Universal Square Wave Generator

Stable all the way up to RF

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A square wave generator is useful in a test environment, and often the harmonic content of a simple square wave signal is advantageous. With an ever widening range of specialized integrated circuits it is now a simple job to build a high quality generator without too much expense. Add to that a display to indicate the signal output frequency and amplitude, and you have a useful piece of test gear.

A universal signal generator is a useful addition to any workbench. They are ideal for squirting signals into electronic circuits and checking to see if the circuit behaves in the way you had anticipated. Of course for any generator it's useful to be able to select the frequency of interest and to adjust the output to give the appropriate signal level. For testing digital circuits it would also be useful to output a TTL compatible signal. All of these criteria are fulfilled with this design. With a potential frequency range extending from 10 kHz to 140 MHz its spectrum is so wide that it really does deserve the title 'universal'.

This universal square wave generator has a classic DC-free 50 Ω output adjustable from 0 V to approximately 1 V. In addition there is a digital TTL output with fixed amplitude. A two line LCD display indicates output frequency and amplitude. Power for the generator can be supplied from a standard AC/DC wall adapter.

Square wave generation

A crystal or ceramic resonator would normally be high up on a list of components you would first reach for to build a stable frequency generator. One disadvantage of this approach is that if you wanted it to produce more than just one fixed frequency it would be necessary to include programmable frequency dividers which would add considerably to the circuit complexity and expense. RC oscillators are a simple solution and can be made adjustable but their long term stability is not sufficient for many applications.

One solution to this dilemma is to use a specialist oscillator IC like the examples shown here from the IC manufacturer Linear Technology. There are two pin-compatible variants of this chip which cover different frequency bands. This has the advantage that by just swapping an IC the same circuit board can be used to make a signal generator which covers two frequency bands. Variant 'V1' fitted with an LTC1799 [1] provides an impressively wide range from 1 kHz up to 30 MHz. For pure RF use variant 'V2' using the LTC6905 [2] covers a range from 17 MHz to 170 MHz. The generators are adjustable and exhibit very low frequency drift.

The chip's output frequency is set by the value of resistance R_{set} between +5 V and pin 3. Pin 4 of the chip also provides access to an in-built frequency divider *N*. In variant V1 the divider has the value 1 (pin 4 to ground), 10 (pin 4 O/C) or 100 (pin 4 to +5 V). Variant V2 with the same levels on pin 4 divides the frequency by 1, 2 or 4.
The frequency output of the two variants is given by:

$$f_{V1} = \frac{10\ MHz \cdot 10\ k\Omega}{R_{set} \cdot N}$$

and

$$f_{V2} = \left(\frac{168.5\ MHz \cdot 10\ k\Omega}{R_{set}} + 1.5\ MHz \right) \cdot \frac{1}{N}$$

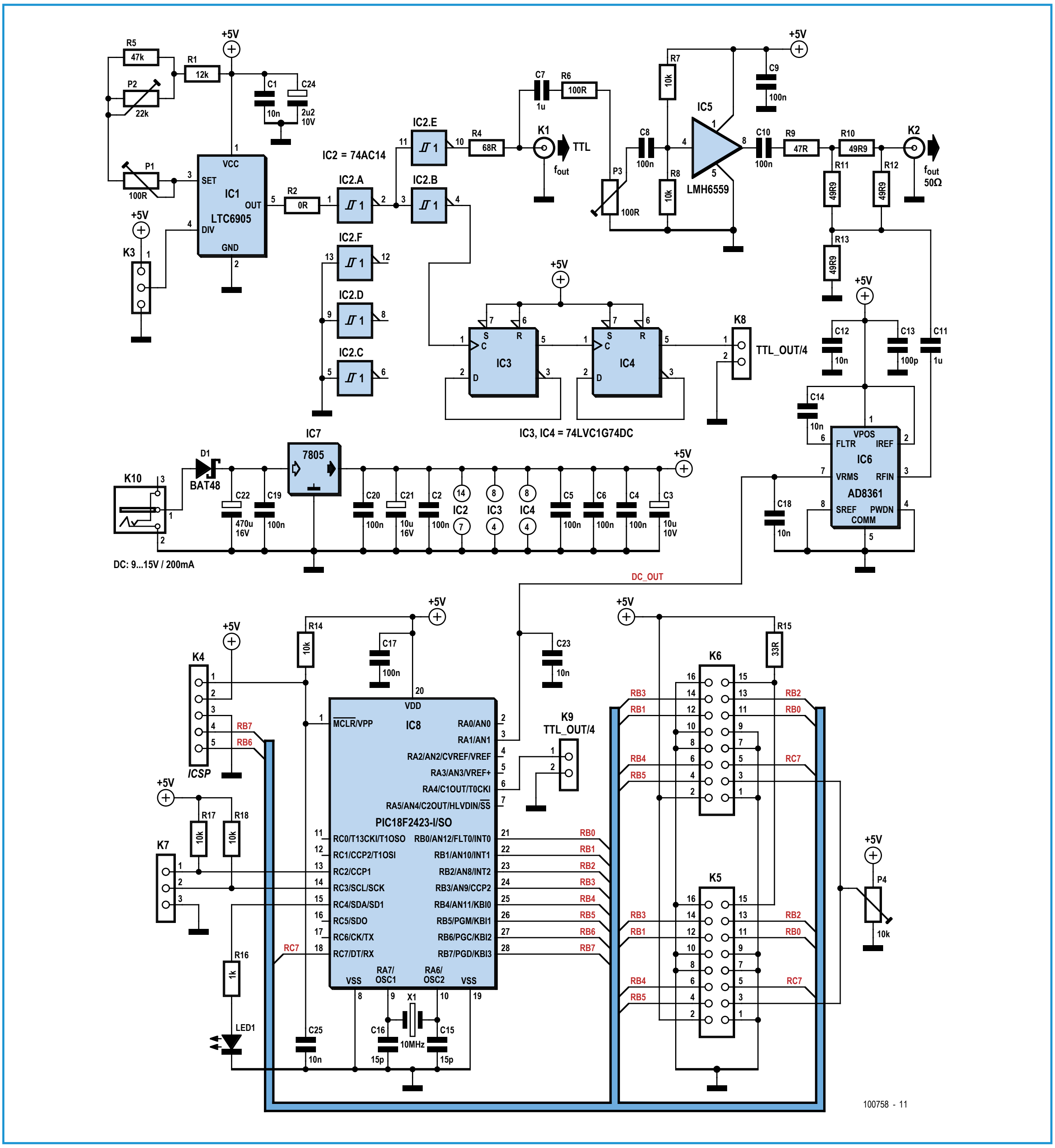


Figure 1.
The universal square wave circuit looks as complicated as it is: IC1 generates the signal, IC5 amplifies it and IC6 measures it.

For best stability V1 should not be used with *N* = 1 at frequencies below 0.5 MHz or above 20 MHz and for variant V2 not above 140 MHz.

The circuit

For simplicity the diagram in **Figure 1** shows the complete circuit for the variant V2. The three-way pin header K3 allows a jumper to select the division factor *N* as 1, 2 or 4. With *N* = 1 the values of P1, P2, R1 and R5 will give an output range between 64 MHz and 145 MHz. The binary dividers 1:2:4 produces three overlapping frequency bands. P1 allows fine frequency adjustment of a few percent. To change the circuit to variant 1 it will not only be necessary to swap IC1 for an LTC1799 but also both pots and resistors responsible for the value of R_{set}. Now using a 4.7 kΩ for R1, omitting R5 and using a value of 2.2 kΩ for P1 and 100 kΩ for P2 gives a frequency range (with N = 1) from 1 to 20 MHz which with the decimal divider 1:10:100 again provides three overlapping ranges. The components values for variant 1 are shown in brackets in the parts list.

The output signal from IC1 is now buffered by a gate of IC2. This TTL compatible signal is available at connector K1. It is also buffered by IC5 (a video amplifier with a gain of 1) to give a DC-free level 50 Ω impedance output from connector K3 adjustable (via P3) between 0 V and approximately 200 mV_{eff}. For the purposes of generating a signal the circuit description is now more or less complete. If we didn't go any further with the circuit then we would not know the frequency or amplitude of the generated or the signal without hooking up some test gear. To add these features we need a display and some electronics to measure the signal frequency and amplitude. We have used a PIC18F2423 (IC8) microcontroller for this task, it has an in-built frequency counter good for signals up to approximately 40 MHz. In addition it has a 12-bit A/D converter allowing an amplitude measurement of 0.2 mV_{HF}/bit.

To measure the output signal the microcontroller IC8 requires a little assistance. For variant V2 a frequency prescaler is required, which is not necessary for V1 (where it is bridged by a 0 Ω resistor). IC3 and IC4 together divide the signal frequency from IC1 by four. This allows the microcontroller to measure signals up to 160 MHz. The 100 ms gate period used to sample the frequency is indicated on LED1. The divided-down signal from IC4 is wired to the microcontroller input pin 6 using a short length of coax from K8 to K9.

The signal amplitude is sampled by the AD8361 which is a very linear high frequency RMS value detector producing a DC output voltage proportional to the RMS value of the measured signal.
A low level on pin 1 of K7 indicates variant 1 configuration to the controller while a high indicates variant 2. K7-2 input RC3 is available for your own use.

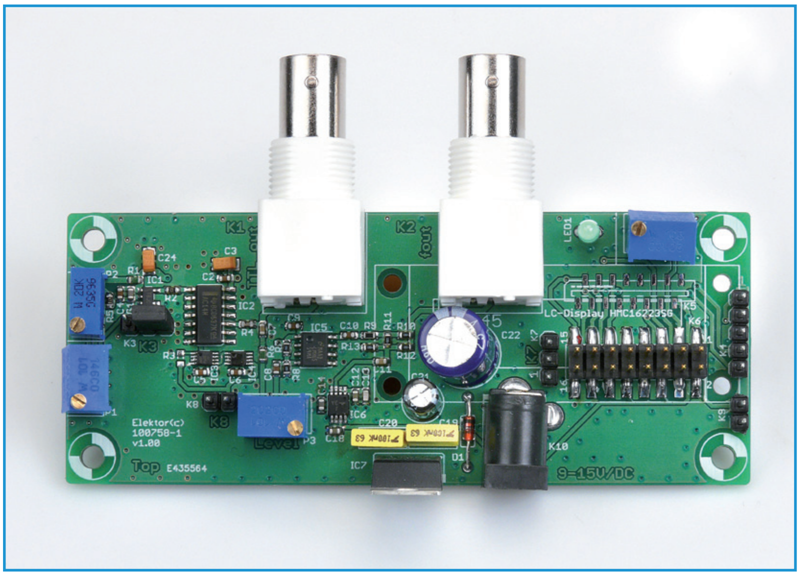


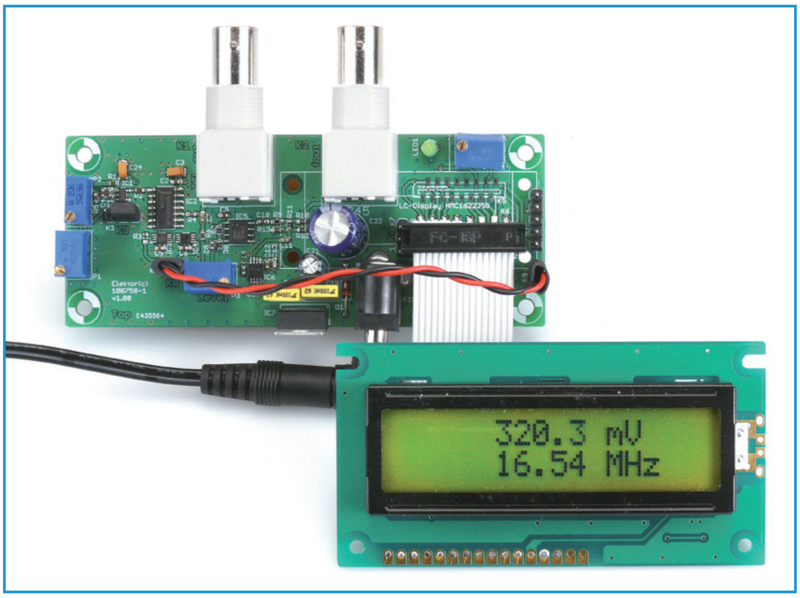
Figure 2.
SMD components mean that the finished design is neat and compact.

The Firmware

The firmware is, as usual available to download for free by going to the Elektor web page for this article [3]. It was developed using Microchip's free evaluation version of the C compiler MPLAB C18. The main features of the software can be summarized:

Timer0 counts the external clock pulses at input T0CKI. Timer1 generates an interrupt after 100 ms. In the corresponding interrupt service routine the counter register of Timer0 is read to give the measured frequency value. An A/D conversion is initiated to measure the output signal level. The frequency measure-

Figure 3.
The prototype generator with display.



Technical Data

A compact universal square wave generator with adjustable frequency and amplitude.

- Frequency range: V1 = 10 kHz to 20 MHz; V2 = 17 MHz to 145 MHz
- Divided into three bands:
  - V1: 10 to 200 kHz; 0.1 to 2 MHz and 1 to 20 MHz
  - V2: 17 to 36 MHz; 33 to 73 MHz and 64 to 145 MHz
- Frequency stability: V1 = ±40 ppm/K; V2 = ±20 ppm/K
- Output waveform: Square wave
- Mark/space ratio: 50 %
- Two BNC outputs:
  - K1: TTL compatible (5 V)
  - K2: Adjustable 0 to 200 mVeff into 50 Ω, DC free
- Display: Two-line LCD display showing signal frequency and amplitude.
- Power requirements: 9 V to 15 V, max. 200 mA

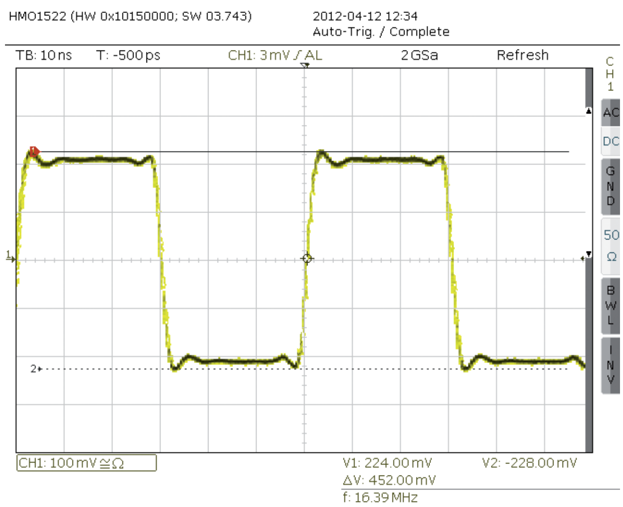


Figure 4.
The square wave output signal has a good shape at this frequency.

ment is then adjusted by a scale factor and together with the level (effective value) of the square wave signal, sent to the display. Once this is complete the timers are again loaded with their initial values and the process repeats.
The pin header K4 is included to allow the controller to be programmed. The microcontroller's memory has a useful amount of free space just waiting for your own improvements and modifications to be flashed to memory.

The assembly

As you can see in **Figure 2** it is possible to build a very compact and neat universal square wave generator thanks mainly to the use of small footprint SMD components. IC8 measures the frequency and amplitude of the generated signal and displays the values on a 2-line LCD.
When the LCD uses a flex-print connector like the HMC16223SG LCD assembly it can be attached over to the PCB using stand-off mounts and connected to K5. Alternatively **Figure 3** shows a standard 2 x 16 display

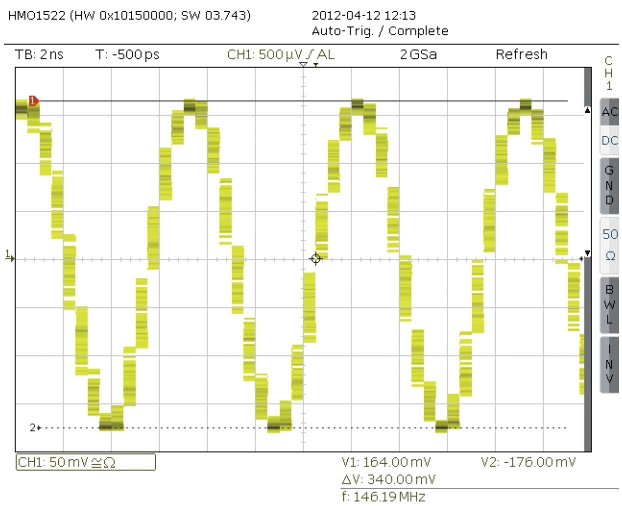


Figure 5.
At the upper frequency limit using variant V2 (at 143 MHz) the signal shape is not as ideal but is still quite useable for undemanding applications.

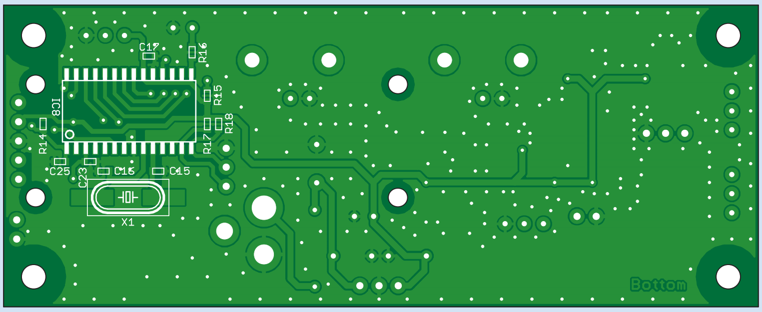
connected to pin header K6 using a flat band cable.

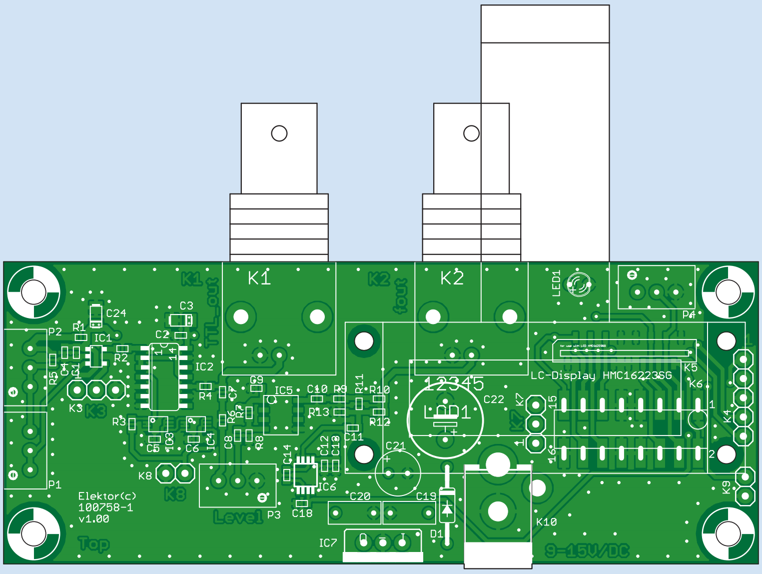
And finally...

A list of the main technical features of both variants is given in the text box. The two oscillograms shown in **Figure 4** and **Figure 5** are output signals from the prototype design of variant 2 at 16 MHz and 146 MHz. While the lower frequency trace shows a very respectable square wave the edges of the higher frequency trace are a little less well defined. This is only to be expected at this frequency and the signal is never the less still useful. It must also be considered that at this frequency in the VHF band it is difficult, even with an expensive scope to get a good representation of the signal.

Finally it's worth noting that despite the relatively low signal levels involved any flying leads connected to the outputs will act as

COMPONENT LIST





Values for V2 (V1 in brackets)

Resistors
Default shape: 0603
R1 = 12kΩ (4.7kΩ)
R2 = 0Ω
R3 = not fitted (0Ω, refer to PCB overlay)
R4 = 68Ω
R5 = 47kΩ (not fitted)
R6 = 100Ω
R7,R8,R14,R17,R18 = 10kΩ
R9 = 47Ω
R10,R11,R12,R13 = 49.9Ω
R15 = 33Ω
R16 = 1kΩ
P1 = 100Ω (2.2kΩ) 10-turn trimpot, vertical *
P2 = 22kΩ (100kΩ) 10-turn trimpot, vertical *
P3 = 100Ω 10-turn trimpot, vertical *
P4 = 10kΩ 10-turn trimpot, vertical *

Capacitors
Default shape: 0603
C1,C12,C14,C18,C23,C25 = 10nF, X7R
C2,C4,C5,C6,C8,C9,C10,C17 = 100nF, X7R
C3 = 10µF 10V, tantalum, Type A
C7,C11 = 1µF, X5R
C13 = 100pF, NP0
C15,C16 = 15pF, NP0
C19,C20 = 100nF, MKT, 5mm pitch
C21 = 10µF 16V, electrolytic, 2.5mm pitch, 6mm diam.
C22 = 470µF 16V, electrolytic, 5mm lead pitch, 10mm diam.
C24 = 2.2µF 10V, tantalum, Type A

Semiconductors
D1 = BAT48, DO-35
IC1 = LTC6905CS5 (LTC1799CS5), TSOT-23-5 case
IC2 = CD74AC14M96G4, SO-14 case
IC3,IC4 = 74LVC1G74DC (not fitted), VSSOP-8 case
IC5 = LMH6559/MA, SO-8 case
IC6 = AD8361ARMZ, MSOP-8 case
IC7 = LM7805, TO-220 case
IC8 = PIC18F2423-I/SO, SOICW-28, programmed, Elektor # 100758-41
LED1 = LED, green, 3mm

Miscellaneous
K1,K2 = BNC socket, PCB mount, right angled, TE connectivity 1-1337543-0
K3,K7 = 3-pin pinheader, 0.1'' pitch
K4 = 5-pin pinheader, 0.1'' pitch
K5 = 16-pin FFC socket, SMD, 1mm pitch, MOLEX 670-6934 *
K6 = 16-pin (2x8) DIL pinheader, 0.1'' pitch *
K8,K9 = 2-pin pinheader, 0.1'' pitch
K10 = wall adapter socket, PCB mount, 2.1mm
X1 = 10MHz quartz crystal, HC49/SMD
LCD, Pollin type HMC16223SG or Elektor # 120061-71 *
PCB # 100758-1

* see text

antennae. Unshielded, un-terminated connections at the TTL output in particular will splatter in the RF bands.

Proper full size pots and an enclosure can be used in place of the presets to make the unit look more professional but be aware that all such wiring must be kept as short as possible otherwise the unit's performance will suffer. This applies to both variants. Pin 3 of IC1 is particularly sensitive to any form of interference. A frequency band selector switch can also be mounted on a front panel instead of the PCB jumper position K3; in this case it will only be necessary to bring out a single wire from the center pin of K3. Pin 4 of IC1 is not as sensitive to interference as pin 3.

As we already mentioned the firmware is available from the web page [3] but that's not all; a bare PCB can also be ordered, as well as a pre-programmed microcontroller and a suitable 2-line LCD display module. Power for the unit can be supplied from a standard wall-wart adapter. There is no requirement for the supply voltage to be stabilized.

(100758)

Internet Links

[1] www.linear.com/product/LTC1799

[2] www.linear.com/product/LTC6905

[3] www.elektor-magazine.com/100758

The Author

Kai Riedel works as a design engineer at a company by the name of Turck in Beierfeld, Germany. He has always had a fascination with all things electronic. His specialty is in the design of test and measurement equipment incorporating microcontrollers, experimenting with RF technology and repairing diverse electrical equipment. He likes to spend his free time playing pianos and church organs.