The *Elektor* DSP radio

DSP world receiver with USB interface

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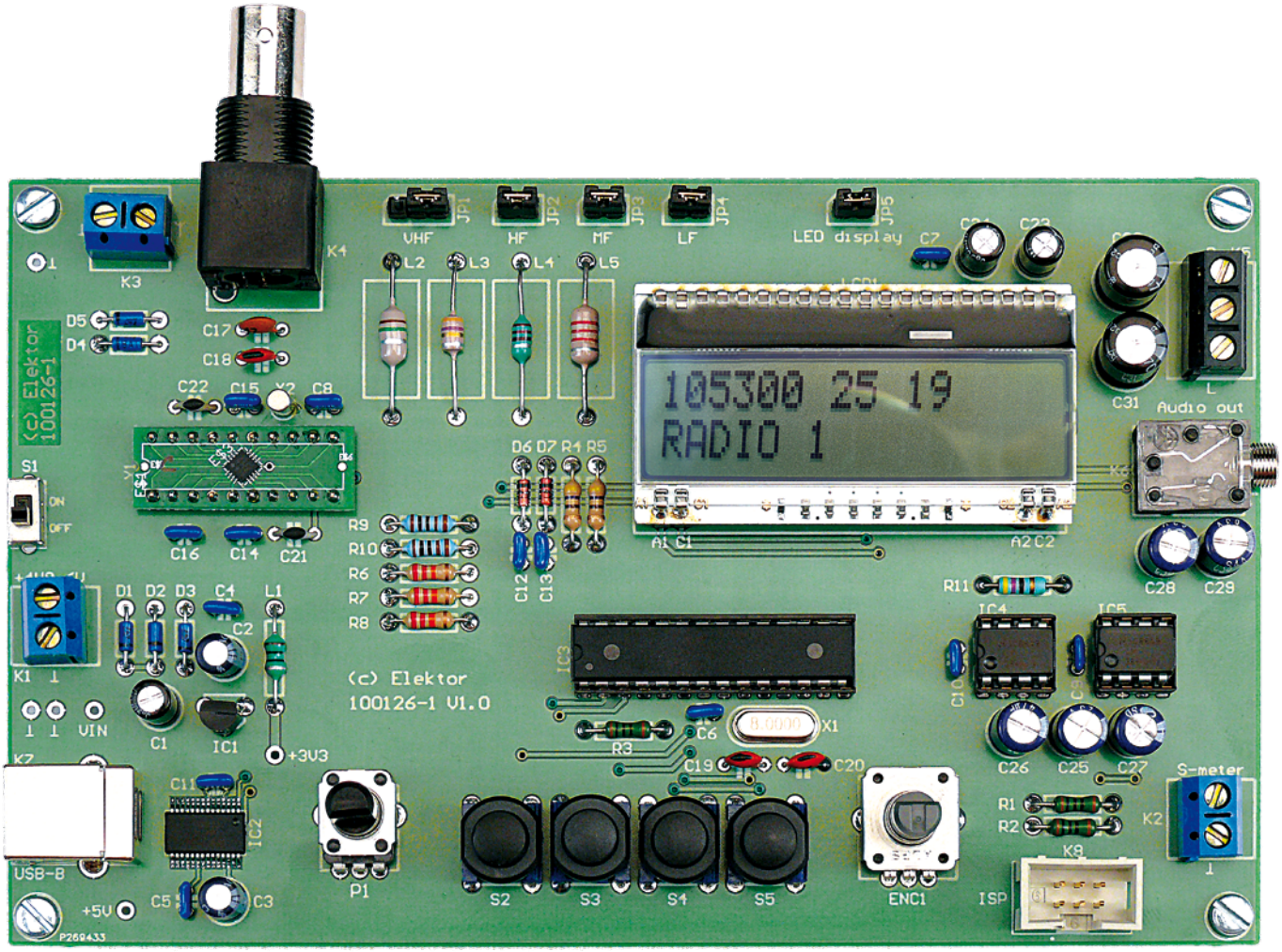

A world receiver that needs no set-up adjustments? It's possible using DSP technology. All the main functions are done in a Si4735 DSP radio IC measuring just 3 mm by 3 mm, with the help of an LCD-based user interface, a stereo audio amplifier and an interface that allows the receiver optionally to be controlled from a PC.

Many radio amateurs in practice use two receivers, one portable and the other a fixed receiver with a PC control facility. The Elektor DSP radio can operate in either capacity, with a USB interface giving the option of PC control. An additional feature of the USB interface is that it can be used as the source of power for the receiver, the audio output being connected to the PC's powered speakers. To allow portable 6 V battery operation the circuit also provides for an audio amplifier with one or two loudspeakers.

Features

Any radio receiver worth its salt should of course offer high-quality FM reception, preferably in stereo and with RDS station information display. The proof of the radio is in the hearing, and this receiver will not disappoint: it has very high FM sensitivity and sound quality. The Si4735 device that we use, unlike its less sophisticated sibling the Si4734, includes an RDS decoder. The Si4734 has recently been finding its way into an increasing number of portable radios.
The second requirement of a world receiver is that it should be able to tune in to distant

Features

- no set-up adjustments required
- Si4735 DSP receiver IC
- ATmega168 microcontroller
- USB interface using FT232R
- backlit 2 x 16 LCD panel
- battery voltage 4.8 to 6 V
- current consumption approximately 50 mA
- 3.3 V internal power supply
- power from PC over USB interface
- stereo audio output
- stereo audio amplifier (2 x LM386)
- RDS display
- AM from 153 kHz to 21.85 MHz
- automatic station search
- antenna signal strength indication in dBµV
- signal strength meter connection
- diode switching of AM band
- automatic tuning of AM resonant circuit
- switchable AM bandwidth
- optional PC control over USB
- tuning using rotary encoder
- four control pushbuttons
- station memory (30 AM presets and 30 FM presets)
- open-source firmware (free download)
- in-system programming interface
- printed circuit board available ready-populated and tested*

* see http://www.elektor.com/100126 and the Elektor shop pages at the back of this issue

AM transmitters. Here the receiver is in a class of its own, offering excellent shortwave reception. In particular it has very good sensitivity in the presence of strong nearby interfering signals, which allows the use of longer antennas. A highly effective automatic level control system brings the signal level into the optimal range, to the point where it can often be difficult to distinguish different antennas. Selectivity is also very high, and the receiver bandwidth can be adjusted in several steps, a feature previously reserved for only the most expensive equipment.

The DSP radio is also capable of receiving mediumwave and longwave signals, with the external antenna input allowing the connection of antennas for any frequency range. If a simple whip or other indoor antenna is used, it will often the the case that too much wide-band interference will be picked up. An alternative is the (optional) connection of a ferrite antenna.

SSB and DRM reception are, unfortunately, not possible. This is a result of the receiver structure. The radio IC uses an homodyne (that is, zero intermediate frequency) IQ mixer with configurable DSP-based filters and demodulator (**Figure 1**). For tuning a PLL is initially activated, and then the receiver locks on to the carrier of the AM signal.

The circuit

The circuit of the receiver (**Figure 2**) does not look, at first sight, much like a traditional RF design. This is because all the important functions are integrated into the Si4735. Only the antenna connection betrays the RF nature of the circuit: the antenna signal arrives at BNC socket K4 or at screw terminals K3 and passes through a diode limiter comprising D4 and D5. L2 is an FM coil with an inductance of 0.1 µH. In normal operation jumper JP1 is set to bridge pins 2 and 3, which connects the end of the FM coil to the AM input.

What is not visible from the circuit diagram is that in FM mode the receiver sets its internal AM 'variable capacitor' to 500 pF, which, as far as RF is concerned, shorts the end of the FM coil to ground. In AM mode, however, the signal from the antenna passes via L2, which now acts to increase the effective antenna length, to the AM resonant circuit comprising L3, L4, L5 and the automatically tuned 'variable capacitor' inside the Si4735 at pin 4 (AMI). Which of the fixed inductances is actually used is determined by IC3 using the switching circuit comprising 1N4148 diodes D6 and D7, which can effectively short a selected part of the inductance in the circuit to ground. In normal use jumpers JP2, JP3 and JP4 are closed; opening these jumpers allows the connection of alternative antenna input circuits or of a ferrite antenna. For example, a mediumwave ferrite antenna can be connected at JP3 or a shortwave loop antenna at JP2. If a whip antenna is to be used for FM reception only, set JP1 to bridge pins 1 and 2.

The stereo audio output of the Si4735 is taken to a stereo jack socket via C28 and C29, for connection to an external amplifier or powered speakers. The output is short-circuit proof, with an output impedance of 10 kΩ and an amplitude of about 80 mV_{eff}. Two LM386 ICs are also provided as a power amplifier, with loudspeakers connected at K5. The maximum output power into 8 Ω is around 300 mW. Surprisingly there is no stereo volume control potentiometer in the

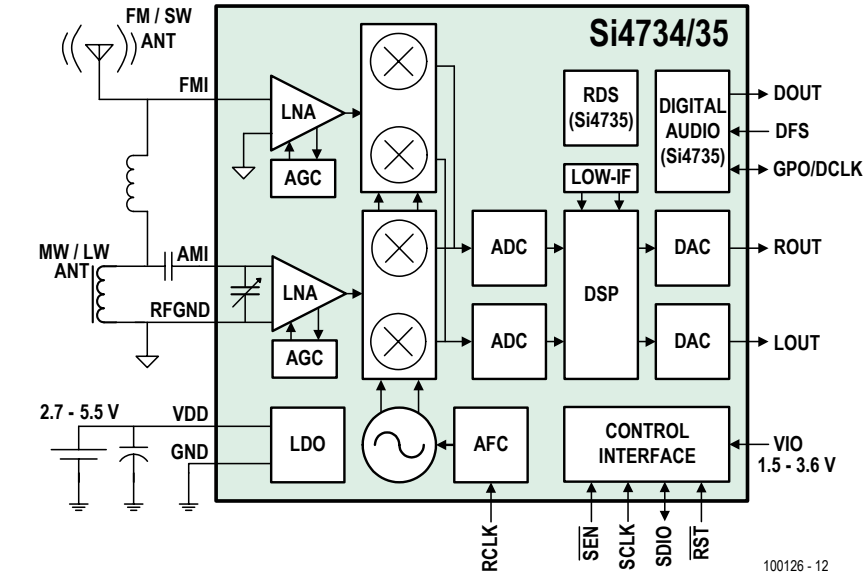

Figure 1. Block diagram of the Si4735 DSP radio IC (courtesy http://www.silabs.com)

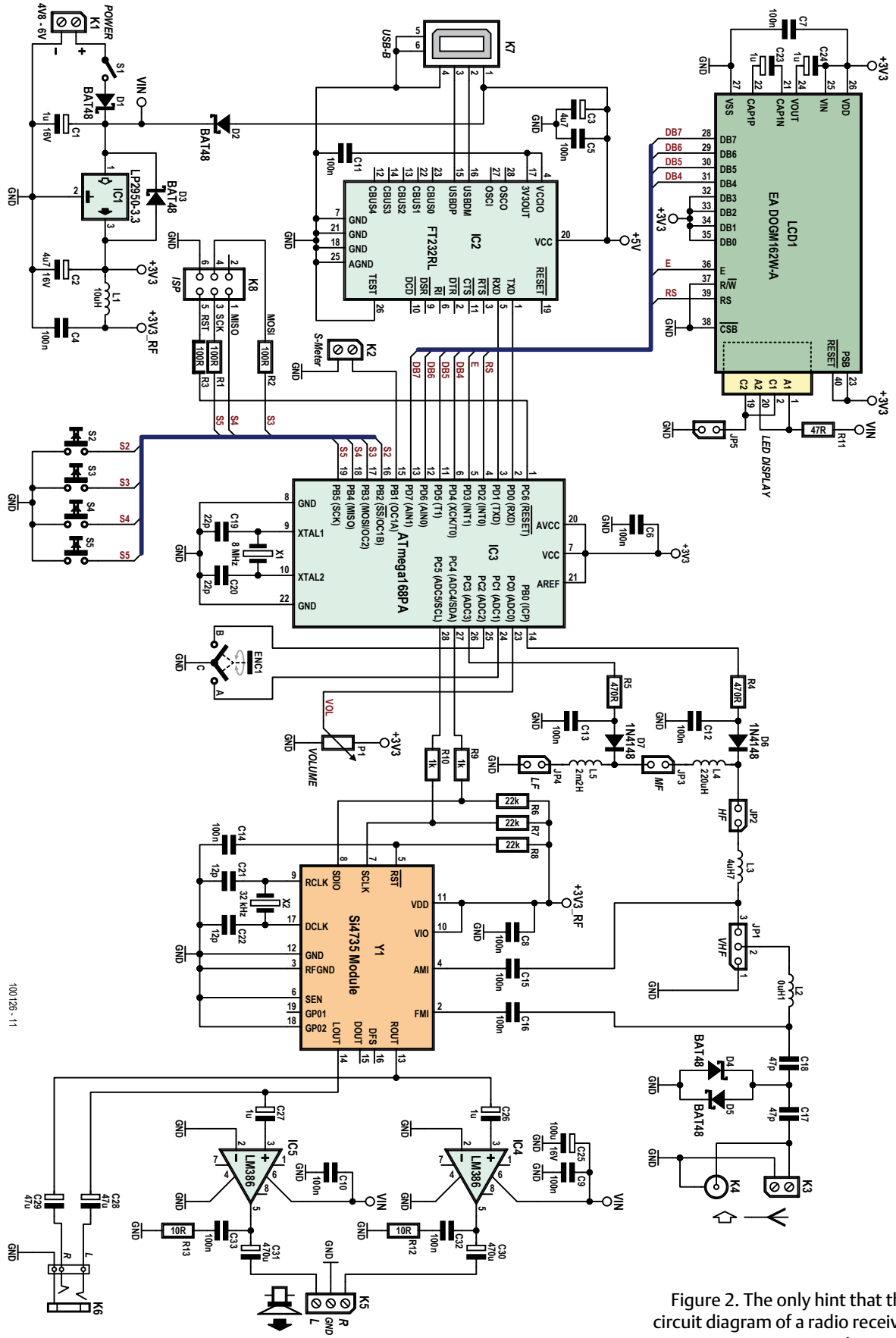

Figure 2. The only hint that this is the circuit diagram of a radio receiver is the antenna input circuitry.

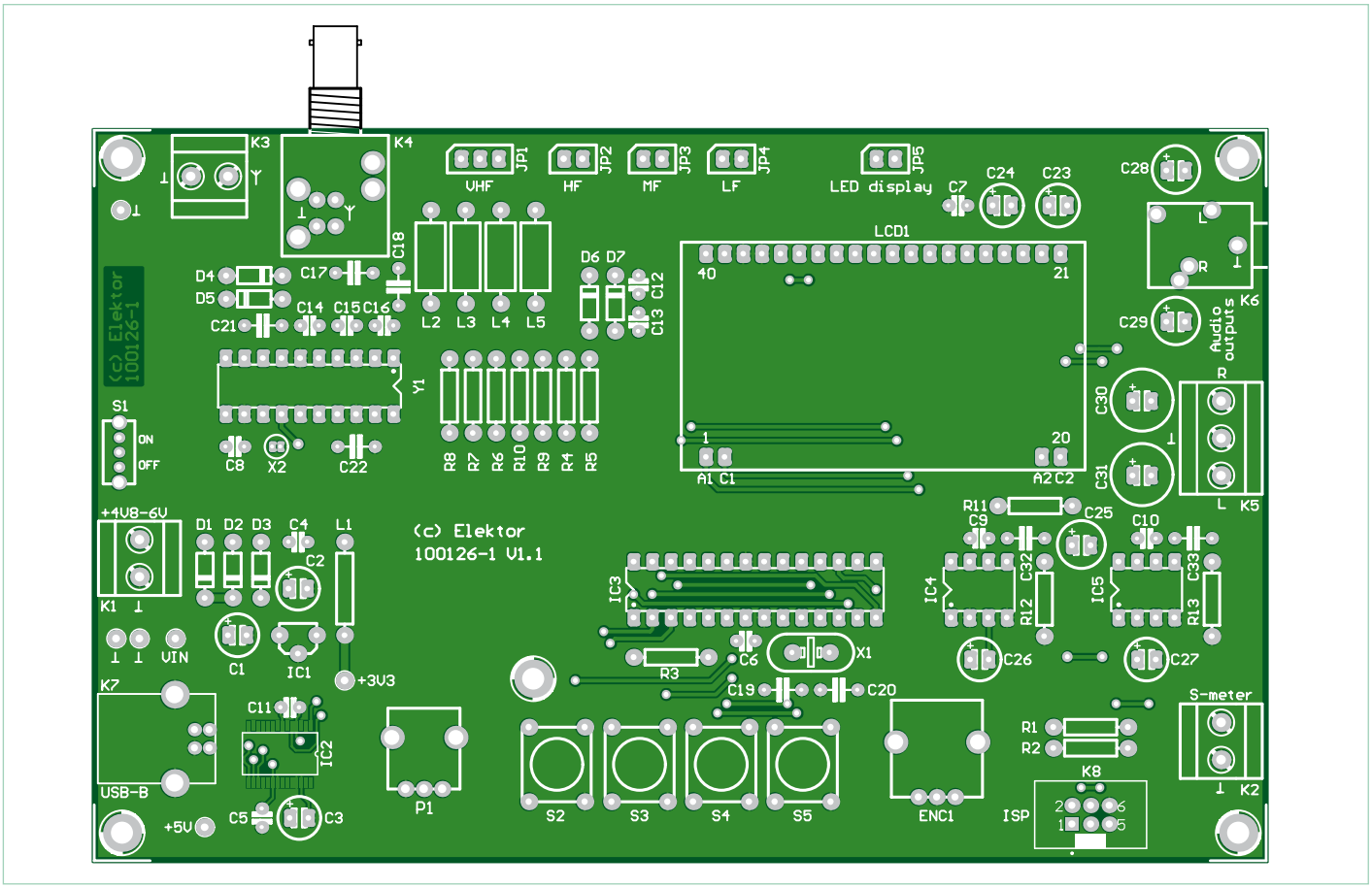

Figure 3. The printed circuit board is Eurocard-sized. All user controls are mounted on the top side of the board for convenience.
Gegenüber dem Labormuster auf den Fotos wurden noch einige Bauteilpositionen geändert.

circuit: this, and all other functions of the Si4735 are controlled by microcontroller IC3 (an ATmega168) in software over the SDA and SCL I²C bus signals. The microcontroller reads a voltage from (linear) potentiometer P1 using analogue input ADC0 and translates this into the appropriate commands for the Si4735. The tuning control is implemented as a rotary encoder (ENC1) connected to two port input bits. Pushbuttons S2 to S5 comprise the remaining user controls: their function will be described in detail below. Finally, a PWM output is provided for connection of a signal strength meter, taking the form of a 500 Hz square-wave with a variable mark-space ratio. The average output voltage varies between 0 V and 3.3 V, and almost any meter with a full-scale deflection of up to 1 mA can be connected using a suitable series resistor.

The ATmega168 is clocked at 8 MHz. This clock is independent of the reference in the receiver, which is derived from a dedicated 32.768 kHz watch crystal.

There are three alternatives for powering the radio: over the USB connection, using

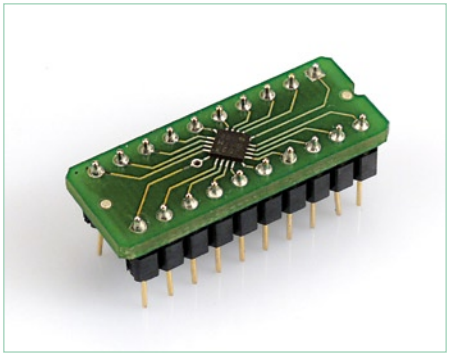

Figure 4. The Si4735 module consists of a daughter board with the DSP IC mounted on it.

a 6 V mains adaptor, or from a four-cell battery pack (4.8 V to 6 V). The voltage at V_{IN} directly powers the two LM386 ICs and the LCD backlight, and also forms the input to voltage regulator IC1 (an LP2950-3.3) which provides the regulated 3.3 V supply for the radio IC, the microcontroller and the LCD. Power switch S1 only controls power from K1 (from a battery or mains adaptor): USB power is not switched. Power can be saved by removing JP5, which will turn off the LCD backlight: the display is perfectly legible in ambient light. The receiver will work without problems with a battery voltage as low as 4.0 V. This, together with the relatively low current consumption of 50 mA, means that the circuit will give good battery life.

Populating the board

The Eurocard format (100 mm by 160 mm) printed circuit board (**Figure 3**) is designed to be built into an enclosure along with loudspeaker and battery holder. All the controls are located on the top surface of the board. If it is important that no components hang over the edge of the board, do not fit BNC socket K4 and audio socket K6. The printed circuit board is available ready-assembled and tested in this form from the *Elektor* shop (order code 100126-91: see the pages at the back of this issue). The layout and parts list are available for download from the *Elektor* web pages for this project [1], and the unpopulated board (order code 100126-

Table 1. The most important terminal commands (38400 baud)	
f5955 <Enter>	tune to 5955 kHz AM
f102800 <Enter>	tune to 102.8 MHz FM
m5 <Enter> 6075 <Enter> DW <Enter>	store AM preset 5: 6075 kHz, label 'DW'
n3 <Enter> 95100 <Enter>	store FM preset 3: 95.1 MHz
p9 <Enter> 1 <Enter>	AM de-emphasis on
p10 <Enter> 0 <Enter>	set AM bandwidth to 6 kHz
p10 <Enter> 1 <Enter>	set AM bandwidth to 4 kHz
p10 <Enter> 2 <Enter>	set AM bandwidth to 3 kHz
p10 <Enter> 3 <Enter>	set AM bandwidth to 2 kHz
p10 <Enter> 4 <Enter>	set AM bandwidth to 1 kHz
p13 <Enter> 0 <Enter>	disable AM soft mute

1) can also be ordered on-line. Ready-programmed microcontrollers (100126-41) and the Si4735 module shown in **Figure 4** (090740-71) are also separately available from the *Elektor* shop, and so if you wish you can populate the main board yourself. Start with IC2, the FT232RL: a little experience in soldering SMD ICs will be useful here. Then fit the USB socket and connect the board to a PC for testing. If the USB interface IC is recognised by the PC, then you have cleared the first hurdle.

The two pin headers have to be soldered to the Si4735 module so that it can be fitted into a normal IC socket.
When assembling the LCD, note that the backlight board must first be soldered in under the LCD panel itself. Then the assembled LCD module can be mounted in a header socket to increase its height above the main board.
The other components should present no problems to anyone with a little experience with a soldering iron. It hardly needs saying that you must of course observe the correct polarity when fitting the electrolytic capacitors and diodes.

Powering up

If you have not previously used an FT232R with your PC, you will first need to install a driver. Run the program CDM_Setup.exe, part of the software download available at [1], and then connect the radio to the PC using a USB cable. When the radio is first connected the driver will be loaded and a COM port allocated. If a connection has already been made several times with the same device, a high COM port number will be allocated. In this case it can be worth using the Windows device manager to change the port number, for example to COM2. To rename a port open the device properties with a double click on the relevant device; go to the 'Port Setting' tab, and then the COM port number will be found under the advanced settings. Change this to the desired value (even if marked as 'in use') and then click on 'OK' to put the new setting into effect. A warning may appear that the double allocation of the interface may lead to problems: confirm that you do indeed wish to use the new setting. The new COM port number will not immediately appear in the device manager, but it will appear of you close the device manager and then re-open it.

Figure 5. The display shows the currently tuned frequency, the signal strength at the antenna in dBµV, and the signal-to-noise ratio (SNR) in dB. When receiving an FM station the lower line of the display shows the RDS station identifier and time of day.

For the first test of the receiver you will need a short length of wire, about half a metre, to use as an antenna. After applying power (or plugging in the USB cable), the message 'Elektor DSPradio' should appear on the upper line of the LCD panel. The receiver will then automatically search for the first station in the FM band, starting at a frequency of 87.5 MHz. It is possible that a signal will be detected at 88.0 MHz, which is the eleventh harmonic of the microcontroller crystal frequency (eleven times 8 MHz). However, this will be rejected immediately, and the search will proceed to the next frequency. The display indicates the frequency of any station found in the format '88300' (meaning 88.3 MHz); immediately next to the frequency the display (**Figure 5**) shows the signal strength at the antenna in dBµV and the signal-to-noise ratio, or SNR, in dB. The signal strength meter will also be driven: for testing purposes, a voltmeter can be connected at K2. The maximum input level of 80 dBµV will give an output voltage at K2 of 3.3 V. For permanent display connect an analogue voltmeter or a moving-coil meter with a suitable series resistor to K2.

After a brief pause the lower row of the LCD panel will show the RDS station identification string; shortly after that, the time of day as transmitted by the station. The potentiometer allows the output volume

to be adjusted, and the output is simultaneously present on the audio jack socket and at the loudspeaker outputs. Turning the rotary encoder will tune the radio over the whole of the FM band to pick up other stations. The four buttons allow manual access to a range of functions such as station search, AM band selection and preset storage.

DSPradio: a user's manual

By default the radio starts up in the FM band. Using button S3 you can switch to the AM band, and S2 returns to the FM band. S4 starts an automatic station search, and finally S5 is used to store stations in the microcontroller's internal EEPROM. The radio uses standard predefined frequency bands, although with manual tuning or with the automatic station search it is possible to tune to frequencies beyond the ranges normally associated with these bands. The lowest frequency in each band is as follows:

Longwave: 153 kHz
Mediumwave: 549 kHz
75 m band: 3965 kHz
49 m band: 5800 kHz
41 m band: 7200 kHz
31 m band: 9400 kHz
25 m band: 11600 kHz
22 m band: 13550 kHz
19 m band: 15150 kHz
16 m band: 17400 kHz
FM: 87.5 MHz

Firmware and PC control

It is almost inevitable that when you have used a device for a while, there are things you wish you could change in its user interface. In this case it is possible: the underlying program, written using BASCOM, is available in source code and as a hex file from the *Elektor* pages for this project [1], and there is a connector on the printed circuit board to allow in-circuit programming of the ATmega168. So there is no reason why you should not modify the firmware yourself. If that is not your cup of tea, there is also a wide range of options for controlling the radio over its USB port: in most cases all you need is a simple terminal emulator program, although you could also develop your own program on the PC side to interact with the radio in more sophisticated ways.

Communication over the virtual COM port runs at 38.4 kbaud. **Table 1** gives an overview of the most important commands available for configuring and tuning the receiver from the PC. Among the options are configuring bandwidth, de-emphasis and soft muting, and storing frequencies and station names in the radio's preset memory.

In the next issue we will look at more advanced antenna configurations and go into more detail regarding the features and subroutines in the radio's firmware, including suggestions for developing PC-based control software to gain access to the various features of the Si4735 as well as direct control of the LCD panel.

So, as you can see, the *Elektor* DSP radio is no common-or-garden world receiver. Using PC-based software it is possible to add features that were not even thought of when the radio was designed, and, thanks to its open-source firmware and in-circuit programming facility, any keen developer can create his or her own style of user interface.

(100126)

[1] www.elektor.com/100126
(project pages including parts list, downloads and other additional information)

In detail, the pushbuttons function as follows:

S2: Switch to FM band/automatic search. A brief press starts an automatic station search with increasing frequency; a longer press (more than 0.5 seconds) starts a decreasing-frequency search.

S3: Switch to AM mode and select between longwave and 16 m shortwave bands. In each case the radio tunes to the lowest frequency in the band. A brief press switches to the next higher band, while a longer press selects the next lower band. If S3 and S2 are used to switch between AM and FM, the previously-tuned station will be remembered and tuned to. This allows easy switching between a local FM broadcaster and a distant AM broadcaster.

S4: AM automatic search. With a brief press, search in the direction of increasing frequency; with a longer press, in the direction of decreasing frequency. The automatic search will not stop at the end of a frequency band. The display is continuously updated with the current frequency; if a sufficiently strong station is found the search will stop, the display showing the station frequency, signal strength and SNR. Also, the capacitance in the tuner circuit (in picofarads) will be shown in the upper right of the display. If no station is found, the search can be stopped by turning the rotary encoder (which switches to manual tuning) or by selecting a new AM band.

S5: Station preset. Up to thirty FM presets and thirty AM station presets can be stored. A brief press of the button stores the currently-tuned station as a preset, and the number of the new preset memory appears on the display, for example as 'M25'. A longer button press allows you to select which preset memory is to be recalled by turning the rotary encoder. Preset recall mode is exited by pressing S2, S3 or S4, or by a further press of S5. A very long press (more than two seconds) transfers all preset stations to EEPROM, from where they can be reloaded at next power-up. After you have been using the radio for some time, it is possible that you will have accumulated a large number of presets, not all of which will still be useful. The preset memory can be cleared by holding down S5 for two seconds while power is switched on to the radio.
Using a terminal emulator program you can associate a text label with each AM station, for example giving its name, that will be shown in the lower row of the display.