

# LED Night light

Design: Dr. Thomas Scherer (Germany)

Some types of night light are fitted with a small 1 W fluorescent tube which provide just enough illumination to stop you bumping into things when you need to visit the bathroom in the middle of the night. The unit shown here fits into a European mains outlet but similar models are also available in the UK and US. In continuous use you can expect the fluorescent tube to last for a couple of years before it packs up. Then of course it will be necessary to think about a replacement. We are gradually becoming more aware of the impact that our throw-away culture is having on the environment, much better to recycle. The dead night light is a case in point; it can be revived with a new circuit and a set of LEDs to produce an improved version of the original design which is not just ecologically sound but also runs more efficiently and will last much longer.

The enclosure shown plugs directly into a (European Continental) mains outlet and is specifically designed to ensure that all parts of the internal circuitry are completely insulated and cannot be accidentally handled. It is important to ensure that any similar enclosure used for this circuit provides adequate insulation, mains voltage is lethal! Firstly when the old night light innards are removed make sure that the fluorescent tube is correctly disposed of and not just tossed in a bin. With the new circuit and LEDs fitted you can expect the light to last over 100,000 hrs which equates to more than 10 years continuous operation! Add to this the improved efficiency and it's clear that this design will save both money and energy.

A mains transformer is normally the first essential component that you would find in any low-voltage circuit powered from the mains. The night light enclosure is however too small. Instead the circuit uses a capacitor as a sort of pre-resistor to drop the voltage. At 50 Hz the capacitor's impedance is given by:

$$Z = 1 / (2\pi \times 50 \text{ Hz} \times C1)$$

One advantage of this approach is that a capacitor represents a reactive load to the supply while the consumer unit measures effective power. Better still; the majority of electrical equipment connected to the national grid has an inductive load, so the nightlight will go some (tiny) way to correct the power factor.

An LED is essentially a diode and only allows current to flow in one direction, connect it across a low voltage AC supply and it conducts only when it is forward biased. Two LEDs connected in anti-parallel will alternately flicker quite



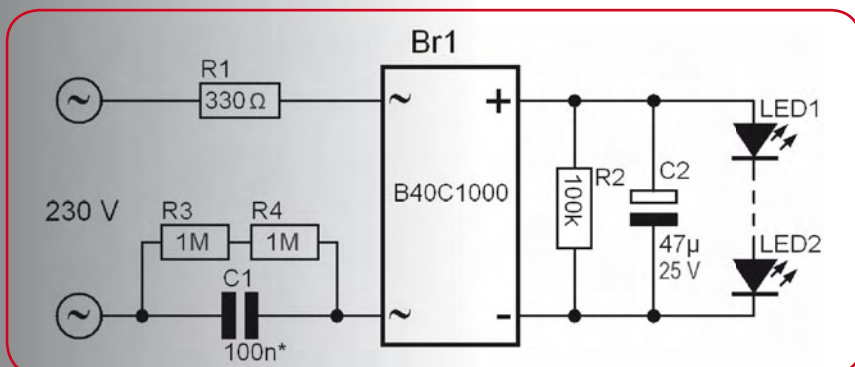
noticeably at 50 Hz. The circuit uses the bridge rectifier Br1 to give full wave rectification resulting in a much less noticeable 100 Hz flicker.

Capacitor C2 performs two functions: firstly it acts as a reservoir capacitor to smooth out the voltage peaks so that the light from the LEDs light does not flicker and secondly it protects the LEDs by absorbing any transient voltage surge which can occur when the unit is plugged in. The worst case would be if the unit is plugged in at the point that the mains voltage is at its peak value. The circuit would suddenly have 330 V across it and across C1, giving rise to a very high value of impulse current which could destroy the unit. R1 limits this surge to 1 A, at switch on C2 will be discharged and thus better able to absorb the voltage transient and protect the LEDs. R2 ensures that C2 is discharged before the unit is next plugged in.

Resistors R3 and R4 discharge any voltage remaining on C1 before it has time to give you a 'surprise' when you handle the unit after it is unplugged from the mains socket. It is important to use two resistors in series here because the voltage rating of a typical resistor is 250 V maximum. Using a single resistor here would mean that this limit is exceeded 100 times a second. It is better to use a  $\geq 0.5$  W carbon film resistor for R1; they tend to be more robust than metal film resistors when subjected to current surges.

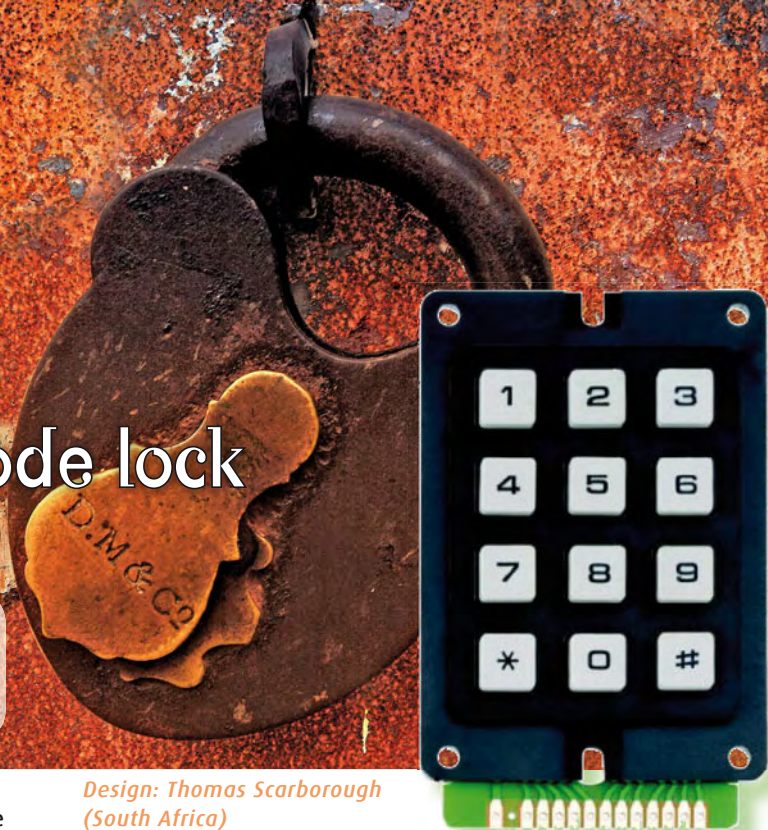
Any worries concerning the lack of brightness of the new light sources were quickly laid to rest when testing the circuit. Instead of LED1 and LED2 shown in the circuit diagram the prototype was fitted with five white high-efficiency LEDs in series, each with a 10,000 mcd rating at 25 mA. The value of capacitor C1 was chosen as 330 nF to give a current of 25 mA but the result was so bright that C1 was changed to 100 nF to reduce the current to 7 mA. Fewer LEDs or less efficient types would also reduce the brightness. The overall real power drawn by the circuit was measured at only 140 mW!

One last word regarding the components; it is important to ensure that C1 is an X2 type of capacitor suitable for use at mains voltages. It should be marked with a voltage rating '250~' or higher. A DC voltage rating of 630 V (and therefore an X2 type) is also sufficient. Finally this circuit is connected to the mains, it is vital to ensure that you adhere to all safety guidelines when building and testing the circuit.



# 6-component code lock

It appears that '6' is the author's favourite number. In the wake of his intercom design, he has now developed a design for a code lock that also consists of six components (if you don't count the buttons).



Design: Thomas Scarborough (South Africa)

A code lock circuit should be able to do more than just release an electromechanical door latch. It must also be able to reliably prevent entry by any potential intruder who doesn't know the code – which is exactly what this circuit does. The lock releases the latch when the right pair of buttons is pressed at the same time. If any other button is pressed (here represented by button S3 in the circuit diagram), the user must wait 90 seconds before making another attempt. This makes any effort to discover the right code by trying all possible combinations a very time-consuming enterprise. For instance, you could use a 12-button keypad with all buttons except the two buttons for the desired code connected in parallel (in other words, connected as shown for S3). The fact that the right buttons must be pressed at the same time instead of in one after the other can also be regarded as a severe obstacle to unauthorised entry, since most code locks operate with sequential code entry.

The circuit is based on a type 4028B CMOS decoder IC, which is designed to convert a 4-bit binary code into a decimal value. However, this function is not used in this case. The only thing that matters here is that a '1' is present at the  $O_0$  output (pin 3) when a '0' level is present on all four inputs (A–D). When this happens, power MOSFET TR1 conducts and the electromechanical latch is energised to open the door.

The C input is tied to ground ('0' level), and in the quiescent state the D input is held in the '0' state by resistor R3. In order to open the door, the user must put inputs A and B in the '0' state as well by pressing buttons S1 and S2 simultaneously.

If an incorrect button (S3) is pressed, input D is put in the '1' state, which prevents opening of the latch (a single '1' is all that is necessary for this). After this happens, capacitor C1 discharges slowly via R3 and prevents the circuit from responding to any further key presses for the next 90 seconds.

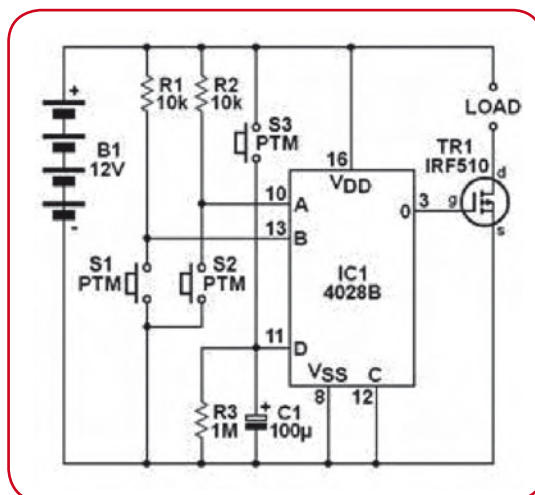
If you wish, you can increase the degree of protection against potential code breakers even further by changing the value of C1. For instance, if the value of C1 is raised to 1000  $\mu\text{F}$  a potential intruder would

be well advised to bring along a tent and sleeping bag ; ). Although using a higher capacitance value may increase security, it also has drawbacks – especially if the legitimate user accidentally presses the wrong button.

As already mentioned, you can use a 12-button keypad for code entry. Select two buttons of your choice for the code and wire them as shown for S1 and S2 in the schematic diagram. Now the latch will not open unless these two buttons are pressed at the same time. Connect the rest of the buttons in parallel and wire them as shown for S3 in the diagram.

Note that many keypads have one contact of each of the buttons connected in to a common terminal. This sort of connection does not present a problem for the 'wrong' (S3) buttons, since they must anyhow be connected together. However, if S1 and S2 are also connected to this common terminal, the connection to the rest of the buttons (represented by S3) must be broken, as otherwise the supply voltage will be short-circuited. In most cases, the connection can be broken by simply scraping away the appropriate tracks on the printed circuit board.

The power MOSFET can easily handle a power level up to 10 watts. For levels higher than this (up to 43 W), it must be mounted (with insulation) on a heat sink.



The choice of mains-powered or battery-powered operation depends on the specific situation. The circuit draws almost no current in the quiescent state, so battery-powered operation is certainly possible. However, the battery must be large enough to supply the high short-term current that flows when the code lock actuates the latch solenoid. Does this mean that mains-powered operation is better in case of frequent use? Perhaps, but you should also consider what happens when there is power failure.

# LED Blinker

Design: Thomas Scarborough (South Africa)

A light draws attention, and two lights draw even more attention. If they also blink or move, you can hardly miss them. This principle has long since proven its worth in the professional spheres of road and air traffic, and it can be put to good use in the private sphere of model building as well. Why shouldn't you build a model airplane with attention-getting lighting?

The simple circuit described here can cause two LEDs to blink alternately at an interval of approximately 1 second. The circuit consists of a type 4093 CMOS IC and a few peripheral components. This IC contains four NAND gates, of which only two are needed here. To avoid generating interference, the inputs of the two unused gates (IC1c and IC1d) are connected to the supply voltage line.

The operation of the circuit is quite simple. NAND gate IC1a and its associated circuitry form an oscillator. It operates at a frequency of 1 Hz and drives the second gate (IC1b), which acts as a buffer. The output of the second gate is connected to LEDs D1 and D2 via capacitors C1 and C3. When the buffer output level changes from low to high, a charging current flows through C3 and causes LED D2 to light up briefly. The capacitor is charged fairly quickly because the current is only limited by the maximum output current

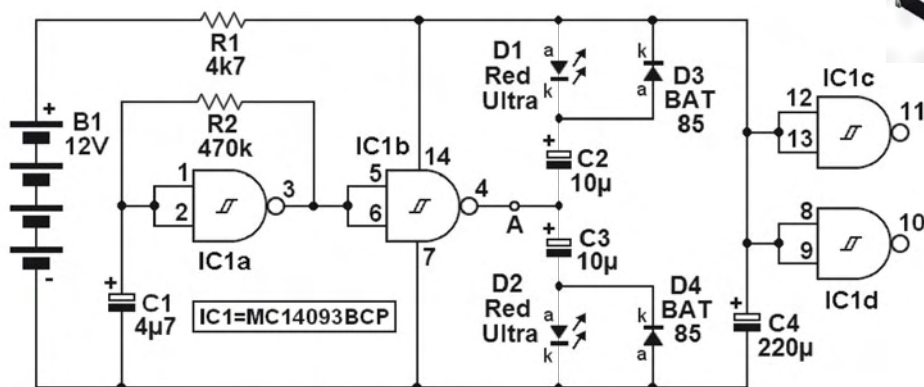
of the gate. This results in a short current pulse, which causes the LED to emit a brief flash of light. The output level subsequently switches from high back to low, which causes C2 to charge quickly in the same manner, with the result that LED D1 flashes in the same way as D2. The net result is that the two LEDs blink alternately.

Capacitors C2 and C3 are discharged via diodes D3 and D4, respectively. These diodes also protect the LEDs against excessive reverse voltages.

The circuit can be operated from a battery with a voltage of 6 to 12 V, and it draws around 1 mA of current. If necessary, the current-limiting resistor R1 can be replaced by a wire link. In this case the current consumption will increase to 2 mA. If the blink interval is too long, the blinking rate can be increased by reducing the value of C1.

If you want to fit even more blinking LEDs in your model airplane, you can use the surplus gates (IC1c and IC1d) for this purpose. In this case, both inputs of each gate must be connected to point 'A' (the output of gate IC1b). Connect a network of the same type as the one shown connected to point 'A' in the schematic to the output of each of additional gates. R1 must be omitted in this case.

4093





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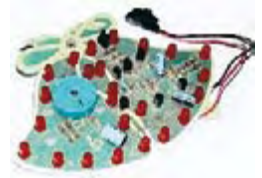


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# DOT NET on a Chip

## Microcontroller programming using C# and Microsoft Visual Studio

Jens Kühne (Germany)

**The .NET ("dot-net") Framework is a powerful tool for programming PCs as it relieves the developer of much time-consuming work. The framework is now also available, in a slimmed-down form, for 32-bit microcontrollers. It allows easy programming of I<sup>2</sup>C, SPI, Ethernet and many other functions without the need to get to grips with the details of the hardware. What's more, a development environment is available for free!**

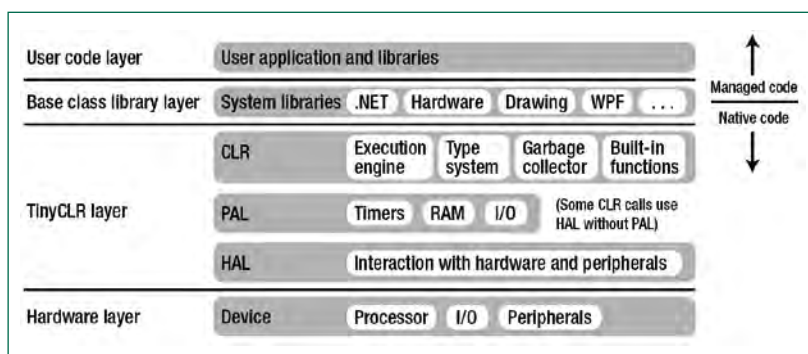


Figure 1. Architecture of the .NET Micro Framework (HAL=Hardware Abstraction Layer, PAL=Peripheral Abstraction Layer).

As computers become faster and faster and are equipped with more and more memory, programming becomes easier and easier. Few software developers bother with assembly code these days as most applications can be realised using higher-level programming languages. Not only does this reduce development time, it also gives the code a much greater degree of independence from the underlying hardware.

The Microsoft .NET Framework takes software development to a new level. The source code, which can be written for example in C#, an object-oriented version of C, is first translated into an intermediate language which is independent of the target hardware platform. This 'managed code' is then translated into machine language only at run-time by the so-called 'Common Language Runtime', or CLR. To this is added a wide selection of base classes which are designed to simplify almost any conceivable programming task, ranging from low-level hardware control to database

interfacing and graphical output. Finally, there is an easy-to-use development environment called Visual Studio, of which the so-called 'Express Edition' is available free of charge. Early next year *Elektron* plans to publish a two-part hands-on series on programming PCs using .NET.

### Embedded .NET

A .NET framework for embedded applications has been available since 2007, following Microsoft's introduction of the .NET Compact Framework for PDAs and similar devices. The .NET Micro Framework is a small and efficient .NET run-time system that can run managed code on 32-bit microcontrollers. Anyone at home with Visual Studio and perhaps with C# will now be able to use this tool and modern programming language for programming microcontrollers. Visual Basic is not currently supported, but this situation may change in the future. Compilation of source code (i.e., its translation into managed code) works in essentially the same way as for the desktop version of the .NET framework (see text box).

The .NET Micro Framework does not require an underlying operating system. A slimmed-down version of the Common Language Runtime communicates directly with the hardware (and is therefore also known as the bootable run-time environment). The run-time environment has only modest requirements: a 32-bit processor with around 100 kByte of working memory is needed. A memory management unit (MMU) is not required.

### An alternative approach

In contrast to conventional microcontroller programming, the developer no longer needs to understand the details of the hardware. The .NET Micro Framework abstracts access

## Highlights of the .NET Micro Framework (Version 3.0)

- Modern programming language: Visual C#
- Powerful and widely-used development environment: Microsoft Visual Studio 2008
- Express Edition of the development environment is free
- Hardware can be treated in an object-oriented way (managed drivers)
- Automatic memory management using garbage collection
- Powerful base class library (part of the standard .NET library, plus extensions for embedded systems development)
- Development boards available from US\$ 100, with QVGA LCD panel from US\$ 300, and modules from US\$ 30
- Rapid prototyping and debugging with the aid of an extensible emulator
- Live on-device debugging
- Extensive hardware support: GPIO ports, serial interfaces, SPI bus, I<sup>2</sup>C bus, Ethernet with TCP and UDP sockets, WLAN, LCD panels, touchscreens, USB devices; USB host functions, CAN and PWM are indirectly supported via hardware manufacturers
- Secure network connections using Secure Sockets Layer (SSL)
- User interfaces using slimmed-down Windows Presentation Foundation classes
- File systems (for example for SD cards)

to hardware using its base class library and treats hardware components as objects.

Instead of manipulating bit masks to configure hardware peripherals, the programmer can simply set the properties of an object. This approach is termed 'managed drivers'. Furthermore, the application program need not concern itself with memory organisation. A garbage collector, a familiar concept from the PC world, tidies up memory when free space is in short supply. A further advantage of this approach is that it makes porting programs between platforms as straightforward as possible.

Although not a full operating system in itself, the Framework does provide services which would normally be provided by an operating system. **Figure 1** shows the layer architecture of the .NET Micro Framework. Although the Framework does not depend on an underlying operating system, it can however make use of an operating system if available and take advantage of its services.

The .NET Micro Framework is, however, unsuitable for real-time programming. Although it is fast, there are no guarantees of deterministic performance. The garbage collector alone can give rise to several milliseconds of timing jitter. Also, managed code is inevitably executed more slowly than native code. In the .NET Micro Framework all managed code is interpreted (in contrast to the PC .NET Framework, where a 'just-in-time' compiler translates managed code into native code prior to its first execution).

### Free IDE

The Microsoft Visual Studio 2008 development environment is required to develop code for the .NET Micro Framework. A free 'Express Edition' for C# is available [1]. The .NET Micro Framework SDK plug-in can also be downloaded free of charge, and so it is possible to begin development without paying a penny for software [2] [3]. However, for each device with an installed .NET Micro Framework a fee is payable. This will be included in the

## Listing 1: Toggling a port pin

```
using System.Threading;
using Microsoft.SPOT.Hardware;

namespace GpioOutputPortSample
{
    public class Program
    {
        public static void Main()
        {
            OutputPort outputPort = new OutputPort(Cpu.Pin.GPIO_Pin0, true);
            while (true)
            {
                Thread.Sleep(500);
                outputPort.Write(!outputPort.Read()); //toggle port
            }
        }
    }
}
```

## Listing 2: Port trigger

```

using System;
using System.Threading;
using Microsoft.SPOT;
using Microsoft.SPOT.Hardware;

namespace GpioInterruptPortEdgeSample
{
    public class Program
    {
        public static void Main()
        {
            InterruptPort port = new InterruptPort(Cpu.Pin.GPIO_Pin3,
                false, //no contact bounce filter
                Port.ResistorMode.PullDown,
                Port.InterruptMode.InterruptEdgeBoth);

            port.OnInterrupt += new NativeEventHandler(port_OnInterrupt);
            Thread.Sleep(Timeout.Infinite);
        }
        private static void port_OnInterrupt(uint port, uint state, TimeSpan time)
        {
            Debug.Print("Pin=" + port + " State=" + state + " Time=" + time);
        }
    }
}

```

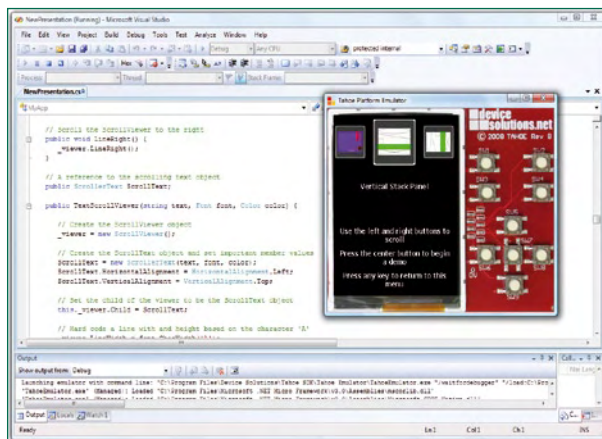


Figure 2.  
An emulator in action, in  
this case for the Tahoe  
development board.

## Listing 3: Transmission over the serial port

```

using System.IO.Ports;
using System.Text;
using System.Threading;

namespace SerialPortWriteSample
{
    public class Program
    {
        public static void Main()
        {
            SerialPort serialPort = new SerialPort("COM1", 9600, Parity.None);
            byte[] outBuffer = Encoding.UTF8.GetBytes("Hello World!\r\n");
            serialPort.Write(outBuffer, 0, outBuffer.Length);
            serialPort.Dispose();
            //keeps the emulator running to see results
            Thread.Sleep(Timeout.Infinite);
        }
    }
}

```



price when a pre-configured module is used, as the manufacturer will already have paid the licence fee to Microsoft. For first experiments no hardware is required, however, as the SDK includes a extensible emulator. In essence this is a port of the CLR to the x86 processor, using an underlying operating system (Windows XP or Vista). Direct emulation is provided of all the hardware components supported by the .NET Micro Framework (see text box). Furthermore, hardware manufacturers offer SDKs with emulators that mimic both the the appearance and the behaviour of development boards (see **Figure 2**). GPIO ports, SPI devices, I<sup>2</sup>C devices, serial interfaces, LCD panels, RAMs, flash memories and many other devices can all be simulated.

More about the .NET Micro Framework can be found on the Internet [2] [3] [4] [5], and in the author's book [6].

### Platforms

Currently the .NET Micro Framework runs on ARM7- and ARM9-compatible processors. Support for Analog Devices Blackfin processors has been announced.

For application and development a number of platforms are available, which include to varying extents the range



Figure 3. The Embedded Master TFT Board.

## Compiling for the .NET Micro Framework

In .NET the compiler converts the source code into 'assemblies' (executable .EXE files and .DLL class libraries) containing code in CIL (Common Intermediate Language) and 'metadata', or self-descriptive code. The CIL code is the same, regardless of the high-level language used (C#, C++ or Visual Basic). This means that parts of a program written in C# and in Visual Basic can interoperate without problems. At run-time the managed code is executed by the CLR (Common Language Runtime) environment, which must be installed on the target processor.

The .NET Micro Framework uses a special compact version of the intermediate language to reduce ROM and RAM requirements on the target device. To this end the .NET Micro Framework metadata processor tool generates optimised 'pe-files' from the managed .NET assemblies. Visual Studio and the .NET Micro Framework plug-in hide all these steps from the user.

Currently the .NET Micro Framework only supports Visual C#. In theory any .NET language compiler could be supported, as the metadata processor reads in ordinary .NET assemblies as generated by all the .NET compilers. In practice, however, Visual Basic still uses a special Visual Basic run-time library, which has yet to be ported to the .NET Micro Framework.

of peripherals supported by the Framework. We shall look at two examples. Device Solutions [7] offers the Meridian CPU, based on a Freescale i.MXS 100 MHz ARM920T processor. It includes 8 MByte of SDRAM and 4 MByte of flash memory. The CPU module, costing US\$ 75, sports an interface for a 2.7 inch QVGA LCD panel, 16 to 32 GPIO ports, two RS232 interfaces, SPI and I<sup>2</sup>C interfaces and one PWM channel. The corresponding 'Tahoe' development board, which includes all the connections, a power supply and an LCD panel, is available for US\$ 400.

GHI Electronics [8] offers its Embedded Master TFT Module for US\$ 80 and a development board including a TFT LCD panel for US\$ 350 (**Figure 3**). The company also has in its portfolio the smallest and lowest cost development system that runs the .NET Micro Framework (**Figure 4**). Priced at US\$ 100, the USBizi includes a 72 MHz ARM processor, 96 kByte of RAM, 512 kByte of flash memory, an SD card slot, 44 GPIO ports (of which 35 can be configured to generate an interrupt), SPI, I<sup>2</sup>C, four TTL-compatible serial ports, a 10-bit ADC and a 10-bit DAC, and much more. The LQFP100 chip from the same company

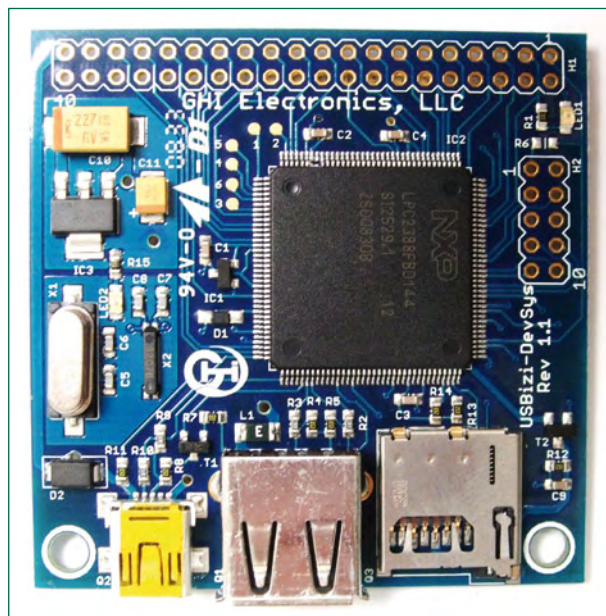


Figure 4. The USBizi development kit.

## Listing 4: Temperature sensor on the I<sup>2</sup>C bus (managed driver)

```

using System;
using System.Threading;
using Microsoft.SPOT.Hardware;

namespace I2CTemperatureSensorSample
{
    /// <summary>
    /// Managed driver for the TMP100 temperature sensor chip
    /// from Texas Instruments on the I2C bus.
    /// </summary>
    public class TMP100Sensor
    {
        #region constants
        private const byte clockRateKHz = 59;
        private const byte REGISTER_Control = 0x01; //command to configure sensor
        private const byte REGISTER_Temperature = 0x00; //command to request result
        private const byte CONTROL_EnergyModeShutdown = 0x01;
        private const byte CONTROL_DataLengthTwelveBits = 0x60;
        private const byte CONTROL_OneShot = 0x80;
        //ms The maximum time needed by the sensor to convert 12 bits
        private const int conversionTime = 600;
        private const int transactionTimeout = 1000; //ms
        #endregion
        private readonly byte address;
        private readonly I2CDevice device;
        public TMP100Sensor(byte address)
        {
            this.address = address;
            I2CDevice.Configuration config =
                new I2CDevice.Configuration(address,
                    clockRateKHz);
            this.device = new I2CDevice(config);
        }
        public float Temperature()
        {
            //write to one shot bit in control register to trigger measurement,
            //that means telling the sensor to capture the data.
            byte controlByte = CONTROL_OneShot |
                CONTROL_DataLengthTwelveBits |
                CONTROL_EnergyModeShutdown;
            byte[] captureData = new byte[] { REGISTER_Control, controlByte };
            WriteToDevice(captureData);
            //the conversion time is the maximum time
            //it takes the sensor to convert a physical reading to bits
            Thread.Sleep(conversionTime);
            //prepare the control byte to tell the sensor to send
            //the temperature register
            byte[] temperatureData = new byte[] { REGISTER_Temperature };
            WriteToDevice(temperatureData);
            //prepare the array of bytes that will hold the result
            //coming back from the sensor
            byte[] inputData = new byte[2];
            ReadFromDevice(inputData);
            //get raw temperature register
            short rawTemperature = (short)((inputData[0] << 8) | inputData[1]);
            //convert raw temperature register to Celsius degrees
            //the highest 12 Bits of the 16 Bit-Signed-Integer (short) are used
            //one digit is 0.0625 ° Celsius, divide by 16 to shift right 4 Bits
            //this results in a division by 256
            float temperature = rawTemperature * (1 / 256.0f);
            return temperature;
        }
        private void WriteToDevice(byte[] outputData)
        {
            //create an I2C write transaction to be sent to the temperature sensor
            I2CDevice.I2CTransaction writeXAction =
                device.CreateWriteTransaction(outputData);
            //the I2C data is sent here to the temperature sensor
            int transferred =
                this.device.Execute(new I2CDevice.I2CTransaction[] { writeXAction },

```

```

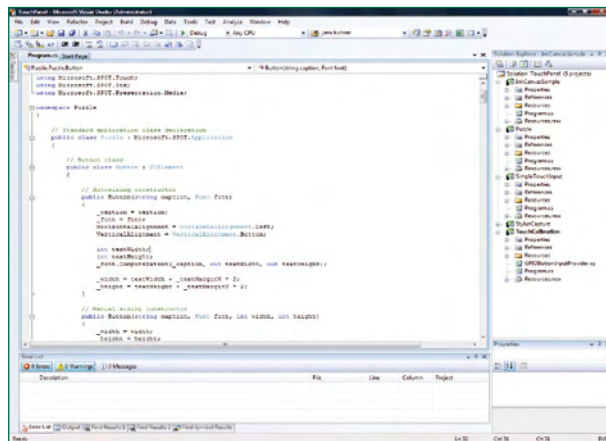
transactionTimeout);
//make sure the data was sent
if (transferred != outputData.Length)
    throw new Exception("Could not write to device.");
}
private void ReadFromDevice(byte[] inputData)
{
    //prepare a I2C read transaction to be read from the temperature sensor
    I2CDevice.I2CTransaction readXAction =
    device.CreateReadTransaction(inputData);
    //the I2C data is received here from the temperature sensor
    int transferred =
    this.device.Execute(new I2CDevice.I2CTransaction[] { readXAction },
    transactionTimeout);
    //make sure the data was received
    if (transferred != inputData.Length)
        throw new Exception("Could not read from device.");
}
public byte Address
{
    get { return this.address; }
}
}
}

```

is a processor with similar features, measuring 20 mm by 20 mm and costing just US\$ 30.

## Practical examples

**Figure 5** shows the Microsoft Visual Studio 2008 development environment with a code window and a .NET Micro Framework application. In the project properties it is possible to set where the program will be sent to for execution: choices include various installed emulators and real hardware connected over USB, network or serial interfaces.



**Figure 5.** The Visual Studio 2008 development environment.

Our listings show how simple it is to program using the .NET Micro Framework. Anyone with a basic understanding of the C programming language will find the code easy to follow. **Listing 1** shows how to use a managed driver to toggle a GPIO output pin every half second, for example to flash an LED. **Listing 2** shows how a method can be called when a GPIO input pin changes state, for example to respond to the press of a button.

It is equally straightforward to send a string of characters out over a serial port, as **Listing 3** demonstrates. Receiving data is equally easy: **Listing 4** shows a managed driver for a Texas Instruments TMP100 temperature sensor connected over the I<sup>2</sup>C bus.

The GHI Electronics website [8] gives a collection of other examples (under 'Projects'), including, among other things,

## About the author

Jens Kühner is a software developer at Vallon GmbH in Germany, working on .NET applications for the .NET Desktop and Compact Frameworks. Jens is also the author of a recently-published book 'Expert .NET Micro Framework' (Apress, 2008). He has been interested in the .NET Micro Framework from the beginning and is an active beta tester of the technology. He also writes regular articles in the .NET Micro Framework forum. He can be contacted at kuehner@web.de or via his blog [4].

source code for a simple web server and Internet radio using an MP3 decoder device.

(080450-1)

## Internet Links and References

- [1] Microsoft Visual Studio 2008 Express Edition for Visual C#: <http://www.microsoft.com/express/product/default.aspx>
- [2] Official .NET Micro Framework pages: <http://www.microsoft.com/netmf/default.aspx>
- [3] .NET Micro Framework team blog: <http://blogs.msdn.com/netmfteam/>
- [4] Author's blog: <http://bloggingabout.net/blogs/jens/>
- [5] Jan Kucera's .NET Micro Framework pages: <http://www.microframework.eu>
- [6] Jens Kühner, 'Expert .NET Micro Framework' (Apress, 2008), ISBN 1-59059-973-X
- [7] <http://www.devicesolutions.net>
- [8] <http://www.ghielectronics.com>



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<b>853A Quartz Infrared Preheater</b>	 Online Price £69.95	<b>950 SMD Hot Tweezers &amp; Station</b>	<b>710 Infrared Welding Station</b>	 Online Price £750.00  <b>TEST-PINS.CO.UK</b> Suppliers of Test-pins, Receptacles & Probes...  For Test-pins & Probes Visit <a href="http://www.test-pins.co.uk">www.test-pins.co.uk</a> Above discount code also applies	

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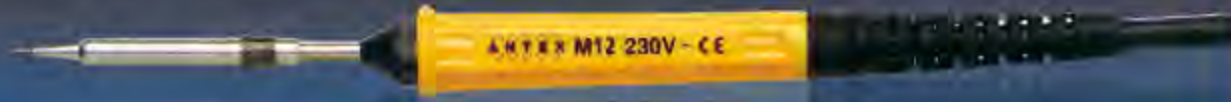
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# BASCOM AVR Course

## (4) Counter and PWM

Burkhard Kainka (Germany)

We have already taken a look at timers in part 3 of the course. The ATmega timer/counters have far more to offer than just measuring time. Here we look at impulse counting, frequency measurement and PWM signal generation.

In the first exercise we set up timer 1 to count impulses over a period of one second. A look at the program **Listing 1** indicates that timer 1 is configured as a counter, counting on the falling edge of the input pulse and with a prescale value of 1.

The counter input is labelled T1 which for example on the Mega8 and Mega88 is pin PD5 (**Figure 1**). In this exercise we connect a low-voltage 50 Hz signal to this input via a 10 k $\Omega$  series resistor. A signal generator is not necessary here; the input impedance is relatively high so just touching the input resistor with your finger will inject a signal of sufficient level from the ambient mains field for measurement. In Europe the signal is 50 Hz, in the USA 60 Hz. The routine counts the number of pulses in 1 second so the screen shows:

```
0
50
100
150
201
251
```

After the fourth value a slight inaccuracy in the measured value creeps in. This is because the `waitms 1000` instruction is not an exact time interval and also we have not taken into account the time necessary to output values to the display. To improve the accuracy of frequency measurements we go on in the next exercise to use timer interrupts.

### Frequency measurement

The timer can reliably count external impulses with a repetition rate of up to 4 MHz. To make accurate frequency measurements we need a precise time window, in this example we use interrupts from two timers. Each time timer 1 overflows, the interrupt is serviced by `Tim1_isr` which increments the variable `Highword`. Without this variable the counter would only be able to measure frequencies up to 65535 Hz (**Listing 2**).

Timer 0 generates an exact time window of one second. When the variable `Ticks = 1`, timer 1 is reset and the measurement begins. Exactly 1000 ms later the counter value of timer 1 is copied to `Lowword` and then added to the number of overflows stored in `Highword` (multiplied by 65536) before storing the result in `Freq`. The main pro-

### Listing 1 Impulse counter

```
Test1:
Config Timer1 = Counter , Edge = Falling ,
        Prescale = 1
Start Timer1
Do
    Print Timer1
    Waitms 1000
Loop
```

gram outputs `Freq` (in Hz) to the display every second. Initialising timer 1 in timer mode with a clock of 16 MHz (`Config Timer1 = Timer , Prescale = 1`) would display a frequency of 16000000 Hz. As a counter however, timer 1 can run at just a little more than a quarter of this frequency and its prescaler is synchronised to the processor clock. When you try to measure a frequency as high as 6 MHz for example the counter gating runs too slowly to register every edge of the input pulses so it misses some and shows a false reading of around 3 MHz. The design can be used to accurately measure frequencies up to and just beyond 4 MHz.

### PWM outputs

Pulse Width Modulation (PWM) is a technique used in

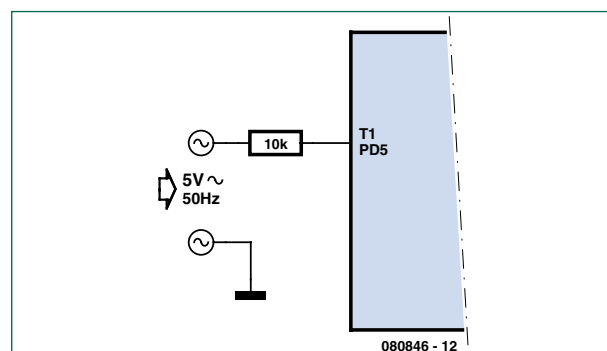


Figure 1.  
A 50 Hz signal on T1.

## Listing 2

### Frequency measurements up to 4 MHz

```

Test2:
Dim Lowword As Word
Dim Highword As Word
Dim Ticks As Word
Dim Freq As Long
Config Adc = Single , Prescaler = 32 ,
    Reference = Off
Config Timer0 = Timer , Prescale = 64
Config Timer1 = Counter , Edge = Falling ,
    Prescale = 1
'Config Timer1 = Timer , Prescale = 1
On Ovfo Tim0_isr
On Ovfl Tim1_isr
Enable Timer0
Enable Timer1
Enable Interrupts

Do
    Print Freq
    Waitms 1000
Loop

Tim0_isr:
    '1000 µs
    Timer0 = 6
    Ticks = Ticks + 1
    If Ticks = 1 Then
        Timer1 = 0
        Highword = 0
    End If
    If Ticks = 1001 Then
        Lowword = Timer1
        Freq = Highword * 65536
        Freq = Freq + Lowword
        Ticks = 0
    End If
Return

Tim1_isr:
    Highword = Highword + 1
Return

```

many applications to provide a quasi-analogue control of power to a load without the need for a true D/A converter. Timers in the ATmega controllers can be used to generate

## Listing 3 10-bit PWM

```

Test3:
Dim Pwm As Word
Config Timer1 = Pwm , Prescale = 8 , Pwm
    = 10 , Compare A Pwm = Clear Down ,
    Compare B Pwm = Clear Down

Do
    For Pwm = 0 To 1023
        Pwm1a = Pwm
        Pwm1b = 1023 - Pwm
        Waitms 5
    Next Pwm
Loop

```

## Listing 4

### Six PWM outputs produce an LED light 'wave'.

```

Test4:
Dim A As Single
Dim B As Single
Dim I As Byte
Dim K As Byte

Declare Sub Wave
Config Timer0 = Pwm , Prescale = 8 ,
    Compare A Pwm = Clear Down , Compare B
    Pwm = Clear Down
Config Timer1 = Pwm , Prescale = 8 , Pwm =
    8 , Compare A Pwm = Clear Down , Compare
    B Pwm = Clear Down
Config Timer2 = Pwm , Prescale = 8 ,
    Compare A Pwm = Clear Down , Compare B
    Pwm = Clear Down

Do
    For I = 1 To 60
        K = I
        Wave
        Pwm1a = Pwm
        K = I + 10
        Wave
        Pwm1b = Pwm
        K = I + 20
        Wave
        Pwm0a = Pwm
        K = I + 30
        Wave
        Pwm0b = Pwm
        K = I + 40
        Wave
        Pwm2a = Pwm
        K = I + 50
        Wave
        Pwm2b = Pwm
        Waitms 50
    Next Pwm
Loop

Sub Wave
    A = 6.1415 * K
    A = A / 60
    B = Sin(a)
    B = B + 1
    B = B * B
    B = B * 63
    Pwm = Int(b)
    If Pwm < 2 Then Pwm = 2
End Sub

```

PWM signals. Timer 1 has two independent PWM output channels with a resolution of 8, 9 or 10 bits.

**Listing 3** shows how both channels Pwm1a and Pwm1b of timer 1 can be programmed to produce output signals with 10-bit resolution. The signals are output from OC1A (PB1) and OC1B (PB2). Their electrical characteristics are the same as other port pins so you can just hang an LED together with a series current-limiting resistor on the output or connect the output to a buffer like the ULN2003 fitted to the Elektor ATM18 AVR board. The program produces increasing brightness signal from channel A and decreasing brightness signal from channel B.

## LED control using six PWM channels

The Mega88 provides six PWM outputs signals. Timers 0 and 2 both offer a resolution of eight bits. The individual outputs are on the following output pins:

- OC1A on PB1
- OC1B on PB2
- OC0A on PD6
- OC0B on PD5
- OC2A on PB3
- OC2B on PD3

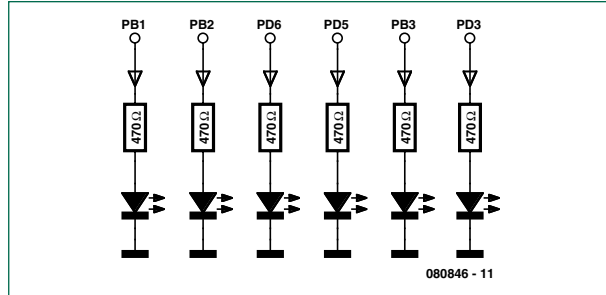


Figure 2. Brightness control of six outputs.

In this last exercise we use all six PWM outputs, for the sake of symmetry in this application, timer 1 is configured with a resolution of only eight bits. The aim of this example (**Listing 4**) is to smoothly control the brightness of a row of LEDs such that a sinusoidal 'wave' of light travels along the row.

A loop with 60 brightness levels per LED is sufficient to produce a smooth transition between levels. The value of variable *l* is used in the sub wave to produce the light level value. It is first multiplied by  $2\pi$ , divided by 60 and then its sine function is found. The result in the range  $\pm 1$  is then offset to the range 0 to 2. The eye's perception of brightness is nonlinear so to compensate, the value is squared. It now lies in the range 0 to 4 so multiplying by 63 converts to the 0 to 255 range (almost) of PWM values used to control the LEDs.

The steps at lower values of brightness are quite noticeable so the lowest possible level is limited to 2.

Using this calculation and the corresponding phase shift generated in the program produces an interesting lighting effect. The overall result is a wave of brightness moving along the line of LEDs. The LEDs can be arranged in a line or as a circle. It is possible to expand the line further by adding six, twelve or more LEDs.

(080846-1)

## Program downloads and forum

As usual the programming examples and additional info can be downloaded from the project page at [www.elektor.com/080846](http://www.elektor.com/080846). We also welcome your feedback on the Elektor forum.

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# Universal User Interface

## with LCD and SD card

Michael Gaus (Germany)

**This module provides a simple user interface for extending microcontroller-based circuits. Graphics and text display commands can be sent to it over a serial interface, and, using its UART, the module reports back when the state of any of six inputs changes. Additional firmware can display a slideshow of images stored on an SD card.**

This article could equally well have been entitled 'two for the price of one': on the one hand the project described here is an update of a design published in *Elektor* in April 2007 [1]. The 'Electronic Badge' used a low-cost display from a mobile phone to display images stored on an SD card. It used an Atmel ATmega8, and we promised a future upgrade to the ATmega168. Here we make good that promise. We have also designed a printed circuit board to make the project even easier to build: the board can be ordered via our website. The ATmega168 microcontroller is a firm favourite with *Elektor* staff and readers alike, and has the benefit of allowing easy debugging using the reset input.

However, the story does not end there. In this project we can also cause the display to show vector graphics and text: using simple commands sent to the ATmega168 over a serial interface we can conjure up rectangles, lines and characters on the tiny screen. In return, the microcontroller will report (asynchronously and autonomously) over the serial interface whenever any one of six inputs changes state. This allows a keyboard, joystick or other digital input device to be connected. The whole thing thus forms a universal user interface module, which is entirely controlled, perhaps from another microcontroller, over a single serial port. This relieves the main microcontroller of

dealing with user interface functions; it also avoids the need to redesign interface hardware and software for each new project.

### User interface

The universal user interface module has the advantage that the only connection required to the host microcontroller or other circuit is a single UART (TXD and RXD lines). The interface is configured to run at 115200 baud with 8 data bits, no parity and one stop bit ('8N1'), but this can easily be changed in the source code. A further advantage is its use of a particularly low-cost display. The LM15SGFNZ07 [2] [3] is used in Siemens A60, A65, C60, MC60, M55 and S55 mobile phones and is available as a spare part for well under ten pounds. The display is capable of showing graphics at a resolution of 101 by 80 pixels in 4096 colours. It takes a few simply-structured commands to the module over the UART to change foreground and background colours, show text, draw lines and rectangles and display bitmaps. This makes it easy to construct menus to control the operation of the host microcontroller or to display readings. The available commands are listed in the **text box** 'Control'.

After many of the commands a brief pause is required before the next command can be sent. As a rule of thumb,

the total delay allowed should be around 10  $\mu$ s per pixel of the LCD that is updated. Commands received while the module is working will be partially or completely ignored. For this reason the user interface module sends out a one-byte status message 'command execution complete' over the serial interface when it is ready for the next command. The host should only send a new command when this status message has been received.

Reports of the status of the inputs to the module are also eight bits long. Whenever an input changes state (for example, whenever a connected push-button is pressed or released) a status byte is output via the UART (see text box 'Status reports'). The need for polling and debouncing of buttons is entirely avoided as a new message is automatically output on each input status change. A further feature is that if input PC0 is held low (button 1 pressed) when power is applied, the module enters a configuration menu, where it is possible, for example, to adjust the LCD contrast.

### Circuit

At the heart of the circuit (see **Figure 1**) is an ATmega168 microcontroller. The LCD is driven over an SPI bus. The protocol was determined by author Michael Gaus by analysing the data traffic in a mobile phone (and so



# Module

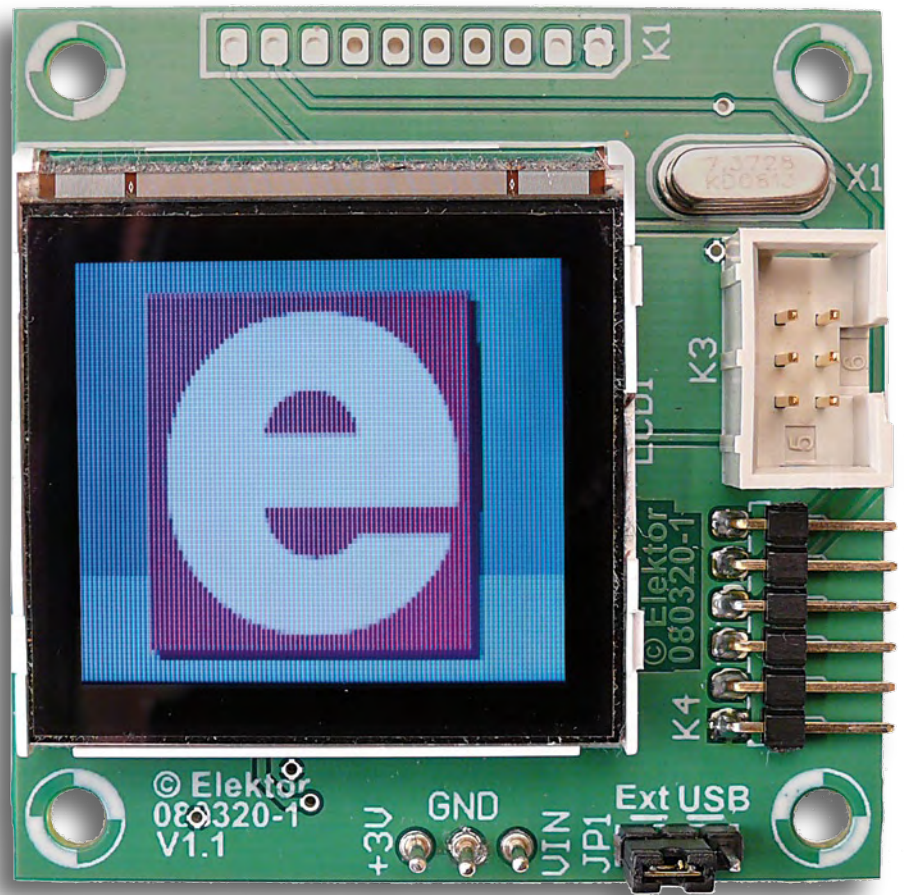
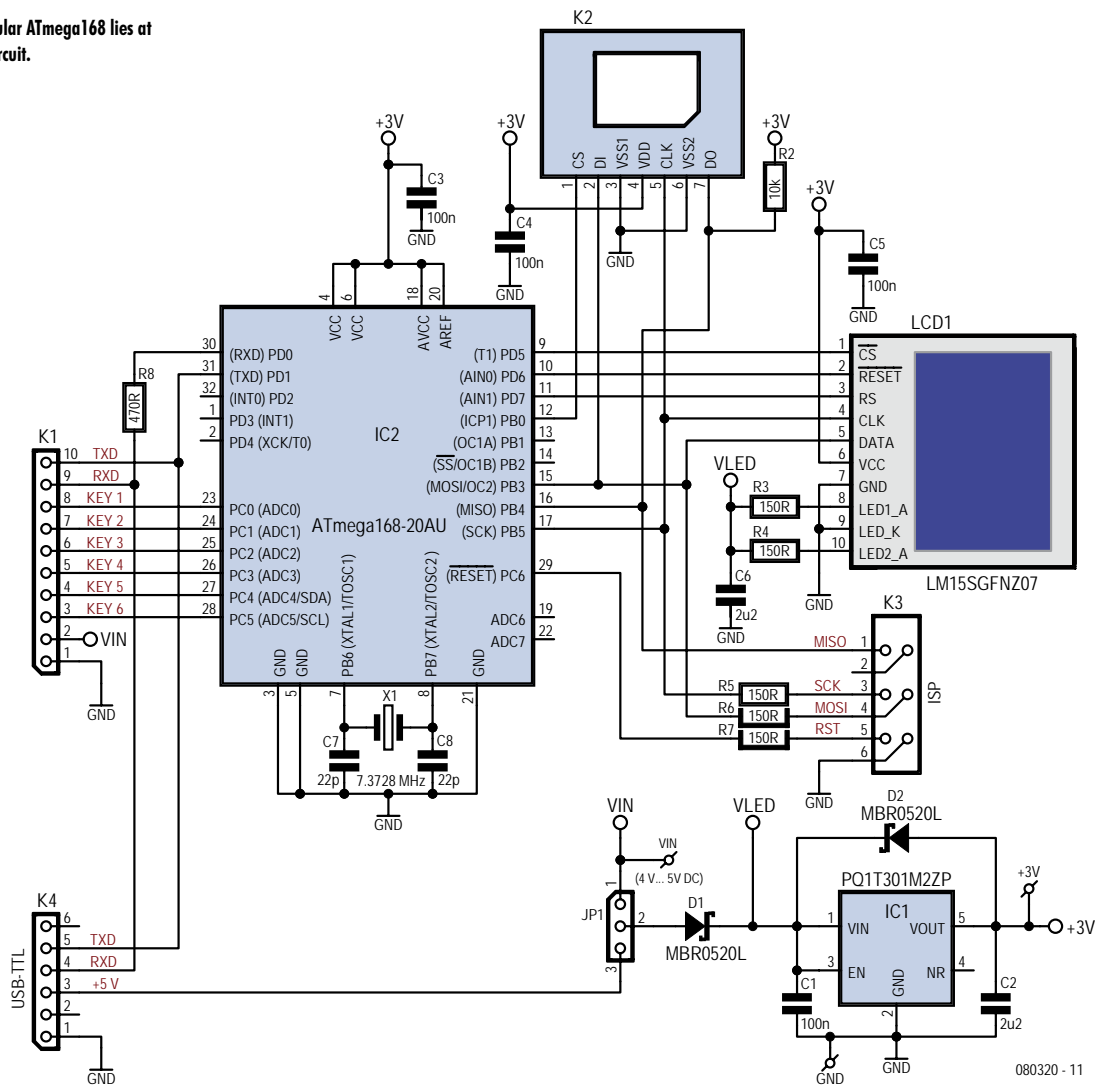


Figure 1. The popular ATmega168 lies at the heart of the circuit.



information is provided here without guarantees of correctness or completeness!). The pinout of the LCD is given in the text box 'LCD pinout'. There are solder pads on the rear of the LCD and so no special miniature connector is needed: simply solder thickish enamelled copper wire to the pads, bend the wire in a right angle and solder to the holes provided in the printed circuit board. The LCD can be further fixed to the board using a short length of double-sided adhesive tape: further advice can be found on the project website [4].

The circuit communicates with the outside world via two headers. K1 has ground connections as well as connections for the pushbuttons or other input devices. If pushbuttons are used, normally-open types are needed. K1 also carries the RXD and TXD signals of the serial interface, for example for connection to another microcontroller. The RXD (and TXD) pins of the ATmega168 are protected by internal diodes and so 5 V levels can be used: for extra safety we have added series resistor R8.

**Care and feeding**

TXD and RXD are also available on pins of K4. The *Elektor* USB-to-TTL serial cable (5 V version) [5] can be connected directly to header K4. The FTDI FT232RQ device used in the cable has an input threshold voltage of typically 1.6 V, and so no level shifter is needed. The interface can of course be made fully RS-232 compatible with the addition of a MAX3232.

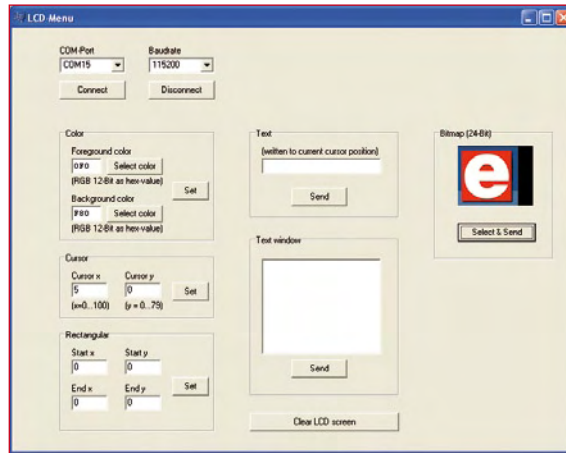


Figure 2. This PC program can be used to send a range of graphics commands to the module.

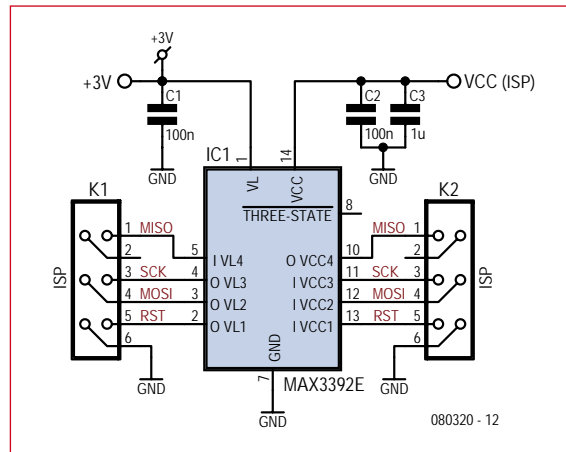


Figure 3. Suggestion for a simple programmer adaptor.

For testing and development it is convenient to connect the system to a PC running a terminal emulator program. Author Michael Gaus has writ-

ten a short Windows program (see **Figure 2**) to exercise the graphics commands. This, along with the firmware for the microcontroller, is available for free download from the project pages accompanying this article [4].

If pins 2 and 3 of JP1 (marked 'USB' on the printed circuit board) are shorted together the circuit will draw its power over the USB interface. If instead three 1.5 V cells (or a regulated mains supply delivering 4 V to 5 V) are to be used, pins 1 and 2 of JP1 (marked 'Ext', for external power, on the board) should be shorted. External power can be connected either at K1 or via the pins marked 'VIN' and 'GND'.

From JP1 the supply goes to voltage regulator IC1 which produces the 3 V operating voltage for the AVR microcontroller and the LCD. In the mobile phone the LCD is operated at 2.9 V.

Diode D1 protects against reverse polarity: a Schottky type is used because of its lower forward voltage drop.

The power supply for the two LCD backlight LEDs is taken from immediately after D1, with R3 and R4 acting as current limiting resistors. D2 protects the voltage regulator in case a voltage should accidentally be applied to its output that is greater than its input voltage.

The crystal is loaded by two type NP0 ceramic capacitors, which have good temperature stability.

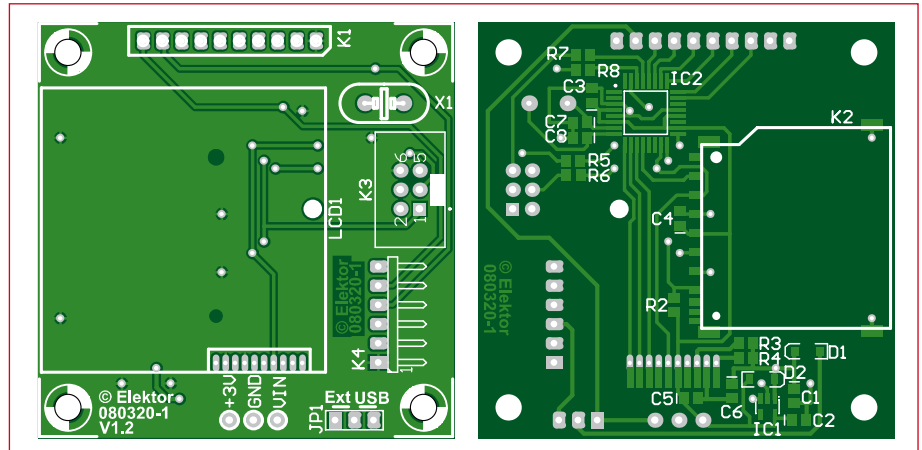
**Status reports**

Whenever the state of one of the inputs changes a byte (whose bits we label D7 down to D0) is output by the microcontroller. The microcontroller also sends a status message when the processing of a command has been completed. The type of status message is encoded in the top two bits, D7 and D6. The coding structure is as follows.

D7	D6	D5	D4	D3	D2	D1	D0	Meaning
0	0							-reserved-
0	1	R	R	R	R	R	1	Command execution complete, ready for next command ('R' indicates reserved bits)
1	0	PC5	PC4	PC3	PC2	PC1	PC0	Sent when pushbutton input state changes. A '1' in one of the lower six bits indicates that the corresponding input is low (button pressed), while a '0' means that the input is high (button released)
1	1							-reserved-

## Programming

An ISP-compatible programmer can be connected to connector K3. The programmer should use a voltage of between 3 V and 3.3 V to indicate a logic '1': if only 5 V levels are available, a MAX3392E (or its pin-compatible bi-directional cousin, the MAX3378E) may be used as a level shifter. **Figure 3** shows a suitable circuit, which we have not tested. The microcontroller can also be supplied with power via this circuit, pin 1 of the level shifter being connected to the terminal marked '3 V' in the main circuit. In principle this 3 V supply could also be connected via pin 2 of K3, which is not



PCB and component layout.

## COMPONENTS LIST

### Resistors

R2 = 10k $\Omega$ , SMD 0805  
 R3,R4,R5,R6,R7 = 150 $\Omega$ , SMD 0805  
 R8 = 470 $\Omega$ , SMD 0805

### Capacitors

C1,C3,C4,C5 = 100nF, SMD 0805  
 C2,C6 = 2 $\mu$ F2, SMD 0805  
 C7,C8 = 22pF, NPO, SMD 0805

### Semiconductors

D1, D2 = MBR0520L, Schottky, SOD-123

(Farnell # 1467521)  
 IC1 = PQ1T301M2ZP, voltage regulator (LDO), 3V, 400mA, SOT-23-5 (Digikey # 425-1674-1-ND)  
 IC2 = ATmega168-20AU, TQFP32 (Atmel)

### Miscellaneous

LCD1 = LM15SGFNZ07 (see text)  
 X1 = 7.3728MHz quartz crystal, HC-49 case  
 K1 = 10-way SIL pinheader, lead pitch 2.54 mm

K2 = SD card socket (Farnell # 9186158)  
 K3 = 6-way (2x3) boxheader, lead pitch 2.54 mm (Farnell # 1096984)  
 K4 = 6-way SIL pinheader, angled pins, lead pitch 2.54 mm  
 JP1 = 3-way pinheader with jumper, lead pitch 2.54 mm  
 PC1,PC2,PC3 = solder pin, 1mm diameter  
 Enamelled copper wire, max. 0.5mm diameter  
 PCB, ref. 080320-1 from www.thepcbshop.com

## Control

The user interface module is controlled over a serial port and can accept commands to draw graphics and display text. The commands available are as follows.

Command (hex)	Parameter	Meaning
01	<0000rrrr> <ggggbbbb>	Set foreground colour (four bits each for red, green and blue components)
02	<0000rrrr> <ggggbbbb>	Set background colour (four bits each for red, green and blue components)
03	<x1> <y1> <x2> <y2>	Draw filled rectangle between vertices (x1,y1) and (x2,y2)
04	<x1> <y1> <x2> <y2>	Draw line from (x1,y1) to (x2,y2)
05	<x> <y>	Set text cursor position to (x,y)
06	<text> <0>	Print text (ASCII); zero byte marks end of string
07	<x1> <y1> <x2> <y2> <bitmap data>	Display bitmap image in rectangle between vertices (x1,y1) and (x2,y2): each pixel of the bitmap consists of two bytes <0000rrrr> and <ggggbbbb>, where four bits each specify the red, green and blue components

### Notes:

- x-coordinates must lie in the range from 0 to 100 (00 to 64 hex).
- y-coordinates must lie in the range from 0 to 79 (00 to 4F hex).
- Twelve bits in total specify a colour: four bits for each of the red, green and blue components.

For example, to clear the screen to blue proceed by drawing a rectangle from (0,0) to (100,79) with the desired foreground colour as follows.

- Set the foreground colour to blue (red and green components set to zero, blue component to 0F hex): 01 00 0F
- Draw a rectangle (100 in decimal is 64 hex, 79 in decimal is 4F in hex): 03 00 00 64 4F

## LCD pinout

Here are the connections to be made to the reverse of the LCD. Pin 1 is to the left, pin 10 to the right. Further information can be found on the Internet [2][3].



Pin	Signal	Meaning
1	/CS	Chip select
2	/RESET	A reset pulse is required when power is applied
3	RS	Register select: 0 = data, 1 = command
4	CLK	Clock
5	DATA	Data
6	VCC	Approximately 3.0 V (2.9 V used in original mobile phone)
7	GND	
8	LED1_A	LED1 anode
9	LED_K	LED1 and LED2 common cathode
10	LED2_A	LED2 anode

## Specifications

- ✓ LCD: LM15SGFNZ07 (for example from a Siemens C60 mobile phone), 101 pixels by 80 pixels, graphics, 4096 colours, LED backlight, driven over SPI connection
- ✓ LCD price: available new on eBay at low cost
- ✓ UART interface to send graphics commands and receive status messages
- ✓ Up to six inputs for pushbuttons or other digital input devices
- ✓ Supply voltage: 4 V to 5 V
- ✓ USB-to-TTL cable can be directly connected; module can be USB-powered
- ✓ SD card interface to display photographs and graphics
- ✓ LCD settings menu included in firmware

currently used, but some programmers allocate this pin as an extra power supply, and so it cannot be used safely. The SD card socket is not used when the circuit is being employed as a user interface module. It is connected to the microcontroller in the same way as described in the 'Electronic Badge' article.

## Badge firmware

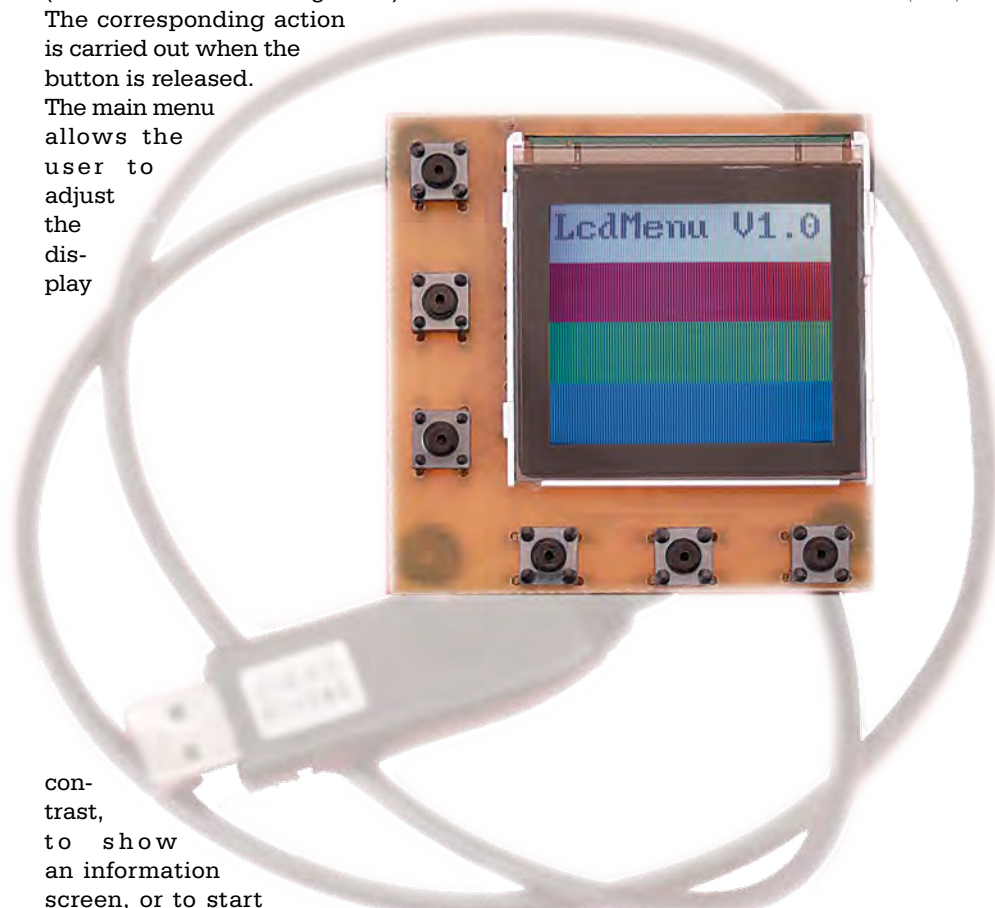
If images stored on the SD card are to be displayed on the LCD the appropriate additional firmware needs to be downloaded into the microcontroller. If PC0 is held low when power is applied (by pressing button 1) a test image appears on the display, followed by a menu. A brief press of button 1 (shorter than 500 ms) advances to the next menu entry; a long press (greater than 500 ms) selects the current entry (shown with a red background). The corresponding action is carried out when the button is released. The main menu allows the user to adjust the display

sequence with an adjustable delay between them. The delay is specified in the file config.txt stored on the SD card.

The image filenames should be at most eight characters long, followed by a dot and a three-character file extension. The bitmaps must be exactly 101 pixels (horizontal) by 80 pixels (vertical) and the colour depth must be eight bits per channel, of which the microcontroller uses only the most significant four bits. The card must be formatted for the FAT16 file system and the files must not be fragmented. This can be achieved by writing all the images to the card in one go immediately after formatting it.

Finally, one further important piece of advice: the card must on no account be inserted or removed while power is applied to the circuit.

(080320)



contrast, to show an information screen, or to start a slideshow. The contrast should only need to be adjusted (if at all) within a small range of its default value of 43. If no button is held down when power is applied a test image is displayed consisting of four coloured bars (white, red, green and blue) and the version string 'Diashow V1.1' will briefly appear. Then the bitmap images stored on the SD card are displayed in

## Internet links

- [1] <http://www.elektor.fr/magazines/2007/avril/badge-electronique.81151.lynx>
- [2] <http://sanding.tripod.com/m55.html>
- [3] <http://forum.lcdinfo.com/viewtopic.php?p=8395>
- [4] [www.elektor.fr/080320](http://www.elektor.fr/080320)
- [5] [www.elektor.fr/080213](http://www.elektor.fr/080213)

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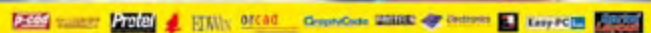
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# Electronic Transformers

## Their anatomy and application

Dr. Thomas Scherer (Germany)

**Low-voltage halogen lamps have grown in popularity since their launch in the 1980s. The same timeframe has seen the development of 'electronic transformers' that are compact, lightweight and economic. What makes them tick — and what other applications can we find for them?**

When low-voltage halogen lamps first appeared their power supplies used conventional iron-cored transformers with 12 V AC secondaries. The same applied to those trendy suspension-wire light systems using three miniature 35-W spotlights dangling from parallel wires; the insubstantial airiness of these light fittings contrasted strongly with the weighty circular core of the 100 watt transformers that fed them. Humming hefty lumps of 12 V transformer did not make installation of built-in downlighters any easier either. It's little wonder therefore that the industry was forced to develop a slimmer and less weighty substitute for the time-served transformer with its bulky iron laminations and copper windings. So please pay respect now to the electronic transformer presented in **Figure 1**.

### Anatomy

Today of course these tiny electronic transformers are all but universal. They have become so widespread and affordable

that three vital questions demand an answer:

- What's actually inside these miracles of miniaturisation?
- What kind of output can we expect?
- What other applications could we dream up for these little gizmos?

No sooner said than done—and bought and dismantled. You probably guessed: inside the plastic case is nothing more than a switch-mode power supply (SMPS). Was this blindingly obvious? Not necessarily, because a close look at the printed circuit board (PCB) in **Figure 2** reveals that the electronics are less conventional than you might have guessed. Certainly we see some diodes, capacitors, an output transformer (right) and two high-voltage power MOSFETs (centre) more or less where you would expect these to be. But there are two surprises:

- For starters, the output does not appear to be provided with any rectification or electrolytics for smoothing.
- Secondly, next to the MOSFETs you might have expected a high-voltage electrolytic for filtering the rectified mains voltage.

For our first observation the obvious conclusion is that our halogen lamps must be run not on DC but on some kind of AC voltage! As far as the second is concerned, the input side of the SMPS must be supplied with a pulsating (rather than smoothed) DC voltage. Consequently we can expect the output waveform to resemble the 100 Hz output of a full-wave bridge rectifier, only the more so because the solitary 68 nF foil capacitor on the output of the diode bridge has far too little capacity to do a proper job of smoothing.

Both dodges make sense: direct current is not essential for lamp bulbs and the absence of rectification not only improves efficiency but also save hard cash. Omitting a high-voltage electrolytic saves both cost and space on the PCB. This elegance of design is matched by the fact that not a single IC is employed. On the rear side of the PCB (**Figure 3**) we discover apart from some SMD-resistors and capacitors merely three transistors and two diodes. The PCB looks a bit flimsy, being only 1 mm thick, but in fact it is made of sturdy epoxy material and not from brittle SRBP (Paxolin, Pertinax). In place of real fuses we have two thin PCB tracks drawn in zigzag fashion. The first 'what' question has now been answered.

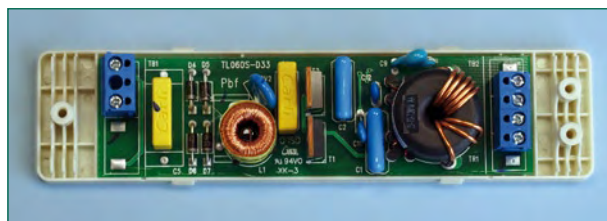
### Curves

The array of components used indicates that AC must appear at the output. And it's a foregone conclusion that the signal there will be in the upper kHz region. Naturally.

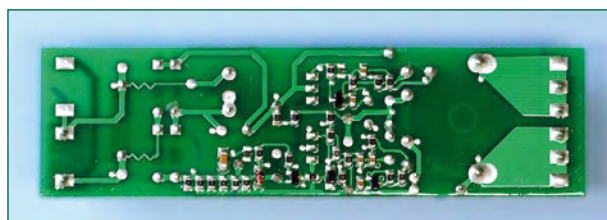
**Figure 1.**  
An off-the-shelf 'electronic transformer' providing 60 W of power for low-voltage halogen lamps.



**Figure 2.**  
Inside the plastic case we find a straightforward switch-mode power supply using discrete components.



**Figure 3.**  
The rear side of the printed circuit board displays a spartan appearance, with no ICs and just a handful of semiconductors.



# Revealed and Explained

So you will be just as astonished as I was when I applied the 'scope to the output terminals. **Figure 4** shows a rather familiar waveform: it's the standard kind of 100 Hz ripple waveform you would naturally expect to see on the far side of a bridge rectifier. But not quite normal, because this waveform displays a mirror image either side of the horizontal.

The riddle is resolved in **Figure 5**: by speeding up the timebase we discover a squarewave signal of about 32 kHz at the output, which is very much what we might expect as the unrectified output of a switch-mode power supply. And as our SMPS is designed to provide a pulsating DC voltage rather than something smoothed and filtered, the output is overlaid with the 100 Hz waveform of the input. The signal of **Figure 4** consists therefore of a 32 kHz squarewave AC voltage amplitude-modulated at 100 Hz.

So, on now to our second 'what' question. Should we be concerned about the overtone frequencies of the 32 kHz squarewave signal, if it is fed to a couple of halogen lamps along two catenary (suspension) wires a metre long? Definitely, because this device would transmit a broad band of radio interference starting in the RF region and extending into medium wave territory. Disappointingly, there's no mention whatsoever of this either on the plastic case or in the instruction leaflet. Despite the pretty CE symbol displayed on the casing (and a number of international technical approval markings), a radiating electronic transformer of this kind should be better screened and ideally not used at all for catenary wire lighting.

## Applications

Now just the final 'what' question remains. Having determined that an electronic transformer is best used only with screened (metal-cased) lamp fittings, we need to say something about the stability of the output voltage. The nominal voltage of 11.2 V (unloaded) drops to 11.0 V when supplying a 5 A load current. That's certainly a fraction less than the 11.5 V marked on the unit but of adequate stability for this voltage.

Because this kind of '12 V transformer' offers such good bang for our buck — models rated at 105 W (around 8.5 A) are available cheaply — it's well worth seeing if this bargain might have alternative applications. Most of these will demand direct current and we could simply rectify and smooth the output voltage. The high switching frequency means that four Schottky diodes of adequate rating would be preferable to a normal bridge rectifier. For smoothing at 30 kHz around 100  $\mu\text{F}/\text{A}$  would be adequate — were it not for the 100 Hz amplitude modulation. So let's remove it altogether.

**Figure 6** shows a temporary lash-up with a foil capacitor soldered on the rear side of the PCB, raising the capacity on the input side of the bridge rectifier to a good 700 nF. You can see how effective this is by looking at the output in **Figure 7**, where we see a signal with the 100 Hz component reduced visibly. We can improve on this: up to 50 W a high-voltage electrolytic rated 100 to 220  $\mu\text{F}/385\text{ V}$  will be fine. At 100 W and more we would need to raise the capacity correspondingly. As can be seen with our modified electronic transformer in **Figure 8**, such a hefty capacitor

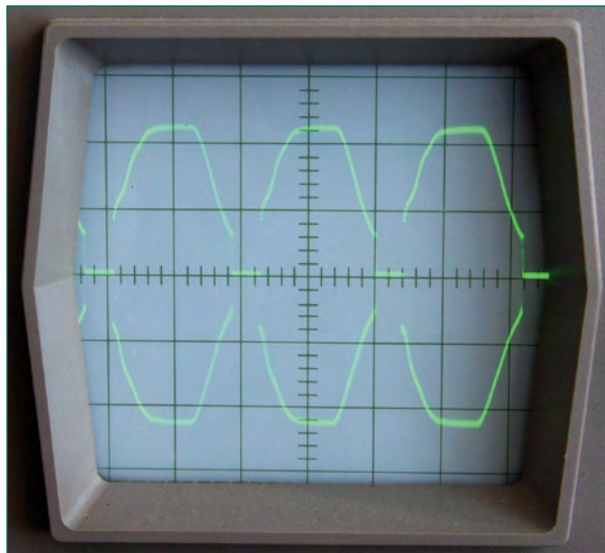


Figure 4. Output signal waveform at a timebase of 5 ms/division.

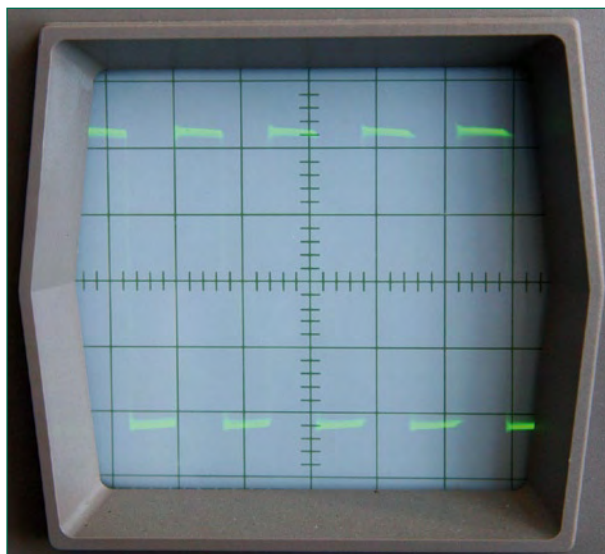


Figure 5. With the timebase reset to 20  $\mu\text{s}/\text{division}$  the high-frequency component becomes visible.

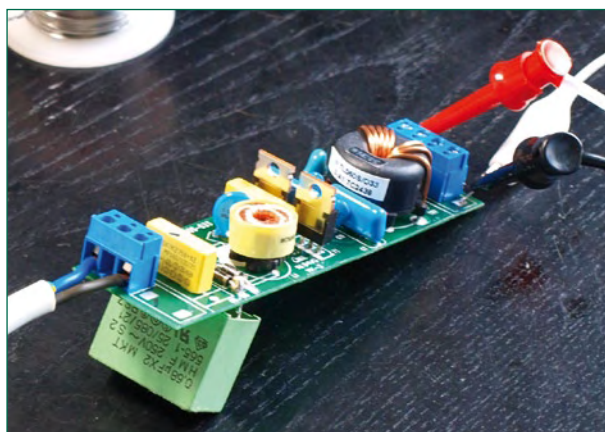


Figure 6. In this experiment a plastic foil capacitor has been soldered in cascade with the input rectifier to raise the filter capacitance value.

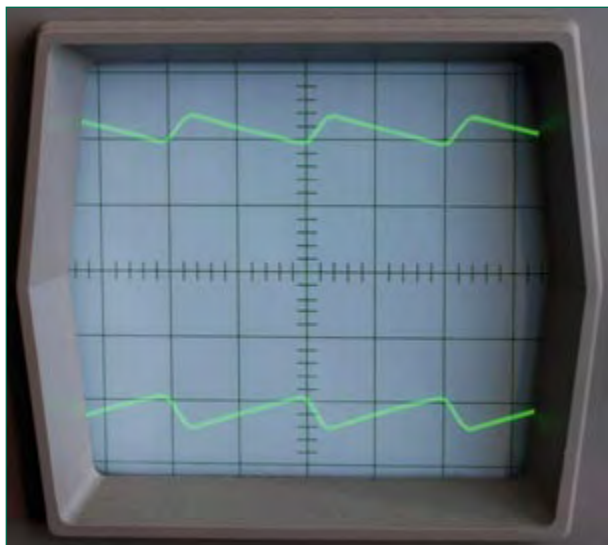


Figure 7. Improved smoothing on the input side lowers the amount of 100 Hz modulation on the output.

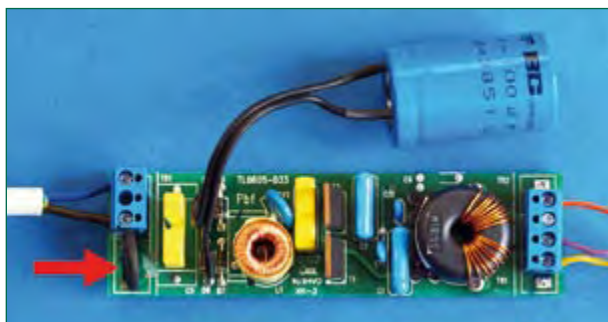


Figure 8. This modified 60 W transformer has been fitted with a 100  $\mu$ F filter capacitor (above) and an NTC thermistor (arrowed). The output transformer (right) has additionally been rewound with 2 x 8 turns to produce two 15 V secondaries.

naturally will no longer fit inside the unit's plastic casing. If you are adding a high-voltage electrolytic of this kind for smoothing you will also need to fit a thermistor (NTC) with around 22  $\Omega$  cold resistance to the mains lead (arrowed in red) in order to keep the switch-on inrush within bounds. Adequate smoothing on the output is achieved with an electrolytic rated at 1000  $\mu$ F/25 V. The 25 V voltage rating is necessary because the output's peak value can rise to around 16 V. With these two modifications made, we have now created an affordable SMPS that delivers around 15 V direct current.

In **Figure 2** the eight turns of the secondary winding of the output transformer are clearly visible. As the primary winding is extremely well insulated with a layer of plastic, this enables us to remove the secondary winding and substitute something different to produce different voltages. On the models we looked at each turn produced 2 V or so. You could for example wind two enamelled copper wires in parallel and produce a winding with a precise centre tap, which would enable you to achieve full-wave rectification with just two diodes. That would save one diode path and reduce losses in the process.

Conclusion? An electronic transformer makes an ideal basis for a cheap, lightweight power supply. And 'green' too — the example illustrated develops a measured efficiency of 90 % when operating with its nominal load!

(080691-1)

## Warning!

**Any experimentation involving mains voltages demands extreme care and absolute respect for electrical safety guidelines and separation distances.**

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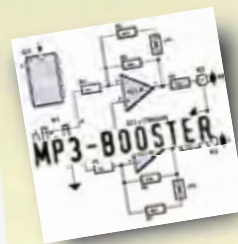


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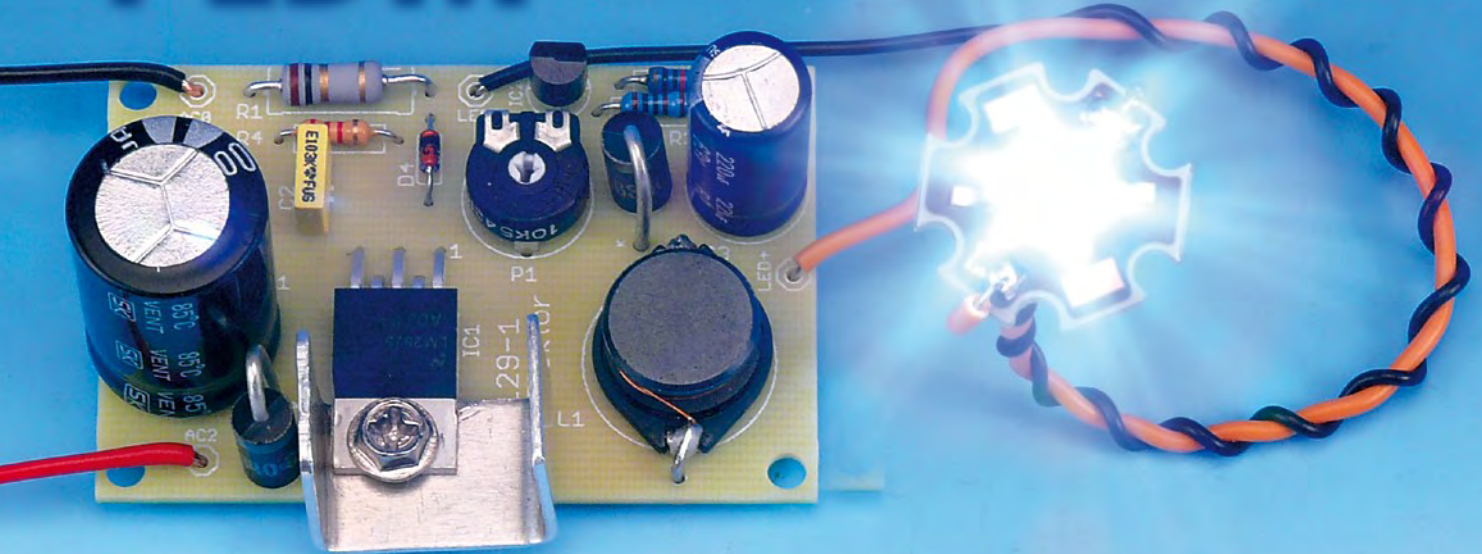
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# PLDM



## Power LED driver module

Dr. Thomas Scherer

**This year, for the first time, the efficiency of LEDs has overtaken that of fluorescent tubes. Power LEDs are thus now a realistic and energy-saving alternative to other forms of lighting. Getting them to light up, however, needs a bit of electronics, and hence the universal module described here.**

One thing is for sure: the twenty-first century will be the age of semiconductor light sources. How can we be so certain? See the text box 'LEDs today'.

### Current for LEDs

Their low dynamic resistance and markedly negative temperature coef-

ficient of forward voltage makes operating LEDs from a constant voltage source impractical. Instead, a constant current is needed. It is for the same



Figure 1. The 3 W LED from Cree used by the author in his experiments is a particularly beautiful piece of electronics.

### Technical characteristics

- Universal switched LED current source
- Efficiency: up to 87 %
- Input voltage: 2 x 6 V AC to 2 x 27 V AC
- Maximum input voltage: 40 V
- Output current adjustable from 0.1 A to 1 A (maximum 2 A)
- Up to eight white LEDs in series
- Maximum output voltage: 34 V
- Several modules can be powered from one transformer

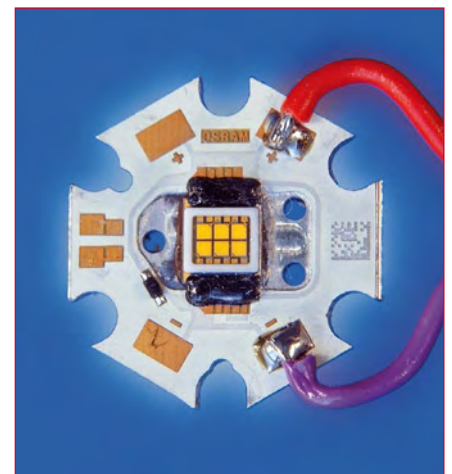


Figure 2. OSRAM's presence in the semiconductor lighting market includes OSTAR, a hex 3 W LED.

# LEDs today

## For:

A light bulb with the standard colour temperature of 2700 K has a maximum efficiency of 15 lm/W, or 3%. It has a life of 1000 h. A halogen lamp has four times the life expectancy, and gives out somewhat more light: a typical efficiency is 25 lm/W, or 5%.

Fluorescent lamps can reach efficiencies of over 20% (up to 100 lm/W) and have life expectancies of over 10000 h. Modern energy-efficient bulbs, because of their small size, only manage around 60 lm/W, and unfortunately only reach their normal brightness after a delay: at low temperatures normal brightness is never reached. They are not suitable for frequent switching.

A modern white [1] high-power LED has the following features.

- Light output efficiency of over 100 lm/W (over 150 lm/W has been achieved).
- Life of over 50000 h.
- Rapid and problem-free switching on and off.
- Small physical size opening up new opportunities for lamp design.

## Against:

The advantages of power LEDs are so clear that it is surprising that they are not more widely available. The devices currently available that contain a large number of 5 mm LEDs are of little use. The main obstacles to adoption of LED lights are their high price and their cooling requirements.

A single good-quality white 3 W LED of the sort shown in **Figure 1** today costs several pounds. Special high-efficiency LEDs, 5 W types, multiple-LEDs (see **Figure 2**) and RGB LEDs (see illustration) are considerably dearer. Also, to prolong their life, the LEDs must not be allowed to get too hot. Efficiency reduces as temperature rises, and so is also improved by adequate cooling. Good cooling is, however, difficult to provide and so it is understandable that good-quality LED lamps tend to come with a 'designer' label and a price to match.

**Warning: bright LEDs!**  
Under no circumstances look directly into the LEDs! The very bright light will not just cause discomfort, it is dangerous to the eyes as it can damage the retina.

reasons that LEDs are normally wired in series rather than in parallel: otherwise device-to-device variations would lead to an unequal distribution of load and hence brightness.

In the case of power LEDs designed for lighting applications energy efficiency plays an important role. This means that there is no real alternative to using a switching regulator to drive the devices. Unfortunately commonly-available integrated switching regulators are designed for constant output voltage rather than constant output current. It is not easy to convert them to constant current operation because the internal reference voltage used by the error amplifier is usually in the region of 2.5 V, and is rarely less than 1.2 V. Even with a 1.2 V reference regulating the current by simply measuring the voltage drop across a shunt resistor leads to unacceptable losses: at a current of 1 A a 1.2 V voltage drop calls for a 1.2 Ω shunt resistor which will dissipate 1.2 W in wasted power. Special-purpose LED driver ICs are available, but almost invariably in hard-to-solder SMD packages. A clever little circuit offers an alternative approach.

## PLDM circuit

If we want to make use of a low-cost integrated switching regulator in a five-pin TO-220 package, such as the LM2575-ADJ, then the trick in converting it into a constant current source lies in artificially raising the level of the error signal. The circuit in **Figure 3**, which forms a universal driver module for power LEDs, is surprisingly simple and easy to adapt. D1 and D2 rectify the voltage from the mains transformer, which must have either two identical secondary wind-

ings or a single winding with a centre tap. In comparison to a full-wave bridge, the arrangement shown saves on the losses associated with the voltage drop across one diode. Schottky diodes keep the remaining voltage drop down to below 0.5 V. The rectified voltage supplies switching regulator IC1, a so-called 'buck' step-down converter, on pin 1. The input voltage must always be greater than the output voltage. The IC includes an error amplifier which drives a pulse-width modulator and switching transistor. The PWM signal produced appears on

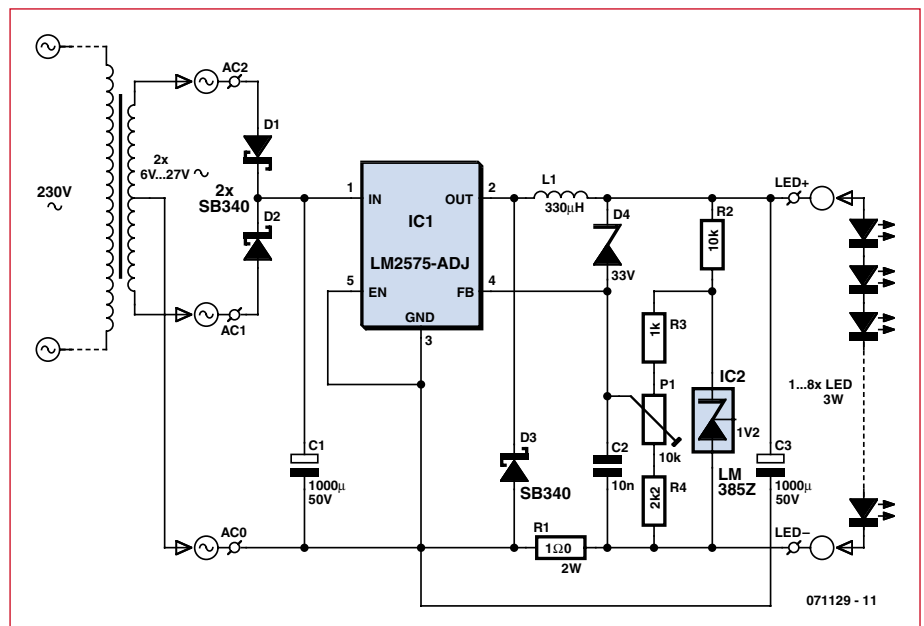


Figure 3. Circuit of the switching voltage/current regulator.

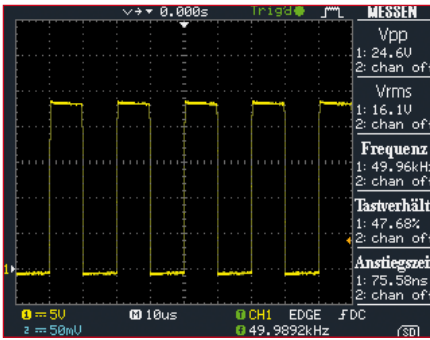


Figure 4. With a supply voltage of 25 V and five 3 W power LEDs connected to the PLDM, the mark-space ratio of the switching regulator is approximately 50 %.

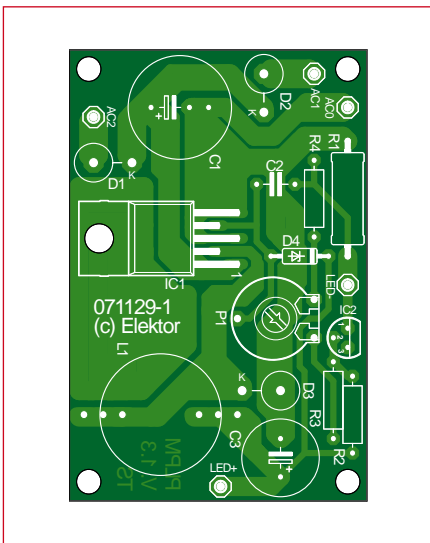


Figure 5. The PLDM printed circuit board measures just 60 mm by 40 mm.

## COMPONENTS LIST

### Resistors

- R1 = 1Ω / 2W (carbon film or metal film)
- R2 = 10kΩ
- R3 = 1kΩ
- R4 = 2kΩ
- P1 = 10kΩ

### Capacitors

- C1 = 1000µF 50V\*
- C2 = 100nF
- C3 = 220µF 35V\*

### Semiconductors

- D1, D2, D3 = SB340\*
- D4 = ZPD33V\*
- IC1 = LM2575Z-ADJ\*
- IC2 = LM385Z1.2

### Miscellaneous

- L1 = 330µH / 1.9A\* (SMD power inductor, e.g. FASTRON PISR-331M-04 (Reichelt # L-PISR 330µ))
- Tr = 2 x 6-27 V\*
- PCB, ref. 071129-1

\* see inset 'Power & Components'

pin 2 (see Figure 4). IC1 adjusts the signal so that exactly 1.2 V appears on input pin 4.

Coil L1 is a low-cost fixed inductor whose exact value is not particularly critical. It is, however, important that it is suitable for operation at around 2 A and that D3 is a Schottky diode. And here is the clever part: the voltage dropped across shunt resistor R1 is increased by 1.2V by voltage reference IC2. Using the suggested values for R3 and R4 the output current can be varied continuously between 100 mA and 1 A. Finally, D4 limits the maximum output voltage to 34.2 V.

## Construction

The text box 'Power and components' discusses tailoring the circuit to the number of LEDs to be connected. Since no SMDs are involved, there are only two points to note when populating the small printed circuit board shown in Figure 5.

First, diodes D1 to D3 have thick leads. Since they are mounted vertically, one of the wires has to be bent. To avoid damaging the device by excessive force on the diode's package when bending the lead it is essential to hold it firmly at the point where it enters the package using a pair of pliers.

Second, as long as the output power is less than 10 W, IC1 can be fitted flat against the printed circuit board and fixed with an M3 bolt. The M3 nut is soldered to a copper area on the reverse of the board (Figure 6) which will conduct the heat away. If the output power is more than 10 W a small heatsink is needed.

Figure 7 shows the populated prototype board, fitted with a small extra piece of aluminium angle to provide adequate cooling for an output power of up to 15 W. A PLDM can drive a maximum of eight white LEDs connected in series. Several PLDMs can of course be connected in parallel across a single transformer.

## PLDM installation

If a large number of individual 1 W LEDs is used, as shown in Figure 8, arranging for adequate cooling is relatively straightforward. The LEDs can simply be attached to the (usually painted) sheet steel of the light fitting using a little thermal paste and nylon screws.

Things are less easy with 'proper' power LEDs rated at 3 W and above: Figure 9 shows how the PLDM electronics can be installed along with a repurposed 'electronic transformer'. In the middle is a warm white OSTAR hex LED rated at some 15 W.

Sadly, of the 15 W at least 12 W is dissipated as heat. Tests have shown that sheet steel is poor at conducting the heat away and that in operation the LED can reach blistering temperatures well in excess of 110 °C! A piece of sheet aluminium works more effectively.

(071129-1)

## Warning

**Never connect LEDs to the PLDM while power is applied to it! If C3 is charged the discharge current will almost certainly damage the LEDs. First switch off power to the PLDM, connect the LEDs, and then reapply power.**



"ACULED" from PerkinElmer Elcos

## Internet links and literature

### [1] Theory of white LEDs:

[http://en.wikipedia.org/wiki/Light-emitting\\_diode#White\\_light\\_LEDs](http://en.wikipedia.org/wiki/Light-emitting_diode#White_light_LEDs)

### [2] LED cooling (PerkinElmer):

[http://optoelectronics.perkinelmer.com/Content/ApplicationNotes/APP\\_ThermalManagementofACULEDVHL.pdf](http://optoelectronics.perkinelmer.com/Content/ApplicationNotes/APP_ThermalManagementofACULEDVHL.pdf)

## Power and components

Certain components in the module can be selected according to the number of LEDs connected in series to its output. The universal values, as shown in the circuit diagram, are indicated in bold.

Number of white LEDs				
LEDs	Transformer secondary	C1	C2	D4
1	2 x 6 V	16 V	16 V	ZPD12V
1 or 2	2 x 9 V	25 V	25 V	ZPD22V
1 to 3	2 x 9 V	25 V	25 V	ZPD22V
1 to 4	2 x 12 V	25 V	25 V	ZPD22V
1 to 5	2 x 15 V	25 V	25 V	ZPD22V
1 to 6	2 x 18 V	35 V	35 V	ZPD27V
1 to 7	2 x 24 V	50 V	35 V	ZPD33V
<b>1 to 8</b>	<b>2 x 27 V</b>	<b>50 V</b>	<b>35 V</b>	<b>ZPD33V</b>

The required power rating of the transformer is calculated by dividing the power required by the LEDs by the efficiency of the converter and adding a safety margin. For example, suppose we wish to connect four 3 W LEDs. The current through the LEDs is 750 mA. In the worst case the forward voltage of the LEDs is 4 V and the load is  $4 \times 3 = 12$  W. The overall efficiency of the converter is around 85 %: using 80 % to be on the safe side, we calculate that the transformer must be capable of delivering at least  $12 \text{ W} / 0.8 = 15$  W. An 18 VA transformer with two 12 V secondary windings is thus suitable.

It is possible to alter the circuit for higher power output (up to approximately 50 W). If R1 is replaced by a  $0.47 \Omega$  2 W resistor, C1 by a  $2200 \mu\text{F}$  capacitor, diodes D1 to D3 by type SB540, IC1 by an LM2576T-ADJ and L1 by a  $100 \mu\text{H}$  inductor, it will be possible to achieve currents of up to 2 A. The P3596 is also available as a substitute for the LM2576.

When using RGB power LEDs it is important to select devices with separate anode and cathode connections for each LED. All the red LEDs can be wired in series and driven from one PLDM, the green LEDs from a second PLDM and the blue LEDs from a third PLDM. The trimmer potentiometers can then be adjusted to obtain the desired mixture of colours in the light output.

When the current through the LEDs is being adjusted using P1 it is possible to monitor the voltage drop across R1 using a voltmeter. For experimenting like this it is recommended to use a 'pseudo-LED' (consisting of a  $10 \Omega$  resistor rated at 10 W) to avoid accidentally shortening the life of the real LEDs.

## Light and temperature

It is of course a good idea to take a look at a LED's data sheet before building a LED lamp and associated driver electronics. In particular, thermal behaviour varies considerably from manufacturer to manufacturer. Graphs showing the typical spectrum of a white LED and the dependence of efficiency on temperature, and tables of typical characteristics all provide useful guidelines. Commercially-available power LEDs do not, unfortunately, yet reach laboratory-record efficiency levels of  $150 \text{ lm/W}$ . A good rule of thumb is that one LED watt is worth about four incandescent watts.

It is essential to cool power LEDs. It is simplest to use LEDs which are already mounted on a small aluminium carrier. More information on the thermal management of power LEDs can be found in [2], which is also our source for the picture of the 'ACULED'.

### Typical values for a white 3 W power LED

Light output	100 lm to 200 lm
Viewing angle (to 50 % brightness)	$120^\circ$
Life (70 % brightness)	up to 50000 h
Maximum junction temperature	$150^\circ\text{C}$ to $185^\circ\text{C}$
Thermal resistance, junction to package	less than $15 \text{ K/W}$
Operating current	700 mA
Forward voltage at 0.7 A	3.1 V to 3.9 V
Temperature dependence of forward voltage	$-2 \text{ mV/K}$
Dynamic resistance	less than $1 \Omega$



Figure 6. For lower power applications it is sufficient to solder an M3 nut to the pad on the reverse of the printed circuit board to help dissipate heat.

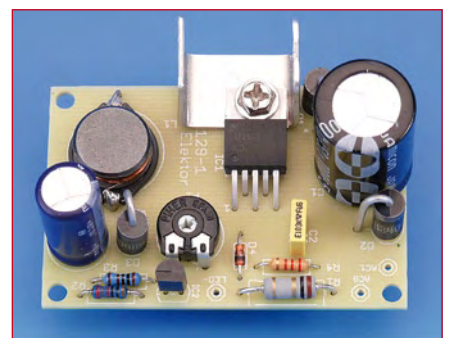


Figure 7. The prototype: IC1 is screwed to a small piece of aluminium to provide cooling.

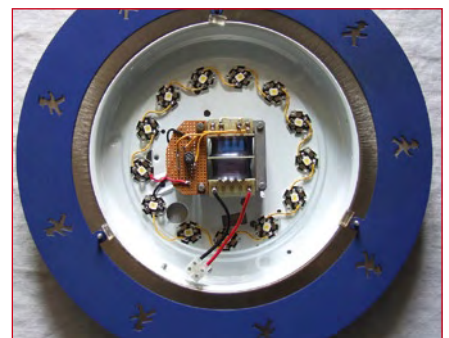


Figure 8. An early experiment using thirteen LEDs, each rated at 1 W, in series: here without the PLDM.

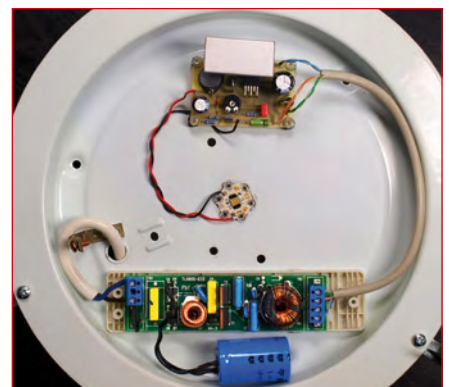
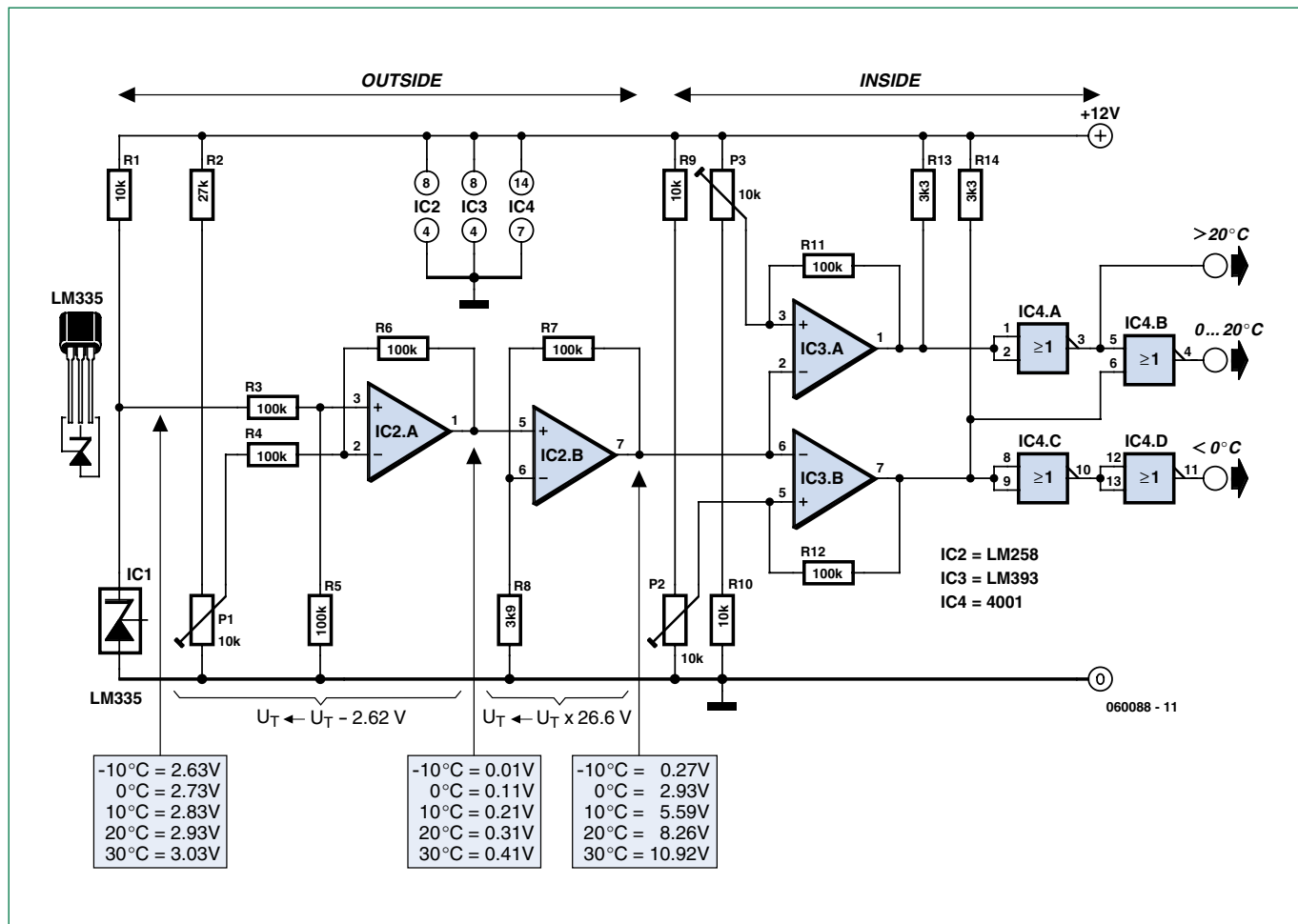


Figure 9. Building the electronics into a ceiling light. A modified 'electronic transformer' and a PLDM can be seen, with the OSTAR LED in the middle.

# Temperature Switch



-10°C = 2.63V
0°C = 2.73V
10°C = 2.83V
20°C = 2.93V
30°C = 3.03V

-10°C = 0.01V
0°C = 0.11V
10°C = 0.21V
20°C = 0.31V
30°C = 0.41V

-10°C = 0.27V
0°C = 2.93V
10°C = 5.59V
20°C = 8.26V
30°C = 10.92V

**Heino Peters**  
(The Netherlands)

The LM335 is a low-cost temperature sensor with a range of -40 °C to +100 °C. In this circuit, it is used to show whether the outside temperature is below freezing or above 20 °C. In the first case, you have to worry about icy roads and the outside taps freezing, while in the second case you can open the windows and switch off the heating. You can adjust the switchpoint temperatures to suit your wishes.

The output of the LM335 provides a potential of 10 mV/K. You can obtain the temperature in °C by subtracting 273 from the output value. For example, at an output voltage of 2.98 V the temperature is 25 °C (298 - 273).

In this case, we only need to be able to measure over the range

of -5 °C (2.68 V) to +25 °C (2.98 V), which is a span of only 0.3 V. Consequently, we first expand this range using two of the opamps in IC2.

A reference potential of exactly 2.62 V is set using P2. IC2a compares the output voltage of IC1 with the reference potential and passes the difference on to IC2b. The combination of IC2b, R7 and R8 forms a gain block that amplifies this signal by a factor of 27.

As a result, the output voltage over the temperature range of approximately -10 °C to +30 °C is mapped into a voltage range of approximately 0 V to +11 V. Bear in mind that the indicated voltages can vary slightly due to tolerances in the resistor values. Also be sure to use a stabilised 12-V supply, because any fluctuations in the supply voltage will also be amplified by IC2b.

Next, we use two of the comparators in IC3 to determine whether the outside temperature is below freezing or above 20 °C. IC3a and P3 provide the setpoint for around 0 °C, while IC3b and P2 do the same for 20 °C. As it is a bit difficult to precisely set P2 and P3 in practice (you would have to wait until it is 0 °C or 20 °C outside), you can initially set them to the calculated values (2.93 V for P2 and 8.26 V for P3). You can adjust the settings later on if the switchpoints differ too much from the desired temperatures.

Finally, four NOR gates are used to derive three switching signals from the two output signals. These switching signals can be used to drive three LEDs (for example) to indicate which range the temperature lies in. You should preferably use low-current LEDs to avoid overload-

ing the CMOS gates, and connect each of them to ground via a 3.3-kΩ resistor.

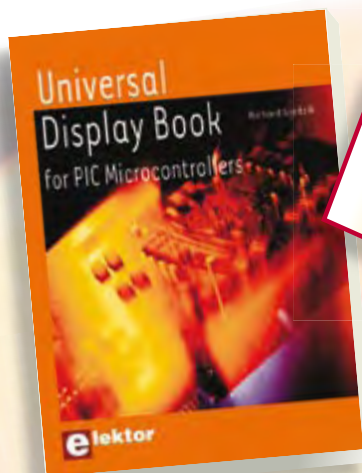
It's a good idea to place the left part of the circuit (up to and including IC2b, R7 and R8) indoors and the right part outdoors. An interconnecting cable of 10 metres will not present any problems. However, you should connect a 100-μF, 16-V capacitor across the supply voltage on the outdoor circuit board.

In principle, you could also use an LM358 in place of the LM258, but its operation is not guaranteed by the manufacture at temperatures below 0 °C.

(060088-1)

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# Omni Pendulum

## The ultimate classroom project

Pavel Grodek (Russia)

**Most people seem to think that the only thing digital electronics is good for is blinking LEDs. After all, everything in this world is “analogue” – and there is no easy way to interface a microcontroller to the real world without some arcane ‘input stage’ with amplifiers and filters. Or is there?**



Admit it... most microcontroller-based projects tend to be digital in their nature: some buttons (binary signals), LEDs (binary outputs), maybe a piezo speaker (binary sound output).

This project is different. The microcontroller in it is directly connected to a small coil — and there is nothing else (except, maybe, a power source and some noise suppressing capacitors). And yet it manages to achieve something that's almost impossible with any kind of traditional analogue setup: *perpetual motion*. Well, as long as the batteries last...

### The pendulum

There are two major kinds of pendulum: linear — rotating around the fixed axle, and omni-directional — generally

some weight on a bit of string. It could swing in any direction, with any speed and trajectory. The first kind is widely used in clocks — it's easy to detect its exact position and push it just in time with some kind of mechanical device or an electromagnet. The second kind is tricky — there is no easy way to make it swing forever. At some point it will, most probably, travel a round, slowly tightening spiral, and come to rest in the centre position.

If you browse the Web there are a few designs that attempt to make the omni pendulum swing forever with analogue tricks. Basically, you take two hand-wound coils: one to detect the approaching magnetic pendulum, and the other one to push it away as soon as it passes the centre position. Well, they seem to work most of the time, but they are pretty complex, require a

lot of fine-tuning, and are not infallible: if you stop the magnet manually or if it rotates in a circle — there is no current in the detector coil and, of course, no signal to the electromagnet. They also tend to be power-hungry and inefficient. Let's design something better — with a microcontroller!

### Hardware

The 'mechanical' part is very easy: take a small rare earth magnet and attach it to a string with one pole pointing down. I've used a fishing line — it lasts longer than a string, and that's important when there are about ten million swings every year! I attached the magnet with a bit of Scotch tape, and it holds well.

The electronic part is a bit more difficult, but still one of the easiest in your



(embedded) life. The minimal version requires only two parts: the microcontroller itself and one coil. Let's do it properly, though, and design it from the ground up. The result is shown in Figure 1.

First, we'll select a microcontroller. An ATmega8 chip from a previous project was chosen; they are very cheap and easily available anywhere, even in my country.

To power the project we need some stabilized power source, preferably +5 V DC. It's easy to make one – just buy a 'wall wart' that provides + 8 or more volts for charging or powering some device and use a linear regulator like the LM78L05 or its bigger cousin the LM7805. We don't need a lot of power, about 25 mA in very short bursts, so any kind will do. Don't forget to add a couple of capacitors – one electrolytic on the input and one small ceramic on the output of the stabilizer, as its datasheet indicates.

There is an easier approach, though – if you have a computer with an USB port, it provides a very nice, well-stabilized +5 V, even if a bit noisy. It's also well protected: the USB standard says that it has to survive shorting any of its pins to each other for 24 hours.

Next we'll need a coil. Not just any coil, but we'll certainly be able to use many types. It does not need to have a core – just enough turns of wire (say, a few hundred), so it will produce a good strong signal, and we also want to have some reasonable resistance to limit the current and protect the microcontroller pins. The current that they could survive is indicated in the datasheet – about 25 mA. Ohm's law says that at 5 V we need to have about 200 ohms, so if our coil has less resistance we'll just add a resistor (R1) in series to get the safe total value. For example, if our coil is wound with a very thick wire and has 1  $\Omega$  of resistance, we'll just use a resistor close to 200  $\Omega$  (the nearest standard value that's easily available is 220  $\Omega$ ) and it will work just fine.

For the first design a coil was used from an old dead hard drive that moved its head assembly. It was about 100  $\Omega$  and easy enough to cut out from the aluminium head frame.

Finally, even though it's not strictly necessary, it's nice to have some UI in the form of buttons, LEDs, etc. Following the KISS approach one button (S1) and one LED (D1) are available optionally for h/w as well as used in the source code (available free on the

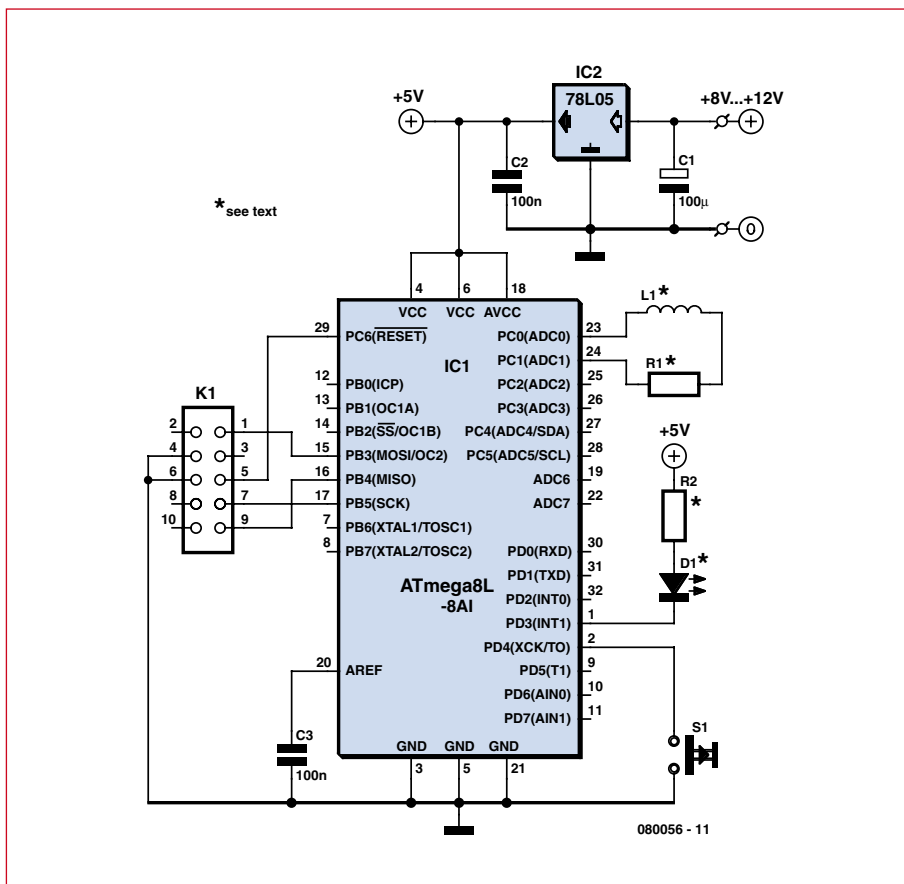


Figure 1. Circuit diagram of the Omni Pendulum controller. By clever programming of the AT micro, the coil is used as an actuator as well as a sensor!

Elektor website [1]). The LED is connected using series resistor R2 to limit the current – depending on the LED colour you'll need 220  $\Omega$  (for white and blue ones) or 470  $\Omega$  to 1000  $\Omega$  for good old red/green/yellow ones.

Next comes the programming connector, K1. After all, you will certainly like to play with this circuit a lot, adding new features and modifying them. So, while it's possible to simply solder the five wires where they should go and cut them later, it's a good idea to install a connector.

And, finally, it's recommended in the ATmega8 datasheet to install some 0.1  $\mu$ F capacitors between the Vcc and GND pins of the microcontroller. It's not strictly necessary, it will almost certainly work without them, but it's better to be safe than spend hours trying to debug the device.

So, while the minimal version takes its power straight from the USB port and has no external parts except for the coil, if you want to mod & tweak this circuit, it would be useful to build it on a breadboard or to make a small PCB for it. The PCB artwork files (designed by the author) are available as a free

download [1].

## Programmer

If you have never programmed a microcontroller before – well, it's a good time to start! You can buy some AVR in-system programmer or build your own. If your computer still has an LPT port, the programmer could be as simple as five wires with series resistors of, once again, about 220  $\Omega$ . In this case you'll need to learn a bit about the innards of the Avrdude program that comes with WinAVR and actually programs your chip. It's certainly not difficult, but if you want to have it even easier – just buy a commercial programmer.

## Software

First we'll have to download and install two things: AVR Studio [2] and WinAVR [3]. They will find each other during installation and provide an environment where you will be able to write your C code, compile, emulate and debug it, and then program your final result into a real device. Create a new project, import the

*OmniPendulum.c* file that you downloaded – and that's it. Read about setting the fuses to get 8 MHz from the internal RC oscillator and learn how to compile and upload the code, and you are good to go. Let's see what's inside the code and how it all works.

The coil is connected to two pins. They could be used as digital outputs, of course, and that's what we do to power the coil and push or pull the magnet. But they could also be used as analogue inputs – we can read the voltage that's generated in the coil by the moving magnet. It's very small, of course, so if our coil doesn't have enough turns, you may want to get a microcontroller that has an amplifier built in (ATtiny25, 45, 85, or ATmega16 are all good examples) and add its initialization to the code. But it's easy enough to find a coil that would generate enough voltage, just look for more turns.

What we do is program the pins as analogue inputs, and keep reading the voltage. If we receive some non-zero value there (the exact value depends on the coil, of course) then here's our magnet! The physics says that the magnet generates the current first in one direction, as it approaches, and then in reverse, as it flies away. We want to push the magnet as soon as it crosses the central point, so we are trying to detect the second situation (by measuring at the appropriate pin and grounding the other one).

Now, as soon as we have detected the magnet where we want it, we can push it. To do that we set both pins to outputs and output +5 V to one side of the coil while grounding the other side. Then we pause for a short time (actually, pushing) and then switch the current off and return to watching.

## Installation

I've chosen to install the pendulum in IKEA shelf case and hide the circuitry, so it looks like a 'perpetual motion' device. To do that I removed a board from the shelf, and used a router to make a cavity (not a through hole of course). The coil is located only a few millimetres from the magnet, and that's enough for good readings and strong pushes. Nothing is visible from

the upper side, and little enough is visible from below to fool most people. The **photo sequence** printed here tells the story, also of the PCB making and alternatives.

One interesting side effect of mounting this way is the asymmetrical movement obtained by tying the fishing line around the board above, see the sketch in **Figure 2**. When a pendulum is supported in this way it doesn't oscillate in any direction indifferently, instead it wants to go in some complex orbits that relate to the famous Lissajous

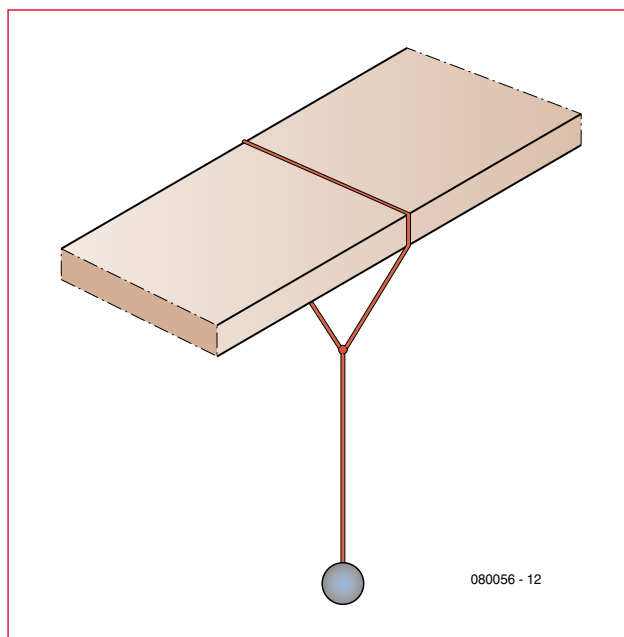


Figure 2. Simplified graphics illustrating a pendulum support that gives oscillating motion of the magnet.

curves. Google the web for 'harmonographs' (not hormono...).

If you want to have a 'real omni pendulum' you may want to put a nail or a hole in the top support and tie a string to that. It would produce some interesting patterns, but they would change slowly and most of the time will look less attractive. The asymmetrical support gives more predictable movements, but keeps them changing constantly. It's your choice — what you like best.

## Tricks

It's certainly nice to use one coil for both purposes (so our digital design is ahead of the game already) but it's even better to add some clever tricks so the magnet never stops. If it goes in a circle (or, in fact, a slowly tightening

spiral) it will not induce any noticeable current in our coil, so we will not notice that it's stopped. If someone stops the magnet just to see what happens, it's essentially the same problem. And, finally, if there is no electricity for a while — the magnet will stop and the microcontroller, as soon as starts up, will have to start the swings again somehow.

To do that we can simply wait for some time (say, five seconds – about four times as long as it normally takes my pendulum to swing), and if there were no readings all that time – well, we can assume there is some problem and perform the 'emergency startup'. One push is not strong enough, so the simplest method would be to execute a blind series of forceful pushes and pulls with a reasonable frequency. If they are strong enough – they will make the magnet swing wide enough to register normally and then to be pushed exactly right. That's what the current code does, and it works very nice. Of course, there are some smarter methods discussed in the **Mods inset** – but this one is certainly good enough.

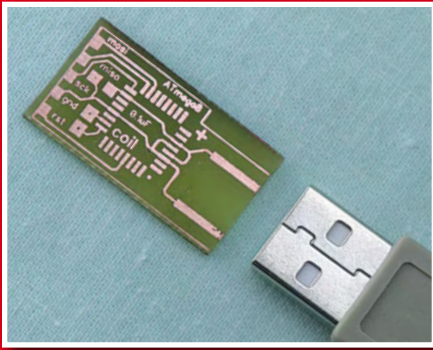
As you remember, we have added some extra things, a button and a LED. We can make a simple game, let the user try and beat the microcontroller! As soon as someone pushes the button, the microcontroller detects this and switches to manual mode.

It will time out back to automatic in 20 seconds after the last button press, of course. In the manual mode the coil is active and repels the magnet as long as the button is held down. Even with this forceful method it's rather difficult to make the pendulum swing as wide as in automatic mode (where repulsion is only 50 ms long). The LED blinks to indicate the detection and repulsion, and it can be switched on and off by holding the button for a few seconds.

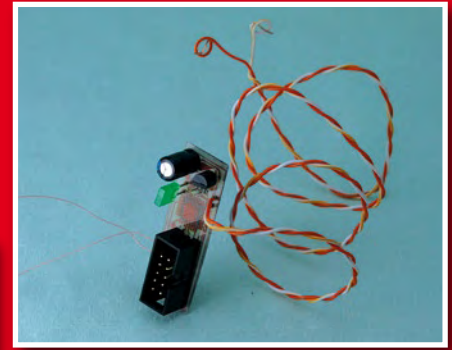
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## Internet Links

- [1] [www.elektor.com/080056](http://www.elektor.com/080056)
- [2] [www.atmel.com/dyn/products/tools\\_card.asp?tool\\_id=2725](http://www.atmel.com/dyn/products/tools_card.asp?tool_id=2725)
- [3] <http://winavr.sourceforge.net/>



The minimal version of the board, not yet populated, next to a USB connector for size comparison.

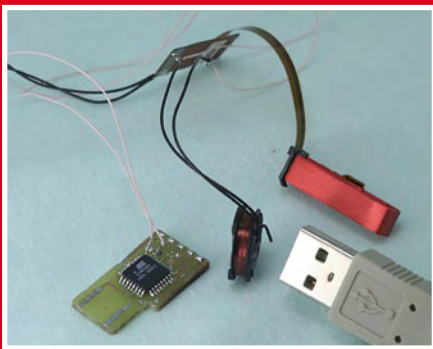


Alternate, 'full' version of the board. From top to bottom: input capacitor, 78L05, LED, power supply wire, (transparent) controller on the other side, programming connector. To the left is a coil wire. The button is not installed; it should be attached by another wire and placed conveniently (two holes for it are visible just below the 78L05).

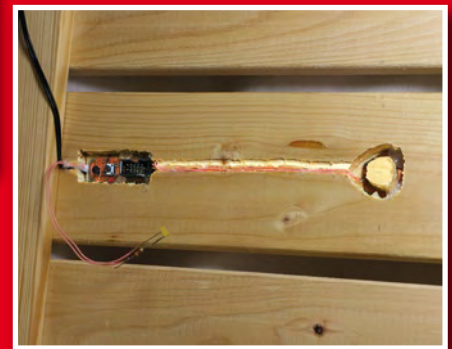
The wire with the magnet on it installed in the IKEA bookshelf case (wire and magnet highlighted for clarity).



Minimal version, with two different coils (the red one, being only 4 ohms, needs a resistor).



View from below; the board and the coil are secured in the routed hole and slot.



## Mods — over 2 U

Well, the device works and it's a lot of fun to see it always swinging without any visible means of propulsion. What's next? It's a perfect platform for experimenting with your first microcontroller project. Nothing could be simpler or easier, and yet it's full of possibilities.

- Make the magnet stop at will by reversing the process and repelling the magnet as it approaches and then attracting it as it flies away;
- Position multiple coils below the magnet and control them to achieve a particular trajectory;
- Make it a full-scale game! Add a few constraints to limit the repelling time and see if you could still achieve a pendulum action (the microcontroller, of course, works perfectly with extremely small repelling times; could a human beat it?), implement 'difficulty levels' by shortening the pulses as the game progresses;
- Make the pendulum react (using some other sensors) to its environment: swing less in the dark, more when it's hot, etc...
- Add a tiny piezo speaker (no extra components are required, just the speaker itself) and make a metronome;
- Add some means of reporting: a UART or an LCD, and discover for yourself what exactly happens in the brief time of interaction between the coil and the magnet;
- Improve the efficiency — use the inductor's properties: select a low-resistance coil, put some current in it (rapidly; a few microseconds only, while the induction limits the current growth!) and then immediately short it to produce a longer push with minimal energy requirements (it would work from batteries for months!);
- Put a plate of fine sand below it and attach some kind of small 'feeler' (a bit of fishing line, for example) and enjoy the beautiful ever-changing patterns;
- Use some clever mathematics to detect the resonant frequency of your pendulum in real time and modify the startup sequence to start very slowly and gradually — it will look as if the pendulum starts by itself.
- Good luck and have fun — that's what electronics is all about!

# Hexadoku

## Puzzle with an electronics touch

Addicts to the Hexadoku puzzle, here is another bunch of numbers (called 'hexadecimal' by pundits) to contend with using pencil, rubber and some brain activity. Go for it and try to enter the right hex numbers in the boxes. Send us your solution and enter a prize draw for an E-blocks Starter Kit Professional and three Elektor Shop vouchers.

The instructions for this puzzle are straightforward.

In the diagram composed of 16 x 16 boxes, enter numbers such that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once in each column and in each of the 4x4 boxes (marked by the thicker black lines).

A number of clues are given in the puzzle and these determine the start situation.

All correct entries received for each month's puzzle go into a draw for a main prize and three lesser prizes. All you need to do is send us the numbers in the grey boxes. The puzzle is also available as a **free download** from our website.

**SOLVE HEXADOKU AND WIN!**

Correct solutions received enter a prize draw for an

**E-blocks Starter Kit Professional**

worth **£249**

and three **Elektor SHOP Vouchers** worth £40.00 each.



We believe these prizes should encourage all our readers to participate!

The competition is not open to employees of Elektor International Media, its business partners and/or associated publishing houses.

**PARTICIPATE!**

Please send your solution (the numbers in the grey boxes) by email to: **editor@elektor.com** - **Subject: hexadoku 12-2008** (please copy exactly).

Include with your solution: **full name and street address.**

Alternatively, by fax or post to: **Elektor Hexadoku Regus Brentford - 1000 Great West Road - Brentford TW8 9HH United Kingdom - Fax (+44) 208 2614447**

The closing date is **1 January 2009.**

**PRIZE WINNERS**

The solution of the October 2008 Hexadoku is: **AB749.**

The **E-blocks Starter Kit Professional** goes to: Terje Daleng (N).

An **Elektor SHOP voucher worth £40.00** goes to: David Chester (USA); Lizzie Lever (UK); Ciril Zalokar (SLO).

**Congratulations everybody!**

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

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

## 'QQE' RF power double tetrodes (ca. 1950)

Jan Buiting  
(Elektor UK editorial)

Happy with the good response I got to two previous Retronics stories about little known valves like the Dekatron and E1T, I decided to dig out some more 'rare glass'.

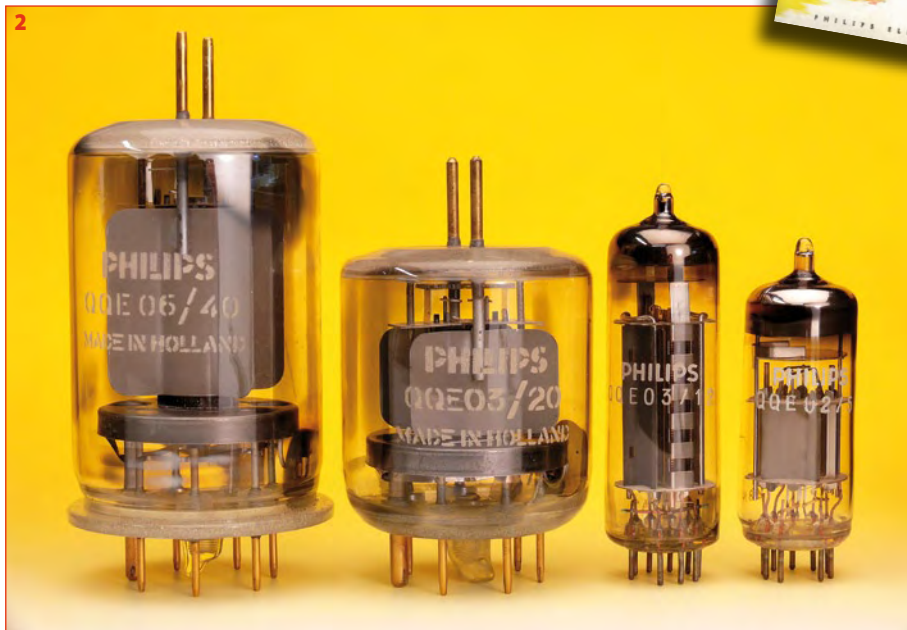
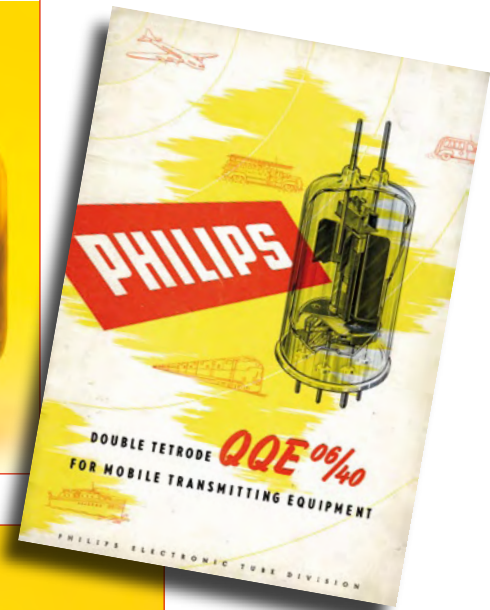
The principle of the push-pull power output stage is well known for its application in audio amplifiers using valves like the EL34 (6CA7), 6L6 or EL84 (6BQW5) to mention just three. And it works for RF too using golden oldies like the 807 beam tetrode

which will happily work up to 30 MHz or so. Drive two of these in antiphase using class C(-ish) biasing, link the anodes through the output coil and apply decoupled HT (high tension) to the coil's centre tap. RF output power is then available from a 'tank circuit', which basically is no more than a few turns of wire inductively coupled to the anode coil.

Probably as a result of the increasing significance of VHF (i.e. frequencies above 30 MHz) and centimetre waves (up to 1 GHz), designers at various radio valve industries soon were able to squeeze two RF tetrodes into a single glass envelope, usually with the anode pins at the top. The construction eliminated to a large extent those horrid stray capacitances and inductances associated with two individual 'audio' valves (like the 807) in push-pull configuration. The type 832A (CV788) dual beam RF power tetrode (**Figure 1**) could be used up to about 250 MHz but it was a pain to keep stable even in CW. At higher voltages and frequencies above 100 MHz, the valve behaved erratically. The cause was known: parasitic cross-

inductance between the two screen grids in the valve would set up perfect conditions for oscillation high up in the VHF band! Cancelling out these parasitics required an advanced technique called external neutrodynisation (or 'neutralisation') — don't try this at home!

Around 1950, it was discovered that *frequency-independent* neutralisation could be implemented *inside* RF double tetrodes to achieve VHF-plus frequencies without stability problems. The trick: two small right-angled



rods, each welded onto the supporting rod of one control grid, to act as a minute ( $<0.08$  pF) capacitance with the anode of the other tetrode [1]. In 1951 Philips Holland were the first to put this into mass production with their QQE series, which knocked the socks off the old 832As and 829Bs from the US.

For nomenclature we have: QQExx/yy where Q = tetrode, E = indirectly heated oxide cathode, xx = anode voltage in kV; yy = output power in watts in class C. Thus, QQE03/20 = 300 V, 20 W RF out. These are 'conservative ratings' — in practice, the valve can be made to do considerably better.

By about 1965 the series was consolidated to comprise the QQE02/5, QQE03/12, QQE03/20 and QQE06/40 — see the family portrait in **Figure 2**. The 03/20 and 06/40 have a special design using anode pins at the top and gold-plated pins at the base. The 02/5 and 03/12 are less conspicuous with their ordinary 9-pin noval base. The 02/5 has remained a rare bird while the other three achieved stardom among RF fans of the transmitting variety, and today adorn mantelpieces or just the highest bookshelf in the radio shack, often fitted in their specially designed ceramic 'septar' sockets. All family mem-

bers except the 03/12 can be used as high up as 430 MHz.

These valves are extremely rugged, long lasting and reliable, witness their use in 1950s/1960s PMR base and mobile equipment, in some cases with transistors driving them. Genuine Philips QQEs were produced well into the 1970s with lots of clones (CV/QQV/JAN)

and special quality versions (SQ/YL) also appearing on the market. Remarkably I've never seen a valve tester supporting the QQE03/20 or 06/40, but then, live testing is a simple matter — plug in, retune and see how many watts of RF out you get. All will be fine for years to come if you get above 70% or so of the value found in the manual. Stay well clear of the HT though!

(080771-1)

**[1] Double Tetrode QQE06/40 for Mobile Transmitting Equipment:**

<http://frank.pocnet.net/sheets/084/q/QQE06-40.pdf>

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

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(October 2008)

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New!

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(November 2008)

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## Communicating with CAN

(October 2008)

The CAN (Controller Area Network) protocol was originally developed for use in the automotive sector. It is now over 20 years old, but is still frequently used these days. It was specially designed for use in environments where you have a lot of electromagnetic interference. Despite the fact that the CAN protocol is a serial protocol, it can't just be connected to (the serial port of) a computer. The all-round USB-CAN adapter described in last month's Elektor is a compact and simple solution. With the help of the accompanying software you can follow all data communications taking place and carry out operations such as filtering and storage at the flick of a (mouse) switch.

PCB, partly populated

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## DCC Command Station

(September 2008)

Electronics is making more and more inroads into the domain of model trains. Trains are now controlled with digital codes, and in many cases the entire system can be operated from a computer. Elektor presents a design for the device that forms the heart of a digitally controlled model railway: the DCC Command Station. The computing power in this design is provided by a highperformance ARM7 processor.

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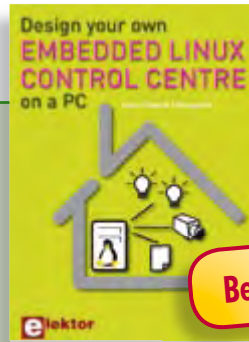
## DigiButler

(May & April 2008)

A low-cost home automation server based on a Freescale Coldfire 32-bit microcontroller. The project has been designed with open source in mind and doubles as a powerful Coldfire development system using free CodeWarrior software from Freescale. DigiButler activates electrical appliances in and around the home, accepting on/off commands from a WAP phone, through an Ethernet network or via a webpage at an allocated IP address and with full access security.

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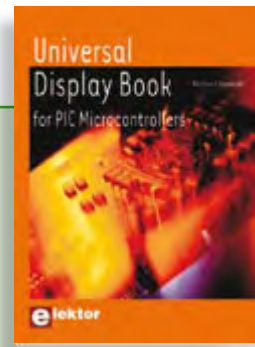
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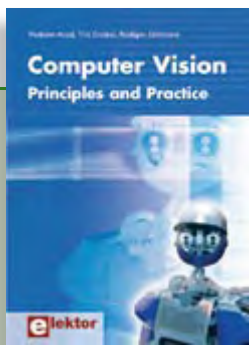
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5.0, 6.0, VBA, .NET, 2005

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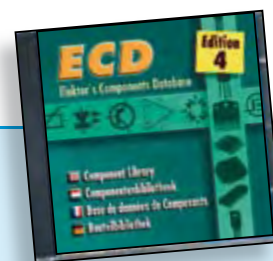


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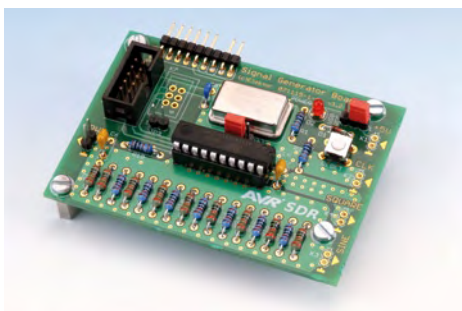
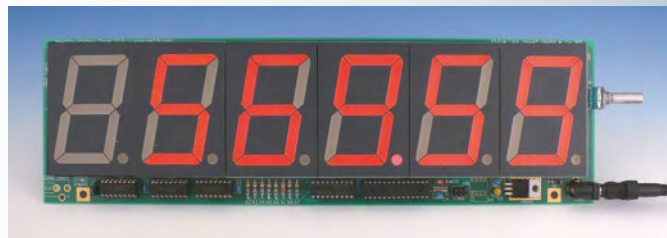


### Mini FM radio

Nowadays miniature FM radios are integrated into all sorts of devices, such as mobile phones and MP3 players. NXP has a very nice little IC in its product line for anyone who wants to build a simple DIY receiver: the TDA7021T. This is a 16-pin SMD, and we have designed a small PCB that makes it easier to put everything together. The full receiver measures only  $3.2 \times 2.7$  cm, but it delivers surprisingly good sound quality despite its compact size.

### Meeting cost meter

Especially in these troubled economic times, it's a good idea to avoid wasting money. In many companies, people are trying to work more efficiently in many different ways in order to keep costs (including labour costs) better under control. Long meetings, which can easily consume several hours of the working time of dozens of highly-paid employees, are notorious 'cost guzzlers'. In many cases, meetings can be conducted much more efficiently. To help you keep an eye on the actual meeting cost, we have designed a special meter that constantly shows the total cost of the meeting on a large display. The number of participants and their hourly rates can be set by a knob.



### Stand-alone SDR receiver

In order to receive digital radio broadcasts, you normally need a simple receiver board and a PC to perform the complex decoding operations. Although a few commercial stand-alone SDR receivers are available, the selection is limited and the quality is often only so-so. Starting with the January issue, we will publish a series of articles that show you how to build an SDR receiver using a computer system built around several AVR microcontroller ICs. This series also forms a sort of mini programming course for AVR microcontrollers. A true don't-miss feature!

Article titles and magazine contents subject to change, please check 'Magazine' on [www.elektor.com](http://www.elektor.com)

The January 2009 issue comes on sale on Thursday 18 December 2008 (UK distribution only). UK mainland subscribers will receive the issue between 13 and 16 December 2008.

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