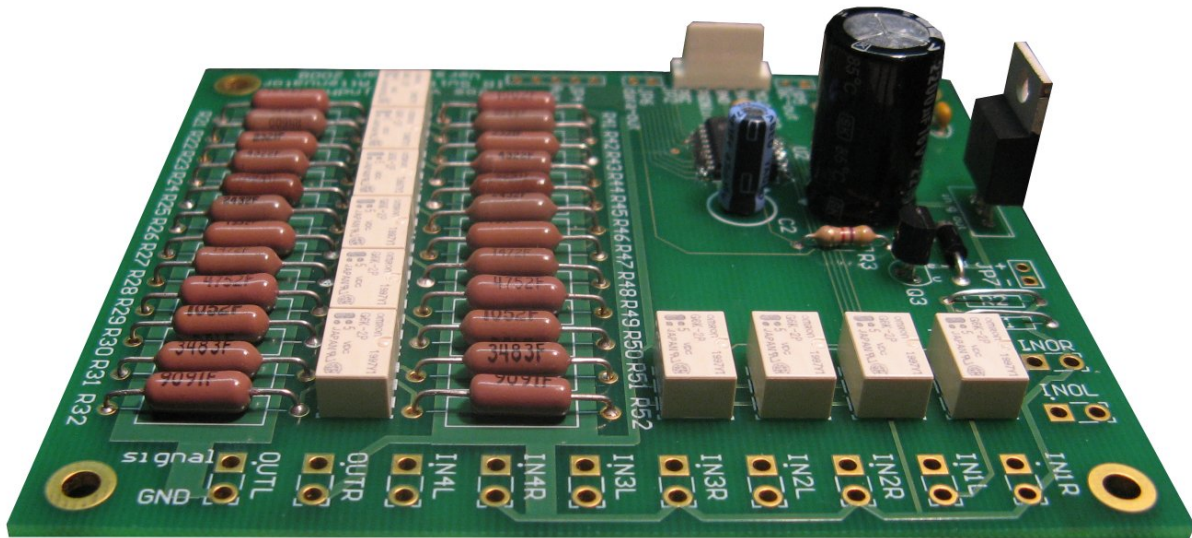# Attenuator build and use guide

This document describes the audio attenuator design as of January 2008.
It is part of the design documentation on the website at: http://jos.vaneijndhoven.net/switchr/design.html

Document version Jan. 4, 2009
(Updated to reflect the remote-control behavior of a new firmware version.)

Characteristics

The described attenuator provides infra-red remote control for audio volume and input channel selection. Both volume and channel selection is performed through miniature relays. Six tiny relays implement a stereo 64-step logarithmic attenuator. The combination of relays with high-quality (small signal) contacts and prime quality resistors provides a top-class audio volume control, audibly better then conventional potentiometers that employ a sliding contact over a resistive layer. The chosen sealed relays will maintain their contact quality over an extremely large time span. A standard setup employs a small front (control) PCB for IR-reception with a visual (display) feedback and a switch for manual control, next to the main relay PCB that performs the actual audio handling. This relay PCB provides relays for a 2-channel (stereo) volume control and input channel selection. Multiple of these relay PCBs can be tied to a single front control module: 2 prints can be used for balanced (symmetrical) audio systems, 3 prints for 5.1 surround systems, or 4 prints for 7.1 systems. The front-PCB and the relay-PCB have a three-wire connection for control, there is no audio passed over this link. The PCBs have a gold finish on their soldering contacts. This gives a great look, but also solders nicely, and some believe that it helps to improve sonic quality.

Traditional potentiometer usage provides a constant input resistance, and variable output resistance. The switched-attenuator in this design in principle works the other way around: it has variable input resistance and constant output resistance. You could use this attenuator as a complete passive pre-amplifier. It depends upon your power amplifier whether the relatively high output resistance is OK for your system. In general, tube amplifiers feature a high input resistance, and might do fine. Also, integrating this passive attenuator into your audio amplifier has worked out nice in many earlier projects. Otherwise, you can actively buffer the output signal of the attenuator, In general, I would hesitate a little to drive inter-chassis audio cables from just this passive attenuator. On the positive side, the passive nature of this attenator without any semiconductor in the signal path provides an extremely clean and open sound, which is very hard to match by an active amplifier.

The device has volume levels from 00 up to and including 64. Volume levels 01 to 64 span a dynamic range of 64dB with 63 steps of 1.0 dB. Volume level 00 really disables the input signals giving zero output.

The default resistor set that I apply, is a series of 12 resistors per channel (R21-R32 and R41-R52), with values of 10K, 82.5K, 2.32K, 43.2K, 5.23K, 24.3K, 13.3K, 14.7K, 47.5K, 10.5K, 348K, and 9.09K. The input resistance of the attenuator circuit depends upon the relay setting (the volume), but will always be above 22Kohm. The attenuator output impedance is a constant 8.9 Kohms. At some later time I will add here a table with alternative resistor values should you want a lower or higher-resistance attenuator. In that case you should find and order such resistors yourself, I do not intend to stock and offer different sets as part of the kit.

The attenuator PCB provides 4 relays for the selection of 4 stereo input channels. If you strongly desire more input channels, you can extend this to 5, 6, or 7. The microcontroller firmware and display do have support for that. For such extension you would need to connect up to three extra input channel relays outside the PCB. The relay-coil control wires are provided through the JP4 connector, pins 1, 3 and 4. (Probably you would like to ask me for the extra relays.) Clearly, if you just seek a volume control and don't want any channel selection, you can of course omit the 4 input relays from the PCB.

With all my documentation on the website, other DIY audio hobbyists might feel inspired, and are invited to design and build their own variation based on this example. However, I do not intend to provide my firmware in source or binary form.

Building the attenuator

You will receive the front-PCB and the relay-PCB from me with their microcontrollers already mounted and programmed with their firmware, as shown in this foto:
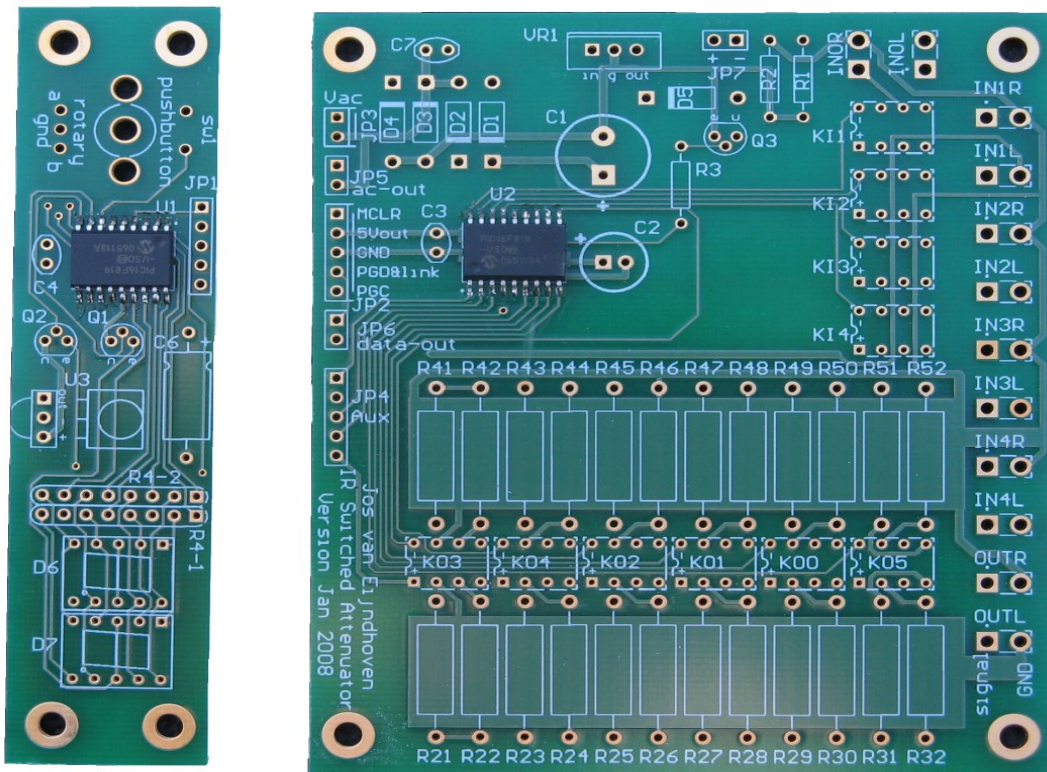
All required (PCB-mount) components are provided seperately, for your own mounting&soldering. Choose a mounting sequence with the lowest profile components first. That allows easy fixing of the components while PCB lies upside-down on your desk.

1. **Resistor set**
    The resistors that I provide are 'RN60D' USA-milspec resistors manufactured by Dale, which have a reputation for their excellent sonic quality. They indicate their value with a 4-digit number and one character. The first 3 digits provide a base value, and the 4th digit provides a powers-of-ten multiplier. This 4th digit must be read as the number of 0's after the first three digits. For example, a code of '8252F' indicates a value of '82500' ohms or 82.5 Kohms. The final 'F' indicates a 1% tolerance.You should mount the Dale resistors with their value-identification facing upwards, allowing you to verify their mount position. The picture below is an example of my own test version, showing their readable values. It has been increasingly difficult for me to acquire these Dale resistors at reasonable cost. Unfortunately this has resulted in a resistor set where for many of you a single value (47.5K) is replaced by a highly similar 'RN60D' milspec resistor from a different brand, that has a black coating instead of the typical brown.
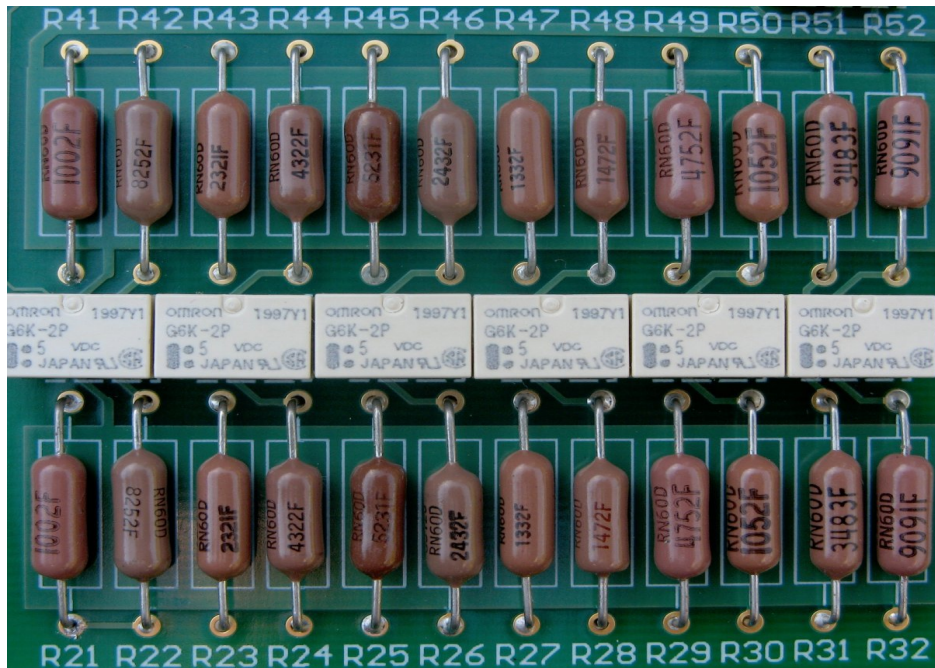
2. **Relays, displays, ...**
   Be VERY careful about mounting these components in the proper orientation!!!
   The annotation on the PCB is probably clear by itself. Additionally (for all
   components) their 'pin 1' is identified by a square soldering pad. With the through-
   metalised holes as in this PCB, it is almost impossible to remove (unsolder) an
   already mounted component.
   The kit contains a pair of red 10mm 7-segment displays. Occasionally I get a request
   for a blue display. Sometimes I can provide you with the pin-compatible blue 'FN1-
   0392B050JGW' made by Forge Europe. Normally I do not keep these in stock: in my
   opinion they are too expensive (adding about E18,- to the kit), and the red seems for
   my eyes easier to read from some distance.

3. **AC Input power**
   AC power should be applied to the small 'JP3' 2-pin connector. The circuit will operate
   from a 6.0 to 7.5 Vac transformer. A pair of a display and a relay PCB together take a
   maximum current of 250mA. A relay PCB alone takes a maximum of 190mA. You can
   check that the DC voltage on C1 is between 6.5Vdc and 10Vdc. Higher voltages
   cause the LM2940 to get warm, requiring a small ('clip-on') heatsink. If you connect
   the attenuator to a 6.3Vac of your tube amplifier transformer, you will like to avoid that
   this rectifier back-fires dirty effects into your precious tube amplifier transformer.
   Schottky-type diodes are applied in stead of basic rectifier diodes, since schottky
   diodes do not generate 'reverse-recovery' spikes. To further eliminate such effects a
   small 22nF decoupling capacitor was added to filter the AC voltage. The low-drop
   schottky diodes and low-drop regulator together enable operation from the low 6Vac.
   If you buy a separate transformer for the attenuator, a small 6V / 2.3VA type would be
   sufficient. In power-down mode, the circuit remains to consume 25mA, corresponding
   to about 0.2W.

4. **Rotary switch**
   Connecting a rotary switch for manual volume control and channel selection is
   optional, the circuit can be used fine from an IR-remote only. The applied type of
   switch is a 'rotary pulse generator' which can be turned around and around without
   mechanical blocking. It uses 3 connections: one common pin connected to ground,
   and 2 signal pins, denoted 'Vol a' and 'Vol b' in the schematics. The microcontroller
   has a weak pull-up on these two signals. The switch will -in steady state- leave either

both pins open (at 5V) or short both to GND (0V). When the switch is in transition, one of the pins will precede the other in its transition. The rotation direction is derived from this transition order. Next to that, this switch has a built-in push-button, activated by pressing the shaft. This function is used to switch to the next input channel, or for power-up and power-down. Several users of my earlier attenuator version chose to NOT mount this switch on the PCB, but mount it elsewhere in their front panel, using a set of 5 wires to connect the switch to the PCB. Be aware that once soldered-in, it would be almost impossible to get it off the PCB again without damage.

5. **Power relay output**
   The relays PCB allows to optionally connect a power-switch relay to switch on/off other equipment from your IR remote. Obviously, this function only works if the AC power of the attenuator itself remains on. Power-switching is triggered by a dedicated button on your remote control, or by keeping the rotary switch pressed-down for about 5 seconds. When switched to the 'off' state, pin 5 on the programming header ('PGC') will be 5V, otherwise it will be +5V (active high). Note that you cannot directly connect a heavy power-relay between this PGC pin and the digital ground (pin 3 on this connector), due to the 5V and 25mA current limitation of the microcontroller. This new version of the attenuator includes an extra buffer stage (R3, Q3, D5) to drive a power relay. You can connect such relay to JP7. If your relay has a polarised coil, connect its '+' to pin 2. To JP7 you can connect relays with 5Vdc coils, up to 100mA coil current, corresponding to a coil resistance of at least 50 ohm. This a large choice, such as the Omron G6K-1117P-US-5VDC and G2RL-1 5DC, or Multicomp HRM-S DC5V.

6. **Connecting the display PCB with the relay PCB(s)**
   The display PCB must be connected to the relay PCB. Each PCB has a 5-pin connector location, and a connector set is provided. Connecting a pair of PCBs through these 5 wires works fine. The 5-pin connection is also used (by me) to download the firmware into the PIC microcontrollers. For normal operation however, only the middle three pins are actually needed. For symmetric (balanced) audio or multi-channel audio set-ups, see the description in the next section.

6. **Grounding**
   The PCB (-duo) implements three electronic circuit sections that are electrically totally isolated from each other: a) The digital control circuit with the microcontrollers, the power supply, the display and the relay coils, b) left audio resistors and relay contacts, c) right audio resistors and relay contacts.
   Each of these three circuits has its own ground, respectively GND, LGND, RGND. Because the PCB doesn't tie these together, you can still choose/apply your own grounding policy as to whether and where to connect these grounds. However, a totally unconnected digital ground seems to induce hum and interference in the audio part of the attenuator. For typical usage, I would recommend to tie together all your ground signals (power and signal) by soldering two small wires in the locations R1 and R2. Maybe there are a few special cases, such as with totally separated monoblock amplifiers, where you might choose to keep LGND and RGND separated. Some of you might also prefer not to use wire bridges but couple the grounds through damping resistors, e.g. 47Ω.

After mounting all components, your PCBs are supposed to look as in the following foto:
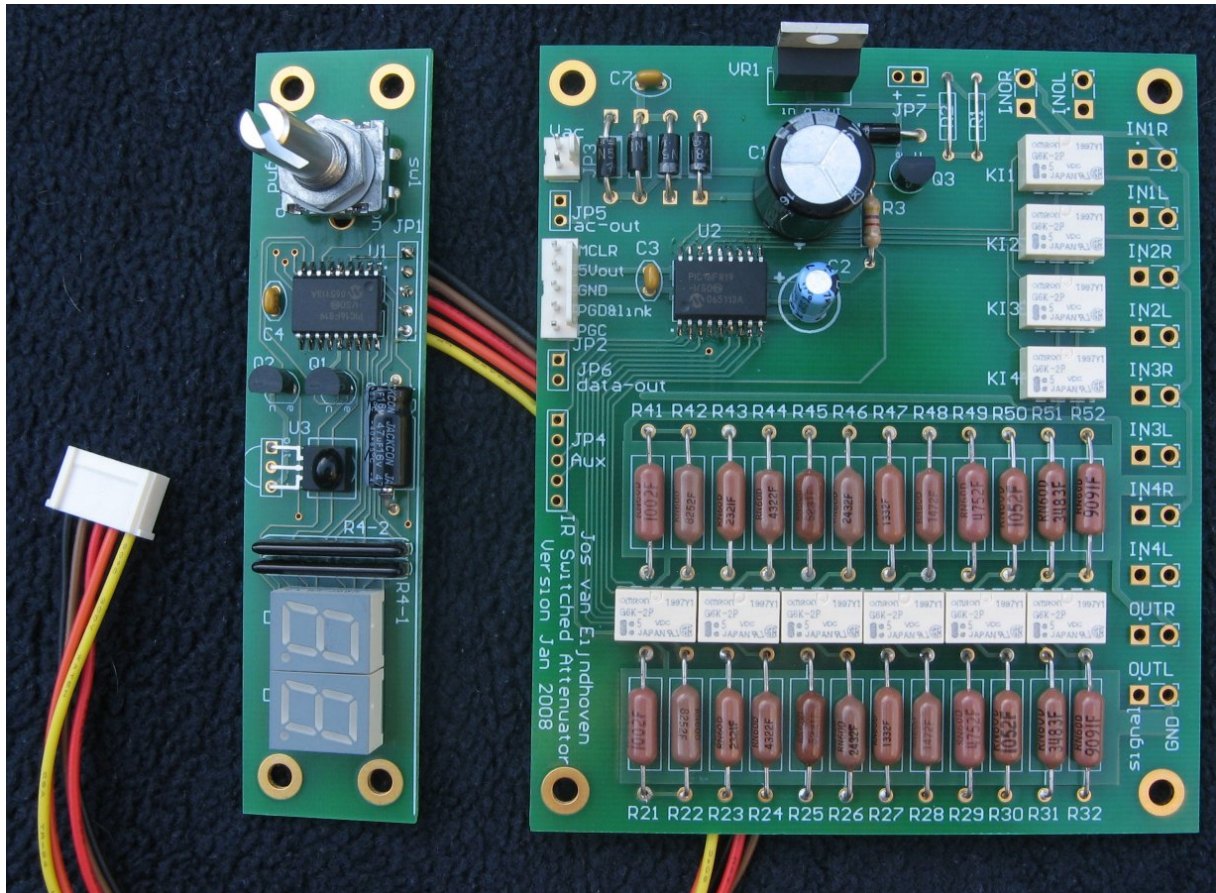
Of course, remarks about basic soldering techniques are not needed, as you already have good skills in soldering... A nice smooth and shiny soldering joint is made by having your soldering wire close to the soldering pad, so that it melts on the pad. If you melt the solder on the tip of your soldering-iron, and wait a few seconds before applying it to the pad&component, it will not attach nicely. If you do a faster job, you get a better result, and reduce the risc of overheating your components. Traditional solder wire has a tin-lead metal mixture with about 40% lead. This the easiest type to work with. For environmental reasons, lead is currently being avoided for soldering. A beautiful alternative is the tin-copper-silver mixture. The (typically 3%) silver content is by some audio enthousiasts appraised for giving better sounding results. As all lead-free types, this has a somewhat higher melting temperature. Finally, thin soldering wire like 0.7 or 0.8 mm, is strongly preferred for this kind of PCB assembly. Your soldering joints are supposed to look like this: ☺
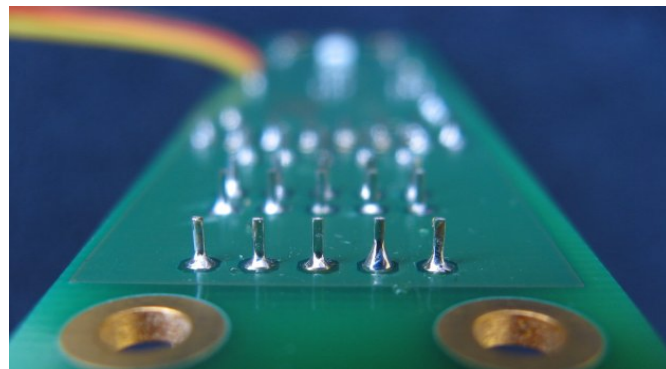

(Note the golden through-metalised holes...)

Multi-channel set-up

The design does support symmetric (balanced) audio or multi-channel (5.1 or 7.1) surround audio. The extra audio channels are handled by connecting extra relay boards to the same front display board. Multiple relay boards connect to one display board in the following way:

- Each relay board connects to the 6V-7.5V AC power. The new PCBs (of Nov. 06) provide an 'AC-out' pair of pins for daisy-chain wiring.
- One relay board connects with (at least) the 3 center pins of the 5-pin connector to the display board. Connecting the left-most and right-most pins is optional but has no function. (These pins are primarily added for programming the PIC micro-controller.)
- All relay boards connect their GND and PGD, located at pins 3 and 4 of the 5-pin connector. The PCBs provide 2 extra output pins for these signals for daisy-chain wiring. The drawing below shows this set-up for a 2-board symmetric audio configuration.
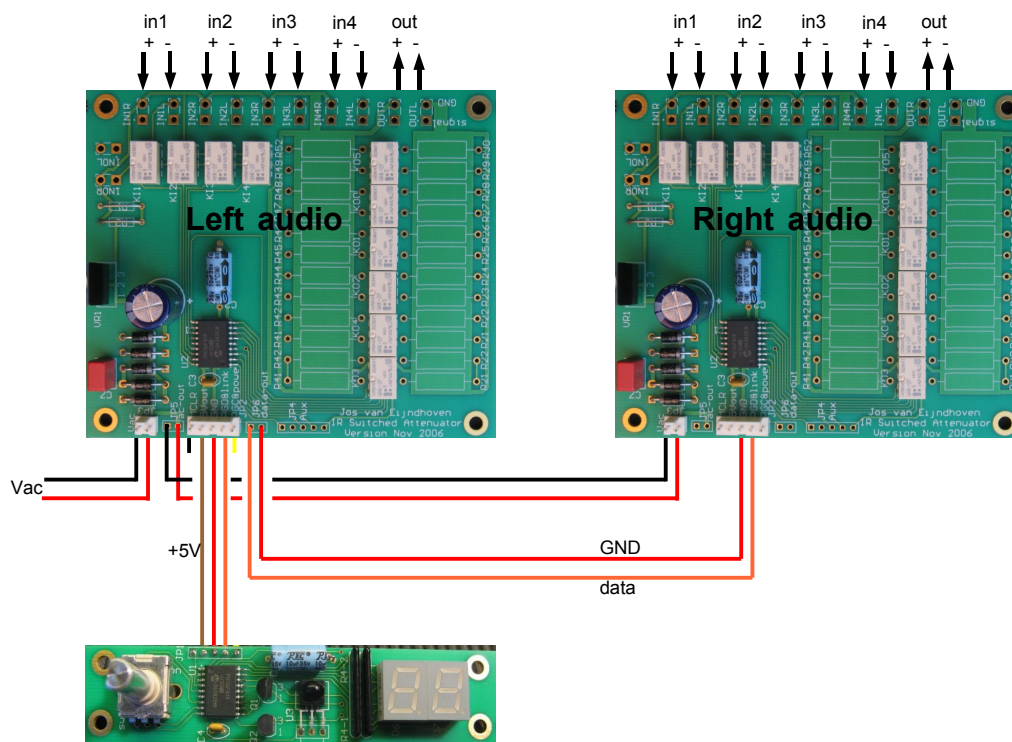
In special applications, it might be nice to operate the attenuator relay PCBs further away from the display PCB, in particular integrating a relay PCB inside each monoblock amplifier. In that situation, only the data signal (pin 4) and the digital GND (pin 3) needs to be distributed, and the display PCB can take its 5V supply from a local source. It is for such a configuration, that each relay PCB has its own 'power down' output signal. A series resistor of 220ohm is recommended in the data signal between the display PCB and off-case connectors to improve safety and damping.

Remote controller compatibility

First thing to do, is to find your own remote control hand-held that transmits IR signals in a format that is understood by the attenuator. There are many different formats, some of them are shared by multiple companies/brands. Clearly, within each format, many different codes are used for activating different functions on different devices. Your attenuator understands the classic Philips RC5 and their newer RC6 format, as well as the Sony SIRC protocol with both its 12-bit and 15-bit versions. For technical information on these formats see for instance the nice website at http://www.sbprojects.com/knowledge/ir/ir.htm. All generic (multi-brand) IR remotes can send these formats. Personally I am using a left-over 'Hauppage' remote from some old PC-TV card. For some remotes the operation is not reliable if you hold them too close to the attenuator: they seem to overdrive the IR receiver.

The attenuator can be operated with above mentioned IR protocols. I verified with some remotes from JVC and Samsung (that use other protocols) that those do not interfere by causing unintended activity.

Note: the text below, including the following chapters, was revised to reflect the new behavior of the Jan.'09 firmware release.

If you power-up the attenuator (the front PCB), and everything works fine, the display starts to count up from '*10.*' to '*30.*' in steps of 2, about a second per step. This reflects the ramp-up of the audio volume, towards the volume that was used before power-down. During this volume-rampup immediately following power-up, the attenuator is sensitive to enter a special programming mode.

In sending a IR signal to the device during this volume-rampup three reactions are possible:

- '*--.*' This indicates that the device cannot deal with the format of the received IR signal. You have to find yourself a different remote (or, for a multi-brand remote, experiment with a different mode) to control the attenuator.
- '*P1.*' A 'P' and one digit indicate entering programming mode. More on that in the next chapter. This mode is automatically left after idling for about 5 seconds.
- '*31.*' A two-digit numeric result means that the device performs a volume adjustment on an understood button function.
- '*C1.*' A 'C' and one digit indicate the selection of another audio input channel.

After the initial volume-rampup is finished, and program-mode isn't activated, only the latter two reactions can appear on the display. The attenuator will silently ignore all IR-signals that are not understood. (Assuming they target some other device.) In its initial firmware state, the attenuator is sensitive to volume and channel IR commands in Philips' RC5 protocol, in accordance with a default (television) device setting.

Configuring IR reception

With a compatible IR-remote you can proceed with learning your attenuator to react properly on your favourite buttons.

    a. Within 10 seconds or so after power-up, during the volume ramp-up, you press the '9' digit button on your remote. The attenuator reacts with '`P1.`' on its display. (The attenuator will detect this '9' button from all RC5/RC6/SIRC remotes, irrespective of any device selection.)

    b. You can freely press '9' repeatedly, thereby cycling through '`P1.`', '`P2.`', … '`P9.`', '`P1.`'… If you do not press anything for about 5 seconds, the display will go back to show '`C1.`' (the currently selected input channel) and '`15.`' (the current volume), indicating that you have left the programming mode.

    c. If the display shows '`P1.`', and you press any button other than '9', that button code is stored in non-volatile memory and will be used later for 'Volume Up'. The display reacts with '`1.`' to confirm the programming of function 1. If you receive a '`PF.`' reaction, the attenuator failed to extract a proper IR code. In any case, pressing '9' again will move you to the next button to configure.

In repeating steps b. and c. (and/or a.), you can configure the following button codes:

    '`P1.`' Volume Up
    '`P2.`' Volume Down
    '`P3.`' Mute on/off
    '`P4.`' Input channel Up
    '`P5.`' Input channel Down
    '`P6.`' Input channel select number 1
    '`P7.`' Input channel select number 4 (highest channel number)
    '`P8.`' Power-down
    '`P9.`' Display mode

The numeric keypad on your remote can be used to select the audio input channel. For this purpose, the signals of the first button '1' and the last button '4' must be programmed. As an exception, by choosing another value then '4', you may program a different number of input channels. Programming a value of '2' restricts later channel selections from 1 to 2 only. You can program a value up to 7 when you connect the extra required relais.

Some persons prefer to use a small remote in combination with the attenuator, which only has 4 or 5 buttons. With these, you can do volume up/down and channel up/down, but obviously not numeric input channel selection. To program the codes of such a remote in the attenuator, you seem to miss the '9' button to enter programming mode. In this case, you can use the '9' button of some other remote that you will not use later to operate the attenuator.

The 'power down' button not only activates an optionally connected power-relay to switch off, but also switches-off all on-board relays, thereby silencing the output signal. In the power-down mode the attenuator does not respond to volume up/down or mute commands. All attenuator functions are activated again if a channel-select or a 'power down' command is given.

P9 is not intended to enable an extra button function. It changes the mode of the display itself. In the default mode, the attenuator continuously displays the current volume setting, except in power-down mode where it only shows '`.`' If the P9 location is programmed with a different key as P8, e.g. some digit, the attenuator displays a reaction to the last command by showing the most recent input channel selected or the newly selected volume level during about a second. Hereafter the display will always return to idle (black). Some

people prefer such a normally-black display. If you program P9 with the same code as P8 (power down) you will have the initial behaviour with a continuous volume-level display.

Note that the attenuator not only learns (stores) the specific buttons that you choose from your remote. It also stores the 'device code' that the remote issues as part of the normal IR protocol. Therefor, if your remote has a 'device select' function to control different devices, the attenuator will learn to only react on your selected device. This will help to avoid confusion with different IR-receivers in your A/V system.

Ready to use

At power-up you see the attenuator ramping-up its audio volume in 10 steps of 2dB, reaching the volume it had before the last power-down. Also, it will select the last used audio input channel. The volume ramp-up is immediately terminated when you select a new volume or input channel. Sending a command will display the new volume set or input channel selected. Channel select up/down wraps cyclic over the available inputs. Pressing digit 1 to 4 selects the corresponding input channel. The 'mute' command both mutes and un-mutes. Unmute is also implemented with stepwise volume ramp-up. Changing the volume during mute directly restores the previous volume. The 'power down' command performs power down but also power-up when issued after after a short delay. Power-up is also induced by input channel selection.

The attenuator normally can be built with the rotary switch in the front-panel, although having this switch may be considered optional. Turning the rotary increases or decreases the audio volume. This type of switch has no end-point: it gives purely incremental (relative) updates. At the scale end-points (volume 64 and 00) the volume level is clipped by the micro controller firmware. If the attenuator is in the 'mute' state, turning the volume ends this. The rotary switch type proposed also has a built-in push-button. Clicking this (pressing on the knob), switches to the next audio input channel. After channel '4' it cycles back to '1'. If the attenuator was in 'power down' mode, the first click will only power-up the attenuator. If you keep the button pressed for about 5 seconds the attenuator will turn-off (go to power-down state).

One last warning: For its audio signals, the attenuator is truly passive. Its maximum output resistance is not higher then that of a normal potentiometer, but it retains its high resistance across the volume range. Some power amplifiers do not like to be driven by such resistance, or in some system set-ups humming might be picked up. Please verify in your own system that an output resistance of about 9Kohm (for my default Dale resistor choice) does not cause you any problems. If 9K is problematic, the attenuator needs to be followed by a driver stage to lower its output resistance.
Of course, mounting lower resistor values can also give you a lower output resistance at the cost of a lowered attenuator input resistance.

Layout and sizes

Below is a picture of the PCB layout, printed slightly bigger then real size. The top layer is in pink, the bottom layer in blue. The size annotations are in millimeters.
Mounting holes are 3.2mm diameter. The height of the components above the relay/resistor print is typically 22 mm. The height of the components above the display PCB surface is 9mm, which is the height of the 7-segment displays itself.
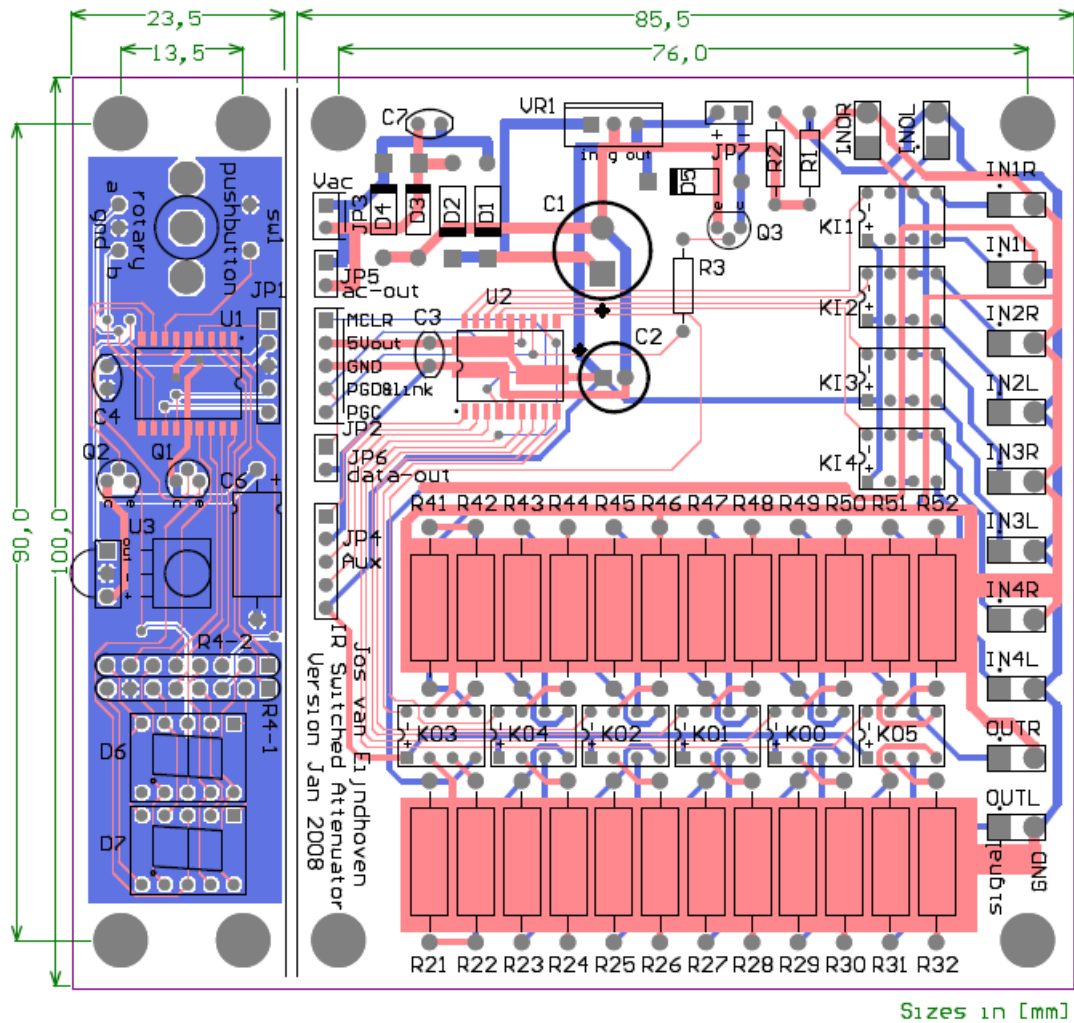
Success with building your attenuator,
and happy listening,

Jos van Eijndhoven
January 2009

Appendix: Optional things to buy

The kit that I distribute contains the PCBs and all PCB-mountable components. Of course you need some extras to complete your amplifier project. The table below shows a selection of a few things that might be useful. They are taken from the web-store at http://www.conrad.com, a convenient (internet-)store through Europe.

Description	Art.nr.	Price
Power supply transformer (6V, 2.3VA)	504426-89	€ 4,77
Power switch relay (coil 5Vdc, contact 250V 8A)	504734-89	€ 5,62
Red transparent window	530700-89	€ 0,90
Neutrik chassis cinch connector, red	731085-89	€ 1,54
Neutrik chassis cinch connector, black	731071-89	€ 1,54
Solder wire Tin/Silver/Copper, diameter 0.5mm, 100gr.	588337-89	€ 18,95
Spacer 5mm / M3 for PCB chassis mounting	526355-89	€ 0,06

You can surely find cheaper alternatives, but I typically perfer the higher-quality components....