linux or HyperTerminal or TeraTerm for Microsoft Windows. The communication settings are

- 115,200 databits/second
- 8 data bits
- no parity
- 1 stop bit
- no flow control

Power up the board and push switch S1 to reset it. This will cause the application software to communicate with the DHCP server in the router to acquire an IP address for the board. On the PC screen, the terminal window will display the board IP address, like 192.168.0.2, indicating connection to the network and ability to be accessed remotely. Note that it takes a few seconds for the board to obtain an IP and include it in the message sent to the terminal. Got the complete message? Congratulations, your hardware is working.

If you just want to connect the board direct to a PC, you will need a crossover RJ45 cable and a fixed IP address in the application software.

Ethernet setup and access security

We have assumed so far that DigiButler will be connected to the Internet via an Ethernet router. A router allows many computers on a local network to share the same internet connection. It also prevents unwanted Internet visitors accessing those same computers unless authorised.

Preventing access to your private DigiButler could be a problem if it were not for a router feature called Port Redirection or Port Forwarding, see Figure 5 for a typical example. Port Forwarding lets through Internet traffic destined for a given IP address and port and then sends it to a computer or other device on your local network. Let’s say the local IP address of the server is 192.168.0.2 and the address of your router — given to you by your Internet Service Provider (ISP) — is 86.131.222.120. Login to the administration pages of the router and change the router settings to forward any incoming traffic destined for port 80 to DigiButler at address 192.168.0.2. Anyone who now enters http://86.131.222.120 in their web browser will be taken to your DigiButler board.

Be aware that you probably won’t be able to see the server if you try this from a PC on the same local network. Instead you will have to use http://192.168.0.2.

Another important point to note is that each port can only be forwarded once. It’s not possible to have port 80 forwarded to multiple IP addresses so you won’t be able to run a web server on a local network and also run DigiButler as they both use port 80.

The end result: network, web and WAP

The home automation server is ready for access over a network as soon as the Coldfire device has been programmed and the network cable is

(re-)Flashing your board

The following procedure was recorded with a PE Micro parallel programmer / debugger pod connected to J1 on the DigiButler board, a laptop PC running Windows XP and a down-loaded version of CodeWarrior 6.3. TBCLF may require different jumper settings and steps, please consult the TBCLF documentation. Updates to this procedure may become available at www.elektor.com/digibutler_en.

1. Fit jumper JP2 and set jumper JP1 to the right-hand position (2-3).
2. Start the CodeWarrior IDE, open the project ‘elektor.mcp’ using the File → Open command in the IDE menu bar. Connect the debug pod to connector J1 and apply power to the board.
3. Use Tools → Flash Programmer to bring up the Flash Programmer dialogue box.
4. In the Target Configuration menu, Browse to the Target Initialization files and there select and Open: M52235EVB_Pne.cfg
5. In the Flash Configuration menu, select: CFM_MCF52230 25 MHz.
6. Go to the Erase /Blank Check menu and run an Erase action. This is useful to check if the connection to the target is okay. If erasure is successful, the comms are okay. Click on Save Settings.
7. Now go to Program/Verify and browse to the file ‘web co ordinator’ (without an extension). This is a precompiled binary image, included for those who do not wish to recompile the source code.
8. Program the device! With the device programmed, the board is ready to be used.
Successful authentication brings up the default main web page, *index.htm*. As illustrated in Figure 7, a graphic image on the example default web page shows the status of the relay. The project source code allows you to substitute your own image! A dark image signifies that the relay (RE1) (lamp) is off, while a bright image shows that the relay (lamp) is on.

The process for talking to DigiButler over the Internet is exactly the same. Entering the router IP address in the browser of an Internet connected PC gives the same results, but only if the router has been set up for forwarding port 80 to the DigiButler’s local IP address. In our example, the router address is 86.131.22.120. Be aware that it might not be possible to access the server from a PC within a local network, if you use the router IP address. If you are having difficulty remembering the IP address, NO-IP [3] offers a free service which maps the IP address to an easy to remember sub domain name.

Finding an Internet connected PC is not always possible or safe, so WAP phone access is also supported. Nearly all modern mobile phones have WAP, but the service is subject to what your provider is offering you. DigiButler’s default WAP page is *wap.wml*. Entering our example URL,

http://86.131.22.120/wap.wml

from the browser of a WAP enabled phone, gives similar results as before but without the images. The WAP pages have been tested using Nokia and Samsung mobiles, but may need to be changed to support other manufacturers’ handsets.

### Creating and uploading web pages

A neat feature of the software is its support for dynamic uploading of new web pages. The following is intended for those having some experience in programming web-connected devices.

By implementing an Ethernet writeable FLASH based file system, it’s possible to update web pages remotely without reprogramming the Coldfire device. Two files systems are actually implemented — a static compile time system and the dynamic writable system. Both can be used to store web pages, graphic files and other content and both allow directory structures and file names up to 255 characters. Since the application looks in the writable system for a requested file before searching the compile time file system, it’s possible to override the compiled files. For example, if an image file exists in both file systems with the same name, then the file in the writeable system will be used and the one resulting from the compile will be ignored.

Example web pages and Ethernet loading utilities can be found in the *web_page* directory of the project. The files required to upload new web content to the automation server are *make.bat*, *filelist.txt*, *emg_dynamic_ffs.exe* and *emg_web_uploader.exe*.

The batch file *make.bat* conveniently calls the necessary utilities to compress and upload the web-resultant content image file using the files listed in *filelist.txt*. Before executing *make.bat*, change the IP address in the line

```
emg_web_uploader 10.171.88.63 dynamic.ffs joshua
```

in *make.bat* to the board’s IP address as shown in the terminal window. The parameter *dynamic.ffs* is the name of the compressed file image generated by compression utility *emg_dynamic_ffs.exe*. This compresses the files in *filelist.txt* into a single image. The parameter *joshua* is the upload security key, used to prevent unauthorized upload of web content. DigiButler will verify the supplied security key with the version in memory and upload only if both match. The security key can be changed in the server source code if required.

An example of the contents of *filelist.txt* is shown below. These files will be compressed into one image for upload to the server. The last line in the file must be a blank line with only a CRLF (i.e. hit Enter in the last blank line).

```
* This is a list of the files stored in the bin file.
```
Overcoming firewalls

Both FTP or TFTP protocols are commonly used to upload files to web servers. However, many firewalls and routers consider these protocols as dangerous and block the transfer, which causes a problem if trying to upload new content to the automation server. To overcome this, the utility `emg_web_uploader.exe` uses TCP and port 80 thereby getting around the problem.

Enhancements and your contributions

DigiButler opens up many exciting opportunities for controlling devices remotely and for remote real-time data measurement. Analogue and digital signals can be captured, measured and subsequently analysed from a web browser. For example, a sensor could be added to the DigiButler analogue inputs and be read remotely using the HTML VARS function described in AN3455. With some modification to the software, images could be captured using a VGA camera module such as the C328-7640 [4].

The prototyping area on the board allows you to build your own extension circuits. Many signals to and from the microcontroller are conveniently found on J11 and J12, while the V_{ext} pin close to the fuse may help to power the extension(s). The same for the +3.3 V rail which can be ‘tapped’ near J11 (but watch the extra current consumption of your extension circuit). If you duplicate the existing relay circuit for the control of a second 230 VAC load, be sure to observe electrical safety precautions.

The authors look forward to seeing your applications and extensions as the project was designed and published with the open-source concept in mind. A dedicated web page will be ‘at your service’ at www.elektor.com/digibutler_en.

Web Links


[4] VGA camera module
www.electronics123.com/s.nl/it.A/id.2027/.f?sc=8&category=233

Changing the IP address

You may wish to use a fixed IP address instead of having an IP address assigned by the router’s DHCP server functionality. This is possible by making two simple code changes. The first is to switch off the DHCP functionality by commenting out the line

```c
#define DHCP_CLIENT     1    /* include DHCP client code */
```

in the file ‘ipport.h’. The second is to set the IP and gateway addresses and subnet mask. Example values for these parameters are included in file ‘main.c’. Change them according to your setup and remember to change the #if 0 statement to #if 1.

```c
#if 0
IP_ADDRESS(213,194,223,49);
DEF_GATEWAY(213,194,223,1);
SUBN_MASK(255,255,255,128);
```

Figure 7. The first web page the user sees when accessing DigiButler from a PC web browser.
You can switch the kitchen lighting on and off.

Tools, Tab
This LCD expansion module for the ATM18 test board opens up a huge range of applications. Although the design might look like a standard interface between microcontroller and LCD panel, there is an elegant technical detail: in order to minimise the number of port pins required, a special two-wire interface has been developed.

An ordinary LCD panel can be driven from a microcontroller using either four or eight data wires. In addition to these, an RS signal is needed to distinguish data from commands, and an E signal is needed to clock the data into the panel. This large total number of connections is unfortunate in our application because it ties up a number of port pins that could be used for other purposes.

**Data transfer**

All ordinary LCD panels are connected using 14 wires, plus any connections needed for the backlight. It is here
that models differ, as the manufacturers are not consistent as to whether the backlight supply should be located next to pin 1 or next to pin 14. Our printed circuit board is designed for displays where the backlight connections are on pins 15 and 16, and two pads are provided to which the backlight power supply can be soldered. If a different display is used it is simplest to use just the 14 main connections and leave the backlight unconnected. The display we used has the following pinout:

- Pins 14 down to 7: data bus
- Pin 6: E (enable signal), active high
- Pin 5: R/W, 0 = write, 1 = read
- Pin 4: RS, 0 = command, 1 = data
- Pin 3: V0, contrast adjustment from 0 V to 2 V
- Pin 2: VDD, +5 V
- Pin 1: VSS, 0 V

The direction of data transfer is specified by the level on the R/W signal. Here we only use write mode, and so the pin is connected permanently to ground in the circuit (Figure 1). The internal registers of the display controller are selected using the RS signal, which is used to distinguish between data and commands.

Two-Wire Interface

The circuit is based around a port expander that uses two port bits. A natural choice for such a design would be the PC bus, but we have chosen a faster and cheaper approach. All that we need is a type 4094 shift register (see Figure 1). This allows clock rates of sev-

C Compiler

Advanced C programmers who wish to control an LCD using the expansion module described here can take advantage of two example programs available for download from the Elektor website. One example is for use with WinAVR (GCC) and the other is for use with CodeVision.

Software house HPInfoTech has produced a special free-of-charge version of their popular ‘CodeVisionAVR’ compiler for this Elektor project. The compiler supports the ATmega48, ATmega88, ATmega168 and ATmega328 with a maximum object code size of 4 kB.

A version limited to 16 kB code size costs around fifty pounds and a 32 kB version is around sixty pounds, within the reach of many hobbyists.

The compiler produces very efficient code and includes a so-called ‘smart linker’ that only includes in the final object file functions that are actually called. It is therefore possible to use comprehensive libraries without having to tailor them to each application.

CodeVision makes setting up a project very straightforward. The integrated ‘CodeWizard’ automatic program generator generates a complete skeleton for your program. Beginners in particular will find it helpful to use this as a model for their programs in the same way as they can learn from our example programs. Automatic generation of libraries and selection between application and bootloader code, as well as code templates for frequently wanted program functions, make it easier to get started. Built-in drivers for all current programming adapters allow devices to be programmed directly from within CodeVision. Internal EEPROM and fuse bits can also be programmed, and there is a built-in terminal with file transfer and hexadecimal debugging output. The compiler offers powerful optimisation features for advanced users including global register allocation and freely-programmable ISR entry and exit code, comprehensive help (also available on-line) and a debugging interface to AVR Studio.
eral MHz rather than the 400 kHz maximum that can be achieved using I²C. At first sight things might look a little complicated. First we have to send the data bits D4 to D7 and RS, and then we have to generate an enable pulse on the E wire. To achieve this, the data input to the shift register is logically ANDed with output Q7 using a resistor and a diode. Only when Q7 is high will a pulse on the data input be transmitted to the LCD as a pulse on its E input. To make sure that no spurious E pulses are generated, the following sequence must be observed.

1. Clock eight zero bits into the shift register by setting the data signal low and generating eight clock pulses. The bits are clocked in on each rising clock edge. Now all the Q outputs of the shift register are low, and in particular no E signal can be generated.

2. Now send seven data bits. The first bit must be high and will ultimately appear on Q7, where it will allow an E pulse to be generated. The second bit is destined for the RS signal on Q6; the next four bits are data. The final bit is zero, ensuring that the data signal is left low. After a total of seven clock pulses the data bits will appear as required on the Q outputs, and in particular Q7 will be high.

3. Now we emit a pulse on the data signal, which in turn generates a pulse on the E line because Q7 is high.

The above procedure must be carried out twice, once for the high data nibble (bits D4 to D7) and once for the low data nibble (bits D0 to D3). **Listing 1** shows an excerpt from the BASCOM example program that can be downloaded from the Elektor website. Data can be written to the LCD (with RS being set high) using Lcd_write_data, while commands can be sent (RS low) using Lcd_write_ctrl, for example when initialising the display controller.

### Initialisation

The display recognises a large number of commands, all of which are sent with RS set low. The commands are grouped into families according to the number of zeros that appear in the high-order bits of the command byte (see Table 1). The display also includes an internal cursor register that points to an individual character position on the display. In the case of a two-by-sixteen display we have:

- Row 1: addresses 00h to 0Fh
- Row 2: addresses 40h to 4Fh

while for a four-line display with 20 characters per line we have:

- Row 1: addresses 00h to 13h
- Row 2: addresses 40h to 53h
- Row 3: addresses 14h to 27h
- Row 4: addresses 54h to 67h

The cursor advances automatically as each character is written, or the address can be set directly in order to write to any desired position. On power-up a number of initialisation commands must be written to the command register. **Listing 2** shows an example of how an LCD can be initialised.

---

**Listing 1**

**Data transfer using the shift register**

```vbnet
Sub Lcd_write_data(byval D As Byte)
    Rs = 1
    Low_nibble = D And 15
    High_nibble = D / 16
    Lcd_write_nibble High_nibble
    Lcd_write_nibble Low_nibble
End Sub

Sub Lcd_write_ctrl(byval D As Byte)
    Rs = 0
    Low_nibble = D And 15
    High_nibble = D / 16
    Lcd_write_nibble High_nibble
    Lcd_write_nibble Low_nibble
End Sub

Sub Lcd_write_nibble(byval D As Byte)
    Pe_clock = 0
    Pe_data = 0
    'Clear all stages of shift register
    For N = 1 To 8
        Pe_clock = 1
        Pe_clock = 0
    Next N
    'Set E level at Q7
    Pe_data = 1
    Pe_clock = 1
    Pe_clock = 0
    'Set level for RS at Q6
    Pe_data = Rs
    Pe_clock = 1
    Pe_clock = 0
    'Shift in 4 bits
    Mask = 8
    For N = 1 To 4
        State = D And Mask
        If State = 0 Then
            Pe_data = 0
        Else
            Pe_data = 1
        End If
        'Clock in data with rising edge
        Pe_clock = 1
        Pe_clock = 0
        Shift Mask, Right
    Next N
    'Shift in zero bit
    Pe_data = 0
    Pe_clock = 1
    Pe_clock = 0
    'Set E
    Pe_data = 1
    Pe_data = 0
End Sub
```

---
Figure 2. Printed circuit board for the LCD expansion module.

### COMPONENTS LIST

**Resistors**
- R1 = 10kΩ (SMD 805)
- P1 = 10kΩ preset (SMD)

**Capacitors**
- C1 = 10µF 6.3V (SMD)

**Semiconductors**
- D1 = BAS70 (SMD)
- IC1 = 4094 (SMD SO16)

**Miscellaneous**
- K1 = 4-way SIL pinheader
- LCD1 = LC Display 4x20 characters (HD44780 compatible)
- 14-way SIL pinheader
- PCB with SMDs premounted, incl. all parts and 4x20 LCD; Elektor Shop # 071035-93

---

<table>
<thead>
<tr>
<th>Function</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear display</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Cursor home</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>Entry mode</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>(ID=1/0: right/left, S=1/0: without/with scroll)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display, Cursor</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>D</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>(D,C,B=1/0: display, cursor, blink on/off)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scroll</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>SC</td>
<td>RL</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(SC=1/0: scroll/cursor moves to RL=1/0: right/left)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>0</td>
<td>1</td>
<td>DL</td>
<td>N</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(DL=1/0: 8-/4-bit bus, N=1/0: two lines/one line)</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>User-defined character memory</td>
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<td>Character</td>
<td>Column</td>
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</tbody>
</table>

**Text output**

In order to display text at a defined position we must first set the cursor address. It is convenient to express the position in terms of the column (x-coordinate) and row (y-coordinate). Then a call to Lcd_pos will move the cursor as over its four-bit data bus.

**Listing 2**

Initialisation

```vbnet
Sub Lcd_init
    Waitms 50
    Lcd_write_ctrl &H20
    Waitms 50
    Lcd_write_ctrl &H20
    Waitms 50
    Lcd_write_ctrl &H20
    Waitms 50
    Lcd_write_ctrl &H28
    Waitms 50
    Lcd_write_ctrl &H0C
    Waitms 50
    Lcd_write_ctrl &H01
    Waitms 50
End Sub
```

**Listing 3**

Text output

```vbnet
Sub Lcd_pos(byval X As Byte , Byval Y As Byte )
    D = 127 + X
    If Y = 2 Then D = D + 64
    Lcd_write_ctrl D
End Sub

Sub Lcd_text(byval Text As String )
    J = Len(text)
    For I = 1 To J
        Char = Mid(text , I , 1 )
        D = Asc(char)
        Lcd_write_data D
    Next I
End Sub
```

---

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required. For example, Lcd_pos 1,1 will move the cursor to the leftmost column of the first row. Then Lcd_text can be used to write a string of characters, as illustrated in Listing 3.

### Printed circuit board

The interface circuit can be constructed on the compact printed circuit board shown in Figure 2, which uses SMD components. Those wary of soldering SMDs can purchase ready-populated boards from the Elektor shop, with just the external connections left to be soldered by hand. The four-way connection to the ATM18 test board is best fitted with a header socket so that temporary connections can be made for test purposes using lengths of solid-core wire. The 16-way connection can also be fitted with a socket or plug to mate with a connector on the LCD, or direct connection can be made using header pins or a ribbon cable. The four connections to the microcontroller are $V_{CC}$, GND, data and clock. Data and clock can be connected to any two port pins: the example software uses port B.1 for clock and port B.2 for data.

### In use

Using the display module is very easy. Listing 4 shows a simple example program that displays a measured voltage on analogue input ADC(0). The analogue-to-digital converter is configured to use the external 5 V reference, and the 10-bit conversion result, in the range 0 to 1023, is written to the display. The complete example program is available for free download from the Elektor website at www.elektor.com.

#### Listing 4

**Outputting a measured value**

```c
Config Adc = Single , Prescaler = 64 , Reference = Off
Start Adc

Lcd_init

Lcd_pos 2 , 1
Lcd_text "adc(0) = "

Do
    Lcd_pos 2 , 2
    Value = Getadc(0)
    Text = Str(value)
    Lcd_text Text
    Waitms 500
Loop
```

---

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Elektor AVRprog

Benedikt Sauter and Dr. Thomas Scherer

Two events triggered the conception of this AVR programmer: the feedback received on USBprog from Elektor, October 2007 and a series of articles started last month around our ATM18 project. The outcome is a plug-and-play AVRISP mk2-compatible USB programmer for AVR controllers!

Since the launch of USBprog in October 2007 [6] many readers have explored Benedikt Sauter’s website [1] and discovered his amazing open source circuit, on a par with the all-in-one animal of mythology that provided mankind with eggs, wool, milk and meat. This little printed circuit board (PCB) has aroused deserved admiration and to the extent that it fulfilled the requirements of a number of Elektor readers it was certainly a success story. All the same, feedback from other readers indicated that the capabilities offered in Benedikt’s solution (USB-serial converter and ARM programmer for instance) were not exactly top of their wants list. They were mainly interested in using the device as a straightforward AVRISP mk2-compatible programmer for deploying with a diverse range of software applications.

Simple solution

A sample wish list for a new programmer would include the phrases ‘simple to construct’, ‘user-friendly’ and ‘inexpensive’ (OK, let’s be honest — ‘cheap’). A quick opinion poll indicated that reinventing the wheel was not what people wanted, so Mr. Sauter got on with slimming down the circuit of USBprog to produce a kind of dedicated programmer for AVR controllers with a user outlay that would be a whole lot cheaper than the more complex circuits already available.

Doing without a bootloader and other technical frills in this programmer made it possible to employ an ATmega16 instead of an ATmega32. The cir-
Simple AVR universal programmer with USB

The circuit of the Elektor AVRprog has much in common with its predecessor, USBprog, published in Elektor, October 2007. A USB bridge and a microcontroller are the only other components.

Figure 1. The circuit of the Elektor AVRprog has much in common with its predecessor, USBprog, published in Elektor, October 2007. A USB bridge and a microcontroller are the only other components.

cuit of the Elektor AVRprog is little altered from the source design, as you can see in Figure 1. Space on the PCB is optimised by using a miniature USB connector and a 6-pin (instead of 10-pin) ISP interface. The resulting PCB is commendably petite, measuring just 4.0 x 1.7 cm (Figure 2).

We decided against offering this programmer in semi-kit form as a part-populated board; not everybody feels comfortable soldering microscopic surface-mount components in confined spaces. It seemed more logical to provide the ready-programmed ATmega16 along with the remaining electronics and PCB as a ready-to-use module that readers could employ without fiddling about. So that’s what we decided to produce: a remarkably cheap AVR programmer for instant use, supplied complete with a matching USB cable and the necessary 6-way ISP cable.

Software

As an AVRISP mkii clone the Elektor AVRprog is usable with a broad range of software—effectively every program that supports this variant of AVRISP. That said, even the best USB hardware will achieve precious little without suitable drivers. The program AVR Studio 4 [2] from Atmel solves this problem at a single stroke; simply installing AVR Studio as shown in Figure 3 with its own integrated drivers does everything necessary. Once this is done, you can plug the Elektor AVRprog into your PC straightaway.

Under Windows the new hardware is recognised automatically, using the...
dedicated driver. On many Windows XP installations, a false error message can occur at this stage, with the file ‘libusb0.sys’ not found and the user asked to indicate where the computer should look for it. Simply ignore this and click on ‘Cancel’. The driver will in fact be found — assuming it is actually present — and installed without any further problems.

With the driver now installed you can deploy your Elektor AVRprog with a variety of software. For example, you can program it directly from CodeVision-AVR [3], but currently not directly from BASCOM [4] owing to a lack of AVRISP mkii protocols.

The Elektor AVRprog will also work with non-Windows computers. For Linux you have plenty of choice (search Google for Linux + AVRISP mkii + software), whilst the popular Open Source program AVRDUDE [5] is a stand-out solution for both Linux and Mac OS X. The command line interface of this program may be unfamiliar for Mac users, which is why the Elektor website has a PDF file explaining how to integrate AVRDUDE into a ‘normal’ graphical interface.

Warning: speed trap!

AVR microcontrollers cannot be programmed at any frequency you might desire. The ‘bitrate’ for programming must be set no higher than a quarter of the clock frequency of the controller being used. If the controller’s clock frequency is 8 MHz, the frequency you set in Elektor AVRprog must not exceed 2 MHz. This is the top limit feasible with this programmer. The lower limit is a rather tranquil 249 Hz. In truth this value is largely theoretical and not actually practicable. In any case AVR Studio version 4.13 will not allow you to program frequencies below 5 kHz. To see how you set this so-called ISP Frequency in AVR Studio take a look at Figure 4.

The programmer is, as already mentioned, an Open Source project. Among other things this means that not absolutely 100 per cent of AVRs are fully supported. No problems should arise with the usual types, however. Nevertheless, if something nasty crops up then it’s worth taking a look at reference [1] to see if newer firmware exists. Although it may not be obvious, it is in fact possible to change firmware on the Elektor AVRprog. For this you need to link the two holes directly next to the crystal (it might be better to sol-
der a small two-pin header and insert a jumper). Then, using a second programmer connected via the 6-pin ISP connector, you can introduce new firmware ‘backwards’ so to speak. Bear in mind too that the Elektor AVR-prog is designed to operate on 5 V. If the target chip is powered with 3.3 V or less during programming, the operation may fail under some circumstances. In this case the target controller should be powered with 5 V and ‘transplanted’ onto a small experimenter board if necessary.

About the lead author

Benedikt Sauter is a passionate Open Source hardware and software developer and keeps himself busy with his website where he documents the Open Source applications he has developed.

Web Links and Literature

[1] Project page: www.embedded-projects.net/usbprog
Since more and more electronics components are now available from their manufacturers only in SMD versions it is as a designer impossible to avoid using SMD parts. But making a single circuit or a small run of a few boards does not justify (certainly for use at home!) the purchase of a real SMD oven, which is necessary to mount all those little, leadless parts on the board. Can’t we think of a simpler solution?

Yes, of course we can! As we already wrote in the December 2007 article, with a special control circuit you can transform an ordinary kitchen oven into a handy SMD baking station. The control circuit that is required for this is now available from Elektor as a kit, so that there is no chicken and egg problem. To solder the SMD parts on the PCB you really need a reflow oven. But this is not ready yet because you need this board for that... etcetera. Now, that is no longer a problem because of this handy kit.

The kit available in the Elektor Shop under part number 060234 contains all the parts for building the controller section. The only other thing you need is a cheap electric oven that you can buy from any appliance store.

A quick recap of the requirements for this oven. Use a simple analogue type, that is fitted with a mechanical thermostat and a mechanical clock. The temperature has to be adjustable to at least 225 ºC and preferably a little higher still.

It is also beneficial if the volume of the oven is as small as possible. This allows the temperature of the oven to increase rapidly. A power rating of 1.5 kW is usually enough. There is no need to make any changes to the oven itself.

Harry Baggen

The latest version of The Elektor DIY SMD oven, which goes by the name of ‘Reflow Control’, makes easy work of doing your own soldering of SMD parts on printed circuit boards, using a simple little electric oven. We already introduced the electronics for this project in last December’s issue. There is now a comprehensive kit available for this project, which allows even electronics enthusiasts with two left hands (do they exist even?) to easily build such an SMD oven.
The plug on the end of the standard power cord is replaced with the appliance connector that is included in the kit. The thermocouple from the kit is attached inside the oven.

Contents of the kit
The kit for the Reflow Control circuit contains a completely assembled main board, a display and control panel board, and an enclosure with pre-milled front and rear panels. Plus of course all the other required little bits and pieces such as thermocouple, sockets, nuts, cables, cable ties, self-adhesive feet, mains switch, IEC connectors and a mains cable.

You only need to mount the boards in the case and make a few connections between the PCBs and the sockets/switch on the rear of the box.

The kit includes a clear construction manual which gives a step-by-step description of what you have to do. Even without electronics knowledge it is easily assembled within an hour. A separate operating manual describes how to use the Reflow Control circuit. This manual also discusses the calibration, the changing of the temperature profile and drying of components ('baking') using the oven.

With this kit you can build a very handy SMD oven in no time at all. A very useful device that quite possibly you may end up using more often than your ordinary soldering iron.
paX: a Power Amplifier with Error Correction

Part 2: The voltage amplifier and input

Jan Didden
Part 2: The voltage amplifier and input buffer stages

Last month we discussed the principle of error correction and developed an error-correction power output stage. In this instalment we will use H.ec in a voltage amplification stage and present the complete amplifier.

Let’s revert to the conceptual circuit of error correction as defined by Malcolm Hawksford, shown in Figure 1a. We know that if summing circuits S1 and S2 are unity gain summers, we get $V_{out} = V_{in}$, an ideal gain-of-one amplifier stage. But for our voltage amplification stage ($V_{out}$) that drives the output stage, we need much more than unity gain. Common amplifier gains are around 26 to 30 dB, a gain of some 20 to 30 times. I like the lower value because it is better to have less gain in the power amp than to have a lot of unnecessary gain, only to turn down the volume control to get rid of it. It turns out we can use H.ec in voltage amplifiers quite easily if we insert an attenuator in the $V_{out}$ sense leg, similar as we would do in a regular negative feedback circuit. We do that in Figure 1b. The sums are slightly different:

$$V_c = (V_{out}/\beta) - V_{in},$$
but still

$$V_e = V_{in} - V_c.$$

Substitution and rearranging shows us that $V_{out}/V_{in} = 1/\beta$. So, if we make $\beta$, as is customary, from a simple resistive 1:20 voltage divider, we have now an amp with gain, linearised by error correction.

There is one other very important thing to note here. When we found that the open loop gain no longer is part of the amplifier transfer equation, we said that the gain of the amplifier block no longer has any bearing on the final result. That is true in theory, but not in practice. In the case of the power output stage, we said the gain is “about 1.” A realistic value would be 0.98 at mid frequencies and light load, down to 0.95 at higher frequencies and higher loads. That means that the error correction circuit needs to add 0.02 to 0.05 times the signal level to the input to straighten out the amp. Intuitively we feel that it is advantageous to have only small signals in the error correction circuitry that helps it to work linear and with low distortion. But in the case of the $V_{out}$, if the forward gain block would have only a gain of 1, the error correction circuit would have to add 19 times the signal level, and it would be much more difficult to design simple circuits that could handle those levels with high linearity. So, what we would want is to make the open loop gain of the $V_{in}$ amplifier block such that the signal levels in the error correction circuit are minimized. This will be the case when the open loop gain is as close as possible to the closed loop gain. Then, there will be quite small differences between the input of the actual amplifier and the scaled down output (by $\beta$), and that small difference then is the error signal. This limits the signal levels in the error correction circuit, greatly relieving the burden on the H.ec loop. In other words, you set the $V_{in}$ open loop gain as close as possible to the required amplifier closed loop gain. This of course is totally at odds with what you would do for a negative feedback amp. There, you would try to get the highest open loop gain you can get away with, stationarity wise, to have a lot of excess gain for the feedback loop to work with. Not so with H.ec, and a corollary to this is that your $V_{in}$ can now be a very simple gain-of-20 amp.

Voltage amplifier

The particular topology I chose is in Figure 2. It’s very simple. U1 is a unity-gain buffer. $V_{in}$ applied appears at the buffer output across R7. The output current through R7 comes from the supplies, of course, so we find a signal current $V_{in}/R7$ in the current mirrors formed by Q1 and Q3. The quiescent current for the buffer (I will tell you later which buffer type I used) happens to be about 7 mA. With an R7 value of 220 $\Omega$, and a current of 14 mA peak-to-peak available, this buffer can handle a little over 3 V peak (about 2 Vrms) before running out of class-A, which of course is good for linearity. With an amplifier gain of 20 that is enough to deliver 100 W in 8 $\Omega$.

That same signal current in Q1 and Q3 is mirrored through Q2 and Q4, and flows through R16 to generate the output voltage. As a first approximation, because the same signal current flows through R7 and R16, and the signal across R7 is the same as $V_{in}$, the gain (open loop) of

---

**Figure 1.** Basic H.ec topology for gain-of-1 stage (a) and arbitrary gain stage (b).
this circuit is simply R16/R7 which is then set to 20. So, this is our $V_{\text{as}}$ stage. But in the discussion in Part 1 we said that the amplifier output stage needs to be driven by a low (and constant) source impedance (ideally zero) for the output stage $R_{\text{e}}$ to work; so we add a low output impedance emitter follower stage to the basic $V_{\text{as}}$ stage (G10, Q9). This emitter follower stage is also biased at about 7 mA. Because of D3, the voltage drop across R6 and R8 is about the same, so if we chose $R_6 = R_8$, the same current flowing through Q2 and Q4 will flow through Q10 and Q9. D3 and D4 also provide a measure of temperature stabilization to the emitter follower output stage bias current.

Now that we have the main gain block for the $V_{\text{as}}$, we enclose it in an error correction loop similarly as we did with the output stage: **Figure 3**. There are a few things to note here. Although both the ec sense and the ec generation resistors are given as ‘R’, they are not equal. The sense resistance actually is the sum of resistor R plus the output resistance of the β-network (R11/R12). It is the total resistance of R plus R11/R12 that determines the error current into the CCII. That same current generates the ec voltage when flowing through the left side R, and these voltages should be equal, so similarly, the left side R is actually the series resistance of the nominal R and the output resistance of whatever will drive the $V_{\text{as}}$. We’ll revert to this issue later.

The second thing to note is that the gain of this amp is not strictly 1/β. Terminal Y is a virtual earth point. To calculate the exact attenuation from $V_{\text{out}}$ to the node R11, R12 and R, we need to account for the fact that for the attenuation, seen from the $V_{\text{as}}$ output $V_{\text{drive}}$, R appears in parallel with R12. So, the attenuation, and thus the gain, is slightly higher than 1/β. We need to consider both of these issues when we dimension the error correction sense and generation resistors. Just as with the output stage, we will use an AD844 for the ec circuit, while the buffer is used in the amplifier input stage to drive R7. The complete $V_{\text{as}}$ circuit is shown in **Figure 4**.

D14. In Part 1 of this article we have discussed what would happen if we overdrive the amplifier. The positive feedback loop is regenerative and will continue to increase the input signal until stopped by some physical limit like the supply voltage or current or voltage limitations in the circuit. (We also saw in Part 1 that, because of the lower open loop gain, overdrive can be expected to be less severe; but we still need to deal with it). In the $V_{\text{as}}$ stage, this is taken care of by the four diodes across the error correction generation resistor R29 (Figure 4). When the amplifier is overdriven, the error correction current out of pin 5 of the AD844 CCII will increase considerably. This current will start to generate a large correction voltage across R29, to the point that the threshold voltage of the diodes is reached. At that point, the impedance of R29 collapses to just the dynamic diode impedance that is only a few tens of ohms. Further increases in the error correction current will not generate more error correction voltage and the positive feedback loop is broken. This makes the clipping clean, and recovery fast. But we run the risk that the diodes increase the distortion because they may already conduct a small current before the threshold, upsetting the error correction accuracy. It turns out that because of the very small error correction voltages across R29, this can be avoided. In **Figures 6 and 7** you see that if we would use a single pair of soft clipping diodes, the distortion starts to rise before maximum output. With the dual pairs, the difference is very small.

**Figure 8** shows this effect from a different perspective. The soft clipping diodes for the negative signal part have been temporarily removed so only the positive signal is affected. You can see that without the diodes, clipping recovery is delayed (negative part), while with the diodes (positive part) there is only a hint of delay.

**Buffer stage and DC offset**

All that is needed now for a complete amplifier is the input buffer and the DC offset servo. This is shown in **Figure 5**. Just as with the output stage, we need to drive the $V_{\text{as}}$ input resistor, which develops the ec voltage (R29), with a low impedance source. You guessed it: we will again call upon the open loop buffer in an AD844 to drive the $V_{\text{as}}$ from $V_{\text{as}}$. The signal enters the buffer in U2 through R1 and R33 at pin 5 and exits at pin 6. The enemy of your loudspeakers (and the amp as well) is DC offset at the output terminal. Most amplifiers have some sort of means to avoid that. In this amplifier, the output stage doesn’t need any additional measures: the error correction ideally duplicates the driving voltage (from the $V_{\text{as}}$...
to the output terminal, with zero offset, although there will still be some offset from the error-correcting AD844, which will generate a small DC offset of a few millivolts. The only requirement is that the $V_{as}$ has negligible DC offset. The $V_{as}$ however has higher gain and will amplify its own AD844 offset with that gain. I decided to implement a DC servo to keep the $V_{as}$ offset under control.

The servo uses a low offset opamp, a TL051CP. We will use the uncommitted current conveyor in that input AD844 (U2, Figure 5) to couple the servo signal to the amplifier.

The way this works is as follows. Remember that whatever current flows in or out of the low impedance input pin 2, also flows (in opposite direction) out of or into pin 5. We also know that the voltage at pins 2 and 3 will track accurately. When we couple the servo signal to the reference input pin 3, it will cause a current in R50 to keep pin 2 at the same level. That same current will flow through R33 in R49 (and R1 if the source is DC coupled), and in this way the offset correction will be added to $V_{in}$. R49 assures that this current, which essentially is DC, can flow even if the $V_{in}$ comes from a coupling capacitor. Finally, this input buffer and servo amp have their own $\pm 15$ V supply from two zener diodes, D5 and D6. With this circuit, composite offset of the whole amp is just a few millivolts.

**Protection circuitry**

There is a separate protection system for this amplifier that protects the speakers against DC output as well as the output devices against overload. It also provides delayed switch-on and immediate switch-off. This is described in a separate article in this issue.

**Power supply**

The power supply for this amplifier should deliver about $2 \times 44 \, V_{DC}$. Although the output devices are rated for higher voltages, it is not advisable to increase the supply in trying to get more output power. The allowed dissipation at higher $V_{in}$ is much less than the rated DC dissipation due to secondary breakdown limitations of the SOA (Safe Operation Area). With loads that dip substantially below $4 \, \Omega$, even temporarily, the SOA may be exceeded and an output Darlington destroyed (or the protection activated). The supply

![Figure 4. Full circuit of the H-ec $V_{as}$ stage.](image)

![Figure 5. Input buffer and offset servo circuit to drive the $V_{as}$ stage.](image)
for the error correction circuit in the output stage is bootstrapped from the output, that part of the circuit can actually drive the output devices beyond the supply voltage. Consequently, it is the $V_{as}$ that determines how close the output can get to the supply rails. Since the $V_{as}$ will clip first, there is no clipping overdrive and overdrive delay in the output stage. The output can swing within a few volts of the supply, which is better than in most amplifiers (unless separate, higher voltage, $V_{as}$ supplies are used).

The power supply for this amplifier is uncritical. The error correction not only corrects internal amplifier non-linearities, but also any power supply ripple or noise that makes it into the circuits. (The supplies for the error correction AD844’s is stabilized separately with zener diodes). Therefore, a classic rectifier-and-reservoir capacitor supply delivering $2 \times 44 V_{DC}$ under load is sufficient for about 100 W in 8 Ω, 200 W in 4 Ω. The power supply circuit details are given in Figures 9 and 10. For a stereo version, a 300 or 400 VA transformer should be sufficient; after all, you will not drive both channels at full power for a long period (except maybe on the test bench). You can use the common transformer with a centre-tapped secondary, but other configurations can also be used. One nice option for a stereo amp is to use two completely separated supplies, each with a 250 or 300 VA transformer. That would make it easier to maintain strict star point grounding.

It is important to get the grounding right. Ground currents back to the supply from the speaker, as well as from the reservoir electrolytics, can be quite large and have all kinds of ripple and noise. Such ground currents generate voltages across the ground return wiring. If the ground for the signal is connected to this ground wire at another point, you have effectively created a small ripple signal that appears in series with the input signal. This may seem far fetched, but with very low distortion and very clean amplifiers, even a few mV of these noise signals can be enough to ruin the linearity and distortion figures of an otherwise very good amplifier. Usually one tries to prevent this by using a star ground: All ground returns come together at a single point, and no signal return runs through the same ground wire with another return loop. If you look at the amplifier PCB layout you see that the power connections get to a central star point. On the PCB itself, care has been taken to do the same. There are two or three separate traces that bring the returns for the regulator zener diodes and the decoupling capacitors to the same point. The signal returns from the input network, the gain setting resistors R7, R16 and the error attenuation network R11, R12 are also brought to this point separately. All return wires from the supply, the transformer and the speaker are returned to the star ground. The signal grounds in the amplifier are then returned to this point via a low-value resistor R28, which is then by definition the ‘clean’ ground point (pad J1 on the PCB is the clean ground and should be used as ‘ground’ for measurements as well). Any error voltages generated by ripple and pulsating currents in the ground wires cannot end up in the signal, except through radiation. This in turn we can minimize by making all high-current wires short and as far away from sensitive signal areas as possible.

Finally, the rectifier diodes should be types that recover quickly from voltage reversal when switching off, and do so ‘softly’, that is, without very sharp current steps. Diodes that take a long time to reverse themselves and in the process generate sharp current steps may cause high-
frequency noise that is difficult to filter out. Fast, soft recovery types don’t need capacitors or snubbers; indeed, such capacitors would only increase the transmission of mains-borne noise to the amplifier. My recommendation is to use Philips BYV32E-200 diodes. These are TO220 dual types with a common cathode; the two diodes should be paralleled. They have a relatively low threshold voltage, and are quite inexpensive. They don’t need to be heatsinked so they can be put on a PCB in free air. For the reservoir capacitors, a minimum of 15,000 μF should be used per supply polarity. 63 V rating is adequate.

A mains filter as shown in Figure 10 should be used to keep out high frequency noise and switching pulses riding on the mains. Good mains filters are not cheap but worthwhile; use a type with at least 6 A rating. Ground the filter ground lug as well as the mains safety ground wire to the chassis only. Use a slow-blow fuse of 3.15 A for a stereo version, larger if you use larger reservoir capacitors. A 275 V AC varistor clamps any high-level pulses that make it out of the filter.

**Conclusion**

So, there you have it, a complete, high quality yet simple error correction power amplifier. The parts list shows all components for one (mono) amplifier. Note that the values of C11, C12, C17 and C18 (output stage) were given as 330 μF in Part I but 470 μF fits on the PCB so these should be used. A separate Construction Guide is available as free download from the Elektor website as archive file # 071085-w.zip.

Although harmonic distortion measurements do not always correlate with sound quality, they do give an indication of linearity and behaviour of an amplifier. Therefore, a few performance curves are given in Figures 6 and 7. If you work in a step-by-step fashion as described in the Construction Guide, checking your work after each major part, it will help to avoid errors and, if errors are made, to quickly isolate and fix them. Also check on my website for any last-minute information, additions or corrections.

This is not a very difficult project but it provides you with an excellent amplifier, which reproduces your source music faithfully, adding nothing, taking nothing away. This amplifier is stable and will happily drive a wide range of different speakers. In short, an amplifier that will let you enjoy your music for many years to come!

**Additional information**

www.linearaudio.nl

Availability of construction kits: www.pilghamaudio.com
Protection System for Power Amplifiers

An indispensable companion for the paX amplifier

Jan Didden

In Part I and part 2 about the paX amplifier we developed a complete error-correction power amplifier. In this accompanying article a protection system is described that’s constructed on a separate small circuit board for mounting directly on the speaker binding posts. We will also discuss the Safe Operation Area for the output devices and how it is modelled in the protection system.

A good protection system for an audio amplifier has two important tasks: speaker protection and amplifier overload protection. Speaker protection concerns a possible excessive DC voltage at the amp output due to either excessive ultra-low frequency signals, or from a circuit failure inside the amp. By the way, you can also get excessive DC output if you have a DC coupled power amp and your preamp gives out DC. If you go on tour with your amp, it would be wise to insert – even temporarily – some input coupling caps.

There are many convoluted circuits to disconnect the speaker from the amp through a high-power relay in case of significant DC offset at the output. These circuits often do double duty in delaying the closing of the relay until after the turn-on transient, as well as immediately opening the relay when power is switched off – again to avoid transient thumps in the loudspeaker. I used a low-cost, purpose-designed, but not too well known IC: the uPC1237 from, among others, NEC. The NTE7100 from NTE Electronics, is pin- and functionally compatible. It’s an 8-pin single-in-line (SIL) chip with all the functions mentioned above. The datasheet gives the formulas for calculating the component values. It can handle two channels for a stereo amp, but I used one chip per channel to make it easier to construct the amp as dual mono.
For the speaker relay I used a little-known device specially designed for this function and sold by the Dutch company Amplimo. The relay has two parallel internal contacts, one heavy-duty tungsten 100 A contact and a smaller gold contact pair. When the relay closes, the tungsten contact closes first, and is then bridged by the gold contact. The reverse takes place when opening the relay.

Circuit diagrams

The overall protection system is shown in Figure 1. The blocks for the Indicat or and the Safe Operation Area protection will be described later. The uPC1237 has an internal 3.4 V shunt regulator at pin 8, and the supply current is provided by R19 and R20. The relay switching output (pin 6) drives the relay through R18. Jumper J6 sets the circuit operation. If J6 is closed, the circuit becomes 're-entrant': if there is an error input, the relay falls off, and after a short delay is activated again. If, at that point, the error has disappeared, the relay stays activated, if not, it falls off again and the cycle repeats. If J6 is not closed, the relay is deactuated when an error is present and you have to switch the power off and on again to reset the circuit.

DC offset shut-off

Pin 2 of U2 is the DC offset input. AC on the amplifier output signal is removed by R17-C3 and the DC offset is sensed. Although the uPC1237 only has a unipolar supply (the amplifier’s VCC+), pin 2 does accept bipolar signals. The calculations are a bit complex because the internal positive and negative thresholds are not equal. It is all explained in the datasheet. With some care you can set the threshold for positive and negative offset to the same value at 0.6 V DC. These values are set by R17 and C3 as shown in Figure 1.

Switch-on delay

You will also see that a sample of the AC from the supply transformer is connected to the uPC via R21 and D8 to C6. This part of the circuit will delay the loudspeaker switch-on after a power up to make sure the amp has stabilized and there are no switch-on thumps. When the power is turned off, this signal will disappear immediately, before the supply capacitors have a chance to discharge. This way the speaker relay will be opened before the turn-off thumps occur.

Safe Operation Area

The second main part of the protection system is to guard the output devices against excessive low impedance loads and short-circuits. Michael KIwanuka has written a very informative article on Safe Operation Protection in audio power amplifiers [1]. My own protection circuit is different, but was inspired by Mike’s design and has many things in common with it. Figure 2 shows the circuit. The circuit receives two types of information from the power amp: the $I_r$ in the output devices through $V_{protP}$ and $V_{protN}$ (via connector J7 in Figure 1): this actually is the voltage across the emitter resistors. Secondly, through the components connected to the supply and $V_{out}$ a voltage is developed that represents $V_{ce}$ of the output devices. (There is a separate part to this article that explains the circuit in detail and how
Calculating and setting up the protection system

Figure 1. SOA, load lines and protection locus. See text for explanations.

The paX amplifier uses Safe Area Operation (SOA) protection. In this section we will address the specific design equations and how to develop the circuit values for the SOA part.

Figure 1 shows the various curves that we need to develop the SOA protection for two pairs of output devices. \( I_c (\text{A}) \) is on the vertical scale, \( V_{ce} (\text{V}) \) is on the horizontal scale. When \( V_{ce} \) is zero, it means that \( V_{out} \) is equal to \( V_{supply} \). In practice, there will always be a few volts \( V_{ce} \) remaining at maximum output, but we will disregard that for the moment. The cyan curve shows the safe combinations of DC \( I_c \) and \( V_{ce} \) for two parallel STD03 Sanken Darlington devices used in this amplifier. The yellow curve shows this for loads lasting no longer than 100 ms. That means that combinations of \( I_c \) and \( V_{ce} \) that fall below and to the left of the curve, are safe, but as soon as the curve is crossed, the protection system should activate. Since music is impulsive and not DC, one could argue that protection for the yellow curve would be sufficient, but if we use the cyan curve we have an additional safety factor and we also are protected against DC shorts.

Figure 1 also shows some load lines, which are combinations of \( I_c \) and \( V_{ce} \) required to drive a (resistive) load, assuming \( \pm 40 \text{V} \) supplies. The lower one, in pink, is on \( 8 \text{Ω} \) load, the light blue one is on \( 4 \text{Ω} \). For example, in the \( 4 \text{Ω} \) case, we see that when \( V_{ce} = 0 \), the output voltage is the supply voltage (40 V in this case) and thus \( I_{out} \) in 4 \( \text{Ω} \) is 10 A. The brown curve is also for 4 \( \text{Ω} \) load, but now with a maximum reactive component of 90° phase shift. This is a particularly mean load. At \( V_{ce} = 40 \text{V} \) we are exactly between the supplies (assuming \( V_{supply} = \pm 40 \text{V} \)).

I calculated the various component values.

The purpose of the SOA protection is to limit the combinations of \( V_{ce} \) and \( I_c \) for the power devices to a safe value. Normally, such a protection circuit would be arranged to take away the drive from the output driver transistors to limit the available output current. The protection transistor (Q1 or Q2, Figure 2) collector would normally be connected to the base of the (pre) driver transistor in the output stage. Q1/Q2 turns on when its \( V_{be} \) exceeds about 0.65 V, shunting driver base signal away. But in my experience, even with a \( V_{be} \) of only a few 100 mV, the protection transistor starts to influence the driver base signal, resulting in increased error correction and increased distortion.

For this reason I decided to make this an on/off protection circuit: the protection transistors drive the ‘overload’ pin (1) of the uPC1237 through the dual op-tocoupler U1, an MCT6. If overload occurs, pin 1 of the uPC is set high via R1 (Figure 1) and the uPC opens the speaker relay. I have the uPC set for auto re-entry by jumpering J6; in this mode, the speaker relay will be periodically closed.
ate the remaining 0.37 V across R14. So this current needs to be \( I_{\text{q}} = 0.37/270 = 1.37 \text{ mA} \), which also flows through R6 of course. With a \( V_{\text{ce}} \) of 20 V (we disregard the small \( V_{\text{be}} \) loss across \( R_{\text{e}} \)), that would make \( R_5 + R_6 = (20-0.65)/1.37 = 14.1 \text{ k}\Omega \). It doesn’t really matter how we split up the total value (it does matter for the other values of course, but not for the functioning), so let’s make them equal: \( R_5 = 7 \text{ k}\Omega \) and \( R_6 = 7 \text{ k}\Omega \).

At this breakpoint, \( V_{\text{ce}} = 20 \text{ V} \), diode D3 should be on the verge of conducting so we can disregard it, and R8, for now.

Now let’s move to the next point, 50 V/4 A. Analogous to the 20 V/13 A point, D2 should be on the verge of conducting so we can do:

\[
\text{As before we calculate the contribution of } I_c \text{ at } V_s: V_s = 12/(12+50) \cdot (0.11 \cdot 4) \text{ which is } 85 \text{ mV}, \text{so the } V_{\text{ce}}, \text{derived current from } R_5 \text{ and } R_6 \text{ should add } 0.65-0.085 = 0.565 \text{ V at } V_b, \text{therefore we have 5.35 V across } R_7. \text{The voltage across } R_6 \text{ now is } V_{\text{be}} = 50-15.35 = 34.65 \text{ V so } R_6 = 34.6/7k = 5 \text{ mA}. \text{Since 2.1 mA flows through } R_5, 2.9 \text{ mA must flow through } R_7 \text{ with 5.35 V (}V_{\text{m}}\text{-}10 \text{ V from } D_3\text{) across } R_7, \text{so } R_7 = 1.8k\Omega. \]

Moving on now to 100 V/0 A, it gets pretty boring:

\[
I_{\text{be}} = 0 \text{ so there is no contribution from } R_{\text{e}} \text{ to } V_s, \text{and the } V_{\text{be}} \text{ has } 0.65 \text{ has to be generated by the current through } R_5 \text{ and } R_{14}\text{+}R_4, \text{so } I_{\text{R}_{14}\text{+}R_4} = 0.65/282 = 2.3 \text{ mA}. \text{This current also flows through } R_5 \text{ so } V_{\text{be}} = 2.3 \cdot 7) = 0.65 = 16.75 \text{ V}. \]

The current through R6 is: \( I_{\text{be}} = (100-16.75)/7 = 12 \text{ mA}, \text{so the excess of 12 mA\text{-}2.3 mA = 9.7 mA needs to be shunted away through } D_2/R_8 \text{ and } D_3/R_7. \)

\[
V_{\text{be}} = 16.75-10 = 6.75 \text{ V with } R_7 \text{ at 1.8 k}\Omega \text{ so } I_{\text{be}} = 3.75 \text{ mA}, \text{which sets } I_{\text{be}} = 9.7-3.75 = 6 \text{ mA}. \]

\[
V_{\text{be}} = 16.75-15 = 1.75 \text{ V so } R_8 = 290 \text{ k}\Omega. \]

So, there you have it, but it would be nice if there was some way to verify this before committing solder (and parts). We have disregarded several things, for instance the loss of \( V_{\text{be}} \) for \( V_s \) and several roundings in the calculations. I have developed a spreadsheet to try to double check all this (available on www.linearaudio.nl and www.elektor.com). It works backwards from what we just did: using the component values in the circuit, it calculates at each \( V_{\text{ce}} \) the \( V_b \) contribution from the current through \( R_5 \), and then finds the \( I_c \) that would add just enough voltage across \( R_{\text{e}} \) to make \( V_{\text{be}} = 0.65 \text{ V}. \text{Plotting those pairs of } V_{\text{ce}} \text{ and } I_c \text{ then should give us the actual (blue) SOA curve we wanted in the first place. What we see is that the spreadsheet shows reasonable correspondence to our values, but there are some deviations. The reason is that once I had the spreadsheet, I ‘played’ with the component values to get the best fit to the SOA curve, or to get ‘nice’ values for parts. I used a \( V_{\text{cc}} \) of 44 V and a \( V_{\text{be}} \)\text{(min)} of 2 V in the spreadsheet. Also, manipulating the \( R_5 \) and \( R_6 \) ratio lets you home in on standard zener values. The way to do that is to use Excel’s solver to find the ratio of \( R_5 \) to \( R_6 \) that results in say \( D_3 = 12 \text{ V}. \text{Some more playing then gets you to } D_2 = 18 \text{ V}. \text{In the end, I used the values from the spreadsheet in the actual circuit as given in the main article. Since we stayed on the safe side with the blue protection curve, small deviations won’t cause disaster. Just try it, you can’t break anything, but don’t mess with the formulas unless you know exactly what you’re doing!}

I developed this spreadsheet for this particular application and did a fair amount of checking, but I cannot guarantee that it is without errors. If you find any, please let me know and I will update it, giving credit where it is due, of course.

It is not so easy to test the accuracy of such a protection system in real world, and mistakes could be expensive. So this double check of calculating the values and then working backwards to verify them is important to gain confidence in the circuit.

![Figure 2: SOA protection circuit.](image)

\[I_{R_{14}} = 0.565/270 = 2.1 \text{ mA}. \text{This 2.1 mA also flows through } R_5 \text{ and } R_6, \text{so } V_{\text{be}} = 0.65 + (2.1 \times 7) = 15.35 \text{ V}(\text{This of course means that } D_2 \text{ should be a } 15 \text{ V zener, and we will use that later}).\]

With \( V_{\text{be}} = 15.35 \text{ V} \) and \( D_3 \) a 10 V zener as calculated above, we to see if the overload still exists, and if so, it is opened again immediately.

It can be argued that the protection system should work by limiting the output in case of overload and not by disconnecting the speakers. I would agree that for PA duty this would be preferred, but for home use it is a very minor nuisance, if at all. But doing it this way prevents influencing the music signal by the circuit when there is no need for protection activation. Having used this amp for about a year now, I have never seen the protection system disconnect the speakers, except in one case where I had a problem with a balanced cable which put a signal with 2.5 V\text{DC} on the amplifier input. I immediately heard the on-off cycling of the amplifier, so I switched it off and managed to find the problem. After solving the problem all was as it should be. So, for me, this works quite well.

**Status indicator**

Then, lastly, there is a small bi-stable circuit that takes the relay drive voltage to drive a bi-colour LED which you can place on the front panel. The LED will be one colour when the amplifier is in turn-on delay or in protection and another colour if the amplifier is oper-
point) to the protection board at J1 as shown. Don’t connect a speaker yet, and don’t yet connect the speaker wire from the amp to the protection circuit. Now, when you switch on the amplifier, you should hear the relay pull in after a few seconds. If you find it too fast, you can increase C6 for a longer delay. If you switch off the amp, the relay should immediately open again.

Next we will check the DC offset protection. Temporarily connect a resistor of 100 kΩ from the positive or the negative supply to the speaker input point on the protection board (J4). The relay should deactuate. Check this with both J6 set and removed to verify correct operation.

Then, install all components for the status indicator in Figure 3. The PCB has labels ‘ON’ and ‘OFF’ at J2. That indicates which pin will be active at which status. If you use a red/green LED you would connect the RED pin to J2/OFF and the GREEN pin to J2/ON. You may want to repeat one of the tests described above to verify the correct operation of the status indicator.

The last part will be to complete the Safe Operation Area (SOA) protection components. Put all remaining parts on the protection board. Connect the flat cable, and connect the speaker output from the amplifier (Amplifier J3 to o/p board J4), as well as the star ground wire (o/p J3 to supply star ground).

Switch on the amplifier and verify that it works normally. Then, to simulate an overload situation, connect a resistor of 10 kΩ between the positive supply and the node Q1(base)/R14/R5/C1 and verify that the relay falls off. Do the same with the negative supply and the node Q2(base)/R12/R15/C2.

Note: If you do not mount the o/p board directly on the speaker output posts, you can connect the speaker return wire directly from the output post to the supply star ground without going through the o/p board. The loudspeaker’s ‘hot’ connection then goes from the o/p board J8 to the output post.

Stand-alone!

This article focused on using this o/p board with my ‘paX’ amplifier. But you can use it with any amplifier, provided you adjust the SOA circuit values as required.

**Construction**

Before building the o/p board, first complete the amplifier. We need the amplifier to test the o/p board. The o/p board can be populated first with the DC and delay circuitry around U2. Start with the components shown in Figure 1.

Next, construct the 6-wire flatcable as shown in Figure 1 in the Construction Guide. Be sure to orient the notches in the 6-pin headers exactly as shown! Connect the two boards with the flatcable, again noting the header notch position as indicated on the PCB silk screen. Also connect one side of the power transformer secondary (the AC supply) to the protection board at J1 as shown. Don’t connect a speaker yet, and don’t yet connect the speaker wire from the amp to the protection circuit. Now, when you switch on the amplifier, you should hear the relay pull in after a few seconds. If you find it too fast, you can increase C6 for a longer delay. If you switch off the amp, the relay should immediately open again.

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**Stand-alone!**

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COMPONENTS LIST

**Resistors** (0.25W metal film)
- R1 = 10kΩ
- R4,R9 = 12kΩ
- R5,R12 = 8kΩ
- R6,R13 = 6kΩ
- R7,R11 = 2kΩ
- R8,R10 = 560Ω
- R14,R15 = 270Ω
- R16,R22 = 3kΩ
- R17 = 36kΩ
- R18 = 510Ω
- R19 = 16kΩ
- R20 = 56kΩ
- R21 = 18kΩ
- R24,R25 = 22kΩ
- R23 = 3.9kΩ 1W

**Capacitors**
- C1,C2 = 100nF ceramic
- C3 = 330µF 6.3V
- C4 = 22nF ceramic
- C5 = 33µF 10V
- C6 = 4µF 25V

**Semiconductors**
- D1,D6-D11 = 1N4148
- D2,D5 = zener diode 18V 0.5W
- D3,D4 = zener diode 12V 0.5W
- J2 = dual colour LED
- Q1 = 2SC2910
- Q2 = 2SA1208
- Q3 = BC546B
- Q4 = BC556B
- U1 = MCT6 (Fairchild)
- U2 = UPC1237 (NEC) or NTE7100 (NTE Electronics)

**Miscellaneous**
- J6 = header 2 x 1 pin
- J7 = 2 x 3 pin DIL flatable header
- RL1 = Amplimo LS relay
- DIL socket 2 x 4
- SIL socket 1 x 8 pin

PCB, # 071086-1 from the author or www.thepcbshop.com

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**Figure 4.** Component placement of the double-sided PCB for the o/p board.

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The in- set in Figure 1 shows the connections you need to make from your amplifier to the o/p board through J7.

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**Literature**

Out of Belgrade comes a vast line of microcontroller development tools and related goodies that’s sure to make microcontroller geeks drool and students and other beginners start examining their wallets, savings or budgets — the prices sure are attractive! We examined EasyPIC5, one of the flagship dev kits from MikroElektronika.
Many moons ago, development systems for microcontrollers were supplied by none other than ... the manufacturers of the relevant devices. Alas, these kits were expensive or hard to come by if you were not a journalist/reviewer or a manager commanding 20 or more staff in the product design department. Also, in the early days, manufacturer-specific dev kits, although comprehensive and with technically fine contents, would give you an uneasy feeling of being chained to, again, the microcontroller manufacturer for support and hardware extensions (“sure, that can be done with our product xyz, I’ll connect you to sales...”).

Today, that’s changed a lot and anyone with a reasonably defined target for hardware product development, or an educational interest, should be able to buy microcontroller development systems that can be relied on to give a head start. Although prices generally have come down, the link to the device manufacturer seems inevitable. Or is it?

Unpacking

The EasyPIC5 box is compact yet sturdy and in general shows good packaging standards applied. The board, measuring 25 × 21 cms and having rounded corners, struck me as well laid out and extremely solid (it’s 3 mm thick). It has lots of useful markings on the silkscreen overlay and, remarkably in this day and age, no SMD parts except one voltage regulator. The general finish of the board is superb — no hand-soldered wires or knifed PCB tracks revealing design errors a.k.a. ‘hand revisions’. A pity, though, some of the jumper setting instructions are obscured when the graphic LCD (GLCD) is installed on the board.

The review board came with the 2 × 16 character LCD and DS1820 temperature sensor in a separate package — this is an optional add-on costing $15 extra. MikroElektronika sell a variety of additional add-ons, including a touchpanel and a 128 × 64 pixel character LCD and DS1820 temperature sensor project as my first attempt to use the board and it was up and running in less than half an hour, including a short experiment with the MikroICD feature.

The kit and the software tools supplied succeed in freeing your mind from hardware intricacies and instead concentrating on software and understanding and optimising the PIC code (in that order). For example, using MikroBasic it wasn’t too much trouble to program the temperature sensor project as my first attempt to use the board and it was up and running in less than half an hour, including a short experiment with the MikroICD feature.

EasyPIC5 overview

Despite claims in favour of competing devices, Microchip PIC microcontroller users have a leading position in terms of acceptance among not only enthusiasts and students, but also seasoned workers in the embedded industry. At the heart of the EasyPIC5 board sits a PIC16F877 in its 40-way DIP case. However you can remove it — besides the DIP40 socket, DIP20, DIP18, DIP14 and DIP8 sockets are available on the board to take PICs with fewer pins. The EasyPIC5 documentation tells you which are suitable.

I/O-wise the PIC is totally accessible with all its ports bonded not only to connectors and DIP switch arrays but also LEDs for easy visualisation of logic states as you program along (and make errors!). Input to the digital ports is easy to simulate by means of 36 pushbuttons labelled with port line names. The analogue world is not forgotten either with PIC pins RA0-R5 on pinheaders and two potentiometers on the board to simulate discrete analogue levels between 0 and 5 V.

For higher level connectivity, the board has RS232, PS/2, USB and a 4-digit 7-segment display, not forgetting the USB comprised in the MikroICD of course.

Hardware fans will like to know that the complete schematic and board layout of EasyPIC5 may be found on the CD in the kit.

POS and NEG

My only criticism of the EasyPIC5 kit proper is that the 2×16 LCD and the DS1820 should have been included in the package instead of supplied as an option at $15 extra. These add-ons make for a lively start for first time users like myself. I took the DS1820 temperature sensor project as my first attempt to use the board and it was up and running in less than half an hour, including a short experiment with the MikroICD feature.

At $129 (plus P&P and options) and the dollar in the toilet at the time of writing, EasyPIC5 is good value for money.

Web Links

MikroElektronika: www.mikroe.com
UK distributor: www.paltronix.com
US distributor: www.circuit-ed.com

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At $129 (plus P&P and options) and the dollar in the toilet at the time of writing, EasyPIC5 is good value for money. A wide distributor network is available as well as support, both directly from MikroElektronika themselves and from knowledgeable users in their online Forum, where critical users are not shunned either and all the latest on updates etc. can be found. Further encouraging points to mention are the neatly produced manuals, the non-SMD approach, the wide range of low-cost add-on boards, and a fine selection of get-you-going examples. Users will also appreciate the trial versions of MikroC, MikroPascal and MikroBasic on the CD with the kit. Registration keys for these compilers can be obtained online from MikroElektronika.

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A remarkable built-in feature of the board is called MikroICD. This in-circuit debugger allows you to monitor (on your PC), the state of all registers inside the MPU while it executes object code. The associated PC software called PICFlash2 is a free download as well as supplied on CD.

Besides the EasyPIC5 User Manual, the box also contains ‘hard copy’ i.e. printed documentation of the PIC-Flash2 and mikroICD utilities — a rare find in this day and age of CD-ROMs and Internet. All printed matter is bright, copiously illustrated and has a consistent layout and use of colours, from the Quick Start leaflet right up to the print on the CD-ROM.

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Frequency counter module using ATtiny2313

Most small function and signal generators do not have a very accurate frequency control and do not offer a built-in frequency counter. Help is at hand with the tiny frequency counter module described here, which consists essentially of just an ATtiny2313 microcontroller and an LCD panel. The microcontroller is clocked at 20 MHz, and so the counter module can be used at frequencies of up to 5 MHz without the need for a prescaler.

This counter module is therefore ideal for retrofitting to an existing signal generator or as the main component of a tiny self-contained frequency meter. In the former case it will probably be possible to derive power for the module from the unit’s own power supply, and the signal input of the module is best connected to an existing squarewave (5 V level) output. The display ranges from 0 Hz to 5 MHz with automatic selection between units of Hz, kHz and MHz according to the input frequency.

Mini counter

The starting point for the module described here was the minimalist 1 MHz frequency counter design by Hergen Breitzke described in the July/August 2005 issue of Elektor Electronics [1]. That design employed an AT90S2313 programmed using the BASCOM AVR Basic compiler. This version is based on the same principles but uses an ATtiny2313 rather than the AT90S2313. The newer device can be clocked at up to 20 MHz, which allows us to extend the maximum frequency from 1 MHz to 5 MHz. Fortunately 20 MHz crystals are readily available off-the-shelf. The processor clock speed directly determines the maximum frequency that can be counted: according to the datasheet, the maximum allowable frequency at the counter input pin is one quarter of the processor clock frequency, and this is how the 5 MHz limit arises.

To make the display as easy to read as possible the frequency value is shown in MHz, kHz or Hz as appro-
Appropriate, with the decimal point being shifted as needed. The display does not change to and fro rapidly when the unit switches between ranges.

The frequency value is deliberately shown as only five digits. In the highest range (MHz) the 10 Hz and 1 Hz digits are suppressed so that the display is steady and easy to read. If required, the software can easily be modified to show these digits. The hex file and source code for the software are naturally available as a free download from the Elektor website.

It is also possible to cause the suppressed digits to appear without modifying the software. The circuit diagram in **Figure 1** shows a button (S1) connected to pin 2 of the microcontroller. When the button is pressed and pin 2 is taken to ground, the counter will show the 10 Hz and 1 Hz digits when in the MHz range. A switch could be used instead of the button or, if this facility is not required, the button could simply be omitted altogether.

### Construction

As can be seen from the circuit diagram in Figure 1, there are no special components in the design and the unit is very simple, consisting essentially of just the microcontroller, a voltage regulator IC and the LCD panel. Just a few components are required to support the operation of the microcon-

### Features

- Frequency range 0 Hz to 5 MHz
- Accuracy dependent on crystal, typically 50 ppm to 100 ppm
- Display in units of Hz, kHz or MHz with automatic selection
- Stable display even when range changes
- Selectable 5-digit or 7-digit display using pushbutton
- Indication of gate open and display update via red and green LEDs
- Power supply: 5 V DC regulated or 6 V to 9 V AC or 9 V to 12 V DC unregulated
- Current consumption approximately 40 mA (when display specified in parts list is used)
- Simple construction
- No SMDs, no special components
- Printed circuit board and ready-programmed microcontroller available
controller: decoupling capacitor C4, and crystal X1 along with load capacitors C5 and C6. We allow ourselves the luxury of two LEDs connected to a spare processor pin. These light alternately in synchrony with the gate time of the counter (which is fixed at 1 s). The red LED lights when a measurement is taking place, and the green LED lights when the reading is transferred to the display. If the signal source has a very stable frequency, the display will not change from reading to reading, and the LEDs then give comfort that measurements are indeed taking place.

A socket (K1) is provided on the printed circuit board (Figure 2) to connect a mains adaptor. The power supply circuit consists of a bridge rectifier (B1), a smoothing capacitor (C1) and a 5 V regulator (IC1) with a further smoothing capacitor (C3) at its output. The bridge rectifier suggested in the parts list can be replaced by four individual type 1N4001 diodes arranged as shown in the circuit diagram. Because a full-wave rectifier is used, the circuit can be powered from an AC source (6 V to 9 V) or a DC source (9 V to 12 V) of either polarity. Current consumption is only around 40 mA if the display specified in the parts list is used, and so even the smallest of mains adaptors will be adequate. If the counter module is installed in a device that already has a regulated 5 V supply, components IC1, C1, C2, B1 and K1 can be omitted and power wired directly to the pin of IC1 connected to the positive side of capacitor C3 and to ground.

The double-sided printed circuit board uses no SMDs and all but three components are mounted on the top side of the board. The LCD panel is mounted on the back of the board, connected using a 14-way header and secured using four screws (see photographs). The two LEDs (D1 and D2) are also mounted on the back of the board so that they face the same way as the LCD.

In operation

Before applying power, check that all the components have been fitted correctly and inspect all the solder joints. When power is applied the two LEDs should flash once...
per second as described above, and, if the input is shorted to ground, the display should show 0 Hz. If the input is allowed to float it will probably pick up mains hum (a piece of wire can be used as an antenna to help) and the counter will read 50 Hz.

If the display is blank, the problem can most likely be rectified using the only adjustment point on the module: display contrast potentiometer P1.

If a TTL-level square wave signal with a frequency of at most 5 MHz is now connected to the input its frequency should be displayed. The accuracy of the reading depends on that of the processor clock frequency, which in turn depends on the crystal. An error of 100 ppm in the crystal frequency corresponds to a measurement error of 100 Hz at 1 MHz, and a crystal error of 50 ppm corresponds to 50 Hz at 1 MHz. In the audio frequency range an accuracy of better than 1 Hz can be expected.

For applications where a TTL-level signal is not available a small preamplifier is required to produce the necessary square wave. We will be addressing the subject of preamplifiers and prescalers for frequency counters in Elektor in the near future.

Where is the counter?

In order to measure frequency the circuit needs a timer to define the gate time and a counter to count the number of pulses that arrive during the gate time. However, there is no counter in the circuit diagram, just a microcontroller IC.

The solution to this puzzle is that the counters are inside the microcontroller. There are two internal hardware counters, one of eight bits and one of 16 bits, which can be configured as timers or as counters at will. In our application the 16-bit counter is configured to count the 5 V (TTL- or CMOS-level) pulses that appear on input pin 9. The maximum value that the counter can store is 65535, and this limit is overcome by arranging for an interrupt to occur each time the counter overflows.

The number of interrupts that occurs is counted in the interrupt service routine (ISR). At the end of the gate time the interrupt count is multiplied by 65536 and added to the current counter value. If the gate time is one second, the result will then be the input frequency in Hz:

\[ f = \text{interrupt count} \times 65536 + \text{Timer1 value} \]

The gate time is derived using the 8-bit counter, which is configured as a timer with a divide-by-1024 prescaler. In this way the 20 MHz processor clock is divided down to create a constant gate time of one second.

Reference

Computers nowadays are fast enough to be useful for making measurements. That is a far cry from 20 years ago when a computer had a 286 processor, 1 MB of memory and a 10 MB hard disc. But now, when we have all those gigabytes and gigahertz at our disposal we can very easily do FFT and other complicated calculations in near ‘real-time’. What follows is a selection of software packages that have been purposely developed for transforming a PC into a test instrument.

Different purposes
Within this limited group of software applications a further division can be made into three subgroups: software that is

Cris Badea & Thijs Beckers

Virtually every computer these days is equipped with a reasonably decent sound card. In addition to its audio uses it can also be used for measuring purposes. Install the appropriate software and you have a versatile measuring instrument that can accomplish the most complicated measurements in no time. But which software is the most appropriate? In this article we help you get oriented by giving you an overview of what can be found out there.
intended for the design of loudspeakers and to make spatial measurements of loudspeakers, software which is designed for general purpose electronic measurements and software intended specifically for audio measurements. There is actually a further subgroup of software that specialises in the acoustic measurement of rooms, but we have included these with the loudspeaker design software. For this evaluation we used an RME Multiface [1] card. This card is supplied with various drivers such as MME, WDM and ASIO2. The Multiface is capable of sampling 24-bit signals at 96 kHz with a latency of 0.37 ms. This makes this card very interesting for ‘fast’ measurements such as MLS-measurements (Maximum Length Sequence). The card has 8 analogue inputs and outputs. This makes the card also of interest when more than two channels need to be measured, for example when testing 5.1-configurations, where the perfect position of the loudspeakers needs to be determined for a particular room.

**Loudspeaker design and room simulation**

When designing a loudspeaker it is important that the frequency characteristic and the impulse response of the loudspeaker are either known already or can be measured. The impulse response of the room used for the test is also very important, since this affects the acoustics. In recording studios, for example, special attention is paid to the design of the room and what effect this has on the sound. Measuring the frequency characteristic is very simple in principle. Connect a noise source to the loudspeaker and measure the frequency response with a measuring microphone and a spectrum analyser. It is best to do this in a ‘dead room’, a room that is virtually free of reflections and rejects practically all sound from the outside. Except that this situation is not very realistic in practice. You don’t listen to music at home in a dead room now, do you?

So it is preferable to do the tests in the listening room itself. And if that happens to be your living room than it would be nice if the barking dog next door or the car that happens to drive past are not included in the measurement. The MLS measurement has been invented to allow all disturbing influences from outside the measurement to be excluded. With this measurement technique all parameters are derived from the impulse response.

The Maximum Length Sequence is a periodic pseudo-random binary sequence that functions as the test signal. This signal can be generated using a shift register with feedback. It is possible to mathematically calculate the ratio between the sent and received (measured) signals. The result is a curve with information about the source or the room, depending on what the goal of the measurement was.

**Software for electronic applications**

In this category fall the various applications that make it possible to use the PC as, for example, an oscilloscope, spectrum analyser or function generator. Since the signal to be measured has to enter the PC in one way or another, some kind of interface is required. The sound card is the most obvious candidate, because nearly all computers these days are fitted with one.

The quality of the measurement is strongly dependent, of course, on the quality of the sound card. The frequency range also is usually considerably smaller compared with ‘dedicated’ equipment. A sound card is therefore unsuitable for high frequency applications, but is quite usable at lower frequencies, especially with some of the currently available sound cards that can handle a sampling frequency of 192 kHz at a resolution of 24 bits. Accurate measurements up to 96 kHz belong to the possibilities. The limitations of a sound card can be overcome with special interface cards, for example from National Instruments or Agilent. These are generally intended for industrial applications and are typically priced accordingly.

**Software for audio measurements**

A wide variety of different software packages are available for professional audio applications. The amount on offer is so large that it is impossible to cover all of them here, so we made a selection.

What is typical of this software is that it can be divided into two groups: stand-alone and VST-plugin. VST stands for ‘Virtual Studio Technology’. It is a standard that has been developed by Steinberg [2] for virtual musical instruments (VSTi) or effects (VSTfx).

As already mentioned, the amount on offer is huge, but when it comes to features there is remarkable similarity: volume level meters, oscilloscopes, spectrum analysers and correlation measurements. These are, of course, the most frequently used tools when working with audio.

Extensive information about potential measuring techniques can be found on the internet, among those is a document written by Swen Müller and Paulo Massarani [3]. This not only contains information on the ‘stepped sine’ technique but also MLS and the differences between these two techniques.

**Loudspeaker design and room simulation software**

**WinMLS 2004**

As the name of the program indicates, WinMLS 2004 can be used to make MLS measurements. The program generates a very detailed frequency characteristic. There is a selection of signal sources available. The setting options are nearly endless, which makes this software very comprehensive. Except that how to use it is not always very clear. The software is very reliable and accurate and optimal for system calibration and spacial measurements, help when designing loudspeakers and is even suitable for resonance measurements of buildings.

The screen shot shows several features such as time- and frequency-windows and room acoustics.
WinMLS is available in various configurations which vary in price from $100 to $1000. The software is only suitable for Windows and can use any sound card that is compatible with Windows. For more information: www.winmls.com

**Praxis**

The Praxis software from Liberty Instruments Incorporated is essentially the same as WinMLS. But Praxis has a few extras. For example, an RTA-function (Real Time Analyser). This can be used to make direct (‘real-time’) measurements. The settings can be stored as presets.

The documentation is quite extensive and there are a large number of wav-files that can be downloaded from Liberty Instruments that can be used to carry out measurements and tests.

On this website you can find many examples and explanations how certain measurements should be made including the required files and descriptions.

For programmers, the manufacturer also has made a Script Designer available online. Script Designer can be used to write applications for Praxis. The script is based on Microsoft Visual Basic and Borland Delphi. It was during our evaluation not at all obvious how the AudPOD interface is circumvented to enable you to use your own microphones, but the website clearly indicates that this should be possible.

The accompanying screen shot shows the important windows of Praxis, which allow most of the settings to be changed and measurements performed. Praxis is clearly a Windows based application. The price amounts to $998. The ‘free’ version lets you do quite a lot but not all the program’s features are available. For more information: www.libinst.com.

**ARTA, STEPS and LIMP**

A fantastic set of programs has been developed at the electronics university in Split in Croatia. The set comprises three applications: ARTA for impulse response measurements, real-time spectrum analysis and frequency analysis, STEPS, which uses ‘stepped-sine’ excitation for frequency response measurements and LIMP for the measurement of loudspeaker impedance.

ARTA can be used for loudspeaker measurements, room parameters and speech intelligibility analysis. It is very user friendly and well-organised. The software offers various measurement sources which are completely configura-

ble. Among others, you can use white noise, pink noise, MLS, linear/log ‘stepped sine’ and periodic white and pink noise. The test results are very clearly displayed and further calculations using these results are very easily made.

The manuals are very extensive and easy to follow. There are examples of different configurations, measurements and settings.

A comprehensive procedure for the calibration of the sound card is also available. This calibration is obviously very important when doing these types of tests.

The software is only suitable for Windows and costs from £36 (€49) to £110 (€149). The demo version does not allow anything to be saved, but is otherwise fully functional. More information at: www.fesb.hr/~mateljan/arta

**FuzzMeasure Pro 3**

Attention Mac users! This is one of the few applications of this genre for OS X.

FuzzMeasure was originally intended for room measurements, but its application is much broader however. The main purpose of this software is to calibrate rooms such as live podiums, auditoriums, studios, etc. FuzzMeasure is not only suitable for measuring delays and reflections in rooms but can also be used to generate loudspeaker characteristics, for example.

The program uses the swept-sine method, which avoids ambient noise and distortion.

The software is only suitable for OS X Leopard and costs $150. At the time of writing the software is up to version 3.0.2, which contains a few bug fixes compared to version 3.0. You can find more information at www.supermegaultgroovy.com.
EASERA

EASERA is the most complete software package that we came across. With a price tag varying from $750 to $2250, EASERA has a very big arsenal of measuring features. What makes the package very interesting is that it still uses a sound card and not an expensive expansion module. EASERA gives the option of choosing between several different drivers, such as the ASIO drivers, which are famous as the fastest drivers for audio processing.

The software consists of four modules: a measurement module, a signal generator, real-time analyser and post-processing module. If this is not enough you can expand the software package with the Time Delay Spectrometry module from Gold Line (www.gold-line.com).

EASERA can perform measurements using, among others, swept sine and MLS and with these can take into account the room and different types of background noise. The program can also analyse wav-files and it can use the inputs of the sound card to record signals.

Calibrating the sound card is simple, provided the card has a synchronisation clock. If the card has multiple inputs or outputs, a second input or output can be used for synchronisation and to determine the delay. All the settings are quite easy to use, despite the large number of options available.

EASERA also has automated functions, such as microphone calibration, adjusting the input sensitivity and compensating for the frequency characteristics of the hardware used. Comprehensive FFT measurements can be made in real-time, volume meters can be consulted and spectrograms can be displayed. Presets can be stored, so that they can be used again or later on during post-processing. The real fun starts at post-processing. Available to you are calculations for Room Acoustics, Electro Acoustics, RMS, noise levels, echo grams, etc. Here it is also possible to manipulate the various signals in both the time and frequency domains.

EASERA can monitor up to 32 inputs with a sampling frequency of 192 kHz, which is also of interest for PA-applications at concerts.

EASERA is the perfect tool for the professional sound engineer. The functionality is practically endless and the reliability is high. More information can be found at www.sda-softwaredesign.de and www.easera.com.

Software for electronic applications

Multi-instrument 3

Multi-instrument 3 is a very intelligent and functional program. It provides the following measuring instruments:

- a digital oscilloscope with transient recorder, data recorder, voltmeter, Lissajous plotter and digital filter.
- a spectrum analyser with amplitude spectrum analysis, power spectrum analysis, octave analysis, phase spectrum analysis, correlation analysis, frequency response measurements, distortion analysis, noise analysis, dynamic signal analysis, etc.
- a signal generator with a function generator, an arbitrary waveform generator, a burst generator, a white and pink noise generator, a multi-tone generator, an MLS generator, a musical scale generator, DTMF generator, and frequency and amplitude sweep.
- a multimeter with voltage measurement, SPL measurement, frequency measurement, RPM measurement, duty cycle measurement, etc.
- an LCR meter with inductance meter, capacitance meter, resistance meter and impedance meter.

A matching probe makes this software quite unique. The probe has an audio plug which can be connected directly to the input of the sound card. An attenuator is built into the probe which protects the audio inputs of the computer against over-voltages. The probe can be used to safely measure voltages up to ±24 V.

The price of Multi-Instrument is between $50 and $200, depending on which version and options you choose. The probe costs $30. There is also a version intended for Pocket PCs, Pocket Multi Instrument 1.0. This version does however have fewer features compared to its ‘big brother’. For more information surf over to: www.virtins.com

Zelscope

Zelscope turns a PC into a dual-channel storage scope and spectrum analyser. It uses the sound card as A/D-converter and shows in real-time the wave shape and spectrum of the signal.

The program is quite easy to use and reliable. Zelscope costs $20. For more information surf to www.zelscope.com.
OscilloMeter 6.0

This Russian software is not likely to win a beauty contest, but there are no complaints about its functionality. It is quite comprehensive, but the cluttered design makes it quite hard to use. What is convenient however, is that as soon as you start the software you have four information windows, a dual-channel oscilloscope and spectrum analysis (optionally in 3D) of the left and right channels. Additionally there are extensive generator functions and multimeter options.

The demo version is restricted to only 15 seconds of unlimited functionality. After this the measurement stops. It does work again when you restart it. To remove this limitation you need to send $500 to the designer, who will then send you a registration code. More information can be found at http://shmelyoff.narod.ru

AudioTester

AudioTester is quite a simple Windows application which consists of an oscilloscope, a spectrum analyser and a signal generator. The signal generator WaveGen is a very comprehensive module that is intuitive to use. It offers various waveforms and step and pulse signals. The design gives the appearance that you’re using a physical instrument and not software. You can find more information at www.sumuller.de/audiotester

Software for audio measurements

Digcheck - RME

This free software works only with sound cards from RME. It is a very intuitive to use, stand-alone program (only for Windows) with various functions: stereo and multi-channel level measurements, spectrum analysis, vector audioscope, correlation measurements and bit statistics. The program can record multiple channels simultaneously (Global Record). The picture shows the Tatalyser, which shows the spectrum analyser, the level meter and vector audioscope. More info at www.rme-audio.com

Spectre

The layout of Spectre is very nice and well-organised. It is set up in modular fashion so that you can arrange your own desktop. The software is very extensive. A few of the test instruments are: level meter, VU-meter, BBC meter (peak meter with BBC scale), oscilloscope, spectrograph, low end
meter, high end meter (separate parts of the audio range), level history meter, waveform meter, spectrogram, Lissajous meter, power balance meter, correlation meter, etc. In addition, spectrum comparison, phase comparison, coherence measurement and playing of sound files also belong to the feature list.

On the website www.audiofile-engineering.com you can find more information about Spectre. The software package costs $120 and is only suitable for Mac OS X.

**Electroacoustics Toolbox and SignalScope pro 2.0**

These two applications by Faber Acoustical are only suitable for Mac OS X. Electroacoustics Toolbox is a comprehensive package that consists of several modules. There is a Dual FFT analyser which can, among other things, make the following measurements in the frequency domain: amplitude transfer function, phase transfer function, coherence, group delay, signal to noise ratio, etc. In the time domain the following measurements are possible: impulse response, quadratic impulse response and cross-correlation.

There are several other modules available, including an FFT analyser, an octave band analyser, an oscilloscope, a sound level meter, a 3D spectrogram plotter and an X/Y plotter.

SignalScope is a comprehensive oscilloscope with FFT features. Signal scope is really a ‘lite’ version of Toolbox. It uses a single window where everything is set up and measured.

Electroacoustics Toolbox costs about £370 (€500) and can be ordered from the Faber Acoustical website: www.faberacoustical.com. SignalScope, which costs about £55 (€70), is considerably cheaper than Toolbox and can be purchased from the same website.

**SpectraPLUS**

SpectraPLUS is an audio spectrum analyser which is mainly targeted at real-time measurements. It is only available for Windows and comprises various ‘options’ (modules), which have to be bought separately. The most important functions are: real-time FFT analysis of the signal at the sound card input, recording and playing of wav-files, displaying the measured signal in the time domain, in the frequency domain and in 2D and 3D spectrograms.

The FFT measurements are very extensive and the resolution is high, 1,048,576 points. The octave analysis can be set from 1/1 to 1/96. The measurements can be made at up to 24 bit and 200 kHz sampling frequency, depending on the capabilities of the sound card.

Ten different options are available which are suited for different applications. For example, the base package offers you only a mono channel that can be used for measurements, an FFT analysis which is limited to 1/1 and 1/3 octave analysis, phase measurement and microphone compensation.

The base package of SpectraPLUS costs $295. Each additional option or module costs a further $200.
also bundles for $595 and $795 and the complete package costs $995. You can find more information about SpectraPLUS here: www.telebyte.com/pioneer/index.html

EASERA SysTune
Most of the description of EASERA also applies to SysTune. It is very comprehensive and reliable, but quite expensive. In addition to the fact that you can use SysTune to measure 8 channels at a sampling frequency of 192 kHz, simultaneously and in real-time, SysTune also offers the following capabilities: the program gives a choice between live input signals or internally generated signals, impulse response measurements, spectrogram measurements, multiple-channel FFT, phase measurements in real-time and much more.

For the price of $600, SysTune comes as a complete test system, which not only lets you make all kinds of measurements on the incoming signal, but can also do spatial measurements and measurements for the positioning of loudspeakers in studios and auditoriums. More information: www.easerasystune.com

VB Audio
VB Audio is a company who mainly develop VST plugins. They have developed a range of plugins which are intended for audio measurements, for example, Frequencies Analyser, LF Generator and VU Meter. The names already indicate what they do.

What is very interesting, is the stand-alone application FFX16. This application can ‘load’ several plugins. This transforms the PC into a real-time audio processing and measuring instrument. The ‘stacking’ of plugins makes it possible to measure several frequency ranges at the same time, by first separating the desired frequencies with band-pass filters.

The Frequencies Analyser has this function built in. In addition to level measurements in the frequency domain the plugins can measure the difference in frequency between left and right channels and display spectrograms.

You can generate various waveforms with the LF Generator. Impulse and sweep modes are also included. The VU Meters is a very stable and accurate meter that is very flexible to use.

On the VB Audio website you can find much more information about these plugins: www.vb-audio.com.

Conclusion
With a simple sound card you can quickly measure all kinds of things using a computer. The results of these measurements depend of course on the application for this ‘test set-up’ and the quality of both the hardware and the software. Cheaper cards often have high latency and a low maximum sampling frequency. This can cause problems when calibrating, which leads to inaccurate measurements.

Software that is much too cheap often means that there is no money and therefore no time for development and testing, so that it is less reliable and the test results may be questionable.

A small step up and still reasonably affordable are for example TiePie [4] and Picotech [5]. The best solution depends on the measurements required and the financial room available.

In conclusion we can state that there are plenty of programs available that are very good at making measurements using the sound card. Obviously, this type of solution cannot compete with professional test instruments from, for example, National Instruments. But then, these cost considerably more.

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A simple programming method used to monitor multiple events within a program, and react accordingly, is to continuously test and react as each event occurs. This methodology is termed ‘Polling’ and it can be achieved relatively easily and successfully in simple loop program with a series of ‘IF’ statements and associated subroutines. But as programs become complex the use of subroutines, which may include delays and tests for further external events, means that it is increasingly difficult to guarantee the response of a program to an external event within the required response time. On top of this the use of polling is inefficient as every failed test for an event is a waste of system resources.

To overcome this problem the internal circuitry of microcontrollers is designed to allow programmers to run predetermined subroutines on the occurrence of an external, or internal, event — separate from the main program. This provides interrupts with two big advantages:

1. the main program does not need to test for the interrupt events, simplifying the program structure;
2. Response to an interrupt event will be quick!

Examples, please
An external digital input interrupt
As an example, consider a domestic burglar alarm: if polling alone was used then it would not be possible for the alarm to be triggered whilst a user was entering a key code to unlock the system: the program would be waiting for the
user to enter a key and could not service the alarm trigger routine. However if the sensor input is connected to an interrupt pin then the programmer can develop a system where the alarm trigger routines are run whatever the rest of the program is doing.

**Internal timer interrupt**

An example of an internally generated interrupt is the timer interrupt. Within a microcontroller, a digital counter block, made up from a chain of flip-flops, is connected to the main system clock. The counter block generates an internal interrupt signal each time the counter overflows. The design of the counter block is enhanced so that the effective length of the counter block is determined by the contents of a writable memory register within the chip, allowing the programmer to determine the effective length of the counter. Together this digital block of circuitry and the memory register is called the ‘prescaler’ and it allows programmers to generate an interrupt every, 2, 4, 8, 16, 32, etc. counts, depending on the length of the counter.

The timer interrupt is incredibly useful: if you have a microcontroller clocked with a crystal at 19660800Hz with a 16-bit prescaler counter then it produces an internal interrupt at 19660800/65536: an interrupt 300 times per second. So all you have to do is have a small timer interrupt routine that counts 300 of these and you can accurately produce a clock that shows time passed in seconds.

In practice there are many variations of the external digital interrupt and the timer interrupt: external interrupts can be active low or high, some microcontrollers have timer interrupts that can be triggered on an exact count match, etc.

**Other internal interrupts**

Most microcontrollers are integrated with a collection of peripheral devices. Each peripheral device contains hardware that is optimised to perform task that would be difficult, time consuming, or even impossible for an unaided microcontroller to undertake. Most of these devices have the ability to generate interrupts when special events occur. Here are just a few more examples:

- UART, SPI, I2C: interrupts can be triggered when data is received or a transmission complete.
- A/D converter: interrupt triggered when the A/D conversion is complete and sample available.
- Data EEPROM: interrupt triggered when write operation is completed.
- Comparator: interrupt triggered when the input has changed from previous status.

**Putting it into practice**

The example program you can download from the Elektor website (archive #071069-11.zip) shows how a Flowcode program written for the ATMEGA32 can use two interrupts to create a high speed analogue data logger. Download it, unpack and open it with Flowcode for AVR.

When a microcontroller is powered up, all interrupts are off by default – so the first task a programmer has is to turn them on. The ‘main’ flowchart contains a sequence of three icons which configure the chip to be suitable for our purposes.
The properties of the Timer 0 interrupt.

Figure 3. The properties of the Timer 0 interrupt.

For those who are curious, here is the maths on Figure 3:
The clock is 20 MHz. The prescaler is 1:64 – effectively a 6 flip flop counter. $2^6 = 64$. However the clock feeds into an 8 bit counter before it reaches the prescaler – effectively a 14 bit counter. $2^{14} = 16384$. So the actual interrupt frequency is $20000000/16384 = 1220.703$Hz.

In this case the TMR0 interrupt has been configured to generate an interrupt at a frequency of 1220.7Hz (819.2µs), see Figure 3. From the ‘Interrupt on’ drop box shown in Figure 2 you can see that other interrupts are available which are as follows:

- INT0: interrupt when a selected transition is detected on the INT0 pin;
- INT1: interrupt when a selected transition is detected on the INT1 pin;
- INT2: interrupt when a selected transition is detected on the INT2 pin.

If you are just starting out with interrupts then use of the timer and INT interrupts will be as far as you want to go for now. Once you have mastered these then you may want to learn a little C code, dig into the datasheets of the microcontroller and you can then take advantage of more advanced interrupts as follows.

The second icon in the flowchart configures a second interrupt in the Atmega chip: the A/D Converter Conversion Complete interrupt. Once this is on the flowchart if you click on the icon and select the ‘Custom...’ option from Figure 2 you will get a new dialogue box as shown in Figure 4. Here you need to enter appropriate C code which enables the interrupt by setting the status of the ADCSRA register (ADC Control and Status Register A), and then additional C code which ensures that the selected Flowcode macro is called. Using interrupts like this requires some knowledge of the inner workings of the microcontroller device itself, and a little C code.

The third icon in the program sets up several variables for the program. After this we get to the main program loop. As you can see this is a ‘loop while 1’ pair which simply loops the program round the loop forever. The odd thing about this program is that there are no instructions in the main loop at all!

The TMR0ISR macro is called each time a timer-0 interrupt is issued. This macro contains a single C command that initialises the ADC conversion in the Atmega chip. Note that a Flowcode ADC conversion hardware macro is not used here as these require a response from the ADC hardware inside the chip (curiously enough using the Polling technique) suspending operation of the main program until conversion is complete, or a timeout period has elapsed.

Techtalk ‘onINT’

After a Power-On-Reset, interrupts are usually disabled. The microcontroller has several levels of control over its interrupts. A Global Interrupt Enable (GIE) flag is available in one of the system registers to allow the entire interrupt system to be enabled or disabled in a single instruction. Individual interrupt enable flags (e.g. TMR0IE) are contained in various system registers allowing each interrupt to be enabled and disabled independently.

An interrupts will only be generated when they are enabled both individually and globally. When an interrupt is generated it will set a flag in one of the system registers (e.g. TMR0IF). This can be used to confirm the presence of the interrupt request, and should be cleared before returning to the main program.

There are several different requirements for clearing interrupt flags, depending on the interrupt type, device family etc. Reference should be made to the device data sheet.

Interrupt operation

When an active interrupt condition is detected, the microcontroller completes the machine instruction it is currently executing, saves the address of the next instruction to be executed in the main program onto the stack, and loads the program counter with an alternative address — similar to a programmed subroutine call. The address loaded into the program counter is that of an interrupt vector. What the microcontroller expects to find at the interrupt vector address depends on the device type.

Two popular devices are the PIC16F877a and the ATMEGA32. The PIC device has a single interrupt vector and expects to find a sequence of instructions starting at the vector address. One of the first tasks to be carried out is to identify which of the potential sources generated the interrupt, before branching to the appropriate service subroutine.

The ATMEGA32 has a separate interrupt vector for each interrupt source. There is no need to identify the source of the interrupt in this case so the device expects to find the address of the service routine at the vector address.

The outcome of the response to an active Interrupt ReQuest (IRQ) is that the program flow is diverted from the main program and directed to the appropriate Interrupt Service Routine (ISR) that performs the tasks required by the interrupt event, clears the interrupt, re-enables the interrupt system (if necessary), and returns the program counter to the next instruction in the main program.
The ADCisr macro is called each time an ADC Conversion Complete interrupt is issued. This macro then reads the sample ADC value and outputs this value onto a bank of LEDs on Port B.

Back to the program
The entire program is handled by interrupts. The TMR0 interrupt generates interrupts at a frequency of 1200.7 Hz. The TMR0 interrupt service routine macro (TMR0isr) starts the ADC conversion and returns to the main program loop. The ADC Conversion Complete interrupt service routine macro (ADCisr) reads the converted ADC value and writes it to PORT B before returning to the main program loop. Almost any program could be written in place of the main While loop, without affecting the operation or timing of the data logging function. Of course this is not necessarily a practical program, but hopefully it illustrates the use of a simple timer interrupt as well as giving an example of a more complex interrupt and an idea how these are set up.

Interrupt pitfalls
It is important that interrupt service routines are completed as quickly as possible. Most will transfer small amounts of data, update a variable, or trigger another event. Program loops, macro calls, and complex calculations should be avoided. The delays involved in writing data to the LCD could cause problems in a multi-interrupt application. In this case the interrupt service routine should transfer any necessary data to a suitable location and create an indicator that the main program can use to detect that an interrupt has been serviced and further action is required.

The fact that interrupt response times are down to individual machine instructions can cause problems if an interrupt occurs during a multi-instruction operation, especially if the interrupt service routine modifies a variable that is in the process of being used by the main program. There are many techniques for avoiding this problem, enough to justify another complete article.
An SPI-networked Microcontroller

Dirk Böhm

A little over a year ago Microchip [1] launched the first Ethernet controller with SPI connectivity — and just 28 pins. With the ENC28J60 available also in a solder-friendly DIP version, this makes embedding a microcontroller in a local network particularly simple and attractive. The basic circuit (see diagram) requires only a handful of extra components, enabling the whole affair to be built conveniently on a piece of Veroboard (stripboard) or on a solderless prototyping breadboard. A MagJack integrated module from Belfuse [2] is our choice for the network connection. Apart from this you will need a 25-MHz crystal oscillating at its fundamental or natural frequency. Online suppliers of the microcontroller, controller and crystal include [3] and [4] but you may well know of other firms that are closer to hand. The 1% tolerance resistors, capacitors and coils are available from the usual mail order firms, such as Maplin, Rapid Online and Conrad Direct. Once you have powered up the module you need to apply a frequency of 6.25 MHz on PIN 3 (CLKOUT), otherwise a link will not be established to the network. This 6.25 MHz signal must come from a crystal oscillator operating on its fundamental frequency. If you cannot detect any trace of the 6.25 MHz signal try removing the capacitors experimentally. For your very first trial you should try activating the LEDs connected to the microcontroller. If this works read out the Revision ID. Should something prevent reading to and from the Register, sending some packets should unblock this. If you don’t feel like developing the TCP/IP Stack from scratch you can download an oven-ready TCP/IP Stack [5]. This lets you log all the packets passing in broadcast mode or direct to and from the controlling PC. One final tip: it’s crucial that you download the errata and update information relevant to the particular Revision ID of the module you are using [1]!

SPI in a nutshell

The Serial Peripheral Interface Bus or SPI (often pronounced ‘sp-i’ or ‘spy’) bus is a synchronous serial data link standard named by Motorola that operates in full duplex mode. Devices communicate in master/slave mode where the master device initiates the data frame. Multiple slave devices are allowed with individual slave select (chip select) lines. Definition from Wikipedia [6].

Web Links
[1] www.microchip.com

Patrick Knöbel

Just about anyone must be familiar with the NE555 by now. It is one of the most common components in do-it-yourself circuits. This IC, however, was not designed specifically to generate a clock signal, and certainly not one with a duty-cycle of 50%, although it is frequently used for that.

There are of course a number of circuit possibilities that could realise a duty ratio of 50%. Figure 1 shows a solution that uses two diodes. Capacitor C is, via the diodes, always charged and discharged with the same resistor value, so there is no asymmetry and the duty-cycle stays at 50%. We can calculate the (clock) frequency as follows:

\[ f = \frac{1.44}{2RC} \]

where \( R_1 = R_2 = R \).

It is however not possible to calculate the frequency exactly because the forward voltage drops of the diodes are not known.

This and the fact that six parts are required make it worthwhile to think about another solution. The engineers that STMicroelectronics [1] thought the same.

Their data sheet for the NE555 contains a circuit that, for a clock generator with 50% duty-cycle, requires only three external components (see Figure 2).

The amount of time that the output is high (\( t_1 \)), is calculated as follows:

\[ t_1 = 0.693 R_1 C \]

The time that the output is low (\( t_2 \)), is a little more complicated:

\[ t_2 = \left( R_2 \times R_1 \right) / \left( R_2 + R_1 \right) \times C \times \ln\left( \frac{R_2 - 2R_1}{2R_2 - R_1} \right) \]

For a duty cycle of 50% it is true that \( t_1 = t_2 = t \). The clock frequency is then:

\[ f = 1 / 2t \]

The disadvantage of this circuit is that it is not easy to select the values for the components. For example, \( R_2 \) may not be greater than \( \frac{1}{2} R_1 \).
So there is an opportunity to do better still. And this is shown in Figure 3. This extremely simple schematic shows a clock generator using an NE555 with a 50% duty ratio in its minimal form. It requires only three components in total, including the timer IC itself.

The frequency can be calculated with this formula:

\[ f = \frac{0.72}{RC} \]

Where most people would normally use a D-flipflop, we solve that with this circuit using only a capacitor and a resistor. It is not likely to get much simpler than this.

Links:
[1] www.st.com
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C 2 6 3 D 5 E A F 0 4 8 7 9 B 1
F 4 E 8 B 9 7 3 1 6 2 A 5 C D 0
0 A B 5 F 1 C 2 D 9 E 7 8 4 6 3
D 8 F BA 4 1 0 9 E 3 5 2 6 7 C
6 3 C E 5 B 9 7 A 2 8 0 D F 1 4
5 9 2 4 E 3 6 F 7 1 C DB A 0 8
A 7 0 1 C 2 D 8 B 4 6 F 3 E 9 5
8 C 3 A 6 F 0 B E D 7 2 1 5 4 9
2 1 5 D 9 A 3 E 0 8 F 4 6 B C 7
B F 9 7 4 C 2 5 6 3 A 1 0 8 E D
E 6 4 0 1 7 8 D C 5 B 9 F 3 A 2
1 0 A 6 8 D 5 C 2 B 9 E 4 7 3 F
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The closing date is 1 June 2008.
Peter Beil

As early as 1972, a telephone answering machine appeared on the market that was second to none: The ‘Alibi-Nota FL’ with remote listening / erasing functionality. Zettler, a company famous for its pioneering telecomms technology, had succeeded in going round the extremely strict regulations laid down by the German telephone authorities, forbidding private users to send control signals of any kind (be it carriers or dial pulses) over the public telephone system (PTS).

The resultant ‘0’ and ‘1’ code allowed the Alibi-Nota (what’s in a name!) to validate the caller/user. The code was programmed using small plug-in boards marked ‘yes’ and ‘no’ and inserted into slots marked 1-10 located at the underside of the equipment.

Pulse dialling was the de facto standard at the time and DTMF (tone dialling), in its infancy.

Pitfalls — sure! ‘Static on the line’ — quite normal at the time — would have upset the operation of the Alibi-Nota machine as it was unable to discern between ‘yes’ and ‘no’. As part of the dialogue, further check tones had to be ‘answered’ correctly, if not, the machine would stop the playback and disconnect. To use the remote erase function, you had to respond to the last tone prompt as well (the last tone naturally was within the call you were making).

Alibi-Nota was a full-fledged tape recorder recording at 2.4 cm/s — fully adequate for the limited frequency response of analogue phone lines. It was fitted with a call counter, a ring pulse counter and adjustable recording length. For each key, the control buttons could be locked in any position. The front side had a replaceable cassette for the fixed message. Inside we find an endless tape with a clearance in it for on/off switching and switching over.

Sporting a microphone, foot-switch and fast tape rewind the machine was also suitable for use as a Dictaphone. The complete Alibi-Nota weighs 15 kgs. The tape recorder proper is quite conventional, but the remote control unit is a masterpiece of engineering. Removing the one kilogramme steel cover of the encoder bay reveals a large vertically mounted board that can be hinged out. The relays allow the equipment to be controlled ‘in parallel’ and the logic circuits used are now long forgotten types from Siemens & Halske like the FLH131, FLJ121 and FLK101.

To date this answerphone is fully functional on the analogue phone system. In 1972 it would have set you back the equivalent of about a month’s wages.

Retronics is a monthly column covering vintage electronics including legendary Elektor designs. Contributions, suggestions and requests are welcomed; please send an email to editor@elektor.com
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Elektor Internet Radio
(April 2008)

In the good old days, you had to modulate audio signals onto an RF carrier so they could be received and demodulated to produce something more or less audible. Nowadays you can access every Internet radio programme in the world by receiving, buffering and decompressing IP packages. This is all very easy with the Elektor Internet Radio. All open-source!

Kit of parts including SMD-stuffed PCB, programmed microcontroller, all leaded parts and CD-ROM containing CodeWarrior, TBLCF documentation, datasheets, application notes and source code files.

Art.# 07001-71 • £115.00 • US$ 230.00

Datalogger “deLuxe”
(March 2008)

We have had the pleasure of proposing various data acquisition units over the last few years. This Datalogger “deLuxe” is a nice exercise in product development. It actually utilises an SD card as the media for data storage. The hardware design is compact and that makes the firmware and software features even more interesting.

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Elektor 2007

This CD-ROM contains all articles published in Elektor Volume 2007. Using the supplied Adobe Reader program, articles are presented in the same layout as originally found in the magazine. An extensive search machine is available to locate keywords in any article. The installation program now allows Elektor year volume CD-ROMs you have available to be copied to hard disk, so you do not have to eject and insert your CDs when searching in another year volume. With this CD-ROM you can produce hard copy of PCB layouts at printer resolution, adapt PCB layouts using your favourite graphics program, zoom in / out on selected PCB areas and export circuit diagrams and illustrations to other programs.


ECD 4

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

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on the testbench: PC soundcards

All PCs are now sold with a plug-in soundcard or equivalent on-board circuitry for processing audio signals. To electronics designers, the soundcard doubles as a fine instrument to do (low-frequency) measurements, effectively turning the PC into an analyser or an oscilloscope.

Sufficient resolution of the soundcard is perhaps the single most important condition for accurate measurement results. Hence we ran laboratory tests on a number of soundcards on the market with different price tags. The results are presented in the June 2008 issue.

Colourful Computer Light

We live in a colourful environment these days. Everything is in colour: TV, advertising billboards, mobile phone displays and LEDs. Philips added a further dimension to all this with their Ambilight, Wake-up Light and Living Colors lamp. We will work with the latter in this Modding & Tweaking article. The wireless remote control offers interesting possibilities once the protocol has been cracked...

Switch-mode audio power supply

Lots of electronic equipment is powered by a switch-mode power supply (SMPSU) because it’s light, efficient and compact. Also, SMPSUs suitable for use with audio power amplifiers are rare finds. That’s going to change with SAPS-400, a module with an adjustable output voltage to ±60 V and good for a whopping 400 watts of output power. SAPS weighs just 500 g and is a little larger than two cigarette packs.

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