Create your own chip

Wind speed & direction meter

Stepper motor ABC
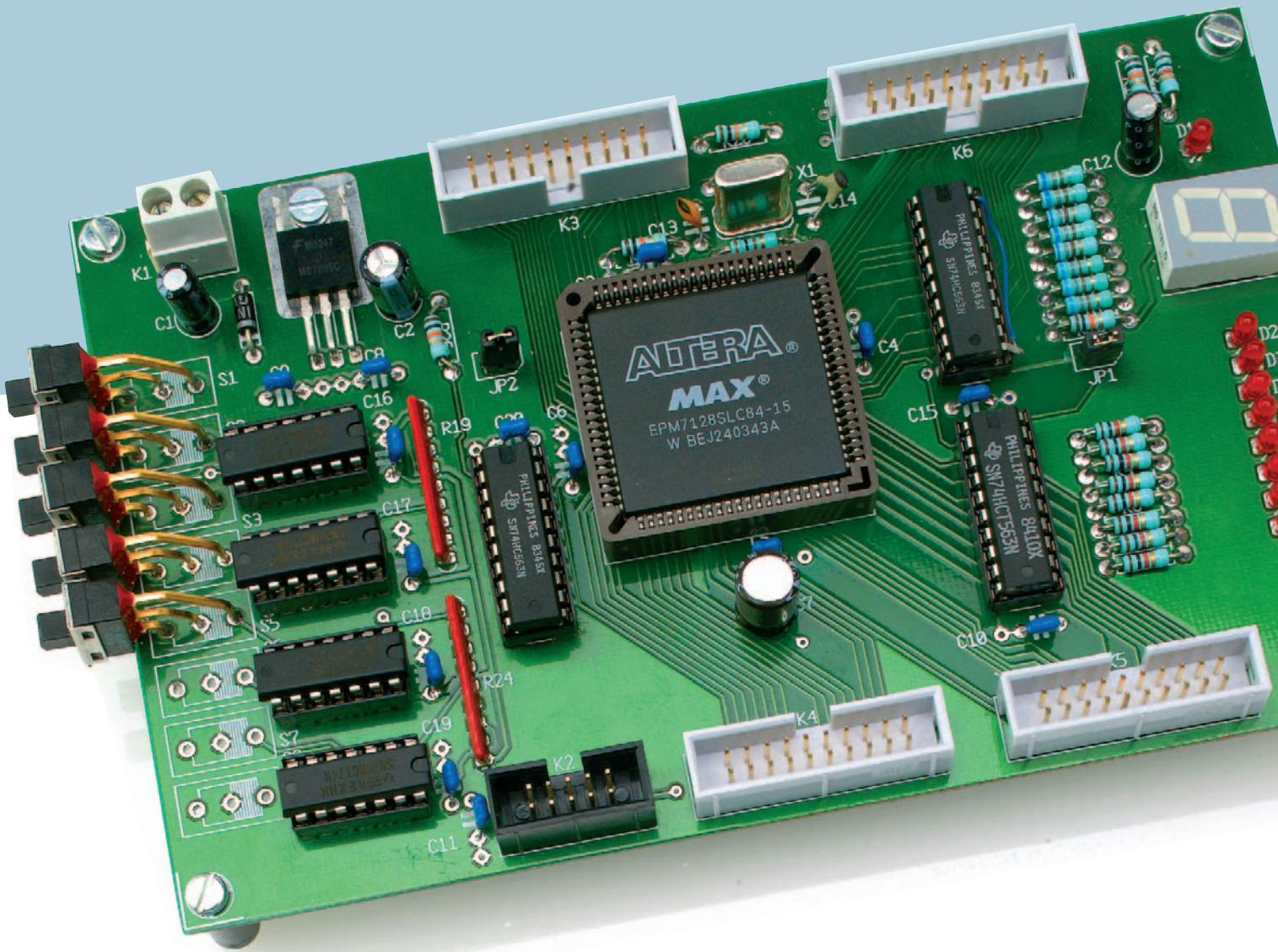
Paul Goossens

Design Your Own IC
Prototyping with CPLDs (part 1)

Designing a circuit always involves several somewhat disagreeable tasks, such as soldering, looking up the pinouts of ICs and laying out a maze of tracks on a printed circuit board. All of this is now no longer necessary, since you can program your own digital circuit in a CPLD.

Experimenter's board features

- **CPLD version: EPM7128**
- **JTAG interface**
- **all I/O lines available via box headers**
- **supplementary I/O can be disabled using jumpers**
- **7-segment display**
- **8 LEDs**

- **8 switches with debouncing circuitry**
- **on-board supply voltage regulator**
- **Eurocard format**
- **extensive development environment available free of charge from Altera**

The CPLD experimenter's board presented here makes an excellent starting point for sitting down at the keyboard and directly designing your own circuit.

For most people, experimenting with digital logic brings to mind an image of an experimenter's board stuffed full of ICs interconnected by countless wires. Anyone who has ever worked in this manner knows that such an arrangement usually takes many hours to construct, not to mention the modifications that have to be made if the circuit does not work properly right off the bat.

A CPLD can be used to replace such a 'forest' of digital logic ICs. CPLD ICs contain a large number of digital building blocks that can be interconnected in a wide variety of manners simply by programming. Such an IC can actually be considered to be the modern version of an experimenter's board full of ICs.

Instead of soldering all sorts of little wires in place, designers and experimenters can now conveniently design circuits while seated in front of a PC, and then program their latest designs into the IC in a trice.

This clearly saves a lot of time, and it has the advantage that it isn't necessary to document modifications afterwards on paper or in some other manner. This is because the circuit is drawn (or described, as discussed later on) on the computer, after which the PC computes how the design must ultimately be realised in the IC.

CPLD organisation

Our experimenter's board is based on the Altera MAX7000 family of CPLDs. The organisation of these CPLDs is shown in **Figure 1**. At the top of the drawing you can see the four special
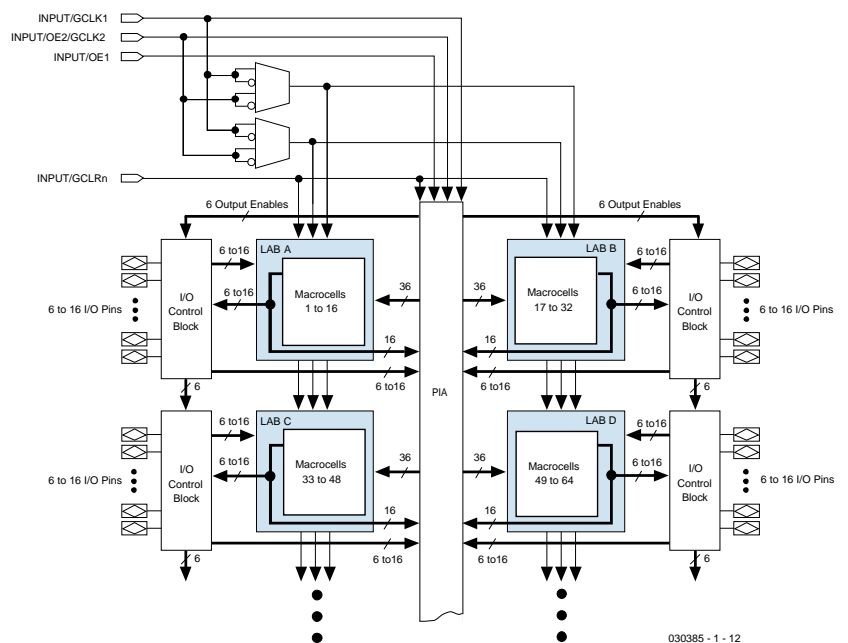

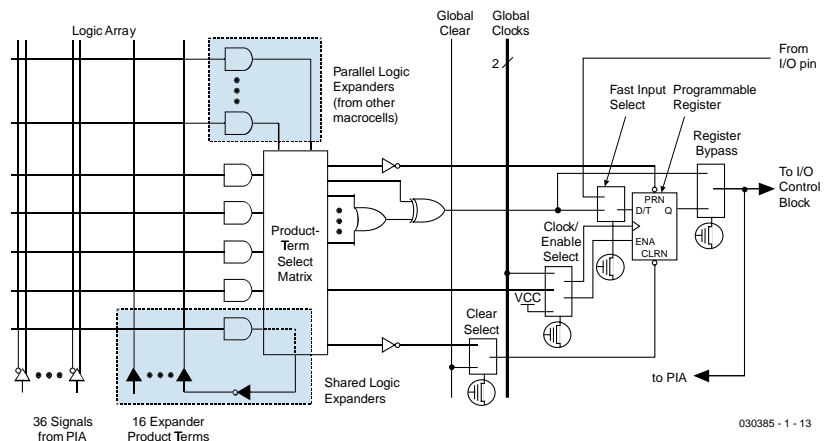Figure 1. Overall organisation of MAX7000 CPLDs.

Figure 2. The structure of a MAX7000 macrocell.

Figure 3. Besides the CPLD, the circuit of the experimenter's board includes several indicators (D1–D8 & LD1) and switches with hardware debouncing (S1–S8 & IC5–IC8).

COMPONENTS LIST

Resistors:
R1,R10,R20,R23,R26 = 10kΩ
R2-R9,R25 = 1kΩ
R11-R18 = 680Ω
R19,R24 = 10kΩ 8-way SIL array
R21 = 100kΩ
R22 = 100Ω

Capacitors:
C1,C12 = 10µF 16V radial
C2 = 100µF 16V radial
C3-C6,C8-C11,C15-C20 = 100nF
C7 = 22µF 16V radial
C13,C14 = 22pF

Semiconductors:
D1-D8,D10 = LED, red, low current
D9 = 1N4001
LD1 = 7-segment-display, common anode,
   e.g., HD1131 O)
IC1 = EPM7128SLC84-10 or
   EPM7128SLC84-15
IC2 = 7805
IC3,IC4,IC9 = 74HCT563
IC5-IC8 = 74HCT74

Miscellaneous:
JP1,JP2 = 2-way header with jumper
K1 = 2-way PCB terminal block, lead pitch

   5mm
K2 = 10-way boxheader
K3-K6 = 20-way boxheader
S1-S8 = slide switch, 1 changeover
   contacts, e.g., APEM A2
X1 = 4.000MHz quartz crystal
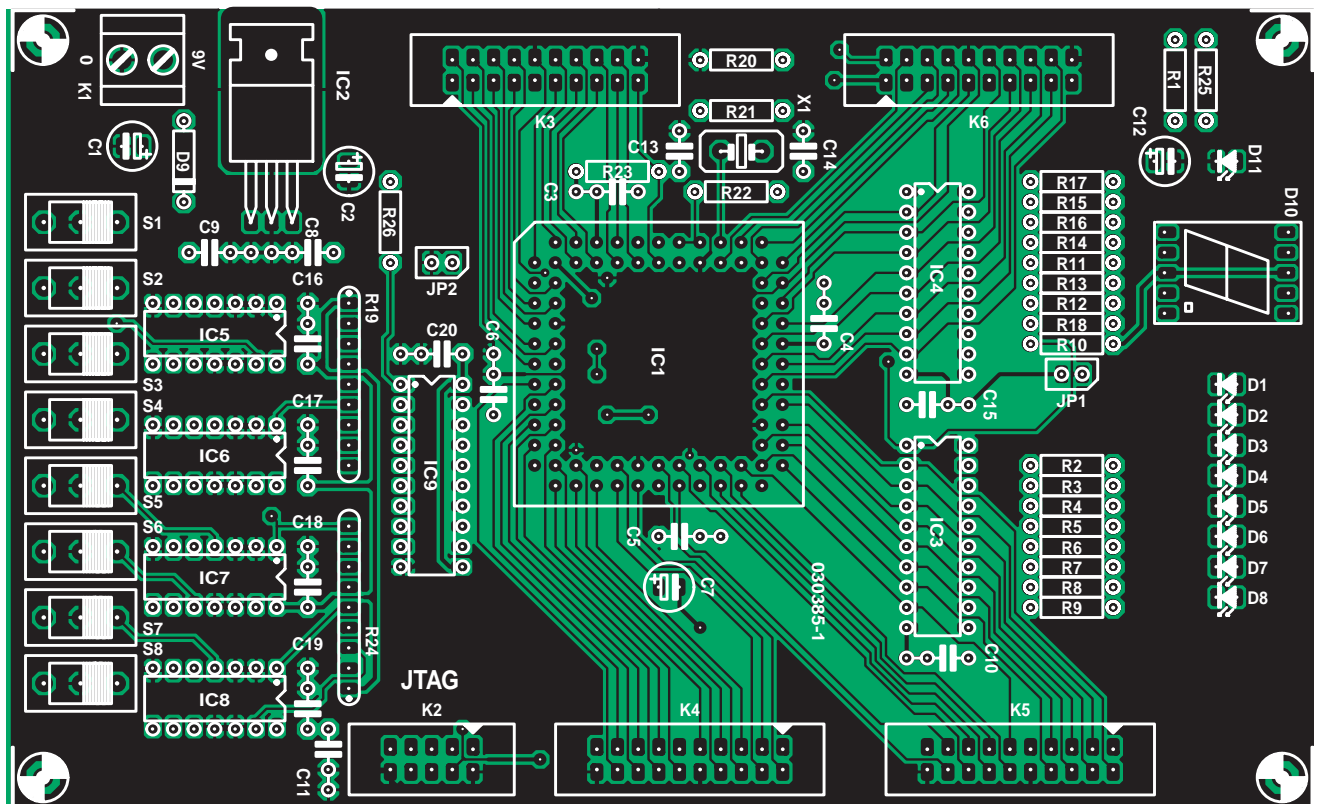84-way PLCC socket
PCB, order code **030385-1**

Figure 4. Component layout of the double-sided through-plated PCB for the experimenter's board. The associated copper track layouts can be retrieved from the Free Downloads section of our website (file no. 030385-1.zip).

inputs for the CPLD. These signals are connected to the macrocells in the IC in a manner that allows them to optimally perform their intended functions (CLK, OE, and CLEAR).

The inputs and outputs of the various macrocells are connected to each other as desired via the Programmable Interconnect Array (PIA). There are also inputs and outputs that are connected to the various I/O Control Blocks. Their job is to connect the internal signals to the I/O pins of the IC.

Four Logic Array Blocks (LABs) are also shown in Figure 1. These LABs contain the actual programmable logic. Each LAB consists of 16 macrocells. Various CPLD versions are available in the MAX7000 family. The type number of the IC indicates how many macrocells are present in the IC.

Macrocells

The actual programmable logic is located in the macrocells. The struc-

ture of a macrocell is shown in **Figure 2**. Each macrocell has its own Logic Array, which consists of 36 inputs connected using a programmable AND function. Four of these AND functions are combined into a single signal in the Product Term Select Matrix. The capabilities of the IC can be increased by further increasing the number of product terms. If you want to know more about this, we recommend reading the data sheet for these CPLDs.
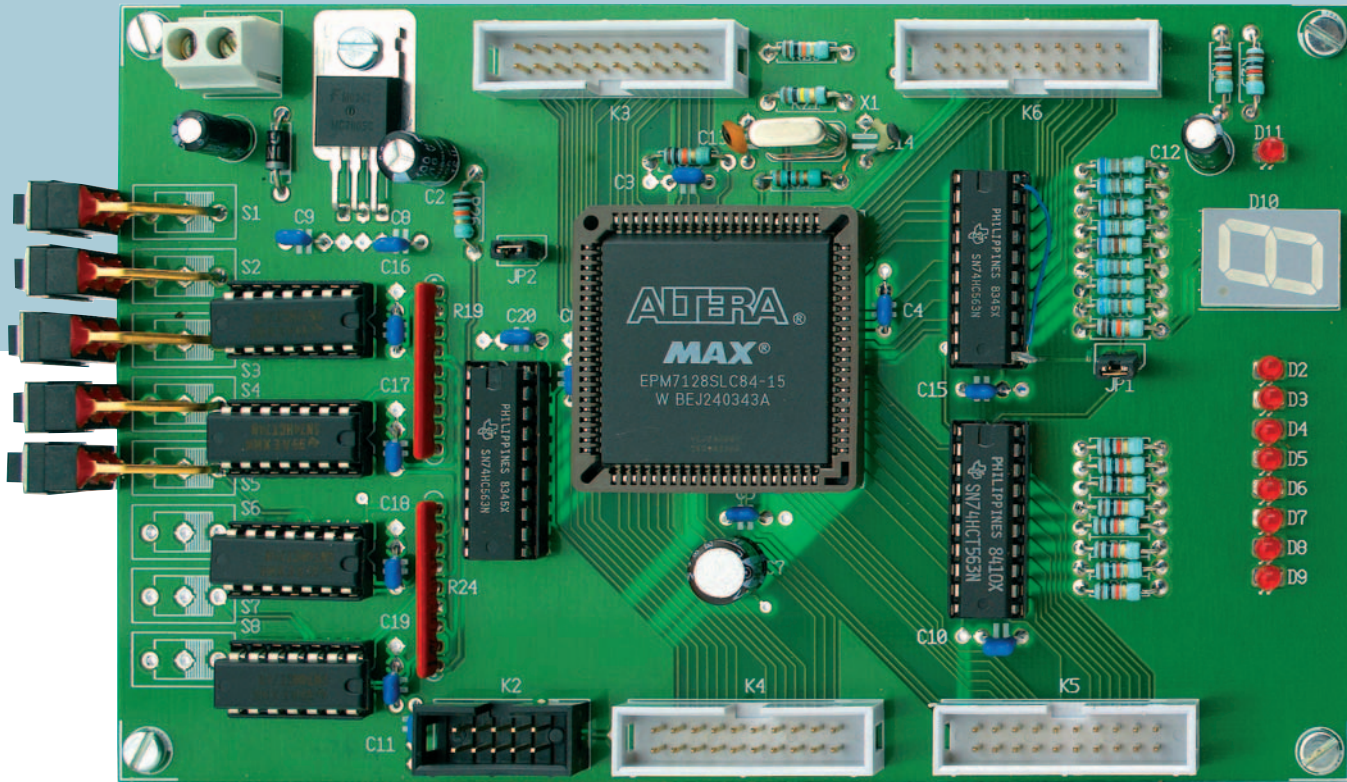
Figure 5. This photo of an assembled prototype of the circuit board shows that the switches can be fitted as desired; in this case five are fitted.

The signal generated by the combination of AND and OR operations then arrives at the register and its surrounding logic. This portion can be used as a D-type, T-type, JK or SR flip-flop, or it can be completely bypassed if no register is needed.

Fortunately, as designers we do not have to be overly concerned about exactly how our designs can be implemented in this manner. This is where the (free) software comes to our aid. But before we delve into the software, let's first take a closer look at the experimenter's board.

Experimenter's board

Our experimenter's board has a reasonably simple design. Nevertheless, it has more than enough I/O for performing our initial experiments with CPLDs. Naturally, all of the relevant pins of the CPLD are brought out via several connectors, to allow external hardware to work together with the board afterwards.

The schematic diagram, which is shown in **Figure 3**, is fairly simple. The

supply voltage of approximately 9 V_{DC} is applied to connector K1. IC2 and its surrounding components provide the 5-V operating voltage for the entire circuit. LED D11 and R25 provide a 'power on' indication.

The CPLD is shown in the schematic diagram as IC1. The JTAG programming interface is brought out via K2. The pin layout of this connector is compatible with the Altera ByteBlaster, which means it is also compatible with the *Elektor Electronic*s Parallel-to-JTAG interface (see the September 2002 issue, page 34). The reset circuit is formed by RC network R1/C12. Finally, an oscillator is implemented using R21, R22, C13, C14 and X1. The manner in which these components can be used together with the CPLD to make an oscillator is described later on in the examples.

A certain amount of simple I/O is indispensable on every experimenter's board. IC3 is a buffer that boosts several signals from the CPLD and uses them to drive LEDs D1–D8. IC4 performs a similar function for driving a 7-segment display. If these I/O functions are not desired, they can be decoupled from the CPLD by

removing jumper JP1.

We decided to use eight switches for the inputs. To make your initial experimenting relatively easy, these eight switches (S1–S8) are equipped with a debouncer circuit. This function is provided by IC5–IC8. These inputs are connected to the CPLD via IC9, but here again this part of the circuit can be decoupled from the CPLD. In this case, JP2 is responsible for coupling the signals to the CPLD.

Finally, connectors K3 through K6 make all relevant CPLD signals available to the outside world.

Construction

The double-sided printed circuit board shown in **Figure 4** is generously dimensioned in order to keep everything readily accessible. All connectors are placed at the edge of the circuit board. Fitting the components to the circuit board should not present any difficulties. Anyone who is interested in CPLDs will certainly have already built other circuit boards. When fitting the components, you primarily have to pay attention to the proper orientation of the ICs, LEDs and electrolytic capaci-
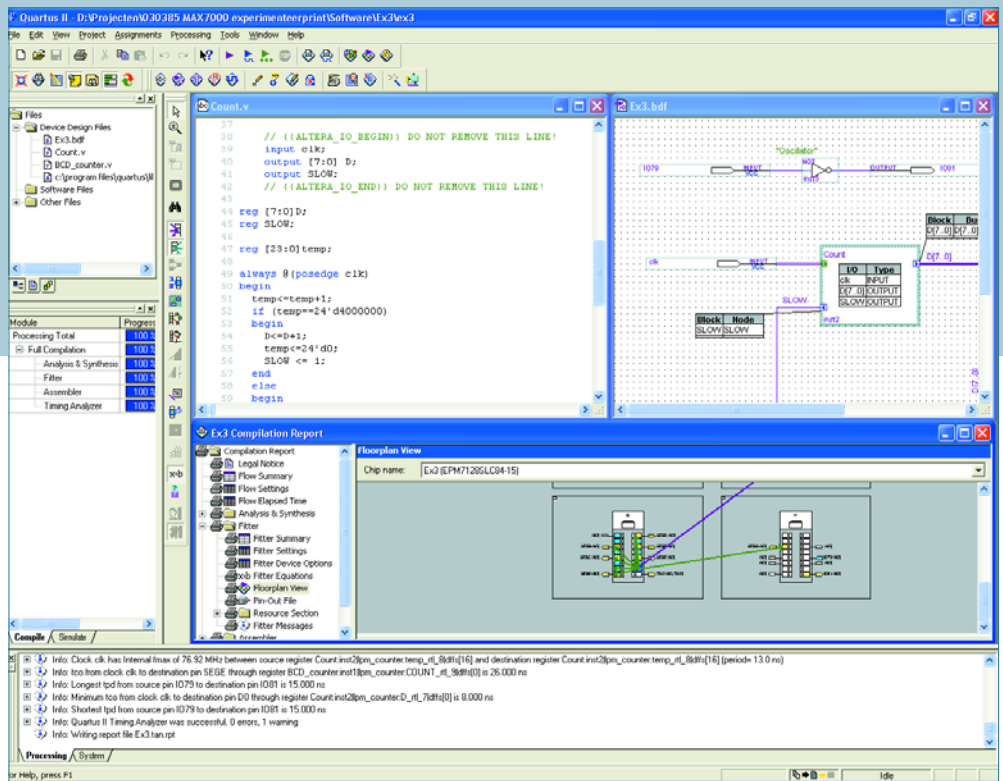
Figure 6. This screen shot gives an impression of Altera's free Quartus software.

tors. Sockets are definitely recommended for the ICs, and a suitable 84-pin PLCC socket is essential for the CPLD. Make sure that the bevelled corner of the PLCC socket is correctly positioned on the circuit board (refer to the component overlay), since it can also be fitted incorrectly into the holes in the circuit board. Incidentally, the CPLD fits into the socket in only one orientation.

Portions of the circuit that are not used can be disconnected from the CPLD by means of jumpers JP1 and JP2. Naturally, you can also simply omit the unneeded components. For instance, IC4 along with LD1 and R11–R18 can be omitted if the 7-segment display is not necessary. The same holds true for IC3 together with D1–D8 and R2–R9 if you don't need any LED indicators. As for the switches, you only need to fit the ones that are needed for the initial experiments.

The voltage regulator (IC2) is fitted flat against the board and secured using a small screw and nut. An additional heat sink is not necessary, at least as long as any additional hardware connected to the board does not draw too much current.

The supply voltage can be provided by a mains adapter that supplies approximately 9–15 V at a current of at least 100 mA. This value applies to the experimenter's board by itself and must be increased by the amount of current drawn by any additional hardware that may be present.

Software

PC software that can generate the necessary programming files and program them into the IC is required for programming the CPLD. Fortunately, the manufacturer of the CPLD has a nice (and free) software package for this purpose (see **Figure 6**). This software is called Quartus, and it can be downloaded from the manufacturer's website (http://www.altera.com/).

On the home page of this site, select *Design Software* under the *Products* heading. This will cause a new window to appear, where you should select *Quartus II Web Edition*. After this, follow the instructions displayed on the screen. However, you shouldn't overlook the size of the download. The file is a hefty 144.9 MB, so if you have a dial-up link, it might be more conven-

ient to have someone else with a faster Internet connection download this file! After installing the software, you must request a free license. Exactly how to do this is clearly explained on the Altera website.

Next month

Next month we will use several examples to explain how you can design a circuit using Quartus, and of course we will describe how to try out these examples using the experimenter's board. For programming the CPLD, you will need a JTAG interface in addition to the experimenter's board. The previously mentioned Parallel JTAG Interface from the September 2002 issue of *Elektor Electronics* is suitable for this purpose.

While you're waiting for the next issue of *Elektor Electronics*, we recommend that you read the Quartus tutorial. It can be found under the Help menu. Using this tutorial, you can already familiarise yourself with the organisation of the software and examine the features of the software.

(030385-1)

High-End-Preamp (II)

Benjamin Hinrichs

The modular design and flexibility of the microcontroller program allow the preamplifier to be built exactly according to the individual requirements of its user.
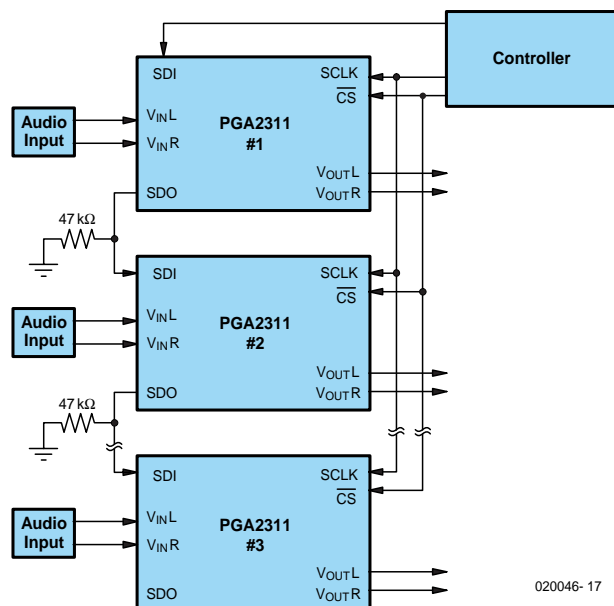
Figure 1. Connecting several volume controls in parallel.

The multitude of options for constructing your 'personalised' high-end pre-amplifier mean that you must read this second part of the article **before** you order the parts and take up your soldering iron. This is because your requirements determine how many circuit boards of which type you will need, as well as which components you will need. You can connect several volume controls in parallel as illustrated in **Figure 1**, in order to adjust more than two channels at the same time. If you do this, you must interconnect the CS, Mute, SCLK, +5 V and Ground terminals of the circuit boards. SADATO from the first circuit board is connected to SDATI of the next circuit board, and so on. This causes the volume level setting to be communicated to all of the circuit boards.

You can choose from traditional audio signal switching, switching the ground leads together with the signal leads, or switching balanced signals. If you know how, you can also give the microcontroller additional functionality or modify the details in the software, such as the designations shown on the display.

Populating the board

What we need now are a few instructions for populating the main preamplifier board. This is because the circuit board shown in **Figure 2** is quite com-

pact. The closely spaced, narrow tracks are not particularly forgiving of mistakes, so the components should be fitted properly the first time, and solder splashes and overheated joints should be assiduously avoided.

On the main circuit board, only JP1 and JP3 can be implemented as jumpers. JP2 (directly underneath IC2) is a wire bridge. There is another wire bridge at the inner edge of K5, which should be fitted immediately: done is done!

Now you should consider whether the programming and/or paralleling connections are necessary. If you arrive at a positive conclusion after studying the two text boxes, then you must fit the associated connectors (refer to the components list) and the solder pins for the audio signals. Despite all the claims to the contrary, it certainly makes sense to fit the solder pins before the other components. Generally speaking, they need a bit of coaxing, and sometimes they can only be pressed into the holes using (brute) force. Besides this, a 1.3-mm diameter silver-plated steel pin requires a considerable amount of heat to achieve a reliable bond with the solder. And if you find a solder pin standing at an angle to the board, you can start all over again. This can be the kiss of death for small, sensitive components that have already been fitted in the immediate vicinity.

If you use a decent stuffing frame, it doesn't matter very much if the low-profile components (resistors, capacitors, and diodes) are only fitted afterwards. As always, proper polarisation is important for some of the components. Besides the diodes and small electrolytic capacitors, this also includes the resistor arrays and the PLCC socket, which is bevelled on one corner. This marking must match the component overlay on the circuit board. Now it the right time to **not** fit LED D1 if you want to use it as a pilot light on the front panel. This LED, along with IR receiver IC3, should only be soldered in place after the circuit board has been securely fitted in the enclosure and the two components have been fastened in holes drilled in the front panel. If your enclosure layout does not permit the circuit board to be placed directly behind the front panel and you thus must fit the IR receiver off the board, a screened connection cable is mandatory.

The fixed voltage regulators IC4–IC6, which should be soldered in place after pin headers K3–K5 and the high-quality DIL socket for the PGA2311 have been fitted, do not require heat sinks. The soldering work is completed with the fitting of the three large electrolytic capacitors and the two circuit-board terminal strips (K1 and K2).

If you wish to control several volume control boards in parallel, fully popu-

COMPONENTS LIST main board

(020046-1))

Resistors:
R1 = 27Ω
R2,R9 = 47kΩ
R3 = 8-way 10kΩ SIL array
R4 = 4-way 10 kΩ SIL array
R5 = 1kΩ5
R6,R7,R8,R10 = 10kΩ
P1 = 10kΩ preset
P2 = 100Ω preset

Capacitors:
C1,C2,C3,C20 = 10µF 25V radial

C4-C11,C14,C15= 100nF
C12,C13 = 27pF
C16,C17,C18 = 2200µF 25V radial
C19 = 100nF ceramic, lead pitch 5mm

Semiconductors:
D1 = low-current LED (+ 2-way pinheader)
D2.,D3,D4 = zener diode 5V6, 1.3W
IC1 = PIC18LF452-I/L (PLCC). Blank ICs:
  Farnell # 400-9654. Programmed ICs:
  order code **020046-41**
IC2 = PGA2311PA from Texas
  Instruments/Burr-Brown or CS3310 from
  Cirrus Logic (Crystal)

IC3 = SFH5110 (TSOP1836) (+ 3-way
  pinheader)
IC4,IC6 = 7805
IC5 = 7905
T1 = BC550C

Miscellaneous:
JP1,JP3 = 2-way pinheader + jumper
JP2 = wire link
K1 = 3-way PCB terminal block, lead pitch
  5mm
K2 = = 2-way PCB terminal block, lead
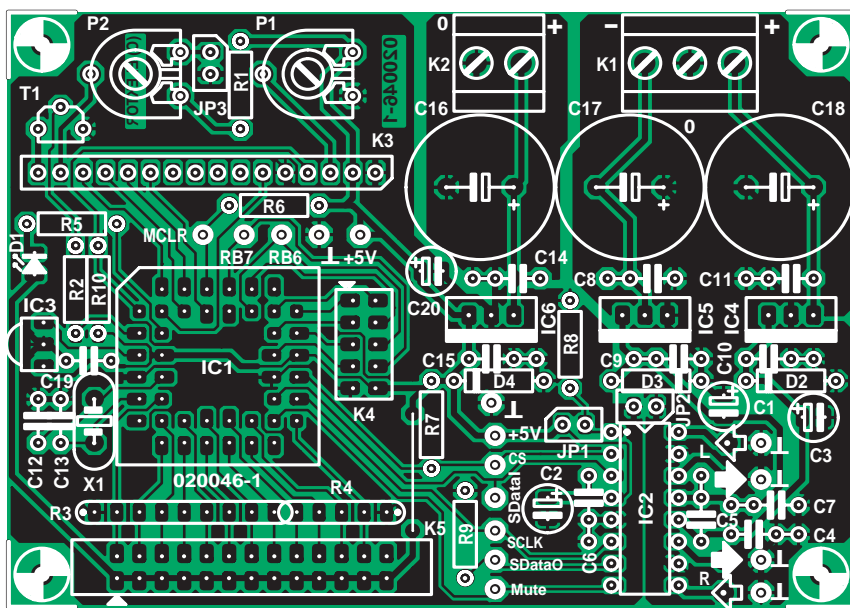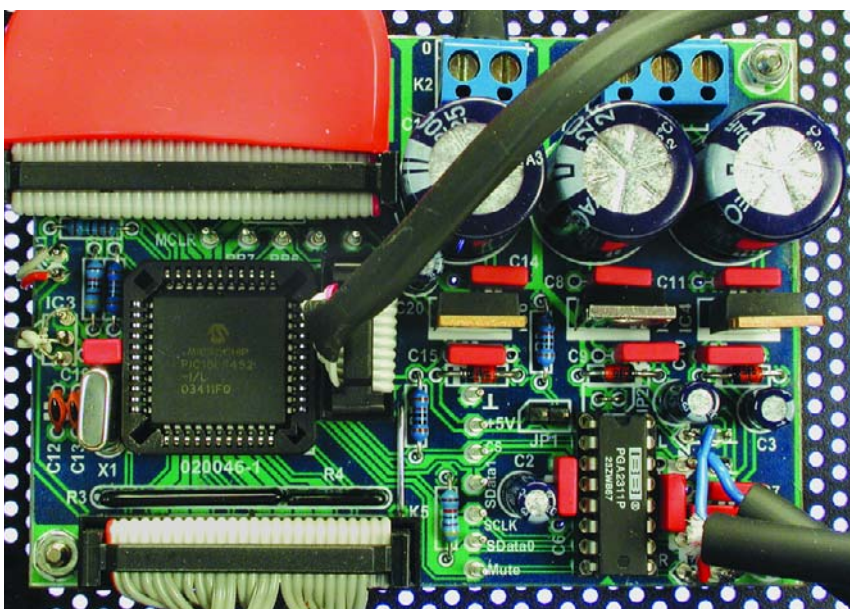 pitch 5mm
K3 = 16-way pinheader

Figure 2. Component layout of the tightly arranged but single-sided main circuit board.

late one main circuit board and fit only the portion with the PGA2311 (including the peripheral circuitry and the voltage regulator circuitry) on the other boards.

The system has been tested using a single controller board and two parallel circuit boards. All of the necessary connection points are located in a row on the circuit board.

Channel switcing

The input channels are switched on the relay board. The circuit shown in **Figure 3** allows two different wiring options.

With the **traditional** option, all eight inputs from the Cinch sockets are used, with a single output to the main circuit board. This requires JP2 and JP3 to be fitted. Each relay is then responsible for one stereo channel. If standard twin screened audio cable is used, one channel is connected to A and the other to B, and the screen braid is soldered to the bottom of the circuit board. **Ground isolation**, which may be desired to improve channel separation or avoid interconnecting the grounds of different items of equipment connected to the preamplifier, can be achieved by switching not only the signal lines, but also the associated ground potentials. In this case, for each channel the 'live' lead is soldered to A and the ground lead is soldered to B. In addition, jumpers JP2 and JP3 are left open. In this mode, each pair of relays (RE1 & RE5, RE2 & RE6, RE3 & RE7, and RE4 & RE8) belongs to a single signal source. This yields four stereo inputs and two sets of outputs (OUT1A & OUT1B and OUT2A & OUT2B). Here again A corresponds to the 'live' lead and B to ground. The

K4 = 10-way boxheader, vertical
K5 = 26-way boxheader, vertical
X1 = 10MHz quartz crystal
12 solder pins
External parts:
LCD, 2x16 characters with backlight
12 pushbuttons for chassis mounting
2 Cinch sockets for chassis mounting,
    isolated and gold-plated
Mains on/off switch, chassis mount
IEC mains appliance socket, chassis mount
Disk, hex and source code files, order
    code **020046-11** or Free Download.

(020046-2)

Resistors:
R1-8 = 10kΩ
R9-R16 = 47kΩ

Semiconductors:
D1-D8 = 1N4004
D9-D16 = low-current LED
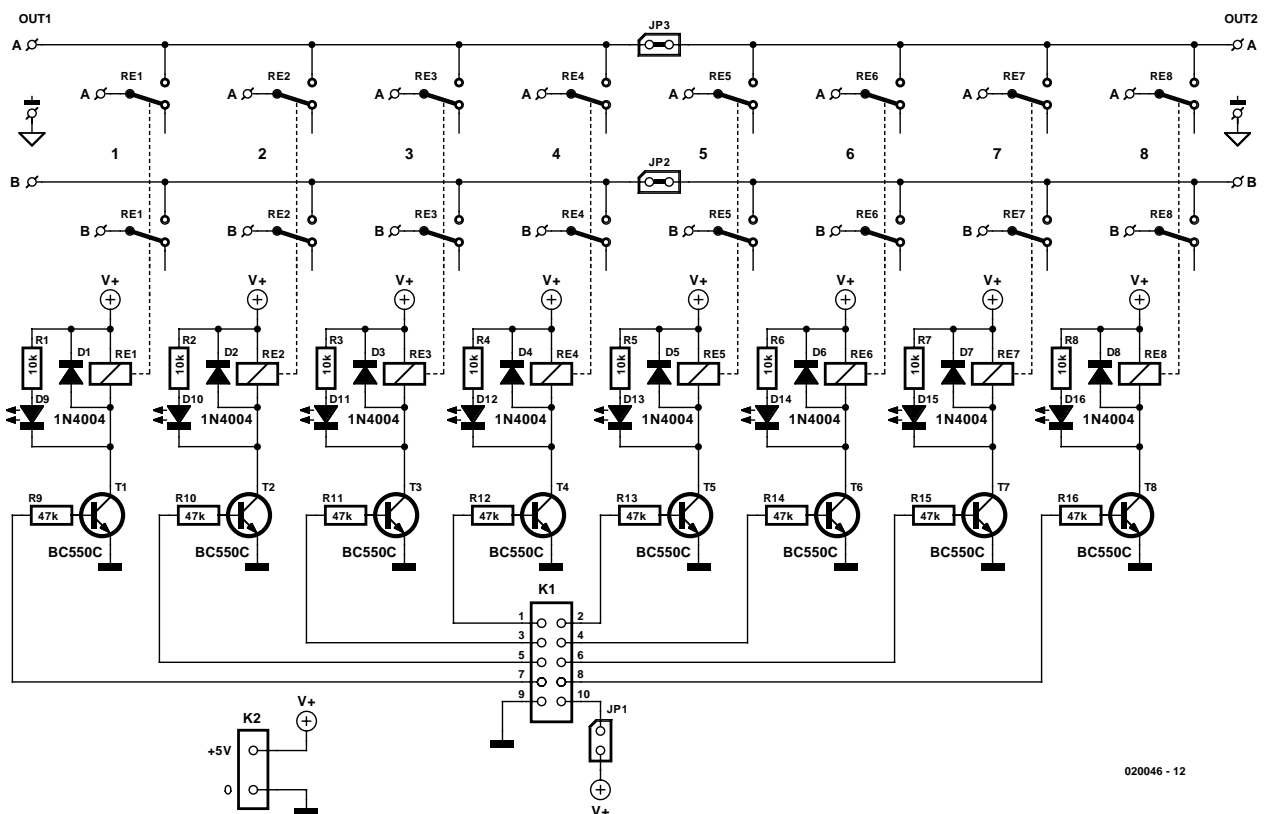T1-T8 = BC550C

Miscellaneous:
JP1 = 2- way pinheader + jumper

JP2,JP3 = wire link
K1 = 10-way boxheader, vertical
K2 = 2-way PCB terminal block, lead pitch
    5mm
RE1-RE8 = RY5W-K (Takamisawa),
    Conrad Electronics # 502852
    (5V/167Ω)
16 Cinch sockets for chassis mounting,
    isolated and gold-plated

Figure 3. The relay circuit also allows ground isolation and connecting balanced signal sources.

only other thing you have to do is to change the Input Type option in the Set-up menu to 'Double'.

In order to handle **balanced signals**, we simply switch two relays simultaneously. In this mode, you also have to add a second, parallel volume control and then connect the balanced signals to one of the input channels (such as Left In) on both volume controls. This works well – quite well, in fact.

Fujitsu (formerly Takamisawa) type RY-5W-K relays are used here. Naturally, other pin-compatible types could also be used, but the specified line has excellent characteristics and is available for less than 2 euros (approx. £1.40), for example from Conrad Electronic (www.conrad.de). This is a plastic-encapsulated relay, which prevents any dust from accumulating inside. The contacts are made from a silver–palladium alloy with supplementary gold plating.

Power for the relay board is taken from the main circuit board via connector K1 (which requires jumper JP1 to be fitted). If you wish to treat the channel switching board to its own power supply or you want to use this board in a different project, you can also connect a 5-V supply to the K2 terminals.

In order to avoid overloading the microcontroller outputs, transistors with base resistors are used as relay drivers. Diodes D1–D8 act as free-

Software modifications

Microcontroller programming is normally not the forte of audiophiles who have dedicated themselves to DIY construction. Consequently, most people will probably be quite pleased to know that the microcontroller can be obtained ready-programmed from Readers Services under order number 020046-41. However, anyone who has a suitable development package for the PIC18LF452-I/L will certainly not have any problems downloading the hex code for the control program into the microcontroller (item number 020046-11, available at no charge from the Free Downloads page of the Elektor Electronics website or on diskette from Readers Services). The easily constructed JDM programmer (see reference [4]) is an example of a suitable programmer.

The software package also contains the source code, so interested users can get an idea of how it is constructed and/or make their own modifications (assuming they have suitable programming experience). The software is written in the JAL high-level language (see reference [5]), which is available from the Internet as freeware. JAL is an excellent choice for getting started with PIC microcontroller programming, particularly since there are also very informative newsgroups on this subject (see reference [6]). Nevertheless, it was necessary to make a few modifications to the JAL files in the assembly code since JAL
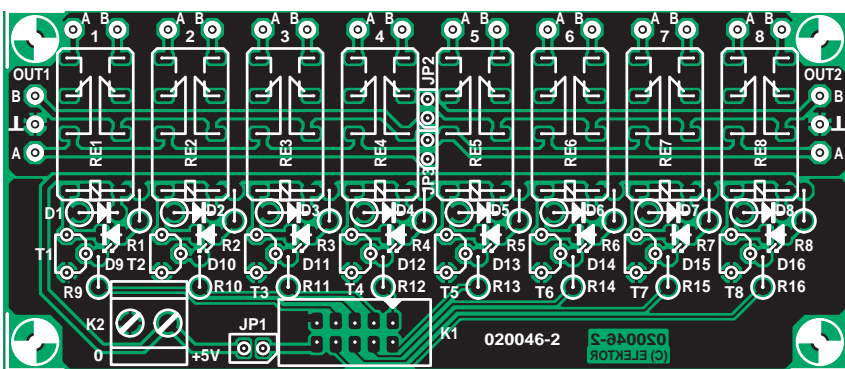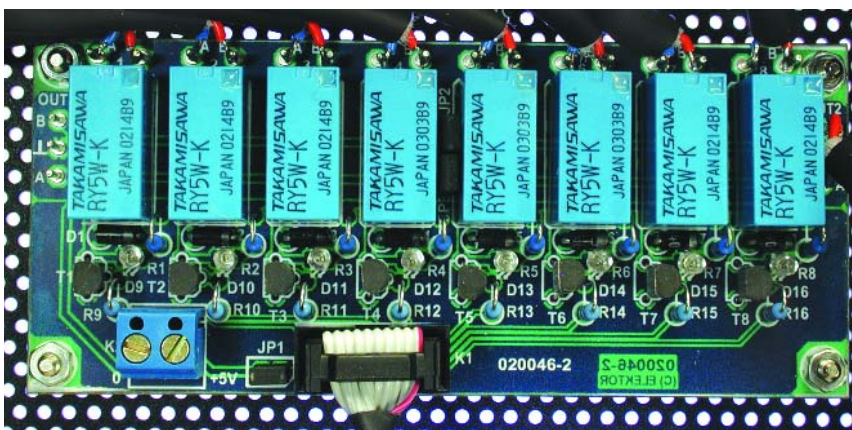

Figure 4. Eight double-pole relays all nicely in a row.

wheeling diodes, while LEDs D9–D16 provide a visual indication of the relay states. The LEDs do not necessarily have to be fitted to the circuit board (**Figure 4**); they can of course be fitted to the front panel instead if you want to do without the display, or they can simply be omitted (along with their series resistors).

JP1 can be implemented as a jumper, but JP2 and JP3 should be implemented as wire bridges. Otherwise there's not anything particularly remarkable about populating the circuit board, particularly if you use the components specified in the components list and everything fits perfectly.

Stable supply

A large part of the stabilisation, decoupling and hum suppression for the supply voltages takes place locally on the main circuit board, for both the digital portion (+5 V) and the analogue portion (5V). The only other thing you need is a sufficiently stable source of symmetrical DC voltages (which shouldn't be a problem with the low current consumption). This provides an opportunity to use a general-purpose low-power mains power supply (**Figure 5**).

The power supply is designed to use Talema 10-VA encapsulated low-profile toroidal transformers (see reference [2]), which can be obtained from DigiKey (among others). Particularly for audio applications, toroidal transformers are preferable to other types of transformers due to their low stray fields.

The power supply circuit board is general-purpose because it can be configured to provide either an asymmetric supply voltage (V+ and ground) or symmetrical supply voltages (V+, ground and V–) by simply fitting either wire bridges 'A' (for asymmetric output) or 'B' (for symmetric output). Naturally, C6 and R2 are not needed if it is configured to provide an asymmetric supply voltage.

The output resistors (R1 & R2) should be wire-wound types, since this further reduces the hum voltage. Fast diodes with a recovery time of less than 200 ns are used as rectifier diodes (D1–D4) — for comparison, the recovery time of standard 1N4004 diodes is 1.2 μs, which is more than six times as long. If you wish to use ultrafast diodes (< 50 ns), you are of course free to do so.

Small foil capacitors are connected in parallel with the rectifier diodes to effectively suppress high-frequency noise, which primarily arises from diode switching transients. Each circuit board is protected by a slow-blow fuse rated at 125 mA.

Fitting the components to this board

does not provide native support for storing code in the EEPROM of the PIC18F452. All of the modified files are included in the project. If you wish to make changes to the source code, you should adjust the path names in the accompanying JAL.BAT file and use them for compiling. The software was compiled against JAL 0.4.59.Win32.

The software was entirely written by the author, except for a few functions such as driving the display, for which JAL provides native support. Functions such as the SPI interface code and acquiring RC5 signals were specifically developed for this project. Modification and/or reuse of parts of this software, including in your own projects, is explicitly desired, as long as the author is named and the software is used for non-commercial purposes (which means at home). More on this subject can be found in the file VV.JAL.

The PIC18LF452 can easily be programmed in-circuit. For serial in-circuit programming, a number of conditions must be satisfied: the PBGA2311 must be removed from its socket, and the connectors for the display and relay board must be disconnected. The programming interface comprises five connections: MCLR, RB6, RB7, +5 V, and Ground. These connections are arranged in a row on the circuit board and fitted with solder pins.

(**Figure 6**) is also about as simple as could be imagined. First solder the wire bridges in place (one circuit board with the three 'A' wire bridges and a second one with the three 'B' wire bridges). Then fit the remainder of the components in any desired order. Mount the series resistors vertically.

Testing, testing, testing… and into the box

Before inserting the microcontroller and the PGA2311 into their sockets and connecting the display, you should painstakingly check all the boards for incorrectly fitted components, dubious solder joints and solder bridges. The first test should be performed with the boards outside of the enclosure. To hold the boards securely in place for testing, screw them to the workbench using standoffs under each of the boards.

First connect the power supply boards and check the voltages at their outputs. Due to the high open-circuit voltage and the combination of rectification and filtering, the measured voltage will naturally be somewhat higher than the 7 V specified for the transformer.

Next, connect all of the boards together and switch on the power. Nothing will happen, but the following voltages should be present at the appropriate IC pins and the display module connector:

+5 V:
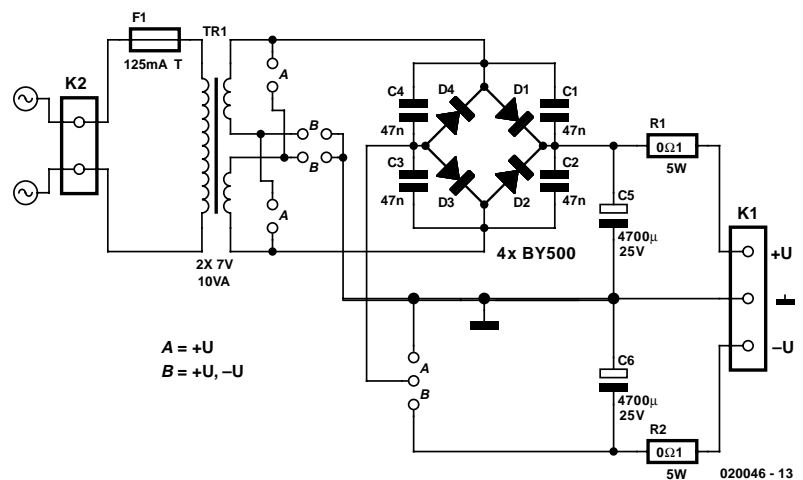K3-2, IC1-12, IC1-35, IC2-4, IC2-12

–5 V: IC2-13

Figure 5. The mains power supply can provide unipolar or symmetric output voltages.

If everything is OK, wait a few minutes to allow the capacitors to discharge, and then insert the ICs and connect the display.

The display, the microcontroller and the volume control IC are highly sensitive to static electricity. As all of these components are not exactly inexpensive, you should work at a suitably earthed workstation.

Figure 7 gives a deep insight into the laboratory prototype of the digitally controlled high-end preamp. The mains filter was fitted because it was 'already on hand', but it is fully adequate. The power supply boards and the main board are separated as far as possible. Nevertheless, the FFT analysis (see Part 1) shows that induced 50-Hz noise is responsible for the majority of the distortion. If you want to improve matters and are not afraid of a bit of effort, you can fit the sensitive audio portion into a suitable tin-plate enclosure.

At the rear, besides the mains input socket there are two sets of eight audio inputs and two audio outputs, all using isolated gold-plated Cinch sockets. After the 'official' completion of the device in the *Elektor Electronics* lab, further tinkering revealed that small RC networks on the inputs suppress induced RF noise on the cables, and that a 100-Ω series resistor in each of the output lines assures the stability of the PGA2311. As shown in **Figure 8**, these components should be soldered directly to the Cinch sockets using the shortest possible leads, or even fitted in the connecting cable, in order to maintain the highest possible degree of screening.

In contrast to the audio connections, which employ high-quality twin screened cable, the keypad (which

COMPONENTS LIST PSU

asymmetrical
(020046-3)

Resistors:
R1 = 0Ω1 5W

Capacitors:
C1-C4 = 47nF, lead pitch 5mm
C5 = 4700µF 25V radial, max. dia. 16mm

Semiconductors:
D1-D4 = BY500-200

Miscellaneous:
F1 = fuse, 125mA, slow, with PCB mount holder
K1 = 2-way PCB terminal block, lead pitch 5mm

K2 = 2-way PCB terminal block, lead pitch 7.5mm
TR1 = mains transformer, 2x7V 10VA, low profile, e.g. Talema 70040 (RS-Components, Digikey)

Fit wire links 'A'
Do not mount R2, C6

symmetrical
(020046-3)

Resistors:
R1,R2 = 0Ω1 5W

Capacitors:

C1-C4 = 47nF
C5,C6 = 4700µF 25V radial, max. dia. 16mm

Semiconductors:
D1-D4 = BY500-200

Miscellaneous:
F1 = fuse, 125mA, slow, with PCB mount holder
K1 = 3-way PCB terminal block, lead pitch 5mm
K2 = 2-way PCB terminal block, lead pitch 7.5mm
TR1 = mains transformer, 2x7V 10VA, low profile, e.g. Talema 70040 (RS Components, Digikey)

Fit wire links 'B'

does not have a circuit board) and the front-panel LED are connected using simple flat cable. This allows a relatively large amount of freedom in the layout of the front panel. For example, the volume buttons can be arranged in a diamond pattern (if sufficient room is available). You can spare yourself the trouble of looking for a distributor for the attractive metal buttons used for the prototype – they were personally turned by the author.

The bright red cable between the main circuit board and the LC display came from a computer shop. But be careful: many of the cables available in such shops have crossed lead pairs. In case of doubt, a 'normal' flat cable is also perfectly satisfactory.

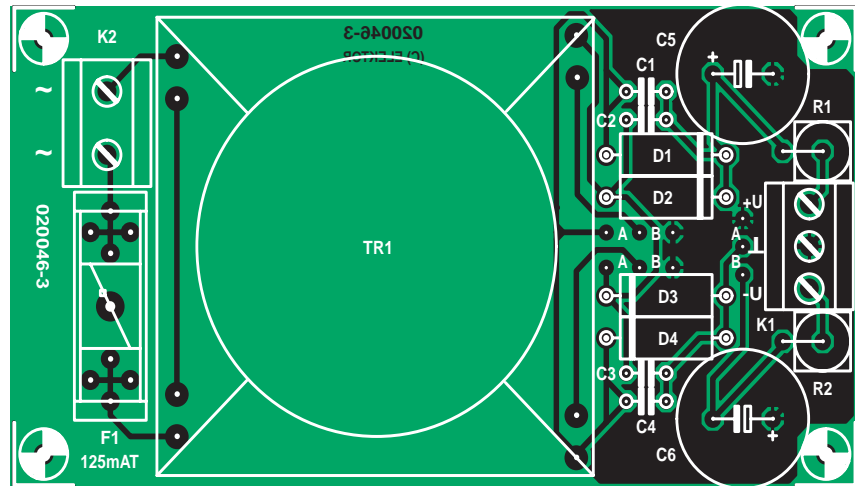(020046-2)

Figure 6. The power supply board should be fitted as far away as possible from the main circuit board.

References and literature

[1]   www.fcl.fujitsu.com/en/ products/relay/index.html

[2]   www.talema.de

[3]   www.avtechpulse.com/ appnote/techbrief9

[4]   www.jdm.homepage.dk/ newpic.htm

[5]   http://jal.sourceforge.net

[6]   http://groups.yahoo.com/ group/jallist
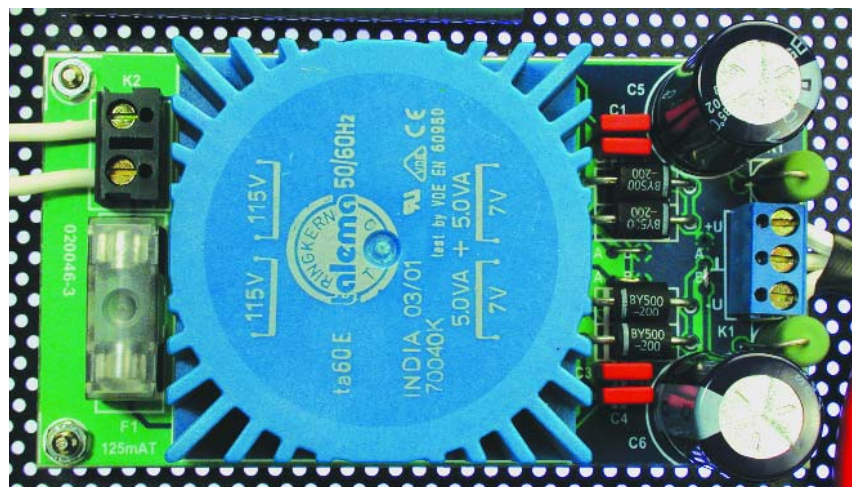
G.Samblancat

Wind Speed & Direction Meter

with a clever touch

This ingeniously designed circuit may be just the ticket for those interested in weather observations, in particular, wind speed and direction. The clever bit about the instrument is that both wind speed and wind direction are measured with a single sensor: a rotational speed meter with three blades, one fitted with a small vane.

deceleration
(vane upwind)

acceleration
(vane downwind)

Δ: 780mV
@ 2.96 V

0°
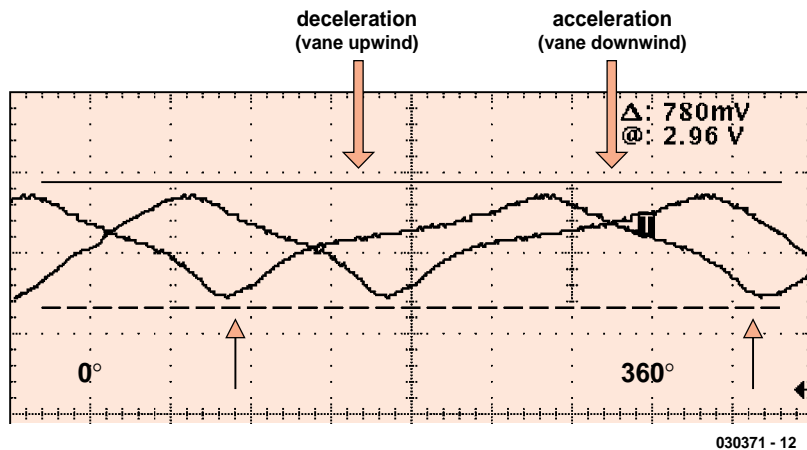
360°

030371 - 12

Figure 1. In practice, the sensor signals shown here may differ considerably from your own because the shape depends largely on the sensor construction. The shape change as a result of the wind will be hardly noticeable on a 'scope.

One advantage of the specific design of the combined sensor is that the mechanical construction of the anemometer is far simpler than that of traditional meters while also reducing the risk of wear and tear as well as breakdowns. The instrument readout showing wind speed and direction is on an LCD as well as via a serial output that allows a PC or an (NMEA compatible) navigation instrument to be connected.

Even if mounted in a single enclosure, wind speed and wind direction meters typically employ two different sensors. Several solutions have become commonplace for the wind speed (anemometer) function, including optical sensors, generators and reed contacts. However, the classic design comprising a rotor with three half spheres causing a magnet to pass across a Hall sensor has the smallest number of disadvantages. The sensor type UGN3503 used in this project supplies a voltage of the order of 1 mV per gauss. These sensors, which are discussed in some detail, in the inset are impervious to dirt ingress and may be totally encapsulated. They consume little energy and unlike reed switches cause hardly any electrical noise.

Wind direction meters are usually realised using potentiometers and optical Gray encoders, but here, too, the linear Hall sensor is a good choice. The circuit presented in this article is a simplified version of the Rotavecta system whose main advantage lies in the total absence of mechanical parts

for the wind direction meter, leaving us just with the three-blade anemometer part.

The principle

The crux of the system is the little vane on one of the half spheres on the rotor. The vane causes a small acceleration or deceleration of the rotor, depending on its position relative to the wind direction. If we assume an angle reference point relative to the wind (on the fixed part) then it has to be possible to determine the wind direction using two sensors fitted at an angle of 90 degrees. The calculation method consists of first measuring the average value (of each sensor) over a couple of revolutions. Each change in the wind direction will result in a small variation of these two average values. Next, using an angular reference table with two inputs, the microprocessor is able to figure out a 'wind vane' angle expressed in degrees. Hence in our wind speed and direction meter, only two Hall sensors are used supplying voltages proportional to their magnetic field. Each sensor supplies a sinewave-like voltage (Figure 1) whose frequency increases with wind speed while the average value is an indirect indicator for the wind direction.

Block diagram

No remarkable things are seen in the block diagram in **Figure 2**. The starting point is the pair of Hall sensors arranged at an angle of 90 degrees. Two amplifiers, one for each sensor, condition the sensor signals for use by

an ADC and then on to the processor. The 'limiter' block prevents overdriving of the capture/compare input on the PIC16F876. The processor is also busy driving the LCD as well as outputting an NMEA compatible serial signal for use by a PC or suitable navigation equipment. That wraps it up as far as the block diagram is concerned and we're ready to have a look at the

Circuit diagram

The schematic in **Figure 3** can not be said to be overly complex, can it? At the heart of the circuit we find a PIC16F876 and a double opamp. There's a 218-page document on the PIC family waiting to be downloaded from the Microchip website mentioned at the end of this article. The PIC usd here has Flash memory and is simple to program over a serial link. On board we find a 10-bit ADC of which two inputs are used, as well as a capture/compare module with one input used to measure the period of the reference signal. Using opamp IC1 (an LM358) the signal amplitude is adjusted for optimum use of the input span afforded by the ADC inside the PIC.
The two UGN3503 sensor chips, IC5 and IC6, are linked to the main board by way of 4-way connector K3.
Together with two small loading capacitors, quartz crystal X1 provides a 16-MHz clock frequency.
Connector K1 allows the circuit to be hooked up to the PC's serial port. The LCD drive employs the R/W signal pair, besides Enable and RS, all on connector K2. Only four datalines are

G. Samblancat

The author was born in 1968 and graduated in electronics at a French polytechnic. He is currently active in the educational field while also studying network engineering at the Conservatoire National des Arts en Métiers. This article is his second publication.
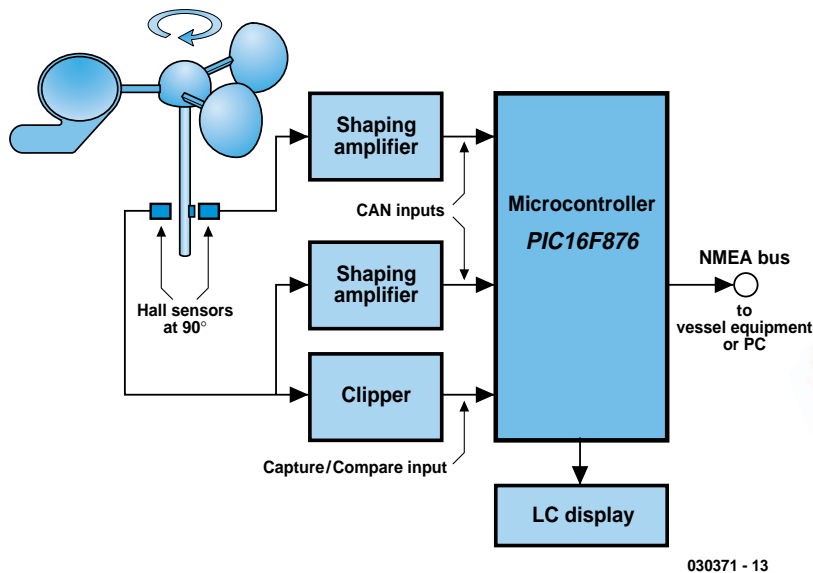
Figure 2. Block diagram of the combined wind speed & direction meter.

required in our case as the LCD is operated in 4-bit mode. Jumpers JP1 and JP2 serve to select between NMEA mode (JP1) and CALibration mode (JP2).

The on-board power supply gets its raw supply voltage from a 12-VDC mains adaptor. Alternatively, the instrument may be powered from a 9-V battery, in which case C7 and regulator chip IC3 are omitted and a wire link installed between the holes normally provided for the input and output pins of the 78L08.
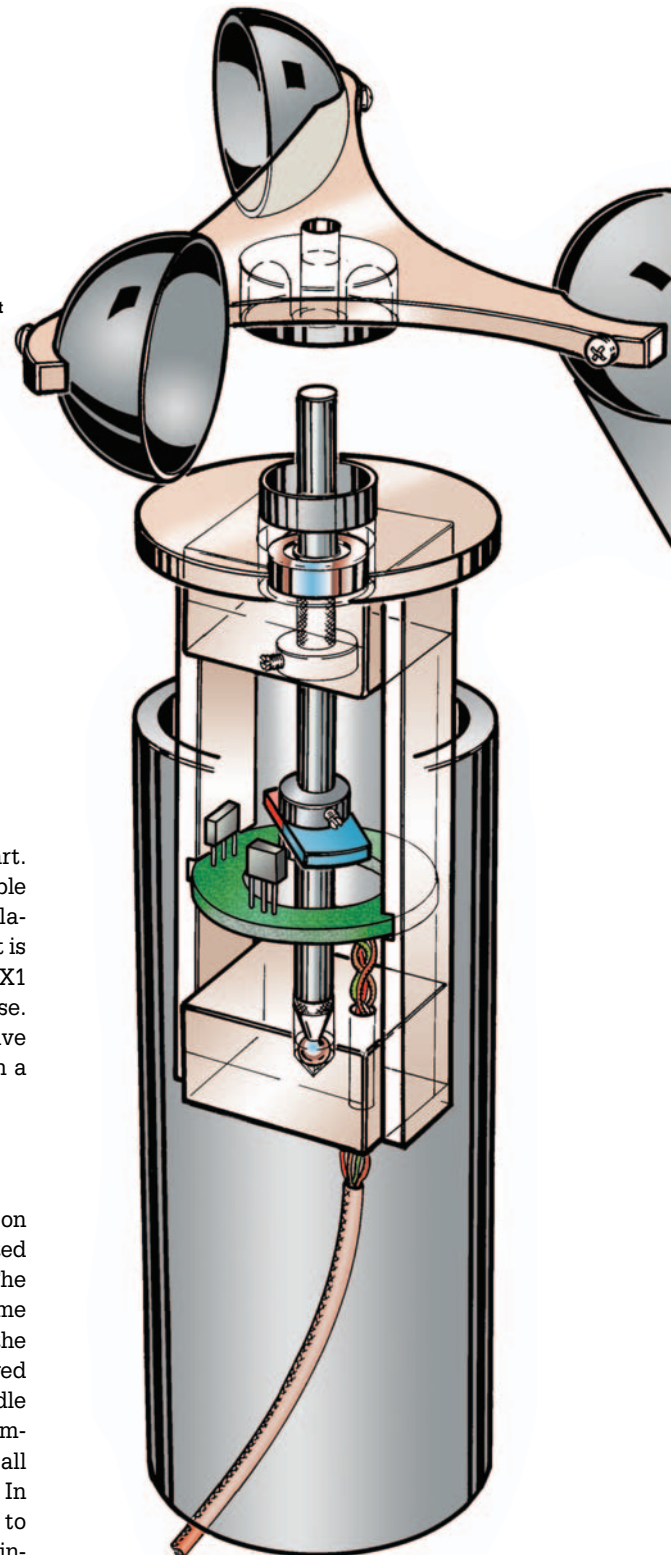
Building it

Figure 4 shows the component overlay. The copper track layout may be found on the PCB Layout pages towards the back of this issue. The board consists of a main section and a sensor section. The elongated shape of the board allows it to be mounted in a 32-mm

PVC tube, just under the sensor part. Note that presets P1-P4 are accessible from the top side. The actual population of the board is straightforward. It is best to start with the smaller parts. X1 is a quartz crystal in a miniature case. The PIC chip is the most expensive part and therefore best installed in a quality IC socket.

Sensor construction

The Hal sensors are accommodated on the small round board that's separated from the main board by cutting. The sensors are fitted at exactly the same height. Next, the board is fitted in the open end of the PVC tube and secured in place with epoxy glue. The spindle is made from a metal pin with a diameter of 3 mm, passing though a ball bearing or a Teflon sleeve bearing. In the prototype we used epoxy glue to secure the little magnet on to the spin-

Figure 3. The circuit diagram remains happily uncluttered. Nearly all functionality is hidden inside the PIC micro.

dle, as well as to secure the ball bearing. The rotor with its three half spheres has to be fixed securely on to the spindle (such rotors are available as spare parts from appointed Auto-helm dealers).

Home construction of a rotor from Ping-Pong balls cut in half look attractive is far from easy. An unexpected difficulty you may run into is the need for perfect mechanical balancing, which is hard to achieve because of the little vane attached to one of the half spheres.

The programs

The program VE16MPU.hex (in INHX8 format) may be blown into the PIC if you have a suitable programmer.

The PC programs called TUNE and ANEMO, written in Delphi, serve for the wind speed/direction adjustments and the PC readout respectively. The subject will be reverted to under the paragraphs on calibration.

The program file, ref. **030371-11**, may be obtained from the Free Downloads section of our website, or on disk under the same order code. If you are unable to program a blank PIC, a ready-programmed one may be obtained through our Readers Services under number **030371-41**.

Amplifier adjustments

The first thing you need to do after switching on the supply voltage is adjust the four multiturn presets P1-P4. Your goal will be to make the IC1a and IC1b output signals cover the full range of 0.5 V to 4.5 V. This may be done with the aid of either an oscilloscope or the TUNE software. In the first case you closely watch the signals at pins 1 and 7 of IC1 while the rotor is made to turn continuously by, for example, a hair dryer. Adjust P1/P4 (amplification) and P2/P3 (offset) to the best of your ability. Do make sure the sinewave signals remain between 0.5 V and 4.5 V and free from clipping. Aim to achieve the optimum setting shown in Figure 1. If you don't have an oscilloscope, use the software instead. TUNE offers a min/max function that draws a line along the discrete values measured. This requires the working meter to be connected to a PC. After starting the program, click on 'Min/Max' and view the message ***Min/Max*** after a few seconds.

Wind speed calibration

The wind speed meter measures the period of one rotor revolution and then computes

COMPONENTS LIST

Resistors:
R1 = 1kΩ8
R2,R3 = 1kΩ5
R4,R5 = 5kΩ6
R6,R8-R11 = 10kΩ
R7 = 1kΩ
P1,P4 = 47kΩ multiturn preset with top
  adjustment
P2,P3 = 4kΩ7 multiturn preset with top
  adjustment

Capacitors:

C1,C6 = 1µF 16V
C2,C3 = 15pF
C4,C5 = 100nF
C7 = 1µF 25V

Semiconductors:
D1,D2 = 1N4148
T1 = BC547
IC1 = LM 358
IC2 = PIC16F876, programmed, order
   code **030371-41**
IC3 = 78L08

IC4 = LM78L05
IC5,IC6 = UGN 3503 (Allegro)

Miscellaneous:
X1 = 16MHz quartz crystal, miniature
   case
K1 = 9-way sub-D socket (female), PCB
   mount
K2 = 10-way pinheader
K3 = 4-way pinheader
JP1,JP2 = 2-way pinheader with jumper
Standard LCD, 2 x 16 characters
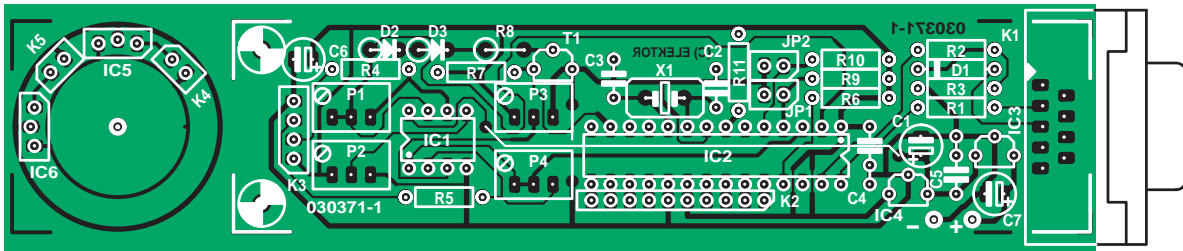
Figure 4. Component mounting plan on the elongated PCB. The small section is intended for the two Hall sensors.
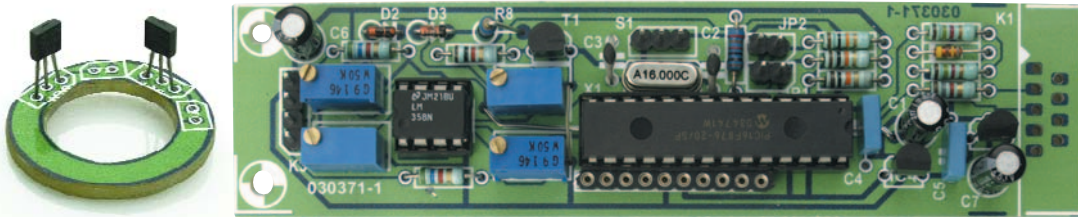
$$speed = K_{anemo} / period$$

The displayed speed is dependent on the constant K which takes a default value of 35500. The adjustment program TUNE calculates the constant based on a comparison between measured speed and real speed (obtained, for example, with the aid of a car speedometer). Adjusting the speed factor K_{anemo} (if necessary, adapt the initialisation value in the .hex file) boils down to comparing (a) the speed shown on the LC display with (b) the real speed and (c) the speed already stored in memory. In each case it is necessary for the PIC to be read out first. The program TUNE will then show 'x.y (z)' where
z = speed factor = y + 256 x

Sensor calibration

Due to the small differences in force and direction of the magnets we're forced to create individual calibration

curves for each UGN3503 sensor chip. The process places rather high demands on the test wind 'quality'. The air stream produced by a hair dryer is too concentrated for an accurate direction measurement — nothing beats a real air stream.

Here we avail ourselves of the adjustment software. To enable the system to calculate the wind direction, each sensor is linked to a lookup table with 72 values (for 5-degree steps). The adjustment program employs 8 points for the interpolation of each curve, so a total of 16 values is needed. In other words, two values have to be measured with each angle of 45 degrees. This calibration method may take a while. In between two measurements, the wind meter has to be turned 45 degrees while making sure the readout remains stable. The values may be viewed continuously on the LCD or on the PC display (via the COM port) after the command 'read PIC'. They have to

be entered in a table like the one shown in **Figure 5**. Once the table is complete, the function 'Curve' computes the 72 values we need, on the basis of the 16 actually measured values. Next, the curves are actually plotted using 2 times 72 reference points.
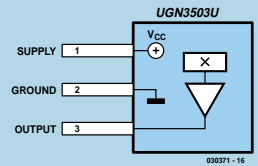
Practical use

After an initial phase in which the system has to determine a number of average values, the wind speed & direction meter will transmit its data to the LCD as well as the NMEA output. Although the NMEA 0183 (or NMEA183) standard is a bit old, it sees wide use in marine electronics. In our case, the NMEA sentence reads:

$WIVWR,dir,L,vit,K

where $WIVWR should be taken to mean 'Weather Instrument'; 'VWR' is the standard prefix for anemometer information; 'dir' is the wind direction

PVC tube, dia. 32mm, length approx.
  200mm
PCB, available through **The PCBShop**
Disk, project software, order code
  030371-11 or Free Download

PCB copper track layout on 'PCB layout'
  page elsewhere in this issue. PCB
  artwork file also available as a Free
  Download.

The UGN3503

Characteristics

The type UGN3503 Hall sensors (models LT, U and UA) are capable of detecting magnetic flux changes of a magnitude so small they can not be measured with a reed switch. Every sensor contains a Hall effect detector, a linear amplifier and an open-emitter output stage. A magnetic field perpendicular to the chip produces a current change, the resultant potential difference causing the Hall effect voltage. This voltage is proportional with, among others, the magnetic field strength.

Operation

In the inactive state, (B = 0 G), the output voltage level is normally half the supply voltage. A magnetic South pole opposite the active part of the sensor produces a voltage above this level, and a North pole, a voltage under this level.   Model –U is not recommended for new design.
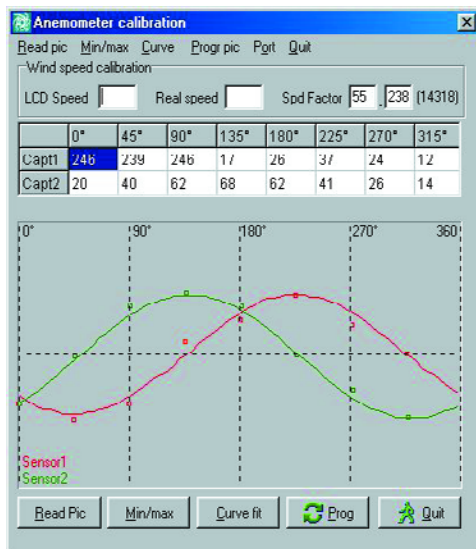

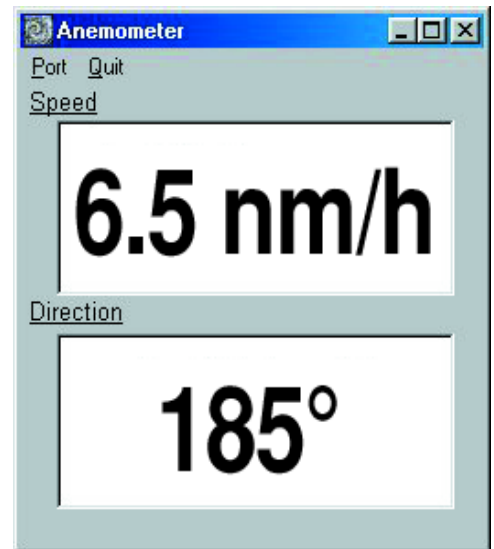Figure 5. Once TUNE has been launched you can start collecting calibration data.

Figure 6. An example of the ANEMO software in action. The values are simultaneously shown on the LCD.

in degrees and 'vit' is the wind speed in km/h. The program ANEMO allows everything to be viewed on your PC in real time.

Admittedly the construction of our wind speed & direction meter requires due attention to mechanical details, but once calibrated the instrument will reward and surprise you with its totally efficient operation.

(0x30371-1)

The Beaufort scale		
0	Calm	<1 knot
1	Light air	1-3 knots
2	Light breeze	4-6 knots
3	Gentle breeze	7-10 knots
4	Moderate breeze	11-16 knots
5	Fresh breeze	17-21 knots
6	Strong breeze	22-27 knots
7	Near gale	28-33 knots
8	Gale	34-40 knots
9	Severe gale	41-47 knots
10	Storm	48-55 knots
11	Violent storm	56-63 knots
12	Hurricane	>63 knots

Web pointers

PIC16F876 family datasheets:
  www.microchip.com/download/lit/pline/picmicro/families/
  16f87x/30292c.pdf

Beaufort scale:
 www.zetnet.co.uk/sigs/weather/Met_Codes/beaufort.htm

Horst Hubert

**Everything you need to know
to drive a stepper motor**

First Steps

Stepper motors have found their way into *Elektor Electronics*
many times, most recently in the November and December
2003 issues. In contrast to previous articles, we'll keep it
practical and won't go into the theory. If you want to know
more about the background, have a look at some previous
articles (listed in the reference section at the end of this article).
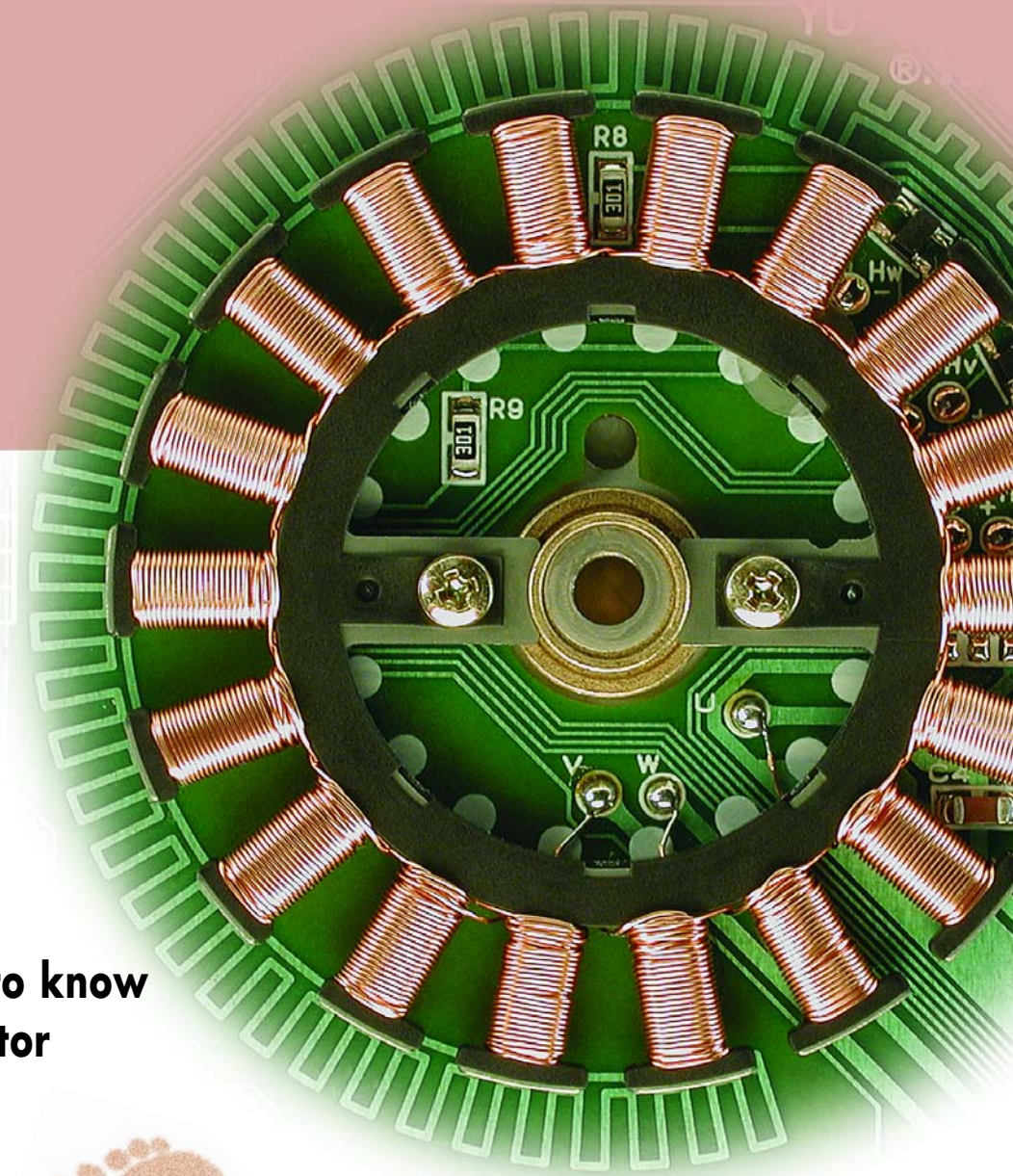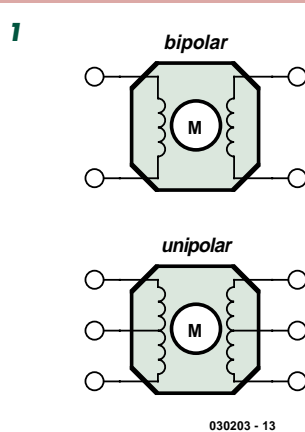
Figure 1. Bipolar or unipolar motor?
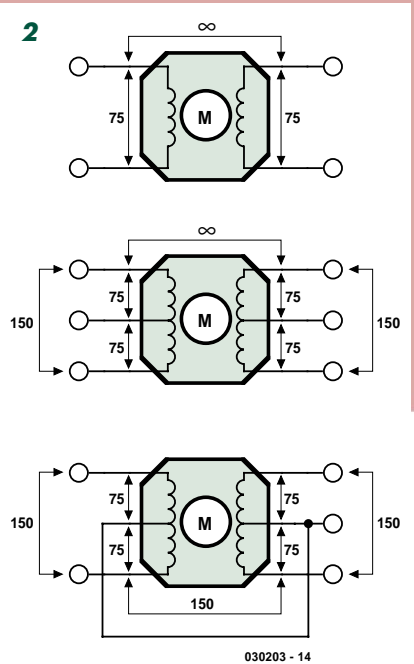
Figure 2. Finding out what the connections are.

To get an unknown motor to work you really need to do two things: find out what properties your motor has and choose the right driver electronics. With the help of this article you will find that it's not that difficult. The following three steps will help you discover the most important properties of a motor. The first step helps you determine whether you have a bipolar or unipolar motor.

1. Type of motor

A bipolar motor (**Figure 1**) has windings whereby the current alternately flows in one direction, then in the opposite direction. This creates a magnetic field that also changes direction, causing the motor to turn. The winding of this type of motor has **two** connections. The driver electronics therefore has to continuously reverse the voltage to the winding. This requires a bridge circuit using four transistors.

A unipolar motor has a winding with a centre tap. This winding therefore has **three** connections. The centre tap has to be connected to the positive supply voltage. If we now connect the start connection to ground (and leave the end connection open), there will be a current flow through the first half of the winding. If we connect the end to ground (and the start is left open), there will be a current flow through the second half of the winding. Since the current in the second half of the

winding flows in the opposite direction, the magnetic field will also be reversed. The driver electronics can therefore be simpler, since we only need to connect either the start or the end of the winding to ground. Two transistors are sufficient for this.

A stepper motor has at least two pairs of windings, so 2_2 or 2_3 connections. When a motor has four leads it is almost certainly a bipolar type. And when it has five or six leads it is almost certainly a unipolar type. It's as simple as that. Should you find a motor with more leads, then you have a problem. There is nothing left but to open up the motor and hope that you can see what the internal wiring is. This is usually not successful. In that case you'll just have to use a different motor!

2. Connections

Once you have determined what type of motor you have, it's time to find out which leads belong to each of the windings. Measure the resistance between the connections using a multi-meter. Go through all possible combinations and make a note of the results. The resistance between the ends of a winding will be low. Between the centre tap and one of the ends of a winding you'll have half the value measured for the full winding. Between separate windings you'll find an infinite resistance, or at least

several megohms. In this way you can determine which two or three connections belong to each winding. When a unipolar motor has a common centre tap (5 leads), it is unfortunately not possible to find out which connections belong to which windings. In that case, the centre tap will have an identical resistance to the remaining four leads. But as you will see later, we have come up with a solution for that as well.

3. Operating voltage

Unless it's written on the motor, there is no way of telling what the operating voltage of the motor is by looking at it. Often you do know what the supply voltage was to the circuit where the motor came from. A stepper motor from a floppy drive will work at either 5 or 12 V. If you have no idea what the voltage was, you can estimate it using the following method. For a bipolar motor connect one of the windings to a variable power supply. For a unipolar motor you connect two of the windings as shown in **Figure 3**. Set the output to a several volts and wait a few minutes. Feel if the motor becomes warm. If not, increase the voltage and check the temperature again after five minutes. Repeat this until the motor becomes almost too hot to touch. This should give you the maximum operating voltage for that particular motor.
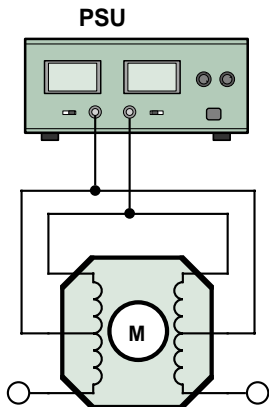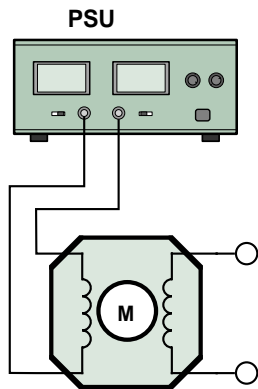
Figure 3. What is the maximum supply voltage?

Figure 4a. Circuit diagram of the stepper motor driver.

Hardware

Now that we have determined what the properties of the motor are, we have to choose the right hardware. But don't panic, we'll work through this in a few simple steps as well.

Our driver stage has several limitations. The maximum operating voltage is 18 V (preferably a bit less, such as 15 V) and the maximum motor current is 2 Amps. If your motor requires a higher voltage or current then this circuit won't be suitable. The current consumption of the motor can be read from the power supply during the previous test, or calculated by dividing the motor voltage by the resistance of the winding.
The supply voltage chosen for the circuit should be the same as the required motor voltage.

The circuit in **Figure 4a** consists of a bridge, so that it can drive bipolar motors. It is also possible to use the same board to drive unipolar motors. In
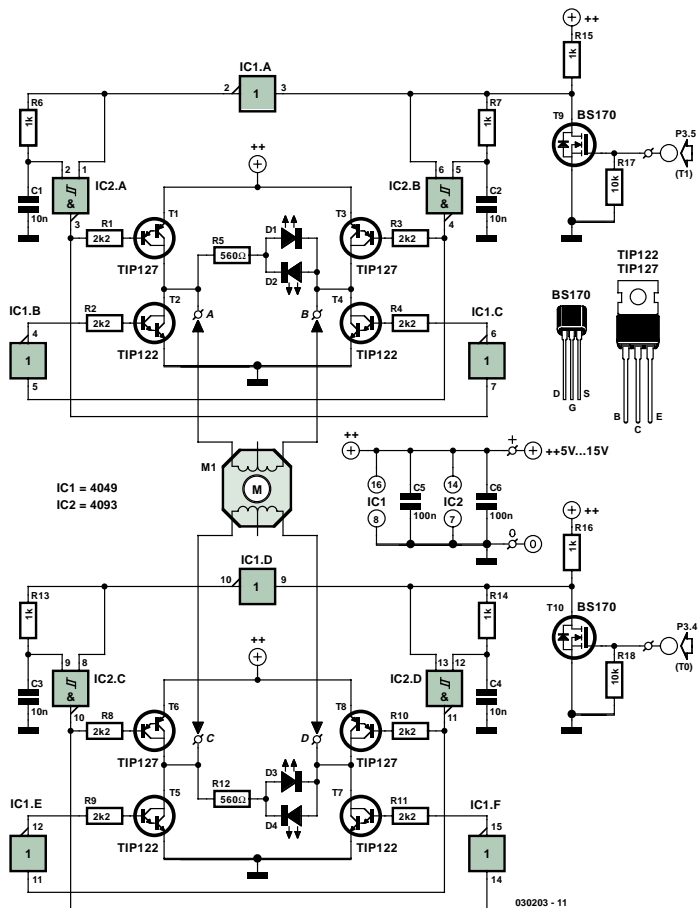
that case the 'top' transistors aren't mounted. Instead of these, a reverse biased diode is put between the collector of the remaining transistors and the positive supply. That means that the cathode, the side with the line, goes to the positive. The other sides go to motor connectors A, B, C and D.
Remember to connect the centre tap to the positive supply for a unipolar motor. The complete circuit diagram can be downloaded from the *Elektor Electronics* website (**Figure 4b**).

The next question is which type of semiconductor to use. It happens that both transistors and FETs are suitable. Transistors are often cheaper and more robust, but have greater losses. In fact, we don't use ordinary transistors, but darlingtons. These consist of two transistors after each other in one case. They behave just like ordinary transistors, but with a much greater gain, usually about 1,000 times. Their disadvantage is that they have a greater voltage drop of about 0.8 V.

FETs are usually a better choice, but take note: P-FETs (for the 'top' semiconductors in the bridge) are a bit harder to find. Their voltage drop is minimal, which makes the FET version particularly suitable for 5 V motors. In the transistor version there would only be

$5 - 0.8 - 0.8 = 3.4$ V

left for the motor.

It may be that you're told to buy so-called logic FETs. These FETs can function with a lower driving voltage on the gate. You can use logic FETs, but they're not strictly necessary, as can be seen from **Figure 5**. With a 5 V supply even a 'normal' FET can switch over 5 A, which is more than enough. In case of a 9530 type P-FET this is less favourable, but 2 A should still be possible.

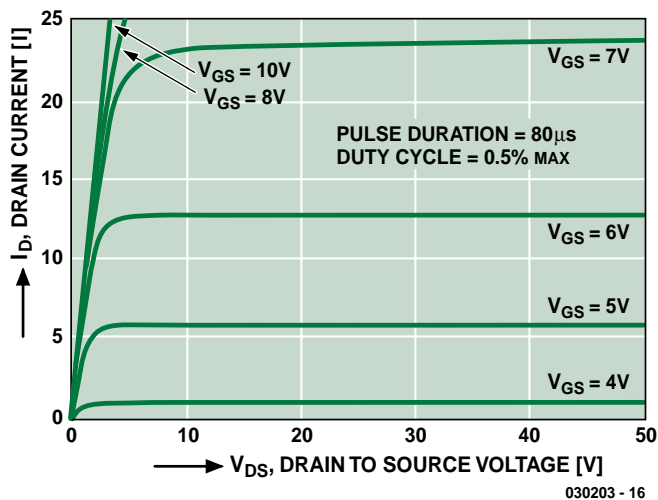The choice of either the darlingtons or the FETs isn't critical. If you can't find

Figure 5. Most FETs can easily pass 2 Amps with a 5 V gate/source voltage (V_{GS}).

Figure 6. Two square waves are required to drive a stepper motor.

the types in the parts list or if you have some spares, you should use a type that has a minimum working voltage of 50 V and a minimum current of 4 A. Many types satisfy these criteria.

Operation

The driver circuit for the stepper motor consists of two identical halves, so we only need to look at one half. The signal at the input is converted by T9 into a square wave with an amplitude equal to that of the supply voltage to the circuit. This is necessary because the driving signal usually has a much smaller amplitude, such as 3.3 or 5 V. So T9 adapts the voltages to each other.

The signal then goes to NAND gate IC2b, once direct and once delayed by 10 µs via R7/C2. There is a purpose to this of course. The trick here is that a transition from '1' to '0' is fed through immediately, whereas a transition from '0' to '1' is delayed. The same occurs via IC1a and IC2a, but on the other diagonal because IC1a has inverted the signal. This exercise is required so that the transistors turn off immediately, but only turn on after a short delay. In this way we avoid that two transistors above each other conduct at the same time, which would short the supply. If you dare, you can leave C1/C2 from the board: you'll then find current spikes of several Amps! During normal operation only two diagonally opposite placed transistors

will conduct. For example, when T1 and T4 conduct point A is positive and point B is connected to ground. LED D1 lights up and there will also be a current through the winding of the stepper motor. If T2 and T3 conduct instead, the polarity is reversed and the current flows through the stepper motor in the opposite direction. Now D2 will light up.

At the time of switching (when the transistors stop conducting) voltage spikes occur because the stepper motor winding is a coil (self inductance). These spikes are suppressed by the LEDs and R5. These components should therefore not be left out. The darlingtons and FETs also have internal protection diodes.

Driving the circuit

The stepper motor PCB has two inputs. These are connected to our 89S8252 Flash Micro Board (see references at the end of the article).

To make a stepper motor turn requires two square waves that are 90 degrees out of phase with each other. If the waves are –90 degrees out of phase, the motor will turn in the opposite direction (see **Figure 6**). The software on the Flash Micro Board generates these square waves. **Figure 7** shows how the board connects to the driver circuit. Push-buttons connected to the board make the motor change direction, although with a little ingenuity they could also vary the speed. The input circuit around FETs T9 and
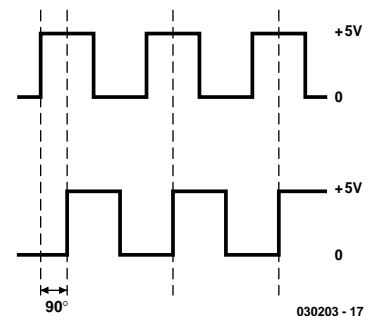
T10 has been added to make sure that the 5 V square wave from the Flash Micro Board connects seamlessly with the (usually) higher supply voltage of the stepper motor driver.

The software, which can be downloaded from the *Elektor Electronics* website, is an example so you can familiarise yourself with the techniques involved and perhaps try your hand at writing your own programs.

Connecting the motor

For a bipolar motor you should connect one winding to A and B, and the other winding to C and D. Should you find that the motor turns the wrong way round, you need only exchange the connections to A and B.

For a unipolar motor with 6 leads the centre taps are connected to the +Ve supply. The ends of one winding are connected to A and B, and the ends of the other winding to C and D. If the motor turns the wrong way round, just swap A and B.

For a unipolar motor with 5 leads the common centre tap is connected to the positive supply and the four ends of the windings are *arbitrarily* connected to A, B, C and D. If you are very lucky, the motor will turn. However, it is more likely that the motor will just vibrate a little bit. This is where plan B comes into action: keep swapping the connections until the motor turns! You won't cause any damage to the circuit or motor. Remember to turn off the

COMPONENTS LIST

For 5-9 V (values for 9-15 V in bracket)

Resistors:
R1-R4,R8-R11 = 2kΩ2 (4kΩ7)
R5,R12 = 560Ω (1kΩ5)
R6,R7,R13,R14 = 1kΩ
R15,R16 = 1kΩ (2kΩ2)
R17,R18 = 1MΩ

Capacitors:
C1-C4 = 10nF

C5,C6 = 100nF

Semiconductors:
D1,D3 = LED, red, high efficiency
D2,D4 = LED, green, high efficiency
T1,T3,T6,T8 = TIP127 or IRF9520 or
   diode MBR745 *
T2,T4,T5,T7 = TIP122 or IRF520
T9,T10 = BS170
IC1 = 4049
IC2 = 4093B

Miscellaneous:
14-way IC socket
16-way IC socket
Flash Micro Board software, Free
   Download, file no. **030203-11**

* if you do not use bipolar transistors or
   FETs, diodes **must** be fitted! This applies
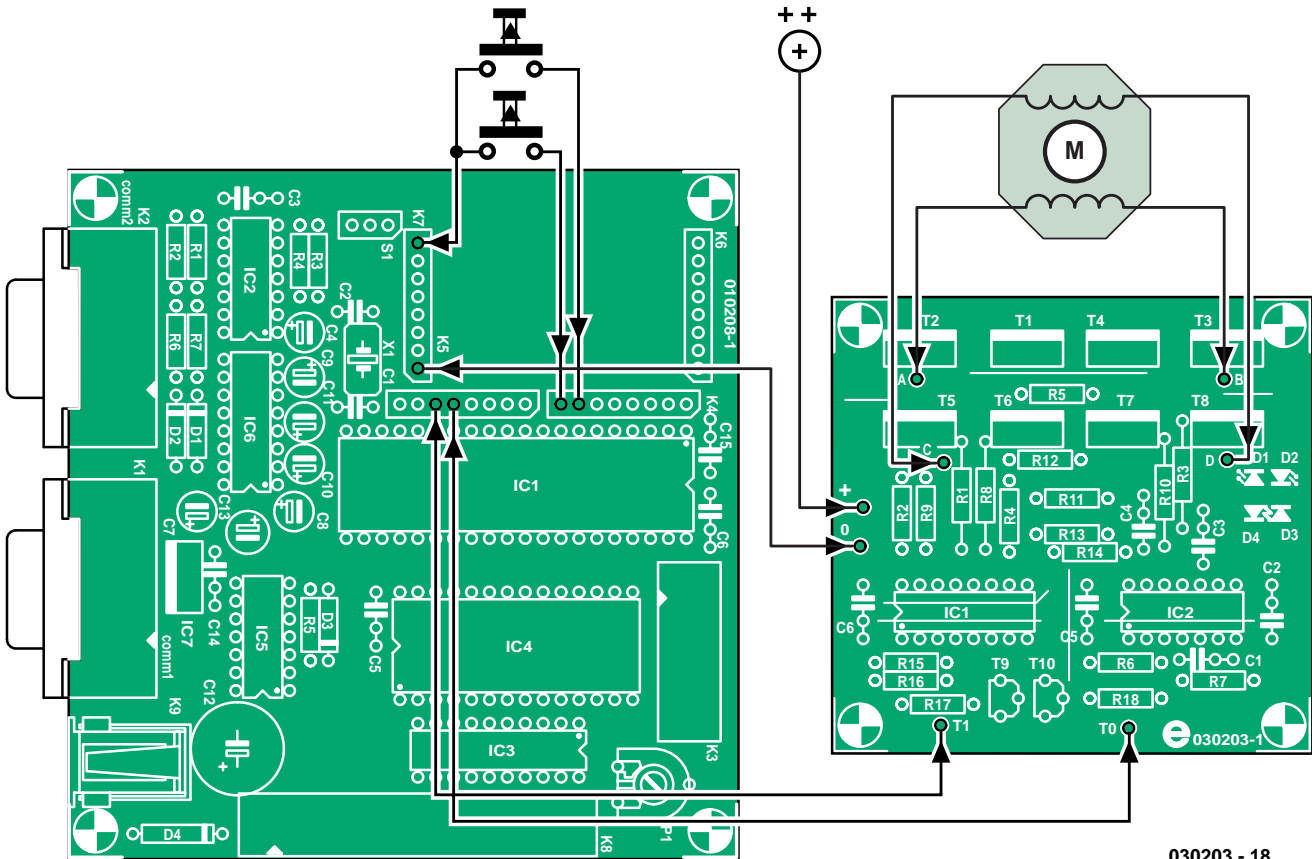   to the use of a unipolar motor.

Figure 7. This is how the Flash Board should be connected to the stepper motor driver PCB.

supply before changing any connections. Swap A and B and turn the supply on again. If the motor still doesn't turn, swap A and C. If you still don't get a result, swap A and B again.

The associated program is described elsewhere in this edition in the article 'Software? We'll do that ourselves!'.

(030203-1)

References:

Stepper Motors Uncovered,
   **part 1, Elektor Electronics
   November 2003.**

Stepper Motors Uncovered,
   **part 2, Elektor Electronics
   December 2003.**

**89S8252 Flash
   Microcontroller Board**,
   **Elektor Electronics
   December 2001.**

Internet

The full version of the circuit diagram, as well as the PCB layout and software for the Flash Micro Board can be downloaded from:

www.elektor-electronics.co.uk/dl/dl.htm,

select month of publication.

Prof. Martin Ohsmann

Project **C+** Solved

The circuit described in the April 2004 edition of *Elektor Electronics* certainly gave rise to a lot of head scratching and raised eyebrows when it was shown to produce an output pulse ahead of the input pulse. Is it possible that such a simple circuit can turn the principle of causality on its head? Read on…
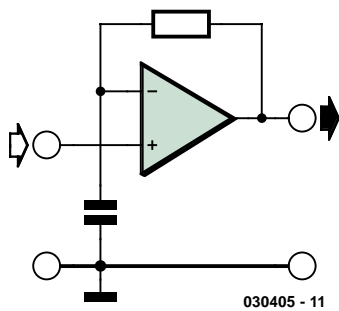
Figure 1. The lead filter with negative group delay.

Figure 2. Block diagram of the experiment.

The idea for this article began when a student asked me if it was possible to build a filter that produced a 'negative group delay'. A quick trawl of the Internet (Google: 'negative group delay') soon gave some interesting hits. In particular Professor Kitano in Japan had published just such a circuit that apparently exhibits a negative group delay [1]. With kind permission from him we were able to use his ideas and circuit (slightly modified) in last month's article. So much for the background, now on to the details…

The concept of speed

If we consider the transmission of information in a communication channel, the first characteristic we need to look at is phase velocity. With a pure sinusoidal carrier wave this is equal to the propagation speed of any point (i.e., constant phase) on this wave. Without any form of modulation it is not possible to send information, so we can see that the phase velocity has no influence on the speed at which we can send information (i.e., the group velocity). Information can, for example, be transmitted on narrow-band signal pulses or envelopes and the speed of the envelope will be governed by the group velocity through the medium. Now back to the original question: if a circuit possessed a negative group delay this would imply that the information accelerates in the medium and travels backwards in time to arrive at the output before it was introduced at the input.
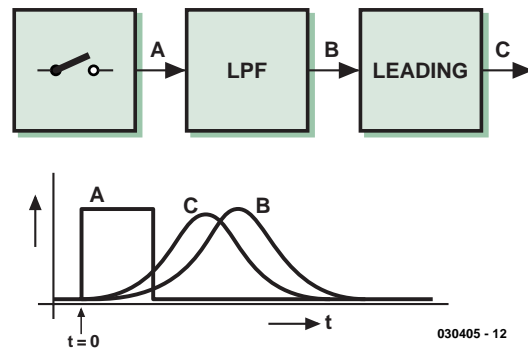
This indeed is what appears to happen in our circuit.

This phenomenon has apparently been observed in the field of optics where anomalous dispersion (in a narrow spectrum) has seemingly produced a negative group delay and a refractive index smaller than 1. It is often the case that these effects occur when the circuit or medium is in resonance and an equivalent electrical experiment is described in a paper [2] which shows an output AM envelope leading the input signal thus yielding an apparent negative group delay.

It is easier to observe these effects by using a filter with negative group delay at low frequencies and DC. The circuit shown in **Figure 1** is a (low-pass) lead filter and produces the necessary effects. When a low frequency pulse from the generator described in the first part of this article is introduced to the lead filter, it should produce an output 'before' the pulse is introduced.

This basic idea has been perfected by Mr. Kitano [1] in a circuit that maintains the pulse shape through the transmission medium and produces a negative propagation delay. The pulse envelope travels at the group velocity and the pulse appears at the output of the filter before the input signal!

Causality

Causality states that in our physical world the flow of events is always the same: first, cause, then effect. You are aware of pain in your thumb after you hit it with a hammer and not before the unfortunate accident. If this principle is universal, is it possible in our simple circuit that a signal arrives at the output of a filter before it was applied to the input? Clearly not. To understand what really is going on in the circuit we need to take a closer look. **Figure 2** shows a block diagram representing the main parts of the circuit. A rectangular pulse is generated when the switch is momentarily closed at t = 0. A low-pass Filter (LPF) is used next to filter out the high frequency components and produce a smoothed Gaussian impulse at B. The pulse is now introduced to the medium and recovered by the lead filter to produce the output pulse C. The recovered pulse is amplified to produce the output pulse C so that its shape is similar to the input pulse.

The circuit doubles-up the pulse shaping and lead-filter stages to optimise the effect. Additional components in the Lead Filter help reduce noise in the circuit. The more observant among you will have noticed that the output pulse rises more quickly than the input pulse. It was found to be impractical to increase 'negative group delay' effect further by adding more lead filters. So there really is nothing unusual about the circuit, the effect is produced using just conventional components. The need for 400 m of cable was also something of a red herring.

The circuit demonstrates that in this case the group velocity is not relevant to the (negative) time difference

Literature

[1] M. Kitano, T. Nakanishi,K.Sugiyama, Negative Group Delay and Superluminal Propagation: An Electronic Circuit Approach, IEEE Journal of Selected Topics in Quantum Electronics, Jan/Feb 2003 (check the Internet).

[2] M.W. Mitchell, R.Y. Chiao, Causality and negative group delays in a simple bandpass amplifier, Am. J. Phys. 66(1), January 1998 (also on the Internet).

[3] J.DF. Jackson, Classical Electrodynamics, Wiley and Sons, New York 1975.

observed between the input and output pulses, here the **front velocity** (the propagation speed of an abrupt change or **front**) of the system is more important.

The effects produced here are still the subject of hot debate on the Internet but in any case you will no doubt be pleased that causality is still intact (at least for the time being) and this experiment underlines how careful you need to be when interpreting test results especially in systems using slow pulses. A similar phenomenon to that shown here occurs with a Mach Zehnder interferometer (no, honest), where light pulses appear to arrive 'too early'. For more information on this subject refer to [2]. If you are still curious about propagation speeds and anomalous dispersion then the classic work by Jackson [3] should fill in any gaps.

(030405-2)

Prof. Martin Ohsmann
mossmann@t-online.de
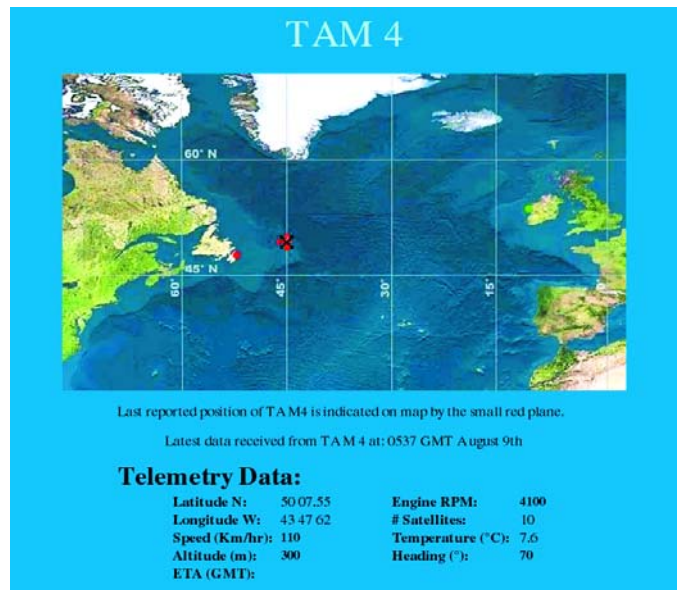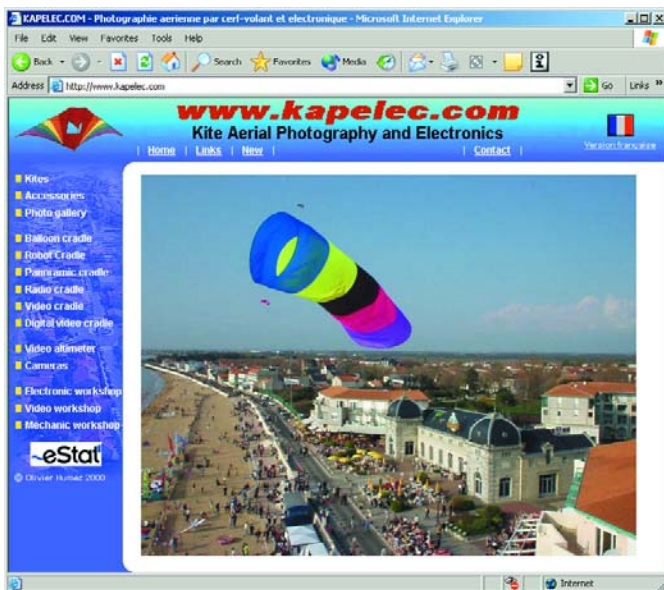
Up, up and away

David Daamen

Telemetry applied to modelling sometimes produces astounding results — especially if electronics is part of the payload…

Model construction and electronics seem to get on like a house on fire, new challenges appearing any time these two fields of interest are combined. The results are often rather special. For example, Olivier Humez on his website [1] describes lots of equipment to enable photo or video cameras to be attached to model planes and even balloons. The images captured during the flight and beamed down to the ground are often stunning.

Of course we do not have to limit ourselves to 'shooting pictures', as Humez proves by the equipment he developed to convey telemetry data. Height, temperature and battery voltage are among the quantities that can be measured in real time and transmitted to 'earth' by a radio link, possibly backed up by a video link you can watch using an on-screen display.

Mr Humez is of course not the only person active in this most interesting field. A team lead by Maynard Hill managed to make a model plane cross the Atlantic ocean. The take-off and landing were accomplished in the traditional way using radio-control transmitters. However, during the actual flight above the vast ocean waters, a microcontroller was in total control of the plane, continuously adjusting its course with the aid of GPS information. A few details: total distance travelled 3,000 kms in 39 hours with a total fuel consumption of just 5.7 litres! More about the flight and the technology used on the team's website at [2].

Among lots of other webbed information on telemetry and data logging we found Dietrich Meissner's site at [3], complete with circuit diagrams and software for PICs, Palm and Windows PCs.

If you are now anxious to learn more about telemetry, have a look at the sites discussed here, or do your own search using Google and the search words [model] in combination with [telemetry].

(040078-1)

[1] **Olivier Humez' aerial photography:**
www.kapelec.com/

[2] **Trans Atlantic Model Homepage:**
http://tam.plannet21.com/index.htm

Dietrich Meissner's circuits and software:
http://home.germany.net/100-173822/d_logg2_engl.htm

FlexiPanel IR

Infrared glue for micros and PDAs

Jan Buiting and Luc Lemmens

IrDA sure looks like an attractive medium for conveying data across small distances. Unfortunately, the associated hardware generally causes sour faces, and is not just 'playing' hard to get. Those days are over.
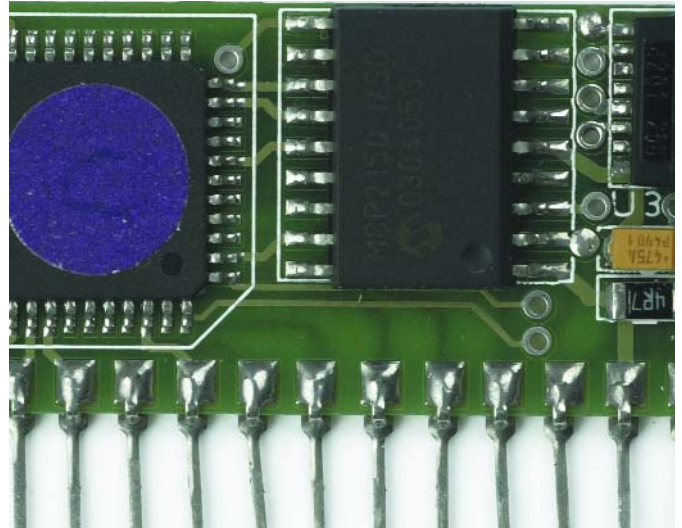
Paris-based Hoptroff sarl (in the UK: Flexipanel Ltd.) recently announced the release of an IrDA module (also called 'irGUI module' or 'Flexipanel') designed for easy connection to microcontroller circuits. This triggered our curiosity and within days a sample of the module arrived in the post along with a hefty information pack.

We were not disappointed. To begin with, free software is available for devices such as handhelds, mobile phones and (portable) computers. In the case of microcontrollers, the FlexiPanel module allows user access to any of these remote devices using a single, simple I^{2}C interface.

As we write this, the module should be available as a one-off, as well as software for PocketPC handhelds. Product distribution has been arranged with **Parallax Inc**. (and its European distributors such as Milford Instruments). A tentative price of US$ 80 has been given for the module, US$ 25 for the chip set and US$ 6-8 for licensing. According to Richard Hoptroff, software for Palm devices, Nokia and

Ericsson mobile phones and Windows laptops is scheduled for release later this year. A **Bluetooth** version is also under development and we hope to report on its release some time in the near future.

Applications

Applications for the FlexiPanel IR module broadly fall into two categories: The first category is 'big guns' comprising handhelds, mobile phones etc. that can employ the generic **Virtual Control Panel (VCP)** software that's available free of charge from Hoptroff. On the device, a graphical user interface (irGUI) provides the link to the VCP. In this way, the irGUI acts as the IrDA server and the VCP as the IrDA client. To connect low-volume (100's) and medium-volume (1000's) products to VCPs, manufacturers should use an irGUI module or a chipset which will manage the user interface. VCP technology licensing is recommended for bulk volume products (10,000's and up) with help available from Hoptroff with the implemen-

tation on he host controller. The second category is much more interesting to the occasional user and lab worker as is comprises a multitude of individual microcontrollers and development systems for which tailored software needs to be written. In principle, any MCU or MCU system may be used as long as it talks and understands I^{2}C (this will include many *Elektor Electronics* microcontroller boards). Fortunately, Hoptroff have made the complete communications protocol for '**FlexiPanel**' freely available as part of an impressive and neatly organised 70+-page datasheet (which is too modest, 'documentation set' would have been a more apt description). FlexiPanel allows electronic products to create an operator interface on remote devices such as handhelds (PDAs), mobile phones and other computers, using an infrared link. The remote device asks the product what controls it wants displayed and then it displays them. The operator reads the display and modifies the controls as required, sending any changes back to the product.

The Flexipanel documentation, then, goes into great depths, discussing everything from product ordering and suggested product development methods down to the nitty-gritty of the (fairly complex) command syntax, not forgetting the hardware specification of the two available FlexiPanel core processors. Towards the end of the manual, lots of example programs are found for functions including the Message box, file control, calibration, test, array control, password control and many more. All this should allow microcontroller enthusiasts to slap together their own irDA interface fairly easily on just about any MCU system sporting I^{2}C connectivity.

Our conclusion is that Hoptroff have not only released a module that avoids many pitfalls associated with irDA hardware construction, but also a good amount of software to back up the product.

BASIC Stamp

Not just to underline their business relation with distributor Parallax Inc., but

1

(components shown dotted are optional)   030357 - 11

2
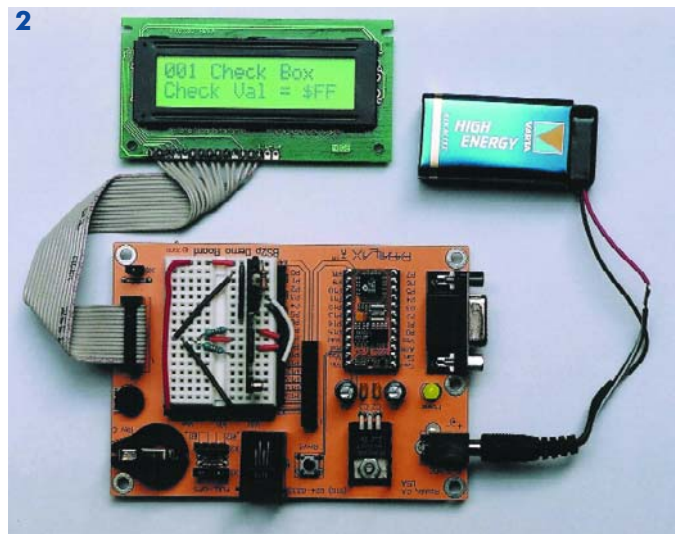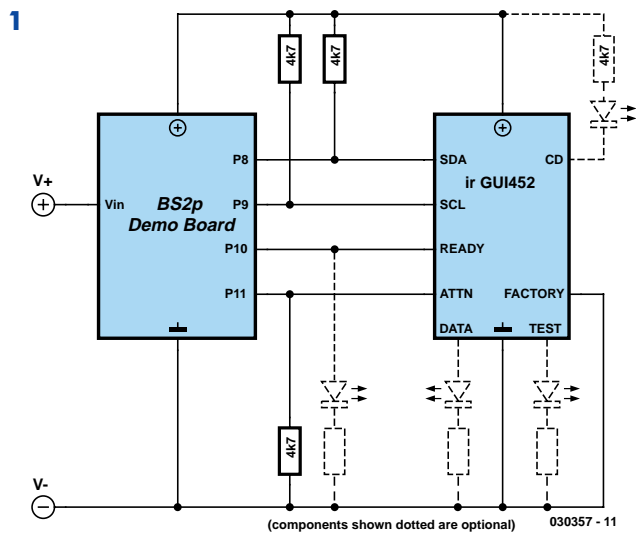
also to encourage lab workers, Hoptroff provide lots of information on linking the Flexipanel to the famous **BASIC Stamp**. And a very welcome bit of information it is because the BASIC Stamp (BS2p) is widely known and extremely popular among budding programmers (and a lot of professionals, too…) if only because it can be programmed in… BASIC!

Figure 1 shows the really simple connections between the BS2p Demo Board and the irGUI452 module. The practical assembly is shown in the photograph in **Figure 2**. LEDs may be added to monitor the CD, Ready, Data and Test pins (shown dotted in Figure 1). If so, 4k7 current limiting resistors should be used to prevent overloading the power regulator on the Basic Stamp.

The 10k resistor between Attn and Vss is only required if nap mode is to be used — it ensures that the Attn pin is not pulled high when Stamp resets. The 4k7 pull-up resistors on the SDA and SCL pins are required in all cases.

In the example application,

two check boxes are displayed on the PDA. When Send is pressed, the state of the second check box is displayed on the LCD display, the value is inverted and written to the first check box. Thus if a Read operation takes place after the Send operation, the first check box's state will be the opposite of the second.

The required resource script is shown in **Listing 1**. It is read using the irGUI configuration tool and used to program the irGUI. Correct irGUI programming can be verified using a PDA to read the controls.

Once the irGUI is configured, the Basic Stamp can be programmed. The required code is found in the Flexipanel documentation. Correct operation may now be checked by pressing the Send button.

It is also possible to connect the irGUI452M directly to the BS24p without the Demo Board. The 40 mA voltage regulator on the BS2p module is then usually sufficient to power the irGUI device, whose consumption peaks at 30 mA during infrared communication. However, if

additional components are added, a more powerful regulator may be needed.

(030357-1)

Listing 1. irGUI452M resource script

```
//————————————————————————
//
//     001 Check Box.rs
//
//     I2C test on basic stamp check box control
//
//————————————————————————

    PARTNUM         irGUI452M
    DEVICENAME      "001 Check Box"
    SERIAL          RANDOM
    RESET
    I2C          0x68
    I2CADDRESSING       1BYTE_INDEX

    CONTROL CHECKBOX
        ID    chk1
        FIXEDSTORE  ROM
        VARSTORE RAM
        TITLE    "Check Box 1"
        VALUE    0
// Initial value is 0; when stamp starts,
// gets inverted
        TEXT     "I'm what he's not"

    CONTROL CHECKBOX
        ID    chk2
        FIXEDSTORE  ROM
        VARSTORE RAM
        TITLE    "Check Box 2"
        VALUE    0
        TEXT     "Try Me"
```

Helmuth Lemme

Sensors go Systematic

**more physical quantities,
more integrated electronics**

Thanks to intensive research, it is now possible to electronically measure many physical quantities for which this appeared to be unthinkable only a few years ago. At the same time, sensors with integrated electronic signal processing are evolving into measurement systems. In this article, we examine a few interesting sensors as representative examples of a large variety of new products.
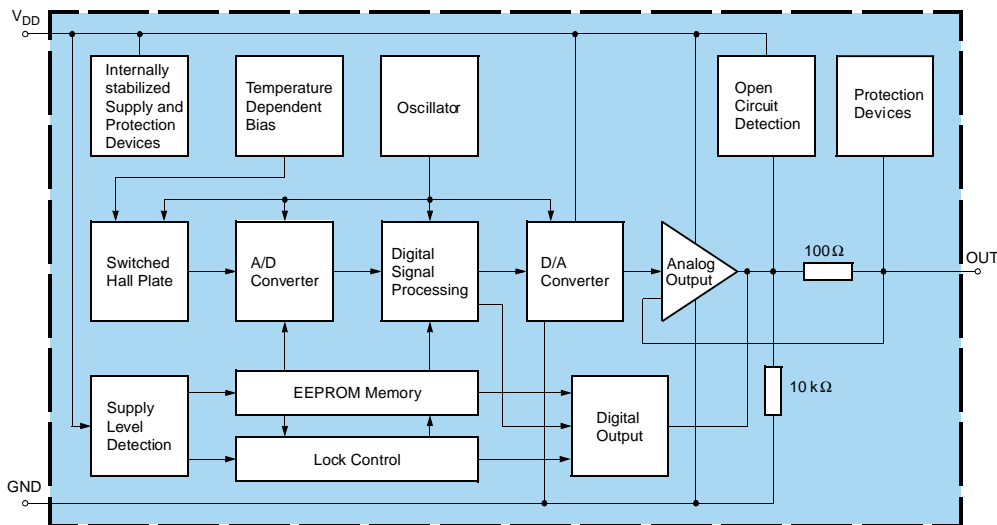
Figure 1. Block diagram of the HAL805 Hall sensor. The measurement parameters are configurable. (Micronas)

Under the increasing time and cost pressures imposed on developing instrumentation devices, building preamplifiers for sensors is increasingly coming to be seen as an irksome secondary task. They must be exactly matched to the sensor output signals, which are usually weak, and if a different type of sensor is used, the entire job has to be done all over again. A far more user-friendly approach is to employ sensors whose signals have been preconditioned to remove distortion factors (such as temperature dependence, offsets and the like) and give them a standardised output format, such as 0–10V or 4–20 mA. This makes it easy to swap sensors.

Fitting the sensor components and measurement electronics into the same package has been common practice for a long time already. In order to further reduce costs, the present trend is increasingly heading in the direction of integrating both of these elements onto a single silicon chip. This requires finding ways to construct the actual sensor element in silicon. In many cases, this has already been successfully accomplished. For temperature sensors, it is especially easy. For pressure sensors, in which the membrane often already consists of a silicon structure bearing piezoresistive tracks, the solution is also simple. Even if such a sensor system may appear to be expensive at first glance, overall costs are reduced thanks to savings realised in development effort. Another reason for integration is failure prevention. Human lives can depend on the reliable operation of sensors, such as in the case of ABS and ESP systems in cars. In the automotive area, a special challenge is provided by the extreme range of temperature variations, which extends from below –20 °C to the engine temperature of +125 °C. As has been shown by experience, failures of soldered joints are much more common than internal failures of ICs. Efforts to achieve increased levels of integration are thus primarily driven by considerations of safety and security. The cost savings that arise at the same time (assuming large-scale mass production) are a welcome side effect. Another benefit is increased interference immunity. If sensor signals must pass through long cables before they are amplified, as was the case in the past, interference will be coupled in. With everything on the same chip, this hazard is eliminated.

Signal conditioning

Amplifying the signal is not the only task of signal conditioning. Many of the physical effects utilised for sensors are temperature dependent. To compensate for this, a temperature sensor that suitably adjusts the gain can be incorporated into

the system. In many cases, the transfer characteristics are non-linear and must be linearised. This is especially true for conventional temperature sensors, such as NTC and platinum resistors, as well as thermocouples.

Regardless of whether linearisation is performed using conventional analogue electronics or software in the signal evaluation computer, it always requires additional effort and expense. If a silicon-based temperature sensor is available, it can be housed on the same chip and the linearisation can be implemented directly adjacent to the sensor. Such components are now in widespread use. One example is the National Semiconductor LM35, which has been manufactured for many years already. It generates an output signal that precisely and linearly increases with temperature at the rate of 10 mV/K. Over the years, it has been joined by a whole group of relatives that operate in similar manner (for more information, see www.national.com/appinfo/tempsensors/products.html).

Sensor/controller combos

Once a sensor has already become an IC, the next step is to integrate functions that were previously wired externally in the form of 'discrete' circuits. An example of such functions is comparators driving outputs that switch if the temperature crosses a certain threshold temperature. The threshold values can be provided externally in analogue or digital form. Integrated A/D converters are also commonly present, usually with serial output in order to save pins. The next logical step is to add a microcontroller to the chip. This makes a multitude of additional functions possible, including externally programmable parameters such as sensitivity and measurement range, calibration, and many others. An EEPROM (also on the chip) can store the calibration data. In this way, the sensor is transformed into a miniature computer.

A significant advantage of such 'intelligent' sensors is reduced type diversity. Instead of making a large variety of types that differ only in their detailed specifications, manufacturers can make just a few basic types, which can then be produced in much larger quantities. The parameters required for operational use are entered by the user, and in many cases they can also be subsequently modified.

A typical example of this type of sensor is the family of Hall sensors made by Micronas. The first model of this family was the HAL800, which was further refined to yield the derivative types HAL805, HAL810 and HAL815 (www.micronas.com/products/overview/sensors/index.php).

Figure 2. Block diagram of the LM87 supervisory IC. The temperature sensor on the chip (lower left) plays only a secondary role. (National Semiconductor)
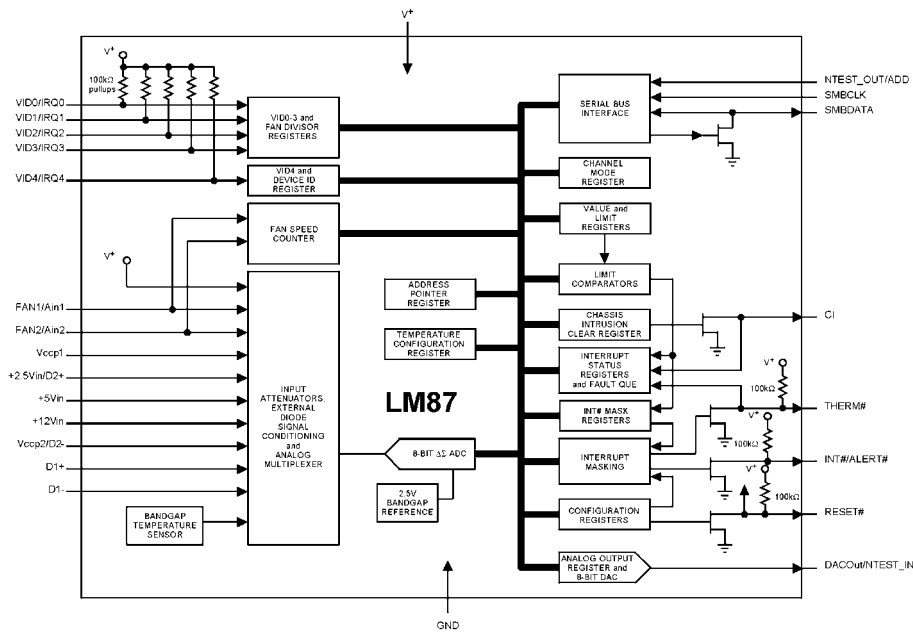

Figure 3. Motion-sensitive comb structures in the ADXL202 micromechanical acceleration sensor. (Analog Devices)
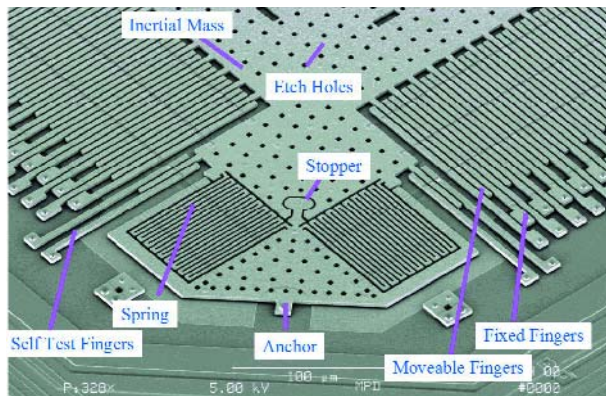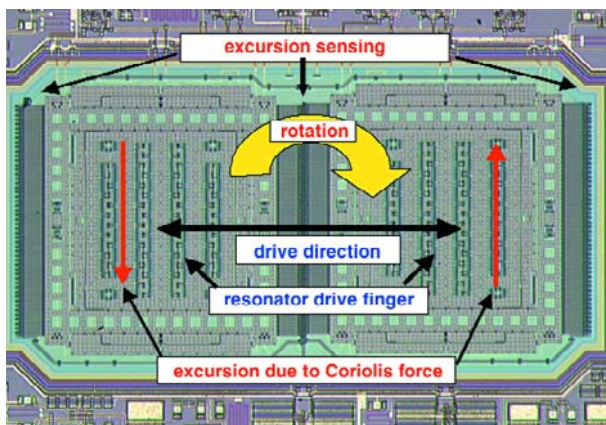

Figure 4. In the ADXRS150 rotational rate sensor, the paths of vibrating mechanical structures are altered when the device is rotated. (Analog Devices)

In this case, processing the measurement signal is especially difficult. The signal voltage from the Hall element is extremely small, and it is superimposed on a large offset voltage. In addition, both voltages are highly temperature dependent. Temperature compensation requires complex circuitry, and optimum results can only be achieved using a switching technique, similar to a chopper amplifier.

With these sensors, users can configure a whole range of parameters according to their wishes: sensitivity, the upper and lower limits of the measurement range, measurement bandwidth and the amount of temperature compensation. A special feature here is that the temperature dependence can either be entirely eliminated (even including its nonlinearity, for which purpose a quadratic correction network in included), or a certain proportion of the temperature dependence can be intentionally retained. This can be useful if (for instance) the sensor is used with a magnet that has its own temperature dependence. In this way, the temperature dependence of the overall system (and thus the temperature dependence of the switching distance, for example) can be reduced to nearly zero.

In normal measurement operation, this sensor is operated from a 5-V supply voltage and generates an analogue signal that is proportional to the local magnetic flux density. It can be programmed by increasing the supply voltage to a higher level and modulating the voltage. A voltage in the range of 5.6–6 V corresponds to a logic Low level, while the range of 6.8–8.5 V corresponds to a High level. The data are written serially. In this mode the sensor output operates digitally, and the internally stored parameter values can be requested and read out serially via the output. The sensor is electronically 'sealed' on conclusion of the programming process, and subsequent programming is no longer possible. The output signal is again analogue after programming.

This approach allows the number of leads to be kept to an absolute minimum: ground, supply voltage and output. This keeps down the cost, which essentially depends on the package type used and thus the number of leads. The packaged

Author profile

Helmuth E.W. Lemme read Physics and Economics in Münster, Saarbrücken and Munich. Having started out as an electronics designer he became editor of a magazine covering industrial electronics in 1978. Since 1986 he has been a free-lance journalist specializing in science and technology.

Email: hewlemme@aol.com

sensor, with dimensions of $4 \times 4 \times 1.5$ mm, looks like a plastic-cased transistor. Its block diagram is shown in **Figure 1.**

Bus connection

In systems with many sensors, it is economical to connect all of them to the computer via a common bus, rather than using individual cabling. This means that each sensor must have a bus coupler, which in many cases can also be housed on the chip. An early example of this type of component was the National Semiconductor LM75, which had a delta/sigma A/D converter and an I^2C bus interface on the same chip. A large demand for ICs of this type quickly arose, so new types were continuously developed and their range of functions was constantly enlarged to meet the wishes of users. They ultimately evolved into complex monitoring components, which (for example) can be used in PCs to monitor not only the temperature but also a whole range of other quantities, such as fan speeds. **Figure 2** shows the block diagram of the LM87, which has so many functions that it has become a general-purpose 'early warning system' for all possible types of faults. Here the actual temperature sensor (at the bottom left) is only one of a host of elements.

MEMS

Now that we have learned how to accurately produce mechanical structures with micrometre dimensions, it's possible to integrate sensor elements that operate using moving parts, such as sensors for pressure, force, acceleration, and rotational motion. Where we previously encountered metallic or ceramic parts with dimensions in the millimetre or centimetre range, we now find miniature structures made from monocrystalline silicon, which together with their associated electronics form a monolithic block. This combination of micromechanics and microelectronics forms a micro-electro-mechanical system (MEMS).

The first products of this type to be manufactured in large volumes were acceleration sensors for triggering air bags in cars. They contain two interleaved comb structures made from silicon, with one of them being firmly attached and the other being suspended such that it can move. Capacitances in the femtofarad range (1 femtofarad = 10^{-15} F) are created between these two structures. When the sensor is subjected to a mechanical impact, the movable comb is slightly displaced due to its inertial mass. This causes one capacitance to become larger and the other one to become smaller, which is sensed using an electronic bridge circuit. Such sensors have proved to be extremely reliable, and more than 100 million pieces have been produced by now. Some of them are even

sensitive in two directions, such as the Analog Devices ADXL202 illustrated in **Figure 3** (www.analog.com). Airbags in cars have already saved many lives, but electronic stabilisation systems can make an even greater contribution. They sense the rate of rotation of the vehicle about its vertical axis as the primary variable, and if it exceeds the maximum permissible value (as occurs with a skid), they initiate suitable steering and braking manoeuvres. In the event of rotation about the longitudinal axis (rollover), the airbags must inflate immediately.

Sensors for use in cars must be produced in large quantities at low costs. The glass-fibre gyroscopes used in avionics and space flight systems would be unaffordable. Here again components containing movable micromechanical structures have proven to be quite suitable, and they are already being produced by many manufacturers. They are based on the physical phenomenon of the Coriolis force: if a mass in a rotating system is displaced linearly in a radial direction, it experiences a deflection in the tangential direction. In the Analog Devices ADXRS150, a flexibly suspended mass is excited into resonant vibration by electrostatic forces, with an amplitude of ± 3.5 µm and a frequency of approximately 15 kHz. If the chip is subjected to rotation, a force perpendicular to the direction of oscillation is exerted on the vibrating element, and in a manner similar to the previously described acceleration sensor, this causes a change in the capacitance measured between two interleaved comb electrodes.

In its practical implementation, the IC uses two sensor cells whose masses oscillate in antiphase. Not only does this neutralise the external vibration of the IC, it also makes it less sensitive to disturbance from vehicle vibration. **Figure 4** shows a portion of the chip, which measures only 3×3 mm. It is housed in a BGA package with dimensions of $7 \times 7 \times 3$ mm.

Modular construction

Despite its considerable success, there is a problem with microsystem technology, which is that the large front-end development costs can only be recovered if the components are produced in large quantities. This is difficult to achieve for small and medium-sized sensor manufacturers.

One solution to this problem is to construct the sensors in modular form using several independent functional blocks, which can then easily achieve large production volumes. A concept employing three modules, which has been developed by AMA Fachverband für Sensorik e. V. (www.ama-sensorik.de) in close cooperation with industry, is shown in **Figure 5**. It consists of the following modules: 1) the measurement module with the sensor element and signal conditioning, 2) a microcontroller for additional signal processing (includ-

Figure 5. A modular microsensor technique using defined interfaces (PrimSens and Buscoupler).(AMA Fachverband für Sensorik e. V.)
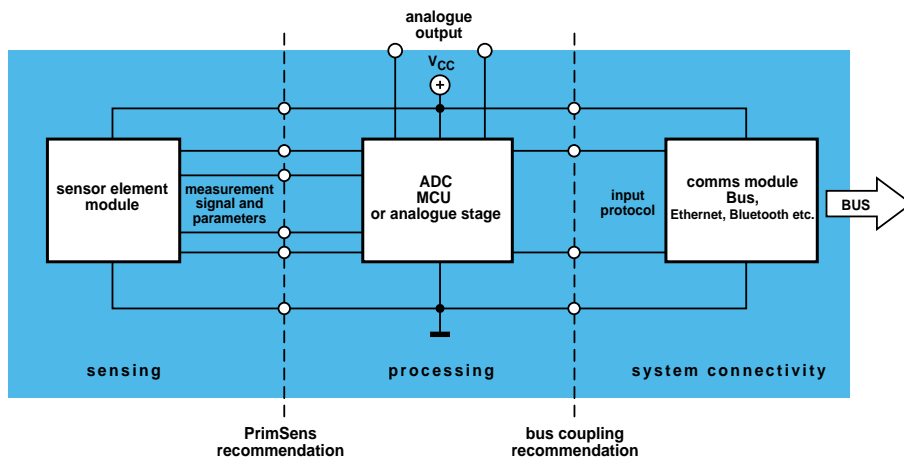

Figure 6. Temperature measurement using fibre-optic sensors inside a 1300-MW generator with extremely high electrical and magnetic field strengths. (Photo: Siemens)
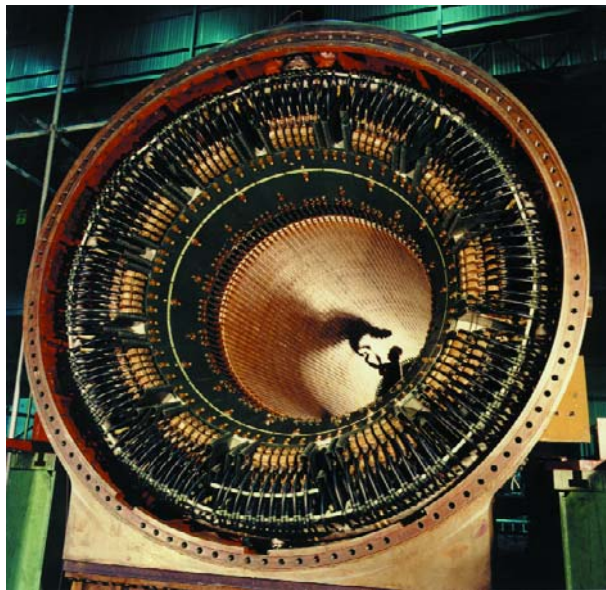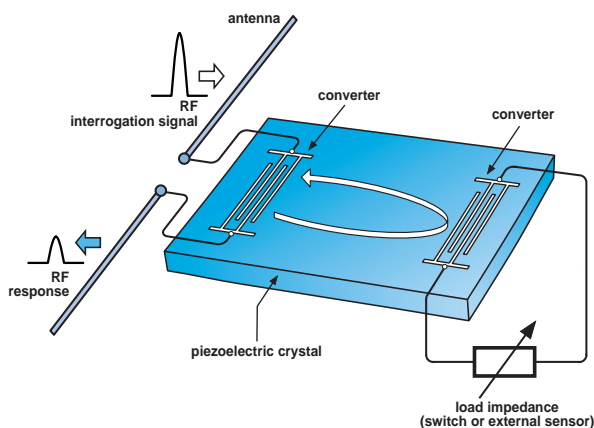

Figure 7. A wireless sensor using surface acoustic waves. The response signal is affected by the attached sensor element.

ing digitising), and 3) a bus coupler if necessary. The modules are separated by two standardised interfaces. The first interface is called 'PrimSens', and the second is called 'Buscoupler'. The first products of this type were shown recently at the Hanover Fair.

Another modular concept defines a component system with small, square circuit boards with dimensions of 10×10 to 45×45 mm, which can be stacked on top of each other (www.match-x.org).

Interference-free measurement without electricity

The sensors we have examined up this point are all 'normal' sensors that work with electrical cables, but there are some places where it is not possible to run such cables, such as where there is an explosion hazard or where there is a risk of voltage discharge in a high-voltage installation – or in environments where there are strong electromagnetic fields, such as in radio transmitters or electrical generators.

In such situation, a different approach must be taken. A highly promising technique is optical measurement using light instead of electricity. The light is conveyed by a glass or plastic optical fibre to the measurement location, where it is affected by the quantity to be measured and then returned via the same optical fibre or a second fibre. The evaluation instrument determines the measurement value from the returning light. An example is the Lumitherm instrument made by the US company Ipitek, which transmits light pulses from an LED through a fibre to a measurement probe, where they excite luminescence in a fluorescent material. The duration of the luminescence depends on the temperature, and this effect is exploited to make measurements using the luminescent light returned to the instrument. Systems of this sort, in which the fibre only acts to convey the light, are called 'extrinsic' fibre-optic systems.

However, it is also possible to use the actual fibre as the measuring element. Such 'intrinsic' fibre-optic systems exploit the miniscule but still present effects of external physical quantities on the propagation of light through the fibre. If the wave nature of the light is also taken into account, very high sensitivity and resolution can be achieved. A widely used technique involves writing a 'Bragg grating' into the fibre. A Bragg grat-

ing is a periodic series of regions having an elevated refractive index, which is generated by means of UV irradiation. Light with a wavelength that exactly corresponds to twice the grating spacing is reflected back to the optical source, while all other wavelengths pass through unaffected. If the fibre is stretched, light with a somewhat longer wavelength will be reflected, and this can be measured optically. This yields a highly sensitive elongation sensor that operates without electricity, cannot be affected by extremely strong ambient electromagnetic fields, and cannot itself interfere with anything else. There are very many physical effects that can influence the propagation of light in a fibre. Quantities that can be measured in this manner include elongation, tensile stress, vibration, flow, filling level, pressure, angle of rotation, temperature, ionising radiation and many others. This makes it possible to make a wide variety of measurements under difficult conditions, in situations where such measurements were previously considered to be out of the question – such as deep inside the 1300-MW generator shown in **Figure 6**.

Passive RF sensors

With rapidly rotating machine parts, a sensor link via commutator rings is frequently not sufficiently reliable. In such situa-
tions, it is possible to use another sensor technology that does not require a local power source: surface acoustic wave chips. These components, which are made from piezoelectric crystals (such as lithium niobate), are used as bandpass filters in radio receivers. An RF alternating voltage applied to the input comb electrodes (typically with a frequency of several hundred megahertz to a few gigahertz) generates a shallow mechanical wave on the surface of the crystal. This wave propagates over the length of the crystal until it is reflected at the other end and returns back to the electrodes, where it again generates an alternating voltage that is slightly delayed from the excitation pulse. If a sensor (for example, a capacitive pressure sensor) is connected to a second set of electrodes at the far end of the crystal, the reflection of the waves will be affected by the sensor in a manner that depends on the pressure. The pressure can then be determined by evaluating the returned signal (**Figure 7**). If an aerial is connected to the input, the sensor can be queried using radio waves. This technology has been studied in the research departments of tyre manufacturers as a means of acquiring measurement data from rotating tyres (pressure, temperature and traction) without using a battery as a power source. For more on this subject, see the article 'Wireless tyre-pressure monitoring' elsewhere in this issue.
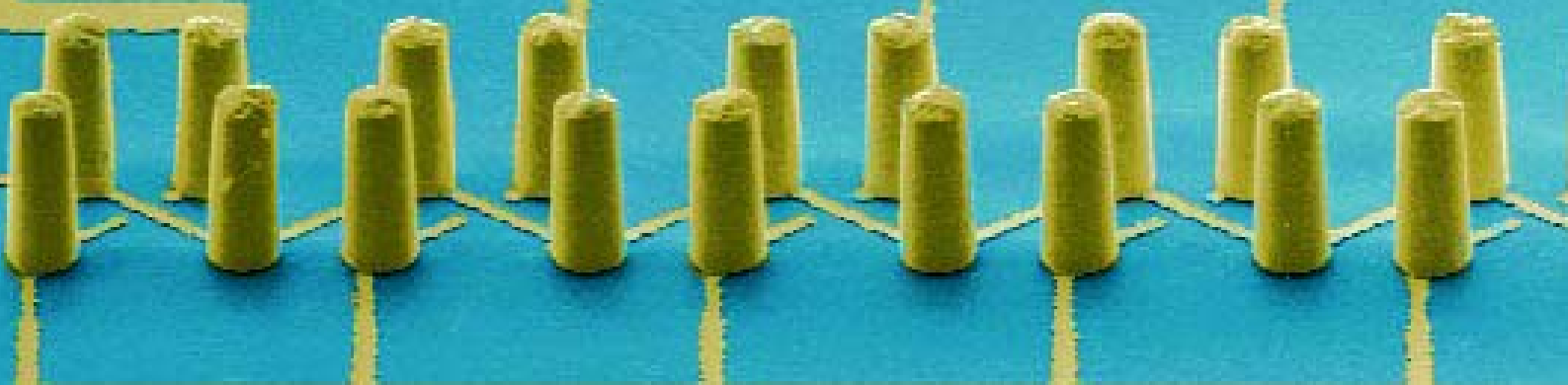
(040129-1)

Delano L. Klipstein

SENSORS FOR HUMANS

Sensor technology at MIT

Polymer electronics for chemical sensors: a new field is developing faster than expected. The first results include nanotechnology sensors that can detect chemical compounds such as TNT with an incredible level of sensitivity.

'Polymer Electronics for Chemical Sensors' was the topic for the tenth research and development conference at the Massachusetts Institute of Technology (MIT), which gave an overview of current developments in the field of plastic electronics. The name of one speaker made us prick up our ears: Professor Timothy M. Swager is associate director of the 'Institute for Soldier Nanotechnologies' at MIT. What was he seeking to achieve?

The MIT professor came straight to the point, summing it up in one sentence: "We want to build sensors so small that they could in principle be constructed from a single molecule". An ambitious target, and certainly not one that can be achieved in the foreseeable future. Or can it? Some substances, such as nitric oxide (NO) are relatively simple to detect using polymer sensors. NO is a colourless, poisonous gas which increases the conductivity of certain polymers. With a good sensor it is already possible to detect as little as a few nanograms. Using more sophisticated polymer systems, more complex mixtures of substances can be detected.

Swager and his colleagues have, as an example, developed a prototype of a detector which can respond to as little as 10^{-6} grams of TNT explosive. With that a very sensitive land mine detector could be built. What interests potential users more at the moment, though, is the possibility of dramatically improving the sensitivity of baggage monitors at airports. In a commercial product such a detector could be more than ten thousand times more sensitive than those currently used. And the chances of being able to smuggle explosive on board an aeroplane in the heel of one's shoe would fall to zero at a stroke. At MIT they are well aware that a lot of development work

lies ahead. At the moment it is only possible to make polymer sensors in the shape of a one-dimensional strip, whereas effective chemical sensors need to have a three-dimensional structure. Two-dimensional planar sensor structures will have to be made before we can even consider going into the third dimension.

Chemistry is being brought to bear on electronics in other areas too. Swager and his colleagues have developed a tiny laser made from a polymer, capable of delivering an output power of up to 75 nW. A ring laser has also been built using microstructures made from dinitrobenzene. Using cunning molecular design techniques signal gains of up to 10^5 have been achieved. The MIT professor is absolutely certain that new results in chemistry will have a dramatic impact on the future of electronics.

Wireless physiological data measurements

Phil Shaltis, research assistant in the Department of Mechanical Engineering, agrees. He reported a sensor in the form of a finger ring which can measure blood pressure and oxygen saturation levels and transmit them wirelessly to a monitoring station.

The challenge in this case is not the instrumentation technology itself, but the problem of minimising power consumption. The data are measured on an artery in the finger. The ring itself was designed using finite element methods to guarantee reliable operation: it must not press too hard against the bones in the finger, or errors will be introduced into the readings,

kinds of data are already used in hospitals, and although they are very advanced they are also comparatively large: the ring developed at MIT is a thousand times smaller. At present it is used in parallel with traditional instruments, including at a stress EKG unit. Early results are already available: identical measurements are obtained from patients at rest, while under stress the ring sensor gives much more accurate readings and, most importantly, fewer artefacts.

Many different approaches were taken in trying to minimise the power consumption of the ring. A high modulation rate is used during data transmission to keep the transmit time as short as possible. A 'sleep mode' for the ring saves yet more power: there is no need to take measurements continuously. For special applications like this one a dual-architecture processor has been developed at MIT which meets the extreme performance requirements better than conventional processors. The device also has an interesting market in the area of fitness. Once the system has proved itself in hospitals, the next project is to create a monitoring system for intensive training.

Other experiments are being carried out to record stress situations while driving. There is a close relationship between brain function and cardiac activity. Stress, anger and physical tiredness are reflected in an increased heart rate. For example, a system which provided continuous medical monitoring of the driver of a long-distance coach could increase safety. As well as this sensor ring, active sensors have been placed in cuffs to be worn on the arm: so-called 'wearable cuffs'. Many people require continuous monitoring of the most important body functions in order to be able to call for help quickly in case of an emergency. Another approach to monitoring such patients is to use 'smart shirts', which connect together a whole network of body sensors. At present they require too much wiring to be used inconspicuously: development work is in progress to reduce the number of connections to just two (for the power supply). The power supply wires can be used simultaneously for signal transmission, forming a bus system for the data to be communicated. Such unprotected bus systems are susceptible to interference, in particular to the inevitable noise. An initial analysis of the noise spectrum indicates that this idea is practical over a wide range of frequencies, certainly above 100 kHz.

ultimately giving rise to incorrect measurements of blood pressure; but on the other hand, the better the ring fits, the better the signal-to-noise ratio achieved. Pressure is therefore only applied locally on the finger in the spots where the artery in question lies. The pressure itself is measured using infrared sensors.

What can we do with a sensor like this in everyday life? This is being researched at the Massachusetts General Hospital (MGH) in Boston, located opposite MIT on the other bank of the Charles River. Similar measurement devices for these

MEMS for biosensors

Joel Voldman, Assistant Professor of Electrical Engineering at MIT, reported on BioMEMS. Cells contain a large quantity of useful pieces of information which are not only of interest to doctors. Modern criminology is also dependent on cell research. Today's typical experiments use cell cultures consisting of more than a million individual cells. The cells' environment is poor: the cells die during the experiments, which changes the nature of the culture. What are wanted are biosensors which can extract the same information, and possibly much more, from just a few cells. MEMS (micro-electromechanical sensors) look as if they might make suitable biosensors.

Using such microminiaturised experimental methods it is possible to aim for better results. For example, micromanipulation of samples can help extract desired information. The problem with experimenting on single cells lies in optical screening: one can only study what one can screen for, and

one can only screen for what one can see. The classical microscope always shows the same section. If the sample being studied is on a glass slide, then there is no difficulty. However, when using dynamic screening, the cell material being studied flows across the screen, and thus there is always the danger that an interesting part of the sample might be lost for ever.

Voldman and his colleagues are looking for a solution between these two extremes of dynamic and static screening, where there might be the possibility of repeating an observation to obtain reliable data. Using MEMS one individual cell can be studied. The cells are kept alive in a transparent nutrient fluid. They can be studied using optical and electrical techniques, as well as by using ultrasound. Using microscopically small grids cell traps can be constructed in which cells can not only be observed, but can also be moved around using electrical impulses.

Using these technologies we hope to gain insight into a secret that also concerns quantum physicists. Today we know very little about what influence observation from outside has on a cell. As in quantum computing, we have to be wary of the problem that when reading or writing information one always runs the risk of distorting the information itself.

(040040-1)

Figure 4. Professor Joel Voldman: "We are looking for experimental methods that allow us to observe individual cells"'. (Image: private)

Resounding Truth
An acoustic lie detector

Burkhard Kainka

There are those cool-headed types, who can lie through their teeth with a straight face. But in the end it is just a matter of asking the right questions. Sooner or later everyone will get sweaty palms.

Lie detectors are always a great deal of fun at parties. Who is prepared to face up to the challenge from technology? And also: who is able to defeat the machine! The latter is also very dependent on the actual situation — the questioner must not make it too easy for the test subject! When the tension increases, even the best liar can't avoid a subtle but inevitable physiological reaction: sweaty palms.

The operating principle of this lie detector makes use of this phenomenon. When the hands of the person in the hot seat become damp, the electrical resistance of the skin will

reduce. This change is relatively easy to detect. In that respect we certainly don't want to claim that the circuit presented here is a feat of brilliant innovation. However, it is the manner in which this device signals the result that sets it apart. That is, this circuit will emit a tone, the frequency of which depends in the resistance of the skin.

Five-five-five

The design of the circuit shown in **Figure 1** is actually a relatively typical application for the well-known 555. This timer-IC has been wired

here as an astable multivibrator, that means that at the output there is a signal, the frequency and duty-cycle of which are determined by two resistors and one capacitor. In this case there are actually three resistors and one capacitor. The resistance of the skin is connected in series with R1. In conjunction with R2 and C1, this series connection determines the duration that the output (pin 3 of IC1) is high. When the power supply is switched on, the capacitor is charged, through these resistors, to $2/3$ of the power supply voltage. An internal comparator compares, via pin 6, the voltage across the capacitor with this

COMPONENTS LIST

Resistors:
R1,R2 = 27kΩ

Capacitors:
C1 = 4n7

Semiconductors:
IC1 = NE555

Miscellaneous:
BZ1 = buzzer
2 PCB solder pins
2 solder pin receptacles soldered to long
    wires (stripped ends)
6 pieces of (bare) wire
PCB, prototyping board, order code
    UPBS-1 (see Readers Services page)
9 V-battery with clip-on leads

threshold value. When this threshold is exceeded, the output of the IC will change state. This means that the inverting output of the internal flip-flop (Q̄ in **Figure 1**) will become high. This causes an internal transistor to conduct which results in the discharge of the capacitor via pin 7 and R2. Note that the length of time that the output remains low is not dependent on R1 or the skin resistance.

Subsequently, the second internal comparator starts to play a part. Again, the voltage across the capacitor is compared with a threshold value (pin 2). When the voltage is $1/3$ of the power supply voltage, the internal flip-flop is set, the output changes state again and the whole process begins anew.

Two pins of IC1 are not used in this configuration. Pin 4, the inverted reset input, can be used to interrupt the charging process of the capacitor prematurely. This can be very useful in other circuits but is not necessary in this design. Here, the reset input has been connected to V_{cc}, so that the internal comparator alone determines when to reset the flip-flop. That leaves the control input (pin 5). Via this input the upper threshold value can be changed. That function is not used here and the input is left open.

Construction

For this project too, we have designed a printed circuit board. However, this time not quite as you have come to expect from us. **Figure 2** shows a PCB layout for our Universal Prototyping Board size-1 (UPBS-1) which can be purchased ready-made through the *Elektor Electronics* Readers Services. A normal piece of prototyping board, stripboard or Veroboard can be used as well, of course.
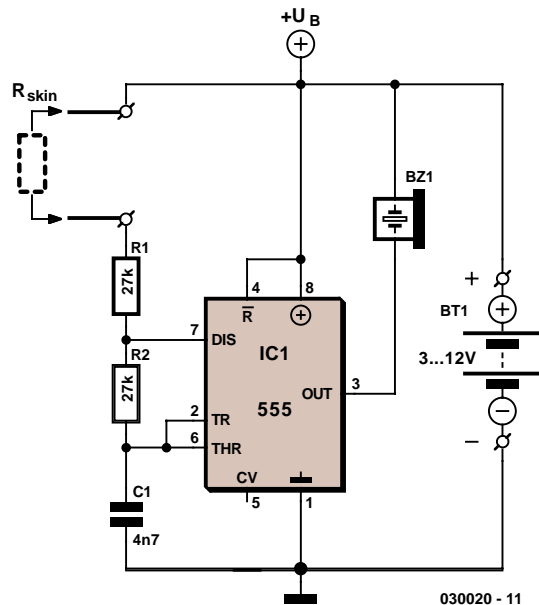
Figure 1. The 555 as an astable multivibrator.

We can be brief regarding the actual construction, the only thing that may need some clarification is how to measure the skin resistance. Very simple: attach two wires, one to the positive power supply and one to R1. The stripped ends are then loosely wrapped around two fingers of one hand. That is all.

Component values

In the inset you can read how the component values in the circuit are calcu-
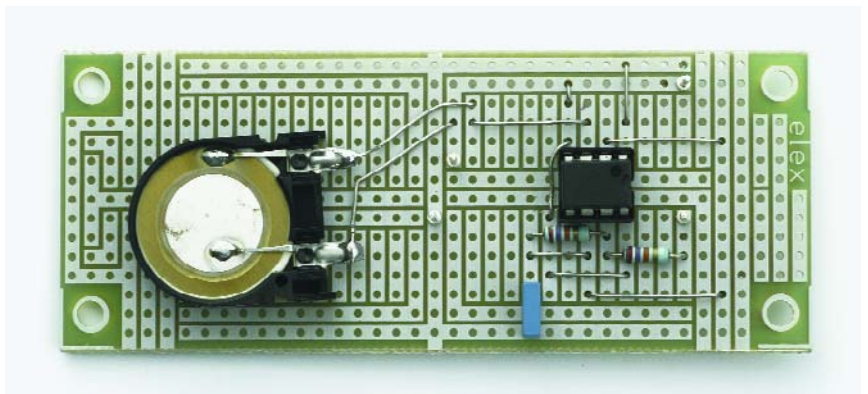
Figure 2. Suggested construction on an UPBS-1 prototyping board.

ReCapping...

When a capacitor is charged through a resistor, the charging current is not constant. As a consequence, the change of voltage across the capacitor follows a typical curve (Figure 3 refers):

$$U(t) = U_b \, (1 - e^{-\,t/RC})$$

In this equation, the product of capacitance and resistance stands out: the RC time constant. This determines how long it will take before the capacitor is charged to a certain value. By rearranging the equation we can determine this time accurately:

$$t = -\, RC \log_e (1 - U(t) / V_{cc})$$

Here $U(t)$ is the desired voltage at instant t and U_b is the charging voltage. The time it takes to charge the capacitor to $2/3$ of the power supply voltage is therefore:

$$t = -\, RC \log_e (1 - (2/3 \, / \, 1))$$
$$= 1.10 \, RC$$

Once the circuit is operating, the capacitor only needs to be charged starting from $1/3$ of the power supply voltage. If we subtract the time this takes from the value previously calculated, we then know the duration of the on-period:

$$t_{on} = 1.10 \, RC - 0.41 \, RC = 0.69 \, RC$$

For the off-period (the discharging of the capacitor) we can write another equation. In general:

$$U(t) = U_0 \, e^{-\,t/RC}$$

or

$$t_{off} = -\, \log_e (U(t) / U_0) \, RC$$

Here we are looking for the time it will take to discharge the capacitor to $1/3$ U_b, when the initial value is $2/3 \, U_b$:

$$t_{off} = -\, \log_e (1/2) \, RC = 0.69 \, RC$$

Now that we know exactly how long it takes for one cycle, i.e., what the period is, we can determine the frequency of the signal at the output:

$$f = 1 / T, \text{ where } T = t_{on} + t_{off}$$

Substituting the capacitance and resistance values into the equations for the on- and off-times (note: when discharging only R2 is part of the RC network) we can calculate the frequency of the tone we'll hear:

$$f = 1 / (t_{on} + t_{off})$$
$$f = 1.4 / C1 \, (R_{skin} + R1 + 2 \, R2)$$

Here:

$$f = 319 \times 10^6 / (R_{skin} + 81 \times 10^3)$$

QED: only the resistance of the skin determines the frequency.
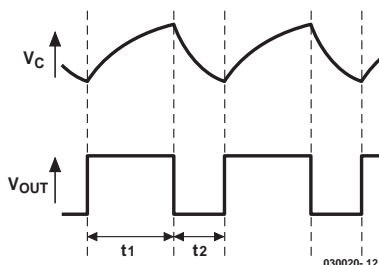
Figure 3. The voltage across the capacitor (top) and the corresponding output signal (bottom).

lated. If you are only interested in the result, then only the last equation is of importance. Normally, the resistance of the skin will be between 10 and 500 kΩ. With the component values as shown, this will produce a tone from buzzer Bz1 with a frequency between 500 to 3500 Hz. The frequency is mainly dependent on the dampness of the skin: the more sweat, the better the conduction and therefore the lower the resistance. When the resistance reduces, that is, the test subject becomes nervous, the pitch increases. Note that the pitch is not an absolute measure of 'the truth'. One person has a naturally better conducting skin than another. That makes no difference here, because it is the change that matters. Human hearing is actually quite sensitive to such changes in pitch. An additional feature is that the test subject can hear the tone as well. This often leads from bad to worse. Despite the best intentions not to break under duress, this psychological feedback is usually the last straw that breaks the camel's back.

(030020-1)

1

+1V6 ... +5V5

IC1
74LVC1GX04

1	NC	Y	6
2	GND	VCC	5
3	X1	X2	4

R1
1M

R2 *
4k7

X1

C4
100n

* C3

C2
39p

C1
47p

1p6...15p

$$T = \frac{1}{f_Q}$$

$$C_L = \frac{C_1 \cdot C_2}{C_1 + C_2} + C_S$$

$$C_1 = C_2 = C:$$

$$C_L = \frac{C_1}{2} + C_S$$

* see text

044012 - 11

2

74LVC1GU04   74LVC1G04   Y

unbuffered

X1   X2   044012 - 12

3

X1

C1   L1   R1

C0

C_L

044012 - 13
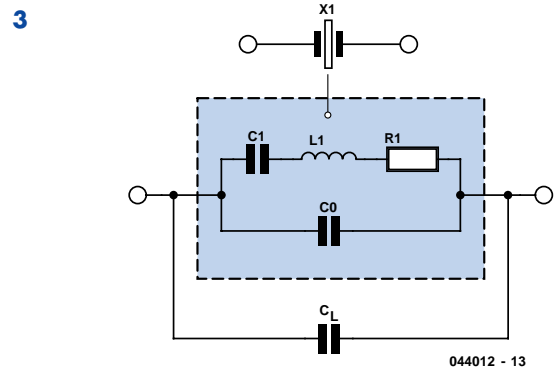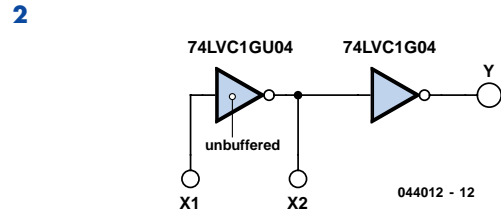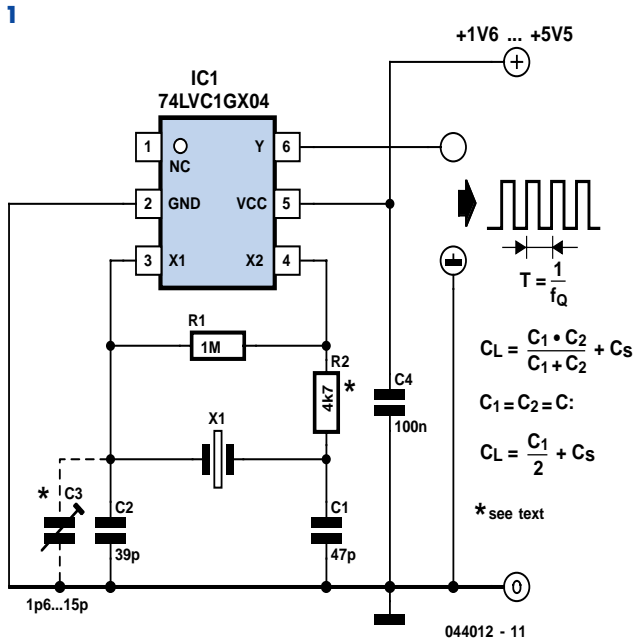
Combi-gate Oscillator IC

Many of you will know that a digital oscillator built from unbuffered inverters in a 74xx04U IC has to be followed by a 'normal' gate. Both functions are now available from a single IC produced by Philips.

A quartz crystal oscillator built around an unbuffered logic gate type 74HC04U traditionally employs a high feedback resistance to be effectively turned into a high-gain linear amplifier (**Figure 1**). The frequency-determining quartz crystal is also inserted in the feedback path, its resonance characteristics forcing the circuit to oscillate at the crystal frequency. This works very well but unfortunately there are also a few disadvantages: not only are five of the six gates in the HC04U package left unused, but you will also need one unbuffered gate to make the signal truly digital-compatible because the output signal of the linear oscillator stage looks more like a sinewave.
The above combination of an unbuffered and a buffered gate

is now available in a single IC package type 74LVC1GX04 from Philips (**Figure 2**). The new IC may be used for oscillator circuits operating at up to 50 MHz and runs happily off supply voltages between 1.65 V and 5.5 V. Its output is capable of 24 mA drive (at V_{cc}= 3.3 V). The first inverter in the new IC is unbuffered and the second one, buffered to ensure the non-digital oscillator signal is properly shaped to meet TTL specifications in regard of swing and absolute high/low levels.

The 74LVC1GX04 requires only a quartz crystal and a small number of external parts. Resistor R1 is the feedback resistance to which the crystal is connected in parallel. Resistor R2 and capacitor C1 together act as voltage divider to keep the quartz crystal dissipation within limits. The dissipation spec may be found in the quartz crystal datasheets, or obtained from the manufacturer. If necessary, the value of R2 may be adapted to your requirements. In **Figure 3**, capacitors C1 and c2 together with the load capacitance C_s form the load on the quartz crystal. The manufacturer will typically indicate that due to

the crystal cutting and grinding method, the nominal crystal frequency is reached at a load capacitance of about 30 pF. Because C_L is in parallel with the crystal, a mode called 'parallel resonance' is required. Here, the crystal 'sees' as its load two series connected capacitors, C1 and C2, not forgetting the circuit stray capacitance C_s, which is essentially formed by the gate input (X1, X2 in Figure 1). In practice, C_s equates to about 5 pF.

$$C_L = [(C1 \; C2) / (C1 + C2)] + C_s$$

$$C1 = C2 = C$$

$$C_L = C/\;2 + C_s$$

With C_L = 30 pF and C1 = C2 =C the latter takes a theoretical value of 50 pF, or 47 pF from the components drawer. C2 may have a trimmer connected in parallel if exact frequency adjustment is required. The value of C2 is then decreased by an amount equal to half the trimmer's full capacitance.
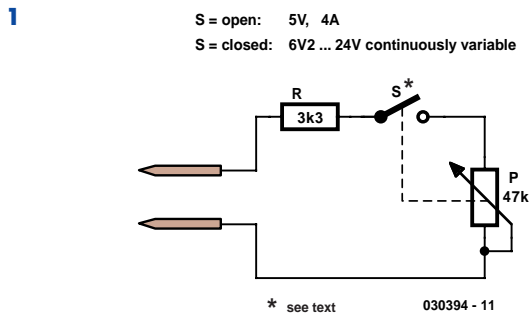
C1 decouples the supply voltage and has to be fitted as close as possible to the 74LVC IC. If nec-

essary, noise suppression may be enhanced by adding a small series resistor or a choke in the supply line.

(044012-1)

Web pointer
www.philipslogic.com/products/lvc/pdf/74lvc1gx04.pdf

1

S = open: 5V,   4A
S = closed: 6V2 ... 24V continuously variable

R
3k3

S *

P
47k

* see text   030394 - 11

2

Global Power Supply

With continuously variable output voltage

Bernd Oehlerking

Small switch-mode power supplies are often available at a low price from jumble sales, electronics surplus outlets and high street electronics shops. We'll show you how these units can be put to good use.

These SMPSUs from surplus lots can handle any power line voltage between 100 V and 240 V, which makes them suitable for use all over the planet. They adapt automatically to the mains voltage measured. Not much larger than a cigarette pack, these SMPSUs are short-circuit and overload proof, offering an output power of up to 50 watts depending on the type on offer. Usually, the output voltage is adjustable over a wide range between 5 V and 24 V in 1-volt increments. The voltage adjustment is carried out using a small rotary switch or — as in our case

— with the aid of labelled code plugs included in the package. These intriguing plugs contain no more than an SMD resistor and two contact pins. Even without a look inside the power supply (which is usually contained in a fully moulded case you can't open without causing permanent damage to the supply) it's not difficult to identify this resistor as part of a voltage divider that determines the voltage at the output of the switch-mode controller IC. Simply by replacing the fixed SMD resistors with a suitable potentiometer, we obtain a continuously variable power supply (**Figure 1**). The potentiometer takes a value of 50 kΩ, linear law. The author used a pot with an end switch (**Figure 2**). When the switch is opened, the output voltage is 5 V. When closed and with the pot at maximum resistance, the level is 6.2 V. Turning the pot towards the zero position causes the output voltage to rise to its maximum value of 24 V. If you use a pot without an end switch you can either fit a separate on/off switch for the 5-V setting or simply unplug the lead to the pot. On the subject of plugs, you'll find that a 2-way pinheader will fit the socket on the SMPSU.

The pot is best built into a small ABS case and fitted with a knob and scale. Once you've measured a couple of frequently used output voltages and marked the associated settings on the scale, any voltage may be adjusted with reasonable accuracy.

The maximum current that can be drawn from the power supply is of course dependent on the output voltage, but inversely proportional for all practical purposes. The SMPSU the author picked up from a shop and used for his experiments was labelled '35

watts'. According to the equipment label, it supplies 1.5 A at 24 V which equates to 36 watts. At 5 V, however, we see that the current spec is just 4 A which means 20 watts of output power. Apparently, internal losses become significant in the lower output voltage range (roughly below 12 V). **Figure 3** shows the actual output voltage as a function of load current. The measurement was carried out in the *Elektor Electronics* design laboratory.

(030394-1)

3
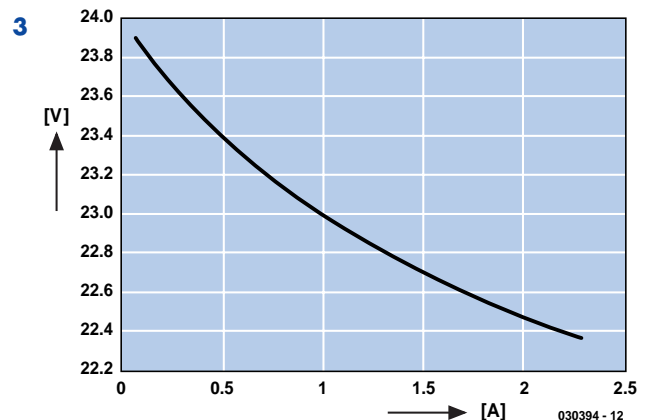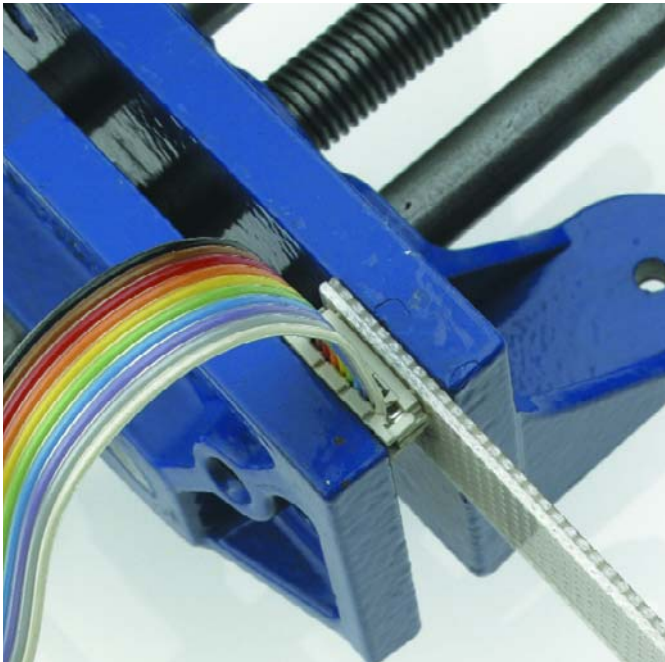
Self-tapping screws

Many ABS but also aluminium, steel and other light metal enclosures like diecast are closed with self-tapping screws secured directly into the carrier material. In general, this works fine but you may run into a problem when a screw has been removed and needs to be secured again. For example, when self-tapping screws are reinserted just like that after a repair or battery replacement, it may happen that the screw appears to cut a new thread into the carrier material. If this happens a few times, the screw hole will be enlarged to the extent that the screw will no longer provide the necessary force to keep the case together.

A simple trick of the trade may prevent such problems: when the screw is reinserted, first turn it counter clockwise until you feel it rising and suddenly dropping again. With metal enclosures this is even audible. Exactly at this point, start turning the screw clockwise again and secure it.

Of course, the thread cut into an ABS or soft metal case is subject to normal wear, hence the above trick cannot be repeated too many times. None the less, the method will help to increase the life expectancy of the screw joint considerably. If things do go wrong, make the hole a bit smaller with a small piece of plastic or a matchstick, if necessary adding a drop of permanently flexible glue.

Pressing matters with flatcable connectors

Although special tools are available to press IDCs (insulation displacement connectors) onto flatcables, a small vise will also do the job. Unfortunately the vise method cannot be applied to DIP IC and mini DIP connectors without squashing the delicate pins. The trick is to insert the pins into a few layers of veroboard or stripboard (the number of layers you need depends on the pin length) and so protect the pins from the pressure exerted by the vise jaws. The holes in the stacked pieces of veroboard have to be accurately aligned before inserting the connector pins. The 'assembly' is then ready for clamping in the vise. You may want to turn the makeshift solution into a permanent tool by using strips of veroboard with lengths and widths to suit different types of IDC connector. Secure the stacked strips with two-component glue.

SOFTWARE?

WE'LL DO THAT OURSELVES!

Three examples explained

Karel Walraven and David Daamen

Elsewhere in this issue is an article for a stepper motor driver. This article describes the demonstration software for this circuit. We explain how these programs came about and find that there are several ways of achieving our goal.

We have purposely kept the software for the stepper motor driver as simple as possible. This makes it easier to follow and allows you to use it as a basis for your own software. Examples are given in assembler as well as C. These two examples are meant for use with the 89S8252 Flash Microcontroller Board (*Elektor Electronics*, December 2001). The third example is in Visual Basic and works on a PC. This lets you generate the required signals without the use of special hardware.

Assembler

We'll first cast our eye over the assembler program, which is the file that ends in **.asm**. The designer of the stepper motor driver has developed the program using Proview32, which also includes an assembler.

The program (**Listing 1**) first specifies which inputs and outputs are used. The pushbuttons connect to pins P1.6 and P1.7, and pins P3.4 and P3.5 output the square waves. If you choose different pin names, the microprocessor will use these as inputs and outputs.

First we test Button_17. If this button isn't pressed, the input is at logic High and the program jumps to label 'ccw'. The code then tests Button_16 and if this isn't pressed either the program jumps back to label 'cw'. As long as no button is pressed, the processor follows this loop indefinitely.

When a button is pressed the input at P1.6 or P1.7 is connected to ground and the program doesn't jump, but executes the following instructions. The following actions now take place: L_1 goes high, delay, L_2 goes high, delay, L_1 goes low, delay, L_2 goes low, delay. The routine has therefore gone through a complete cycle of a square wave. The pro-

```
        ; Stepper motor software for use with the 89S8252 flash board
        ;
        ; Horst Hubert
        ;
        ; Two switches are used to control the motor. One between
        ; P1.7 and GND (Button_17 for turning clockwise) and one between
        ; P1.6 and GND (Button_16 for turning counter clockwise).
        ; Turning cw/ccw is an assumption: the actual direction is of course
        ; dependent on how the motor is connected.
        ; In the cw direction, the motor will turn at higher speed than in
        ; ccw direction.


        ; Declarations                       ;
        ; ------                 ccw1:  setb     L_1    ;coil 1 high
        Button_17 equ  P1.7             call     zsl
        Button_16 equ  P1.6             clr      L_2    ;coil 2 low
                                        call     zsl
        L_1       equ   P3.4            clr      L_1    ;coil 1 low
        L_2       equ   P3.5            call     zsl
                                        setb     L_2    ;coil 2 high
        org    0000h                    call     zsl
                                        sjmp     ccw


        ; Turning cw                     ; Delay for turning cw
        ; ------                         ; --------------
cw:  jb Button_17,ccw             zsr:   mov      R0,#255
        ;                                mov      R1,#20
cw1: setb      L_1    ;coil 1 high zsr1:  djnz     R0,zsr1
        call       zsr                   djnz     R1,zsr1
        setb    L_2    ;coil 2 high      ret
        call    zsr
        clr     L_1    ;coil 1 low        ; Delay for turning ccw
        call    zsr                       ; --------------
        clr     L_2    ;coil 2 low  zsl:   mov      R0,#255
        call    zsr                        mov      R1,#255
        sjmp    cw                   zsl1:  djnz     R0,zsl1
                                            djnz     R1,zsl1
                                            ret
        ; Turning ccw
        ; ------                           end
ccw:    jb        Button_16,cw
```

gram then tests if the button is still pressed and repeats the previous actions.

The delay routine consists of two nested loops. The inner loop decrements register R0 from 255 to 0, and this happens 20 times (the value in R1). By varying this value, you can generate square waves of a different frequency, causing the motor to run at a different speed.

This is just about the simplest driver program that can be written.

C

The C program (**Listing 2**, the name of the file ends in **.c**) is more compact than the assembler listing. This also starts with some declarations. The first line includes a complete file containing a set of standard declarations for our processor. This type of file always ends in **.h**. Many manufacturers make these files available for use with their processors.

Next, we have to define the inputs and outputs, just as in the assembler program. Sbit tells the C compiler that L_1 is one bit in size and is connected to a single processor pin, with an internal microprocessor address of B4. We won't go into further detail here, but more information can be found in the datasheet for the 89S8252 in the section 'special function registers'. Later on in the program use is made of the variables i, j and k. The compiler needs to know about these in advance, since it has to reserve memory space (2 bytes for an integer) and also use the right type of maths routines, in this case routines for integers (abbreviated to int).

In this program the delay routine is implemented as an independent sub-routine (a function), which also has to be declared in advance. The size of the delay is given as an inte-

Listing 2. C program

```
/*Stepper motor software for use with the 89S8252 flash board

  Horst Hubert

  Two switches are used to control the motor. One between
  P1.7 and GND (Button_17 for turning clockwise) and one between
  P1.6 and GND (Button_16 for turning counter clockwise).
  Turning cw/ccw is an assumption: the actual direction is of course
  dependent on how the motor is connected.
  The values of j and k determine the speed of the motor. The motor only runs when
  one of the two buttons is pressed.

  This source code is intended for use with FSI's ProView32 compiler


*/
#include <reg51.h>

sbit at 0xB4 L_1;
sbit at 0xB5 L_2;
sbit at 0x96 Button_16;
sbit at 0x97 Button_17;

int i;
int j;
int k;
void delay(int);      //Function declaration


void main()
{
  while(1)  //infinite loop
  {
    while(!Button_17)  //turning cw
    {
      j=4000;

      L_1 =1;
      delay(j);
      L_2 =1;
      delay(j);
        L_1 =0;
        delay(j);
        L_2 =0;
        delay(j);
      }

      while(!Button_16)  //turning ccw
      {
        k=200;

        L_1 =1;
        delay(k);
        L_2 =0;
        delay(k);
        L_1 =0;
        delay(k);
        L_2 =1;
        delay(k);
      }
  }
}

void delay(int m)
{
  for(i=0; i<m; i++);
}
```
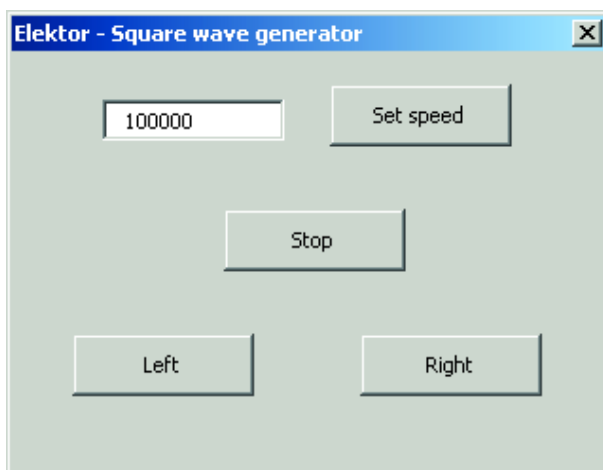

Figure 1. This macro for MS Word generates signals on the printer port.

ger after the name of the function, which is why we have int in brackets after the name of the routine. The delay routine doesn't return a value to the calling program. For this reason the word void is in front of the routine. You will have noticed that with higher level languages there are more declarations. This has the effect of shortening the program code. Everything is declared at the start, so you don't have to worry about these things in the actual program.

And now for the main program. In C this is **always** called main. It is through this convention that the compiler knows where the program starts. Since it is the main program it doesn't take any arguments, nor does it return a result. For this reason there are empty brackets after main and it has void in front of it. This main program starts with a loop (while(1)) that runs indefinitely. This statement really means: do the following while '1' is equal to a logical one. Since the

Listing 3. Visual Basic program: the most important parts

```
'Elektor Example Square Wave Generator for use with Stepper Motor Driver
'030203-II May 2004
'──
'This examples employs ininput32.dll. Copy this DLL to /windows/system32.
'See http://www.logix4u.net/


Public Declare Sub Out Lib "inout32.dll" _        Out (Port), 0     'reset printer port
Alias "Out32" (ByVal PortAddress As Integer,        While Run
_                                                   While Cw
ByVal Value As Integer)   'use external               Out 888, 1    'turn clockwise: make
library for direct LPT access                                       'output 1 high first
Public Delay As Long                                  Sleep Delay   'pause for one half
Public Run As Boolean                                               'period
Public Ccw As Boolean                                 Out 888, 3    'switch on the second
Public Cw As Boolean                                                'output too (90 degrees!)
                                                      Sleep Delay
Sub Sleep(Delay As Long)  'count the value in         Out 888, 2    'switch off first output
Delay and do nothing                                  Sleep Delay
  ThisDelay = Delay                                   Out 888, 0    'switch off second output
 While ThisDelay > 0                                                'too
   ThisDelay = ThisDelay - 1                          Sleep Delay
   DoEvents       'pass control to the OS to          DoEvents      'pass control to the OS
                  'prevent hanging                                  'to prevent hanging
 Wend                                                Wend
End Sub
                                                     While Ccw
Sub Square_Wave_Generator() 'hide the main            Out 888, 3    'reverse: both outputs
Word window and show the macro form                                 'high
            'show Word again after exiting            Sleep Delay
                                                      Out 888, 1    'switch off second output
Documents("Square_wave_gen.doc").Windows(1).Vi        Sleep Delay
sible = False                                         Out 888, 0    'switch off first output
   form.Show                                                        'too
                                                      Sleep Delay
Documents("Square_wave_gen.doc").Windows(1).Vi        Out 888, 2    'switch output 2 on again
sible = True                                          Sleep Delay
End Sub                                                DoEvents
                                                     Wend
Sub Output(Port As Integer) 'generate some           DoEvents
square waves                                        Wend
```
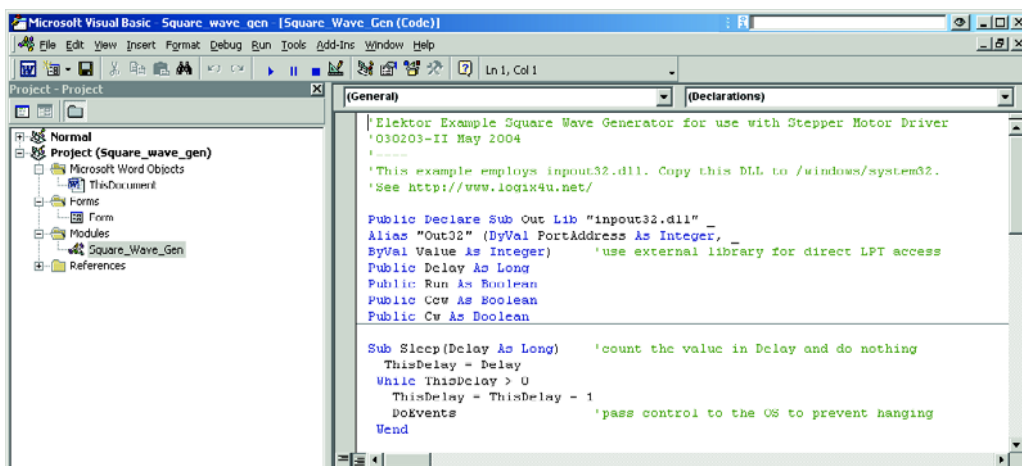

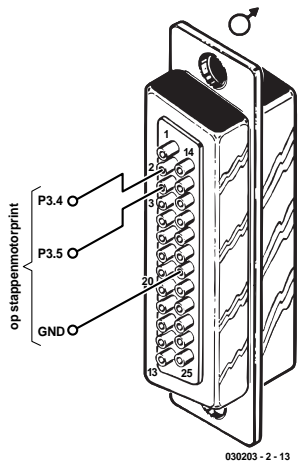*Figure 2. Macro opened in Visual BASIC Editor.*

*Figure 3.
How to connect the
stepper motor
control to your PC.*

030203 - 2 - 13

'1' is never changed, this is always true and the loop will go on forever.

We now come to another loop. This time there is a condition to be met: while Button 17 is not equal to a logic one. The exclamation mark indicates the condition is negated; it is compared to a **not** logic one. When the condition is satisfied (the button is pressed and a '0' is at the input), the program will execute all statements **within** the following curly brackets.

The routine within the curly brackets creates a square wave, just like the assembler program. First, j takes the value 4000. Then output L_1 is set to '1' and the delay routine now creates a delay dependent on the value in j. This continues until a full square wave has been created.

The part of the program following this routine has the same function, but this time the other button is tested.

The final routine is the delay function. Since C programmers don't like typing (and seem to prefer to write compact, obscure code) it's written as a single-line function. As you may have guessed, this is a for-next loop, which begins at zero (i=0) and is incremented by one (i++) as long as the value is less than m (i<m). This m has a value that was given as a parameter when the function was called and in this case is either 4000 or 200.

Visual Basic and the PC

Our final example uses the printer port of a PC. This makes it possible to experiment with stepper motors if you don't have a Flash Micro Board. This example is also very convenient in use, since you are unlikely to need any special programming software: we make use of the Visual Basic environment that is nowadays integrated with Microsoft Office. The only extra software that needs to be installed is a little helper program that permits direct access to the parallel port. Windows NT and XP no longer let normal programs access this port. You therefore have to copy the file inpout32.dll to the folder \windows\system32. This helper program works transparently with some other versions of Windows (98SE and ME): the port will still be driven correctly. Unfortunately, this software

won't work with older versions of Windows.

The actual Visual Basic program is in fact a macro for Microsoft Word. The most important parts are shown in **Listing 3.**

Here too we have declarations, a delay function, a function that pops up the macro window (**Figure 1**) and temporarily hides Word, and finally a function that toggles the output pins in the correct order, just as in the other examples.

There is some other code as well, but there is not enough space to go into details here. The document including the macro can be downloaded from the *Elektor Electronics* website (**030203-11**). Remember to turn off macro security before opening the document. Go to Tools/Macro/Security. Choose one of the lower two options, so don't use 'high'. If you now open the document and permit the use of macros, the program window will appear automatically. When you close this window, Word will re-appear again.

You can now open the Visual Basic Editor using alt-F11 (**Figure 2**). To the right will be a small window showing 'Project (Square_wave_gen)'. Below this project are a few folders with a document (the document containing the macro), the code and description of the form to control the software, a module with the actual program and possible references to other files. If you inspect the code belonging to the form it should soon become clear how the macro operates.

Operation

All software can be downloaded from the *Elektor-Electronics* website. We assume that owners of Flash Micro Boards don't need to be told how to load a program into their boards. But if you do need more information, it can be found in the December 2001 issue of *Elektor Electronics*.

The Visual Basic software is hidden inside a Word file and is automatically started as soon as the document is opened. Its operation is very straightforward. A number can be entered in a text box (defaults to 10000). This value determines the frequency of the signals on the printer port. The effect of this value depends on the speed of the PC's processor. If other programs are running at the same time, they too will influence the output signal. You will have to find the best value for your PC by trial and error.

Finally, **Figure 3** shows the pinout of the sub-D connector, which connects the stepper motor driver to the printer port. Connect pin 2 and 3 of the printer port to P3.4 and P3.5 of the stepper motor board.

(030203-2)

All software for this project can be downloaded under number 030203-11 at

www.elektor-electronics.co.uk/dl/dl.htm,
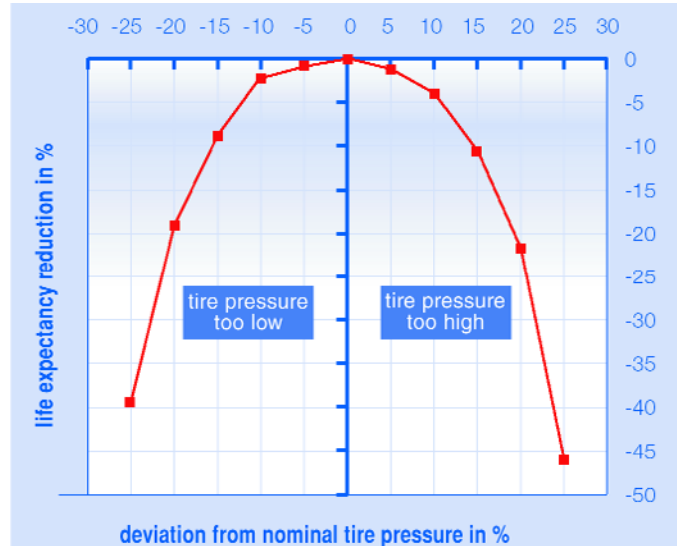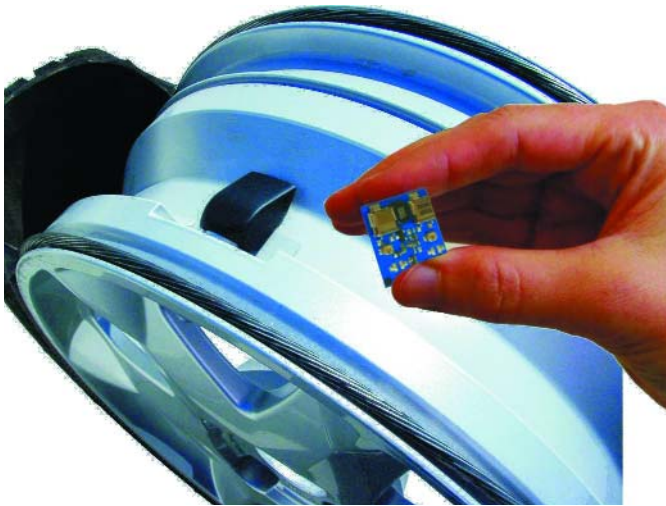
select month of publication.

Figure 1. Relation between tyre pressure and wearing. (Wabco)

Wireless Tyre Pressure Monitoring

Helmuth Lemme

Sudden tyre failure is not only annoying but also downright dangerous. In the future, new technology will help to reduce the number of accidents caused by tyre problems, with recently developed sensor systems constantly guarding tyre pressure and issuing a warning signal well before disaster strikes.

In 85% of all cases, tyre rupture or explosion is caused by too low pressure. The real cause, however, is increased friction leading to excessive tyre temperatures and material failure with often catastrophic consequences. Slightly less worrying, even a small loss of tyre pressure causes not only increased wear but alos higher fuel consumption due to increased rolling resistance. Just as with too high pressure, the life expectancy of the tyre is significantly reduced (**Figure 1**). Since there are no tyres with zero rolling resistance, and pressure checks by the vehicle driver are insufficient, an electronic alternative appears useful and more than welcome. The first systems are now in volume production. Each wheel contains a module measuring the tyre pressure and temperature at regular intervals and copying the resulting data to the vehicle computer. The computer responds to too low or too high values by lighting a warning indicator on the dashboard. In the USA, the National Traffic Safety Administration has made the use of a TMPS (tyre pressure monitoring system) compulsory for new cars as of November 2003. It is expected that Europe and Japan will follow suit in the not too distant future.

From a point of view of technology used, individual manufacturers seem to follow their own ideas. The oldest princi-

Figure 2. Parts constituting Beru's TSS (tyre safety system)

Figure 3. No more batteries in the future: passive-sensor interrogation using RFID techniques (Siemens/Goodyear).

ple works indirectly: a microcomputer compares the rotational speed of all wheels, using data supplied by ABS (anti-blocking system) sensors. This principle is used by, among others, Continental for their DDS (deflation detection system). If the tyre pressure on one wheel drops, the effective wheel radius becomes smaller causing a higher rotational speed. Although such systems are cost-effective, they suffer from a high detection threshold (approx 30% pressure loss). Also, gradual pressure loss on all tyres goes by unnoticed.

Systems with real sensors inside the tyres are far more secure. The technical challenge boils down to the ability to convey measured values from the rotating wheel to the vehicle chassis. Slip rings are too unreliable because they soil easily. Today, the standard principle is a radio link. The measurement module on the wheel not only contains a microcontroller that turns the values supplied by the pressure and temperature sensor into a digital data packet, but

also a small RF transmitter operating in one of the ISM bands (usually 433 MHz, rarely on 2.4 GHz). The unit is powered by a Lithium battery which should last for a couple of years but is nonetheless a serviceable part. The module should be up to harsh conditions: strong vibrations with dynamic peak acceleration exceeding 2000 *g*, dirt, water, salt, ice and snow, yet have the smallest possible dimensions and weight. A receiver antenna is fitted in each wheelcase, or a single antenna centrally located under the chassis. A second microcontroller computes the measured values.

The above systems are available from Beru (TSS, tyre safety system, **Figure 2**), Wabco/Michelin (IVTM, integrated vehicle tyre pressure monitoring), Continental (TMPS, tyre pressure monitoring system) and a few other manufacturers. In principle they are similar, but different when examined in detail. For example, the Beru wheel mod-

ule that forms a compact unit with the tyre valve is fitted inside the tyre on the wheel rim — meaning it can only be built into a vehicle by the factory. The Wabco/Michelin module is fitted outside the wheel rim, secured to the valve with small pneumatic tubes so it can be 'retro-fitted' without so much as having to remove the tyre. Other systems for trucks and utility vehicles differ widely because of the large variations in tyre pressure.

Batteryless systems

The Lithium battery is a source of problems with all systems. Exchanging the battery is time-consuming. The battery is also heavier than the entyre electronic circuit and it obviously requires a very stable mounting method in view of the centrifugal acceleration. When braking hard, the temperature inside the tyre can reach up to 100 degrees C which may easily damage the bat-

tery. Finally, flat Lithium batteries are toxic waste hence have to be disposed of using the proper channels.

A solution to the above problems was found in the use of passive sensor responders that are interrogated over radio. The RF energy allows the transponder to return the instantaneous tyre pressure 'over the air'. The sensor goes inactive again until the next RF trigger arrives. The principle is well established in RFID ('radio tagging') systems that have been around for years. The technology offers several options. One very elegant solution is called 'surface-wave elements'. A system using these devices was developed by the Siemens research labs but never made it to volume production. Instead, Siemens in co-operation with Goodyear are now working on a different system which reportedly is cheaper as well as less complex. Here, the transmission is inductive: inductors are fitted on the wheel and the wheel holder, the assembly producing a
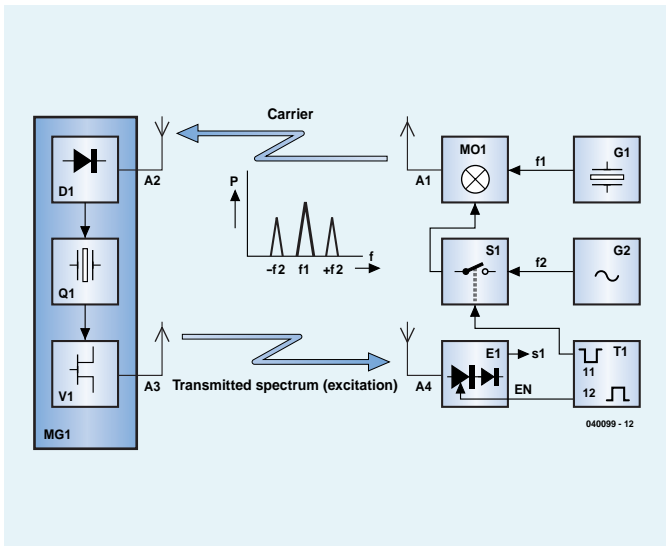
Figure 4. Quartz crystal based sensor: principle of the 'Tyretronic' pressure and temperature sensor system. (Q Mobil)

Figure 5. The 'Darmstadt tyre sensor' measures road contact by interpreting tyre profile deformation.

transformer effect (**Figure 3**). A short RF pulse at a carrier frequency of 125 kHz supplies the energy for the measurement and returning of a data packet containing the current tyre pressure. The system is to be perfected for launching in 2006.

Quartz crystal sensors

Still another principle has been adopted by IQ Mobil (Munich, Germany) for their tyre pressure monitoring systems. The central part is a quartz volume oscillator producing a controlled amount of 'ringing'. The interrogator module emits a microwave signal (at 2.45 GHz) which is amplitude-modulated with a frequency between 6 MHz and 10 MHz. Inside the responder, the RF burst is rectified and the resulting voltage used to excite the quartz crystal (within approx. 1 ms), Next, the AM modulation is removed from the carrier. The quartz crystal will continue to oscillate at its own frequency, but

subject to the capacitance presented by the pressure sensor. The result is crystal 'pulling' to a frequency removed from the excitation frequency. The resultant ringing (oscillation decay, lasting about 2 ms) is mixed with the carrier frequency, hence modulated by it and returned as an RF signal. The control module measures the modulation frequency of the responder signal and employs the deviation from the excitation frequency to calculate the pressure value. (**Figure 4**). The entyre interrogate-and-respond sequence is completed within 6 ms. The (small) temperature coefficient of the quartz element responsible for the pressure measurement is compensated. In this way, pressure measurements can be performed at an accuracy of ± 0.1 bar (1.45 psi).
The second measurement channel is for temperature and employs its own quartz crystal with a different cut angle and a much larger temperature coefficient. In practice, it allows and accuracy of ± 1 K (kelvin) to be achieved. The

return carrier is alternately modulated with the two crystal resonance frequencies. Extensive tests showed that the system is immune to other RF sources in the 2.4-GHz band (say, from other cars). This is achieved by measures including frequency hopping after each sensor interrogation action. The usable range of the RF links is about 1 m. The size of the module is 22×22 mm and its weight, approximately 14 g. The system will be taken into volume production by the Japanese company Alps. Reportedly the unit cost should remain under 1 US$. The chip could also be programmed to contain data on the tyre used. This may be useful for car production logistics or even to inform the car computer new tyres have been fitted.

Road contact sensors

Still more security is afforded by an additional tyre parameter which is actually the most important: road contact. Using

this real-time information, anti-blocking and vehicle stabilisation systems could be made to work even better. The 'Darmstadt tyre sensor' (**Figure 5**) is a joint development by Continental and the University of Darmstadt (Faculty of Vehicle Technology, Prof. Winner). It records deformation of the tyre profile elements when in contact with the supporting surface. The current version employs a surface-wave sensor in the tyre profile and has not yet left the test bench. The adaptation to 'real life' on the road is problematic because the sensor is expected to measure as well as transmit when it is in contact with the road. At that instant, the RF contact is hindered by the wheel rim. There remains a lot to explore and research. If, however, researchers are successful, they can pride themselves in having reduced the number of road accidents even further.

(040099-1)

iAccess — accessible to anyone? Dear Editor, regarding the impressive iAccess project in your February 2004 issue I would be very interested to know how the iButtons are encoded and how we can be sure that the code can not be traced back to the buyer. After all, I would like to be the only person authorised to open my own door! The question can be extended to other protection systems like magnetic cards, transponders, etc. mentioned in the article.
D. Kokta, Germany (by email)

The author, Ilse Joostens, replies: each iButton has a unique serial number consisting of six bytes. This number is preceded by the family code which is 01 for the DS1990A and followed by a CRC checksum (to detect read errors). Dallas Semiconductor (now Maxim), the manufacturer of these iButtons guarantees that every single iButton has a unique serial number, so there are no two iButtons with the same serial number in the world.

Six bytes corresponding to 2.81 × 1014 possibilities, it is unlikely that problems will occur in producing unique iButtons in the future... Having said that, it is possible to copy a DS1990A iButton. Some months ago I saw a circuit using an AT89C2051 microcontroller on a Russian website capable of emulating a DS1990A iButton. In fact you could store up to 30 serial numbers in memory and emulate one of your choice.

It is possible to copy an iButton with this circuit, however chances are small this will ever happen since some knowledge about microcontroller circuits is required and physical access to one of your iButtons is needed in order to get the unique serial number to emulate.

Other systems like magnetic cards

and transponders have also a unique code, but can be copied, too. It is widely known that credit cards and other bank cards have been copied... while even biometric systems employing transponders have some weaknesses. However, the iButton system still provides more security compared to traditional mechanical keys. If even more security is desired, you may consider combining systems, for example, you can combine a biometric system with an iButton system.

Sound Generation using VB Dear Editor, ever since the Commodore 64 was introduced and perhaps even before that, users were capable of controlling the sound chip in their computers. I remember in those days when my hair was still black I created music and tones with various waveform and levels, even white noise and speech fragments. I designed a program to test the hearing response of my whole family by having them push the space key, once they heard a tone whose level was ramped up. Along came the PC and all changed. Users needed sound cards, which made proper music and speech of course, but robbed small-time programmers and enthusiasts of their chance to control tones and sounds in self made games or small technical computer applications, like electronic test programs, filter evaluation etc. Even under DOS BASIC, programs still allowed a sequence of tones to be created by using the "play" command. But then Bill Gates spoke again and said let there be Windows and Visual Basic and he saw

that they were good. I bought many books to teach myself VB 3, VB 4 up to VB 6, never giving up against better presentiment to try to discover somewhere in a hidden chapter a way to create a few modest tones apart from the ugly Beep command, but every time my hopes where crushed. So I gave up hope in books and combed the Internet. Apart from ready-made shareware or commercial programmes the search machines eluded my quest for an answer. Having been a subscriber to *Elektor* for many years I checked thousands of pages hoping to find an article to deal with the generation of tones under the Windows environment, preferably using VB. It is utterly absurd to have a Soundblaster card in your computer playing dozens of instruments simultaneously and no way to create a single tone by your own program code. And now I am coming to the point: will you have mercy on us small-time programmers and show us how to extract tones from our thousand Pound machines?
Klaus Bartges, Cairo, by email

A Google search using the words "Visual BASIC sound" produces a lot of educational web links, including complete tutorials. Here are a few:

www.vbexplorer.com/ VBExplorer/sound1.asp
http://users.bigpond.net.au/ gradley/vbatutor/ VBALesson6.htm
www.officecomputertraining.com /vbtutorial/tutpages/ page41.asp
http://experts.about.com/q/ 1048/3376005.htm

Also, our book PC Interfaces under Windows (ISBN 0 905705

65 3) includes chapters on sound card control at a very elementary level using Delphi, as well as a program to implement an automated hearing threshold test similar to the one you produced way back in the C64 age.

89C equivalent, please Dear Editor, regarding the Rev Counter for R/C Models project (November 2003), I could only find the 89C2051-24PC in Malaysia — the 89C2051-12PC you specify is not available. Is it possible to use the -24PC as a substitute? According to the datasheets, the IC specs are identical and the only difference is the range of supply voltages it can handle: the -12PC accepts 2.7 V to 6 V and the -24PC 4 V to 7 V. And where can I obtain the hex files for the IC?
K. Cheah (by email)

The 89C2051-24PC is suitable. The suffix (24) indicates the maximum clock frequency in MHz. The hex files are available on disk or from our website as is made abundantly clear in the article. Alternatively, the programmed controller can be purchased directly from us.

Evergreen oscillates Dear people a Elektor, I recently built the Compact AF Power Amplifier from the May 1997 issue. With the quiescent current preset turned fully ccw all measured values match those printed in the circuit diagram. Although I am sure there is no ground loop in my construction, both amplifiers (L and R) produce spurious oscillation between

1 and 4 MHz when the pre-set is turned three quarters cw. Do you recognise this effect or did I make a mistake somewhere?
Dick Flanderijn, Holland (by email)

Although the project is now almost seven years old, the Compact Amp has made it to Evergreen status, hence we include this letter in this month's MailBox. Looking at the impressive PCB sales volumes achieved by this project, the problem can only be said to have been reported sporadically. A suggested cure is to fit a 100-pF cap between the base of T16 and ground. This will however affect the amplifier's sonic response to some extent.

Tension rising! Dear Jan, can I ask two questions about the power supply with the Valve Final Amp from April 2003, please?
The required alternating voltage should be 340 V (I_{max} = 0.7 A). I have had a matching transformer made which supplies 365 Vac under no-load conditions and 340 Vac when loaded with 0.7 A. Is 365 Vac too much of a good thing?
Second, you state that the direct voltage after rectification is 440 Vdc. My calculations tell me that $340 \times \sqrt{2} \approx$ 480 Vdc.
The two above factors cause a high tension of about 510 V in my circuit. Is that a problem?
Patrick Görlach (by email)

The designer of the amplifier, Bob Stuurman, replies: Mr. Görlach's transformer is probably beyond reproach. As a safety precaution I would advise loading in the HT PSU with two parallel connected 230-V, 40-watt bulbs. This load

will draw about 200 mA which is about the same as the amplifier under no signal conditions. Replacing the transformer should only be considered if the HT is far off the 440-V mark with the lamps connected.

Those Elektor drawings
Dear Editor, which drawing or CAD program do you use to make your schematics and PCBs? I'm curious because your drawing style appears to have been identical since the early 1990s when there were no drawing programs I know of.
Serdar Ulukonakci (by email)

Well Serdar this question is asked at least once a week hence we print a reply here. We started drawing schematics on PCs as far back as 1985 using OrCAD and PCB artwork using Ultiboard. Today we employ versions of McCad (www.mccad.com) and Ultiboard (www.ultiboard.com), both heavily customised and extended with our own libraries for circuit symbols and shapes.

CORRECTIONS & UPDATES

FMS Flight Simulator Encoder
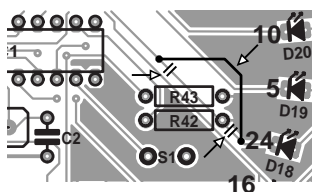January 2004, p. 22-26, 030066-1
In the parts list, the CTS model number for mini joysticks P1 and P2 belongs to the 100-kΩ version. The circuit diagram however shows 10-kΩ joysticks (model no. CTS 25A103A60TB). The 10-kΩ and 100-kΩ versions function equally well in the circuit.

LED Roulette
January 2004, p. 52-55, 030168-1
The PCB has a short-circuit between the anode of D18 and the +5 V rail.
To lift the short-circuit, two tracks have to be cut and a wire link fitted, as shown in the illustration.

Seconds and Minutes Clocks from DCF77
July/August 2003, p. 40, 024005-1
The RC time defined for IC2 needs to be increased by a factor of 10. This requires changing P1 to 1 MΩ and R7 to 330 kΩ.

Stepper Motors Uncovered (2)
December 2003, p. 54-63, 020127-2
On the printed circuit board overlay, the symbols for FETs T1-T16 have been printed the wrong way around. The FETs devices should be mounted the other way around.

Lambda Probe Readout for Carburettor Tuning
July/August 2003, p. 36, 034052-1
In the circuit diagram, the anodes of D1-D10 should be shown as connected to +12 V.

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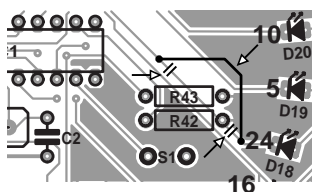January 2004, p. 22-26, 030066-1
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