

# ELEKTOR ELECTRONICS

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## SMS-CONTROLLED MAINS SOCKETS

mains appliance  
control by  
GSM phone



**Electronic RPG  
Dice Roller**

**Active  
Loudspeaker  
System**

**Practical  
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**SMDs? Don't Panic!**



# SMS-Controlled Mains Sockets

remote appliance control by GSM phone

Design by A. Elallali (Unitronic)

Using a simple SMS message sent from your GSM phone, two mains powered loads may to be switched on and off independently, or programmed to do so at a specified time.



Remote control by telephone and other telecommunication systems like transmitters/receivers are no new subjects to *Elektor Electronics* readers. Over a decade ago, we already published the design of a switching unit with seven outputs under the control of DTMF signals sent over the telephone network. Related items in the *Elektor* projects

archive include a Personal Mini Web Server (September & October 2001) and the 535 'Lite Board' which was capable of initiating control actions using SMS.

As far as functionality is concerned, the project described in this article corresponds to the first pro-

ject we mentioned — technology-wise it is more in line with the latter project.

Briefly, the project is about an SMS receiver which has been programmed and configured to take control over two mains sockets — in other words, mains powered loads connected to these sockets may be switched on and off independently by sending an appropriate SMS message. Switching on or off may be immediate, but also at a predetermined time, thanks to the use of a programmable real-time clock.

## GSM modem

As with the Personal Mini Web Server, a special module is employed for the complete telecommunication function (**Figure 1**). In fact, everything related to SMS reception is 'safely left' to the module. The module involved is manufactured by the French company Wavecom ([www.wavecom.com](http://www.wavecom.com)) and may be obtained from their distributors, including Unitronic in Düsseldorf, Germany ([www.unitronic.de](http://www.unitronic.de)). The module type WMOi3 is a dual-band GSM Modem for the 900 MHz and 1800 MHz bands. It is fluent in telephony, Voicemail, SMS transmission and reception, fax (Group 3), data transmission and

many more, all without the need for additional hardware.

The small steel case, which is a bit smaller than a cigarette case, comprises a SIM card tray, an antenna socket and a 50-way connector covering a wide variety of functions and bus systems: power supply, two microphone preamplifiers, two AF power amplifiers, a fully configured RS232 interface, an A/D converter, a keypad terminal, an SPI and an I<sup>2</sup>C bus, connectivity for an external SIM card holder, two digital inputs/outputs and a number of control lines.

Of this plethora of functions offered by the 50-way connector, the present project employs just the two digital I/O lines, two control lines (on/off and busy) and the RS232 port which, by the way, is only required in case you lost the password and would like to return the system to its default values.

### OpenAT

The 'heart' of the SMS-Controlled Mains Sockets unit is certainly not cheap, but definitely worth the investment because it can be programmed in a special programming language called OpenAT. The programmability obviates the need for a microcontroller which is typically expected in such a system.

As you may have surmised from the name of the language, OpenAT finds its roots in the AT command set originally designed by Hayes for telephone modems. An OpenAT application consists of the user-specific, embedded application that was linked to, and developed using, the OpenAT library. The library, in turn, is based on a multitude of different APIs (Application Programming Interfaces) developed by Wavecom:

#### Application Mandatory API

which has to be used by the embedded application.

#### AT Command API

which give access to the set of AT functions (Send AT Commands, subscribe to unsolicited/intermediate indications).

#### OS API

which gives access to the operating system functions (Start/Stop timer,



Figure 1. Heart of the project: the ready-programmed GSM modem supplied by Unitronic.

Read/Write data in Flash memory, Init/Get/Release memory, Delete objects stored in Flash memory).

#### PCM API

which give access to the Flow Control Manager functions, afford sure access to V24 and Data I/O (Open/Close flow, Send/Receive Data).

#### I/O API

for control over the serial link and the

GPIO (here, the two mains sockets).

#### Bus API

which looks after the SPI and I<sup>2</sup>C bus systems.

#### Standard API

with a number of standard C functions.

Figure 2 illustrates the interaction between the APIs and the user application contained in the Wavecom module.

No need to panic at this point — to be able

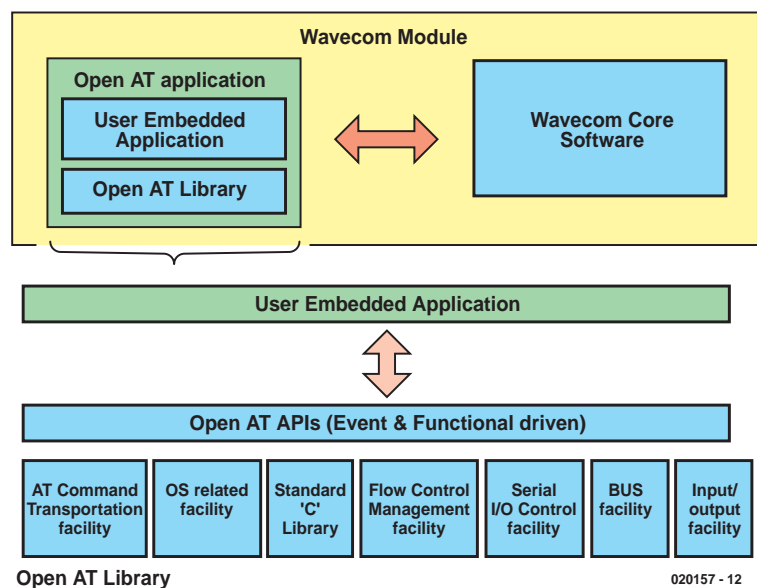


Figure 2. Illustrating the interaction of the APIs with the user application.

to build and use this project no deep knowledge is required of yet another exotic programming language. The crux: all the necessary software is already resident in the GSM modem if you order it from Unitronic. As an exception, the system software can not be offered as a Free Download from the *Elektor Electronics* website, and this may require some explaining. OpenAT (also referred to as the MUSE platform) will set you back about £3,500 and in addition requires an ARM Compiler costing another £2.5 k or so. Such expenditure we reckon belongs in the industrial and high-end professional realms. Obviously, for small volume production and even

one-offs, the software development is better commissioned to Unitronic.

## Around the modem

As you can see from the circuit diagram (**Figure 3**) the additional electronics consist of little more than a level converter, two buffered relay outputs and a mains power supply. The Wavecom GSM module is connected to 50-way connector K5, and the PC (if required) to the 9-way sub-D socket which is wired with the Rx/D and Tx/D lines only. At the

modem side, the RS232 signals appear at TTL level (5 V swing), while symmetrical levels (max.  $\pm 15$  V) are found at the PC side.

The two switching outputs are identical and consist of a buffer transistor type BC547 driving a power transistor type BD139. When the modem output PIO\_x is active High, the BD139 conducts, allowing current to flow through the relay coil. Consequently, the relay contact will pull in, causing the mains voltage to be applied to the relevant load connected to K2 or K3. This is also indi-

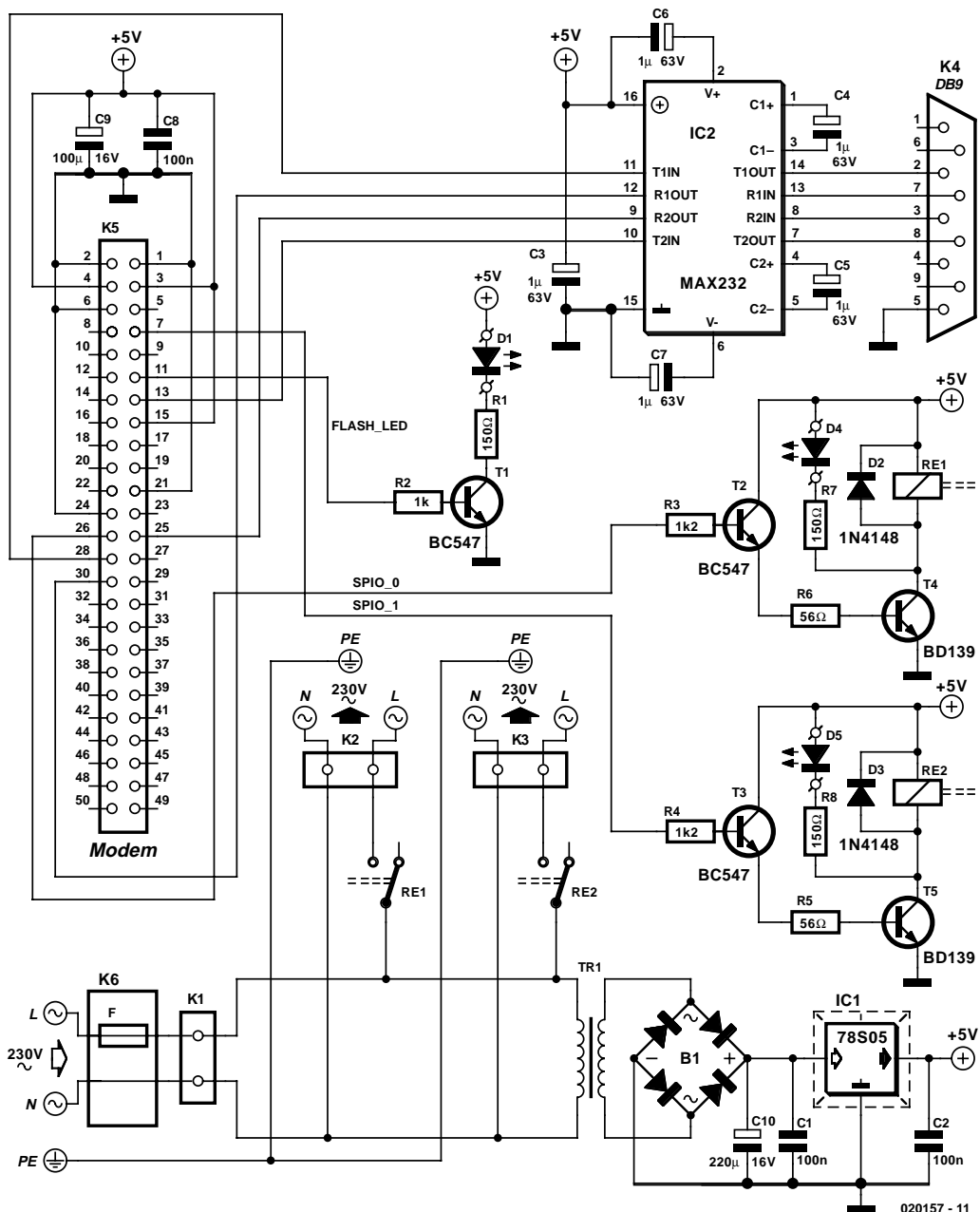


Figure 3. Sparse peripheral circuitry around the GSM modem.

cated by LED D4 or D5 lighting.

The power supply is standard throughout, consisting of a mains transformer, a rectifier, reservoir and smoothing capacitors and a fixed 5-V regulator. The mains transformer must be a **short-circuit resistant** type and the voltage regulator must be **adequately cooled**.

LED D1 is a flashing type. It will flash when the GSM modem receives the network transmitter, and lights constantly when communication takes place, for instance, during power-up and when the

modem attempts to establish a network connection.

### Construction

The PCB designed for the project is shown in **Figure 4**. It complies with relevant electrical safety regulations.

The contacts on connector K5 are spaced just 1.27 mm (0.05 inch) apart, so a soldering iron with a fine tip is required. If necessary, excess solder may be removed using desoldering braid. It is recommended to inspect the soldering job on K5 using

a magnifying glass.

The rest of the construction should not cause problems as the soldering is much more 'spacious'. Be sure to mount polarized components the right way around, and do not forget the five isolated wire links on the board — two of these are under the socket for IC2.

Next, the populated and functionally approved board is mounted in a suitable enclosure. The circuit **must** be built as a Class-1 device. No matter if an ABS or a metal case is used, the protective earth (PE) line must be connected through to the switched sockets as well as to all metal parts of the case.

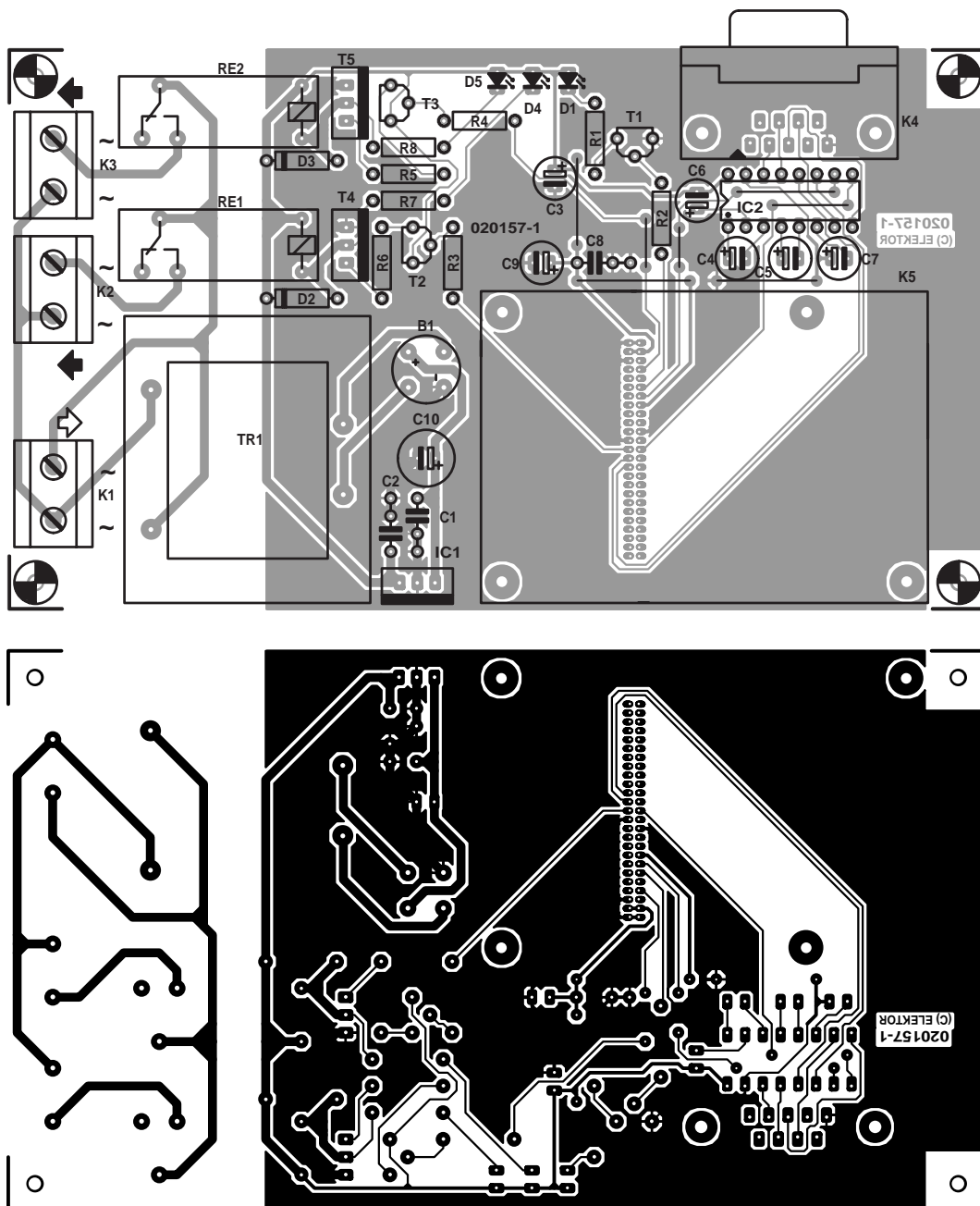


Figure 4. The PCB designed for the project.

## Testing...

During all testing extreme care should be taken to prevent accidental contact with the potentially lethal voltages inside the unit.

Despite all visual checks, the expensive GSM modem should not be inserted into its socket when the circuit is first connected to the mains. The first test is limited to checking the presence of the 5-volt supply voltage. If this is available, unplug the unit from the mains and first prepare the GSM modem.

The modem of course requires a SIM card without a PIN on it (PIN = personal identification number). If a PIN is present, disable it using a GSM phone (if allowed by the GSM provider). Note the phone number that belongs with the SIM card, and write it down somewhere inside the case.

The SIM card inserted into the GSM module using the card tray next to the antenna input. Next, the modem is plugged into its socket. The modem is best secured using screws. Do not use washers or similar rings because of the risk of a short-circuit. Finally, plug on the antenna.

At power-on, some default values are applied:

PIN 0000  
 PIN Check off  
 Reply on

## COMPONENTS LIST

### Resistors:

R1,R7,R8 = 150Ω  
 R2 = 1kΩ  
 R3,R4 = 1kΩ2  
 R5,R6 = 56Ω

### Capacitors:

C1,C2,C8 = 100nF  
 C3-C7 = 1μF 16V radial  
 C9 = 100μF 16V radial  
 C10 = 220μF 25V radial

### Semiconductors:

B1 = B80C1500 bridge rectifier in round case (80V piv, 1.5A peak)  
 D1 = LED, 3mm, yellow, low current  
 D2,D3 = 1N4148  
 D4,D5 = LED, 3mm, red, low current  
 IC1 = 78S05 (do not use 7805)  
 IC2 = MAX232  
 T1..T3 = BC 547B  
 T4,T5 = BD139

### Miscellaneous:

Tr1 = mains transformer, 9 V / 3.6VA, short circuit resistant, e.g. Gerth # 387.09  
 Re1,Re2 = relay, 1 c/o contact, PCB mount, coil voltage 6V, contact rating 250V / 4A (Siemens V23057 B0001-A101)  
 K1,K2,K3 = 2-way PCB terminal

block, lead pitch 7.5mm  
 K4 = 9-way sub-D socket, PCB mount, angled pins  
 K5 = 50-way PCB connector, straight, female, lead pitch 0.05" (Farnell # 672-348)  
 IEC mains appliance socket with fuse (15mA slow) and mains on/off switch  
 GSM Modem = WMOi3 (manufacturer: Wavecom; distributor: Unitronic)  
 GSM antenna with MMCX connector  
 2 mains sockets, panel mount, to BS1363  
 PCB, order code **020157-1**

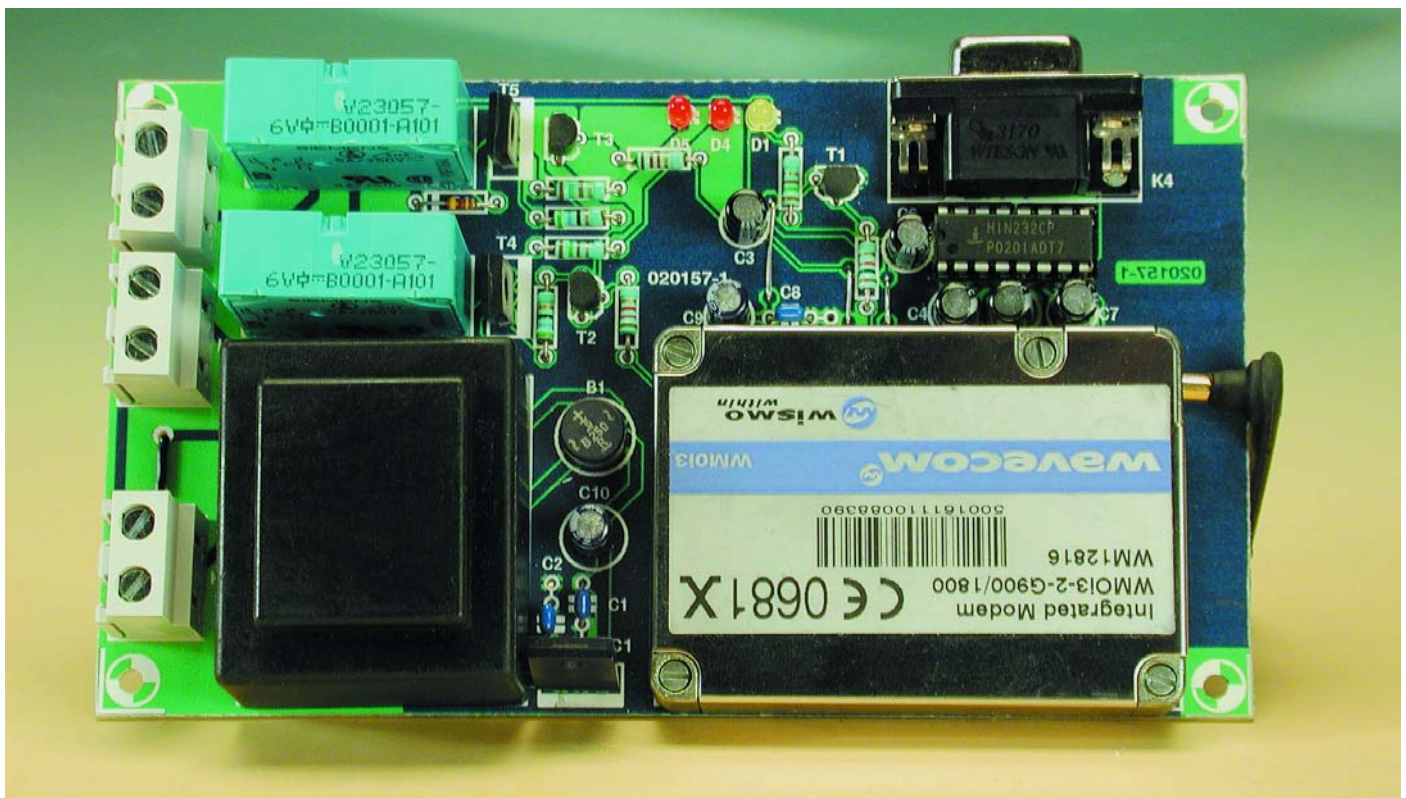
### Suggested suppliers:

#### GSM modem

Unitronic AG, Mündelheimer Weg 9, D-40472 Düsseldorf, Germany.  
 Tel. (+49) 211 9511-0,  
 fax. (+49) 211 9511-111.  
 mail : [info@unitronic.de](mailto:info@unitronic.de).  
 Website : [www.unitronic.de](http://www.unitronic.de)

#### GSM antenna

IMS Connectors Systems GmbH, Obere Hauptstrasse 30, D-79840 Löfflingen, Germany.  
 Tel. (+49) 76 5490 10,  
 fax (+49) 76 5490 1199.  
 Email: [sales@imscs.com](mailto:sales@imscs.com).  
 Website: [www.imscs.com](http://www.imscs.com)



These values may be changed by SMS, in fact this should be done right away to eliminate the risk of anyone being able to switch the sockets on and off! The first SMS to the modem should be used to set a PIN. The command to do so looks like this:

```
change      password;<old
PIN>;<new PIN>
```

For example, if your new PIN is 0815 send this message:

```
change password;0000;0815
```

The GSM modem will change the PIN and return a confirmation message 'password changed'. From then on, the mains sockets can only be switched on and off if the relevant command contains the correct PIN.

Let's try this out straight away by switching on a socket. Her is the

general format:

```
#<password>;socket  num-
ber>,<on/off>,<date>,<time>
```

This may look a bit complex but don't be put off because not all fields have to be filled. If you send this message

```
#0815;1,1,,
```

then the load on socket #1 is switched on instantly. The commas should not be omitted! **Table 1** shows an overview of all available commands.

The RS232 interface should also be tested. The format used is 8,N,1,9600. The OpenAT program is automatically active at power-on. The modem then only responds to the following commands received via RS232:

**AT+RESET**

Returns the modem to its default values. A very useful command if you have forgotten the system PIN.

**AT+WOPEN+2**

Halts the program and returns the modem to normal operation. From then on, the modem may be controlled using AT commands, This mode allows the modem to be installed under Windows and then establish a connection with the Internet. Such a connection is however only possible if the modem was re-programmed with the new GPRS firmware (and if the SIM card you're using is GPRS compatible). The relevant firmware may be obtained from Unitronic.

**AT+WDWL**

This allows a new program to be loaded into the modem. Program loading employs the X Modem protocol which is supported by most communication and terminal emulation programs (including HyperTerminal).

(020157-1)

## SMS Commands

### SWITCHING OUTPUT

Format: `#<password>;<socket number>,<on/off>,<date>,<time>`

This command controls one or more outputs via SMS. Not all fields require data, and some are optional.

<b>Password</b>	When PIN checking is active, the PIN should be entered here.
<b>Socket number</b>	1 = Output #1, 2= Output #2, 0 = both outputs
<b>On/off</b>	1 = on, 0 = off
<b>Date</b>	yy/mm/dd (e.g., 03/09/15 means 15 September 2003). When the field is empty, the current date is used.
<b>Time</b>	hh:mm (e.g., 13.30h). When the field is empty, the current time is used.

It is possible to include multiple switching commands in one SMS message. The second command is simply written after the first one. Subsequent commands do not require the string `#<password>;`  
Up to 16 switching functions may be programmed.

Response: `<command> : accepted`

Examples

<code>#7324;1,1,,</code>	Switch on load #1 immediately
<code>#7324;2,1,03/09/15,12:00</code>	Switch on load #2 on 15 September 2003 at 12:00h
<code>#7324;1,0,03/09/15,13:00,2,0,03/09/15,13:01</code>	Switch on load #1 on 15 September 2003 at 13:00h, switch off load # 2 on 15 September 2003 at 13:01h

### GET SWITCHES

Format: `switch?`

This command retrieves the commands issued to both outputs. The GSM modem replies by sending an SMS containing all received and

accepted actions.

Example  
Command **switch?**

Response **1,1,,;0**  
**2,1,03/09/15,21:00;1**  
**1,0,03/09/15,13:00;2**  
**2,0,03/09/15,13:01;3**

The last digit in each line is an index number. The index is required if the user wants to clear a certain action.

## DELETE SWITCH

Format: **delete switch;<password>;<index>**

This command causes the following action:

**Password** When PIN checking is active, the PIN should be entered here.  
**Index** Index number of the action to be cleared is issued in GET SWITCHES.

Example  
Command **delete switch;7324;1**  
Response **Switch 1 : deleted**

It is also possible to clear all actions in one go by using Index number 16:

Command **delete switch;7324;16**  
Response **Switch 16 : deleted**

## SET REAL TIME CLOCK

This command allows the time and date to be adjusted.

Format: **rtc;<password>;<date>,<time>**

**Date** yy/mm/dd (e.g., 03/09/15 means 15 September 2003)  
**Time** hh:mm (e.g., 13:30h)

Example

Command **rtc;7324;03/09/07,10:49**  
Response **The rtc is set successfully**

## GET REAL TIME CLOCK

Queries the time and date set in the modem.

Format: **rtc?**

Example

Command **rtc?**  
Response **03/09/07,11:01**

## CHANGE PASSWORD

Allows you to change the password.



Format: ***change password;<old password>,<new password>***

***old password*** old PIN  
***new password*** new PIN

Example

Command ***change password;7324,0123***  
 Response ***Password changed***

### DISABLE/ENABLE PASSWORD

Switch PIN checking on and off.

Format: ***password;<password>;<enable/disable>***

***password*** PIN  
***enable/disable*** 0 = disable checking; 1 = enable checking

Example

Command ***password;0123;0***  
 Response ***Password disabled***

### DISABLE/ENABLE RESPONSE

If desired the GSM modem can acknowledge any command entry.

Format: ***response;<password>;<enable/disable>***

***password*** PIN  
***enable/disable*** 0 = switch off acknowledge; 1 = switch on acknowledge

Examples

Command ***response;0123;0***  
 Response none (acknowledge switched off)

Command ***response;0123;1***  
 Response ***Response enabled***

### GET REPORT

This command prompts the modem to supply a status report.

Format: ***report?***

This command is always performed, even if Acknowledge is switched off.

Example

Command ***report?***  
 Response ***Socket 1 : on***  
***Socket 2 : off***  
***Password : enabled***  
***Response : enabled***  
***Time : 11:05***  
***Date : 03/07/29***

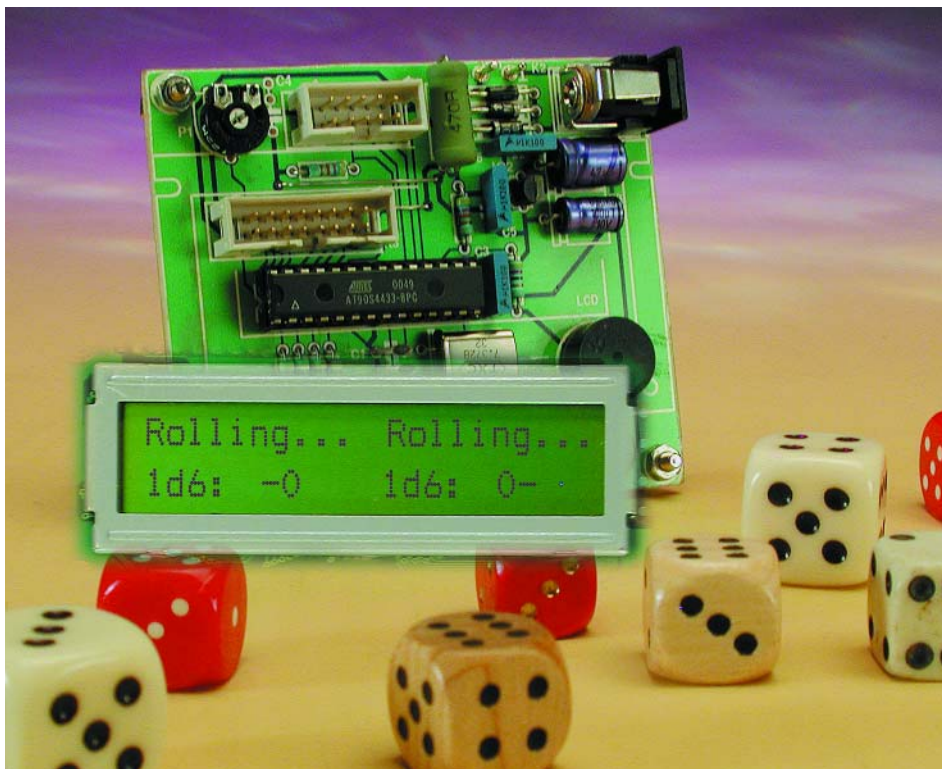
# Electronic RPG Dice Roller

for Role Playing Games

Design by E. Eugeni

[bitlab@tin.it](mailto:bitlab@tin.it)

Role Playing Games (RPG's) are event-driven hence require several kinds of dice, including variants you may never have seen or heard of. This microprocessor-based circuit can generate them all and should delight RPG players.



## Role Playing Games

RPG's require something well beyond the classic six-face cube-shaped die because they are event-driven, and the simulated action can span from a simple coin toss (when players have to choose between yes or no, true or false, black or white, etc.) right up to the full evaluation of a 0 to 100% probability, performed by rolling a die with 100 triangular-shaped, numbered sides. In between these extremes, RPGs employ dice with 8, 10, 20 and even 3 sides. Obviously, the latter does not exist — rather, it is a regular cube with each number (1, 2 and 3) printed, painted or etched on two of the six sides. Baffled? Never heard of RPGs? Have a look at these websites:

[www.webrpg.com](http://www.webrpg.com)

[www.rpgghost.com](http://www.rpgghost.com)

[www.rpg.net](http://www.rpg.net)

If you throw a die on a tabletop and let it roll for a second or two, you expect it to tell you a random number in the range from one to six. This particular range is determined by the physical shape of the die, which — in its classic form — is a cube. Rolling two or more dice gives a wider range of numbers with a

corresponding decrease of the chances that a certain value is obtained.

An electronic version of, say, a fistful of dice requires a circuit exhibiting at least a fair degree of pseudo-random behaviour.

The kind of dice actually used in an RPG is decided by the Game Master. He/she could decide to apply the full range, but equally well, the 6- and 10-scores only, when 100 is achieved by a double throw of 10. However, with the maxim *melius abundare quam deficere* in mind ('better too

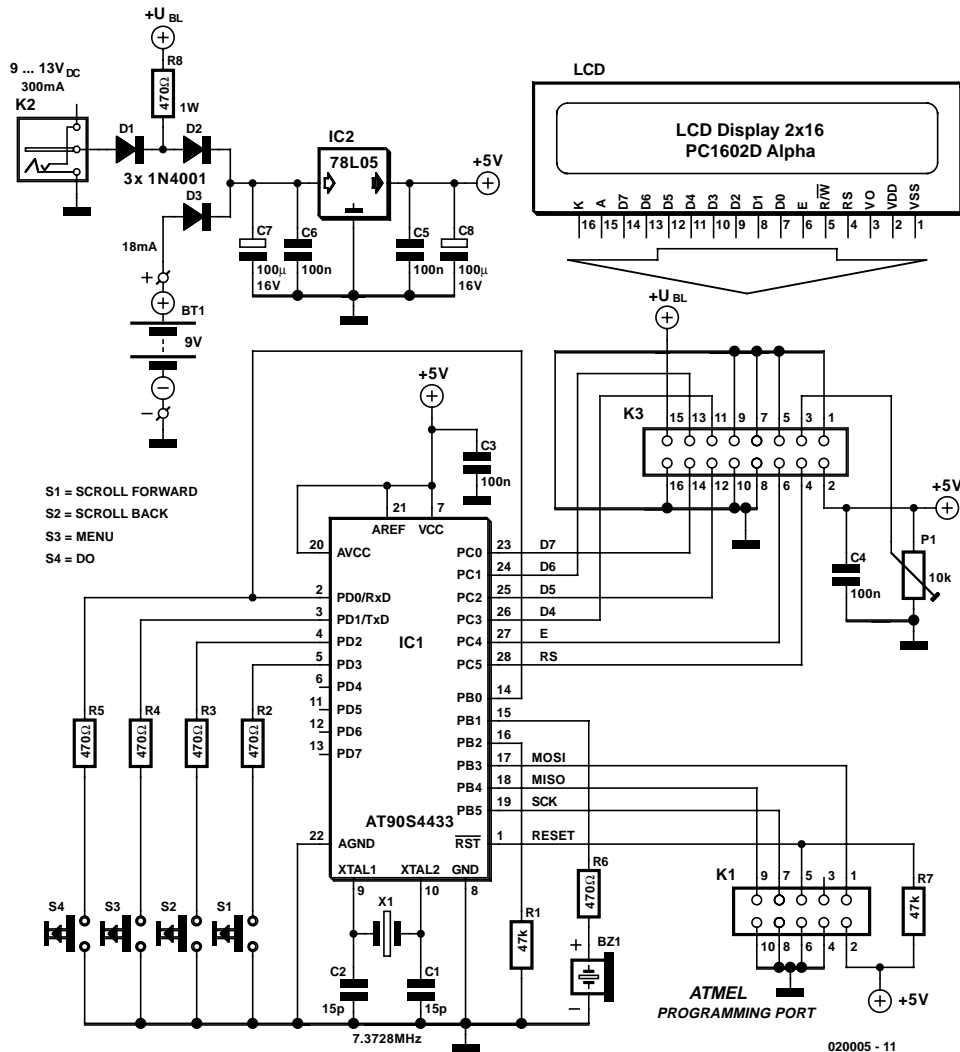


Figure 1. Circuit diagram of the RPG Dice Roller. All intelligence is vested in the Flash microcontroller, IC1.

much than not enough'), the skilled RPG player always carries a small pouch with a dozen or more dice, just in case. In the following text, you'll find the workings of an all-electronic equivalent of such a pouch.

### Circuit description

The circuit diagram of the RPG Dice Roller is given in **Figure 1**. It is a classic application of an Atmel AT90 programmable Flash microcontroller surrounded by input devices (switches S1-S4), output devices (buzzer BZ1 and an LCD) and a power supply (IC2). If you were shown this circuit diagram only, it could just as well be a rocket launcher or an egg timer! Of course, the functionality is determined by the software burned into the AT90 chip.

The circuit has provision for in-circuit programming of the Atmel Flash chip via connector K1. How this may be done will be described in a small article to be published later this year on Atmel ISP (in-system programming). The circuit may be powered by either a 9-V battery or a small mains adapter supplying anything between 9 and 13 volts DC at about 300 mA. Because it is too heavy on the battery, the LCD backlight (BL) (if available) will only light when mains adapter power is applied. The battery may be left connected when the adapter is used. Resistor R8 may have to be redimensioned to suit the BL current requirement of the LCD you're using. The current consumption of the LCD alone is of the order of 18 mA, but this will rise considerably when the BL is used. The indicated value of R8 will establish a

current of just 10 mA in the BL circuit. You may need to change this to a more realistic value (between 47 Ω and 82 Ω) to get a useful backlight level.

These days there is a large choice of LCDs from different manufacturers — new, used basement bargains, NOS, you name it. Here, the commonly seen 2×16 character type is used.

Unfortunately, despite the massive offerings there is no standardisation among manufacturers as far as the position of the 16-way connector on these devices is concerned, and that is why the RPG Dice Roller circuit has a pinheader that allows the LCD to be connected by a short length of flatcable. Pin 1 of the header goes to pin 1 on the LCD connector, pin 2 to pin 2, etc.

The same lack of standardisation is found with the corner holes that enable an LCD module to be secured, hence no holes are provided for PCB pillars on the RPG Dice Roller board.

Not all LCDs with built-in backlighting have the lamp (or LED) connections on pins 15 and 16 as indicated in our circuit diagram. In some cases, these two connections are found elsewhere on the LCD module, and the two wires to them may have to be rerouted a bit. In case of doubt, trail the Internet for a datasheet of your LCD.

Preset P1 allows the LCD contrast to be set for different viewing angles. If you see only black squares, or nothing at all, when the circuit is switched on, turn P1 until text appears. If not, there is a hardware or software problem.

## Construction

Building the RPG Dice Roller should not present problems since a high quality ready-made board is available from the Publishers. The board is shown in **Figure 2**, along with the parts list.

There are no special precautions to mention here, except perhaps that it is recommended to use an IC socket for the microcon-

troller, and that the electrical connections of the pushbutton switches have to be ascertained before fitting these (square) devices on the board. In other words: find the switch in the device and make sure it goes to the right solder pads. The function of each switch is given in the circuit diagram.

Finally, there is no need to connect anything to the Atmel programming port if you use a programmed microcontroller.

- S4 DO (i.e., execute)
- S3 MENU
- S2 SCROLL BACK / '-' (minus)
- S1 SCROLL FORW / '+' (plus)

On power-up, the circuit shows a welcome message for a few seconds, then enters the MENU page and defaults to Roll Dice mode.

Actually, the welcome message is:



## Practical Use

The naming of the four buttons is as follows: (from left to right on the PCB):

and it is accompanied with three short beeps from the buzzer. The MENU page is functionally divided in two rows: the upper one is static, and simply shows the word 'MENU'. The lower is variable, showing the

## COMPONENTS LIST

### Resistors:

- R1, R7 = 47kΩ
- R2-R6 = 470Ω
- R8 = 470Ω 1W (see text)
- P1 = 10kΩ preset

### Capacitors:

- C1, C2 = 15pF
- C3-C6 = 100nF
- C7, C8 = 100μF 16V

### Semiconductors:

- D1, D2, D3 = 1N4001
- IC1 = AT90S4433-8PC, programmed, order code **020005-41**
- IC2 = 78L05

### Miscellaneous:

- BT1 = 9V battery
- BZ1 = DC buzzer, 5V
- K1 = 10-way boxheader
- K2 = mains adaptor socket, PCB mount
- K3 = 16-way boxheader
- S1-S4 = pushbutton, 1 make contact, PCB mount
- X1 = 7.3728MHz quartz crystal
- LCD module, 2 x 16 characters, preferably with backlight, e.g., PC1602D, LM052L, LM016
- Optional: 9-13 VDC 300mA mains adaptor (a.k.a. battery eliminator)
- PCB: order code **020005-1**
- Disk, project source code file, order code **020005-11** (also Free Download)

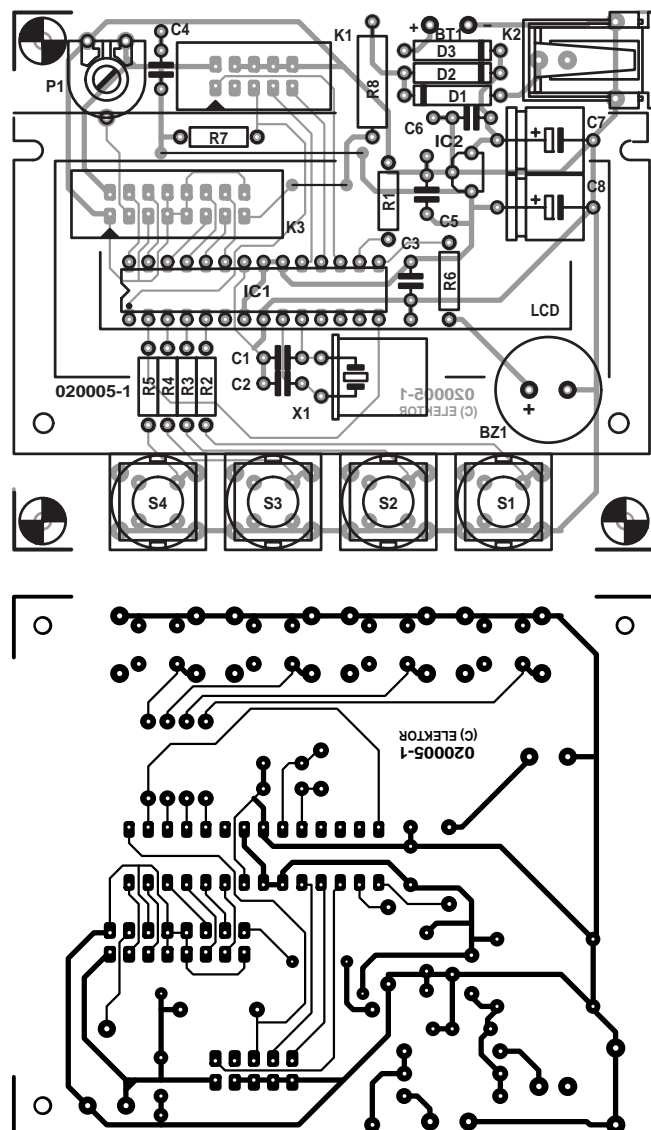


Figure 2. Copper track layout and component mounting plan of the PCB designed for the circuit (board available ready-made).

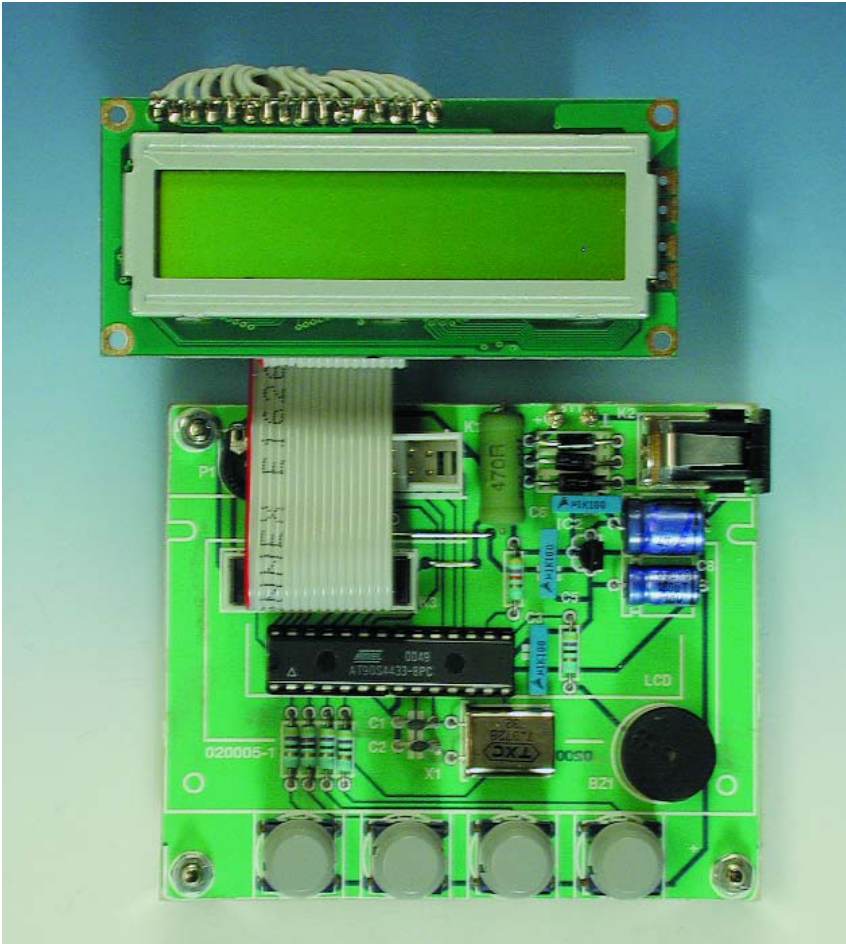


Figure 3. Ready populated board (prototype).

current work mode. You can browse all three work modes by pressing SCROLL BACK or SCROLL FORW.

```
MENU
Roll Dice
```

```
MENU
Armour Class
```

```
MENU
Hit Points Memo
```

Once displayed in the lower line, a given mode can be effectively entered by pressing DO. To get back to the MENU, simply press MENU. Please note a useful shortcut: when you are about to confirm a selection, you can press MENU instead of DO. In other words, the MENU key can be used either to enter or to leave a given mode. This 'unusual' behaviour was suggested by several RPG players, because they often prefer to hit the same key repeatedly instead of two distinct keys.

**Roll Dice mode**

Starting from the first MENU page,

```
MENU
Roll Dice
```

you may press DO or MENU to access the dice selection page.

```
Select dice
1d4:
```

The dice selection page shows a static message, 'Select dice', and the current dice type. According to the standard RPG conventional representation, dice types are shown in compact form '1dn', where '1d' is a prefix, and n is the number of sides (or faces) of the die.

The current version of the firmware performs a simulated throw of the following dice:

- 1d4:** a die with only four sides (triangular base pyramid).
- 1d6:** the classic cube with six

sides.

- 1d8:** a die with eight sides (two square base pyramids glued together).
- 1d10:** a die with ten sides (two pentagon base pyramids glued together).
- 1d20:** a die with twenty sides (it resembles a tiny golf ball).
- 1d100:** also known as the 'percentage die', often replaced with two 1d10's that the user throws twice to get separately tens and units.

As usual, the user can browse the dice type list by pressing the scroll keys. When the desired die type appears on display, the user can 'shake and throw' by pressing and holding DO, or instead he/she can quit by pressing MENU.

Let's follow a step-by-step example of a play action.

**Step 1:**

```
Select dice
1d6:
```

**Step 2:**

Push and hold DO for a while.

```
Rolling... Rolling...
1d6: -0 1d6: 0-
```

The above '-0' and '0-' patterns appear in sequence several times every second, giving a visual confirmation of the roll process. Meanwhile, the buzzer makes a clicking sound, simulating a real dice rolling on the top of a wooden table.

**Step 3:** Finally, you release the button, and the score appears (in this case, 4).

```
[DO] to roll
1d6: 04
```

From now on, to start a new roll you simply push and hold the DO button, repeating the same sequence as step 1. Please note that you cannot now change the dice type, because the prompt message is '[DO] to roll', not 'Select dice' as before. In order to change the dice type, you can push MENU and get back to the dice selection page.

**Armour Class mode**

When the circuit is in Armour class mode,

```
MENU
Armour Class
```

the user can press DO or MENU to access next page:

## May I count on it?

A question that readily arises when you build an electronic counterpart of a well known object like a wooden die, is: "What's the degree of randomness afforded by a true deterministic resource like a microcontroller"? Well, if you try to code some kind of randomness in the firmware, you actually get a pseudo-random algorithm, where the final result can be guessed because it depends on known and foreseeable factors. The approach followed by the author for his project is different, and may be compared to a dart game board which rapidly spins while you throw. How could you guess the landing zone of the dart? You see the target, but since you don't recognize or anticipate the exact position of every numbered section, because the spinning is really fast, you can't aim the dart as you would like to do. Moreover, if you throw tens of darts one after another blindfolded, even at regular time intervals, you could not guess every landing zone. The internal operation of the

PPG Dice Roller software resembles, closely enough, all the above considerations. In order to approximate the random behaviour of real wooden dice, the score you get from every simulated roll is not obtained by a pseudo-random algorithm, but simply capturing a sixteen bit number from a binary counter which is regularly updated hundreds of times every second. Such a counter is physically implemented in the microcontroller, but operates with no direct intervention of the processing unit. When you push the DO key, the firmware takes a snapshot of the count, then computes a final score by applying a set of arithmetic calculations. No need to say, the true 'random' variable in this game is the user, because the score of every throw cannot be guessed, intentionally or not, by looking at the previous results or by following the program execution flow.

Software fans will like to hear that the program source code for the RPG Dice Roller is available as a free download from the Elektor Electronics website, under number 020005-11.

```
Input THAC0
    09
```

where he/she is invited to select a number from 01 to 20, known as THAC0 (THAC zero) value.

The two-digit number can be sequentially incremented or decremented by hitting SCROLL FORW/'+' or SCROLL BACK/'-'. The current version of the firmware does not implement an auto-repeat response of the keys, so you have to push once time for every unit. However, you hear a short beep from the buzzer every time a digit gets changed.

When a suitable THAC0 value is shown, you can press DO to access the next page,

```
[DO] to hit!
Roll: AC:
```

or MENU to leave and get back to the beginning of Armour Class mode.

From here on, the cycle repeats as in Roll Mode: push and hold DO, observe alternating '-0' / '0-' patterns near 'Roll:' and 'AC:', and listen to the buzzer's clicking sound.

```
[DO] to hit! [DO] to hit!
Roll:-0 AC:-0 Roll:0- AC:0-
```

When you release the DO key, you get two numbers as a roll score and armour class hit:

```
[DO] to hit!
Roll:13 AC:-04
```

The above numbers tell you that dice

score was 13, and since your preset THAC0 value was 9, every fighter who holds an AC value equal to or greater than  $9 - 13 = -4$  is to be considered hit or struck. Please note that Armour Class mode is useful every time your RPG scenario involves the 'calculation' of a battle outcome, from the simple man to man fight, to a more complex battle structure or even Star Wars.

### Hit Points Memo mode

This is a simple feature that has little or nothing to do with random numbers and dice rolling. It's only an electronic, hopefully useful, alternative to the paper notebook that's always gone when you need it.

Given that most games involve

## Armour Classes and Neighbouring FAQ

### What's an Armour Class?

An Armour Class is an integer that represents the ability of an enemy to face our attack, in terms of both vulnerability of his armour, bare skin, or whatever else, and ability to dodge and save himself from the hit. Every possible target in a Role Game shall exhibit its own AC value, usually in the range from -19 to 1, as a visible qualification of its fighting skill.

### What's a THAC0 value?

A THAC0 value, acronym of Throw to Hit Armour Class zero, is also an integer, but instead of referring to an enemy being attacked, it qualifies a player who attacks. Every player shall have a THAC0 value, in the range from 1 to 20.

### What's a throw to hit?

A throw to hit is nothing but a single throw of a 1d20, the score of which is subtracted from THAC0 to represent a valid outcome of

the current fight. In other words, combining a THAC0 value from the player who attacks, an AC value from the player who defends, together with the randomness of the dice, your RPG scenario appears both convincing and fascinating.

In order to get a full benefit when operating in Armour Class mode, the user should perform the following steps:

1. Preset a suitable THAC0 value (the circuit always remembers the last value set).
2. Perform a 'throw to hit' action.
3. Discard the roll score and note the AC value.
4. Flag as struck every player who holds an AC value greater than or equal to the noted one.

Please note that roll scores discarded at step 3 are useful in particular game situations, such as the so called fumble, linked to score 1, and the critical hit, linked to score 20. Readers wishing to get closer to the fascinating world of RPG can readily browse thousands of web pages by simply keying 'RPG' or 'Role Playing Games' (sometimes incorrectly written as Roll Playing Games) into an Internet search engine like Google.

some kind of score to keep track of, and Role Playing Games have the so called Hit Points as a measure of the 'vitality' of every character, the Hit Points Memo feature can be a useful resource to permanently note your score between sessions.

As usual, starting from the MENU page,

```
MENU
Hit Points Memo
```

you can push DO or MENU to access the next page,

```
Change HP value
100
```

next, you press SCROLL BACK or SCROLL FORW to decrement or increment the value in the range from 001 to 250, respectively.

As seen for the THACO value, the current version of the firmware does not implement an auto-repeat response of the keys, so you have to push once for every unit. However, to speed up the operation when the digits to scan are tens or hundreds, you can press and hold the DO key, and then hit SCROLL BACK/SCROLL FORW, obtaining a decrement/increment of ten at a time.

If you are curious about Hit Points, please note that every RPG player is given a starting 'vitality' level, usually 4 to 6, times the character level. From

then on, if the player is struck, drinks poison, has an accident or suffers whatever physical damage, he/she drops one or more Hit Points, depending on the relevance of every single negative event.

No need to say, when the Hit Point value reaches zero, the player is out. Now, if the game you're playing is short, you can start with 15 and possibly end with 0 in about three hours, but if the game is long and lasts for days or months, you must carefully keep track of your own vitality history.

The Hit Points Memo can be a useful resource to replace a paper notebook or a lot of loose leaflets, since the internal non volatile memory of the micro maintains its data for tens of years and cannot be erased by a splash of coffee. Have fun!

(020005-1)

# Practical Neural Networks (I)

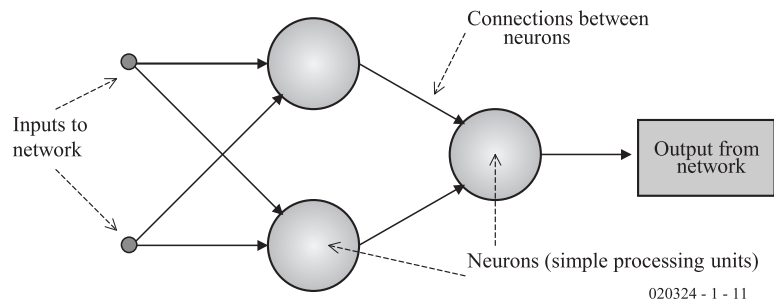
Part I:  
an introduction to Neural Nets



By Chris McLeod and Grant Maxwell

Artificial Neural Networks (Neural Nets or just ANNs for short) are a popular form of Artificial Intelligence (AI). They are based on the operation of Brain Cells and many researchers think that they are our best hope for achieving true intelligence in a machine. If you're a fan of the TV Series 'Star Trek', you'll know that Mr Data is supposed to have a Neural Net brain, as is the robot in the 'Terminator' films.

Although these technological wonders are on the cutting edge of research in Computer Science, they are also well within the grasp of the enthusiastic amateur. The aim of these articles is to introduce this fascinating topic in a practical way, which will allow you to experiment with your own Neural Nets.



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## So, what exactly is a Neural Net?

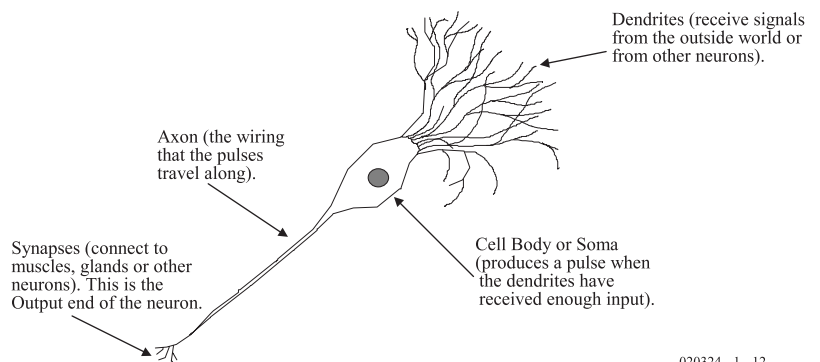
A Neural Net is a network of connected processors. Each individual processor is only capable of a very simple mathematical task, but when many are connected together complex behaviour results. The drawing in **Figure 1** shows a typical neural net.

To understand the Neural Network let's look at its inspiration - the brain.

## It's all in your head

What a layman calls 'Brain Cells' are what a biologist would refer to as Neurons. These are the tiny living cells, which make up our brain and nervous system. There are about 100 billion of them in a typical human. Each one has

Figure 1. A typical Neural Net.



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Figure 2. A Biological Neuron.



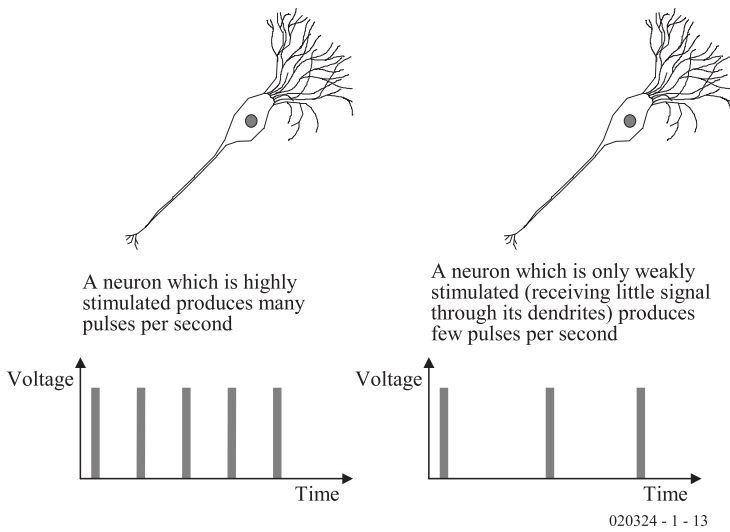


Figure 3. How a neuron processes information.

evolved to be an electronic processor. If you looked at the Neuron under the microscope, it would appear as shown in **Figure 2**.

The Dendrites receive signals from other neurons or the outside world; they are the “receiving end” of the Neuron. When enough stimulus is received by the Dendrites, the Cell Body generates a pulse of electricity which travels down the Axon to the Dendrites of other neurons or to muscles, stimulating them.

As a neuron gets more stimulation through its dendrites, it produces more pulses per second as shown in **Figure 3**. Therefore, the information in the nervous system is frequency modulated.

Some neurons, called Sensory Neurons, collect information from the outside world. The Rods and Cones in your eyes are Sensory Neurons. This stimulus is passed up to the brain along the Axons of the Sensory Neurons. There it is processed by

others, called Interneurons, which are connected only to other neurons. The result of all this is passed to a final set, called Motor Neurons, the axons of which are connected to muscles and glands.

In this way we can read information in from the world, process it and act upon it. These processes are responsible for everything, from simple reflexes to consciousness itself.

### The Birth of the ANN

In 1943 two researchers named Warren McCulloch and Walter Pitts published a paper which started the science of Artificial Neural Nets. It proposed a simple model of the neuron, and Artificial Networks are based on it (in improved form), to this day. The basic idea is shown in **Figure 4**.

The diagram shows four inputs labelled  $i_1$  to  $i_4$ . These are like the dendrites of the biological version and connect to the outside world or

to other neurons. The inputs are “weighted” by four weights  $w_1$  to  $w_4$ . These weights represent the strength of the connections to the cell body in the real neuron. There may, of course, be any number of inputs in reality.

The system works like this. First, each input is weighted by multiplying it by its associated weight and then the result of all the weighted inputs are added together:

$$\text{Sum} = (i_1 \times w_1) + (i_2 \times w_2) + (i_3 \times w_3) + (i_4 \times w_4)$$

Then, if this sum (which in the biological sense is the total stimulus going into the neuron) is above a pre-set threshold, the neuron produces a “1” output; if not it produces a “0”. So, let’s say the threshold is 0.5:

*If Sum > 0.5 then Output = 1*  
*If Sum < 0.5 then Output = 0*

This is a bit like the real neuron which sends out a pulse when its stimulus is big enough.

Let’s try a little example to make sure everything’s clear so far. Suppose we have a neuron with inputs and weights as shown in **Figure 5**, what would its outputs be? Calculate the output from the neuron in the drawing, assuming a threshold of 0.5:

$$\text{Sum} = (0.1 \times 0.5) + (0.5 \times 0.2) + (0.3 \times 0.1) = 0.18$$

Since 0.18 is less than the threshold, Output = 0

### So what’s this good for?

OK, so we have a model of a neuron, but what is it good for? Well, let’s take a visual pattern like that shown in **Figure 6a**. And let’s say we want a device which can recognise it. We can code the dark pixels as ones and the light pixels as zeros. If we connect up our neuron as shown in **Figure 6b**, it will produce a “1” output whenever it “sees” this pattern. You can probably see that even if the pattern isn’t perfect — if the dark pixels aren’t quite ones and the light ones aren’t quite zeros, the neuron will still recognise the pattern (we say that the neuron is noise tolerant).

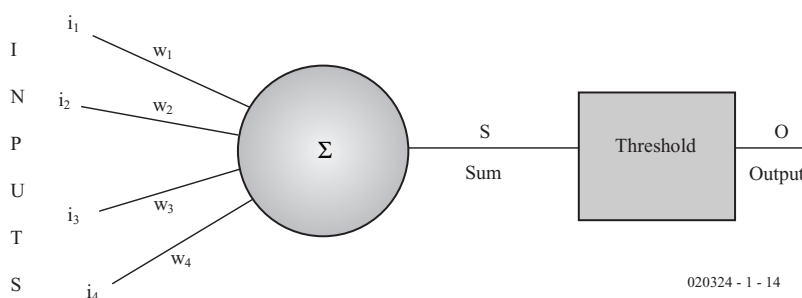


Figure 4. The basic Artificial Neuron.

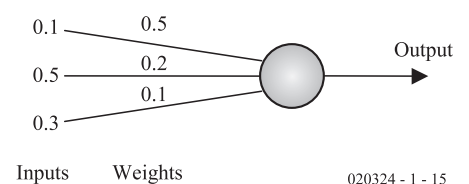


Figure 5. A worked example.

But if we put in a completely different pattern, like that shown in **Figure 6c**, the neuron won't recognise it.

Recognising patterns, even when they're not perfect, is one of the most basic attributes of intelligence. You have to be able to recognise a mate or food or a predator to survive, if you're an animal.

Hopefully, after some thought, you'll be able to see the importance of pattern recognition. Neural nets are arguably the best technique for doing this sort of task. They can also recognise patterns in time, if they are sampled and fed into the network.

## Now Learn!

You'll also see from the example above, that the set up of the weights is critical to the functioning of the network. It's the weights that determine what pattern the network recognises, and setting the weights is the main task of the neural net program.

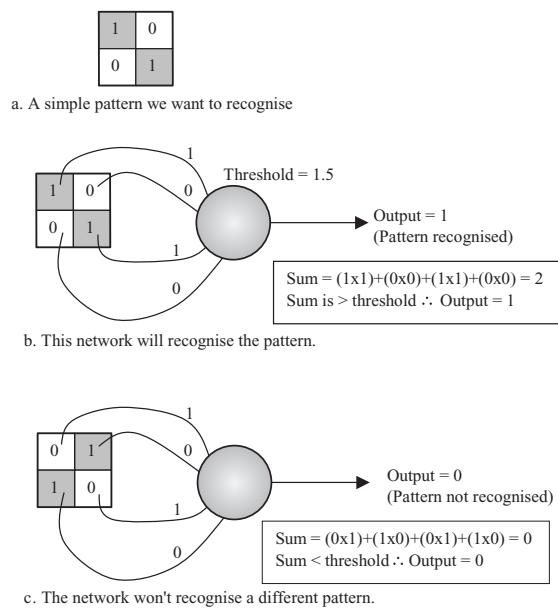
In our example above, these weights have been set by common sense and for a very simple task like this, that is possible. But for complex tasks like recognising hundreds of patterns with a network of neurons, it's impossible. We also want the weights to be set automatically, without a human operator having to interfere; after all, we all learn by ourselves without any external help.

Enter the "Learning" or "Training" Algorithm. This is the part of the neural net which sets up the weights to automatically recognise a pattern. To give a very simple example of how this might work, consider an algorithm for teaching the neuron above to recognise its pattern:

1. If Output is correct then do nothing.
2. If Output is high but should be low, then decrease the weights attached to high inputs.
3. If Output is low but should be high, then increase the weights attached to big inputs.

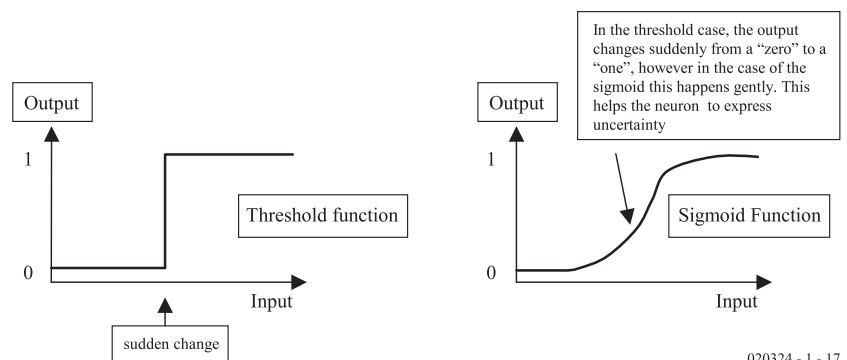
The weights usually start off as random numbers. The other articles in this series are about the various methods of training the network.

Two other points are worth mentioning here. Firstly, by setting up the weights the way you want, you can make the network behave as (almost) any type of logic gate. So don't think of the neural net just as a recogniser — it's more flexible than that. Actually it's more like a trainable combinational logic circuit. Secondly, rather than using a pure binary output as shown in the examples above, we now generally use a mathematical function known as the "Sigmoid" function in



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Figure 6. Using the neuron for pattern recognition.

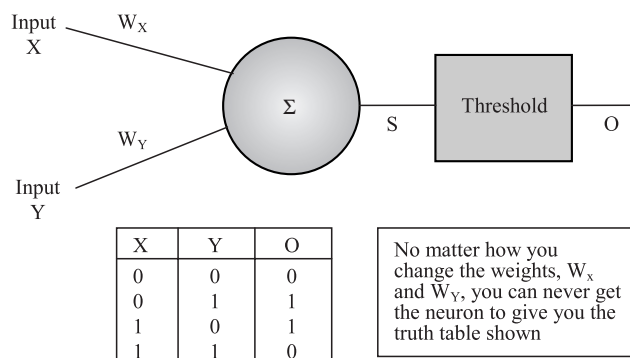


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Figure 7. The Binary and the Sigmoid neuron.

the output of our neurons. This is:

$$Output = \frac{1}{1 + e^{-Sum}}$$



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Fig.8. A single neuron cannot simulate an EXOR gate.

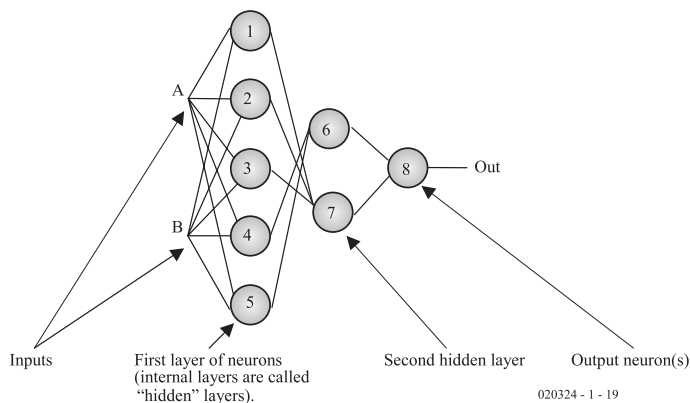


Figure 9. A multilayer neural network.

So, in the example shown in Figure 5 the output of the neuron, using the sigmoid function would be:

$$Output = \frac{1}{1 + e^{-0.18}} = 0.5449$$

Actually, this function always produces an output between zero and one; therefore the output is like the binary threshold. So why use it? Well, its advantage comes in the circumstance of two patterns being very similar. It allows the neuron to express uncertainty by having an output which is "in-between" zero and one. The network is saying "I'm not quite sure". **Figure 7** shows the idea.

### Networks of neurons

Neural Nets had gone from strength to strength in the years since McCulloch and Pitts first proposed their model. But in 1969 a book was published which attacked many of the ideas behind them.

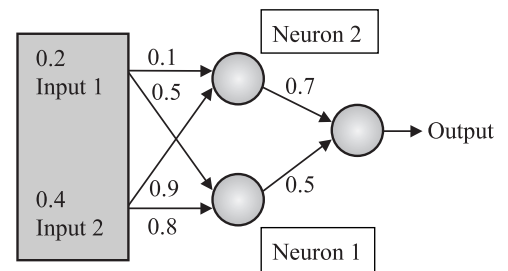
The book was "Perceptrons" by

Marvin Minsky and Seymour Papert. It pointed out a flaw in the basic neuron. The problem was this: No matter what values you set the weights of a two input neuron, it will never be able to simulate an Exclusive OR (XOR) gate as shown in **Figure 8**.

This, along with other arguments in the book, held up progress in neural nets for many years. Most researchers left the field, feeling that if a neuron couldn't even fulfil this simple task, then it wasn't worth researching.

Actually, what was needed to overcome this problem and others like it, was not a single neuron, but a network of them. In fact, a Russian mathematician called Kolmogorov has already shown that a neural network with three layers as shown in **Figure 9** could solve any problem of this kind.

However, although this solution became known, it wasn't until 1982/83 that neural nets really took off as a research area again. At that time, the Back Propagation Algo-



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Figure 10. An example of a neural network.

rithm (to be described in part 2) became well publicised, cheap computing became available to the masses and John Hopfield published his famous paper (to be covered in part 3 of this series).

The neurons in the network work exactly the same way as the ones already covered. Let's do an example to demonstrate with sigmoid neurons, **Figure 10**.

Calculate the output from this network assuming a Sigmoid Squashing Function.

Input to neuron 1 = (0.2 x 0.5) + (0.4 x 0.8) = 0.42.

$$Output = \frac{1}{1 + e^{-0.42}} = 0.603$$

Input to neuron 2 = (0.2 x 0.1) + (0.4 x 0.9) = 0.38.

$$Output = \frac{1}{1 + e^{-0.38}} = 0.594$$

Input to final neuron = (0.594 x 0.7) + (0.603 x 0.5) = 0.717.

$$Final\ output = \frac{1}{1 + e^{-0.717}} = 0.672$$

### Make your own!

You can implement neural nets in hardware, either analogue or digital. A block diagram of an analogue implementation is shown in **Figure 11**.

Three simple amplifiers weight the inputs; these have to have electronically adjustable gains if the network is to learn in real time. The output is then summed and the threshold is applied by a comparator.

This type of circuit has been built using

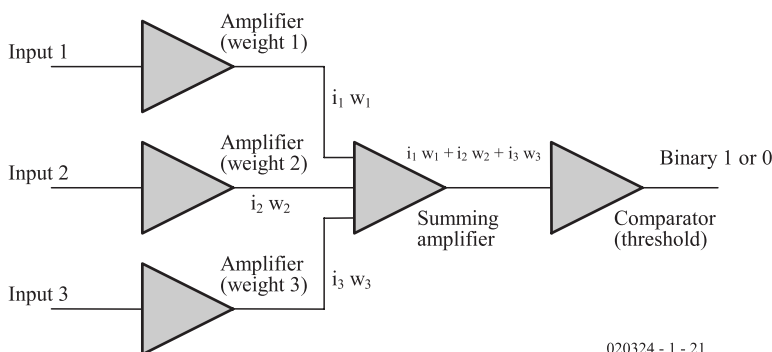


Figure 11. A hardware implementation of a neuron.

discrete components like Op Amps and as part of an Integrated Circuit. The disadvantage of this approach is that it requires a lot of components, should there be many neurons.

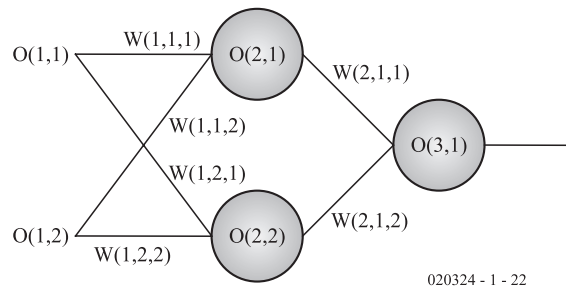
One can fabricate digital circuits in exactly the same way. The weight amplifiers would be replaced by digital multipliers, the summing amplifier by an adder and the comparator by a decoder which would fire if the binary output of the adder was bigger than a threshold value. Digital neural nets are wasteful of resource, however, since there require binary multipliers which are usually large and complex circuits.

By far the most common way to implement a neural net is to simulate it in software. This allows the programmer to quickly change parameters like the number of neurons and how they are connected without costly rewiring and means that large numbers of neurons can be connected easily.

The software approach has many advantages for the amateur experimenter and it is relatively easy to program a neural net in any high level language and many assembly languages (especially those with multiply commands). Given these advantages, it is this approach that we will pursue in the rest of this series.

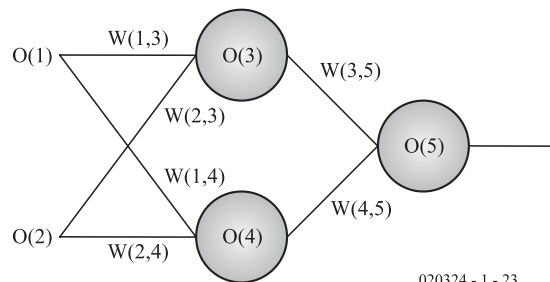
## Software implementation

So how might we code the neural net in software? The easiest way is to store all the necessary parameters in arrays. The inputs to, and outputs from, the network can be stored



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Figure 12. Storing the weights in a typical network.



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Figure 13. A more flexible way of coding the network.

in one array and the weights in another.

For example, we could store all the weights in a three dimensional array:

```
Weights [layer_number, neuron_number, connection_number]
```

And the outputs (and the inputs) from each neuron in a two dimensional array:

```
Output[layer_number, neuron_number].
```

Then the network generated would have the form shown in **Figure 12**.

## Listing 1. Network output calculation

```
FOR L = 1 TO number_of_layers
  FOR n = 1 TO number_of_neurons_in_biggest_layer
    FOR c = 1 TO number_weights_in_biggest_layer
      O(L+1, n) = O(L+1, n) + O(L, c) * W(L, n, c)
    NEXT c
    O(L+1, n) = 1/(1+exp(-1*O(L+1,n)))
  NEXT n
NEXT L
```

## Listing 2. Alternative output programming

```
FOR t = 1 + number_of_inputs TO number of neurons
  FOR f = 1 TO number_of_neurons
    O(t) = O(t) + O(f) * W(f,t)
  NEXT f
  O(t) = 1/(1 + exp(-1 * O(t)))
NEXT t
```

Notice that  $O(1,1)$  and  $O(1,2)$  are the inputs to the network and  $O(3,1)$  is the output. We can make the computer calculate the output from such a network, with the simple algorithm:

1. Initialise all weights and outputs to zero.
2. Set up the inputs, in this case  $O(1,1)$  and  $O(1,2)$ , to the values you want. Layer one is the input to the net.
3. Set up the weights used in the network to the values you want.
4. Calculate the output from the network: see **Listing 1**.

There are actually many different ways of coding the network like this. Another, perhaps more flexible way is to code the weights like this:

```
weight
[neuron_weight_is_coming_from,
```

```
neuron_weight_is_going_to]
```

and just number each neuron's output (and input) sequentially:

```
output [neuron_number]
```

This would give a network of the type show in **Figure 13**.

In this case  $O(1)$  and  $O(2)$  are the inputs and  $O(5)$  is the output. This time the algorithm to calculate the output is:

1. Initialise all weights and outputs to zero.
2. Set up the inputs, in this case  $O(1)$  and  $O(2)$ , to the values you want.
3. Set up the weights used in the network to the values you want.
4. Calculate the output from the network, see **Listing 2**.

Some languages (like C and C++) allow you to dynamically allocate the

array sizes you want, this can be useful in complex networks which change their size. Other languages like FORTRAN and MATLAB allow matrix multiplication which make life easier since all the network equations can be written as matrix operations.

Object Orientated languages allow you to define Neurons and Networks as objects and inherit the parameters of your neurons into your networks.

In low level languages, the weights and outputs may be stored directly in memory and routines written to access and manipulate them.

Calculating the output of the network is known as the *Forward Pass*. The next stage is to change the weights so that the network learns to do better on the next forward pass; this is how the network is trained and is called the *Reverse Pass*.

In the second article we'll have a look at training the network, starting with the most popular learning algorithm — the Back Propagation Algorithm.

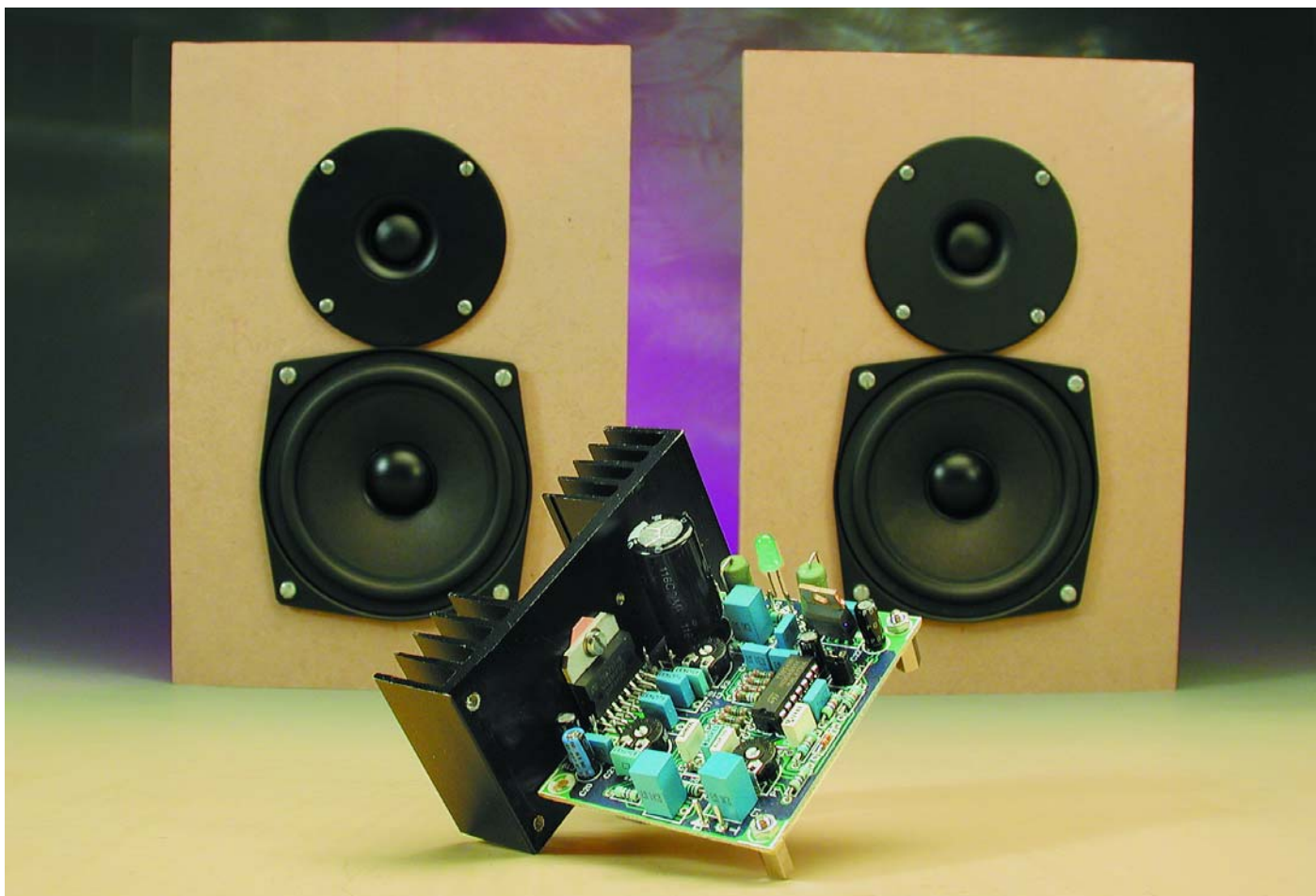
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# Active Loudspeaker System (I)

for multimedia applications

Design by T. Giesberts

The 2-way active loudspeakers described here are primarily intended for use with a PC, but could in principle be used in any other 'medium-fi' application. Since the universal crossover filter can be adjusted to your own liking, you're not tied to using the speakers and enclosure suggested here. Other woofer/tweeter combinations may also be used. An accompanying active subwoofer is currently under design and will be published in the near future.



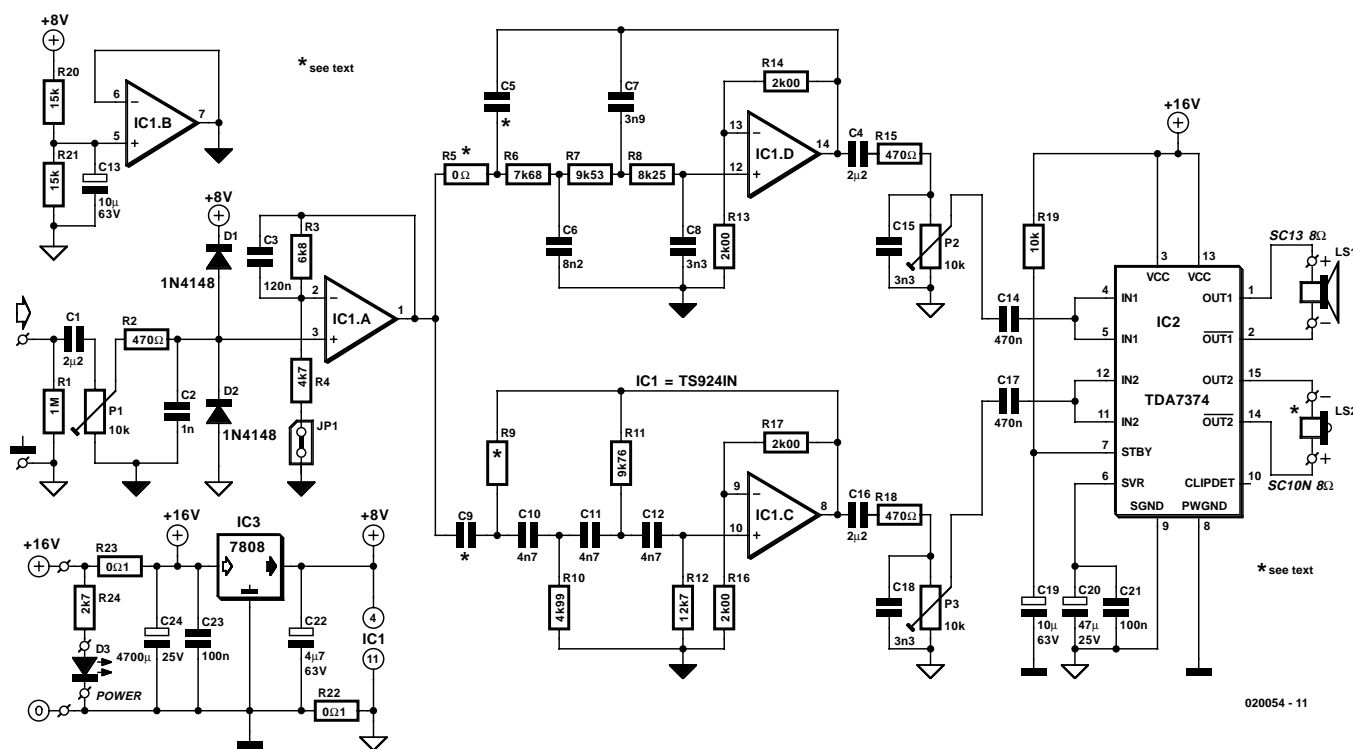


Figure 1. The circuit consists of an input buffer, crossover filter and an integrated dual power amplifier.

The starting point for this design was the irritation with the average to mediocre quality of the majority of PC loudspeakers. We thought that was something that could be improved upon without expending too much effort or money. Of course you don't need the ultimate HiFi quality for the PC, but it would be nice to have a set of loudspeakers that gave a decent reproduction. In that way you could start to enjoy the music from a CD or DVD.

To begin with, we looked for a compact woofer/tweeter combination that gave a good performance at a reasonable cost. Another requirement was that they should be magnetically shielded, because the loudspeakers are likely to be placed close to a monitor or TV, which would be affected by stray magnetic fields. For our prototype we finally decided to use a 25 mm dome tweeter and a 13 cm bass/midrange unit made by Visaton (the SC10N and SC13). Other manufacturers of magnetically shielded speakers worth looking at are Vifa and Monacor (Monarch). For this reason we would like to make it clear that other speaker combinations with associated enclosures

(recommended by the manufacturer) can also be used in this design.

The electronics required to make the loudspeaker active have been kept as simple and yet as adaptable as possible. A two-way crossover filter was designed round a quad opamp, with a choice of slopes, characteristics and crossover frequencies. For use with the speakers recommended by us, the filter was set up as a 3<sup>rd</sup> order Butterworth type with a crossover frequency of 4 kHz.

For the power amplifiers we used an integrated dual bridge amplifier, which requires very few external components. At a supply voltage of 16 V it delivers 2 × 19 W into 4 Ω or 2 × 12 W into 8 Ω. Compared to usual HiFi standards this may seem a bit skimpy, but in combination with speakers with an average efficiency a sound pressure level of about 100 dB can be attained — and that really is very loud!

What else can be added to this summary? One of the advantages is using an 'active' design is that it allows us to overcome a disadvantage found with many small loudspeaker enclosures. Most enclosures with a volume of a few litres tend to

have a poor response at the lower end of the frequency range. For this reason we have included a corrective filter that can be activated with a jumper and which boosts the frequencies between 1000 Hz and 100 Hz up to a maximum of 6 dB at 100 Hz. Our prototype seemed to benefit from this addition and this correction will probably also have a positive effect with other speaker combinations having similar bass/midrange units.

### The electronics design

Now that the introduction is out of the way we can start to look at the circuit diagram. This is shown in **Figure 1** and consists of three distinct sections:

#### Input buffer and supply

When we look at the circuit diagram in the usual way, from left to right, we first see a terminating resistor, isolating capacitor and trim pot P1. This feeds the signal into an input buffer built around IC1a, which forms part of quad rail-to-rail opamp TS924IN. This type is distinguished by its relatively large output current of up to 80 mA.

R2 and C2 form a low-pass filter that suppresses any high frequency interference. The network C3/R3/R4 provides the previously mentioned correction at low frequencies; closing JP1 enables this filter.

In order to avoid the need for a symmetrical power supply, but still obtain the optimum signal processing by the buffer and filters, we have used IC1b to create a stable virtual ground. C13 decouples the output of potential divider R20/R21, providing a virtual ground at exactly half the supply voltage. The large output current capability of the TS924IN is obviously a great advantage in the circuit round IC1b.

To avoid supply-borne interference from affecting the input buffer and filters, opamp IC1 has been equipped with its own voltage regulator (IC3). For proper operation of this 8 V regulator, the supply voltage to the active system should be at least 11 V. Resistor R22 has been added to separate the signal ground and supply ground for cases where a single power supply is used for two or more channels. When each channel has its own power supply then R22 can be replaced with a wire link.

**Filter**

Next comes the crossover filter.

As can be seen in the circuit diagram, the output of the input buffer is fed to two filter sections. These are built round the two remaining opamps of IC1. The low-pass filter is built round IC1d and the high-pass filter is found round IC1c. For the design of the filter we started out with a 4<sup>th</sup> order configuration, so that the same PCB could be used with simpler filters just by leaving out some components.

We have already calculated the values for several variants. **Table 1** shows the component values for a 3<sup>rd</sup> order Butterworth filter and a 4<sup>th</sup> order Linkwitz-Riley filter with crossover frequencies at 1, 2.5 and 4 kHz. With the Visaton loudspeakers used in our prototype we found that a 3<sup>rd</sup> order Butterworth filter with a crossover frequency of 4 kHz gave the best result. The component values given in the circuit diagram are therefore for this type of filter. When we used a 4<sup>th</sup> order Linkwitz-Riley filter at 4 kHz the measurements showed that there were problems with the radiation pattern due to the large phase shifts this filter produces. The 3<sup>rd</sup> order Butterworth variant noticeably suffered less from this. The Linkwitz-Riley values are therefore mainly included for experimentation purposes.

Take care with the connection of the speakers when using the Linkwitz-Riley filter, because the connections to the tweeter are then reversed. On the PCB the polarity indicated is for use with 3<sup>rd</sup> order Butterworth filters. (In this case the tweeter is therefore 'out of phase' compared to the woofer!) And as a final point of interest: the

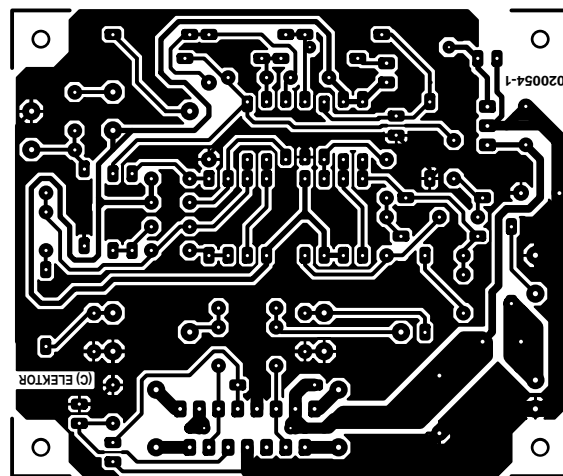
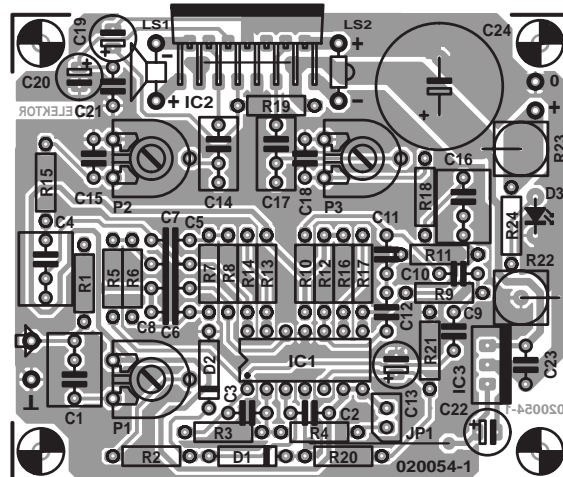


Figure 2. It is amazing that this compact PCB contains a crossover filter as well as a 2 x 20 W power amplifier!

crossover point of Butterworth filters is at -3 dB, for Linkwitz-Riley filters it is at -6 dB.

**Power amplifier**

The output signals of the filters are fed to the power amplifiers via presets P2 and P3. The potentiometers compensate for the different efficiencies of the woofer and tweeter. Many dome tweeters are about 3 dB louder than small bass/midrange speakers at the same input level. However, the loudspeakers chosen for this design do have similar efficiencies, so that in practice both P2 and P3 can be turned to their maximum level.

For the power amplifier we've chosen a TDA7374B double integrated amplifier. These are primarily intended for automotive use, but are obviously also very suitable in appli-

cations such as these. This IC requires surprisingly few external components (no Boucherot network, nor output capacitors) and also contains adequate internal protection circuits against overheating and short circuits. Due to all these features our dual power amplifier is a shining example of compactness. This is clearly seen in the circuit diagram.

We have already mentioned the output power. With a load of 8 Ω loudspeakers IC2 can be cooled using a small heatsink with a thermal resistance of 3 K/W. R19 and C19 ensure that virtually no pops are heard when the amplifier is switched on (there is always a small offset voltage at the output of the amplifier). RC networks R15/C15 and R18/C18 restrict the bandwidth of the power amplifiers in order to min-



## COMPONENTS LIST

### Resistors:

R1 = 1M $\Omega$   
 R2,R15,R18 = 470 $\Omega$   
 R3 = 6k $\Omega$   
 R4 = 4k $\Omega$   
 R5 = 0 $\Omega$   
 R6 = 7k $\Omega$ 268  
 R7 = 9k $\Omega$ 53  
 R8 = 8k $\Omega$ 25  
 R9 = open \*  
 R10 = 4k $\Omega$ 99  
 R11 = 9k $\Omega$ 76  
 R12 = 12k $\Omega$ 7  
 R13,R14,R16,R17 = 2k $\Omega$ 00  
 R19 = 10k $\Omega$   
 R20,R21 = 15k $\Omega$   
 R22,R23 = 0 $\Omega$  5W  
 R24 = 2k $\Omega$ 7  
 P1,P2,P3 = 10k $\Omega$  preset

### Capacitors:

C1,C4,C16 = 2 $\mu$ F2 MKT, lead pitch 5 or 7.5mm  
 C2 = 1nF, lead pitch 5mm  
 C3 = 120nF, lead pitch 5mm  
 C5 = open \*  
 C6 = 8nF2, lead pitch 5mm  
 C7 = 3nF9, lead pitch 5mm  
 C8,C15,C18 = 3nF3, lead pitch 5mm  
 C9 = wire link \*

C10,C11,C12 = 4nF7, lead pitch 5 mm  
 C13,C19 = 10 $\mu$ F 63V radial  
 C14,C17 = 470nF  
 C20 = 47 $\mu$ F 25V radial  
 C21,C23 = 100nF, lead pitch 5mm  
 C22 = 4 $\mu$ F7 63V radial  
 C24 = 4700 $\mu$ F 25V radial, lead pitch 7.5mm, diameter 17mm max.

### Semiconductors:

D1,D2 = 1N4148  
 D3 = LED, green, high-efficiency  
 IC1 = TS924IN (ST, from Farnell)  
 IC2 = TDA7374B (ST, from C-I Electronics, [www.dil.nl](http://www.dil.nl))  
 IC3 = 7808

### Miscellaneous:

JP1 = 2-way pinheader w. jumper  
 LS1 = SC13 8 $\Omega$  Visaton (Conrad Electronics)  
 LS2 = SC10N 8 $\Omega$  Visaton (Conrad Electronics)  
 Heatsink for IC2: 3 K/W  
 Wood: 12 mm MDF — see Figure 4  
 Wadding material (BAF)  
 PCB, order code **020054-1** (see Readers Services pages)

\* see text and Table I

imise the effect of any HF interference. In principle it would have been better to place these networks after the potentiometers, but then the bandwidth will vary noticeably. C20 decouples the internal potential divider, which supplies several stages with half the supply voltage and which is also responsible for supply ripple suppression, which is about 50 dB at 100 Hz.

## The PCB

Figure 2 shows the PCB that was designed to hold the electronics for the active 2-way loudspeaker.

There is not much to be said about the PCB. The layout is fairly well organised and the various connections are clearly marked. At the bottom-left are the input pins, diagonally opposite (top-right) are the connections for the supply voltage and a bit below that we find power LED D3. The connectors for the woofer and tweeter (LS1 en LS2) are on either side of IC2.

The wire links on the board deserve a mention. There are two: one just next to R20 and another underneath (!) the pins of IC2. The last could also be soldered to the underside of the PCB, but in either case an isolated wire should be used for this link. IC2 has been placed near the edge of the PCB, mak-

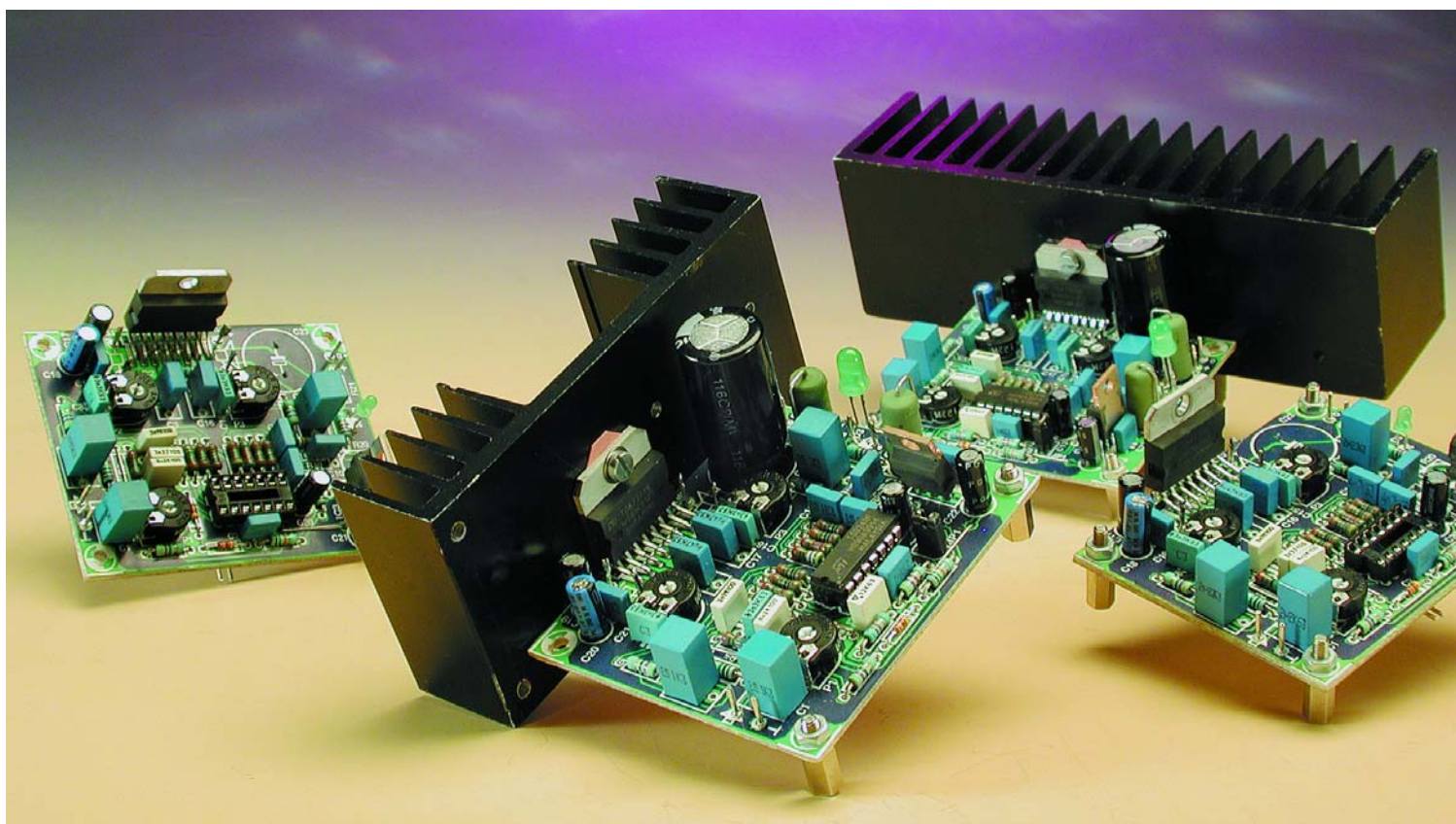


Figure 3. A few prototypes usually precede the final PCB.

ing it easy to mount a small heatsink (3 K/W) to it; remember to use an isolating washer between the IC and heatsink!

Once the PCB has been populated and tested, there are several possibilities for completing the construction. It can be mounted inside the loudspeaker enclosure, it can be mounted in a separate box (probably as a two-channel version) or it can be combined with a subwoofer that will be described in a forthcoming article. A separate box isn't a bad idea since we are thinking of adding a tone control to this system. But at the end of the day the choice is yours.

The supply can be provided by the usual combination of a transformer, bridge rectifier and smoothing capacitor. Each channel requires a transformer of 12 V/15 VA and a smoothing capacitor of 4700 µF/25 V. For a stereo version these values should be doubled. When a stabilised supply is used, the voltage may be increased from 16 V to a maximum of 18 V, which increases the output power somewhat. At the moment we're designing a dedicated power supply for this active loudspeaker system, so it may be wise to wait a little before building the power supply.

### Woodwork

The size and construction of the loudspeaker enclosure depends primarily on the size of the woofer that is used. The Visaton SC13 used here is mounted in a closed box with a volume of about 4 litres. This makes the construction

Table 1

	3 <sup>rd</sup> order Butterworth			4 <sup>th</sup> order Linkwitz-Riley		
	1 kHz	2.5 kHz	4 kHz	1 kHz	2.5 kHz	4 kHz
R5	link	link	link	6k34	6k34	6k98
R6	8k06	6k65	7k68	13k3	9k31	10k7
R7	8k25	8k45	9k53	6k49	7k68	8k25
R8	6k81	8k06	8k25	9k31	7k50	8k45
C5	open	open	open	22 n	10 n	5n6
C6	33 n	15 n	8n2	39 n	18 n	10 n
C7	18 n	6n8	3n9	18 n	6n8	3n9
C8	15 n	5n6	3n3	8n2	3n9	2n2
R9	open	open	open	7k50	6k49	7k15
R10	5k23	4k53	4k99	3k83	3k32	3k65
R11	10k2	8k87	9k76	11k0	9k53	10k5
R12	13k0	11k5	12k7	19k6	16k9	18k7
C9	link	link	link	18 n	8n2	4n7
C10	18 n	8n2	4n7	18 n	8n2	4n7
C11	18 n	8n2	4n7	18 n	8n2	4n7
C12	18 n	8n2	4n7	18 n	8n2	4n7

Table 1. Component values for the filters at different frequencies. For the 3<sup>rd</sup> order Butterworth filter C5 and R9 aren't mounted and R5 and C9 are replaced by wire links.

a fairly straightforward job, since a closed box is little more than six panels that are glued together. This may seem a bit difficult to the inexperienced carpenter, but once the wood

has been cut to size then the rest of the job should be simple if you use some clamps. In any case, it is an advantage that no special baffles or ports are required. The only part that

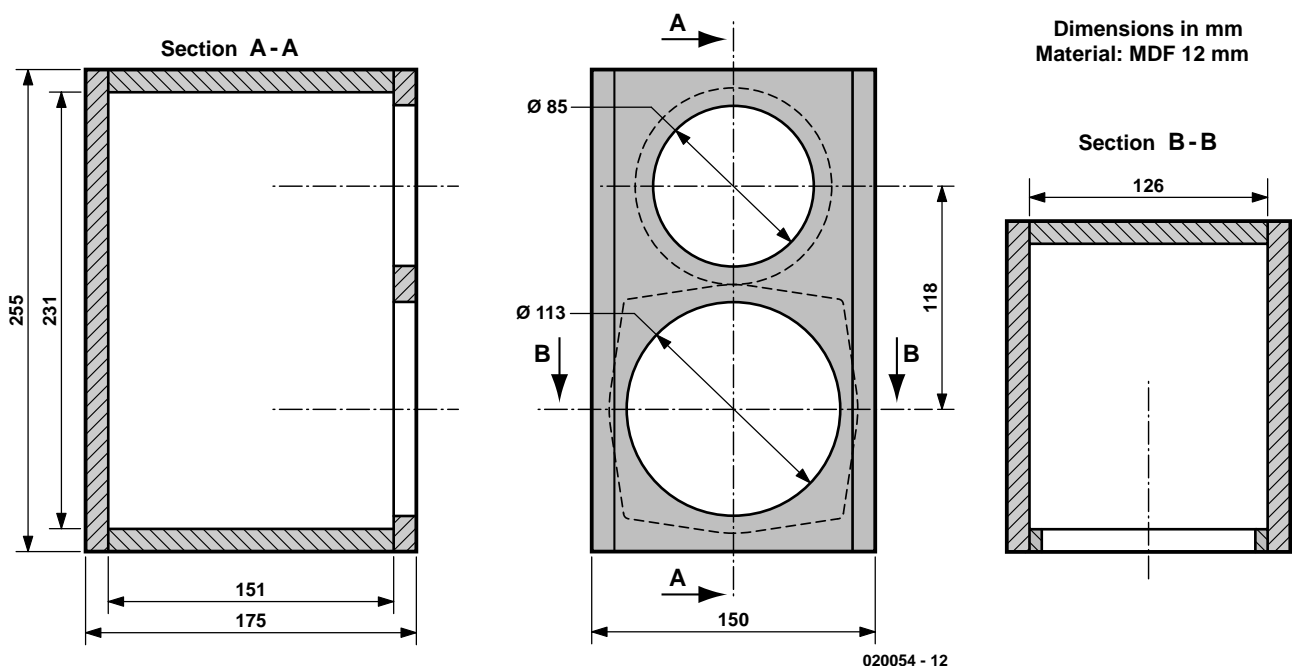


Figure 4. Design drawings for the enclosure, complete with all measurements. We've assumed that 12 mm thick MDF board is used.

is a bit tricky is the cutting out of the holes for the speakers.

Due to the small dimensions of the box, there is no need to use thick wood (although you could if you wanted to). We have therefore based the drawing shown in **Figure 4** on MDF board with a thickness of 12 mm. This drawing shows all the details. The required acoustic damping of the enclosure is done by filling it loosely with polyester wadding. The connectors can be mounted on the back panel. It may be unnecessary to say this, but when the electronics are mounted inside the enclosure it is important that the heatsink

is on the outside.

We would like to make clear that the design shown in **Figure 4** does not have to be strictly adhered to. A different style of enclosure is also acceptable, as long as its volume is near the recommended 4 litres. The main photo with this article shows that we've also deviated from the standard 'shoe box' design for the prototypes. We tried out some triangular designs for our enclosures, mainly for originality. An advantage of this is that there won't be any standing waves, but this comes at the expense of added complexity since three of the five panels now

have edges with 'difficult' angles of 30° and 73.9°! The front and base panels are the easiest to make since they still have normal 90° edges. We've used an equilateral triangle for the base panel and the top panel slopes down from the front at an angle of 30°. Those of you who are interested in this special design can download the drawings from our website.

There are several options for finishing off the enclosures. An 'old fashioned' veneer is of course a possibility, but they could also be covered with self-adhesive vinyl or another material. Spraying with paint is another popular option and for the perfect finish you could ask somebody at a garage to do it for you.

(020054-1)

## Specifications (using a 16 V supply voltage)

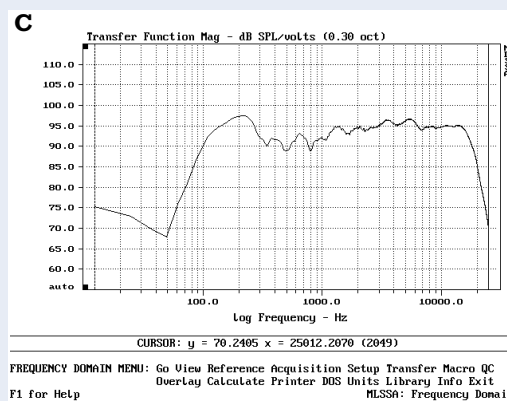
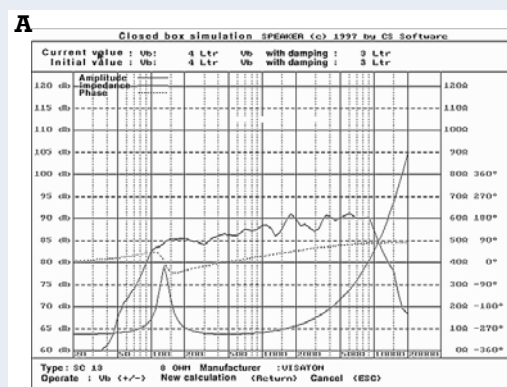
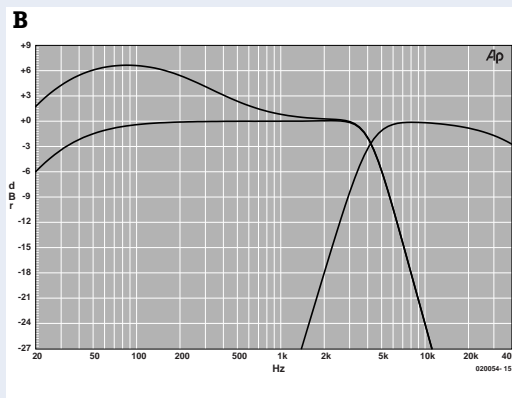
Input impedance	10 kΩ
Sensitivity (12 W/8 Ω, JP1 open, P1/P2/P3 max.)	270 mV
Distortion + noise (1 W/8 Ω, 1 kHz)	0.013 % (B = 80 kHz)
Bandwidth woofer amplifier (P2 max., JP1 open)	32 Hz - 4 kHz
Bandwidth woofer amplifier (P2 half, JP1 open)	25 Hz - 4 kHz
Bandwidth tweeter-amplifier	4 kHz - 45 kHz
Output power per amplifier (THD+N = 0.5 %)	12 W (8 Ω)
	19 W (4 Ω)
Quiescent current (no load)	0.17 A
Bandwidth amplifier + box (-3 dB)	100 Hz - 18 kHz

Apart from this list of figures we've also provided three graphs. The first (A) is a simulation of the frequency response for the SC13 woofer. The absence of prominent peaks or troughs make this graph look fairly neat, but it does show a steep drop at the lower end of the frequency range: at 100 Hz the amplitude is nearly 8 dB lower than at 2 kHz. A low-frequency booster therefore isn't a superfluous luxury.

The second graph (B) shows the measured response of the filters and the low-frequency booster. It is noticeable that the crossover point is neither exactly at -3 dB nor exactly at 4 kHz. This is mainly due to the tolerance of the capacitors used in the filters. In practice these deviations can be completely ignored.

Graph C shows the measured frequency response of the loudspeakers when driven by their amplifiers. From this it is clear that the low frequency boost really should have been set a bit higher. Keep in mind that when the loudspeaker is placed

on a desk or near a wall that the lower frequencies will be boosted more, making the curve somewhat flatter. The small peak near 200 Hz is caused by the positioning of the loudspeaker in the room where the measurements took place and it varies depending where the loudspeaker is positioned!



# Battery Voltage Guard

adjustable to any voltage

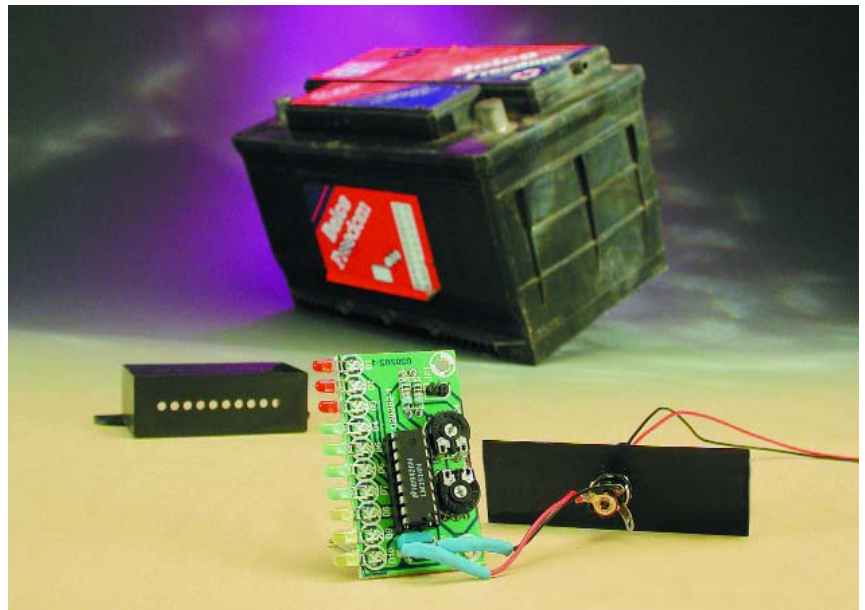
Design by A. Schilp

This month's Mini Project may be used to guard any voltage ranging from a minimum of 3 V to a maximum of 25 V. It can, therefore, be used to keep a constant eye on the voltage of a car battery. But it can also be used with the receiver batteries of a radio-controlled model, for example.

Even though this is an extremely simple electronic circuit, the voltage guard, equipped with a 10-segment LED display, offers a number of distinct advantages. Firstly, this circuit is very compact, it can therefore easily be built into a suitable case — the circuit board is no bigger than a matchbox and there will generally be no problem to find some space for it. Secondly, the circuit (especially when in 'dot-mode') is very thrifty with current. The third, and by no means the least important advantage, is that the circuit can be used in a large number of different applications, because the voltage range that can be guarded can be varied over quite a wide range. A voltage of 3 V is the minimum (the circuit doesn't work below that) and 25 V is the maximum (it will break down above that level). But within that range, the guard voltage can be freely chosen with the aid of two potentiometers. As a consequence, the application need not be limited to a voltage guard for a car battery — the circuit may also be used as an indicator for the batteries used in radio-controlled models, battery-powered drills and lawn mowers, etc. It may also be used as a battery tester, but only with batteries having a terminal voltage of 3 V or higher; testing of individual 1.5 V cells is not possible.

## LM3914

The circuit has been designed around the integrated display driver type LM3914, which



— we can safely assume — is familiar to *Elektor Electronics* readers. This IC by itself is actually a complete voltmeter circuit because it was designed to indicate a varying input voltage directly on an LED scale. Internally, the LM3914 contains 10 comparators with a current source output, plus a reference source and a ladder shaped voltage divider that provides the necessary reference voltages.

**Figure 1** illustrates that the cir-

cuit contains hardly any more components than the LM3914 and the ten (high-efficiency) LEDs. The lower limit of the measuring range, at which the first LED of the scale (D10) will light, is adjustable with P2. The upper limit is set with P1. Every LED in the scale represents one tenth of the measuring range. If the voltage remains below the lower limit then no LED will be on. When the voltage is higher than the upper limit, D1 will remain on.

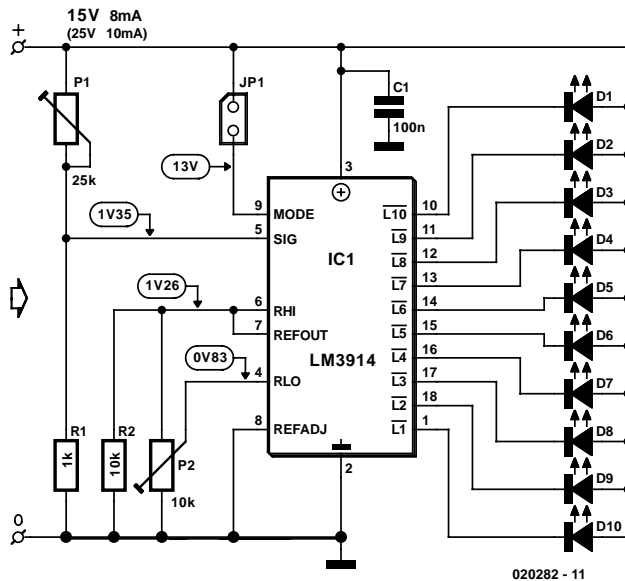


Figure 1. All that is required for the battery guard is already present in the LM3914.

which therefore also acts as the power supply for our circuit. A nice feature is that by making use of the reference voltage of 1.25 V on pin 7, the measurement value indicated by the LEDs always corresponds to the power supply voltage to be measured, without affecting the accuracy.

Indeed, the brightness of the LEDs is not affected by the power supply voltage either — a consequence of the above mentioned current source outputs. The load presented by the parallel combination of R2 and P2 to pin 7 defines the operating point of these current sources. When calculating the current through the LEDs, you'll find that this current is about 10 times greater than the current through R2 and P2. Because the voltage at pin 7 is 1.25 V, the current for each LED amounts to  $1.25/5000 = 2.5$  mA. That is exactly the current to suit a high-efficiency LED. If required, the current may be increased by lowering the value of R2.

### COMPONENTS LIST

#### Resistors:

- R1 = 1kΩ
- R2 = 10kΩ
- P1 = 25kΩ preset
- P2 = 10kΩ preset

#### Capacitors:

- C1 = 100nF

#### Semiconductors:

- D1-D10 = high-efficiency LED
- IC1 = LM3914N

#### Miscellaneous:

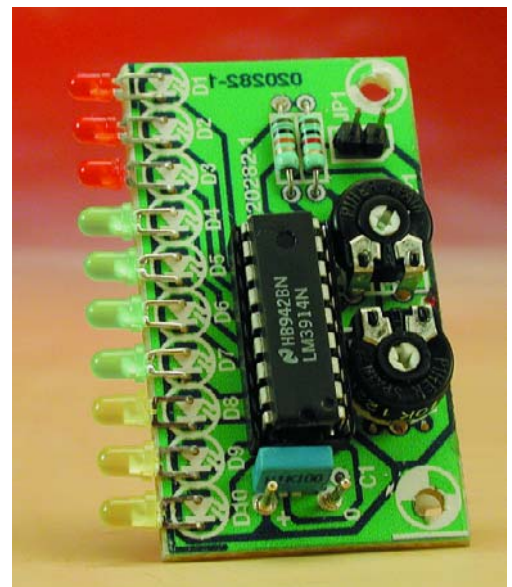
- JPI = jumper

PCB layout also available from [www.elektor-electronics.co.uk](http://www.elektor-electronics.co.uk) (Free Downloads)

### Dot or bar

The LM3914 can operate in either dot- or bar-mode. In the first case, only one LED will be lit. In the second case all the LEDs below the relevant LED will also be on. The selection between the two modes is made using pin 9: if this is left open then the IC operates in dot-mode. When jumper JP1 is in place, bar mode is selected. Keep in mind that the current consumption and power dissipation of the IC are considerably higher in bar-mode. This is not much of an issue with voltages up to 15 V. However when the input voltage is 25 V, the dissipation increases to 625 mW and at that level the LM3914 will become quite hot.

The current consumption of the circuit amounts to about 6 to 7 mA, to which the LED current has to be added. All current is obtained from the voltage source to be guarded,



### Construction

Figure 2 shows the layout for the small circuit board designed for the voltage guard. This board is unfortunately not available ready-made. As you can see, every component has been given a suitable place on the board, and because there are so few of them, there is very little to say about the construction. In practice it is handy to use LEDs of a few different colours, for example, red for voltages that are too low, green for correct and yellow for values that are too high. That way, in one glance you can determine if there are grounds for concern.

Another detail worth noting: on the circuit board near P1 and P2 there are a number of additional holes. The purpose of these is to

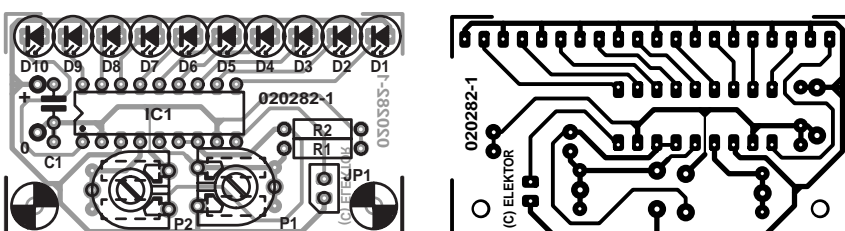


Figure 2. The printed circuit board is so small that building it into a suitable case should not present a problem.

allow the option of replacing the trimpots with fixed resistors, once the correct value has been determined and does not have to be adjusted any more. The advantage is that fixed resistors are much more stable than trimpots and are affected to a lesser extent by dust and ageing.

## Adjustment

P1 and P2 allow practically any desired measuring range to be set. We will use a car battery as an example. Because the charging voltage is typically about 14.4 V, it is appropriate to set the upper limit with P1 to about 15 V, for example. This is easily done by temporarily connecting the circuit to a regulated power supply and turning P1 until D1 lights. Make sure that during this adjustment P2 is turned fully clockwise, otherwise undesirable side effects may occur.

Next, we need to determine which voltage the lowest LED should indicate. If, for instance, we would like steps of 0.5 V per

LED, the series becomes 15-14.5-14-13.5-13-12.5-12-11.5-11-10.5. We now set the regulated power supply to 10.5 V and turn P2 until the lowest LED is lit. Done!

In exactly the same way it is possible, of course, to make steps of only 0.33 V or 0.25 V, or larger steps of 1 V. Start by first turning P2 fully clockwise, adjust the upper voltage with P1, followed by the lower voltage with P2. You will observe that with very small steps, 1/10 V for example, the LEDs will turn on and off slowly; it is possible therefore, that at a certain voltage two LEDs will be on at the same time.

## Measuring

Keep in mind that an unloaded battery, even when nearly fully drained, can still present a terminal voltage that is close to a full battery. So, in

order to obtain a sensible measurement, it is always necessary to test the battery while it is connected to its normal load.

Connecting the indicator to a car battery can be done very easily without touching any of the car's wiring. The cigarette lighter socket is eminently suitable for this purpose. The special plug is widely available, the outside springs are connected to the 'negative' of the battery and the centre pin is connected to the 'positive'.

A final closing remark: because the power supply voltage of the battery guard is equal to the value to be measured, it is, in this case, not possible to add a series diode to protect against reverse polarity. So, each time when connecting the battery to be tested, make e sure the plus and minus terminals are not reversed!

(020282-1)

# SMDs? Don't panic!

## Surface mount techniques at your workbench

By C. Tomanik

Surface Mount Technology (SMT) is responsible for today's ever smaller electronic equipment. Many new IC's are now only available in SMD outline. These tiny components can pose a few problems for the electronics enthusiast, not the least being the cost of special SMT tools. If SMDs make you nervous, don't panic, this introduction will give tips on SMD working methods and help you decide what you really need and what you can do without in the Lilliput land of the SMD.

These days some electronic components are supplied only in SMD package outlines. This can often leave the electronic hobbyist in a bit of a dilemma: should you use SMD components only where there is no alternative and conventional wire-ended components elsewhere in your latest design or should you plump for SMD throughout?

In this series of articles we hope to show that switching completely to SMD is often the most sensible solution and need not incur a great deal of expenditure in tools and spe-

cialist work stations.

Working with SMDs can be easier than you think provided that you are armed with one or two of the more essential tools. It is not necessary to buy expensive solder re-work stations, a standard 30 to 60 W soldering iron is up to the job providing it is fitted with a suitably fine bit.

This article is the result of experience gained while working with

SMDs during the author's graduation studies.

### The basics

As the name suggests, an SMD (Surface Mounted Device) is mounted on the surface of a Printed Circuit Board (PCB). It is not necessary to put a hole in the PCB to take the component leads. Contacts on the component are soldered to 'pads' or 'lands'

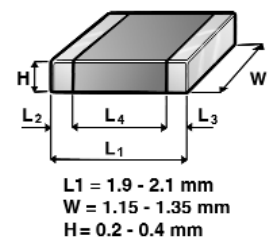
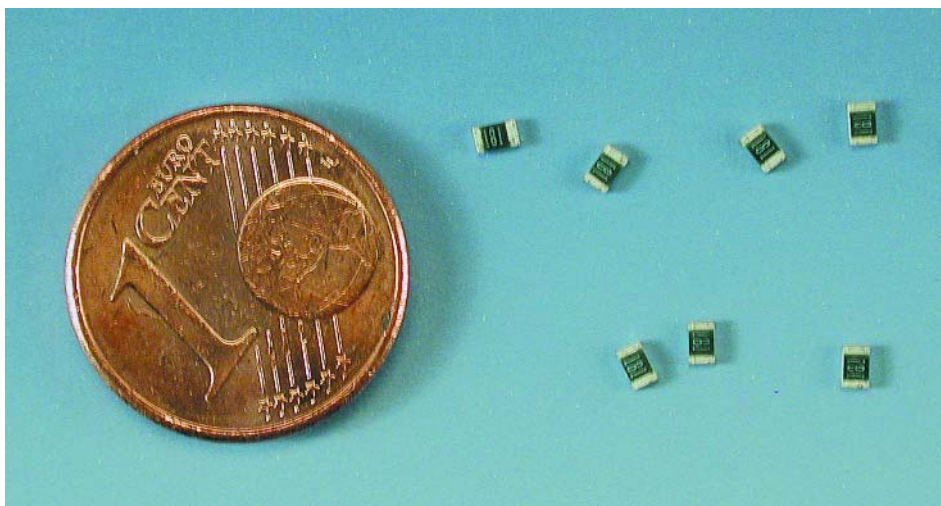


Figure 1. Scale diagrams of the 1206, 0805 and 0603 outlines and illustration of an 0805 size resistor.

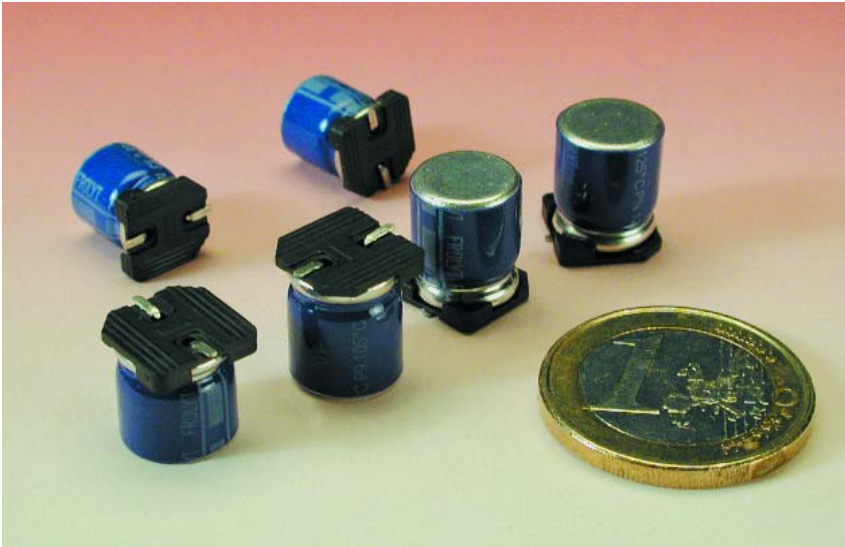


Figure 2. Electrolytic capacitors.

at the ends of PCB tracks. Without leads the SMD components are much smaller and take up less space on the PCB, resulting in a more compact design. The shorter leads also improve the components RF characteristics and when fitted the component will always be at the same height above the PCB. This is important at high frequencies and makes the overall design more reproducible.

To sum up, SMDs offer cheaper, smaller designs but they do require more careful PCB layout (running tracks under components can be very tricky) and fitting components to a PCB is more difficult for the beginner.

### SMD packages

Each type of electronic component is produced in its own range of SMD packages and can be grouped under the following headings:

- Chip resistors/capacitors (0805)
- Chip electrolytics
- Tantalum capacitors (3516)
- Diodes (Mini-MELF)
- Transistors (SOT 23)
- Integrated Circuits (ICs)

There are so many package outlines (especially for ICs) that it would be impractical to go into details for each individual outline. The aim of this article is to provide a basic introduc-

tion to the techniques necessary for working with SMD components. It is always advisable to study package outline information on the data sheet for any IC that you intend to use. Make sure that it is possible to solder the devices by hand because some IC's outlines are specifically designed to be fitted by special placement machines and may be too tricky.

### Chip resistors and capacitors

The most common devices used in a design are resistors and ceramic capacitors. They are available in a rectangular 'chip' outline with a conductive cap at either end to solder to the PCB pads. The chip size is given by the description 1206, 0805, 0603, 0402 or 0201 the first two numbers give the chip length while the last two give the width. The measurements are Imperial so that 0805 means that the chip is 0.08" by 0.05". To convert to metric multiply these values by 25.4, this gives a chip size of 2.032 mm by 1.27 mm. **Figure 1** shows the outlines for 1206, 0805 and 0603 chips. These packages are relatively easy to handle and solder, a standard iron will be sufficient to mount these devices.

### Electrolytic capacitors

SMD electrolytic capacitors use conventional electrolytic outlines with radial leads fitted into a plastic housing that guides the leads out of the bottom of the package enabling it to be surface mounted (**Figure 2**). The capacitor rating determines the outline size. A capacitor with a 4 mm diameter body for example, will take up a board area of 4.3 mm by 4.3 mm and have a height of 5.5 mm. These outlines do not have any special names.

### Tantalum capacitors

Tantalum capacitor outlines can be described using two different systems. The EIA code for a particular size is a four-digit number giving the package size, similar to the way that resistor dimensions are specified. The difference with tantalums is that the dimensions are metric! An outline specified as 3216 will be 3.2 mm long by 1.6 mm wide. The other method of describing the size is to specify its single letter 'case code'. The 3216 package has the case code 'A'. Many data sheets give the EIA codes and their case code equivalent. EIA codes with an 'L' suffix indicate that the capacitor is low-profile and its height will not exceed 1.2 mm. Outlines without the 'L' could be as high as 2.9 mm.

### Diodes

Most general-purpose diodes are produced in the Mini-MELF (Metal Electrode Leadless Face) outline (**Figure 4**). This package is a

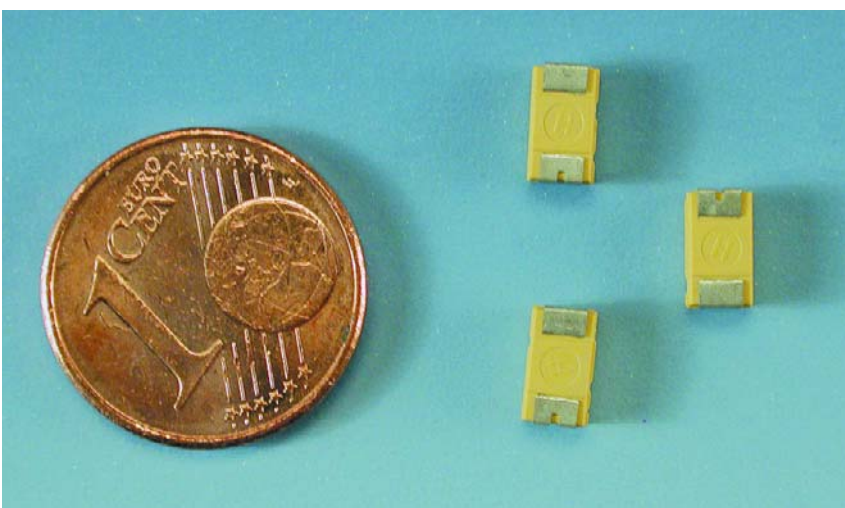


Figure 3. The 3216 tantalum capacitor outline.



1.4 mm diameter cylinder 3.6 mm long and is only used for diodes. It is one of the most tricky to manipulate with standard tweezers and tends to roll away during soldering. A variant on this outline casts the cylinder into a rectangular form to improve its handling properties so that the body of the chip in between the end caps is rectangular.

### Transistors

Transistors are produced in the SOT 23 outline (Figure 5). This outline is a simple rectangular chip measuring 2.8 mm by 2.1 mm with three connections.

### ICs

There is such a wide diversity of IC outlines that we can only look at a few of the more common package outlines. The  $\mu$ MAX series from Maxim is probably one of the most important from the point of view of the home constructor and includes the QFP, SOP and TSSOP outlines. A wide spectrum of IC functions is supplied ranging from A/D converters, logic gates and microcontrollers. When a PCB is designed the most important information for the layout is the thickness of the leads and the lead pitch or spacing for the ICs. All of the IC package outlines use a fixed pitch for spacing the leads. The main pitch spacing has always been 0.1 inch or 2.54 mm and IC Package outlines are multiples of this pitch spacing. To enable higher lead density this pitch has been progressively divided by two to give a spacing of 1.27 mm, 0.635 mm and more recently 0.3175 mm. Some manufacturers such as MAXIM use a non-standard pitch for example with their  $\mu$ MAX package outlines. The general rule is that the more densely spaced the leads are then the finer the soldering iron bit needs to be. At this stage we need to check that we have the basic tools necessary for SMD work.

### SMD tools

There is much expensive SMD equipment and specialist tools available today but before you invest too much of your hard-earned cash it would be wise to try things out on a small scale. SMD work is not everybody's cup of tea and if you are not blessed with a steady hand things can get very frustrating.

The most important tool in your toolbox will be a pair of good quality tweezers. There are many different types to choose from and the most popular for SMD work (and certainly the author's preference) are tweezers featuring a 45° offset with smooth faced gripping points, these are convenient to use and enable you to steady your hand on the work-

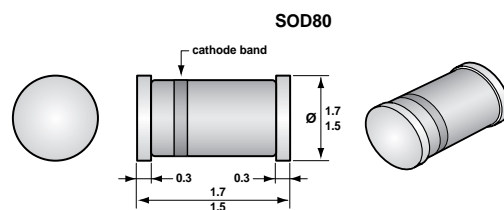


Figure 4. Mini-MELF diode outline.

bench as you pick and place the chip. It is important to buy good quality tweezers and the average price is quite high at around £8 to £10. Titanium or ceramic tweezers

are also available but cost substantially more. Specially shaped tweezers suitable for picking up mini-MELF outline chips are also available but these can only be

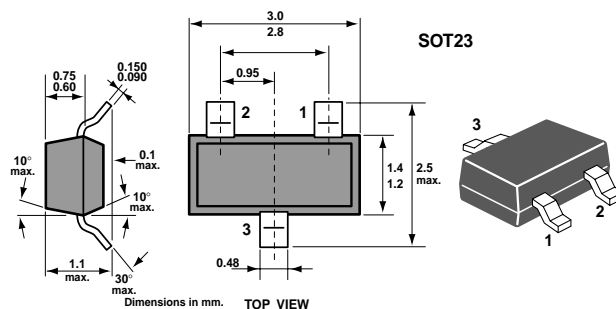
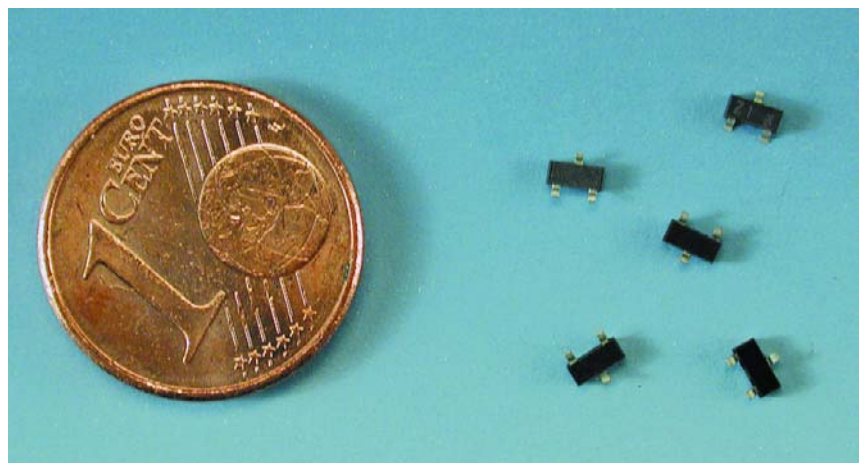


Figure 5. The SOT-23 transistor outline.

recommended if you are mounting lots of these components.

A vacuum pick-up pencil can also be used for component placement but this tool is relatively expensive and will not pick up a chip unless it has a flat smooth upper surface. These pencils are not really recommended for the beginner. An eye-glass with at least eight times magnification is also necessary. Avoid the desk mounted inspection magnifying lens with built-in fluorescent light, these are too awkward to use, best of all get a pair of head-mounted magnifying binoculars, these park on your head and can be easily flipped down when needed. A good level of background and directional lighting (halogen is best) is also important along with an anti-static mat and wristband to avoid damaging sensitive ICs.

The flux-cored solder used for SMDs has a very thin cross-section (26 SWG) and incorporates 2% silver; this lowers its melting point by a few degrees and also produces a better joint. Solder paste is also available in 5 ml syringes. Paste is easy to use but needs a steady hand for application and requires the residue to be cleaned off afterwards. Solder paste is intended for use with a hot-air type of soldering iron, these are expensive and not really necessary for the beginner. Solder paste can also be used with a conventional iron but its more economical to use standard cored SMD solder. When soldering ICs with a large number of connections close together it is necessary to use additional SMD flux paste. The flux should be dabbed onto the PCB pads from a syringe before the component is placed in position on the board. During soldering it burns off quickly leaving very little residue so it is usually unnecessary to clean the joints afterwards providing not too much flux has been used.

De-solder wick (or braid) is used to clean up the soldered joints and remove excess solder or unintentional solder bridges between pads. The most useful wick sizes for SMD work are 1.0 mm and 1.5 mm wide while 2.5 mm is useful for cleaning PCB pads. De-soldering pumps are not used because some of the components are so tiny they tend to dis-

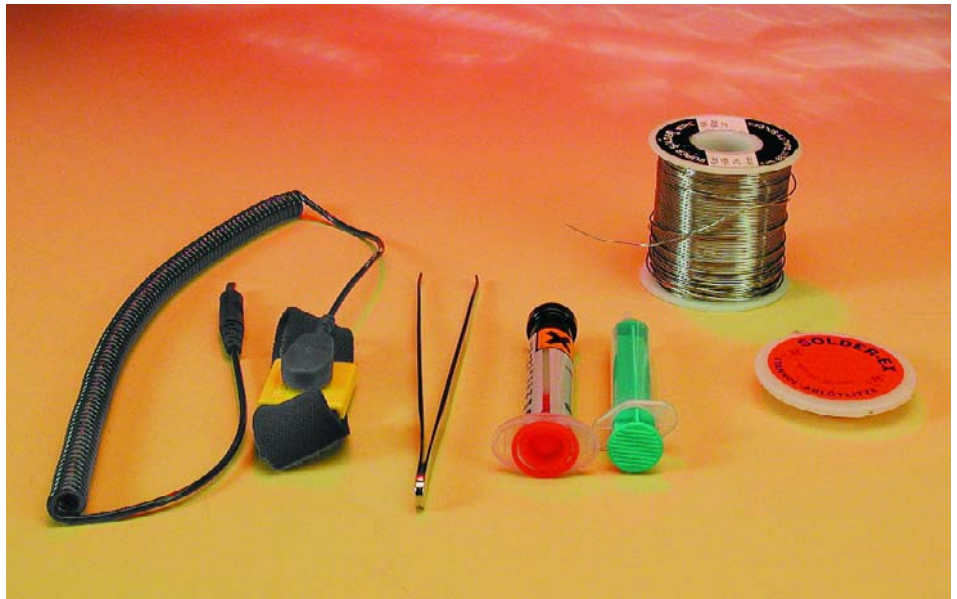


Figure 6. The basic SMD toolkit (from left: anti-static wristband, tweezers, flux, solder and de-soldering wick).

appear up the nozzle along with the molten solder.

In the beginning when you do not have too many components it is not necessary to store the SMDs in boxes, just keep them in the original manufacturers packaging and only remove them when its time to solder them in place. As you gain experience and your SMD component collection increases then a set of chip containers with lids will help organise the workplace. You can purchase sets consisting of boxes of different size and colour or just buy individual boxes as you need them. It is a good idea to use separate containers for each component type and value. Component values are not always stamped on the SMD body so anyone who needs to sort through a pile of mixed capacitors looking for a particular value (sounds like a job for our capacitance meter Mini Project, see the December 2002 issue of *Elektor Electronics*) will soon be convinced of the benefits of a well ordered storage system. These chip containers are not cheap but they are worth the investment. Don't be tempted to store SMDs in plastic 35 mm film canisters, these are too deep for the purpose and are not treated with an anti-static coating so CMOS ICs can be damaged.

## Coming soon...

In a follow-up article we will look at the techniques necessary for successful soldering of different types of SMD components using a standard soldering iron (the Ersa 'Analog 60A'). We also take a close look at a soldering station designed for SMD work (the Ersa SMT Unit 60A).

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## Components, tools and equipment

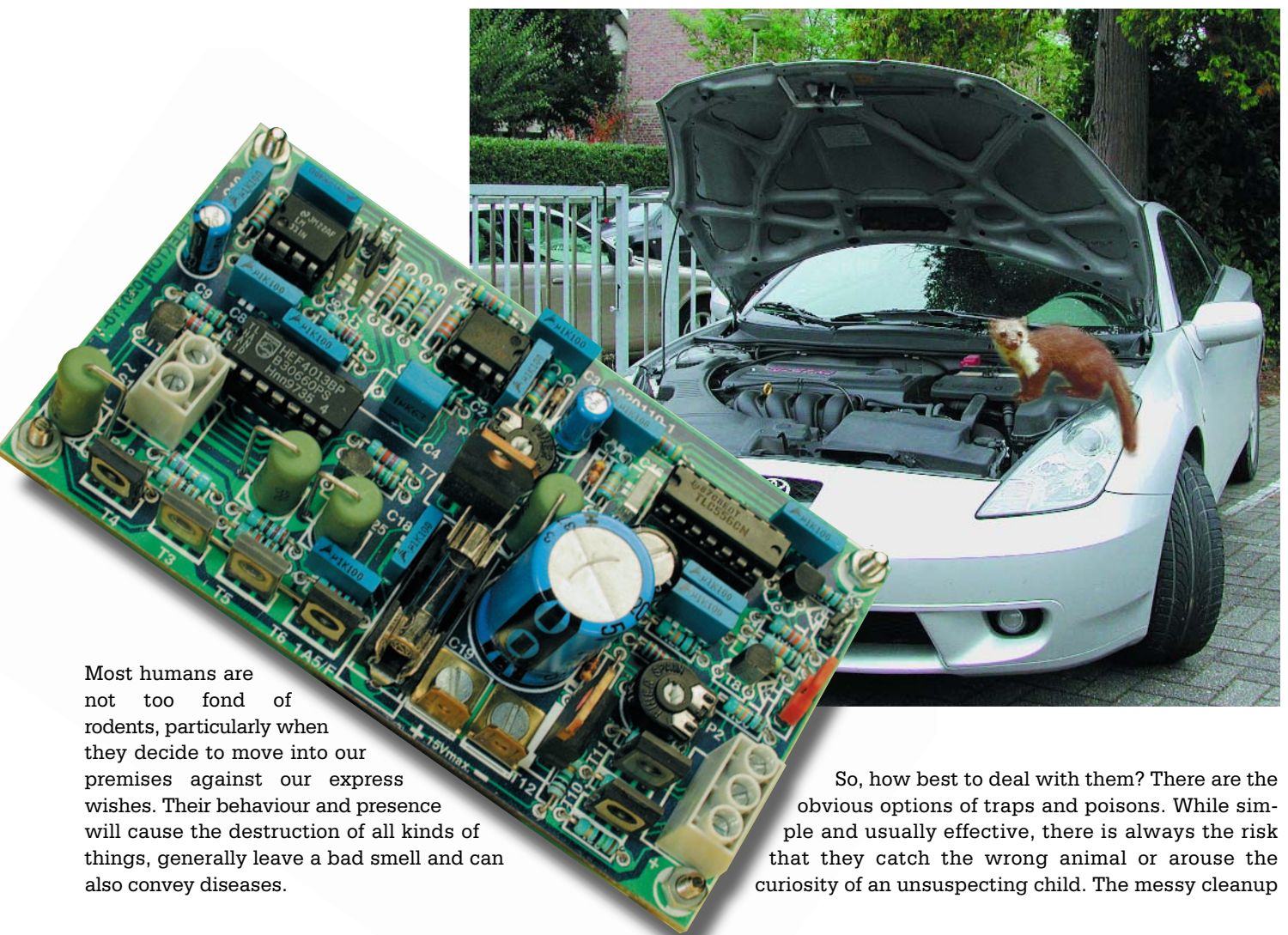
All the major mail order component outlets supply devices in SMD outline and also stock the necessary tools and accessories for working with SMDs. Farnell ([www.farnell.com](http://www.farnell.com)) and RS ([www.rs-components.com](http://www.rs-components.com)) both stock a huge variety of components and tools. Maplin ([www.maplin.co.uk](http://www.maplin.co.uk)) are also a good source. BEC distribution ([www.bec.co.uk](http://www.bec.co.uk)) are distributors for TOKO coils and Electrovalue ([www.electrovalue.com](http://www.electrovalue.com)) stock SMDs and tools. A company worth trying for unusual components is Berend Hendriksen in the Netherlands ([www.xs4all.nl/~barendh/indexeng.htm](http://www.xs4all.nl/~barendh/indexeng.htm)). Cooper Tools produce the excellent Weller range of soldering irons that can be obtained from the above suppliers.

# Rodent Deterrent

environmentally friendly and humane

Design by T. Giesberts

Mice, rats and even the playful and inquisitive marten are rodents that are certain to make a considerable nuisance of themselves whenever they interact with human activity. Their presence will result in unpleasant odours and irritating noises while their sharp teeth will cause havoc with rubbish bags, hoses, (car) electrical wiring and just about everything else. Therefore, suitable measures are in order and electronics can prove itself indispensable here.



Most humans are not too fond of rodents, particularly when they decide to move into our premises against our express wishes. Their behaviour and presence will cause the destruction of all kinds of things, generally leave a bad smell and can also convey diseases.

So, how best to deal with them? There are the obvious options of traps and poisons. While simple and usually effective, there is always the risk that they catch the wrong animal or arouse the curiosity of an unsuspecting child. The messy cleanup

## Main Features

Power supply voltage	9 to 15 V max.
Current consumption (1 tweeter PH8)	400 mA (output on)
Max. current consumption (4 PH8 in parallel)	900 mA (output on)
Standby-current (K2 open)	< 1 mA
Duty cycle	1 min. every 4 min.
Output frequency	19 to 38 kHz
Output frequency (JP1 fitted)	9.5 to 19 kHz
Sweep-frequency	2 to 19 Hz
LED blink frequency	3 Hz
LED current	6 to 40 mA
LL-input	> 2.5 V
OC-input	< 1 mA ( $\approx 15\text{ V}/15\text{ k}\Omega$ max.)

afterwards is not something to look forward to either. Sometimes the rodent in question is actually a protected species, so that killing is not an option that is available in that case. Fortunately there is quite an effective, much more animal-friendly and far less messy way to keep rodents at bay.

A device that produces a reasonably strong acoustic signal with a frequency just above the range of human hearing is perceived as very unpleasant, if not painful, to rodents. After a while they will be persuaded to look elsewhere for food and lodgings.

### Concept

An electronic rodent deterrent based on ultra-sound is not only an effective and environmentally friendly way of solving this nuisance, the design and construction of such a device is also something that is an entirely appropriate subject for us.

What are the design elements of the device that we present here?

We started with a voltage-controlled oscillator (VCO), which is modulated with the aid of a second oscillator in such a way that it produces a continually varying output signal between 19 kHz and 38 kHz. Of course it would have been possible to operate the oscillator at one fixed frequency. However, since we do not know exactly which frequencies rodents dislike most, we made the generated tone cover the entire relevant frequency range. The output signal is amplified considerably and converted into a strong acoustic sig-

nal by a piezo tweeter. The end result is an ear splitting noise level of around 105 to 110 dB. This is unbearable for an animal that can hear these frequencies. The final amplifier stage has been designed so that it can drive up to four piezo tweeters in parallel — this is useful, for example, if you would like to cover all the corners of an attic simultaneously.

Generating such a high sound pressure requires a reasonable amount of current, of course. In order to allow for the possibility of powering the circuit from a car battery, we have limited the current consumption by not running the circuit continuously, but switching it off and on periodically: 1 minute on, 3 minutes off. This will prevent a battery from being drained in less than a day.

Finally, as an optional additional feature, it is possible to extend the circuit with an 'optical deterrent' consisting of a couple of bright flashing LEDs — all this to make the life of the rodents really as unpleasant as possible in and around our homes, under the engine hood of our cars, etc.

### Practical implementation

The schematic, with all the various details worked out, is shown in **Figure 1**. The VCO comes in the form of IC2, an LM331. This IC requires only a small number of external components and can be used to generate square wave signals with frequencies ranging from 1 Hz to 100 kHz. The components that determine the frequency of IC2 are

R8, R9, R10, C6 (+C7) and C8.

The control signal that modulates the frequency of the VCO is applied to pin 7 and is generated by a square/triangle oscillator comprising IC1a and IC1b. This supplies a triangular output voltage, the amplitude of which varies from about 3 to 5 V. The speed at which the modulation takes place (the sweep frequency) can be adjusted with P1 between 2 Hz and 19 Hz. It is possible that the effect of the circuit on the rodents may be influenced somewhat with this adjustment.

All the components around the VCO and square-triangle oscillator are dimensioned such that the final generated frequency varies from 19 to 38 kHz. In order to be able to test the circuit by ear and check that it actually produces a signal, the oscillator frequency can be reduced by an octave by temporarily closing jumper JP1. **Stand clear** — humans can now also hear the output frequency!

Because the duty cycle of the output signal of the LM331 is not constant, a divide-by-two (IC3a) follows the LM331. As a consequence, the duty cycle is always 50%, independent of the frequency. Adding the divide-by-two obviously requires the VCO frequency to be raised by a factor of two: IC2, therefore, actually varies from 38 to 76 kHz.

When designing the output amplifier that drives the piezo tweeter, achieving the highest possible output voltage across loudspeaker LS1 was the prime consideration. In order to realise this, a simple bridge amplifier was chosen, where the final stage transistor pairs T3/T6 and T4/T5 conduct alternately. Although the final stage appears a little unconventional, the operation is actually quite straightforward: T3 and T4 make use of a common base resistor (R18) to come into conduction. T1 and T2 alternately switch off T3 and T4. The values of voltage divider R14/R13 and R15/R16 were selected on the break-before-make principle. The instant the output of IC3a reaches half the supply voltage, both T1 and T2 are on. This way, we prevent both T3 and T4 from conducting at the same time. As a result, it is possible to remove IC3 (if that should ever become necessary) without causing any short circuit currents. The common outputs of T3 and T4 drive T5 and T6, so that either T3 and T6 conduct simultaneously, or T4 and T5.

In order to prevent a short-circuit between T5 and T6 in the simplest possible way, a power resistor (R22/R25) has been added in the collector circuit to limit the current. The added advantage of this measure is that the output stage is now short-circuit proof (for a short period only, otherwise R22 and R25 will go up in smoke). A third advantage of the output resistors is that the current peaks through

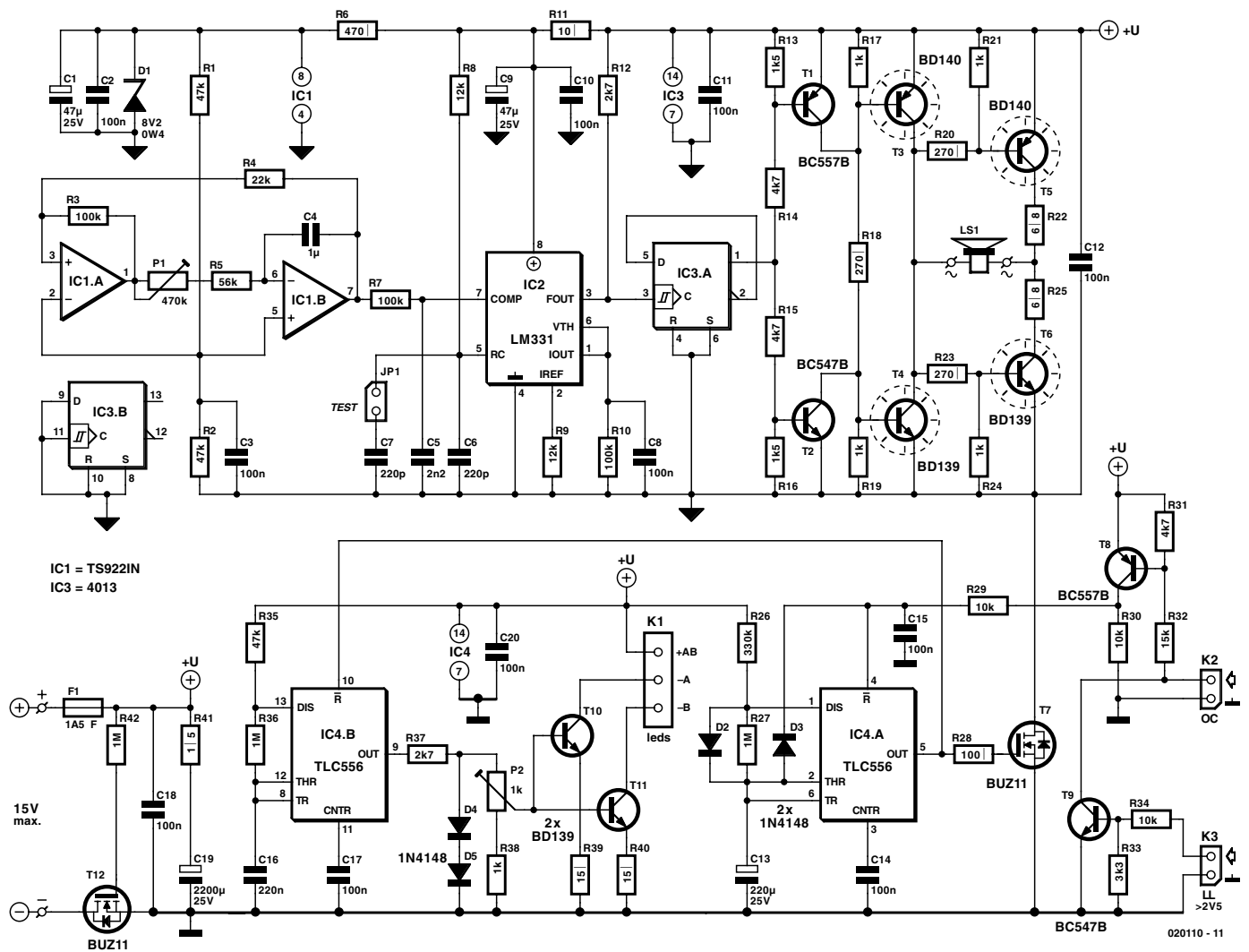


Figure 1. The complete schematic of the rodent deterrent. The top part of the schematic is responsible for the actual sound generation.

the capacitive load of the piezo tweeter(s) are limited, something that will improve the life expectancy of the tweeter(s).

Although it is possible (in principle) to use other makes and types, for the prototype we used a piezo tweeter model PH8 from Visaton for LS1. This tweeter has a small horn and produces a sound pressure level of 96 dB at an input power of 1 W. Since the output amplifier delivers about 20 W, you can work out for yourself what impressive number of decibels our rodent deterrent produces. It is very fortunate that the generated signal is outside our own hearing range...

### Extra features

The energy saving feature implemented by periodically switching the generated ultrasonic signal on and off has been realised with the aid of a 556 (IC4a) configured as an

astable multivibrator. During the 'high-time' of the output of IC4a (pin 5), T7 will conduct and IC1, IC2, IC3 and the output amplifier are powered. During the 'low-time' of IC4a, T7 will block and the ground connection to the oscillator and amplifier sections is interrupted. In order to minimise the voltage drop while generating the acoustic signal, a power-MOSFET type BUZ11 was selected for T7. This MOSFET has a very low on resistance (typical  $R_{DSON} = 0.04 \Omega$ ).

In order to make the circuit as versatile as possible, there is also the provision to drive timer IC4a with an external signal (from a passive infrared motion sensor, for example). The circuit can be activated via T8 with an open-collector output (OC,

K2). T9 has been added for the eventuality that only a logic level (LL, K3) is available ( $> 2.5 V$ ). When T8 is not active, R29 and R30 hold the reset input of IC4a low. Diode D3 has been added to prevent an active output from being muted.

Depending on the amount of charge in C13, it can sometimes take a little longer before IC4a enters the reset state. Another nice feature occurs when the output is not active: at that time, C13 will be discharged by R27. But when T8 turns off, C13 will discharge quicker and the voltage will be below the input threshold of IC4a, causing the output to turn on for a few seconds before resetting.

Finally, the previously mentioned 'optical extra'. This has been realised

with a second timer (IC4b), configured as an oscillator. The oscillator, via two current sources (T10, T11), causes two LEDs connected to K1 to flash at a frequency of about 3 Hz. Because the reference (D4, D5) of the current sources is adjustable with P2, the LED current can be varied from about 6 mA to 40 mA. Make sure that both current sources are loaded, otherwise the unloaded transistor will cut off the reference voltage to the other one. If desired, both outputs can be connected in parallel so that the output current can be doubled ( $1 \times 80$  mA). For the indicator we have superbright LEDs in mind, such as the devices from Sharp listed in the parts list (available from, among others, Conrad Electronics). Depending on the power supply voltage, a number of LEDs can be placed in series. The superbright types tend to have a typical forward voltage drop of around 2.5 V that means that at 12 V, four can be connected in series, and five at 15 V. The anodes of both chains are connected to the common connection +AB, the cathode for each chain has its own separate connection: -A and -B.

### Power supply

The power supply for the rodent deterrent can take the form of a 12-V battery or a separate mains adapter with an output voltage of 9 to 15 V. The output voltage needs to be regulated, while the adapter also has to be able to deliver a considerable amount of current. The current consumption of the circuit typically amounts to about 400 mA during the period when the output signal is active. When four piezo tweeters are connected in parallel the current can increase to 900 mA!

Fuse F1 protects against short circuits, while MOSFET T12 provides protection against reversal of the power supply polarity. Compared to T7, it appears at first glance that the source and drain have been reversed. This is not so however. The channel is definitely conducting, independent of the fact that the current now flows from source to drain, because the gate voltage is positive with respect to the source. The inherent body diode of the MOSFET

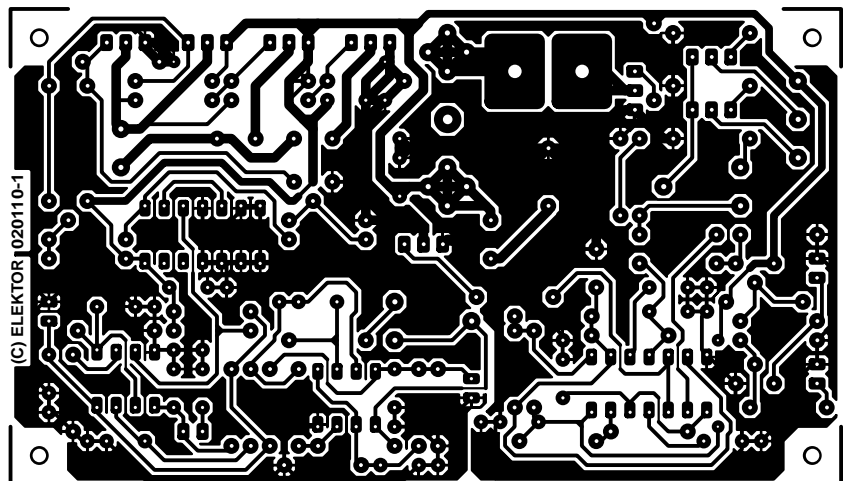
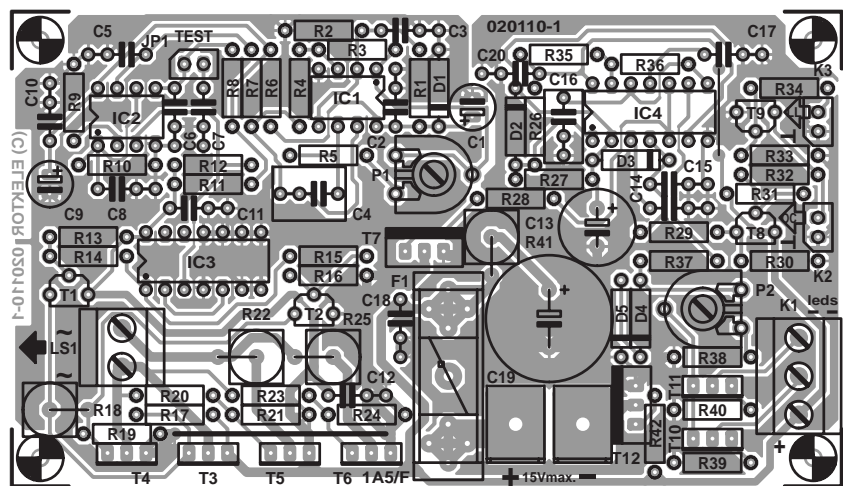


Figure 2. By designing a clever circuit layout, the number of wire links is limited to just two.

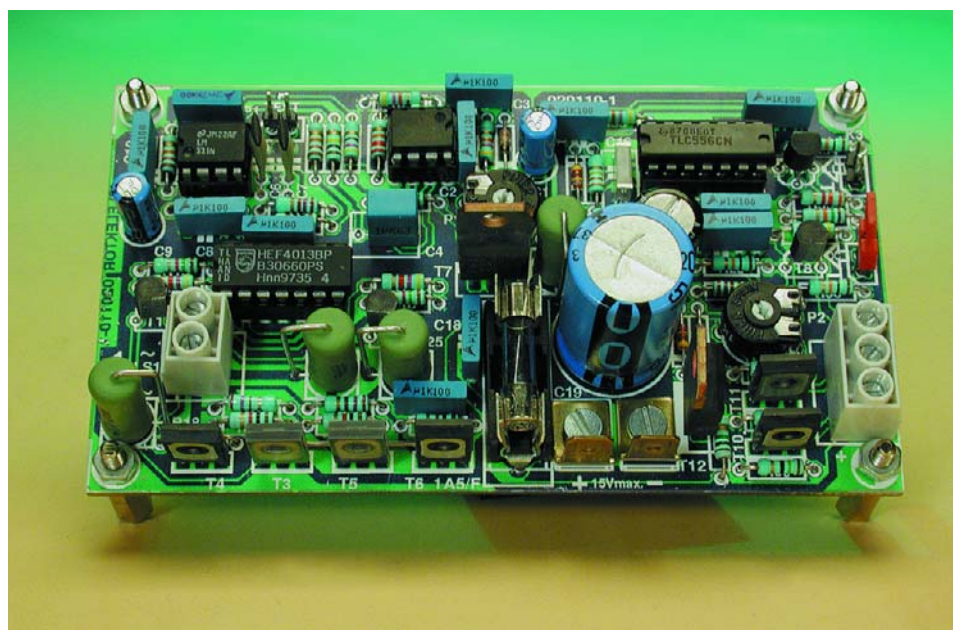


Figure 3. This is what a correctly assembled circuit board should look like. T3, T4, T5 and T6 need to be mounted on a heatsink.

is now connected in the forward direction. If the power supply voltage is applied the wrong way around, the gate voltage will be negative with respect to the source and the body diode will be blocking. This MOSFET prevents the voltage drop that is associated with the diode that is normally connected in series with the power supply.

## Construction

A nice printed circuit board has been designed for the circuit, the layout and component overlay of which is shown in **Figure 2**. Despite the compact dimensions (it measures only 11 × 6.5 cm), the construction is likely to occupy you for a few hours, because the PCB is quite densely populated with parts. Start with the lowest components (resistors, IC sockets), follow that with the taller parts (vertical resistors, transistors, electrolytic capacitors). Make sure not to forget the two wire links. It may actually be best to start with those; one is located next to T3, T4, T5 and T6 and the other to the right of IC4.

The external connections have been clearly marked, so there is very little opportunity for anything to go wrong. PCB screw terminals can be used for the loudspeaker and the LEDs (K1), while we used QC tabs, common in the automotive industry, for the power supply.

Even though the output transistors T3 through to T6 don't get very warm, it is still recommended to provide them with a small heatsink (a small piece of aluminium sheet will suffice). The transistors T3 to T6 have been placed at the edge of the PCB specifically for this purpose. The transistors need to be fastened to the heatsink with insulating washers.

For completeness sake we will mention that if you see no value in the optical signalling, the relevant components around IC4b, including T10, T11 and K1 can simply be omitted.

The choice of enclosure is completely up to you. There are many enclosures that are suitable for this PCB.

A final remark: if you are not going to use a proximity or motion detector then a jumper can be fitted in place of K2. The circuit will then simply oscillate on and off on its own accord.

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## COMPONENTS LIST

### Resistors:

R1,R2,R35 = 47kΩ  
 R3,R7,R10 = 100kΩ  
 R4 = 22kΩ  
 R5 = 56kΩ  
 R6 = 470Ω  
 R8,R9 = 12kΩ  
 R11 = 10Ω  
 R12,R37 = 2kΩ  
 R13,R16 = 1kΩ  
 R14,R15,R31 = 4kΩ  
 R17,R19,R21,R24,R38 = 1kΩ  
 R18 = 270Ω 5W  
 R20,R23 = 270Ω  
 R22,R25 = 6Ω 5W  
 R26 = 330kΩ  
 R27,R36,R42 = 1MΩ  
 R28 = 100Ω  
 R29,R30,R34 = 10kΩ  
 R32 = 15kΩ  
 R33 = 3kΩ  
 R39,R40 = 15Ω  
 R41 = 1Ω 5W  
 P1 = 470kΩ preset  
 P2 = 1Ω preset

### Capacitors:

C1,C9 = 47μF 25V radial  
 C2,C3,C8,C10,C11,C12,C14,C15,C17,C18,C20 = 100nF  
 C4 = 1μF MKT (Siemens), lead pitch 5 or 7.5mm  
 C5 = 2nF  
 C6,C7 = 220pF

C13 = 220μF 25V radial  
 C16 = 220nF  
 C19 = 2200μF 25V radial

### Semiconductors:

D1 = 8V2 0.4W  
 D2-D5 = 1N4148  
 T1,T8 = BC557B  
 T2,T9 = BC547B  
 T3,T5 = BD140  
 T4,T6,T10,T11 = BD139  
 T7,T12 = BUZ11  
 IC1 = TS922IN ST (Farnell)  
 IC2 = LM331N  
 IC3 = 4013  
 IC4 = TLC556

### Miscellaneous:

JP1 = 2-way pinheader with jumper  
 K1 = 3-way PCB terminal block, lead pitch 5mm  
 K2,K3 = 2-way pinheader  
 LSI = 2-way PCB terminal block, lead pitch 5mm  
 Piezo tweeter type PH8 (Visaton)  
 F1 = fuse, 1.5A, fast acting, with PCB mount fuse holder  
 High intensity LEDs (not on PCB), e.g., Sharp Super-luminosity LED Lamp type GL0ZS042B0S (Conrad Electronics # 18 30 08)  
 2 spade terminals, PCB mount using 3-mm bolts and nuts  
 PCB, order code **020110-1** (see Readers Services page)



Figure 4. The piezo tweeter used for the prototype is a type PH8 from Visaton, it has a frequency range from 3 kHz to 40 kHz and is capable of producing very high sound pressure levels.

# Small DC-DC Converters

## DC-DC converters under the magnifying glass

by Prof. Dr.-Ing. M. Ossmann

Switch-mode power supplies are not among the hobbyist's favourite circuits. The specialised components are often hard to obtain, and mistakes are rewarded with noisy and expensive results. If, however, we stick to low voltages and very low power, there are a few universal and readily-modifiable circuits that illustrate the most important principles.

The function of a DC-DC converter is to change one DC voltage into another. The resulting voltage can be higher, lower, inverted and possibly isolated with respect to the input voltage. There are many types of converter, of which we shall examine a few here.

The basic circuits are shown together in **Figure 1**. The input voltages are labelled  $U_{in}$ , the output voltages  $U_{out}$ . All the circuits shown here have the common feature that they employ a switch  $S$ , a diode  $D$  and a coil  $L$  to carry out the essential functions of the circuit.

First we will look at the simplest circuit, the so-called step-down or 'buck' converter. This converts an input voltage into a lower output voltage. In outline, its principle of operation is as follows. When switch  $S$  is closed a positive voltage appears across the inductor  $L$  (since  $U_{in}$  is greater than  $U_{out}$ ). The current in the coil therefore rises linearly, and energy is stored in the coil. When the switch  $S$  is opened, current flows through the coil into the output capacitor via diode  $D$ . The voltage across the coil,  $U_L$ , is now negative, and so the current through the coil falls linearly. The energy stored in the coil is transferred to the output. Switch  $S$  is now closed again, and the process repeats itself from the beginning.

The actual voltage appearing at the output depends on how the switch is controlled. In

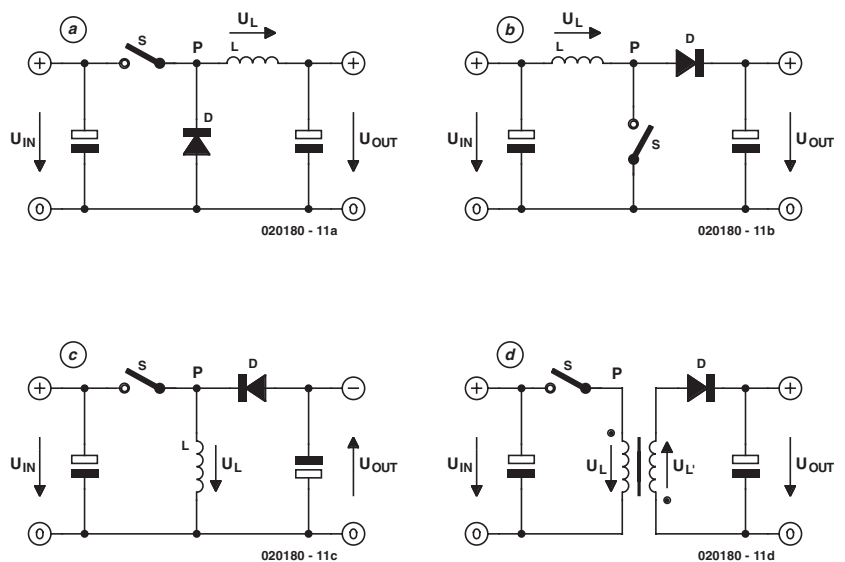


Figure 1. Various DC-DC converters: (a) buck; (b) boost; (c) buck/boost; (d) flyback.

principle there are three patterns of current flow, as illustrated in **Figure 2**. If the current flow in the coil has not reached zero when switch  $S$  is closed, there will always be a current flowing in the coil: this is known as 'continuous mode' (CM). If, as

shown in **Figure 2(b)**, the current is zero for part of the cycle, the circuit is operating in 'discontinuous mode' (DM). If the switch is turned on when the coil current reaches exactly zero, we speak of CM/DM limit operation.



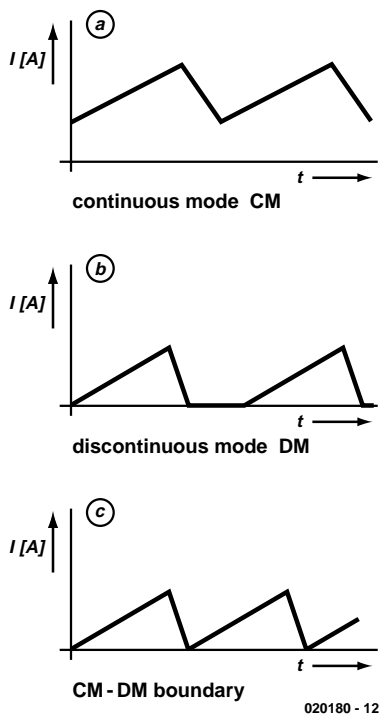


Figure 2. Theoretical current waveforms.

By controlling the 'on' period of the switch (or its mark-space ratio) the output voltage and transferred power can be controlled. So much for theory; now let us look at a simple practical circuit.

### LED driver

The circuit [1] in **Figure 3** drives an LED from an input voltage of 9 V with high efficiency. Note that European equivalents have been substituted for some of the components used in the original design. How does this circuit work?

Transistor T1 plays the role of switch S. Diode D1 and coil L1 form the other parts of the step-down converter. When the circuit is turned on, R3 provides a base current for T2 (since the forward voltage of D2 is greater than 0.7 V) and T2 starts to conduct. T2 now supplies T1 with a base current, and so it starts to conduct as well. The voltage at point P rises and T2 is supplied with a much higher base current.

The voltage at point P now being 9 V, the current in L1 begins to rise. The rate of rise of the current in the coil is determined by its inductance and by the voltage across it. The ris-

ing current results in a voltage drop across R1. When this reaches 0.7 V (at about 70 mA) T3 also begins to conduct and removes the base current from T1. The current in L1 cannot now rise further, and so the voltage at point P begins to fall. T2 is then turned off and finally also T1. The current through L1 now flows through D1 until it falls to zero; then the voltage at T2 rises again and the process repeats from the beginning. The transistors function as a thyristor tetrode with positive feedback, which creates an oscillation. T3 ensures that T1 is turned off at the preset current, and the circuit functions in CM/DM limit operation. A photograph of the prototype appears in **Figure 4**.

### Modifications

If you try to use this circuit to power another circuit, rather than an LED, you will find that it does not oscillate under higher loads. This is because the load will prevent R3 turning on T2 at power-up. A capacitor (0.1  $\mu$ F) between point P and the base of T2 will help avoid this problem. It is also a good idea to connect an electrolytic capacitor (10  $\mu$ F) across the output to smooth the voltage. The converter is unregulated and acts as a current source rather than as a voltage source. For many simple applications this will however be entirely adequate.

### 5 V to 12 V step-up converter

Can a step-up converter be designed in the same way? Let us first look at the basic operation of the step-up, or 'boost' converter, as illustrated in **Figure 1(b)**. When switch S is closed, the coil voltage  $U_L$  is equal to the input voltage and the coil current rises linearly. When switch S is opened the coil will ensure that the current continues to flow, independent of how high the output voltage is: this current now flows through diode D. In the steady state the output voltage is higher than the input voltage and the coil voltage  $U_L$  is negative, which leads to a linear fall in the current flowing in the coil. In this phase energy is again transferred from the coil to the output.

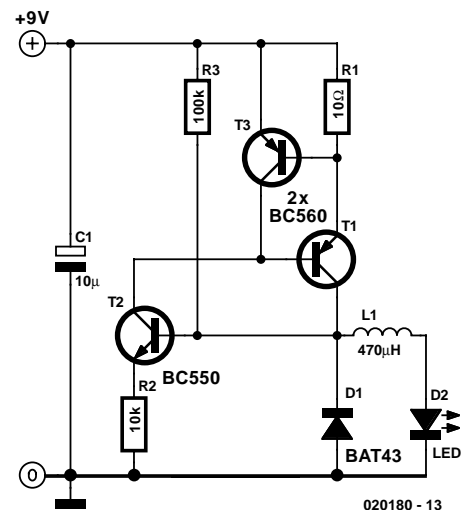


Figure 3. Down-converter driving an LED.

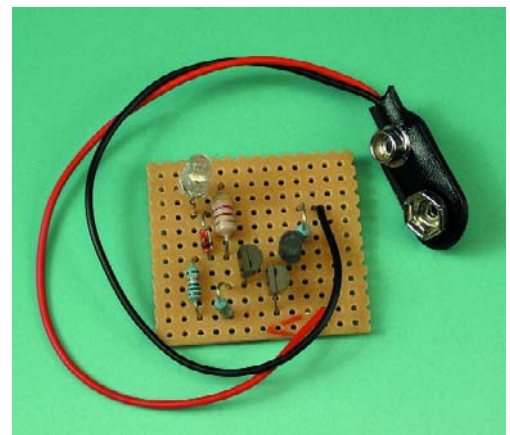


Figure 4. Prototype LED driver circuit.

Switch S is now closed again and the process is repeated.

In order to turn the circuit of **Figure 3** into a step-up converter we first need to turn all the transistors upside-down, so that switch S is now connected to ground as the outline circuit in **Figure 1** indicates. The positions of diode D1 and coil L1 also need to be exchanged. The feedback between T1 and T2 is modified, and we arrive at the circuit shown in **Figure 5**.

Zener diode D2 allows us to regulate the output voltage to 12 V. If the output voltage is too high, the operating point of T2 is shifted so that T1 is turned on for a shorter period (or even not at all). At an output current of 20 mA the output voltage will be 12.6 V; with a 5 V input voltage the input current will be around 64 mA. This corresponds to an efficiency of 77 %, not at all bad for such a simple circuit. The prototype circuit is shown in **Figure 6**.

### Regulated step-down converter

Can we make things even simpler, using only two transistors? Indeed we can: **Figure 7** shows a regulated step-down converter producing 12 V from 20 V. It is described in the references [2]; again, European equivalents have been substituted for some components.

The key components of the step-down converter are transistor T1, diode D1 and coil L1. The PNP/NPN feedback combination will be recognised here. In this converter T1 is controlled not by the maximum coil current, but via RC-combination C2/R4. The Zener diode D2 and the connection of the emitter of T2 to the output together provide voltage regulation. An efficiency of up to 90 % is claimed for this converter.

### 1.2 V to 5 V step-up converter

This step-down converter can also be modified to make a step-up converter. The result

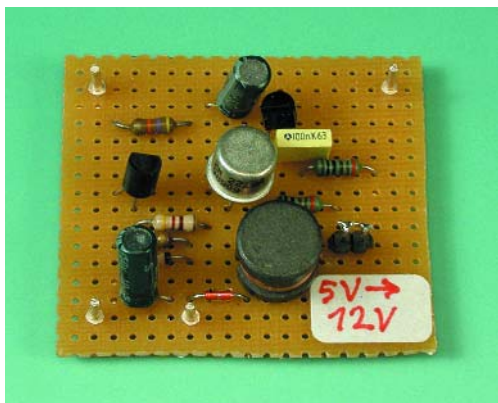


Figure 6. Construction of the converter shown in Figure 5.

can be seen in **Figure 8**. Compared to the circuit of **Figure 5** this arrangement has the advantage that it works perfectly from an input voltage of 1.2 V. Transistor T1, coil L1 and diode D1 form the step-up converter. Regulation is achieved via Zener diode D4, which here operates via the base of T2.

This circuit allows the supply for a 5 V system to be obtained from a NiCd cell (1.2 V). The circuit can deliver at most 10 mA at 5 V, which is enough for today's low-power microcomputer circuits.

Sometimes a low-current negative voltage supply is also required, for example for an operational amplifier or as bias for an LCD. Such functionality can be added to this circuit. Capacitor C4 and diodes D2 and D3 form a simple charge pump converter, providing an unregulated -5 V at up to 0.5 mA.

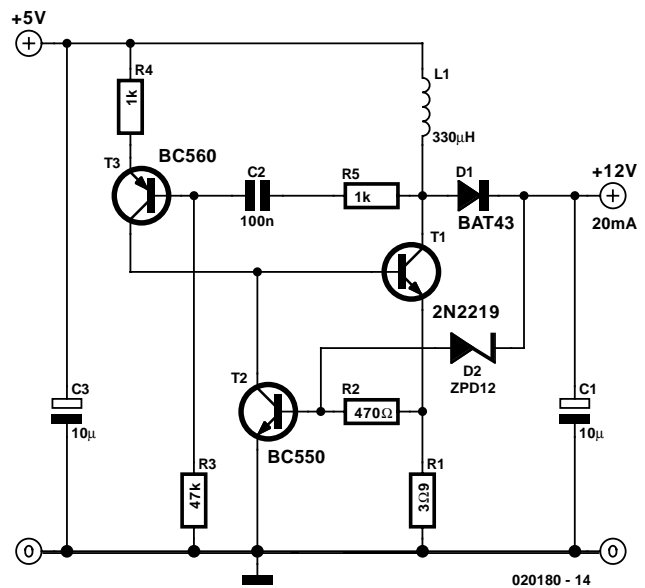


Figure 5. Regulated 5 V to 12 V converter.

The efficiency of this circuit is around 60 %. This is certainly not all that impressive, but with a low input voltage every voltage drop brings a penalty. If the collector-emitter voltage drop of the switching transistor is 0.2 V when turned on, already 20 percent of the energy is being wasted. The transistors must be driven fully on, which demands a high base current; but this again reduces the efficiency of the circuit.

### 5 V to ±12 V and more

The only remaining variation on the

power supply circuit is the inverting converter, which produces a negative output voltage from a positive input. The basic principle is shown in **Figure 1(c)**. When switch S is closed the current in the coil rises linearly. If the switch is now opened, a current continues to flow in the coil, and this current must now flow through diode D. This is how the negative output voltage arises. There is a small difference between this converter and the previous ones: at no point in the operation of the inverting converter is there direct transfer of energy from input to out-

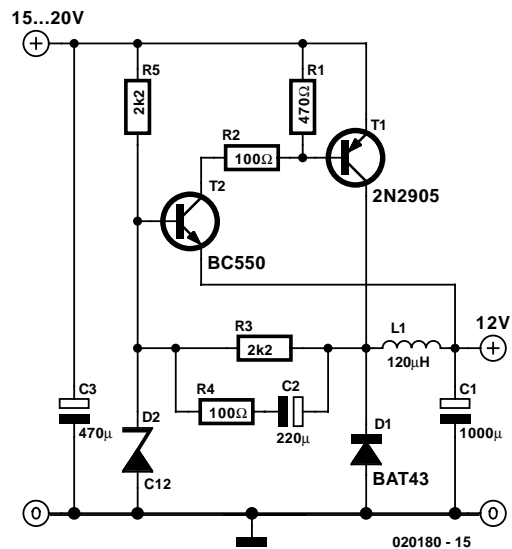


Figure 7. Regulated down-converter using two transistors.

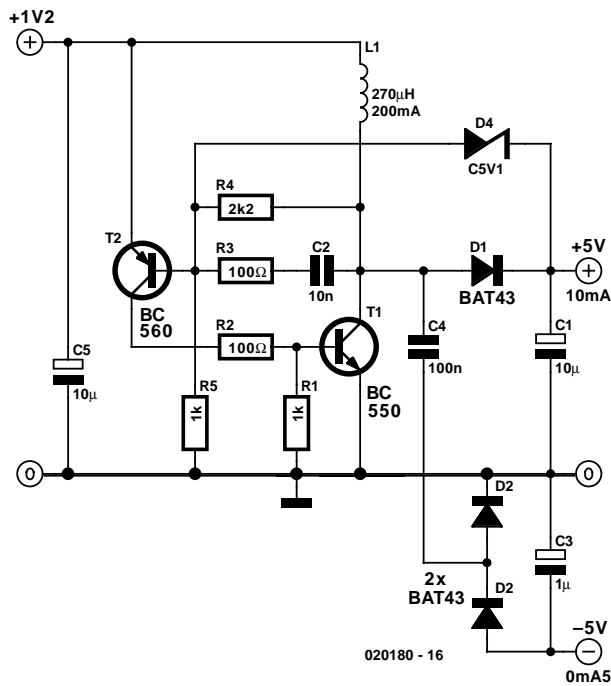


Figure 8. Boost converter from 1.2 V to 5 V.

put. Instead, all the energy is first stored in the inductor. In contrast, in the buck and boost converters energy is transported directly from input to output at certain moments. According to its mode of operation, the output voltage of the inverting

converter can be greater or lesser in magnitude than the input voltage. For this reason, this type of converter is known as the 'buck-boost' or 'step-up/step-down' converter. The experimental circuit shown in **Figure 10** is set up to produce an output of

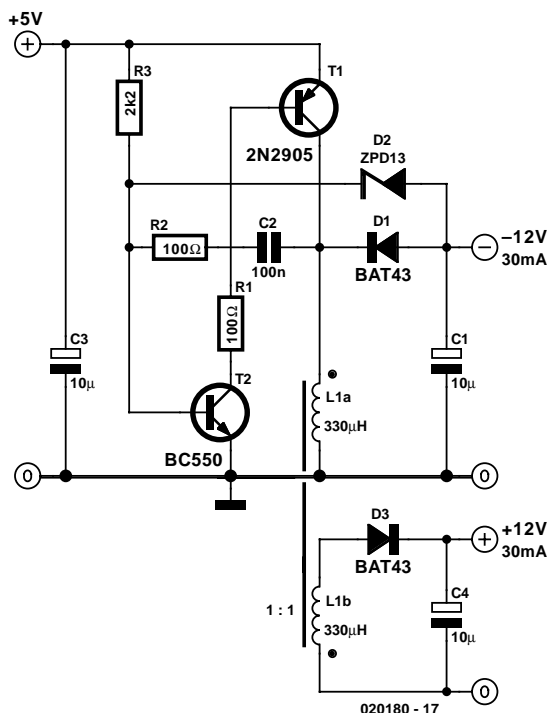


Figure 10. Combined inverting/flyback converter.

-12 V from an input voltage of 5 V. The basic circuit is the same as that shown in **Figure 3** and **Figure 7**.

### Isolating converters

There only remains to explain how to create an isolated supply. The basic principle is shown in **Figure 1(d)**. Instead of a simple coil we have an inductor with two windings. When switch S conducts, the current in the first (or primary) winding rises linearly, as in the inverting converter. Energy is stored in the inductor. Now switch S is opened and now no current can flow in the primary winding; instead current flows in the secondary winding via diode D. Energy is transferred from the inductor to the output. This type of converter is called a 'flyback' converter because the energy flows to the output when the transistor is turned off. As in the case of the inverting converter, all the energy must

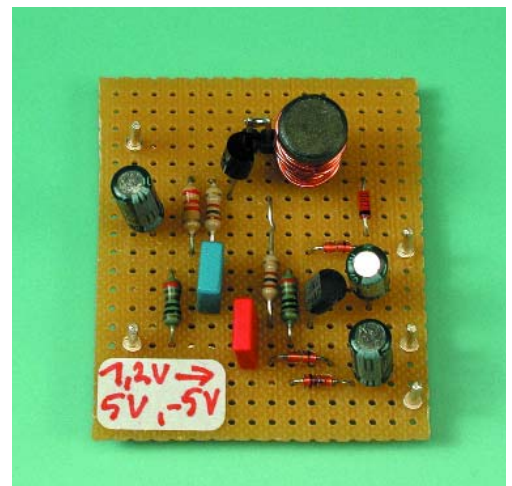


Figure 9. Construction of the converter shown in Figure 8.

be stored in the inductor. For this reason we often speak of 'an inductor with two windings' rather than a transformer.

Since the flyback converter and the inverting converter are so similar, no new circuit diagram is needed. We simply add a second winding to the coil in the inverting converter (observing polarity!) and thus obtain an electrically isolated output. The turns ratio is 1:1, and so the output voltages are the same. By using a different ratio a flyback converter with a considerably higher or lower output voltage can be constructed, without the use of extreme values of switching mark-space ratio. In the circuit of **Figure 10** only the output of the inverting converter is regulated; the flyback output is not. The circuit has an

efficiency of around 60 % and it can conveniently be used to provide a positive and a negative supply for operational amplifiers from a 5 V input.

## Coils

The only special components in our circuits are the inductors, about which a few remarks are in order. Many of the small inductors that are readily available are not suitable for these applications because of their high DC resistance. Larger devices designed for higher currents are generally suitable. Particularly simple to use are the so-called 'bobbin cored' inductors, as shown in **Figure 11**: the diameter and height are both approximately 10 mm. These are sometimes found in PC power supplies and can be dismantled and rewound. In our example wire with a diameter of between 0.2 mm and 0.3 mm was used. The large air gap helps ensure that the core material does not become saturated.

When winding the double inductors for the flyback converter a close coupling between the two windings is needed. In the coil for the converter of **Figure 10** this was achieved by using a bifilar winding, i.e., using two parallel wires.

## Conclusion

As we have seen, a variety of switch-mode power supplies can easily be built. These kinds of economical converter find frequent use in low-cost electronic equipment, causing headaches for service engineers who find that the entire circuit stops working when any one component fails. That is unfortunately the disadvantage of these so-called self-oscillating converters.

(020180-1)



Figure 11. Bobbin core for inductors.

## Further reading:

We hope this article has whetted your appetite for efficient switch-mode power supplies. The following websites provide further information.

Motorola (ON-Semiconductor)	<a href="http://www.onsemi.com">http://www.onsemi.com</a>
Texas Instruments / Unitrode	<a href="http://www.ti.com">http://www.ti.com</a>
Linear Technology	<a href="http://www.linear-tech.com">http://www.linear-tech.com</a>
Maxim	<a href="http://www.maxim-ic.com">http://www.maxim-ic.com</a>
Infineon	<a href="http://www.infineon.com">http://www.infineon.com</a>
ST Microelectronics	<a href="http://www.st.com">http://www.st.com</a>
International Rectifier	<a href="http://www.irf.com">http://www.irf.com</a>

## References:

- [1] S. Rohrer, 'LED Switching Driver Cuts Current Draw to 3 mA', *Electronic Design*, August 7 2000, page 130.
- [2] Eugene E. Mayle, 'Low-Cost Step-Down Regulator', *Electronic Design*, February 6 1995, page 118.

# Tube-Based Crossovers

with a free designer program

By John R. Broskie

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Unless a loudspeaker uses a single full-range driver, a crossover will be needed to split up the audio spectrum into discrete bands of frequencies. But should the crossover accomplish this task passively or actively? And if actively, with solid-state devices or with vacuum tubes?

## Warning.

Some of the voltages used in these circuits are potentially lethal. All relevant safety precautions should be taken to avoid any contact with any point in these circuits while they are in operation.

## Please Note.

This project has not been tested or post-engineered by the *Elektor Electronics* design laboratory.

By applying two or more filters to the input signal, crossovers give each loudspeaker driver its own band of frequencies in which to operate. The filters used come in two fundamental types: digital and analogue, with the latter further subdividing into either passive or active.

Each style of filter has its advantages and disadvantages. At extremely high frequencies, where active devices become bandwidth limited, passive filters work best.

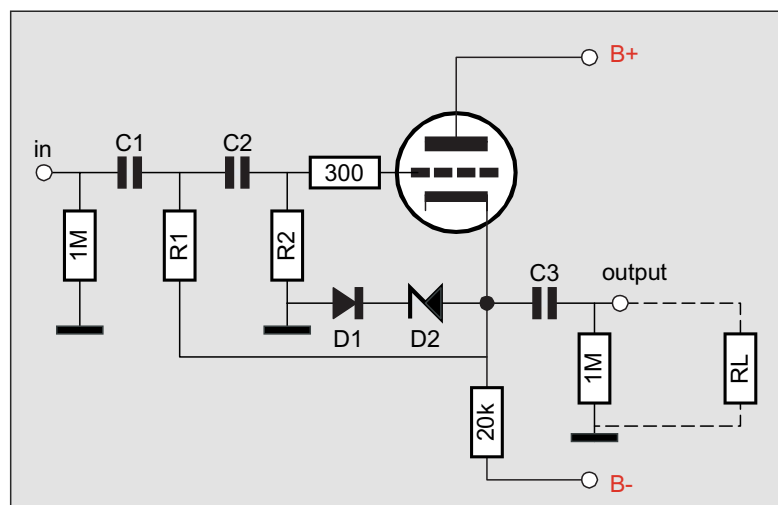
At audio frequencies, however, the active filter wins, as passive filters bring too many liabilities to the job. For example, loudspeakers use passive crossovers that hold a combination of either heavy, expensive inductors along with expensive, bulky, film capacitors; or small, inexpensive, easily saturated, and poor-tolerance inductors and

cheap, low-quality electrolytics placed in series to cancel their polarization.

Adding to these negatives, a loudspeaker's passive crossover must be tweaked to work correctly when working into the reactive load that the loudspeaker drivers present.

Active crossovers, on the other hand, forgo using inductors; instead,

they rely on inexpensive, yet precise, resistors and small, relatively inexpensive tight-tolerance capacitors to set the crossover frequencies. Beyond the savings in cost, active crossovers offer a greater accuracy and a much improved flexibility over passive crossovers. Tight-tolerance resistors and capacitors are inexpensively obtainable and are easily



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Figure 1. Example of a circuit generated by the Tube Crossover Designer software. Note the use of a symmetrical supply voltage. Part values depend on your requirements, and are shown by the program along with this diagram.

swapped for different values, allowing easy changes in crossover frequency. Finally, the active crossover allows a more efficient use of the power amplifier's output, as power-wasting speaker attenuator networks are not needed, when the gain can be reduced efficiently by the mere twist of a potentiometer.

### Tube-Based Crossovers

Tube-based crossovers perform the same function as solid-state crossovers, but use tubes rather than the ubiquitous IC. Why bother with tube-based audio equipment? As they say, if you have to ask, then you haven't listened to a good tube-based audio system. In an active crossover, the tube delivers the same easy-on-the-ear sound it brings to guitar amplifiers and phono preamps.

While realizing a tube-based crossover is no more difficult or complex than the solid-state alternative, it is more expensive. Tubes run on comparatively high voltages, which require comparatively higher prices. For example, a 250-volt 47- $\mu$ F capacitor costs eight times more than the 25-volt equivalent. In addition, the tubes themselves are not cheap, as a handful of ICs can be had for the same price as one good tube, definitely not the cheapest choice. Although tube gear is not easy on the wallet, it is easy on the ears and

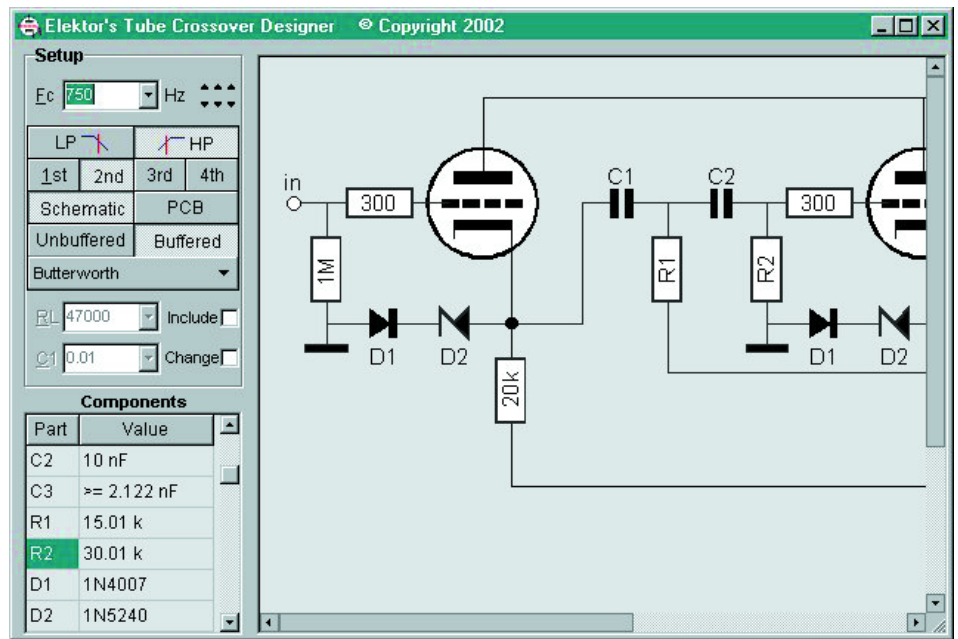


Figure 2. Elektor's Tube Crossover Designer in action. Complete circuits, parts lists and component overlays are produced at the flick of a switch.

eyes. Even when not turned on, tube gear compels attention that no IC-based equipment can match.

### The Plan

This project aims to deliver a tube-based crossover in its most flexible form. Surprisingly, using a printed circuit board can contribute to this goal. While using point-to-point wiring is certainly possible, the PCB

not only offers a consistent physical geometry and helps to prevent miswiring, but it allows a great deal of flexibility, as this PCB resembles a cross between a proto board and a typical PCB. Each board holds two tube sockets (four buffers) and many extra holes.

The flexibility is truly staggering. By reconfiguring the PCB, dozens of arrangements are possible, as 1st, 2nd, 3rd, and 4th order crossover slopes can be easily accommodated on this PCB. Two channels of matching high-pass and low-pass filters (up to 3rd order) fit on one board, as does a single channel's three-way crossover made up of 1st, 2nd, and 3rd order filters (three-way crossovers using fourth-order filter slopes require cascading boards).

But so much freedom can baffle: Which capacitor goes where? Which half of the tube the input? Unfortunately, the formulas and schematics needed to cover all the possible arrangements would fill this entire magazine. Consequently, a Windows software program was created to calculate both the component values and their placement on the PCB. A screendump of the program in action is shown in **Figure 1**. *Elektor's Tube Crossover Designer* program may be downloaded from this month's Free Downloads page at [www.elektor-electronics.co.uk](http://www.elektor-electronics.co.uk). The file number is **020297-11**.

The program covers fourteen basic filter configurations, which by cascading PCBs easily doubles the possible crossover configurations. Unlike many electrical engineering programs, it is easy to use: just key in the

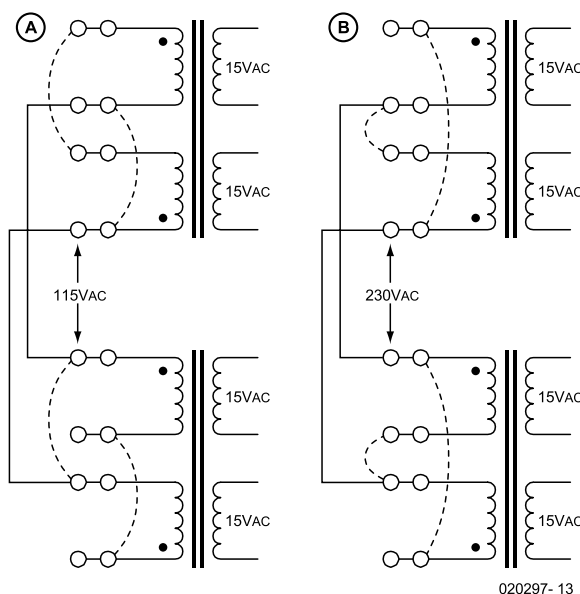
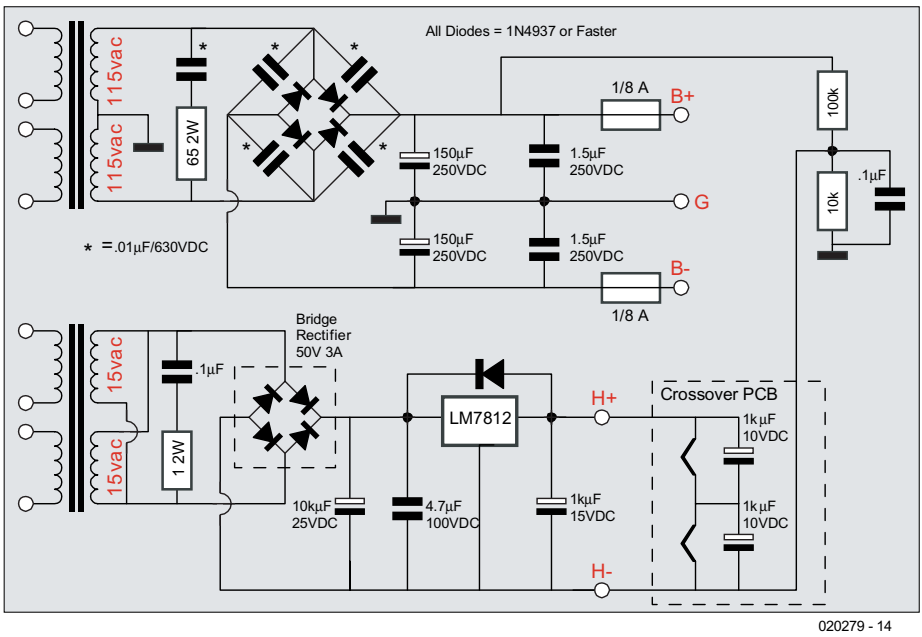


Figure 3. Mains transformer wiring for 115 VAC mains (Figure 3a) and 230 VAC mains (Figure 3b). The mains frequency (60 Hz or 50 Hz) is immaterial.



The power supply

The Signal IF-30-30 and IF-30-230 mains transformers used by the author are encased in plastic and are designed to be mounted on a printed circuit board. Both come with dual primaries, allowing use in countries that use either 115 VAC and 230 VAC. **Figure 3a** shows the layout for 115 VAC; **Figure 3b**, the layout for 230 VAC. The complete circuit diagram of the PSU appears in **Figure 4**. It is a simple affair. Two power transformers are used, one for the high-voltage bipolar power supply for the cathode followers and one for the low-voltage heaters.

Each transformer holds two secondary windings. The high-voltage portion of the power supply uses the two 115-VAC windings to create a centre-tapped full-wave bridge configuration that yields the positive and negative 165-volt rail voltages. Because the cathode follower does such a good job of rejecting power supply noise at its output, no regulation is used on these high-voltage rails. Instead, conventional RC filters are used.

The low-voltage heater power supply uses two windings to create full-wave centre-tapped configuration that yields the single positive rail voltage. This raw DC power supply then feeds a fixed 12-volt three-pin IC regulator. The tubes contain 6.3-volt heaters, which when placed in series across the 12-volt power supply see only 6 volts. This lower voltage is within acceptable voltage tolerances and will only serve to extend the tubes' lives.

Filter Alignments

In audio applications, the Butterworth filter is the most popular type. This makes sense, as it boasts a fairly flat time response, a fairly crisp transition shape and the flattest passband response. Its chief competitor, the Bessel filter, offers flatter time response, but not as sharp a transition shape nor as flat a passband response. Other filter alignments, such as the Chebyshev and the elliptic, are seldom used in audio because of undesirable characteristics such as ripple in the passband or sharp phase shifts.

Figure 4. Circuit diagram of the power supply unit (PSU).

desired crossover frequency, the filter type (high-pass or low-pass), the filter order (1st, 3rd, or 4th), and the filter alignment (Bessel, Butterworth, or Linkwitz-Riley), the part values are displayed in a grid. Pressing the 'Schematic' and 'PCB' buttons toggles the view between the circuit's schematic and its part placement on the PCB.

The Circuit

This tube-based crossover, of which a randomly chosen variant is shown in **Figure 2**, makes use of cathode followers to offer both a low output impedance and a buffering of the crossover's tuning elements. Cathode followers provide no gain and little distortion, as all of the triode's potential gain is used as degenerative feedback to lower its output impedance and flatten its frequency response. Because the cathode follower's output follows its input in phase, its input capacitance is free of the Miller Effect. Additionally, the cathode follower allows the crossover's output to be recirculated into the filter network to create a positive feedback loop.

Many filter alignments need some positive feedback to eliminate the need for inductors within the network, and to compensate for the otherwise drooping output from a solely capacitive and resistive network at the transition frequency.

The crossover uses either 6DJ8 or 6N1P tubes (or any other dual triode that shares the same pinout and heater voltage and has a low  $R_p$  and high  $\mu$ , e.g. 6BQ7, 6BS7, ECC85,

ECC88, 6DJ8, 6AQ8). Referencing the cathode follower's input to ground sidesteps the need for additional input coupling capacitors. In fact, this circuit has been designed with a goal of eliminating as many coupling capacitors as possible. (While this also serves to cut the cost, the savings are somewhat offset by the need for a symmetrical power supply ( $\pm 165$  volts), rather than the more conventional mono-polar power supply of most tube equipment).

Protective Diodes

One problem we face is that the power supply will come up to full voltage much more quickly than the triodes will begin to conduct. This means that at turn-on the triode's grid will see 0 volts and its cathode will see -165 volts. Such a large differential can damage the triode by 'cathode stripping', wherein pieces of cathode's surface are pulled away by the severely positive grid when the tube is still cold.

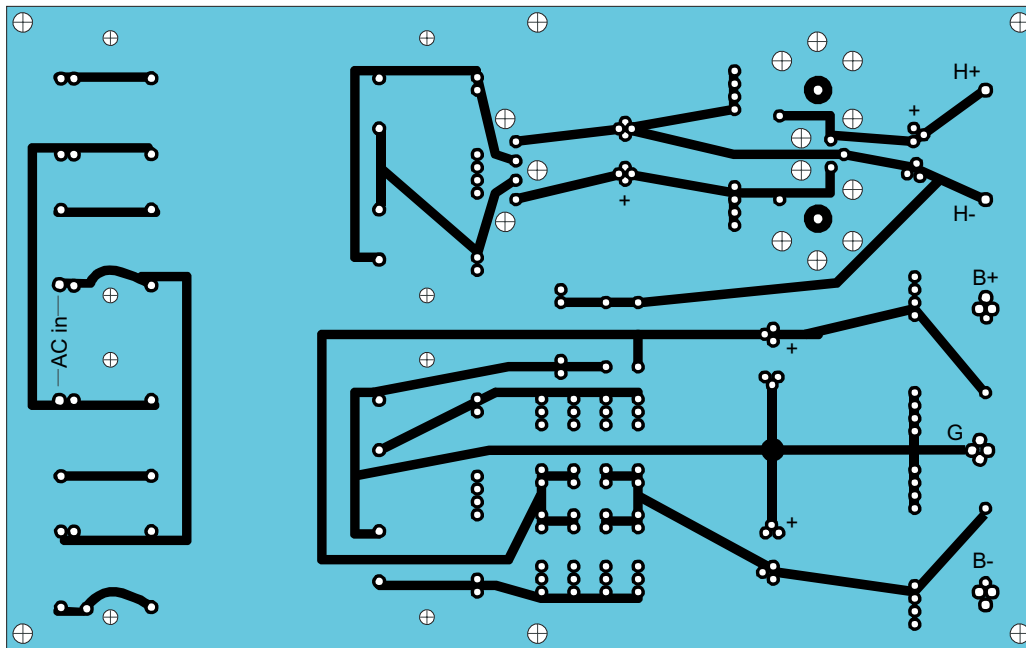
Adding a diode and zener in series solves this problem. When the triodes are hot, the pair of diodes do not conduct and are effectively out of the circuit. When the triodes are cold, they conduct, forcing the cathode to be only a safe -11 volts relative to the grid.

The Linkwitz-Riley variation on the Butterworth is particularly useful for feeding loudspeakers, as it yields a flat transition region by providing a  $-6$  dB output at the crossover frequency. When two loudspeakers play the exact same frequency without amplitude or phase differences (when using even order filters, e.g. 2nd and 4th), the sum of

their outputs is a twofold increase ( $+6$  dB boost) in volume. But as Butterworth filters are designed to have a  $-3$  dB output at the transition frequency, the loudspeaker will experience a  $+3$  dB hump at the crossover frequency, as even-order Butterworth filters produce an even multiple of  $90$  degrees of phase shift (i.e.  $180^\circ$ ,  $360^\circ$ , and  $540^\circ$ ) per number of

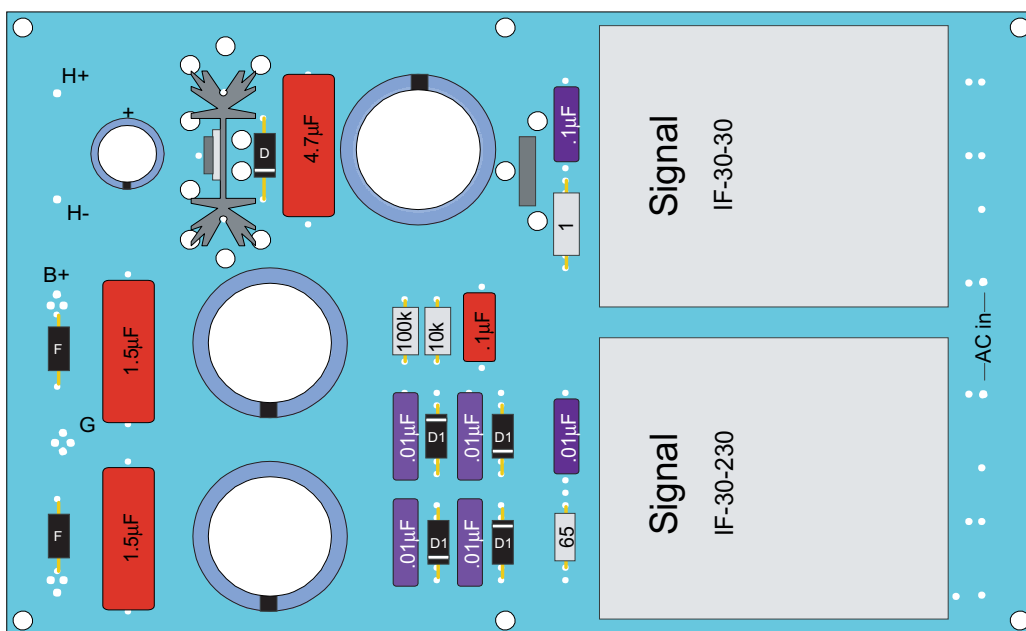
filter order at the transition frequency. Depending on the phasing of the speaker drivers, the result is either a deep null or a boost at the transition frequency.

On the other hand, odd order Butterworth filters (e.g. 1st and 3rd) exhibit an odd multiple of  $45$  degrees of phase shift (i.e.  $45^\circ$ ,  $135^\circ$ , and  $215^\circ$ ) per number of filter order at the transition frequency, which only gives rise to a  $+3$  dB boost, which compensates perfectly



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Figure 5. Copper track layout of PSU board (67% of true size).



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Figure 6. Component mounting plan of PSU board (67% of true size).



with the  $-3$  dB dip in output at the crossover frequency. Thus the odd-order Butterworth filters sidestep the need for an adjustment in output amplitude.

In other words, making a flat even order crossover requires that the signal be not  $-3$  dB, but  $-6$  dB down at the crossover frequency, which the Linkwitz-Riley alignment provides for 2nd and 4th order crossovers. Still, experimentation is the best path. The advantage an active crossover enjoys is that experimentation is much more readily and cheaply done than with a passive crossover.

### 1st, 2nd, and 3rd Order Crossovers

The first-order crossover is at once the most trivial and the theoretically best crossover configuration, as this simple crossover offers the flattest phase and frequency summation at the transition frequency. Unfortunately, its shallow cutoff slopes often fail to protect fragile tweeters and they often fail to curb slow woofers from trying to reach too high. Moving up from two-way to three- or four-way crossovers eases the problem of potential damage to speakers as do robust high-quality (i.e., expensive) loudspeaker drivers.

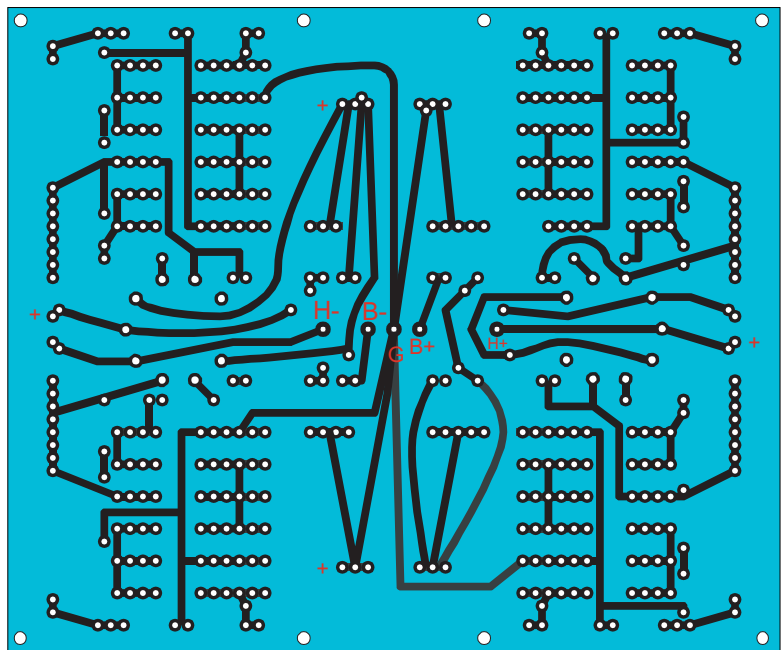
One point to bear in mind is that a first order filter can be used in conjunction with higher order filters. One particularly felicitous pairing is a first-order high-pass filter with a third-order low-pass filter. This combination works well with full-range loudspeakers and subwoofers. To realize this arrangement, as little as one PCB will be needed for stereo, if partially buffered filters are chosen.

In fact, the high-pass section's filter can be defined by its output capacitor working into the load presented by the following amplifier. While this would eliminate one coupling capacitor from the signal path, it would make the crossover less universal, as the output coupling capacitor would have to be changed to match different input impedances from different amplifiers. Furthermore, using two capacitors adds an additional protective high-pass filter at the low frequencies.

Two PCBs will be needed for fully buffered filters, however, as both the high-pass filter and the low-pass filter must be nested between two cathode followers.

Because of the phase differences in low and high outputs at the transition frequency, some experimentation will be needed to yield the best integration between subwoofer and satellite, with subwoofer's phase probably having to be reversed by reversing the speaker cable's plus/minus connections to the subwoofer.

As we move up in filter order, more



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Figure 7. Copper track layout of the multipurpose crossover board (67% of true size).

options become available. The 2nd- and 4th-order crossover can be given Bessel, Butterworth, and Linkwitz-Riley alignments. The 3rd-order crossover can be aligned to Bessel and Butterworth alignments, but not Linkwitz-Riley.

For all three alignments, the PCB may be used in two configurations: completely buffered and half-buffered. In completely buffered version the filter tuning elements are safely tucked between two cathode followers and one PCB will be needed per channel to provide up to 3rd-order filtering. Buffered 4th-order crossovers are not covered, as they would require an excessive number of PCBs. For example, a fully-buffered two-way, 4th-order crossover alone requires 12 cathode followers, i.e. 3 PCBs, which is the power supply's limit; while a fully-buffered three-way requires 16 cathode followers and 4 PCBs.

In the half-buffered version, although the output is buffered, the tuning elements connect directly to the signal source. Thus the assumption is that the filter will be fed from a low-impedance source, such as a line amplifier or CD player output, not a high-impedance source, such as a potentiometer.

Using the half-buffered version allows two channels of two-way crossovers (up to 3rd order) or one channel two-way 4th-order filters to be accommodated on one PCB. Three-way crossovers require cascading PCBs or using one PCB per channel for filters of up to 3rd order. While cascading two PCBs adds more active devices in the signal path, it does offer better attenuation of low frequency signals for the tweeter.

For example, given crossover frequencies of 500 Hz and 5 kHz (2nd order, 12 per dB octave filters), the first PCB splits the frequencies below 500 Hz off to the woofer and sends the frequencies above 500 Hz off to the second PCB, which then applies the 5 kHz split. The result is that the midrange sees 2nd-order slopes at 500 Hz and 5 kHz, while the tweeter sees a 2nd-order slope from 5 kHz down to 500 Hz and a 4th-order slope ( $-24$  dB per octave) from 500 Hz down. This extra low-frequency filtering helps shield the tweeter from low frequencies and is particularly helpful with horn tweeters, as the normally high loading the horn provides to the diaphragm disappears at low frequencies.

## Construction

The PCB artwork and component mounting plan of the PSU board are shown in **Figures 5 and 6** respectively. One power supply board can power up to three crossover PCBs. Both crossover and power supply PCBs can be housed in a single chassis or in separate enclosures. If the latter approach is adopted, an 'umbilical cord' will be needed, which for safety should be shielded and grounded; furthermore, it should end in a female termination (the crossover chassis holding the complementary male prongs) to prevent inquisitive fingers from touching the high-voltage connections.

The copper track layout of the general-purpose crossover board is shown in **Figure 7**. While the *Crossover Designer* program displays the layout on the crossover board(s) and the part values, a few guidelines are required. All the filter network defining resistors should be ½ watt and at least 2% tolerance; the filter network's capacitors,  $\geq 160$  VDC and at least 2% tolerance. The four cathode follower load resistors per crossover board should be 1-2 watt devices and should be mounted with a small gap (2-4 mm) between the

PCB and their bodies. The same holds true for the two 3250-ohm voltage-dropping resistors, which should be 2- to 5- watt devices.

The power supply PCB holds the power transformers and supporting circuitry. The power transformers are quite heavy and could easily be ripped from the PCB during a fall; thus, they should be both soldered and screwed to the PCB. Four #4 self-tapping screws per transformer (along with eight solder joints) will keep the transformer safely in place.

Unlike the crossover PCB, the power supply board offers only one optional wiring configuration: 115 or 230 VAC input. Shrouded wire should be used to create these and all other PCB jumpers.

## Testing

The power supply board should be tested first without any external connections. A variac is recommended, it allows testing at lower, safer voltages.

The low-voltage portion of power supply should put out 12 VDC with no more than a  $\pm 0.5$  V error.

The plus and minus high-voltage portion of the power supply develop much greater voltages when

unloaded than when loaded: hence the need to overspecify capacitor voltages. Expect to see voltages closer to 200 volts than the expected 165 volts.

First test the crossover boards without the tubes; and then if all voltages are in line with expectations, test the board with the tubes in place. Because the heaters are in series, in the absence of the tubes no voltage will be present across the heater (4 & 5) of the tube socket. But across the two sockets, 12 volts should be measured. The plate voltage (pin 6) should exceed 165 volts and cathode voltages (pins 3 & 8) should be roughly  $-11$  volts relative to ground. With the tubes in place, plate voltages for either tube should close to 100 volts; the cathode voltages, +3 volts (the cathode resistor's large value effectively defines an autobias circuit in itself.)

## Using the Crossover

Quite likely, the loudspeaker drivers will not match in efficiency, requiring an adjustment in crossover output level to achieve balance. A white noise generator and a soundlevel meter are needed for precise adjustment. Or you may choose to the following method: adjust the level until it sounds correct, then back off on the bass a tad.

If you have any questions or problems, email the author at [crvquestion@glass-ware.com](mailto:crvquestion@glass-ware.com).

(020297-1)

# The Truth about Batteries

## are Li-Ion batteries really that bad?

By Harry Baggen

Today's society is marked by an increasing amount of 'wireless' equipment. This trend extends to communications as well as to power supplies for portable equipment. The best known examples are the laptop computer and the GSM telephone. Thanks to powerful batteries, such equipment is capable of working for long periods without mains power. But what about the quality of the various kinds of batteries, and how long will they last?

**BATTERIES**  
IN A PORTABLE WORLD  
a handbook on rechargeable batteries for non-engineers

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Isidor Buchmann's latest edition of "Batteries in a PortableWorld" fills the definite need for practical information about rechargeable batteries.

The battery has become our steady travel companion - it helps call a friend; it expands our workplace beyond four walls, and it supports critical missions for people in need. Performance specifications for batteries and chargers are often based on ideal conditions.

Manufacturers carry out battery tests on brand new equipment within protected environments. In Batteries in a Portable World, Mr. Buchmann observes the battery as used by consumers in everyday life. The battery handbook addresses the strengths and limitations of the modern battery. It illustrates which battery chemistry is most appropriate for each application. You will learn about charger technology, battery maintenance to prolong battery life and methods to restore weak batteries with a battery analyzer.

This site is sponsored by Cadex Electronics Inc. the maker of battery analyzers and chargers. Visit the [CADEX](#) site.

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NiMH, Li-Ion and Li-polymer (there's also the sealed lead-acid battery but that's rarely found in modern portable equipment).

Nickel-Cadmium (NiCd) is the oldest type. By virtue of its low internal resistance, it is very suitable for applications requiring relatively high currents. Unfortunately this battery type contains highly poisonous Cadmium and it should have disappeared from the European market within a couple of years. As a replacement the metal-hydride battery was developed, whose performance has been pushed to a level not far from that of the NiCd battery. Although their internal resistance is slightly higher, NiMH batteries may be considered a perfect replacement for a NiCd battery in many applications. For applications in which the energy density is crucial (i.e., a lot of energy from a small device), the Li-Ion battery has been developed. Unfortunately this suffers from one big drawback in that it requires a special charger. A derivate, the Lithium-polymer battery with a flex-

More and more equipment relies on batteries (rechargeable or not) for the power supply. In and around the home, non-rechargeable batteries are used for the central heating thermostat, torchlight, radio and personal stereo. Rechargeable batteries are typically applied in equipment with higher current consumption, such as digital cameras and

portable computers. The GSM phone, too, can't do without a powerful battery because it needs to be on all day so has to be recharged from time to time.

As most readers of this magazine will know, there are several types of battery around these days: NiCd,

Choosing a Battery that Will Last Page 3 Netscape

PowerPulse.Net 19 November 2002

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The Web's Leading Power Electronics Publication

### Technical Paper

#### Choosing a Battery that Will Last Page 3

##### Is Lithium-ion Truly Superior?

Today's battery research is heavily focused on lithium systems, and one could assume that all future applications will be lithium-based. This lithium hype is especially apparent when attending battery seminars where battery manufacturers worldwide meet. The emphasis is on lithium-polymer; older chemistries such as NiCd and NiMH are hardly mentioned.

In many aspects, the lithium-ion battery is superior to nickel or lead-based batteries. There is one weak point with the lithium-ion that, for unknown reasons, is seldom mentioned by the battery manufacturer. It is aging. Capacity deterioration is noticeable after one year, whether the battery is in storage or use. Past two years, the battery frequently fails.

Although less of a concern in the fast-moving cellular phone and notebook market, storage at operational readiness is an important factor in defense applications. In Figure 6, we examine the capacity loss as a function of charge level and storage temperature.

	40% charge level [shipping and storage charge level]	100% charge level [user charge level]
0°C	98% after 1 year	94% after 1 year
+25°C	96% after 1 year	90% after 1 year
+40°C	95% after 1 year	65% after 1 year
+60°C	76% after 1 year	60% after 3 months

## Internet Addresses:

- [1] Digit-life.com:  
[www.digit-life.com/articles/mobileaccumulators/](http://www.digit-life.com/articles/mobileaccumulators/)
- [2] PowerPulse.Net:  
[www.powerpulse.net/powerpulse/archive/aa\\_040201b3.stm](http://www.powerpulse.net/powerpulse/archive/aa_040201b3.stm)
- [3] Cadex: [www.cadex.com](http://www.cadex.com)
- [4] Batteries in a portable world:  
[www.buchmann.ca/default.asp](http://www.buchmann.ca/default.asp)
- [5] Li-ion characteristics:  
[www.buchmann.ca/Article9-page3.asp](http://www.buchmann.ca/Article9-page3.asp)
- [6] LG:  
[http://battery.rnd.lgchem.co.kr/english/file/LG\\_Li-ion.pdf](http://battery.rnd.lgchem.co.kr/english/file/LG_Li-ion.pdf)
- [7] NASDA:  
[www.nasda.go.jp/lib/nasda-news/2002/09/front\\_line\\_e.html](http://www.nasda.go.jp/lib/nasda-news/2002/09/front_line_e.html)

ible shape, is applied in, among others, PDAs.

All of these battery types have their own advantages and disadvantages. A good overview of their characteristics may be found at the **Digit-life.com** website [1].

If we are to believe the results of tests carried out by consumer organisations in different countries, modern NiCd and NiMH batteries differ only marginally in performance. The infamous memory effect associated with NiCd batteries has practically disappeared. And yet, some tests found on the Internet still claim the opposite and as always it is hard to tell who is right in such cases. The characteristics may be specific to certain brands or types, but in general these battery types can now be said to have similar characteristics.

Li-Ion is often considered the ideal battery for mobile and portable equipment: lots of capacity at small size, little self discharging and a low internal resistance. On the down side, Li-Ion is critical in respect of charging. Thanks to all kinds of smart chemical links in these batteries, the otherwise very explosive Lithium is constrained. Unfortunately, the excellent reputation of Li-ion has suffered somewhat by a number of articles in German computer magazines, their research indicating that Li-Ion batteries are affected by natural ageing caused by the intrinsic chemical composition.

Apparently, it is irrelevant if the battery is actually used or not. According to these reports, a Li-Ion battery has only half the nominal capacity after a year or two. According to the testers, the industry assumes that laptop PCs and GSMs have an economic life cycle of just two years in any case. This is also said to apply to new batteries for GSM phones or laptops. After all, a battery that has been left in storage for a number of years may already have lost a part of its capacity although the full price is charged for it! Most manufacturers remain silent about this alleged characteristic of their Li-Ion batteries and usually do not print a production date on their product.

On the Internet, several websites may be found covering the above mentioned effect, for example, the article *Choosing a Battery that Will Last* on **PowerPulse.net** [2]. Most other information we came across on the Internet is based on research and articles by Isidor Buchmann of the Canadian firm **Cadex** [3]. Cadex is a manufacturer of, among others, battery analysers. Buchmann also runs his own website called **Batteries in a portable world** [4], which contains some interesting articles on battery-related subjects. For instance, a description of the characteristics of Li-Ion batteries is rendered in [5]. From his research Buchmann concludes that Li-Ion cells also age if they are not actually used.

After about two years, this process has progressed to the stage where the batteries often fail altogether.

Little or no information on this subject may be found with the manufacturers. After some searching, we came across a datasheet from **LG** [6] about their Li-Ion batteries. A graph is shown indicating that after 6 months of shelf storage the capacity of a Li-Ion battery degrades to about 90% of its initial value, and not owing to self-discharging! These figures apply at an ambient temperature of 20 °C — at higher temperatures the same decrease occurs much sooner.

Unfortunately all our searching produced just one serious test mentioning this phenomenon. The other sites only refer to it and have not done any testing themselves. Our impression is that the ageing effect is dependent on the chemical composition of the battery, and will therefore differ from brand to brand. Besides, the technology behind Li-Ion batteries is being improved all the time, so the latest types may be expected to be much better than the ones manufactured a few years ago.

As an aside, it is worth mentioning that space agencies and manufacturers of electrically powered cars are busy researching the application of large Li-Ion batteries. Especially with satellites, life expectancy of the battery is a major issue! Up there, a battery is expected to last 10 years or longer without any degradation in quality. A nice example of this may be found at the **NASDA** website [7]. Maybe the Li-Ion battery is not as bad as some would have us believe?

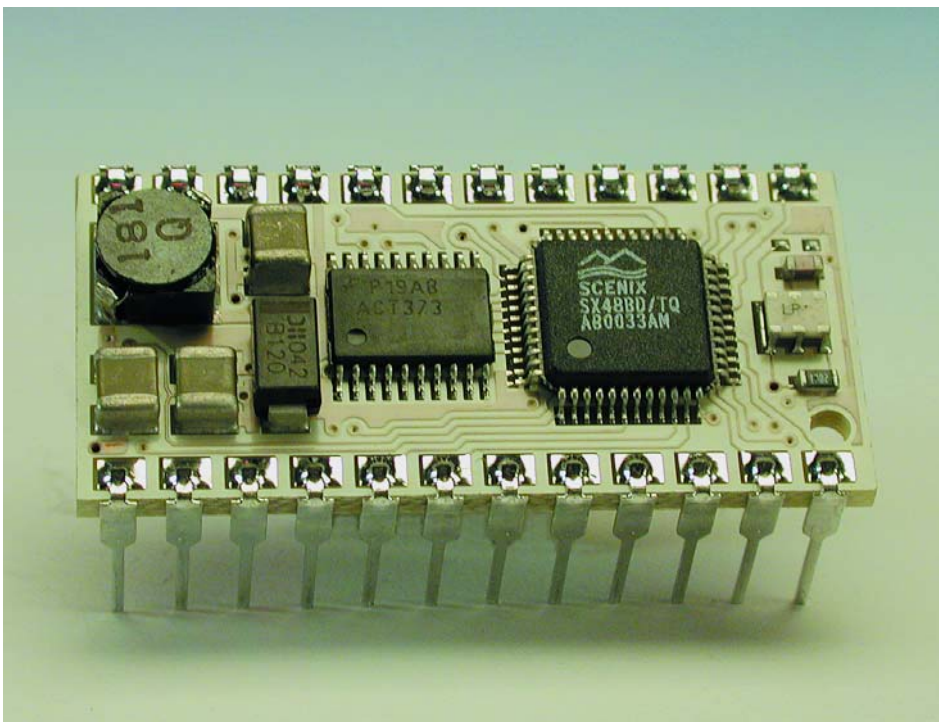
(035005-1)

# The Javelin Stamp

## Parallax goes Java

By Harry Baggen

Parallax Inc. from the USA are known the world over for their BASIC Stamps, a series of microcontroller modules that can be programmed in BASIC. The youngest member of the family not only offers more memory than its predecessors, it also talks a different language: Java!



Rocklin (CA) based Parallax Inc. has acquired name and fame with their Stamp microcontroller modules (The Editor remembers when they were a garden-shed company). The basic idea they had was simple and effective: launch a microcontroller product that's easy to program and apply, allowing relatively inexperienced users to quickly develop an application without deep knowledge of the dreaded phenomenon called assembly code. The idea evolved

into a product called Basic Stamp, a small module containing a PIC running a BASIC interpreter, some memory, a voltage regulator and a resonator to furnish the microcontroller clock signal. As we write this the Parallax company have been in business for 15 years, shipping, directly and via their distributor network, impressive numbers of BASIC Stamps, not only to profes-

sional users, but also to hobbyists and educational institutions.

Over the past 15 years, the Stamp 1 matured and customers got ever better products, with more I/O lines, more memory capacity and higher clock speeds: the BASIC Stamp 2, 2e, 2sx and 2p24/2p40. They all have one thing in common: programming is achieved using the PBASIC language designed by Parallax.

The arrival, last summer, of the Javelin Stamp indicates that Parallax have had the wherewithal to change to Java, a programming language that should be known to everyone who's ever been on the Internet. The Java language offers the user more possibilities than PBASIC, while many programmers have already acquired some knowledge of it, having written applets for websites.

### Features

Just as its predecessors, the Javelin Stamp consists of a miniature PCB with the footprint of a 24-way DIP case (see introductory photograph). It is pin compatible with the BASIC Stamp and may be plugged onto any BASIC Stamp board having a 24-pin socket.

In addition to the Javelin Stamp module proper, Parallax also supply a dedicated starter kit (**Figure 1**), which consists of a Javelin module,

a prototyping board, a manual, an RS232 cable, a zero-modem adapter, a CD-ROM and a set of components for various worked out examples discussed in the manual.

The microcontroller used is an SX48C from Ubicom. It gives you, the user, 32 kBytes RAM, 32 kBytes EEPROM, 16 I/O lines and 2 RS232 ports. The miniature, on-board switch-mode power supply accepts a wide input voltage range while it is capable of supplying appreciable current. Components are found at both sides of the double-sided board.

The Javelin architecture is different from that used for the BASIC Stamp we have come to appreciate so much. Although the program is stored in EEPROM, the actual executable code is fetched from a super-fast SRAM (static RAM). The firmware is designed such that besides the main program a number of tasks may be performed in the background.

### A Java dialect

The Javelin Stamp employs a subset of Java 1.2 as developed by Sun Systems. It contains firmware extensions (known as Virtual Peripherals, VPs) that emulate hardware like UARTs, timers, A/D and D/A converters, and so on. Using these VPs, interfacing the Stamp to peripheral equipment is straightforward. Although the VPs cause the development of a Javelin Stamp program to deviate from that of a Java program for the PC, all it takes is a little getting used to, practicing and experimenting — just the kind of thing many of our readers will have no objection to.

The following VPs are available: UART, PWM, 32-bit timer, pulse counter, pulsewidth measurement, pulse generation, 1-bit DAC, sigma-delta DAC, ADC with RC timer and SPI master.

BASIC programmers will need to 'think differently', though, because programming in Java is a totally different kettle of fish not vaguely resembling BASIC. Fortunately, the extensive manual supplied with the Javelin Stamp supplies a fair number of example programs to make the migration to Java as painless as possible.

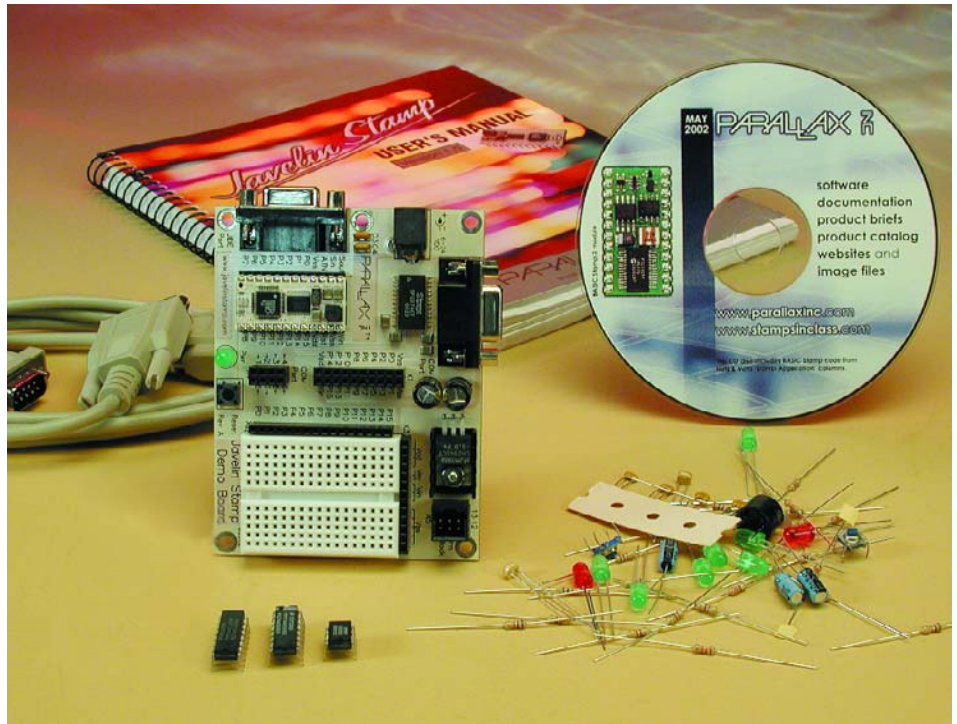


Figure 1. The starter kit contains everything to get started straight away.

The two programs in Listing 1 illustrate some of the differences between practical Java Stamp and BASIC Stamp programming. Both programs cause an LED to flash as long as a certain key is pressed. Most of you will recognize program

A as intended for the BASIC Stamp — 'B' shows the Java Stamp equivalent.

### PC software

At the PC side, the user has available an integrated Design Environment (IDE) containing

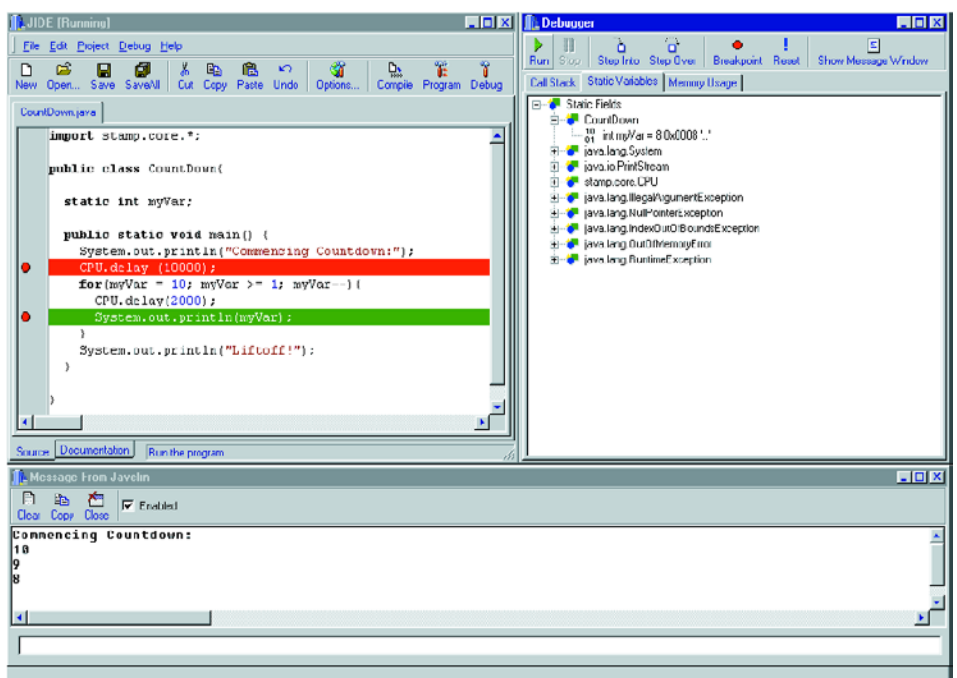


Figure 2. The development platform for the javelin Stamp contains an extensive editor and debugger.

## Listing I

### A. LED flasher with pushbutton control, BASIC Stamp version

```

output 0           ' make P0 an output
out0=1            ' make P0 "high"
Input 2
recheck:          ' a label
if in2=0 then blink ' check to see if P2 is a "0", if it is
                  ' then go and blink the LED
goto recheck      ' if P2 was a "1", then go back
                  ' and check again

blink:            ' a label
low 0             ' turn on the LED
pause 200         ' wait .2 seconds
high 0            ' turn off the LED
pause 200         ' wait .2 seconds
goto recheck      ' loop back & do it again
    
```

### B. LED flasher with pushbutton control, Javelin Stamp version

```

import stamp.core.*;

public class ButtonLED {

    static boolean P0 = true;

    public static void main() {

        while(true) {
            if (CPU.readPin(CPU.pins[1]) == false) { // If button pressed
                P0 = !P0; // Negate P0
                CPU.writePin(CPU.pins[0],P0); // LED [On]
                CPU.delay(1000);
            } // end if
            else {
                CPU.writePin(CPU.pins[0],true); // LED [Off]
            } // end else
        } // end while
    } // end main
} // end class declaration
    
```

an extensive editor, debugger and a Message window (**Figure 2**). The debugger is marked by the following features:

- multiple breakpoint allowed
- stack backtrace
- variables and objects checking
- single-step, run, stop, reset
- inbuilt bi-directional serial Message Terminal

Online help is available, giving access to extensive documentation on the library classes and some weblinks to Parallax.

## Support

Just as with the BASIC Stamp series, a vast resource of information is available on the

Javelin Stamp. The whereabouts of this information is also unchanged — you'll find it all on the Parallax website. All documentation and PC software is always available in the latest versions. The website also hosts an extensive Java library as well as a page with applications. This page is sure to grow in content as an increasing number of programmers get their teeth in the Javelin Stamp. A separate forum is available on the website for users to exchange ideas and practicalities.

(020355-1)

### Parallax distributor for the UK

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Website: [www.milinst.com](http://www.milinst.com)

## Websites:

[www.parallaxinc.com](http://www.parallaxinc.com)

[www.javelinstamp.com](http://www.javelinstamp.com)

# Programming AVR Microprocessors

easy with BASCOM AVR

By Mark Alberts

This article shows that working with microprocessors has become very straightforward these days. Thanks to the AVR-microprocessor and the well-known BASIC programming language success is assured.

There are several different AVR-microprocessors available. The AT90S2313 is an inexpensive 20-pin version with 2 kB of flashable code memory. Flash memory is the area where the program is stored. The main advantage of this type of memory is that it can be reprogrammed a thousand times. An even bigger advantage is that you do not have to bother with special programmers or UV erasers — a simple cable connected to the LPT (parallel printer) port of your PC is all you need to program a flashable micro.

## The 90S2313

First, let's have a look at the most important characteristics of the 90S2313 (Figure 1):

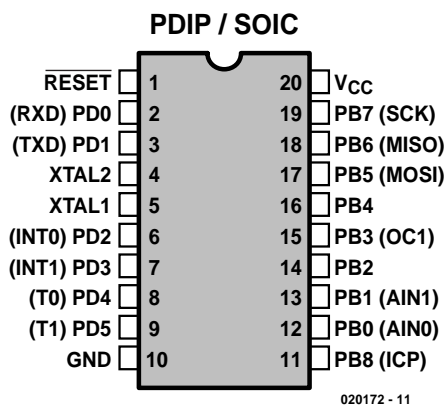


Figure 1. The connection details of the 90S2313.

There are two available ports: PORTB and PORTD  
 Internal memory: 128 bytes  
 EEPROM memory: 128 bytes  
 Flash program memory: 2 kBytes

A noticeable feature is that 15 of the 20 pins have been used for IO ports. It is these pins that provide the measurement and control capabilities of the processor. The ports normally consist of 8 pins (bits) each. However, pin PD7 on the 90S2313 is not actually connected to a physical external pin.

Any pin can function as an input or an output. If the pin is functioning as an output, it can be assigned a logic level of '0' or '1'. The processor can do this for each pin individually, but it is also possible to address them as a group. Pins PD0 to PD6 together form the group called PORTD. By assigning a value to PORTD we can change the value of

all pins in one go.

Most of the pins also have an alternate function. The alternate function is shown in brackets. (INT0) PD2 means: the pin name is PORTD.2 and the alternate function is INT0. For the purpose of this article we will limit ourselves to the normal functionality of the pins.

## Working with BASCOM AVR

Before we can actually get started, we first have to install the programming software. The software is called BASCOM-AVR (BASIC COMPILER) and can be found on the *Elektor Electronics* 2002 Freeware-CD-ROM. Alternatively, download the files from the MCS Electronics web site at

[www.mcselec.com/elektor.htm](http://www.mcselec.com/elektor.htm) where you can read which files you need to download, as well as find

## Listing 1

```
CONFIG PORTB = OUTPUT ' use port B pins as output pins
PORTB.0 = 1 ' pull pin PORTB.0 high
PORTB.0 = 0 ' pull pin PORTB.0 low again
PORTB = 255 ' pull all pins high
PORTB = &B10101010 ' make pins 1,3,5 and 7 high
END
```



instructions on how to install the software. The software that has been used here is a demo version, which is however fully functional. The only limitation is that the compiled processor code is limited to 2 kB in size — the same as the flashable memory of the 90S2313!

Start BASCOM AVR and select *Files ? New* from the menu. A window will appear. In this window we will type our first program (**Listing 1**).

Save the program with *File → Save As* and give it the name **sample1.bas**.

You've now written your first program. The microprocessor will understand very little of this program however, it can only understand the so-called object code. Object code is generated by compiling the BASIC program. Press F7 to accomplish this.

If you do not get any error messages, then you have entered the program correctly. If you do get an error message however, correct the mistake and compile the program again.

Before you program the microprocessor with the generated object code, you will first have to simulate the program. Only if you are satisfied with the results of the simulation, the program may be loaded into the microprocessor.

When no more error messages pop up, you may press F2 to open the simulation window.

The program as entered is shown at the bottom of the window (**Figure 2**). At the top of the window are the buttons controlling the simulation. Click the 'LCD' button in order to open the hardware simulation window.

There is now an LCD-panel at the top of the hardware-simulator window (**Figure 3**). Ports PORTB and PORTD are shown at bottom left. The purpose of the green LEDs will be explained later. We can now go through our program step by step. By clicking the step button (<), some invisible code is executed. The purpose of this code is to prepare the microprocessor for use. Once you click the step button again, the first line of the program is executed. This

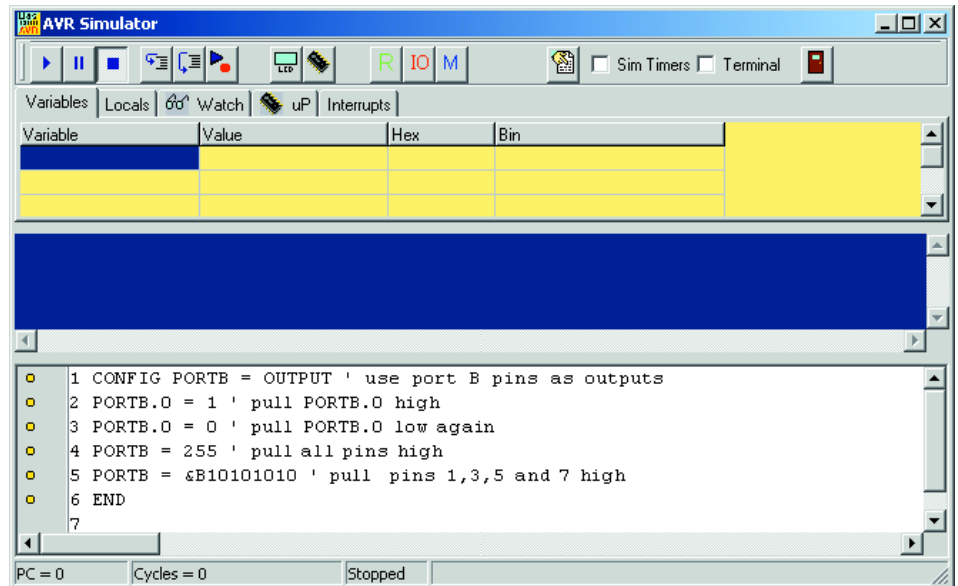


Figure 2. The simulation window of Bascom AVR.

line 1 has no visible effect. Click the step-button again to execute line 2. LED 0 of PORTB will now light up.

This is because with 'PORTB.0 = 1' we gave the instruction to make PIN 0 of PORTB a '1'. This simulator indicates a logical one at a pin as an illuminated LED. The outcome of the following step will not surprise you: the LED goes out.

Line 4 causes all pins to go '1' by writing to PORTB. With this instruction we can change the level of all the pins in one go.

Line 5 is interesting because it shows that we can also use binary notation to provide the value of the port. The binary notation is prefixed with &B, followed by all the bit values. The first bit corresponds to pin 7, the last one to pin 0. For example, 'PORTB=&B1001' makes only pins 0 and 3 high.

Now that the program works, we can program it into the microprocessor. Press F4 to make this happen. After programming is completed, you will see that LEDs 1, 3, 5 and 7 are lit. Because the program is executed so rapidly by the microprocessor, you will not see the result of lines 2 through 4!

Naturally, it is possible to replace the LEDs with a relay or some other output circuit.

You may now like to know what the purpose of the green LEDs in the simulation window is. The AVR-

microprocessor is also able to determine the logic level of a pin when the port is configured as an input. In this case the ports are

## Listing 2

```

CONFIG PORTB = INPUT
PORTB = 255
DO
    PRINT PINB
LOOP

```

called PINB and PIND.

Next, you remove the END statement from the program and add the following lines: Compile the program (F7) and press (F2) again to start the simulator.

Then press the Run button (>). You will see that in the centre of the screen the value of PINB is displayed. This is '0'. By clicking the green LEDs of PINB you can change the levels of PINB in the simulator. You will see that the value changes accordingly.

There is also a switch in our circuit. It is connected to PINB.0.

You now enter a new program:

## Listing 3

```

CONFIG PINB.0 = INPUT : CONFIG
PINB.2 = OUTPUT : PORTB.0 = 1
DO
    PORTB.2 = PINB.0
LOOP

```

Compile this program and program the micro using F4.

If you now press button S1, the LED will turn off. Pin 2 of PORTB is now made equal to the logic level at input pin 0 of PINB.

In the BASCOM help file you can find the effect and explanation for each of the statements that were used here.

(020172-1)

**Note:**

The author of this article, Mark Alberts, is the designer of the BASCOM compilers for the 8051 and AVR-processors. More information can be found by visiting his website at [www.mcselec.com](http://www.mcselec.com).

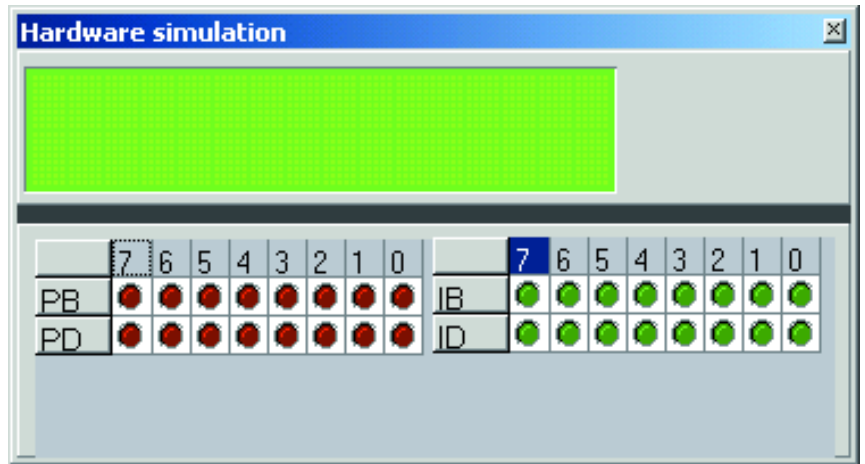


Figure 3. The hardware simulator consists of an LCD section with below it the input and output levels of the two ports.

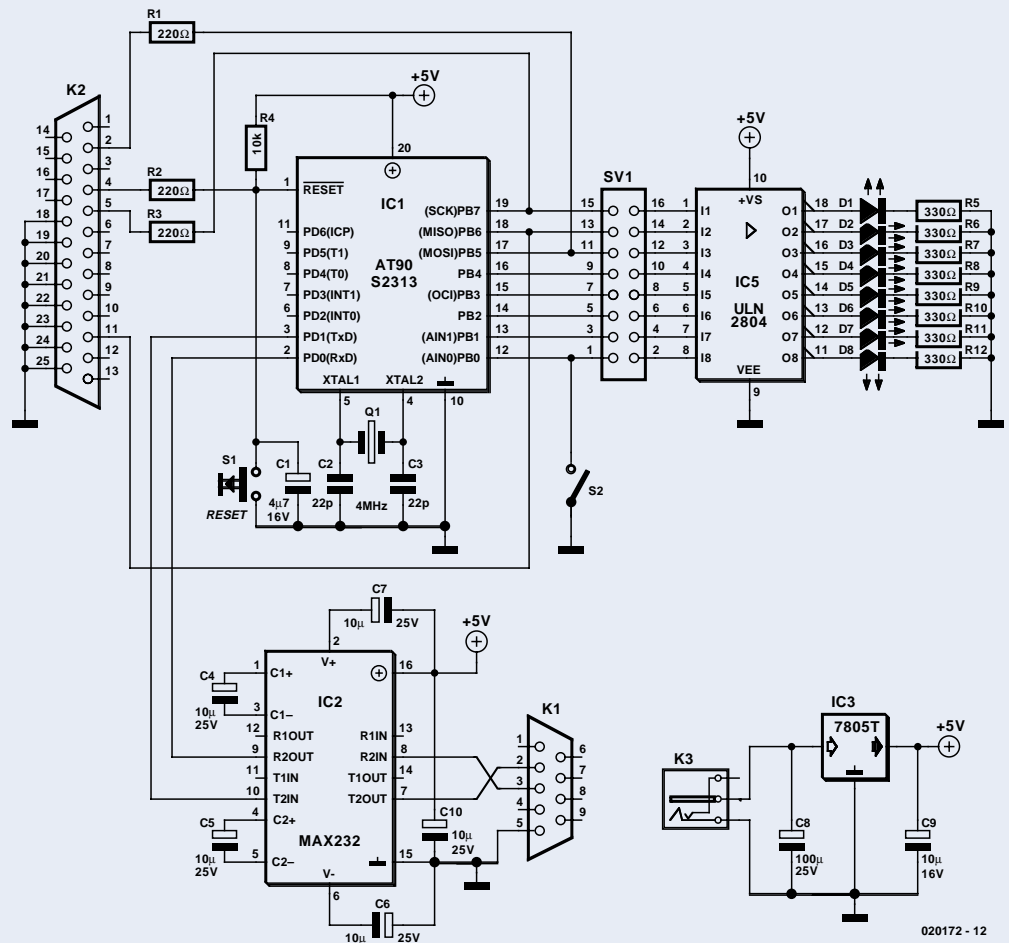
## Test example

The schematic shown here may be used to check various things.

Using the LPT connector, the so-called Sample Electronics programmer may be made. The series resistors are included for protection. It should be noted that it is best to connect the hardware via a separate IO card.

The DB9 connector, together with the MAX232, forms a serial input and output that can be connected to the COM port of a PC.

In the example, a switch is connected to PB0. SV1 is a header on which jumpers may be placed. The driver chip (ULN) is necessary in this case. Normally this IC is not required when the LEDs are wired the other way around and connected to  $V_{CC}$  via a resistor. It is also possible to drive relays with the ULN if the power supply to this IC is connected to 12 V. The only purpose of this schematic is to provide a straightforward example. Very likely you already have a large number of simple AVR schematics in your archive that you can use as well.



020172 - 12

# Results of our Flash Design Competition

chess computer is the clear winner

By Harry Baggen

The projects received in response to the Flash Design Competition we ran in the Summer Circuits 2002 issue were generally of a very high level. What's more, nearly all projects were extensively documented. The result: much deliberation among the Jury members, but one clear winner: a chess computer designed by Pedram Azad and Tilo Gockel.

## The Winners

**First Prize: £300 in cash (approx. €500)**

**Chess computer 'Deep Evelyn'** by Pedram Azad and Tilo Gockel (Germany)

**Consolation Prizes: Elektor vouchers worth £60 (approx. €100)**

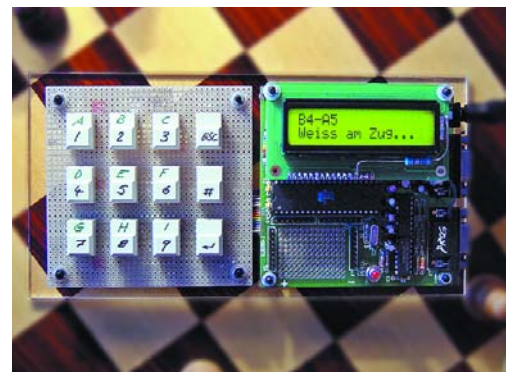
**Programmable Switching Clock**, by Wilfried Wätzig (Germany)

**LED Message Board**, also by Wilfried Wätzig (Germany)

**Realtime Clock with DCF Synchronisation**, by Mark de Martelaar (Belgium)

**RGB generator/converter**, by Alexander Steiger (Germany)

**DALFlash Extension Card**, by Alain Desalle (Belgium)



The competition entries proved beyond doubt that *Elektor Electronics* readers are downright power users of the 89S8252 Flash Micro Board published in the December 2001 issue. The proof was in the results of our Flash Design Competition which did not fail to attract a number of well-designed circuits and excellent software. Most participants managed (some in the nick of time) to include extensive descriptions and sometimes even photographs of their projects, all clearly aiming to impress the Jury and provide as much information as possible on the project.

The Jury consisted of the editors of the four (main) language editions in which Elektor is produced (Dutch,

French, English and German), to which was added the head of our in-house design department. After all, an international competition requires an international Jury!

Having scrutinized the competition entries and added up the individual scores given to each project by the Jury members, it became evident that the Jury was unanimous in awarding the First Prize to Pedram Azad and Tilo Gockel of Germany for their Chess Computer design called Deep Evelyn. This computer comprises a Flash board, an LCD, a keyboard and software turning it all into a powerful chess computer. Remarkably, all software is contained in the microcontroller. At this point we should hasten

to add that the designers replaced the original 89S8252 micro with the pin-compatible 89S53 which has more memory (12 kBytes). This was deemed acceptable by the Jury because the hardware change does not require 'major surgery' on the Flash board.

We congratulate the winners with their prize of £300 (approx. €500) in cash and will not fail to prepare the chess computer design for publication in a future issue of *Elektor Electronics*. Unfortunately none of the entries received from readers of the English edition of Elektor made it into the prize region.

Besides the chess computer, several other competition entries were found worthy of publication, so watch the next six or so issues of this magazine for more designs based on the highly popular Flash Micro Board!

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