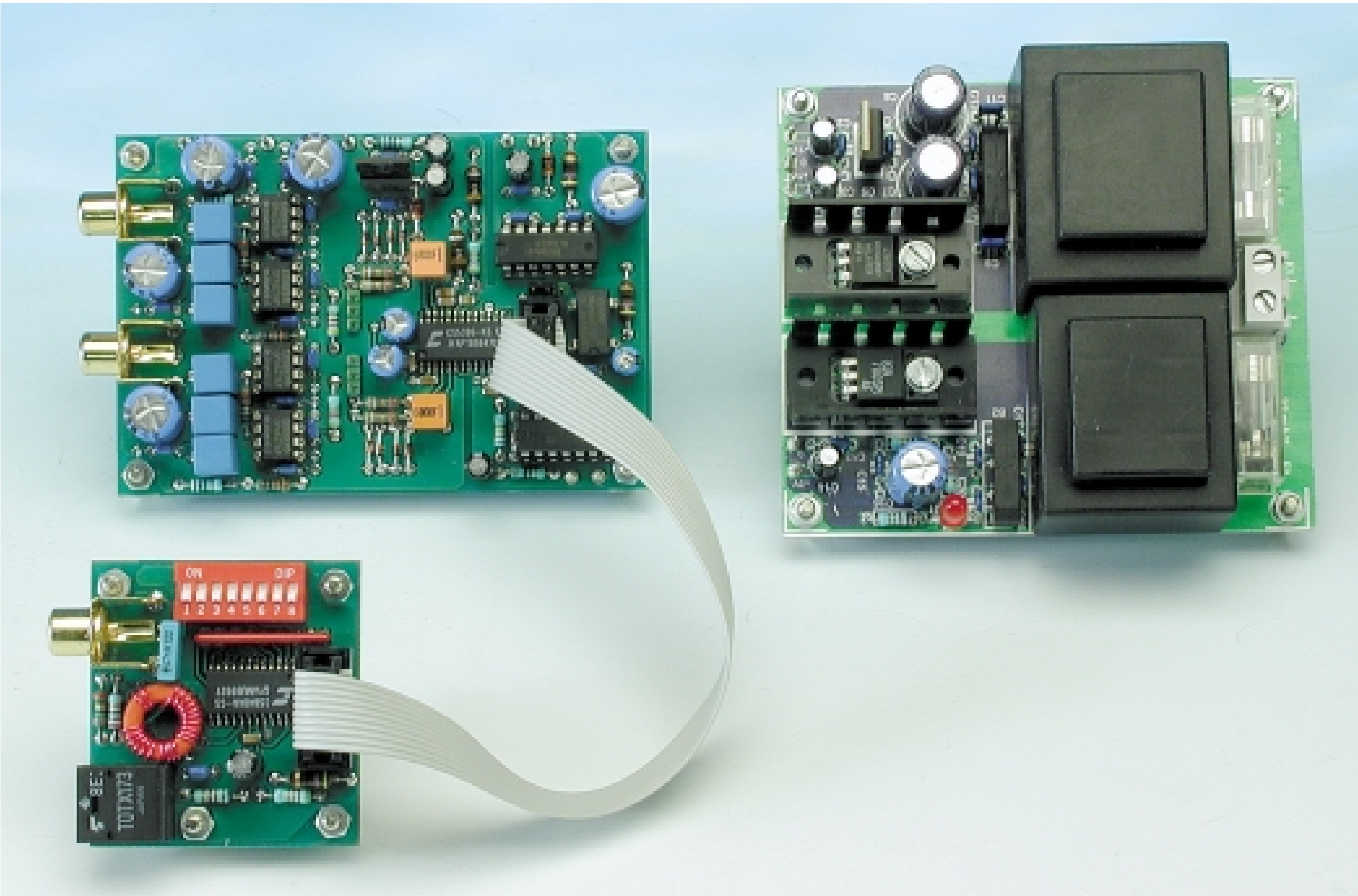
Audio ADC 2001

24-bit, 96 kHz sampling

Design by T. Giesberts

It is barely four years since we presented our 20-bit A/D Converter as the newest of the new. However, development continues at a rapid pace. At the present moment, 24-bit, 96-kHz sampling is the standard. It's thus high time for a successor that is completely up to date!



Anyone who is a bit familiar with the subject will immediately see that the A/D converter described here is almost the twin of the 20-bit design of four years ago. The only difference is that the resolution and speed have been increased by the use of more recent components, so that the present design is fully state of the art. This circuit can thus be regarded as a sort of 'Mark II' version of the previous circuit.

Once again, an integrated A/D converter made by Crystal, the CS5396, occupies the central position in the design. This successor to the 'old' CS5390 converter, which was used in the previous design, has been specially developed for 24-bit A/D conversion of stereo audio signals with sampling rates up to 100 kHz. The CS5396 employs a seventh-order, tri-level delta–sigma modulator and a digital filter, which makes an external anti-aliasing filter unnecessary. The differential architecture produces exceptionally good noise rejection: the maximum signal/noise ratio of the IC is 105 dB and the dynamic range is no less than 120 dB! We have intentionally chosen the CS5396 for this design, instead of the closely related CS5397, since the former type has a linear-phase filter that is optimised for audio applications. It has a pass-band ripple of only ±0.005 dB and a stopband rejection of >117 dB.

On the output side, we also find a pin-compatible successor to the previously used IC. Here the CS8402 has given way to the brand new CS8404A, which Crystal designates as a '96 kHz digital audio transmitter'. This IC is especially intended to be used for coding and transferring audio data according to one of the well known interface standards (AES/EBU, IEC958, S/PDIF or EIAJ CP-340). Inside the CS8404A, the digital audio data are multiplexed and encoded before being sent to the output. In addition to the S/PDIF output, which is electrically isolated by a transformer, the circuit also has an optical output.

Input section

The input stage of the converter has been intentionally simplified in comparison to the 'old' 20-bit design, with the result that it can process only asymmetric signals. This means that it is now possible to place Cinch sockets on the printed circuit board, which reduces the likelihood of interference problems.

Now let's look at **Figure 1**, which shows the complete schematic diagram of the Audio ADC 2000. For each channel, the input signal is first DC decoupled, since the converter has an asymmetric power supply and each input stage thus has an input offset. VCOM is used to set the input stage to the proper voltage. For this purpose, VCOM is supplied to the opamps by separate decoupling networks (R4/C4/C5 and R10/C10/C11).

The CS5396 has one symmetric input

Measured results

A few measurements have been made in the digital domain using a special measurement system from Crystal ('CDBCapture+ board'). In such cases, the signal from the optical output has been sampled and further processed.

The first figure, **Figure A**, shows a FFT analysis of 16,384 samples taken from the left channel with the converter driven to just about full scale. The THD+noise is here more than 104 dB down. Measurements on the right channel show similar results, with the THD+noise lying below –105 dB.

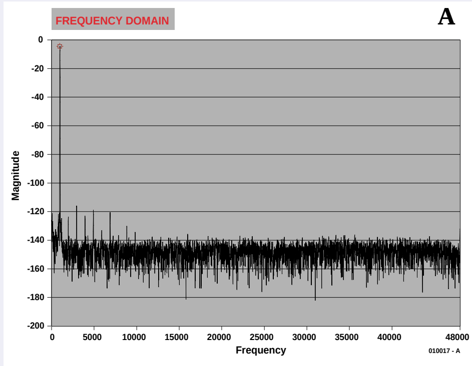


Figure B shows a FFT of a 20-kHz signal at full drive. The only harmonic that can be seen is a second harmonic at –114 dB, and there are also a few interference products (probably crosstalk from the digital part of the converter), but these lie below –120 dB! The right channel was clean, with only a second harmonic at –123 dB.

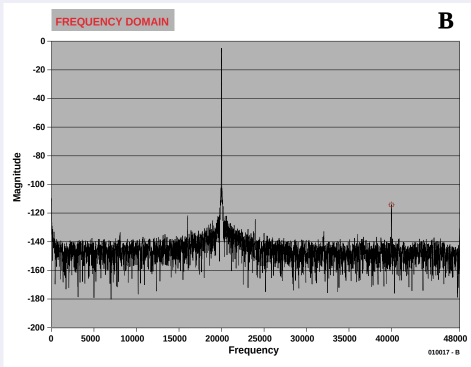
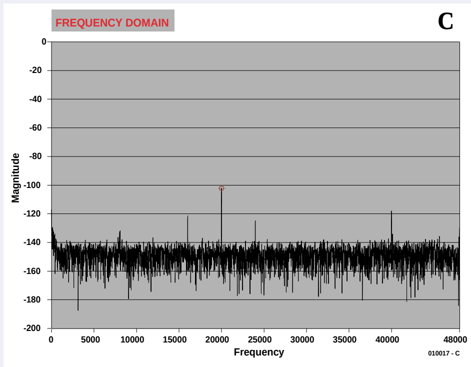
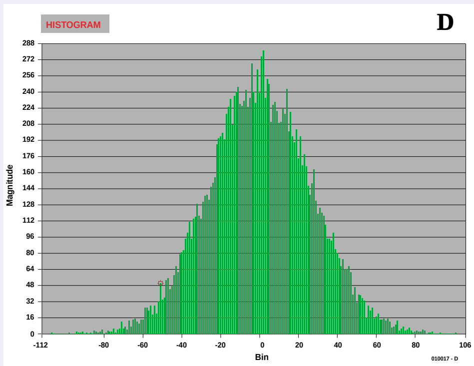


Figure C shows an FFT of the crosstalk from the right channel to the left channel for a 20-kHz signal with full drive. The channel separation here is greater than 102 dB. In the other direction (from left to right), this is 96 dB, but in the latter case only the 20-kHz component is visible.



Finally, **Figure D** presents a simple statistical measurement in the form of a histogram showing the distribution of the output values with the input shorted. This is a 'normal' distribution that shows a regular Gaussian shape.



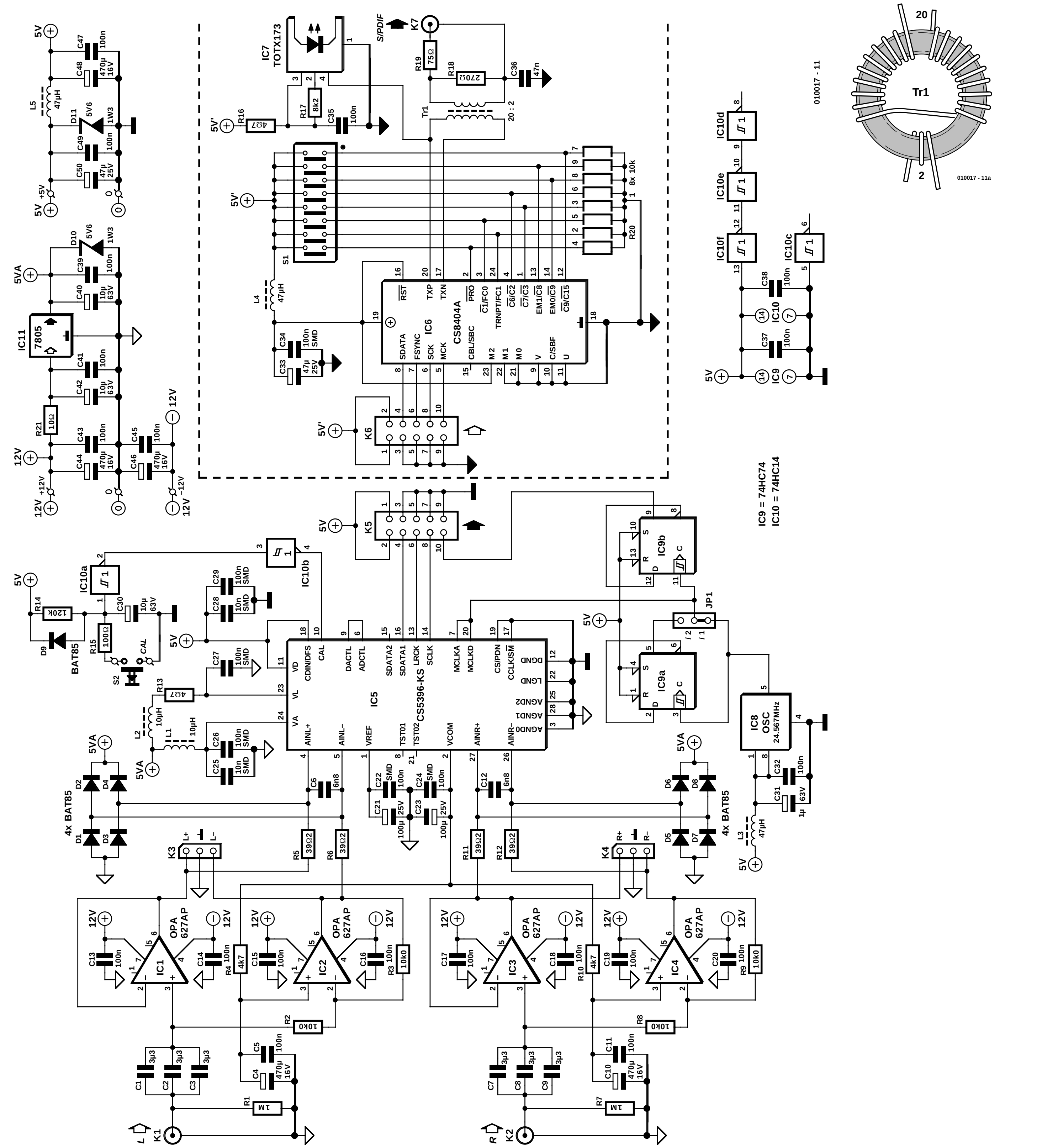


Figure 1. The actual converter consists primarily of a single IC, the CS5396-KS. The well-known CS8404A is used for the S/PDIF output.

for each channel. In order to allow asymmetric signals to be connected, AINL– and AINR– are provided with input signals via two inverters (IC2 and IC4). A pleasant side effect of this is that the input is thus made somewhat more sensitive (700 mV_{rms} full scale).

Each of the input capacitors is made up of three 3.3µF MKT capacitors connected in parallel. They combine with the 10-kΩ input impedances (R2 and R8) to form high-pass filters with a corner frequency of 1.6 Hz. In order to allow an (external) symmetrical input stage to be connected, a

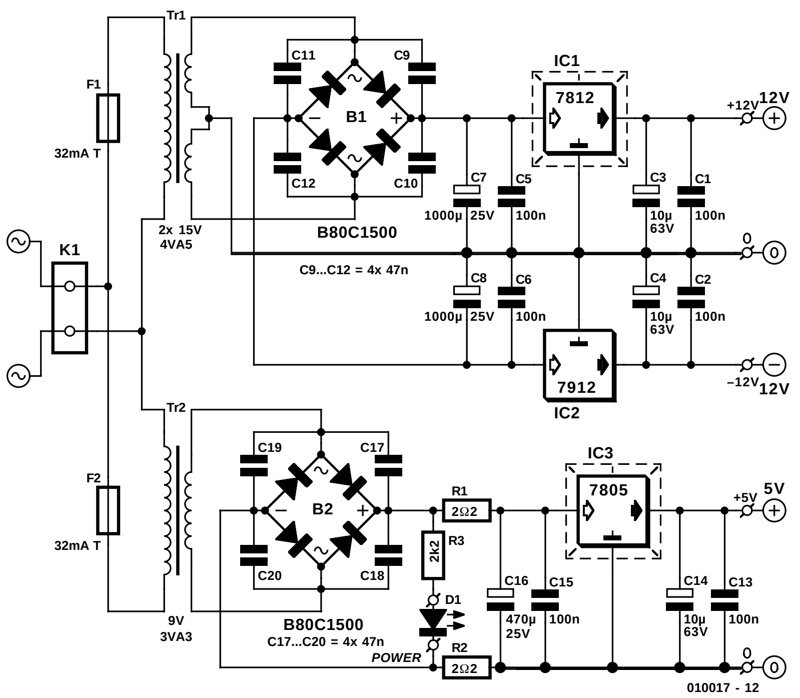


Figure 2. A double power supply is provided: one for the analogue part and one for the digital part.

three-way pin header is provided on the circuit board for each channel (K3 and K4). If this option is used, the input stages (IC1–IC4 and the associated components) should not be fitted. The pin headers can also be used as test points.

Converter

As shown in the schematic diagram, the A/D converter is liberally provided with decoupling. SMDs are used in part for this purpose, for the supply voltage as well as for the reference voltage and VCOM. Incidentally, the CS5396 is also an SMD (28-pin SOIC).
The converter is used in the stand-alone mode, with the sampling rate determined by the master clock. At 96 kHz, 64 times oversampling must be used, so a master clock frequency of 24.576 MHz is required.
Power Down (PDN) is not used, so this pin is tied to ground. DFS determines the output format; a High level here selects the I^2S-compatible mode. S/M is Low to select Master mode and thus ensure that the digital outputs are all derived from the master clock.
The tri-level delta–sigma modulator is calibrated when power is first applied (CAL). The calibration sequence can be re-initiated during operation via S2 and IC10. During the measurements, it was found that the quality is improved if the converter is recalibrated after having warmed up for at least 30 minutes (do this with no input signal present).
The two divide-by-two circuits (IC9) provide the converter with a bit more flexibility with regard to the sampling rate. If you use a 24.576-MHz oscillator (IC8), you can choose a sampling rate of 48 kHz (÷2) or 96 kHz (÷1) using JP1. Alternatively, you can insert a 12.288-MHz oscillator, in which case your only choice is 48 kHz (÷1).

Output section

Connector K5 acts as a universal I^2S output. All sorts of digital signal processing equipment can be connected here, such as a volume control, tone control, equalizer and so on. This output is also suitable for connecting a recording level meter, such as the digital VU meter described in the April and May 1996 issues of *Elektor Electronics* (but note that the pinout is different here).
Naturally, coaxial and optical S/PDIF outputs are also provided. This subcircuit is it built around the CS8404A (IC6), and is actually located on its own part of the circuit board that can be separated from the main board and then connected to the converter board using K5 and K6. This part of the output section is marked with by a dotted outline on the schematic diagram. The split design has the advantage that the digital output can be placed precisely where it best fits, such as immediately adjacent to the analogue outputs at the rear of the enclosure.
With regard to design, the CS8484A is practically identical to the CS8402 that we used in the previous circuit. Consequently, we need not describe its operation any further, beyond referring to Tables 5 and 6 in the manual for the CS5396 Evaluation Board (www.crystal.com) for the DIP switch settings. The default settings for dipswitch S1 are as follows:

S1-1	1
S1-2	0
S1-3	0
S1-4	0
S1-5	1
S1-6	0
S1-7	1
S1-8	1

where 1 = closed and 0 = open.

Power supply

The power supply section (see **Figure 2**) has been kept separate from the rest of the circuit. Its design strongly resembles that of the power supply for the 'old' A/D converter. Here again, it has been completely split into separate analogue and digital parts. A standard symmetric ±12 V supply is used for the opamps, with the main components for this part being Tr1, B1, IC1 and IC2. Power for the digital part is supplied by the lower portion of the circuit, which basically consists of Tr2, B2 and the 5-V regulator IC3.
The CS5396 requires three supply voltages: two for the analogue side and one for the digital side. The voltage for the digital side is taken directly from the digital supply. The analogue +5-V supply is derived from the +12-V supply using a separate voltage regulator (IC11) on the converter circuit board. Two 5.6-V Zener diodes (D10 and D11) are provided to protect both the analogue and the digital +5-V supplies. Although it would have also been possible to work on the basis of a single transformer, with the analogue supply

voltage being obtained by half-wave rectification of one half of the secondary winding and the digital +5 V from the other half, we intentionally chose to use two transformers. This lets us avoid unnecessary power dissipation in IC3, and it also has the advantage that the analogue and digital voltages can be completely separated from each

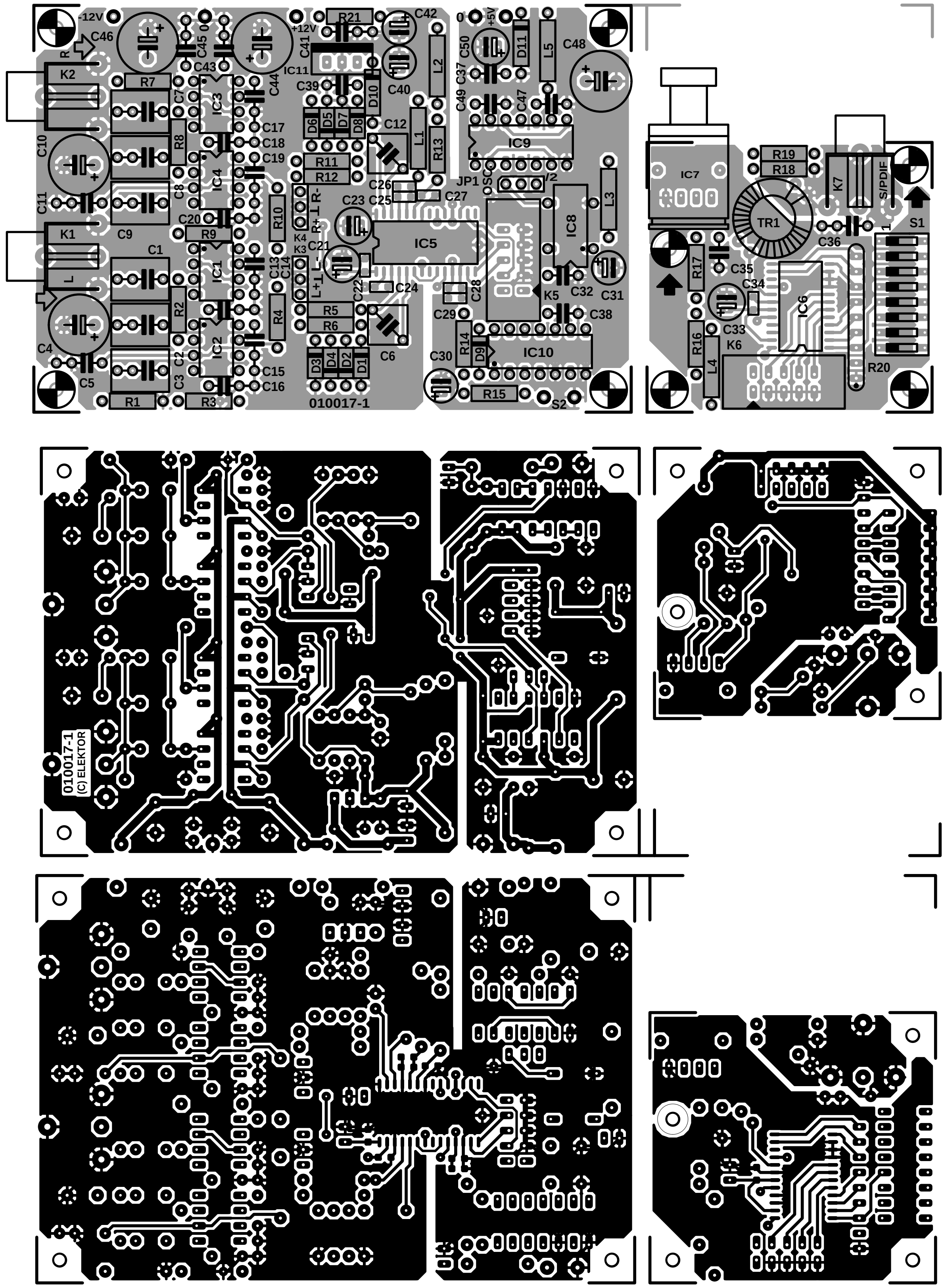


Figure 3. The copper track layout and component layout of the double-sided converter circuit board. The output circuit board can be sawn free from the rest of the circuit board.

other. Their ground points are tied together only on the converter circuit board next to the A/D converter.
The supply current of the CS5396, which is 285 mA in total, can be regarded as unusually high. The total dissipation of this small IC is more than 1.4 W, so it becomes quite hot! IC1 and IC3 on the power supply board also have to dissipate a fair amount of power, which is why heat sinks must be provided for these regulator ICs. For safety reasons, fuses are provided for the primaries of the two mains transformers.

Printed circuit boards

From the above, it should be obvious that there are two separate printed circuit boards: a double-sided board for the converter plus the S/PDIF output, and a normal single-sided board for the power supply. The copper track layouts and component layouts for these boards are shown in

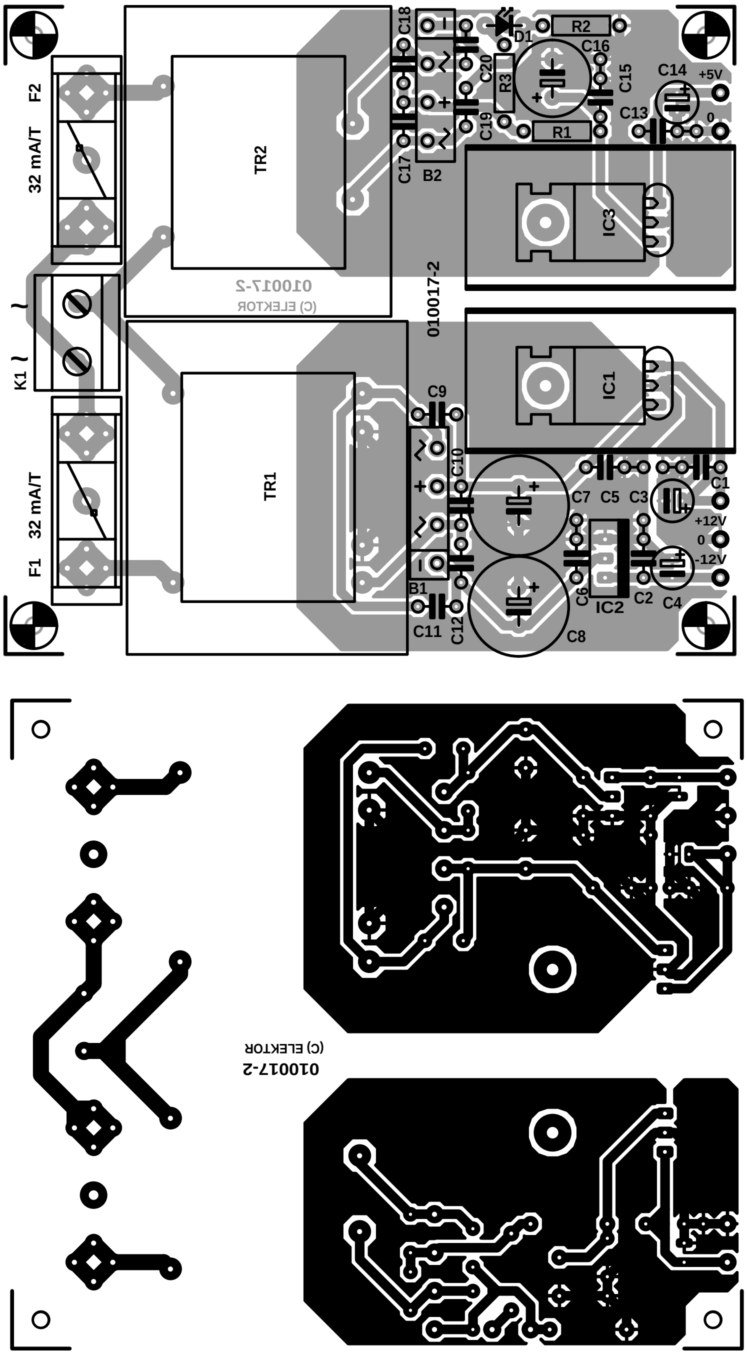


Figure 4. The power supply circuit board even has space for the two mains transformers.

COMPONENTS LIST
Converter board

Resistors:
R1,R7 = 1MΩ
R2,R3,R8,R9 = 10kΩ0
R4,R10 = 4kΩ7
R5,R6,R11,R12 = 39Ω2
R13,R16 = 4Ω7
R14 = 120kΩ
R15 = 100Ω
R17 = 8kΩ2
R18 = 270Ω
R19 = 75Ω
R20 = 10kΩ, 8-way SIL array
R21 = 10Ω

Capacitors:
C1,C2,C3,C7,C8,C9 = 3µF3 MKT, lead pitch 5 or 7.5mm
C4,C10,C44,C46,C48 = 470µF 16V radial
C5,C11,C13-C20,C32,C35,C37,C38,C39, C41,C43,C45,C47,C49 = 100nF ceramic
C6,C12 = 6nF8 1% polystyrene/polypropylene (EMZ)
C21,C23 = 100µF 25V radial
C22,C24,C26,C27,C29,C34 = 100nF SMD (case size 0805)
C25,C28 = 10nF SMD (case size 0805)
C30,C40,C42 = 10µF 63V radial
C31 = 1µF 63V radial
C33,C50 = 47µF 25V radial
C36 = 47nF MKT

Inductors:
L1,L2 = 10µH
L3,L4,L5 = 47µH

Semiconductors:
D1-D9 = BAT85
D10,D11 = 5V6 1W3 zener diode
IC1...IC4 = OPA627AP (Burr-Brown = Texas Instruments)
IC5 = CS5396-KS (Crystal) (Atlantik Elektronik)
IC6 = CS8404A (Crystal) (Atlantik Elektronik)
IC7 = TOTX173 Toshiba (Conrad Electronics)
IC8 = 24.576MHz oscillator block, type SG531P (Seiko Epson)
IC9 = 74HC74
IC10 = 74HC14
IC11 = 7805

Miscellaneous:
JP1 = 3-way pinheader + jumper
K1,K2,K7 = T-709G (Monacor/Monarch)
K3,K4 = 3-way pinheader
K5,K6 = 10-way boxheader, male (straight)
S1 = 8-way DIP switch
S2 = pushbutton, 1 make contact
Tr1 = ferrite ring core Philips TN13/7,5/5-3E25, primary: 20 turns, secondary: 2 turns 0,5 mm dia. (26SWG) enamelled copper wire

COMPONENTS LIST
Power Supply Board

Resistors:
R1,R2 = 2Ω2
R3 = 2kΩ2

Capacitors:
C1,C2,C5,C6,C13,C15 = 100nF ceramic
C3,C4,C14 = 10µF 63V radial
C7,C8 = 1000µF 25V radial
C9-C12,C17-C20 = 47nF ceramic
C16 = 470µF 25V radial

Semiconductors:
D1 = high-efficiency-LED, red
IC1 = 7812 + heatsink type ICK35SA (Fischer, Dau Components)
IC2 = 7912
IC3 = 7805 heatsink type ICK35SA (Fischer, Dau Components)

Miscellaneous:
K1 = 2-way PCB terminal block, lead pitch 7.5 mm
B1,B2 = B80C1500 (rectangular case) (80V piv, 1.5A peak)
Tr1 = 2 x 15 V/4VA5, e.g., VTR4215 (Monacor/Monarch)
Tr2 = 1 x 9 V/3VA3, e.g., VTR3109 (Monacor/Monarch)
F1,F2 = fuse 32mA/T (time lag) + PCB holder

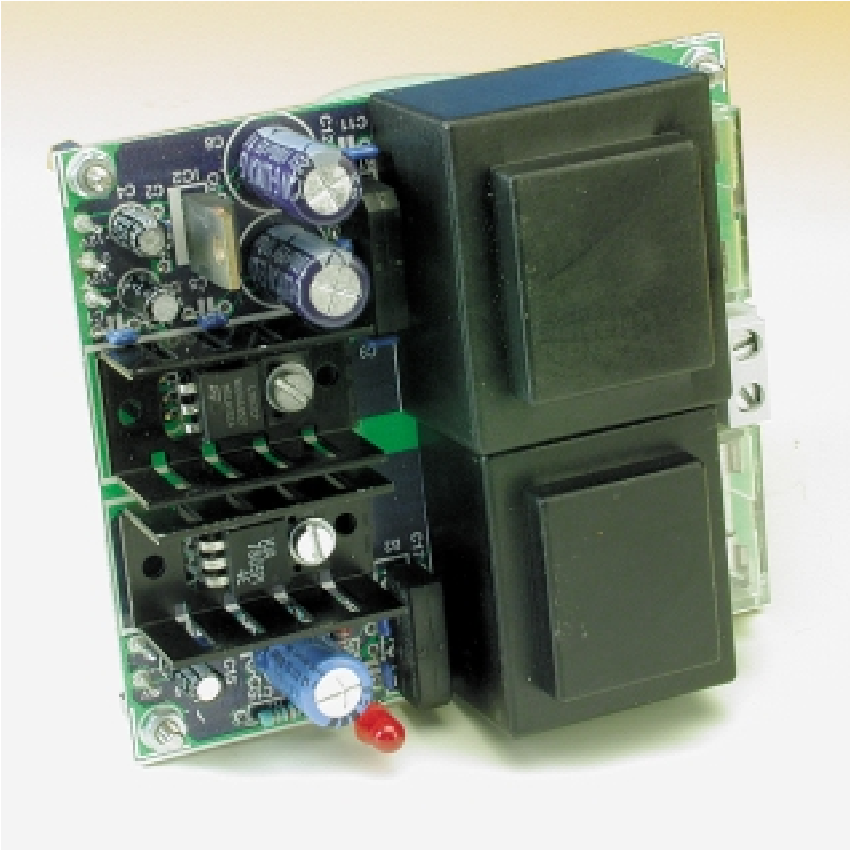


Figure 5. Small heat sinks must be provided for voltage regulators IC1 and IC3.

Figure 3 and **Figure 4**, respectively.
The construction of the power supply board is by far the easiest, since the dimensions of this board are quite generous and it holds relatively few components. If the transformers noted in the Components List are used, they can be mounted directly on the circuit board. IC1 and IC3 each have a small heat sink. The ±12-V and +5-V connections (and both ground connections) should be linked directly to the correspondingly marked points on the converter circuit board. The latter points can be found in the vicinities of C44/C46 and C50. The completely assembled power supply circuit board is shown in **Figure 5**.
The component density on the converter board is quite a bit higher, which means that the construction of this board requires significantly more care and attention. However, it shouldn't be all that difficult if you work methodically and stick precisely to the component layout and the suggested components. Capacitors C22, C24-C29, C34 and C35, as well as IC5, are SMD components, and soldering them requires a certain amount of experience. Soldering the capacitors is relatively easy if you first place them in the proper locations on the circuit board and hold them in place while soldering one end. You can then check their positions before soldering the other end. A soldering iron with a very fine tip is naturally essential, and it is important to pre-tin the connecting surfaces of the capacitors.
With the ICs, the procedure is roughly as follows: place the IC in its proper position on the circuit board and press it firmly against the board, solder a single pin at one of the corners, check the position and alignment of the IC, and then solder one pin at the diagonally opposite corner. After this, you can calmly solder the remaining pins with a steady hand. Make sure that no short circuits occur due to excessive solder; use solder braid to remove any superfluous solder!
As already noted, the S/PDIF output portion of the circuit board can be separated from the rest of the circuit board, and it is naturally best to do so before starting to assemble the board. A length of 10-way cable between K5 and K6 provides the connections between the two parts of the circuit board. The supply voltage for the output circuit board is also provided by this link.
The output transformer (Tr1) cannot be bought ready-made, so you will have to wind it yourself. That sounds more difficult than it actually is. The transformer consists of a 20-turn primary and a 2-turn secondary on a TN13/7,5/5-3E25 toroidal core. Use enamelled copper wire with a diameter of 0.5 mm. First wind the 20 turns for the primary and distribute them neatly over the entire core. Leave a bit of space in the middle, where you can then wind the two turns of the secondary winding. That's all there is to it!
The fully assembled converter board is shown in **Figure 6**, and the small output circuit board is shown assembled in **Figure 7**. The output transformer can be clearly recognised in the latter photo.
Before putting the converter into service, it is a good idea to once again carefully check the assembled circuit boards with reference to the photos of the assembled boards and the component layouts shown in **Figure 3** and **Figure 4**. After this, it is a

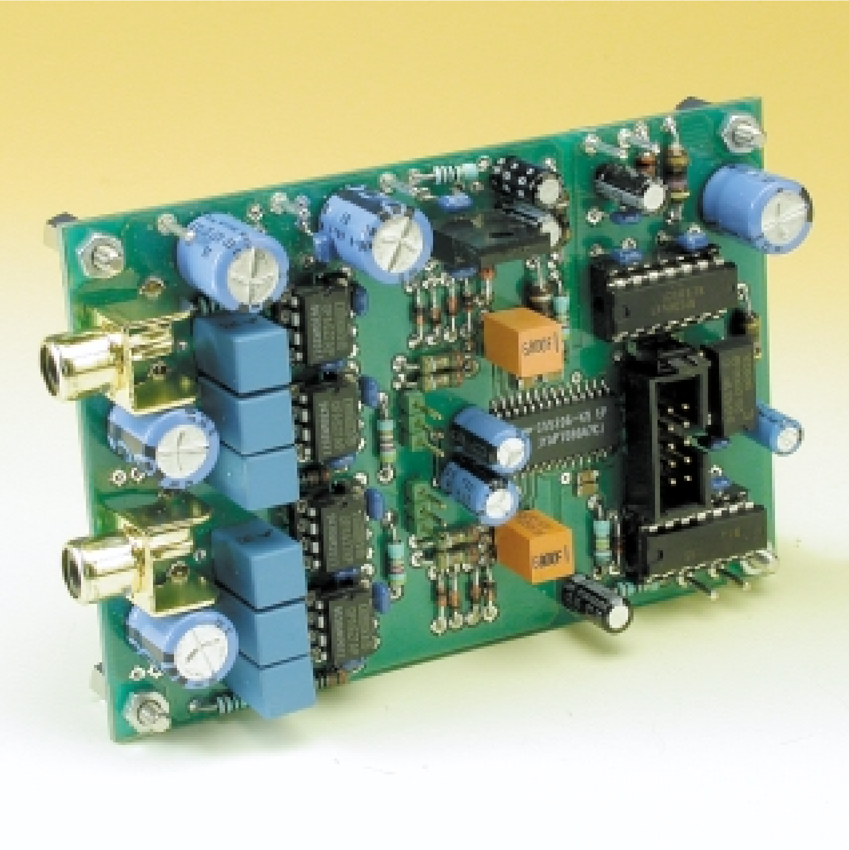


Figure 6. The fully assembled converter board.

good idea to check whether the power supply provides the correct output voltages. To do so, temporarily connect 2.2-kΩ resistors between terminal pairs PC1–PC2, PC3–PC2 and PC4–PC5, and connect K1 to the mains using a well-insulated mains cable (the on/off indicator D1 should be illuminated). Now you can check the three output voltages using a multimeter. Only after you are sure that everything is in order should you remove the resistors and connect the ±12 V and +5 V terminals to the converter board.

Enclosure

Depending on the application, this A/D converter can be built into an existing piece of equipment or provided with its own enclosure. In the latter case, we would expressly advise you to use a metallic enclosure.

If the circuit boards are mounted such that the input and output connectors (K1, K2 and IC7, K7, respectively) project through the rear panel of the enclosure, the necessary wiring can be kept to a minimum. In this case, only the power supply has to be connected to the converter board, and the link to the output board must be provided.

Naturally, a mains power input socket must be mounted at the rear of the enclosure, and this must be connected to K1 on the power supply board via a length of well-insulated mains cable. A mains power switch can be placed between mains input and K1, if so desired. The mains switch, on/off indicator D1 and calibration pushbutton S2 are the only front-panel controls and indicators. Pay careful attention to electrical safety with regard to mounting the mains input, cable and switch, and try to make the most of the advice given in the Safety Guidelines published from time to time in *Elektor Electronics* (e.g. January 2000).

For a metallic enclosure to provide effective screening, it is essential that it be tied to circuit ground. This can be easily done by connecting a wire between the ground terminal of input socket K1 or K2 and a solder lug fastened to the enclosure. Finally, place a label on the back of the enclosure that indicates the mains supply voltage, the fuse value and the circuit number.

Conclusion

We probably don't have to say very much about using the A/D converter. Its most obvious application is as a supplement to digital audio equipment whose A/D conversion is no longer up to date. In this regard, we have a handy tip for audio fans. Terratec can presently supply sound cards that support 24-bit, 96-kHz recording, in a wide variety of price classes. The converter described here would certainly be a major improvement to the converter that is already present on the sound card, especially since this converter is located external to the PC and can be connected to the sound card via an electrically isolated TosLink interface.

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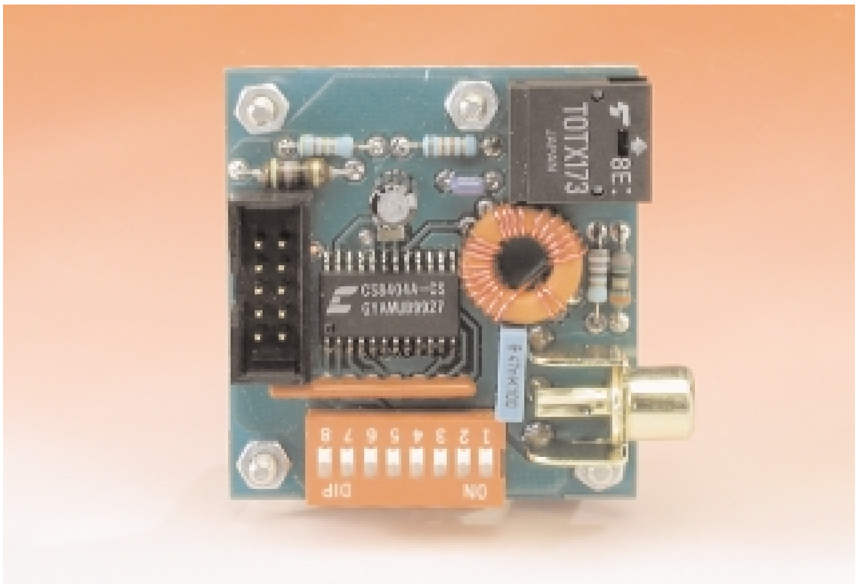

Figure 7. The fully assembled output circuit board. The toroidal transformer can be clearly seen.