GBPLC – GameB

use a Nintendo GameBoy as a programmable logic controller for home automation

Sascha Koths & Stephan Ruloff,
in collaboration with Christian Müller

Home automation tasks – ranging from controlling roller shutters and awnings to alarm systems – can be handled nicely by small programmable logic controllers (PLCs). Here we present a very attractive approach that is convenient and inexpensive: the GBPLC, a PLC based on the Nintendo GameBoy. Ready-assembled and tested boards are available!

The key to this GameBoy transformation, like that of the legendary *Elektor Electronics* GameBoy oscilloscope (GBDSO), consists of a plug-in card with memory ICs for the application software and an I²C interface for communication with the outside world, but without its own processor. That allows the PLC to be programmed directly with the GameBoy (via a menu-driven interface) or indirectly using a program running under Windows on a PC connected to the module.

Here we describe the hardware of the GameBoy module and briefly sketch the structure and features of the software, which also includes ready-made sample applications. The associated I/O switching module ('I²C I/O box') is described in a separate article in this issue.

Overview

Among mass-produced game computers, the various models of the Nintendo GameBoy are not only the least expensive to acquire (via eBay, for example), but also the best documented. The standard model, with hardware built around a Z80-derivative microprocessor, can be programmed directly in C. A development environment tailored to this hardware is available free of charge on the Internet. With its microprocessor system, graphic LC display, serial interface and handy packaging, the GameBoy is a quite suitable for use as a platform for a programmable controller.

All GameBoy models based on the original ('classic') version (GameBoy, GameBoy Pocket, GameBoy Light, GameBoy Color, GameBoy Advance,

Boy PLC

Table 1.
GBPLC Module Features

- Available as a ready-assembled and tested PCB
- Load, delete and store up to 8 'logic programs'
- Disable under password control
- Program simulation
- Programming and simulation also possible in battery-powered mode
- Standard logic functions (AND, OR, NOT, XOR, SR)
- Two timers
- Two timing functions
- 64 flags
- Analogue comparator (less than, equal, greater than)
- Rising and falling ramps on analogue output
- PLC cycle time less than 500 ms
- Input and output names can be assigned freely in the software
- Names can be assigned to logic programs
- Run and Stop modes
- Log file can be viewed on the display
- Battery-backed real-time clock
- EEPROM for data storage
- Most recently loaded (active) logic program starts automatically after switch-on

Table 2.
GBPLC I2C I/O Box Features

- Available as a ready-assembled and tested PCB
- 8 digital inputs (for potential-free contacts)
- 8 digital outputs (relay or transistor)
- 4 analogue inputs (8-bit resolution)
- 1 analogue output (8-bit resolution)
- Inputs can be simulated by connecting pushbutton switches to the I/O box
- Socket for optional I2C SMS chip (with connector for Siemens S25 or C35i mobile phone)
- Port for linking to a Siemens S25 or C35i mobile phone
- All switch states can be indicated by connecting LEDs

Figure 1. Suitable GameBoy models. The unit in the centre is the GBPLC I²C I/O Box, which drives the GameBoy fitted with a GBPLC module.

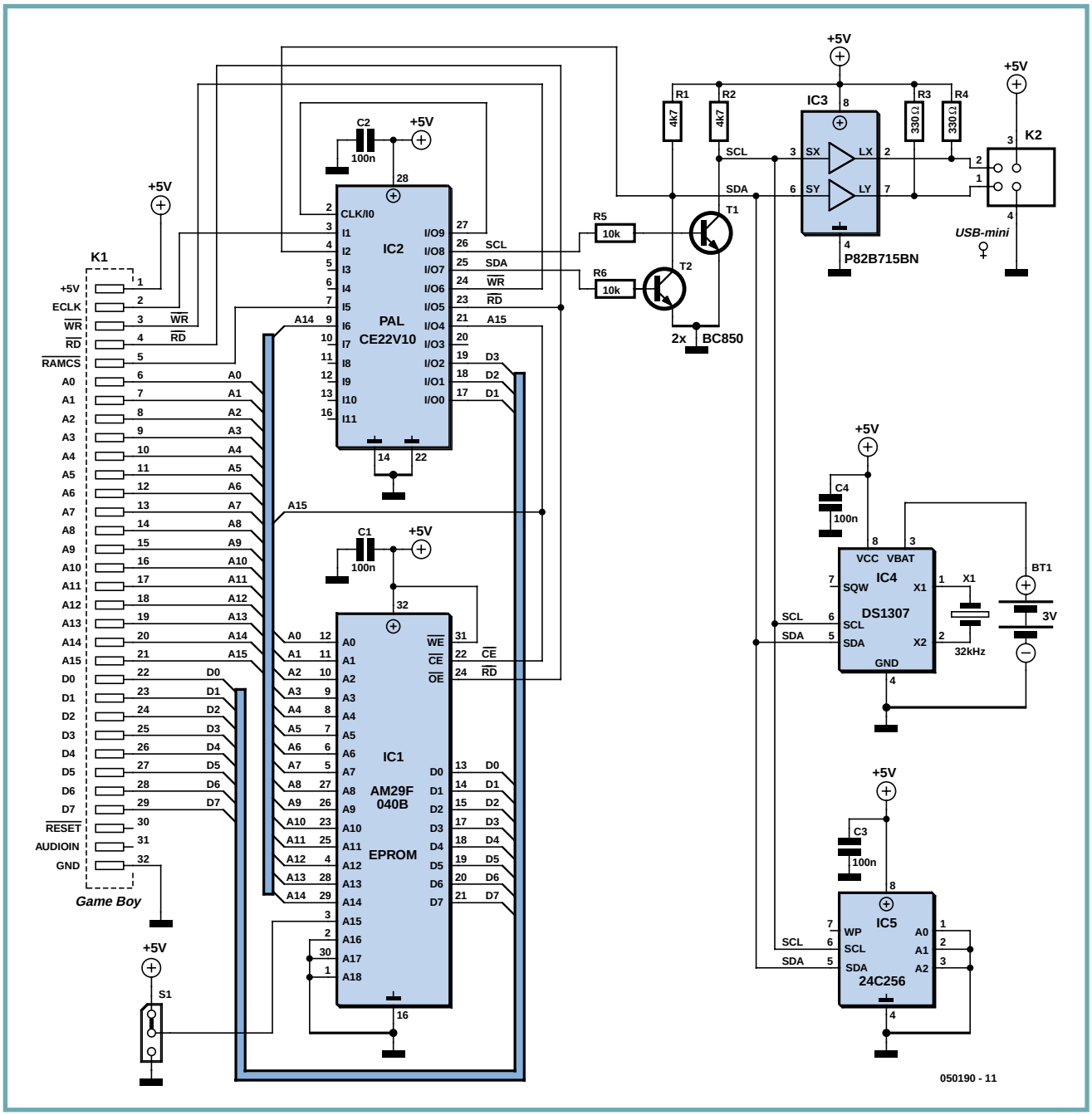


Figure 2. Schematic diagram of the GBPLC module, which transforms the Nintendo GameBoy into an easily programmed PLC.

and GameBoy Advance SP) are suitable for this project. **Figure 1** shows a few examples. The Nintendo DS and DS Lite (which actually do not belong to the GameBoy family) and the GameBoy Micro are **not suitable.**

The core of the system consists of the GBPLC module, which is inserted into the bay on the back of the GameBoy instead of the usual game cassette (ROM cartridge). This module consists primarily of memory: a flash EEPROM for the firmware and an I²C EEPROM for the display messages and the PLC data, which constitutes the PLC application programs (also referred to as the 'logic programs' in the rest of this article). The I²C EEPROM allows data to be exchanged between the GameBoy and a PC application running under Windows. The GBPLC module has an I²C interface that can be connected to all types of commonly used PC ports (serial, parallel or USB) using suitable adapters.

Table 1 lists the key features of the GBPLC module. The PLC program can be generated on a PC using a convenient Windows-based program. The PC software can also run real-time simulations and exchange program code and data with the GameBoy. If necessary, PLC programs can also be generated, modified and simulated directly on the GameBoy. Up to eight PLC program sequences ('logic programs') can be stored in the GBPLC module, from which they can be individually retrieved and run. The data read in by the application can be shown on the GameBoy display as a log file and read out from the GBPLC module to the PC.

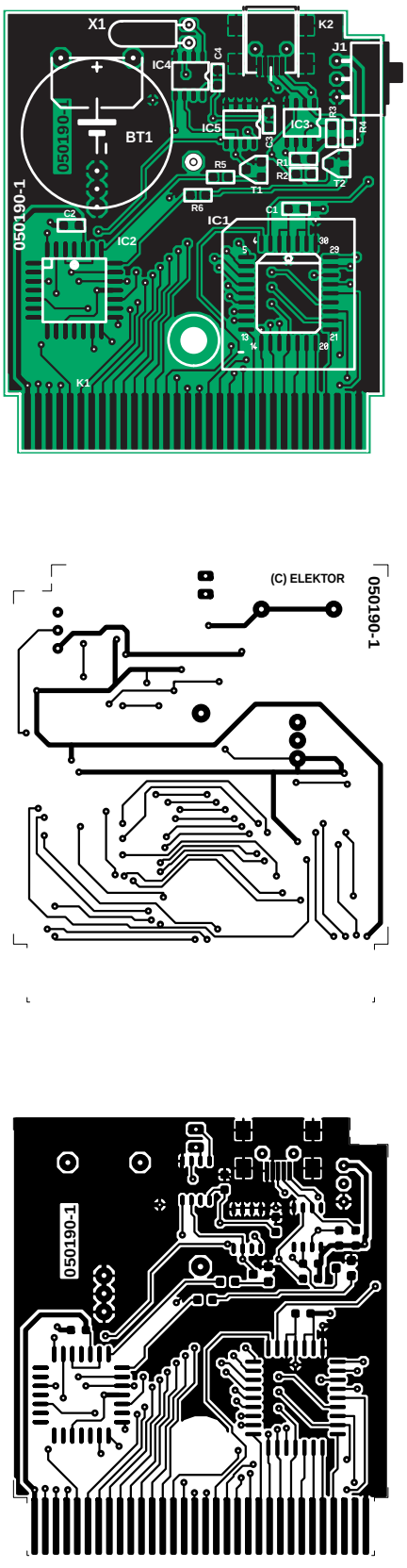


Figure 3. **The double-sided, through-hole plated printed circuit board of the GBPLC module, which is assembled using SMDs. Board also available ready-assembled and tested.**

For program execution, the GameBoy is connected to the circuit board of the I²C I/O Box, which is described in a separate article in this issue. The principal features of the I²C I/O Box are listed in **Table 2**. In addition to eight digital inputs and eight digital outputs, the I/O module has four analogue inputs and one analogue output. One of its special features is a socket for a small daughterboard fitted with an I²C SMS chip. This optional extension also has an I²C interface and allows the unit to be controlled and queried remotely by using SMS messages ('texting') and a mobile phone.

GBPLC module

As you can see in **Figure 2**, the circuit of the GBPLC plug-in module essentially consists of only five ICs. IC1 is a flash EEPROM that stores the application software (firmware), IC2 is a PAL that provides address decoding and generates the I²C signals, IC3 is an I²C bus extender, IC4 is an I²C real-time clock, and IC5 is an I²C EEPROM. From a functional perspective, the GBPLC module adds program and data memory, an I²C interface, and a battery-backed real-time clock to the basic GameBoy platform.

The GameBoy microprocessor, which resembles the Z80, has a direct address range of 64 K. However, the upper 32 K are used for the LCD, RAM, sound and so on, leaving the range 0000–7FFF available for external ROM and the range A000–BFFF available for external RAM. Consequently, the GameBoy uses only 15 of the 19 address lines of the flash EEPROM, which means that all programs in the flash memory are restricted to 32 KB. However, the 16th address line (A15 of IC1) can be addressed via switch S1, which can thus be used to select one of two programs stored in the flash memory. One of them is the actual application program (the PLC firmware), while the other is an editor that can be used to program or modify PLC application software directly on the GameBoy. As S1 should only be operated with power off, the circuit board layout (Figure 3) is arranged such that S1 is only accessible when the module is not fitted in the GameBoy. The assembled prototype board is shown in **Figure 4**.

IC2 (PALCE22V10) provides address decoding, and it generates the I²C bus signals SDA (data) and SCL (clock) with the assistance of transistors T1 and T2 and pull-up resistors R1 and R2. The programs held in the flash memory (IC1) are stored 'permanently' and can only be overwritten by a software update (which requires a flash programmer), but the content of the EEPROM (IC5), which is addressed via the I²C bus, is always accessible. It is used primarily to store the PLC application programs (eight maximum). The messages for the display are also stored in the I²C EEPROM. That means the firmware in the flash memory does not contain any messages, so it does not have to be re-assembled for every minor change to a message. That also has the advantage that it is easy to load different language ver-

COMPONENTS LIST

GBPLC Module

Resistors (SMD 0805)
R1,R2 = 4kΩ7
R3, R4 = 330Ω
R5,R6 = 10kΩ

Capacitors (SMD 0805)
C1-C4 = 100nF

Semiconductors
T1,T2 = BC850
IC1 = AM29F040B with socket, programmed *
IC2 = PALCE22V10, programmed *
IC3 = P82B715TD
IC4 = DS1307Z
IC5 = 24C256, programmed *

Miscellaneous
S1 = slide switch, sub miniature, angled pins, PCB mount (APEM type 236W)
Bt1 = 3V Lithium button cell, PCB mount, CR2032H
K2 = Miniature USB-B socket, PCB mount (Lumberg type 2486 01, Farnell # 4739826)
X1 = 32.768kHz quartz crystal
PCB, bare, order code **050190-1** (supplied together with 050190-2)
Set of ready-assembled and tested boards of 1 pc. GBPLC Module and 1 pc. GBPLC I²C I/O Box; order code **050190-91**

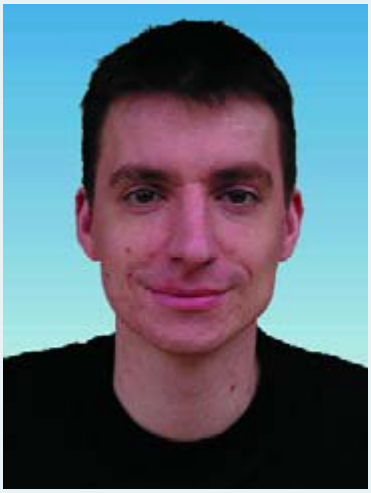
* set of programmed Flash (IC1), PAL (IC2) and EEPROM (IC5); order code **050190-51**.

For all items **050190-xx**: see SHOP pages and/or www.elektor-electronics.co.uk

About the authors

Sascha Koths and Stephan Ruloff developed this design as a graduation project at Bertolt-Brecht-Berufskolleg in Duisburg, Germany. During their studies for the Certified Electronics Technician diploma, the idea of using a GameBoy as a controller led to their graduation project. After receiving their technician diplomas in the field of data processing technology, they are now both enrolled in the Niederrhein University of Applied Sciences in Duisberg. Naturally, the only conceivable course of study for them was Engineering Informatics.

A word of thanks is also due to Christian Müller, who assisted in the project work.



sions. Display messages in German and English are included in the ready-made software.

The I²C real-time clock (DS1037) provides the time of day in 12-hour and 24-hour format along with the date and day of the week, to allow switch-on and switch-off times to be programmed using the PLC and events to be logged. Thanks to the back-up battery, the clock is specified to operate for up to 10 years without losing track of the time. The internal 56-byte RAM of the DS1307 is not used in the GBPLC application.

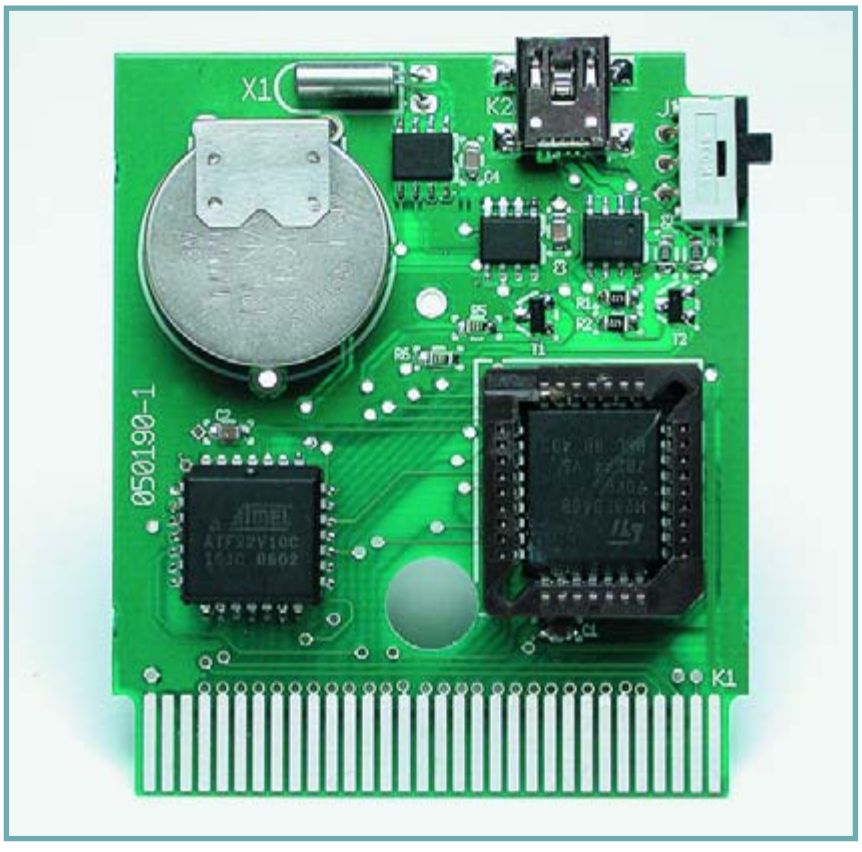


Figure 4. **Fully assembled prototype board of the GBPLC module.**

The 32-way card-edge connector of the module board (shown at the left in the schematic diagram) automatically connects the module to the GameBoy when the module is inserted. The only connection to the outside world is the I²C port, which is located on the edge of the board that remains accessible when the module is inserted. The board is fitted with a miniature USB-B socket (K2) for the I²C bus. In contrast to the GBDSO, the serial interface port of the GameBoy is not used in the GBPLC application.

GBPLC programming adapter

As the GBPLC module can only be accessed via the I²C bus, an interface adapter that can be connected to a PC is necessary for linking the module to a PC. The circuit shown in **Figure 5** can be used for connection to a serial port or a USB port with a USB to serial interface adapter. However, using a 'virtual COM port' with a USB adapter is only a makeshift solution due to the very low data transmission rate.

A circuit board with a USB-A connector for the I²C bus (**Figure 6**) has also been designed for the programming adapter corresponding to the circuit shown in Figure 3. If you use this adapter, you will need a cable with a USB mini plug at one end and a USB-A plug at the other end for the link to the GBPLC module. The same cable can be used to connect the GBPLC module to the I²C I/O box. As the I²C I/O Box has two I²C connectors (a USB-A socket and a USB-B socket), the programming

adapter and the GBPLC module can **both** be connected to the I²C I/O Box at the same time. That requires using the following cables, which are available as standard items:
Mini USB to USB-A for connecting the GBPLC module to the I²C I/O box.
USB-A to USB-B for connecting the programming adapter to the I²C I/O box.
The supply voltage (+5 V) for the programming adapter is tapped off from the I²C I/O box via the USB cable. An advantage of this arrangement (with the programming adapter connected to the I²C I/O box) is that the GBPLC module in the GameBoy remains permanently connected to the I²C I/O box. That eliminates unplugging and replugging cables to connect the GameBoy to the PC, since the 'spare' USB connector of the I²C I/O box can be used for that purpose as necessary.

Construction and assembly

Given the available space, the circuitry of the GBPLC module can only be assembled using a double-sided, through-hole plated PCB with SMD components. Due to the difficulties of assembling such a board, the GBPLC module is optionally available as a fully assembled and tested PCB, which only has to be fitted into an empty GameBoy cartridge housing. As such housings are not commercially available, you will have to remove the innards of a second-hand (cheap) GameBoy game cartridge and use its housing. As you can see from the photo of the GBPLC module (**Figure 7**), four openings must be made in the housing to accommodate the flash memory (IC1 with socket), the back-up battery, the external connector, and the slide switch on the edge of the board (S1).

GBPLC software

The firmware for the GameBoy (PLC application software and editor) has already been mentioned. These two programs, which can be selected using S1, are pre-installed in the flash memory of the assembled and tested GBPLC module. The I²C EEPROM is also already loaded with the display messages in one language (English). If you assemble the board yourself, you can order IC1, IC2 and IC5 pre-programmed (refer to the components list). All files necessary for programming these ICs are also available on the Internet for downloading (refer to the links at the end of this article). A

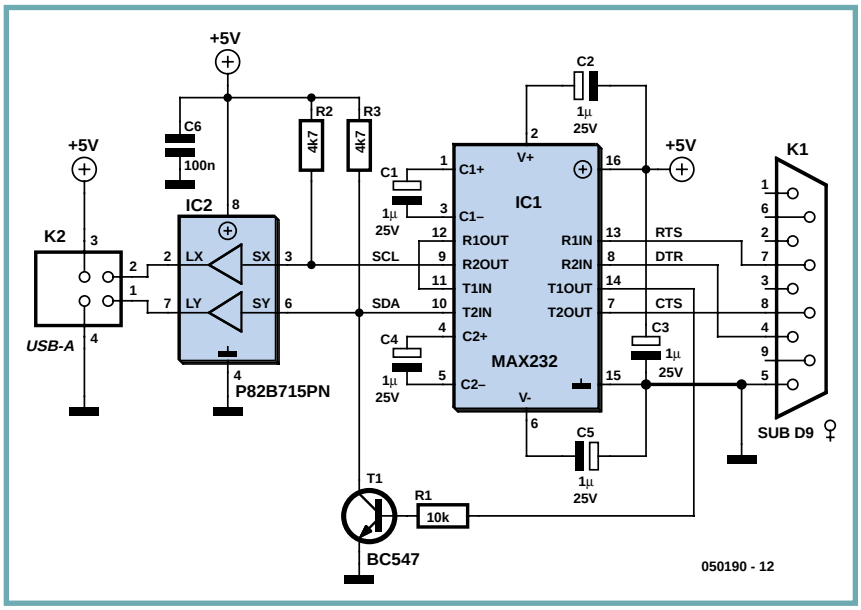


Figure 5. **Schematic diagram of the programming adapter for connection to a serial PC port. The USB-A connecter is used here for the I²C bus signals.**

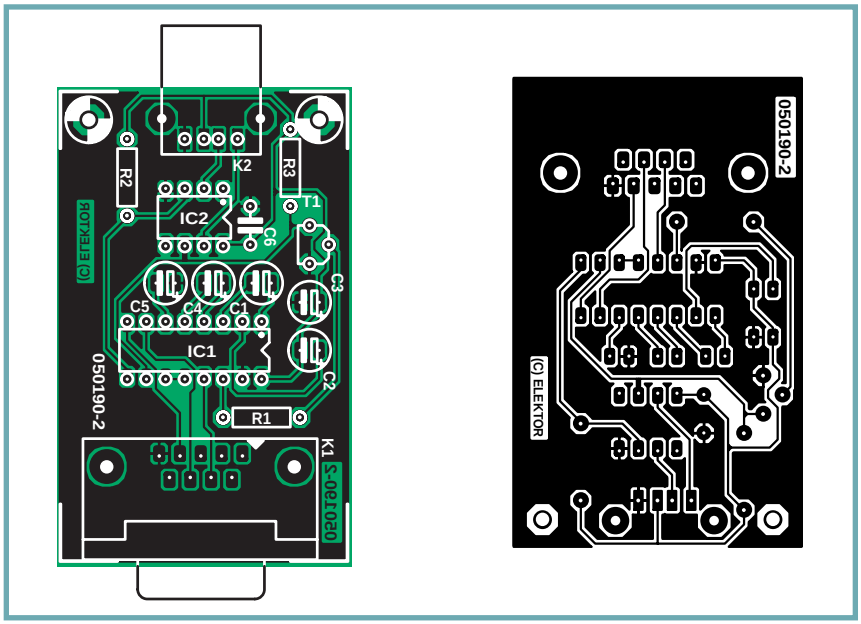


Figure 6. **Circuit board track layout and component layout for the serial interface programming adapter. Board also available ready-assembled and tested.**

COMPONENTS LIST

GBPLC Programming Adapter

Resistors
R1 = 10kΩ
R2,R3 = 4kΩ7

Capacitors
C1-C5 = 1µF 25V radial
C6 = 100nF

Semiconductors
T1 = BC547
IC1 = MAX232
IC2 = P82B715PN

Miscellaneous
K1 = 9-way sub-D socket, angled pins, PCB mount
K2 = type-A USB socket, PCB mount
PCB, bare, order code **050190-2** (supplied together with 050190-1)
Set of ready-assembled and tested boards of 1 pc. GBPLC Module and 1 pc. GBPLC I²C I/O Box; order code **050190-91**

For all items **050190-xx**:
see SHOP pages and/or www.elektor-electronics.co.uk

Table 3. GBPLC Windows Software

System requirements
- PC with Pentium-class processor
- Windows 95 with 32 MB RAM; Windows 98/ME with 64 MB RAM; Windows NT 4.x with Service Pack 4 or higher; Windows 2000 or Windows XP with 128 MB RAM (minimum requirement in each case)
- Administrator rights if Windows NT, Windows 2000 or Windows XP is used
- Microsoft Internet Explorer 5.0 or later
- Serial or parallel interface (USB can be used with a USB to RS232 converter but is very slow)

Ready-to-use PLC programs
- Aquarium/terrarium controller
- Alarm system
- Roller shutter controller

GBPLC Manager
- Generate and edit logic programs
- Print system logic and labels
- Buttons for running other program modules
- Configure interface

GBPLC Simulator
- Load logic programs
- Start and stop programs
- Real-time simulation of inputs
- Generate outputs

GBPLC Log Viewer
- Read log data from GBPLC module
- Display characteristic curves (plotted versus time)
- Freely selectable colours for characteristic curves
- Export to Excel or other programs

SMS Configuration (for optional I2C SMS chip)
- Configure short message service carrier (SMSC) number
- Configure recipient number
- Write SMS ('text') messages

Figure 7. The finished GBPLC module fitted in the housing of a salvaged GameBoy game cartridge. On the prototype pictured here, an IC socket was used for IC2, and a jack socket for K2. The ready-assembled module on sale through Readers Services has IC2 soldered on the board, and a mini USB socket for K2 (see Figure 4)

suitable programming device must be used to program IC1 and IC2. The I²C EEPROM can be programmed using a simple programming circuit and software, such as PonyProg. You can also start up the GBPLC with IC5 empty (unprogrammed) and use the GBPLC PC software and GBPLC programming adapter to load display messages in the language of your choice into IC5. Even with a pre-programmed EEPROM, the selected language for the displayed messages can be changed at any time via the PC. The details of configuring the module for initial use are described in the 'Step by Step' guide (included in the download for the project).

After all the above-mentioned ICs have been programmed, you can also use the editor stored in the flash memory to generate an application program (PLC sequence program) directly on the GameBoy or modify a program that has already been loaded. However, it is more convenient to use the GBPLC PC software for that purpose and then use the programming adapter to download the program into the EEPROM of the GBPLC.
The documentation of the internal structure of the controller and the menus of the GBPLC is also contained in the download files for this article. However, you do not need to bother about the internal structure and byte

organisation if you use the Windows software.
The structure of a sequence program is the same, regardless of whether it is generated using the PC software or directly on the GameBoy. Up to eight PLC program sequences ('logic programs') can be developed in a single 'project'. The project programs (up to eight) can be stored in the 24C256 of the GBPLC module. They can be individually retrieved and run via the menu interface on the GameBoy LCD or from the PC. Each of these programs consists of a maximum of 64 blocks. Each block corresponds to a 4-byte line of program code that defines a function (also known as a 'logic gate'). The available functions are listed in **Table 1**. Each logic gate has a maximum of two inputs and a single output. The terminals of the I²C I/O Box listed in Table 2 can be selected as the inputs or outputs. It is also possible to define 'block flags' ('flags' for short) for the inputs and outputs. These block flags interconnect the inputs and outputs of different blocks.

Windows software

A package consisting of three programs that run under Windows is provided to simplify using the controller. Like the firmware, it is available for downloading free of charge. Borland C++ Builder was used to develop the Windows software. Each of the three programs (GBPLC Manager, Simulator, and LogView) performs a specific task. A fourth program (SMS Configuration) can be used to configure the optional I²C SMS chip. All the other programs can be run from GBPLC Manager, so all the Windows software can be used in the GBPLC Manager environment.

Table 3 summarises the major features of the Windows programs. Typical screen shots are shown in **Figures 8, 9 & 10**. The extensive help files for the Windows programs form an excellent tutorial with detailed explanations and examples. Three complete example projects that you can also use for your own applications are also available: a controller for aquariums and terrariums, a roller shutter controller, and an alarm system. For demonstration purposes, the authors installed these applications in a model display home that is also shown in the photos.

If you want to get an exact idea of the functions and capabilities of the GBPLC, you can download the Windows software free of charge and at no obligation and familiarise yourself with the display of the GameBoy PLC. After that, it's only a small step from a simulation to the real thing (see the 'Step by Step' guide included in the download file), with the added benefit that you know in advance that it will be worth the effort.

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Links for downloads

www.elektor-electronics.co.uk
(Elektor Electronics articles, software and documents)

www.rk-tech.org
(authors' website, software and documents)

http://gbdk.sourceforge.net
(GBDK – GameBoy Developers Kit)

www.work.de/nocash/gmb.htm
(NO$GMB – GameBoy emulator for Windows)

www.lancos.com/prog.html
(PonyProg)

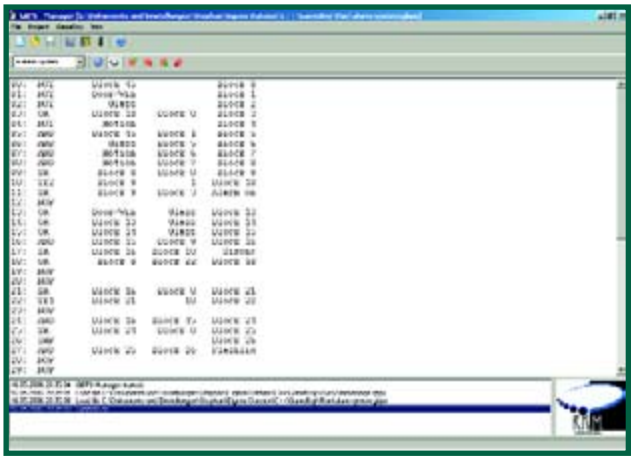


Figure 8. Screenshot of GBPLC Manager, the main program for operating and programming the GameBoy PLC under Windows.

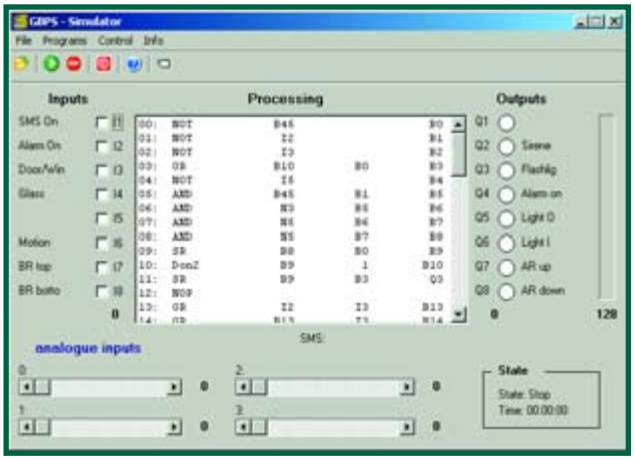


Figure 9. GBPLC Logic Simulator, which can be run from GBPLC Manager, can be used to test application programs without the GameBoy. The GameBoy functions are integrated into the simulator.

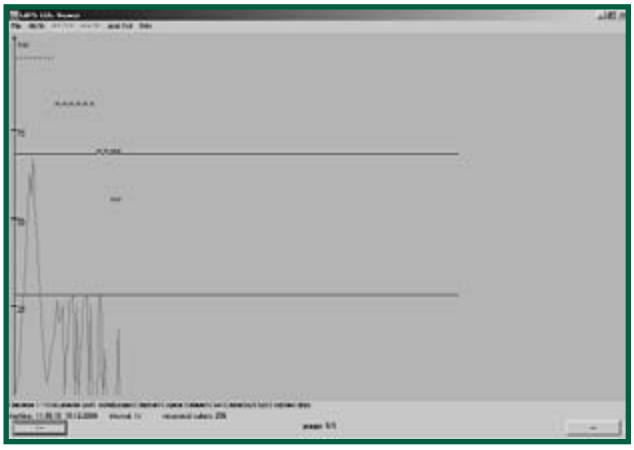


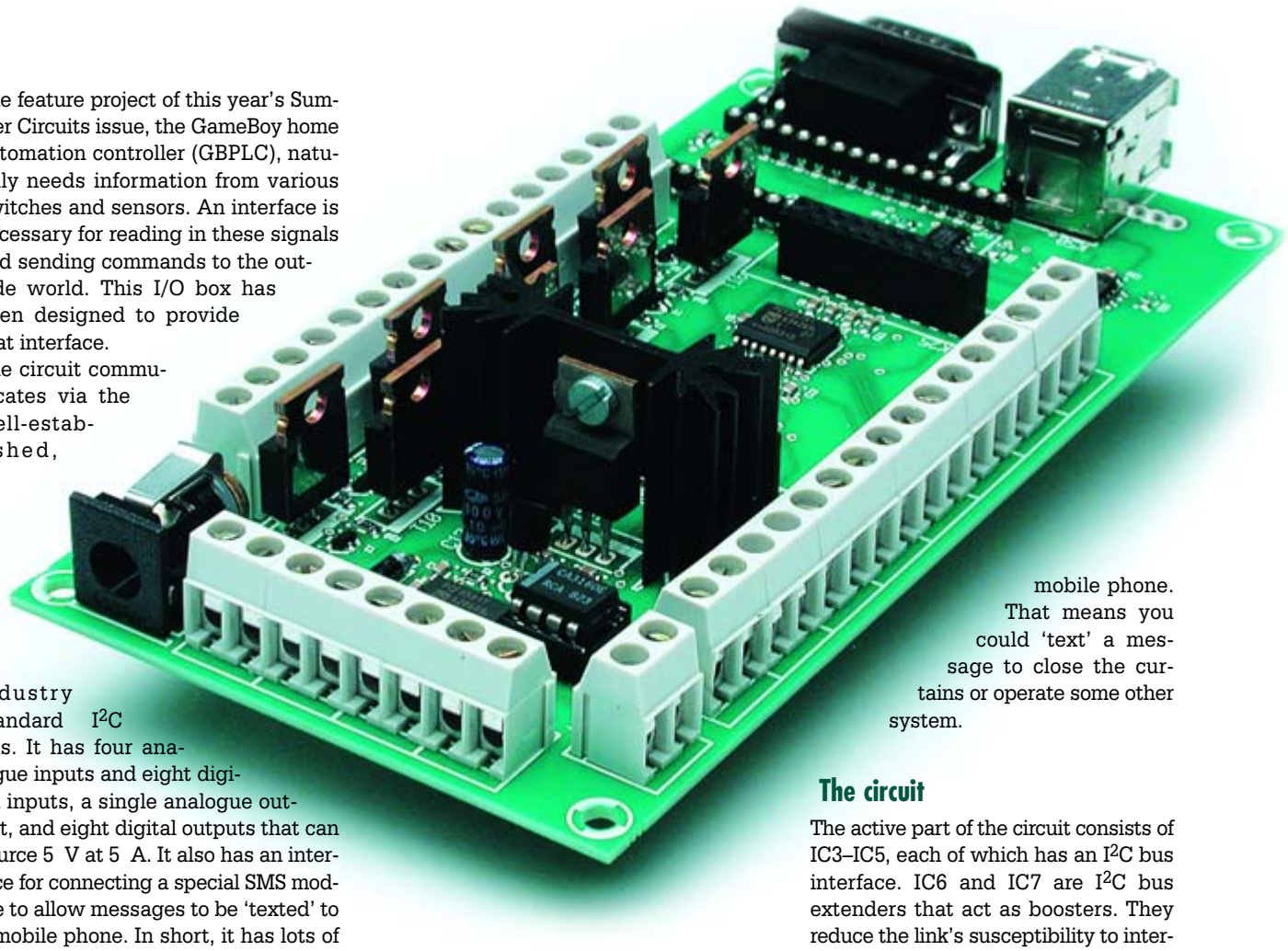
Figure 10. GBPLC LogView can be used to display and export control data collected by the PLC.

GBPLC I²C I/O Box

analogue, digital I/O plus TXT (SMS)!

Sascha Koths & Stephan Ruloff

To use the Nintendo GameBoy as a system control centre, you need an I²C interface in addition to the special plug-in card. The circuit presented here is cut out for the job. It has a total of 24 inputs and outputs, including 4 analogue inputs and 8 digital inputs. That's sufficient to control roller shutters, outside lighting, curtains, an alarm system, the central heating system and even more, possibly even remotely via TXT (SMS) messages.



The feature project of this year's Summer Circuits issue, the GameBoy home automation controller (GBPLC), naturally needs information from various switches and sensors. An interface is necessary for reading in these signals and sending commands to the outside world. This I/O box has been designed to provide that interface.
The circuit communicates via the well-established, industry standard I²C bus. It has four analogue inputs and eight digital inputs, a single analogue output, and eight digital outputs that can source 5 V at 5 A. It also has an interface for connecting a special SMS module to allow messages to be 'texted' to a mobile phone. In short, it has lots of capabilities. The SMS module also allows the circuit to be controlled by a mobile phone. That means you could 'text' a message to close the curtains or operate some other system.

The circuit

The active part of the circuit consists of IC3–IC5, each of which has an I²C bus interface. IC6 and IC7 are I²C bus extenders that act as boosters. They reduce the link's susceptibility to interference by increasing the current on the I²C bus and reducing its capacitance.

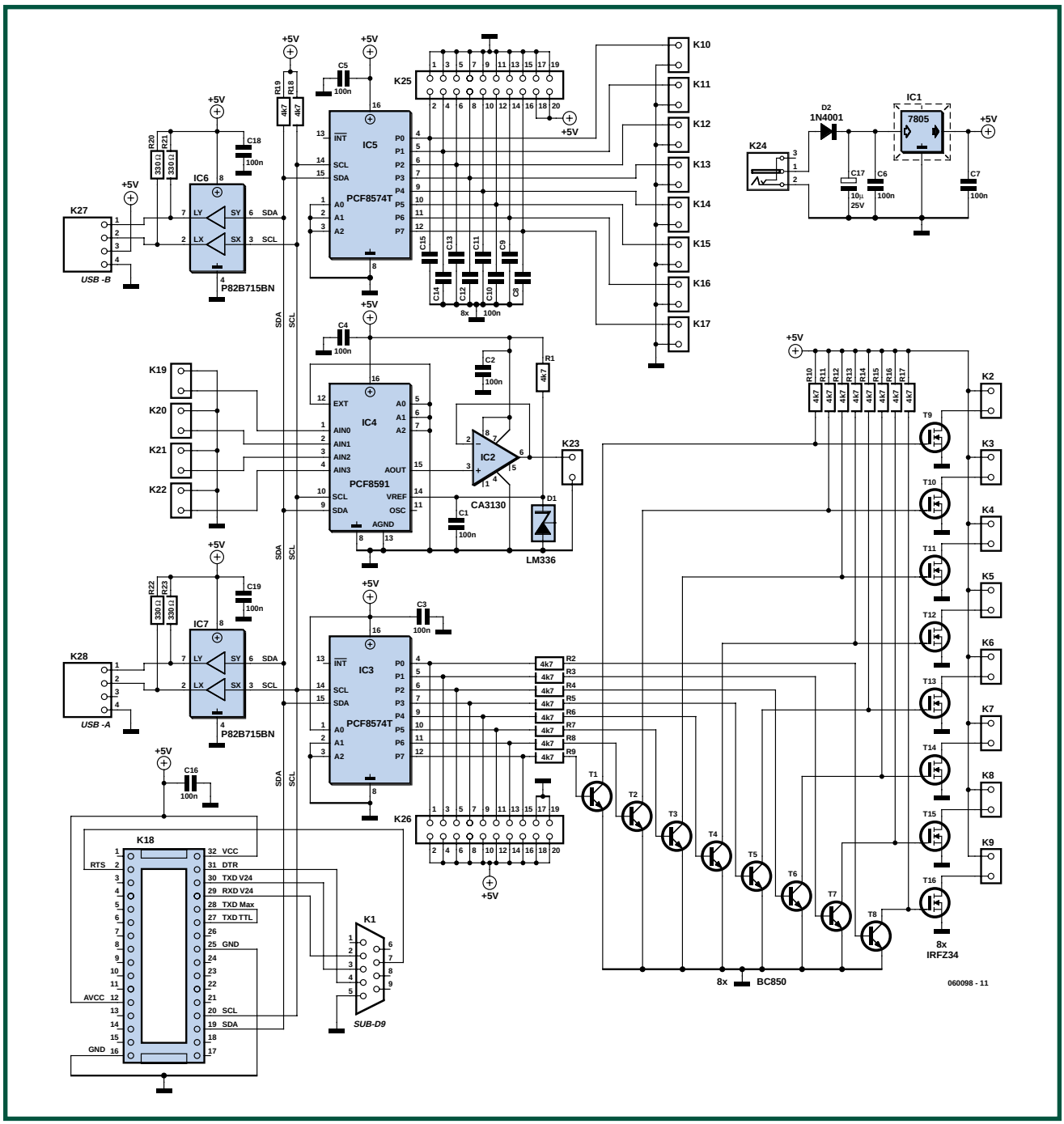


Figure 1. The main components of the circuit are the I²C drivers and the bus extender.

IC4 converts analogue signals into 8-bit digital data suitable for the I²C bus. The reference voltage on pin 14 is set to 2.5 V, which yields a resolution of approximately 10 mV. TTL signals can access the I²C bus via IC5. Capacitors C8–C15 decouple noise on the inputs. That's hardly an unnecessary luxury for signal lines that doubtless run over a considerable distance through your house.
Digital and analogue signals are output to the outside world via IC3 and IC4. The PCF8574 contains an 8-bit quasi-bidirectional port with internal latches. The latch retains the most recently configured output state. IC5 obviously does not use this data, since none of its outputs are used in the circuit.

The addresses of IC3, Ic4 and IC5 are hardwired in the circuit by tying address pins A0, A1 and A2 to fixed potentials. The PCF8591 has a different internal base address, which explains why IC4 and IC5 can apparently be assigned the same address. If you want to couple several of these modules to a single bus for a different application, you will have to modify address portion of the PCB track layout.

Standard USB connectors are used for the connection to the I²C bus. They are thus not real USB ports. K28 is a USB-A connector for connection to the

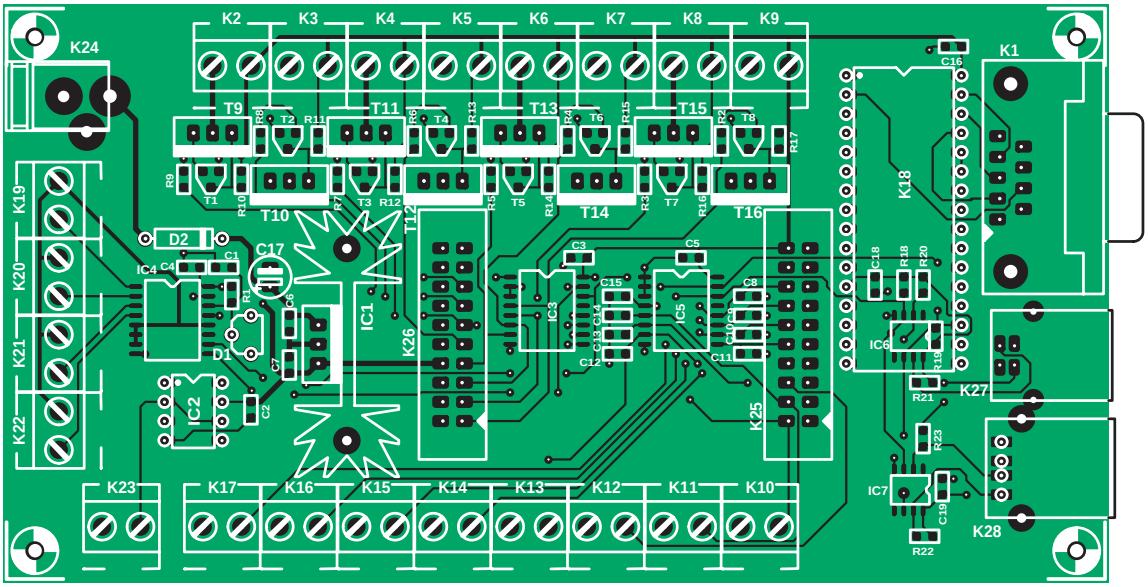


Figure 2. Practically the entire outer region of the board is occupied by a large number of connectors.

COMPONENTS LIST

Resistors
R1-R19 = 4kΩ7
R20-R23 = 330Ω

Capacitors
C1-C16,C18,C19 = 100nF (SMD 0805)
C17 = 10µF 25V radial

Semiconductors
D1 = LM336Z (TO92 case)
D2 = 1N4001
T1-T8 = BC850
T9-T16 = IRFZ34N
IC1 = 7805
IC2 = CA3130
IC3, IC5 = PCF8574T
IC4 = PCF8591T
IC6,IC7 = P82B715TD

Miscellaneous
K1 = 9-way sub-D plug (male), angled pins, PCB mount *
K2-K17,K19-K23 = PCB terminal block, lead pitch 5mm
K18 = 32-way DIL socket *
K24 = mains adaptor DC socket, PCB mount (CUI Inc. type PJ-002B, Digikey # CP-002B-ND)
K25, K26 = 20-pin (double row) socket, pitch 0.1"
K27 = USB connector type B
K28 = USB connector type A
PCB, order code **060098-1**
Ready assembled and tested board, order code **060098-91**

* only required in combination with SMS chip

For all items **060098-xx**: see SHOP pages and/or www.elektor-electronics.co.uk

GameBoy module. K27 is a USB-B connector intended to be used for connection to a PC. That makes it unnecessary to constantly disconnect and reconnect cables when you want to control the module from the GameBoy while linking it to a computer at the same time via an I²C to RS232 adapter. All digital inputs and outputs are directly accessible on K25 and K26. That means you can check the outputs by connecting low-current LEDs directly to K26. Don't forget to use current-limiting resistors for the LEDs. The PCF8574T has open-drain outputs that can source adequate current for that purpose.

We use the SMD version of the well-known BC550 here for inverters (T1–T8, BC850) that drive MOSFETs T9–T16. Otherwise the outputs would go high immediately after the circuit was switched on, due to the initial state of the PC8574.

As already mentioned, the MOSFETs can handle currents up to around 5 A. Incidentally, you can also use the pin-compatible BUZ11 in place of the IRFZ34N. It is no longer being made, but you can doubtless still find it on the shelf here and there.

The power supply is a simple design using a 7805. That means you can simply use a standard AC adapter with a voltage of 9 V or more as a power source. D2 provides reverse-polarity protection in case you accidentally connect a different adapter with the wrong polarity.

Construction

Assembling the circuit board is not difficult. Start by soldering all the small SMDs. Next in line are the DIL and SMD ICs. IC2 can optionally be fitted in a socket. After that, you can fit the rest of the components.

You can connect a mobile phone directly to the circuit via a serial data cable connected to K1 if the optional SMS module is also fitted. You can order the SMS module at www.rk-tech.org.

Of course, this circuit is also perfectly suitable for use as a general-purpose I²C bus interface — it doesn't have to be restricted to use in combination with the GameBoy module. An I²C-based system with all sorts of control and switching capabilities can be used for innumerable purposes aside from a home bus system. That makes this I²C I/O Box suitable for a wide variety of applications.

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