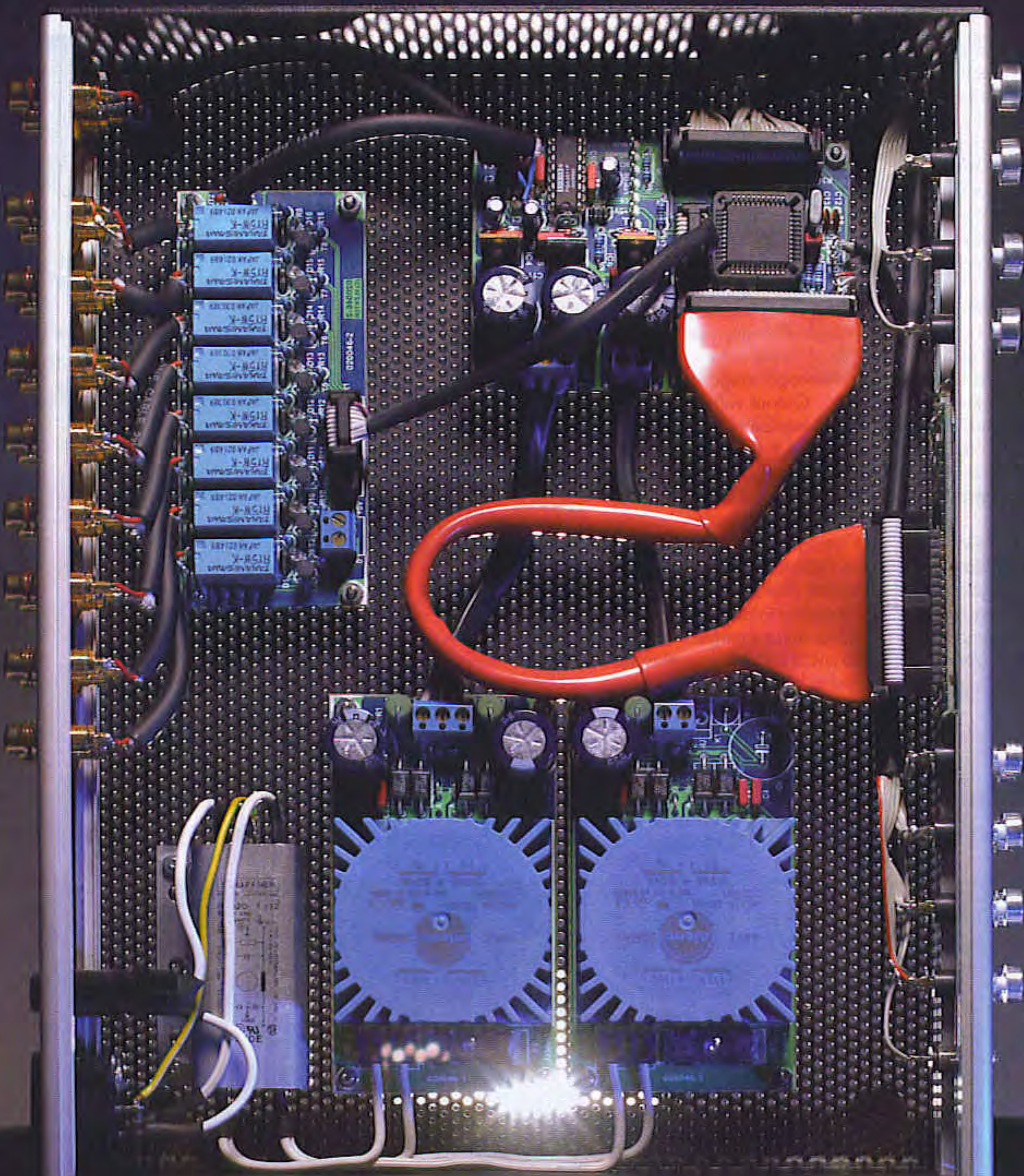
High-End-Preamp

Benjamin Hinrichs



The modern design of this preamplifier yields audiophile specs, convenient operation and an attractive price. This is made possible by using a top-end digitally controlled attenuator/amplifier IC.

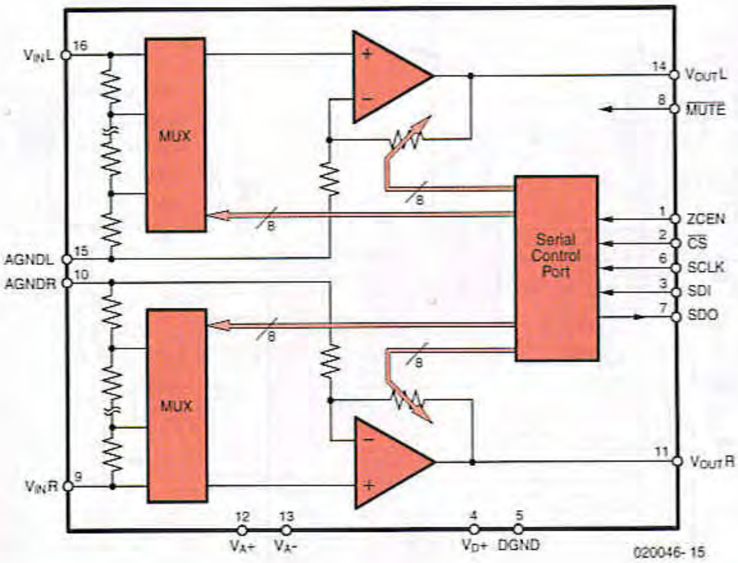


Figure 1. Functional block diagram of the PGA2311. The attenuation and gain are configured using a 3-wire serial bus.

Analogue audio electronics appears to have entered a dormant stage. In our present age of CDs, DVDs and MP3, traditional preamplifiers have been relegated to the role of signal distribution and, primarily, adjusting the volume level.

Our expectations for a modern high-quality preamplifier are that in addition to being easy to use, it should perform these signal distribution and volume adjustment functions with the greatest possible accuracy and the least possible distortion. And that is exactly where things start to get difficult.

Volume controls are commonly implemented using potentiometers, which are available in a wide variety of price ranges and types. Since we are normally dealing with a stereo signal, we need two mechanically coupled potentiometers. The decisive factor is the tracking of the two potentiometers, since this determines how closely the volumes of the right and left channels will match each other. Poor tracking is especially noticeable (and disturbing) at low volume settings. If we also want to have a balance control, we need an additional set of coupled potentiometers, and the tracking errors will add together.

The maximum permissible tracking error for 'audiophile' sensibility is 3 dB, but ideally it should be less than 1 dB. As can easily be seen from **Table 1**, these values are clearly exceeded by normal carbon-film potentiometers, and even high-quality carbon-film potentiometers have difficulty maintaining adequate tracking accuracy with increasing age.

An audiophile alternative to potentiometers is to use high-quality, multi-position rotary switches with close-tolerance resistors. However, the right-hand column of the table shows that suitable special rotary switches having extremely low crosstalk and contact resistance cost around £80–90, which is rather expensive.

The disadvantage of this solution involves more than just the price (we will need two or three such switches for the volume and balance controls and the input selector switch, if present), since rotary switches cannot be remotely controlled.

If we wish to have the convenience of remote control as well as excellent tracking, there's no getting around a design using conductive-plastic potentiometers with a motor and the associated control electronics and mechanical parts. This also involves considerable effort and expense, and just about everything must be duplicated for a balance control.

The PGA2311 stereo audio volume control IC

Admittedly, the idea of using a 'digital' IC for volume adjustment, and furthermore controlling it using a microcontroller, may evoke a sceptical frown from many an audiophile. Ten years or more ago, this scepticism would certainly have been justified, but the semiconductor industry has made enormous progress in this area. All of the major functions can now be integrated into a single chip, with results that can easily hold their own against the best mechanical solutions.

The Texas Instruments PGA2311 volume control IC used in this project is moderately priced and provides out-

Table 1. Tracking errors and price indications of various types of volume control

Type	Tracking error [dB]	Approximate price [£]
Carbon-film potentiometer	>3	3
High-quality carbon-film potentiometer	0.5 - 3	10 - 20
Conductive plastic potentiometer	0.1 - 0,3	25 - 55
Rotary switch	0.1	80 - 90
Motor and accessories	–	12 - 80
PGA2311PA	0.1	2.5 - 12

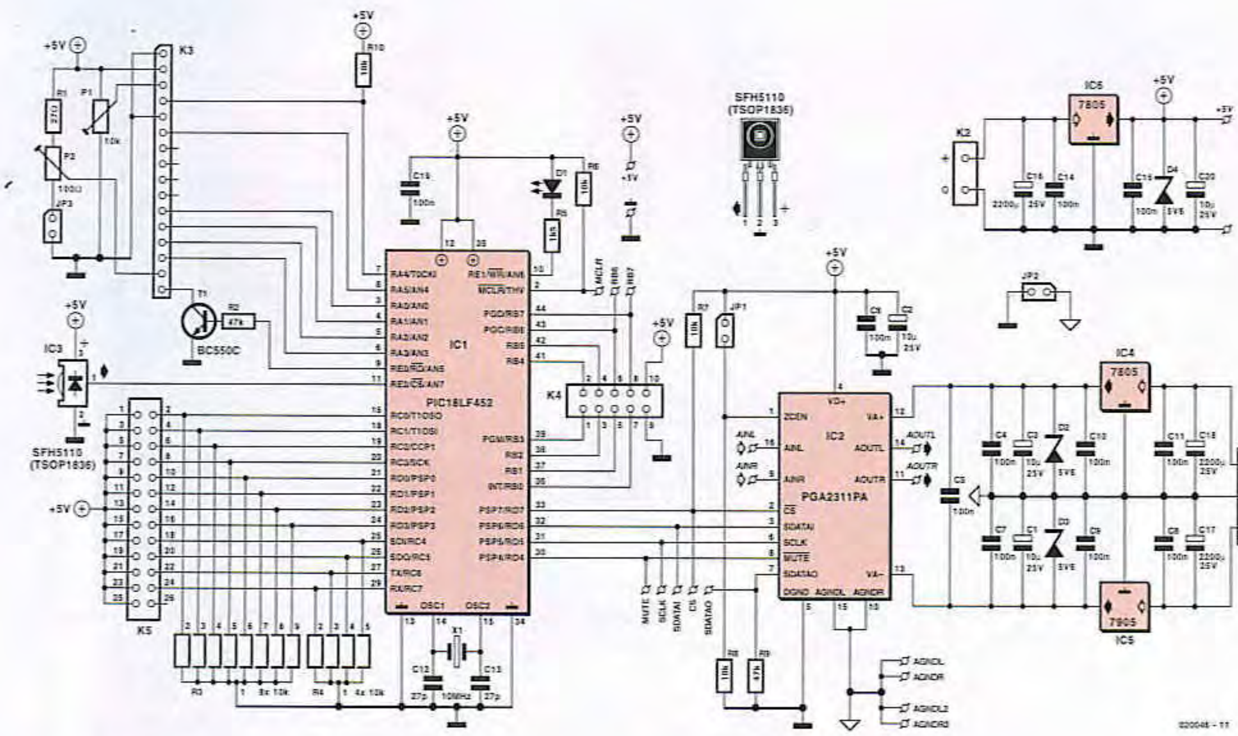


Figure 2. Circuit diagram of the main circuit board, which is divided into an analogue part and a digital part.

standing tracking without any degradation of tracking accuracy when balance adjustment is used, and it also has very good technical specifications. Another major advantage is that it can be digitally configured. This makes user-friendly operation possible (including remote control). An example of a high-end builder who uses this technology is Jeff Rowland.

The PGA2311, whose internal structure is shown in **Figure 1**, is a digitally controlled analogue stereo volume control with certain refinements. The two channels can be independently adjusted over a range of –95.5 dB to + 31.5 dB in steps of 0.5 dB, which yields an adjustment range of 127 dB. The tracking error between the two channels, as well as the absolute setting accuracy of each of the channels, is ±0.05 dB. This naturally means that a balance adjustment can also be implemented without any problems, since the high absolute setting accuracy prevents any offset from occurring. Another noteworthy feature is that the IC can directly drive 600-Ω loads.

The multiplexer (MUX) switches individual resistors to set the attenuation. After the attenuator, the signal passes through an output buffer, which can also provide gain via an adjustable feedback resistance.

The IC is controlled via a serial SPI interface. Clock signal SCLK transfers a single 16-bit word to the IC via the SDI line. The first eight bits set the volume level for the right channel, while the second eight bits set the level for the left channel. The minimum value (0) represents Mute, and the maximum value (255) represents a gain of +31.5 dB.

For fully noise-free switching, zero-crossing detection can be enabled via the ZCEN lead. If it is enabled, the IC analyses the music signal and attempts to perform the switching during a zero crossing. If no zero crossing is detected within 16 milliseconds, the switching is performed without waiting any longer. Due to system design constraints, the ramp function of the software does not work properly if zero crossing detection is enabled.

In principle, four different types of ICs can be used in this circuit. **Table 2** lists the differences among these ICs. The original design was developed for the Crystal (Cirrus Logic) type CS3310. The equivalent competitive product from Texas Instruments is the PGA2310, which is not only pin-compatible, but also has significantly better internal specifications. A particularly attractive feature of the latter IC is that it can handle signals up to 27 V_{PP} if the analogue supply voltage is increased to 30 V. The improved type PGA2311 has even better channel separation, and the selected 'A' version has a better specification for total harmonic distortion plus noise (THD+N). For this reason, we selected the PGA2311A for his project.

We can also mention the PGA4311 in passing. This is a four-channel version of the PGA2311 and is only available in the SOIC package. It can be used with only minor modifications to the circuit board layout and software.

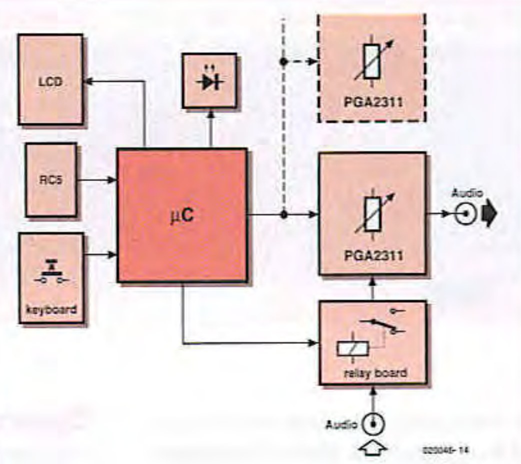
The control centre

The main circuit board, which forms the control centre for the preamplifier, requires surprisingly few components. This is due to the high integration density of the two ICs used here. By far the majority of the components are used to generate clean supply voltages.

The circuit is split into an analogue portion and a digital portion. The digital portion contains a Microchip PIC18LF452 microcontroller clocked at 10 MHz by a crystal oscillator. This microcontroller has 8-bit registers and 16-bit instruction words. Microchip has not shown much flair in assigning part numbers to its PIC microcontrollers. For instance, the PIC16F84, PIC16F628, PIC16F877 and PIC12F675 belong to the PIC14 family, while the

The project

This project has a modular structure, so it can easily be adapted to individual preferences. It consists of a general-purpose power supply board, an input selector board and the main circuit board, which holds the volume control IC and microcontroller. An LC display module, a keypad and an IR remote control unit complete the package. The hardware and software are described in this article, which is the first of two parts. The other two circuit boards are described in Part 2, which will appear in next issue of *Elektor Electronics*. Modifying the control program for the microcontroller is also described in Part 2.



Block diagram of the preamplifier. The option of connecting additional PGA2311 ICs in parallel, as indicated by the dashed outline, is described in Part 2.

If you build all of the circuit boards as described, you will have a complete, remotely controllable preamplifier with input selection and function display. However, you can also dispense with the input selector and use only the volume control capability. If you wish, you can also omit the display, or you can omit the volume control IC on the main circuit board and use the remainder of the circuit as a remotely controllable relay circuit board for various applications. It is also possible to operate several volume controls in parallel, for instance in order to construct a multi-channel amplifier. For this purpose, only the volume control ICs have to be fitted to the main circuit boards for the additional channels. The control software for the microcontroller can be adapted to suit almost any imaginable application without reprogramming the microcontroller.

PIC18LF452 used here belongs to the PIC16 family.

The PIC18LF452 has a Flash program memory with a capacity of 32 KB (which is adequate for the rather extensive software), 1.5 KB of RAM and a 256-byte EEPROM. Its 31 stack levels provide adequate manoeuvring room for calling functions and procedures if the contents of all of the registers are written to the stack to allow the called procedure to use the registers. When control is returned to the calling procedure, the register contents are retrieved from the stack to allow the calling procedure to continue processing from the point where it transferred control. If frequently used subroutines are implemented using functions and procedures, the resulting interleaving of program execution can quickly exceed the capacity of a relatively shallow stack.

Before discussing the software in any more detail, let's have a look at the peripheral resources available to the microcontroller. The volume control (IC2) is connected to the microcontroller via the serial SPI bus. In addition, the microcontroller can select the PGA2311 using the CS line, and it can mute the output by placing a Low level on the MUTE line. These four lines, as well as the data output line (SDO), are externally accessible to allow several volume controls to be connected in parallel (as described in Part 2 of this article).

The remainder of Port D and all of Port C are fitted with pull-down resistors (consisting of the two SIL arrays R3 and R4) and routed to pin header K5, to which the pushbutton switches for controlling the preamplifier are connected.

K5 pins	Function
1&2, ..., 15&16	Channels 1–8
17&18	Volume Down
19&20	Volume Up
21&22	Volume Left
23&24	Volume Right

The functions are essentially self-explanatory, but as you might imagine, additional functions are also implemented using combinations of buttons. All of the functions can also be selected using a remote control unit. IC3 is a 36-kHz infrared receiver, which filters, demodulates and cleans up the received light signal and boosts it to TTL levels, all without a single external component. An RC5 decoder is built into the software, so all types of RC5 remote control units (Philips, Grundig, etc.) can be used to control the preamplifier. The IR receiver is connected to RE2, which is one of the three Port E lines.

Table 2. Volume control ICs suitable for use in this project.

Type	Dynamic range [dB]	THD+N [%]	Channel separation [dB]	U_{out} (max) [V_{pp}]
CS3310-KP	116	0.001	−110	7.5
PGA2310PA	120	0.0004	−126	27
PGA2311P	120	0.0004	−130	7.5
PGA2311PA	120	0.0002	−130	7.5

The configuration options are so manifold that without a clearly organised display presentation you could quickly loose track of where you are, particularly when programming the basic settings. Via Port A, the microcontroller software drives an LC display with two lines of 16 characters and background illumination. In normal operation the display shows the channel names and volume setting, while in Set-up mode it is used to select channel designations and basic volume control settings. Pull-up resistor R10 connected to RA4 is necessary because this port lead has an open-drain output and thus cannot switch to a High level without a pull-up resistor. Trimpot P1 adjusts the display contrast, while trimpot P2 adjusts the brightness of the background illumination. JP3 extends the adjustment range. The microcontroller can switch the background illumination on or off via port line RE0 and transistor T1.

The microcontroller drives the relay board via K4. Each of port lines RB0–RB7 selects one of the eight audio inputs. The behaviour of the Status LED (D1) can be configured using the Set-up menu. This is described in more detail later on, along with the significance of the three lines MCLR, RB6 and RB7 that are led out from the board.

The main circuit board has separate power distribution for the analogue and digital portions. The ground potentials must be connected at a suitable location via wire bridge JP2. The single +5-V digital supply voltage and the symmetrical ±5-V analogue supply voltages are stabilized in the traditional manner using fixed voltage regulators with the customary buffer and decoupling capacitors. For all three voltages, 5.6-V Zener diodes are provided as 'backup' safety devices in case excessively high voltages appear on the outputs of the fixed voltage regulators.

Operation

After switch-on, the software checks whether reasonable value are located in the EEPROM. If this is not the case, such as immediately after the microcontroller has been programmed, default values are loaded. Otherwise the software loads the stored values and configures the volume control accordingly.

When a volume control button is pressed (Up, Down, Left, or Right), the software checks whether the adjustment is possible and whether the lower or upper limit of the adjustment range has been reached. Pressing the Up and Down buttons simultaneously causes the preamp output to be muted. Pressing the Left and Right buttons simultaneously restores the balance to the middle position, with the volume being set to the average of the values for the two stereo channels.

If one of the input channel buttons is pressed, the channel is changed, with the output being muted during switching. Alternatively, the preamplifier can be configured via the Set-up menu to use a ramp. In this case, when the channel is switched the volume is first ramped down and then ramped back up again after the channel change.

An offset can be assigned to each channel, which is useful if the signal sources have different volume levels. The offset is applied to the set volume level when the associated channel is selected, and when a different channel is selected it is automatically removed. If an offset would cause one of the volume limits to be violated, it is ignored. The channel name selected using the Set-up menu is shown on the display.

All of the functions of the preamplifier can be controlled using an RC5-compatible remote control unit. Naturally, the preamplifier can be freely configured using the Set-up menu to allow an existing RC5 remote control unit to be used to control all of its functions.

The selected configuration settings are stored in the microcontroller EEPROM and are thus available each time the preamplifier is subsequently used.

Set-up

The software has default values for all configuration settings. All of the functions of the software can be adapted to individual needs via the Set-up menu. To enter the Set-up mode, hold the Channel 1 button pressed while switching on the preamp.

The Set-up configuration can only be modified using the control buttons on the preamplifier; it cannot be adjusted using the remote control. The buttons have the following functions in the Set-up mode:

DOWN	Next entry
UP	Previous entry
LEFT	Exit
RIGHT	Enter

1) RC5 IR Set-up

Reads an RC5 code from a remote control unit, displays the code and assigns it to one of the following buttons: Channel 1–8, Down, Up, Left, Right, or Mute.

Defaults

Configured for a Grundig remote control unit.

Buttons

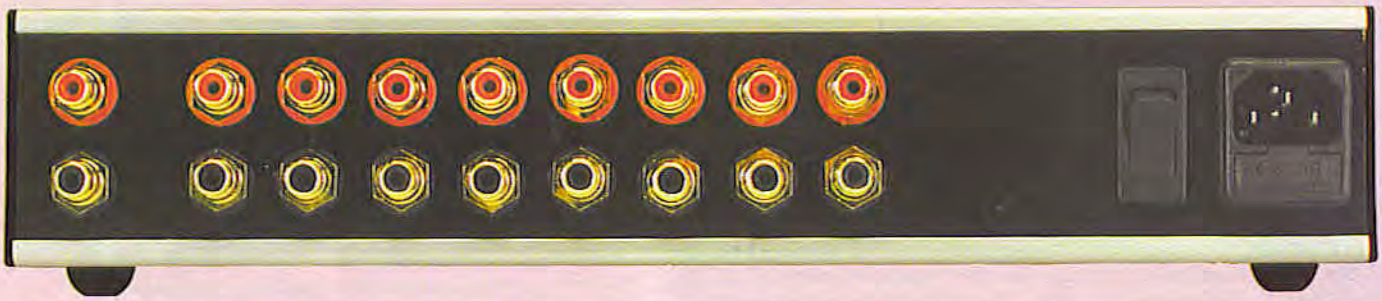
LEFT	Exit
RIGHT	Next

2) RC5 IR Test

Reads and displays an RC5 code from a remote control unit. Intended to be used to check settings made using IR Set-up. Can also be used to test an RC5 remote control unit.

Button

LEFT	Exit



3) Maximum Volume

Sets the maximum allowable volume level in dB.

Default
+31.5 dB (maximum)

Buttons

DOWN	Reduce volume level
UP	Increase volume level
LEFT	Exit

4) Ramp

The ramp function gradually decreases the volume before switching channels and gradually restores it afterwards. The ramp function can be enabled or disabled, and the delay between successive volume steps can be configured. Enabling the zero crossing detection function (JP1) can impair the operation of the ramp function.

Defaults
Use ramp: Yes
Ramp delay: 15 ms

Buttons

DOWN	Use ramp: Yes/No Ramp delay: – 1 ms
UP	Use ramp: Yes/No Ramp delay: + 1 ms
LEFT	Exit
RIGHT	Next

5) Relay Test

Energizes all relays for testing.

6) Input Type

This allows the input configuration to be set to either 8 channels (Single) or 2 × 4 channels (Double). This is useful if you want to switch not only the signal leads but also the ground leads. The input type should also be set to Double for balanced signal sources. In the Double mode, the relays are switched in pairs as follows: RE1+RE5, RE2+RE6, RE3+RE7, and RE4+RE8.

Default
Single

Buttons

DOWN	Single / Double
UP	Single / Double
LEFT	Exit

7) Offsets

An offset can be defined for each channel. It is applied when the channel is selected and removed when a different channel is selected. If applying an offset would violate one of the volume limits (Mute or Maximum Volume), it is not used. The value is shown in dB.

Defaults
Channel 0–8: 0 dB

Buttons

DOWN	– 0.5 dB
UP	+ 0.5 dB
LEFT	Exit
RIGHT	Next

8) Channel Names

Each channel can be assigned a name selected from the following list:
Aux, Aux2, CD, CD2, DAC, DAC2, DVD, DVD2, DVD-Audio, DVD-Audio2, Line, Line2, Phono, Phono2, SACD, SACD2, Tape, Tape2, Tuner, Tuner2, TV, TV2, VCR, VCR2, Video, Video2, Sat, Sat2, DCC, DCC2, MD, MD2, DAT, DAT2, PC, PC2.

Defaults

Channel 1:	CD
Channel 2:	Phono
Channel 3:	DVD
Channel 4:	SACD
Channel 5:	DVD-Audio
Channel 6:	DAC
Channel 7:	Tape
Channel 8:	Line

Buttons

DOWN	Next list item
UP	Previous list item
LEFT	Exit
RIGHT	Next

9) Hardware Set-up

Configures the type of hardware used. This only affects what is shown on the display. The options are Normal (preamp), Input Only (channel selection only), and Volume Only (volume adjustment only).

Default
Normal

Buttons

DOWN/UP	Normal / Input Only / Volume Only
LEFT	Exit

10) LED Set-up

Sets the LED behaviour. Options: Delay Off, Always Off, Always On.

Default
Delay Off

Buttons

DOWN/UP	Delay Off / Always Off / Always On
LEFT	Exit

11) LED Set-up

Sets the behaviour of the LCD background illumination. Options: Delay Off, Always Off, Always On.

Default
Delay Off

Buttons

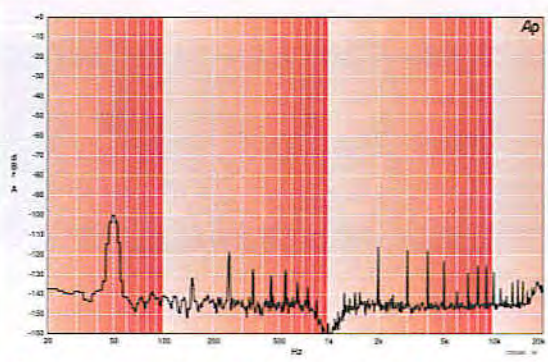
DOWN/UP	Delay Off / Always Off / Always On
LEFT	Exit

12) Power-up Volume

Sets the switch-on behaviour. This menu can be used to configure two settings. The first setting controls the switch-on behaviour and has the following options: Last (set the volume to

Measured performance

Confidence (in the data sheets) is good, but measurement (by the *Elektor Electronics* lab) is better! The results of the FFT analysis of a 1-kHz signal with an amplitude of 1 Veff indicate two things. First, the overall harmonic distortion figure of 0.0012 % is dominated by the induced 50-Hz mains noise (at –100 dB) if the measurement is made over a bandwidth of 20 Hz to 20 kHz. Second, the first three harmonics of the test frequency are located in the range of –116 dB to –118 dB. If the bandwidth range for the measurement is shifted to 100 Hz – 200 kHz, the THD+N value drops to only 0.0005 %. This is a fantastically low value.



The harmonics of the 1-kHz signal lie below –116 dB.

In order to further reduce the effect of mains interference, it is recommended to separate the mains input and power supply board as far as possible. Fully enclosing the main circuit board and relay board (inside a tinned sheet-metal box located inside the main enclosure, for example) could also have a beneficial effect.

Test results at unity gain (0 dB)

Nominal input sensitivity	**200 mV**
Nominal output voltage	**200 mV**
Maximum output voltage	**2.4 Vrms (THD+N = 0.01 %)**
Input impedance	**10 kΩ (input selected)**
	∞ (input not selected)
Output impedance	**< 0.6 Ω**
Bandwidth *	**0–3 MHz**
	0–150 kHz (gain 31.5 dB)
Harmonic distortion (THD+N) *	**0.0005 % (1 kHz, B = 100 Hz – 22 kHz)**
	0.0012 % (1 kHz, B = 80 kHz)
	0.002 % (20 Hz – 20 kHz, B = 80 kHz)
Signal to noise ratio (S/N) *	**100 dB (B = 22 kHz)**
	113 dBA
Channel separation **	**> 88 dB (1 kHz)**
	> 62 dB (20 kHz)
Crosstalk **	**< 98 dB (1 kHz)**
	< 88 dB (20 kHz)

*** at Vout = 1 V**
**** with open input terminated in 560 Ω**

the same level as when the preamp was switched off), Mute, Mute → Last (muted on switch-on, with the previous volume setting being restored after a button is pressed), and Preset (always use a configurable preset value).
The second setting is the preset value. The current volume level can be stored as the preset value by pressing Up or Down.

Default
Last
Preset values: Mute, Mute

Buttons
DOWN/UP Last / Mute / Mute → Last / Preset (store current volume as preset)
LEFT Exit
RIGHT Next

13) Restore Defaults

Restores the predefined default configuration settings. This also occurs if a newly programmed microcontroller without reasonable configuration values in the EEPROM is fitted.

Default
Volume: Mute
Channel: 1
All others: see above

(020046-1)

References

[1] www.ti.com
http://focus.ti.com/docs/prod/folders/print/pga2311.html

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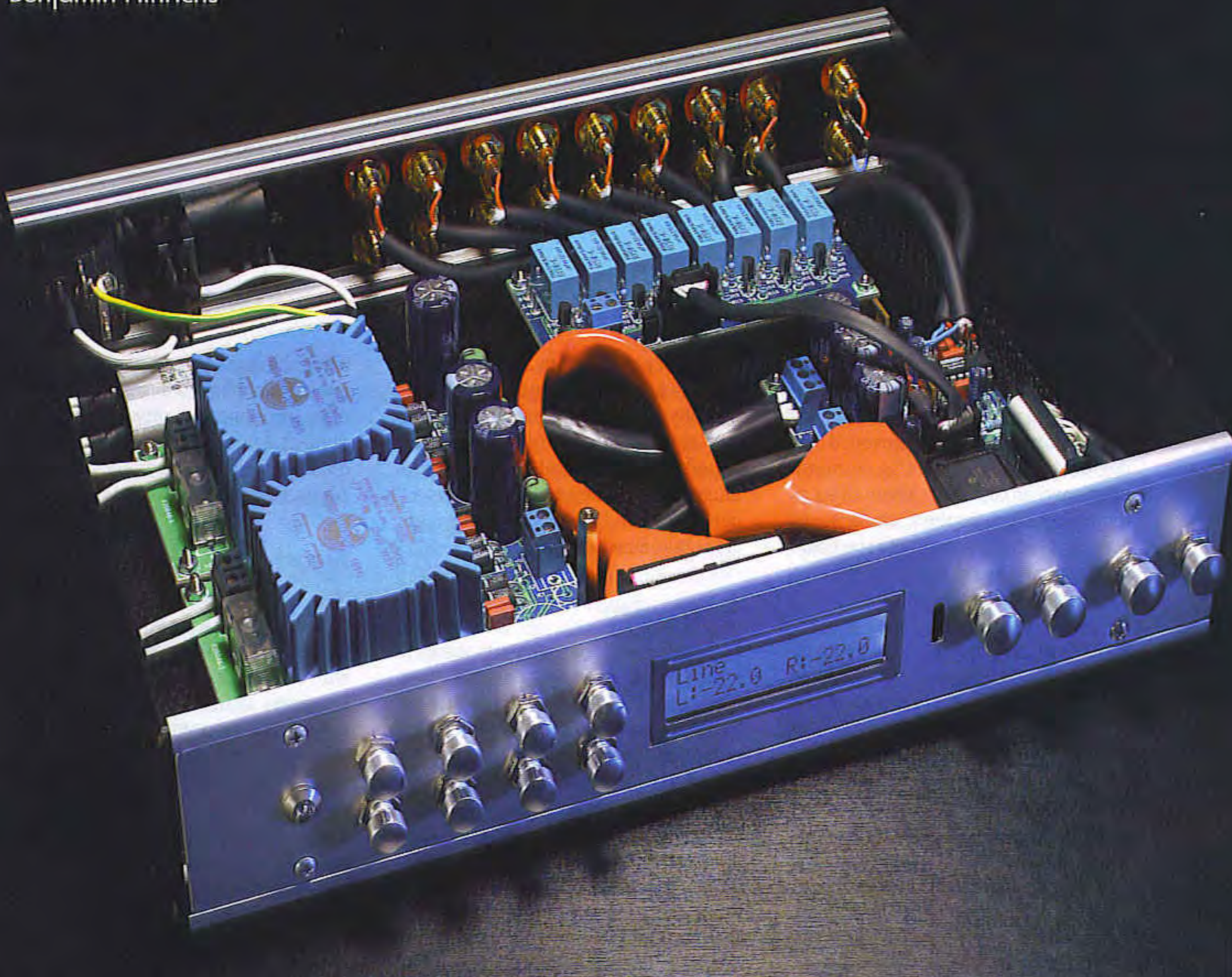
High-End-Preamp (II)

Benjamin Hinrichs



The modular design and flexibility of the microcontroller program allow the preamplifier to be built exactly according to the individual requirements of its user.

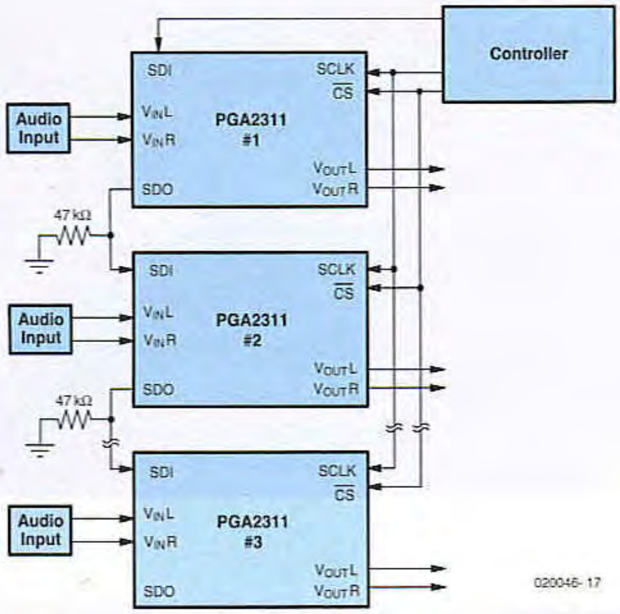


Figure 1. Connecting several volume controls in parallel.

The multitude of options for constructing your 'personalised' high-end preamplifier mean that you must read this second part of the article **before** you order the parts and take up your soldering iron. This is because your requirements determine how many circuit boards of which type you will need, as well as which components you will need. You can connect several volume controls in parallel as illustrated in **Figure 1**, in order to adjust more than two channels at the same time. If you do this, you must interconnect the CS, Mute, SCLK, +5 V and Ground terminals of the circuit boards. SADATO from the first circuit board is connected to SDATI of the next circuit board, and so on. This causes the volume level setting to be communicated to all of the circuit boards.

You can choose from traditional audio signal switching, switching the ground leads together with the signal leads, or switching balanced signals. If you know how, you can also give the microcontroller additional functionality or modify the details in the software, such as the designations shown on the display.

Populating the board

What we need now are a few instructions for populating the main preamplifier board. This is because the circuit board shown in **Figure 2** is quite compact. The closely spaced, narrow tracks are not particularly forgiving of mistakes, so the components should be fitted properly the first time, and solder splashes and overheated joints should be assiduously avoided.

On the main circuit board, only JP1 and JP3 can be implemented as jumpers. JP2 (directly underneath IC2) is a wire bridge. There is another wire bridge at the inner edge of K5, which should be fitted immediately: done is done!

Now you should consider whether the programming and/or paralleling connections are necessary. If you arrive at a positive conclusion after studying the two text boxes, then you must fit the associated connectors (refer to the components list) and the solder pins for the audio signals. Despite all the claims to the contrary, it certainly makes sense to fit the solder pins before the other components. Generally speaking, they need a bit of coaxing, and sometimes they can only be pressed into the holes using (brute) force. Besides this, a 1.3-mm diameter silver-plated steel pin requires a considerable amount of heat to achieve a reliable bond with the solder. And if you find a solder pin standing at an angle to the board, you can start all over again. This can be the kiss of death for small, sensitive components that have already been fitted in the immediate vicinity.

If you use a decent stuffing frame, it doesn't matter very much if the low-profile components (resistors, capacitors, and diodes) are only fitted afterwards. As always, proper polarisation is important for some of the components. Besides the diodes and small electrolytic capacitors, this also includes the resistor arrays and the PLCC socket, which is bevelled on one corner. This marking must match the component overlay on the circuit board. Now it the right time to **not** fit LED D1 if you want to use it as a pilot light on the front panel. This LED, along with IR receiver IC3, should only be soldered in place after the circuit board has been securely fitted in the enclosure and the two components have been fastened in holes drilled in the front panel. If your enclosure layout does not permit the circuit board to be placed directly behind the front panel and you thus must fit the IR receiver off the board, a screened connection cable is mandatory.

The fixed voltage regulators IC4–IC6, which should be soldered in place after pin headers K3–K5 and the high-quality DIL socket for the PGA2311 have been fitted, do not require heat sinks. The soldering work is completed with the fitting of the three large electrolytic capacitors and the two circuit-board terminal strips (K1 and K2).

If you wish to control several volume control boards in parallel, fully popu-

COMPONENTS LIST main board

(020046-1))

Resistors:
R1 = 27Ω
R2,R9 = 47kΩ
R3 = 8-way 10kΩ SIL array
R4 = 4-way 10 kΩ SIL array
R5 = 1kΩ5
R6,R7,R8,R10 = 10kΩ
P1 = 10kΩ preset
P2 = 100Ω preset

Capacitors:
C1,C2,C3,C20 = 10µF 25V radial
C4-C11,C14,C15= 100nF
C12,C13 = 27pF
C16,C17,C18 = 2200µF 25V radial
C19 = 100nF ceramic, lead pitch 5mm

Semiconductors:
D1 = low-current LED (+ 2-way pinheader)
D2.,D3,D4 = zener diode 5V6, 1.3W
IC1 = PIC18LF452-I/L (PLCC). Blank ICs: Farnell # 400-9654. Programmed ICs: order code **020046-41**
IC2 = PGA2311PA from Texas Instruments/Burr-Brown or CS3310 from Cirrus Logic (Crystal)
IC3 = SFH5110 (TSOP1836) (+ 3-way pinheader)
IC4,IC6 = 7805
IC5 = 7905
T1 = BC550C

Miscellaneous:
JP1,JP3 = 2-way pinheader + jumper
JP2 = wire link
K1 = 3-way PCB terminal block, lead pitch 5mm
K2 = = 2-way PCB terminal block, lead pitch 5mm
K3 = 16-way pinheader

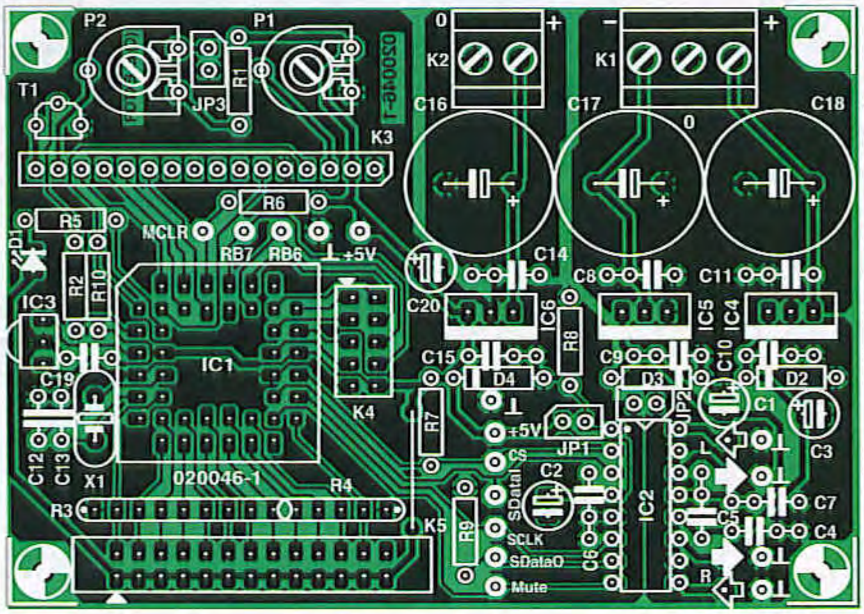
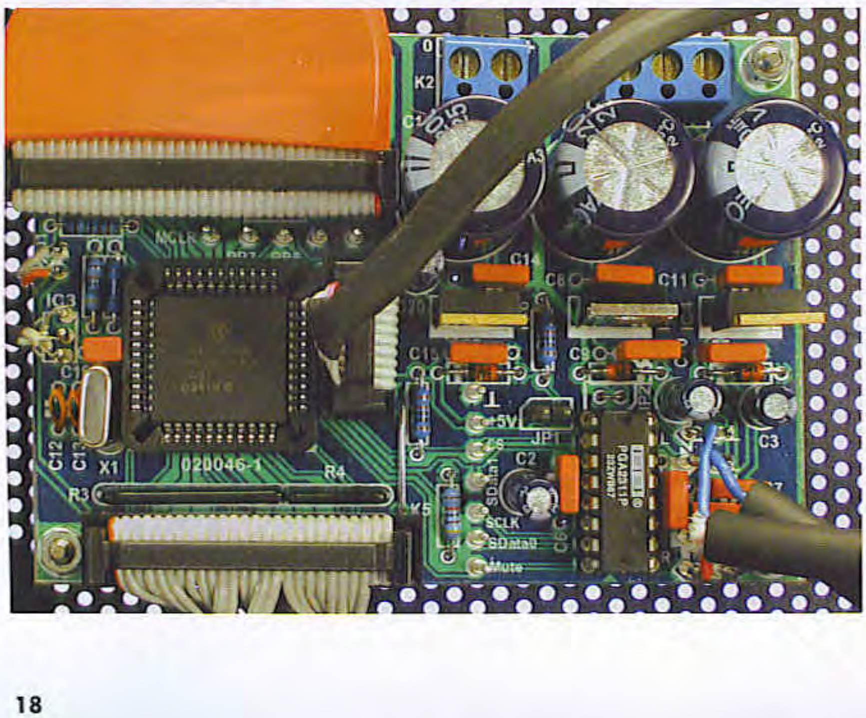


Figure 2. Component layout of the tightly arranged but single-sided main circuit board.



late one main circuit board and fit only the portion with the PGA2311 (including the peripheral circuitry and the voltage regulator circuitry) on the other boards.

The system has been tested using a single controller board and two parallel circuit boards. All of the necessary connection points are located in a row on the circuit board.

Channel switching

The input channels are switched on the relay board. The circuit shown in **Figure 3** allows two different wiring options.

With the **traditional** option, all eight inputs from the Cinch sockets are used, with a single output to the main circuit board. This requires JP2 and JP3 to be fitted. Each relay is then responsible for one stereo channel. If standard twin screened audio cable is used, one channel is connected to A and the other to B, and the screen braid is soldered to the bottom of the circuit board. **Ground isolation**, which may be desired to improve channel separation or avoid interconnecting the grounds of different items of equipment connected to the preamplifier, can be achieved by switching not only the signal lines, but also the associated ground potentials. In this case, for each channel the 'live' lead is soldered to A and the ground lead is soldered to B. In addition, jumpers JP2 and JP3 are left open. In this mode, each pair of relays (RE1 & RE5, RE2 & RE6, RE3 & RE7, and RE4 & RE8) belongs to a single signal source. This yields four stereo inputs and two sets of outputs (OUT1A & OUT1B and OUT2A & OUT2B). Here again A corresponds to the 'live' lead and B to ground. The

COMPONENTS LIST relay board

K4 = 10-way boxheader, vertical
K5 = 26-way boxheader, vertical
X1 = 10MHz quartz crystal
12 solder pins
External parts:
LCD, 2x16 characters with backlight
12 pushbuttons for chassis mounting
2 Cinch sockets for chassis mounting, isolated and gold-plated
Mains on/off switch, chassis mount
IEC mains appliance socket, chassis mount
Disk, hex and source code files, order code **020046-11** or Free Download.

(020046-2)

Resistors:
R1-8 = 10kΩ
R9-R16 = 47kΩ

Semiconductors:
D1-D8 = 1N4004
D9-D16 = low-current LED
T1-T8 = BC550C

Miscellaneous:
JP1 = 2- way pinheader + jumper
JP2,JP3 = wire link
K1 = 10-way boxheader, vertical
K2 = 2-way PCB terminal block, lead pitch 5mm
RE1-RE8 = RY5W-K (Takamisawa), Conrad Electronics # 502852 (5V/167Ω)
16 Cinch sockets for chassis mounting, isolated and gold-plated

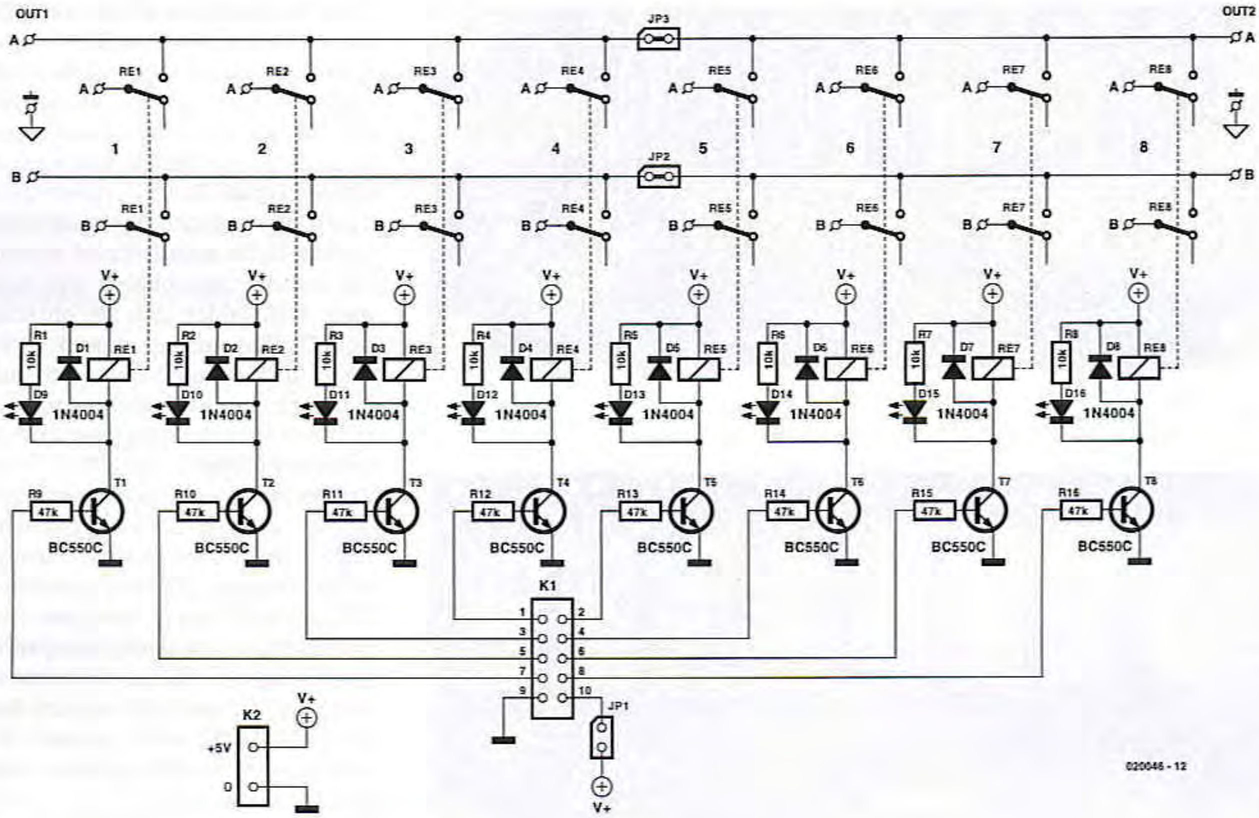


Figure 3. The relay circuit also allows ground isolation and connecting balanced signal sources.

only other thing you have to do is to change the Input Type option in the Set-up menu to 'Double'.
In order to handle **balanced signals**, we simply switch two relays simultaneously. In this mode, you also have to add a second, parallel volume control and then connect the balanced signals to one of the input channels (such as Left In) on both volume controls. This works well – quite well, in fact.
Fujitsu (formerly Takamisawa) type RY-5W-K relays are used here. Naturally, other pin-compatible types could also be used, but the specified line has excellent characteristics and is available for less than 2 euros (approx. £1.40), for example from Conrad Electronic (www.conrad.de). This is a plastic-encapsulated relay, which prevents any dust from accumulating inside. The contacts are made from a silver–palladium alloy with supplementary gold plating.
Power for the relay board is taken from the main circuit board via connector K1 (which requires jumper JP1 to be fitted). If you wish to treat the channel switching board to its own power supply or you want to use this board in a different project, you can also connect a 5-V supply to the K2 terminals.
In order to avoid overloading the microcontroller outputs, transistors with base resistors are used as relay drivers. Diodes D1–D8 act as free-

Software modifications

Microcontroller programming is normally not the forte of audiophiles who have dedicated themselves to DIY construction. Consequently, most people will probably be quite pleased to know that the microcontroller can be obtained ready-programmed from Readers Services under order number 020046-41. However, anyone who has a suitable development package for the PIC18LF452-I/L will certainly not have any problems downloading the hex code for the control program into the microcontroller (item number 020046-11, available at no charge from the Free Downloads page of the Elektor Electronics website or on diskette from Readers Services). The easily constructed JDM programmer (see reference [4]) is an example of a suitable programmer.

The software package also contains the source code, so interested users can get an idea of how it is constructed and/or make their own modifications (assuming they have suitable programming experience). The software is written in the JAL high-level language (see reference [5]), which is available from the Internet as freeware. JAL is an excellent choice for getting started with PIC microcontroller programming, particularly since there are also very informative newsgroups on this subject (see reference [6]). Nevertheless, it was necessary to make a few modifications to the JAL files in the assembly code since JAL

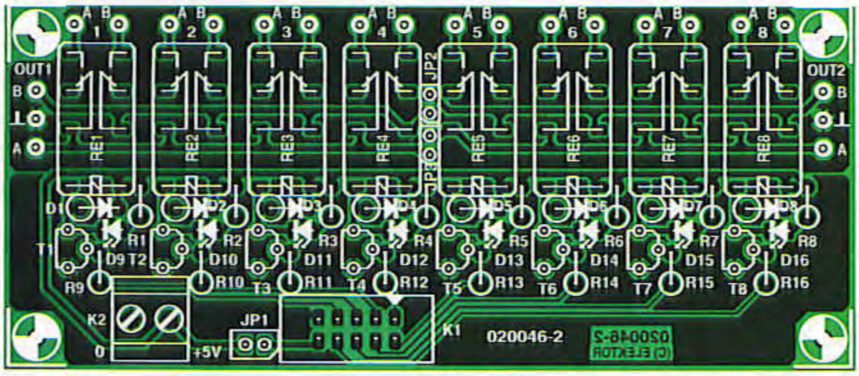
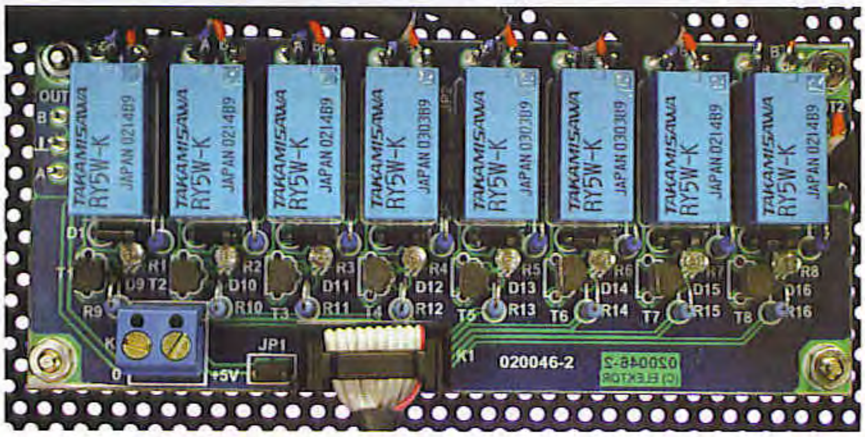


Figure 4. Eight double-pole relays all nicely in a row.



wheeling diodes, while LEDs D9–D16 provide a visual indication of the relay states. The LEDs do not necessarily have to be fitted to the circuit board (**Figure 4**); they can of course be fitted to the front panel instead if you want to do without the display, or they can simply be omitted (along with their series resistors).

JP1 can be implemented as a jumper, but JP2 and JP3 should be implemented as wire bridges. Otherwise there's not anything particularly remarkable about populating the circuit board, particularly if you use the components specified in the components list and everything fits perfectly.

Stable supply

A large part of the stabilisation, decoupling and hum suppression for the supply voltages takes place locally on the main circuit board, for both the digital portion (+5 V) and the analogue portion (5V). The only other thing you need is a sufficiently stable source of symmetrical DC voltages (which shouldn't be a problem with the low current consumption). This provides an opportunity to use a general-purpose low-power mains power supply (**Figure 5**).

The power supply is designed to use Talema 10-VA encapsulated low-profile toroidal transformers (see reference [2]), which can be obtained from DigiKey (among others). Particularly for audio applications, toroidal transformers are preferable to other types of transformers due to their low stray fields.

The power supply circuit board is general-purpose because it can be configured to provide either an asymmetric supply voltage (V+ and ground) or symmetrical supply voltages (V+, ground and V–) by simply fitting either wire bridges 'A' (for asymmetric output) or 'B' (for symmetric output). Naturally, C6 and R2 are not needed if it is configured to provide an asymmetric supply voltage.

The output resistors (R1 & R2) should be wire-wound types, since this further reduces the hum voltage. Fast diodes with a recovery time of less than 200 ns are used as rectifier diodes (D1–D4) — for comparison, the recovery time of standard 1N4004 diodes is 1.2 µs, which is more than six times as long. If you wish to use ultrafast diodes (< 50 ns), you are of course free to do so.

Small foil capacitors are connected in parallel with the rectifier diodes to effectively suppress high-frequency noise, which primarily arises from diode switching transients. Each circuit board is protected by a slow-blow fuse rated at 125 mA.

Fitting the components to this board

does not provide native support for storing code in the EEPROM of the PIC18F452. All of the modified files are included in the project. If you wish to make changes to the source code, you should adjust the path names in the accompanying JAL.BAT file and use them for compiling. The software was compiled against JAL 0.4.59.Win32.

The software was entirely written by the author, except for a few functions such as driving the display, for which JAL provides native support. Functions such as the SPI interface code and acquiring RC5 signals were specifically developed for this project. Modification and/or reuse of parts of this software, including in your own projects, is explicitly desired, as long as the author is named and the software is used for non-commercial purposes (which means at home). More on this subject can be found in the file VV.JAL.

The PIC18LF452 can easily be programmed in-circuit. For serial in-circuit programming, a number of conditions must be satisfied: the PBGA2311 must be removed from its socket, and the connectors for the display and relay board must be disconnected. The programming interface comprises five connections: MCLR, RB6, RB7, +5 V, and Ground. These connections are arranged in a row on the circuit board and fitted with solder pins.

(**Figure 6**) is also about as simple as could be imagined. First solder the wire bridges in place (one circuit board with the three 'A' wire bridges and a second one with the three 'B' wire bridges). Then fit the remainder of the components in any desired order. Mount the series resistors vertically.

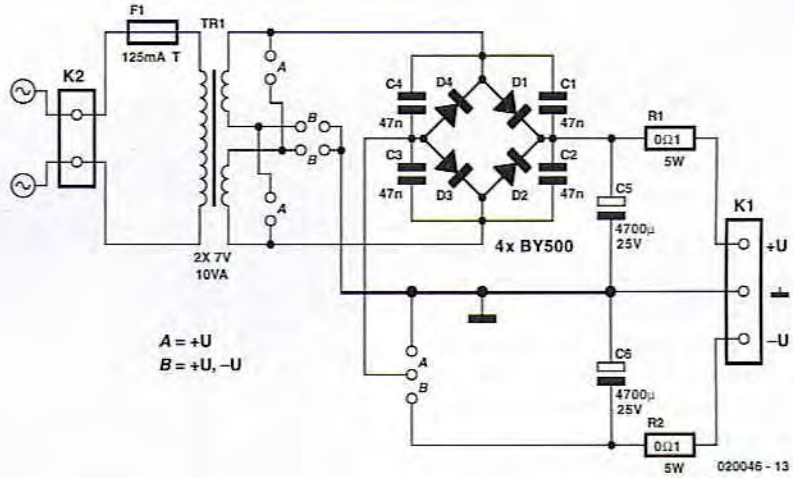


Figure 5. The mains power supply can provide unipolar or symmetric output voltages.

Testing, testing, testing... and into the box

Before inserting the microcontroller and the PGA2311 into their sockets and connecting the display, you should painstakingly check all the boards for incorrectly fitted components, dubious solder joints and solder bridges. The first test should be performed with the boards outside of the enclosure. To hold the boards securely in place for testing, screw them to the workbench using standoffs under each of the boards.

First connect the power supply boards and check the voltages at their outputs. Due to the high open-circuit voltage and the combination of rectification and filtering, the measured voltage will naturally be somewhat higher than the 7 V specified for the transformer.

Next, connect all of the boards together and switch on the power. Nothing will happen, but the following voltages should be present at the appropriate IC pins and the display module connector:

+5 V:
K3-2, IC1-12, IC1-35, IC2-4, IC2-12

–5 V: IC2-13

If everything is OK, wait a few minutes to allow the capacitors to discharge, and then insert the ICs and connect the display.

The display, the microcontroller and the volume control IC are highly sensitive to static electricity. As all of these components are not exactly inexpensive, you should work at a suitably earthed workstation.

Figure 7 gives a deep insight into the laboratory prototype of the digitally controlled high-end preamp. The mains filter was fitted because it was 'already on hand', but it is fully adequate. The power supply boards and the main board are separated as far as possible. Nevertheless, the FFT analysis (see Part 1) shows that induced 50-Hz noise is responsible for the majority of the distortion. If you want to improve matters and are not afraid of a bit of effort, you can fit the sensitive audio portion into a suitable tinplate enclosure.

At the rear, besides the mains input socket there are two sets of eight audio inputs and two audio outputs, all using isolated gold-plated Cinch sockets. After the 'official' completion of the device in the *Elektor Electronics* lab, further tinkering revealed that small RC networks on the inputs suppress induced RF noise on the cables, and that a 100-Ω series resistor in each of the output lines assures the stability of the PGA2311. As shown in **Figure 8**, these components should be soldered directly to the Cinch sockets using the shortest possible leads, or even fitted in the connecting cable, in order to maintain the highest possible degree of screening.

In contrast to the audio connections, which employ high-quality twin screened cable, the keypad (which

COMPONENTS LIST PSU

asymmetrical
(020046-3)

Resistors:
R1 = 0Ω1 5W

Capacitors:
C1-C4 = 47nF, lead pitch 5mm
C5 = 4700µF 25V radial, max. dia. 16mm

Semiconductors:
D1-D4 = BY500-200

Miscellaneous:
F1 = fuse, 125mA, slow, with PCB mount holder
K1 = 2-way PCB terminal block, lead pitch 5mm
K2 = 2-way PCB terminal block, lead pitch 7.5mm
TR1 = mains transformer, 2x7V 10VA, low profile, e.g. Talema 70040 (RS-Components, Digikey)

Fit wire links 'A'
Do not mount R2, C6

symmetrical
(020046-3)

Resistors:
R1,R2 = 0Ω1 5W

Capacitors:
C1-C4 = 47nF
C5,C6 = 4700µF 25V radial, max. dia. 16mm

Semiconductors:
D1-D4 = BY500-200

Miscellaneous:
F1 = fuse, 125mA, slow, with PCB mount holder
K1 = 3-way PCB terminal block, lead pitch 5mm
K2 = 2-way PCB terminal block, lead pitch 7.5mm
TR1 = mains transformer, 2x7V 10VA, low profile, e.g. Talema 70040 (RS Components, Digikey)

Fit wire links 'B'

does not have a circuit board) and the front-panel LED are connected using simple flat cable. This allows a relatively large amount of freedom in the layout of the front panel. For example, the volume buttons can be arranged in a diamond pattern (if sufficient room is available). You can spare yourself the trouble of looking for a distributor for the attractive metal buttons used for the prototype – they were personally turned by the author.

The bright red cable between the main circuit board and the LC display came from a computer shop. But be careful: many of the cables available in such shops have crossed lead pairs. In case of doubt, a 'normal' flat cable is also perfectly satisfactory.

(020046-2)

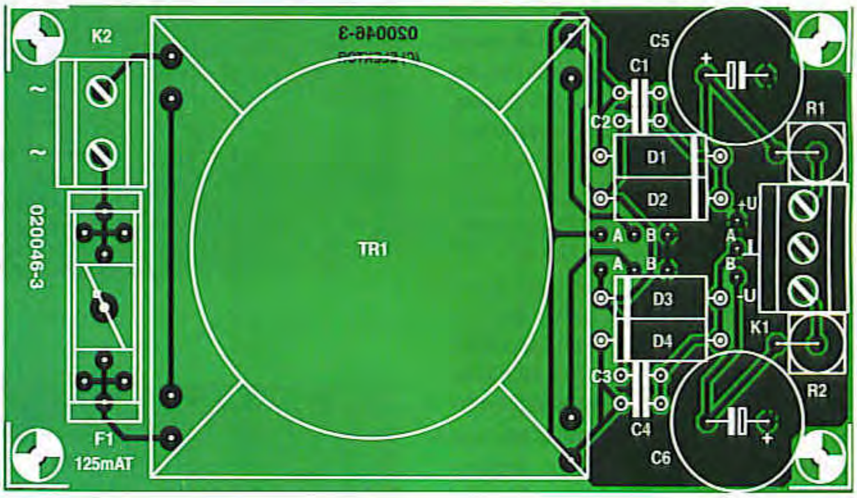
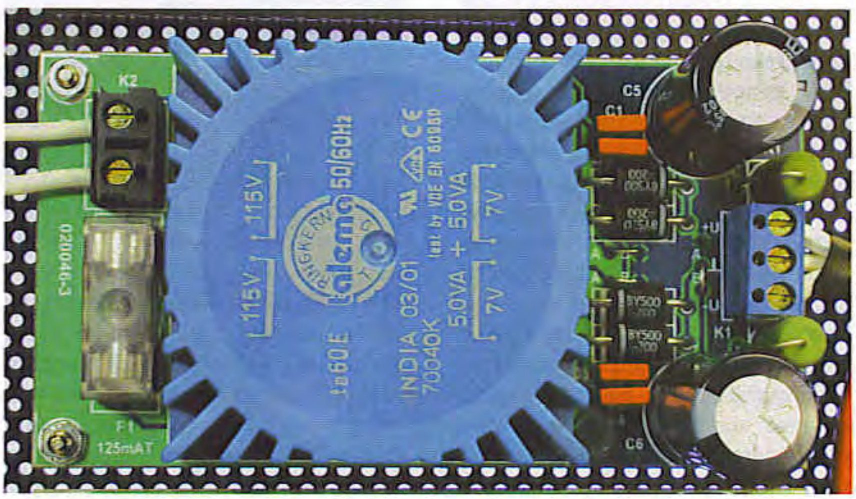


Figure 6. The power supply board should be fitted as far away as possible from the main circuit board.



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[4] www.jdm.homepage.dk/newpic.htm

[5] http://jal.sourceforge.net

[6] http://groups.yahoo.com/group/jallist