High-End-Preamp

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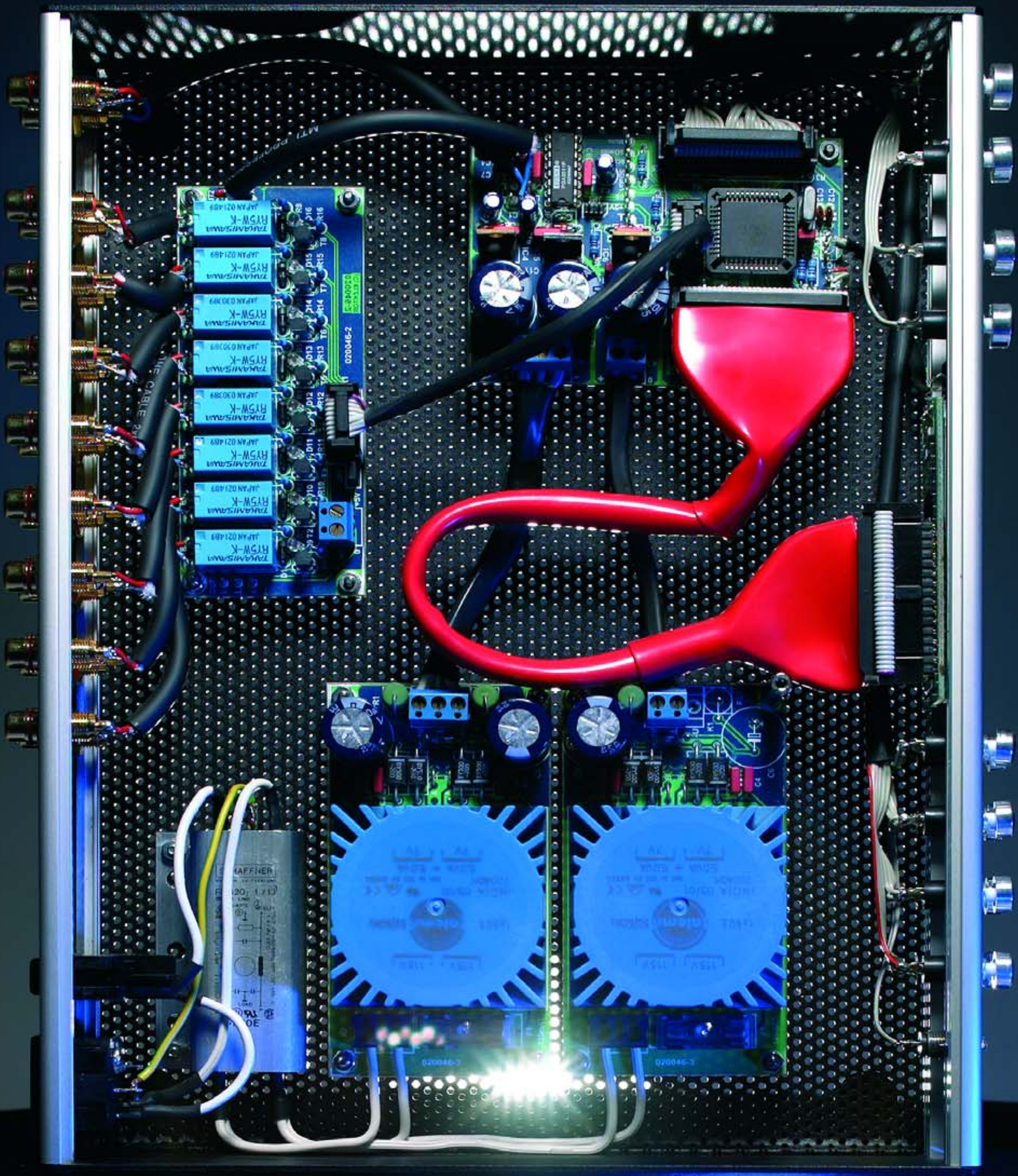


The modern design of this preamplifier yields audiophile specs, convenient operation and an attractive price. This is made possible by using a top-end digitally controlled attenuator/amplifier IC.

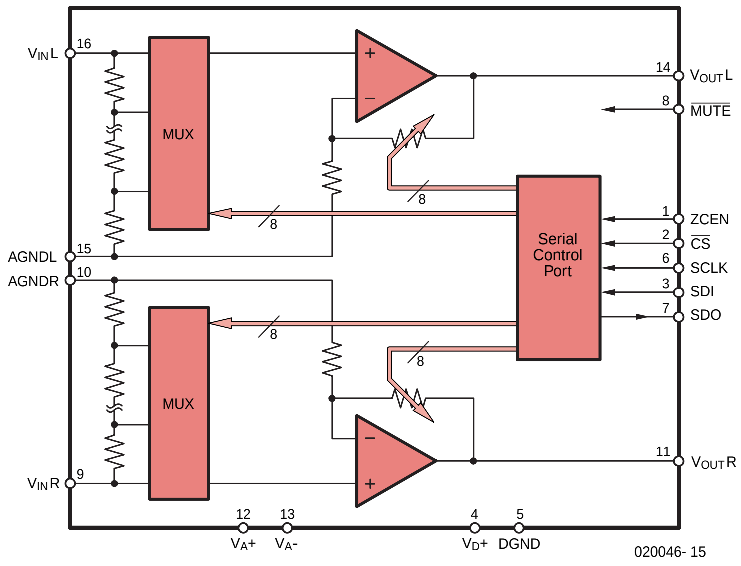


Figure 1. Functional block diagram of the PGA2311. The attenuation and gain are configured using a 3-wire serial bus.

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

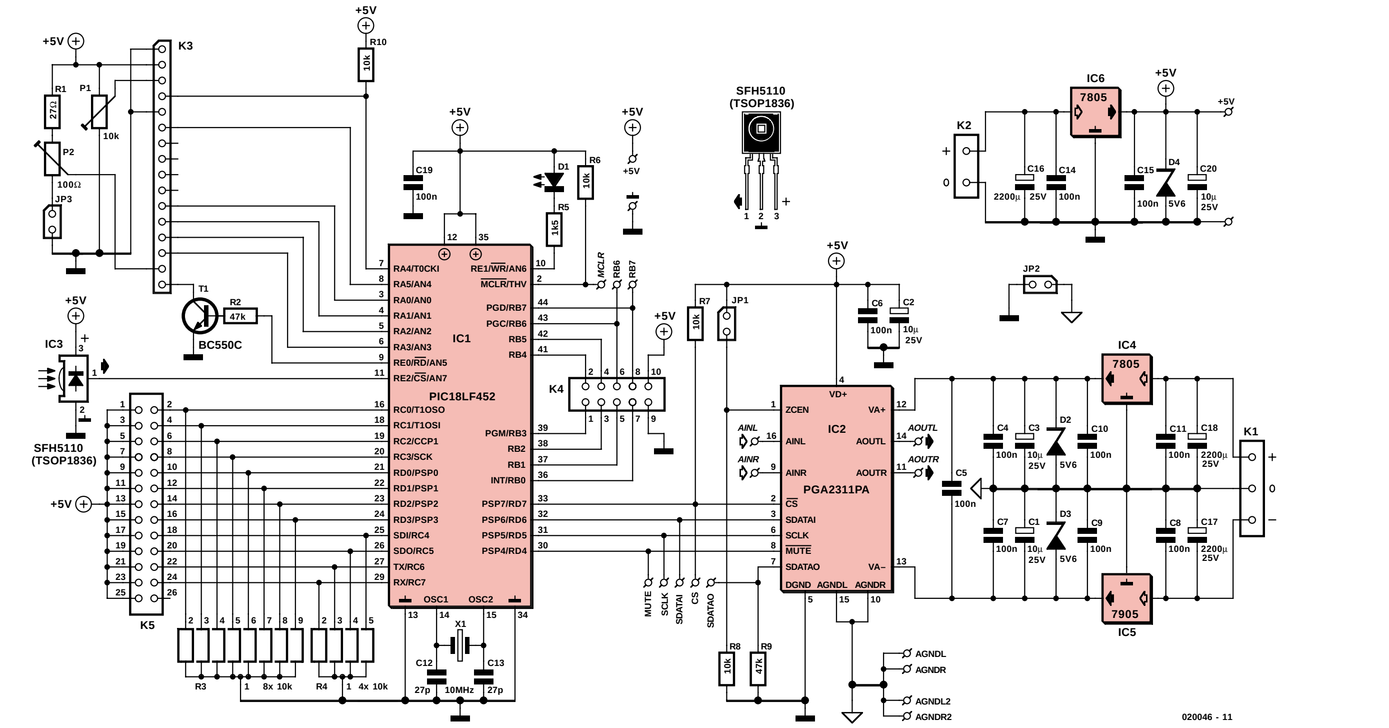


Figure 2. Circuit diagram of the main circuit board, which is divided into an analogue part and a digital part.

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.

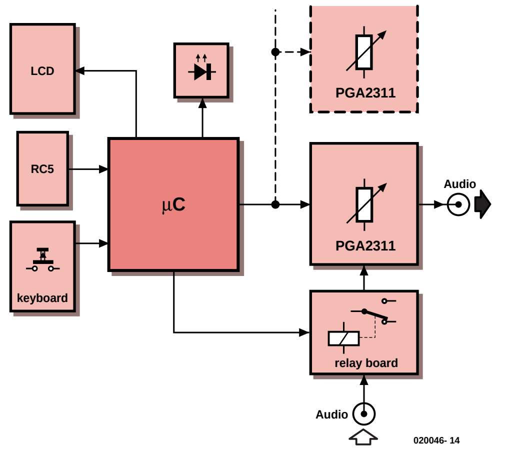
The control centre

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

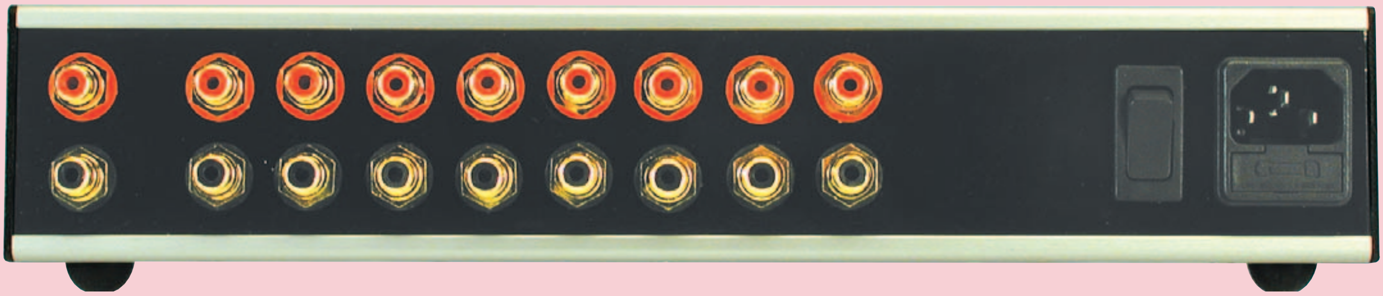
LEFT	Exit
RIGHT	Next

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 (pre-amp), 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

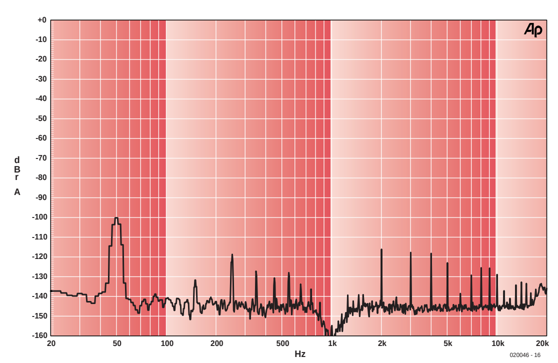
DOWN/UP	Delay Off / Always Off / Always On
LEFT	Exit

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-I)

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