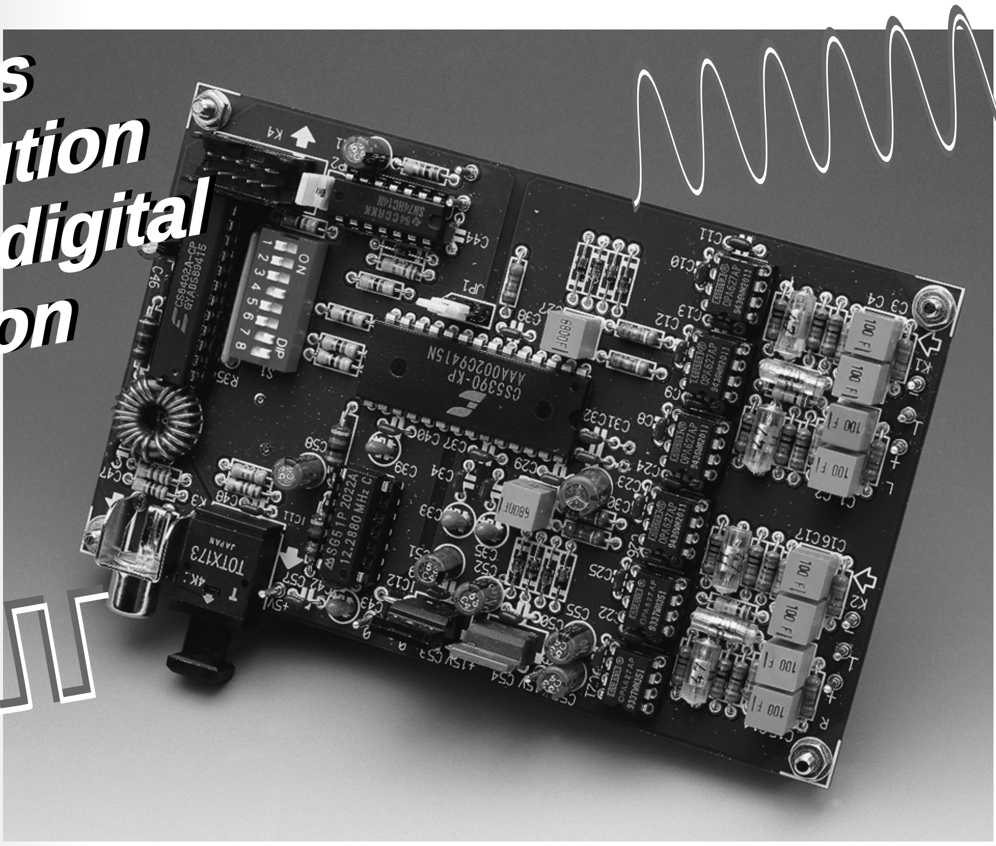
Contents

20-bit A-D converter

provides high-resolution analogue-to-digital conversion



The converter described in this article is, technically speaking, state-of-the-art as far as analogue-to-digital conversion is concerned. It offers a true resolution of 20 bits, is of superb quality and has symmetrical inputs. In short: it is difficult to imagine a better converter for quality-conscious sound engineers than the present one – and certainly not at the price.

Design by T. Giesberts

The circuit is based on a Type CS5390 integrated stereo analogue-to-digital converter (ADC) from Crystal, which is currently taken as the quality standard and is used in much professional equipment. It uses ×64 oversampling, contains a phase-linear digital anti-aliasing filter, and has a dynamic range of 110 dB. It is pin-compatible with the 18-bit Type CS5389 IC.

The converter stage is preceded by an elaborate analogue input amplifier, whose outstanding property is its ability to accept symmetric as well as asymmetric signals. The quality of this amplifier can be improved even more by the use of rare (expensive) operational amplifiers.

The coding and sending of the converted audio data is effected with the aid of a Type CS8402A integrated digital audio interface. This IC is used in the same configuration as in the 'sampling rate converter' published in the October issue of this magazine.

The amplifier has an electrically isolated S/PDIF output, but there is also provision for an optical output.

SYMMETRIC INPUTS

Attaining a true resolution of 20 bits places a heavy demand on the circuit designer, whose ingenuity is taxed from the inputs onwards.

If optimum use is to be made of the symmetric inputs of the CS5390 (IC_7), the input amplifier and source signals must also be symmetric. Since, however, many users do not work with symmetric signals, the converter must also be capable of processing asymmetric signals.

Such considerations have led to the converter being given a fairly complex input circuit, whose special property is its capability of processing differential as well as single-ended signal without the need of switching. In the circuit diagram in **Figure 1**, the circuit for the left-hand channel consists of op amps IC_1–IC_3 and that for the right-hand channel of op amps IC_4–IC_6. Otherwise, the channels are identical.

The following discussion is based on the left-hand channel; components in the right-hand channel are stated in brackets.

Input socket K_1 is followed by attenuator R_1–R_4 (R_{12}–R_{15}), which is necessary for presetting the input stage, particularly in case of asymmetric signals. Op amps IC_1 and IC_2 (IC_4 and IC_5) are arranged as ×10 amplifiers

1

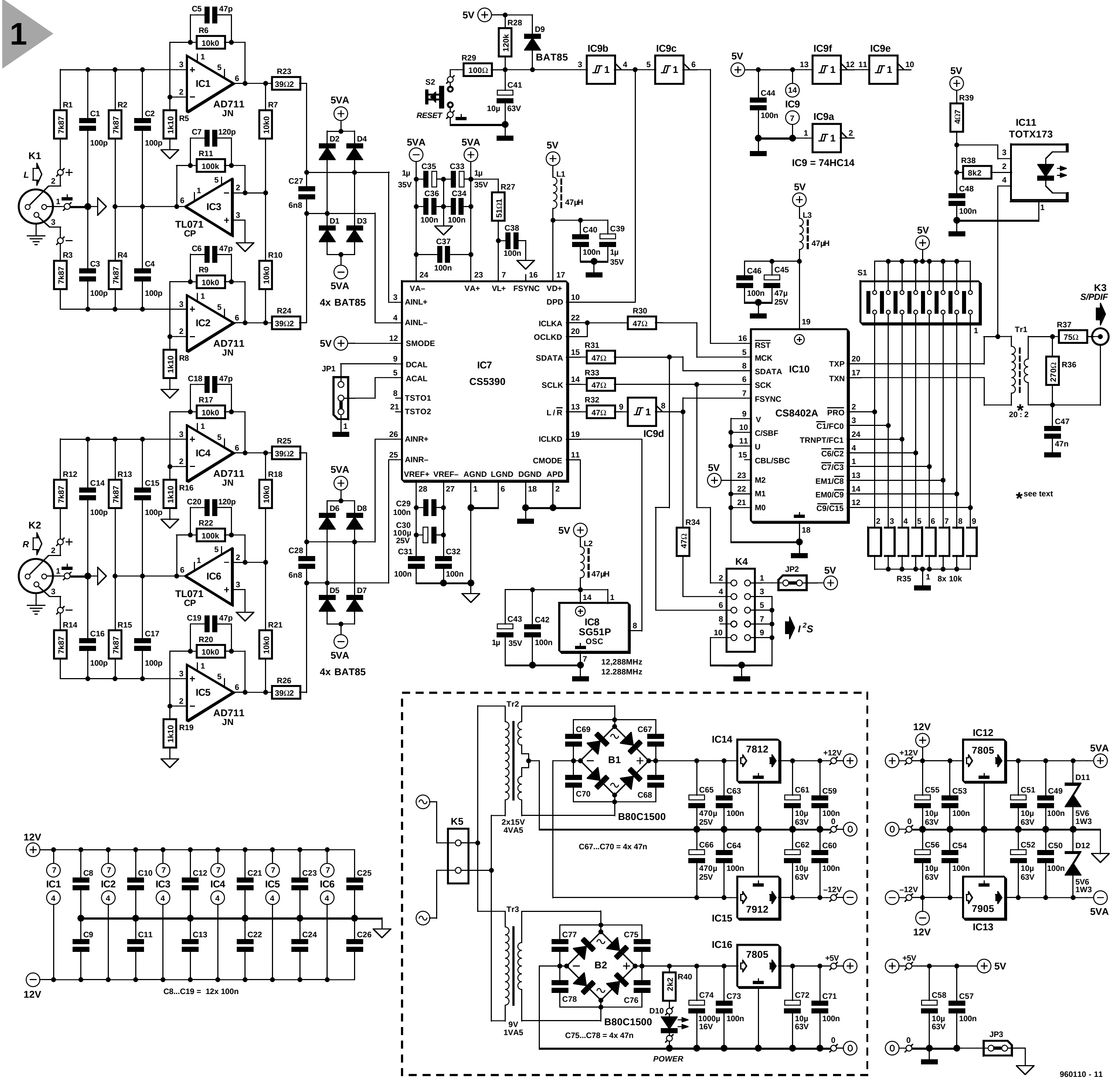


Figure 1. The circuit consists essentially of four sections: the analogue input amplifier, IC_1–IC_6; the ADC proper, IC_7; the output interface, IC_{10}; and the power supply, IC_{12}–IC_{16}.

with an input sensitivity of 1 V_{RMS}. When an asymmetric signal is input, the inverting (–) input of the op amps is grounded, which disturbs their setting. However, the consequent imbalance of the signals is corrected immediately by IC_3 (IC_6) with an accuracy of no less than ±0.08 dB.

The quality of the op amps used is, of course, of paramount importance: the Type AD711 from Analog Devices in the IC_1 and IC_2 (IC_4 and IC_5) positions was found to give very good performance. In the IC_3 (IC_6) position, a standard TL071 (which is far less expensive) was found to be perfectly satisfactory. In any case, this latter IC has no role to play in the case of symmetric signals, while with asymmetric signals it is just part of the feedback loop where it has far less effect on the signal quality than the earlier mentioned op amps.

If superlative performance is required, use Type OPA627 chips in the IC_1–IC_3 (IC_4–IC_6) positions. Bear in mind, however, that these ICs are about ten times as costly as an AD711.

CONVERSION

Full data of the Type CS5390 A-D converter (IC_7), as well as its internal block diagram, are given in the data sheets elsewhere in this issue.

Schottky diodes D_1–D_8 and zener diodes D_{11} and D_{12} protect the IC against excessively high input signals. The Schottky diodes protect against

test results

The prototype was, of course, tested thoroughly, including FFT analyses of the output data of the converter chip for which the total harmonic distortion (THD+N) at 1 kHz was calculated in the digital domain. This gave the following results:

Input level	***THD+N***
0 dB	*<–97 dB*
– 3 dB	*<–100 dB*
– 6 dB	*<–99 dB*
– 9 dB	*<–96 dB*
– 12 dB	*<–93 dB*
– 15 dB	*<–90 dB*

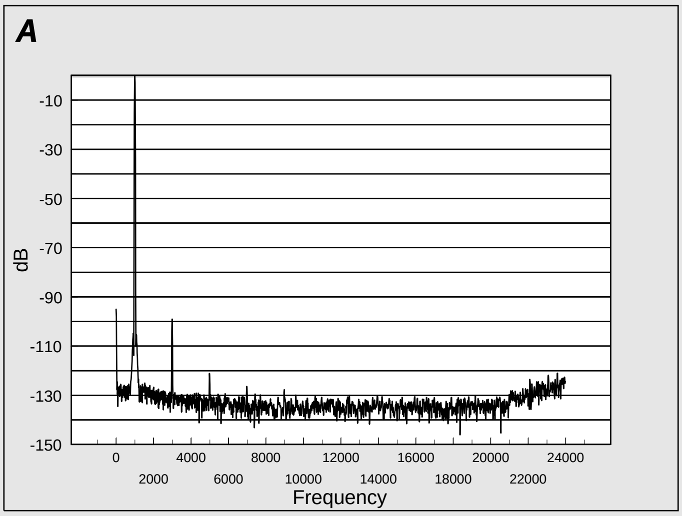
The same calculation was carried out at 7 kHz, since the 3rd harmonic of this falls just within the range of the digital filter. The differences with the results obtained at 1 kHz were negligible.

As the test results show, the manufacturers' stated dynamic range of 110 dB was, in practice, just not attainable. This is partly because of the ×10 amplification in the input amplifiers and the consequent higher sensitivity. When the ratio of the input level (in dB) is added to the THD+N value (in dB), the noise level is effectively 105 dB below full scale. This changes only when the input signals exceed –6 dB. However, from that point on, there is a noticeable increase in distortion. Note that distortion here means deviations of the order of not more than 5×10–6!

In any case, since in digital recording the normal headroom is 12 dB, it may be assumed that for average signal levels the distortion produced by the A-D converter is negligible.

The frequency spectrum of two FFT analyses is shown. Figure A is measured with a signal of 0 dB and Figure B with one of –12 dB. To recover the 7th and 9th harmonics from the noise, four measurements were carried out in each case. At an input level of –12 dB, there was no trace of any harmonics.

To satisfy the curiosity of some readers, the frequency spectrum with shorted input was measured: the result is shown in Figure C. This shows a virtually Gaussian distribution without any remains or effects of clock interference, supply ripple or other possible sources of interference.



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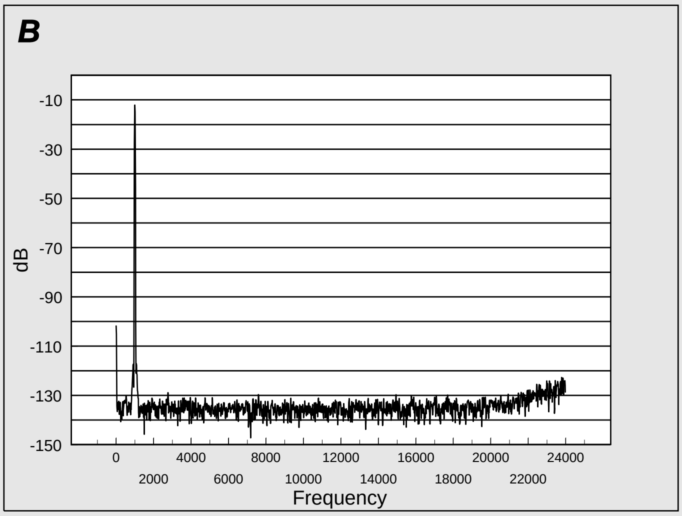

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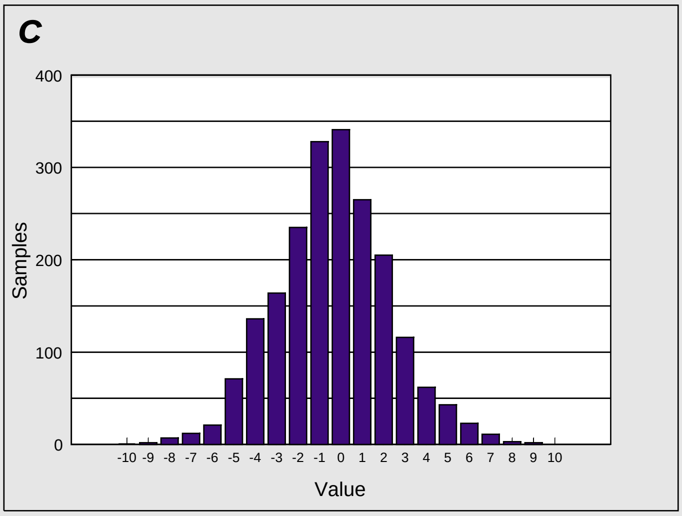

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latch-ups, while the zener diodes limit an increase in the supply voltage in case of overdrive. The latter is vital, because the maximum permissible supply voltage for the CS5390 is ±6 V.

The value of series resistors R_{23} and R_{24} (R_{25} and R_{26}) ensures optimum source impedance for IC_7.

Parallel capacitor C_{27} (C_{28}) must be a close-tolerance type, since it suppresses r.f. noise caused by the oversampling. It is, as it were, complementary to the digital filter, since the suppression range of this does not extend into the r.f. bands.

As far as the operation of IC_7 is concerned, it is best to treat it as a black box, into which analogue signals are pumped and from which digital signals are extracted. According to the manufacturers' data, the chip uses delta-sigma modulators with ×64 oversampling for the conversions. The modulators are followed by a digital filter, whereupon the sampling frequency is reduced to 48 kHz. Because of the very high oversampling rate, a separate anti-aliasing filter is not required.

Most of the remaining circuitry, except the reset circuit connected to the digital power down (**DPD**) input, and jumper JP_1, serves to decouple the power supply and reference voltage lines.

When switch S_2 is pressed, network R_{28}-C_{41} and Schmitt trigger IC_{9b} provide a 1 s long positive pulse at the **DPD** input. This results in an overall reset of the entire digital section of IC_7. After the pulse has decayed, an offset calibration cycle is started automatically. During this cycle, the offset in either channel is measured and deducted from the sampling values. It is thus possible to start this calibration at any desired moment, without having to switch the entire converter off and then on again, simply by pressing S_2. In other words, this design makes possible a conversion without having to worry about any offset voltages, which for certain applications is of vital importance. It should be borne in mind that each and every cold start results in a (small) drift of any offset voltage in both the converter chip and the input amplifiers.

The level at the **ACAL** input determines whether the offset is measured in the input amplifiers or not. If this input is grounded via JP_1, the offset in the input amplifiers will be measured. In this case, there must be no input signal to the amplifiers, since that may lead to measurement errors. If **ACAL** is linked to **DCAL** via JP_1, the offset in the input amplifiers is ignored. Note that the output of **DCAL** remains high for 4096 clock pulses after **DPD** has gone low.

By means of the logic level at **CMODE**, the serial output interface of IC_7 enables the value of the requisite **ICLKD** clock, which has been fixed for an output word rate – **OWR** – of 48 kHz, to be determined. In the present design, **CMODE** is permanently low, which results in a clock frequency of 256 × **OWR** = 12.288 MHz.

The level at **SMODE** determines whether the **IC** operates in a slave mode or a master mode. A high level at this terminal results in **SCLK**, **FSYNC**, and **L/R** functioning as outputs whose level is derived from **ICLKD** by internal dividers.

The 20-bit samples in 2-complement code are available at output **SDATA**.

The clock generator is a module containing both the crystal and the requisite active circuitry. This arrangement saves space and also minimizes the risk of r.f. interference.

The converted data at the output of IC_7 are applied to output socket K_4 via stoppers R_{30}–R_{34} and the output circuit. The timing of the data is nearly, but not quite, **I^{2}S** compatible: it lacks an inverted **L/R** signal, but this is provided by IC_{9d}.

OUTPUT

The general **I^{2}S** output is taken from K_4. A miscellany of signal-processing equipment (for volume control, tone control, interface for test purposes, and so on) may be connected to this socket. The output is also well suited for receiving the 'digital **VU** meter' (a special test instrument for digital audio signals, fitted with a double 30-segment **LED** bar and 3.5-digit displays) described in the April/May 1996 issues of this magazine.

Short-circuiting JP_2 links the +5 V supply line to K_4, which is usable if the equipment connected to the socket draws a current of not more than a few milliamperes. In all other cases, the equipment must have its own power supply.

There is, of course, an **S/PDIF** output. For this, use is made of the same digital audio interface transmitter (IC_{10}) as used in the 'sampling rate converter' described in the October 1996 issue of this magazine. The most significant channel-status bits of this **IC** are set with octal **DIP** switch S_1.

Apart from coaxial output K_3, an optical output is provided by IC_{11}.

POWER SUPPLY

Since the power lines to the digital and analogue sections of the circuit must be isolated, two separate mains transformers are used: Tr_2 for the analogue section, and Tr_3 for the digital section.

The output of Tr_2 is rectified by B_1, smoothed by a number of electrolytic capacitors, and regulated by IC_{14} and IC_{15}. The resulting ±12 V output is used to power the input amplifiers, and also to provide the ±5 V lines for the analogue circuits in IC_7. The ±5 V lines are regulated by IC_{12} and IC_{13}.

The output of Tr_3 is rectified by B_2, smoothed by several electrolytic capacitors, and regulated by IC_{16}, resulting in a single-ended supply line of +5 V.

The only link between the two supply lines is JP_3, which commons their earth returns.

The supply lines are copiously decoupled for r.f. Also, the arms of the bridge rectifiers are shunted by anti-rattle capacitors, while the electrolytic buffer capacitors are without exception shunted by 100 nF ceramic capacitors.

PRINTED-CIRCUIT BOARD

The converter is best built on the printed-circuit board shown in **Figure 2**. This board is through-plated an double-sided and has, at the component side, two large earth planes, one each for the analogue and digital circuits.

The board consists of two distinct parts: that for the power supply (shown in dashed lines in Figure 1) must be cut off and built up independently. Not all mains transformers may fit neatly on the supply board, which must then be adapted accordingly. The ±12 V and +5 V lines must be linked to the corresponding terminals on the converter board via flexible circuit wire. None of the voltage regulators needs a heat sink.

Populating the converter board is fairly straightforward but, in a quality unit such as the converter, the utmost care must, of course, be observed in the work. Whether or not **IC** sockets should be used is immaterial: from a technical point of view it is better to solder the **IC**s directly to the board, but some less-experienced constructors may prefer to use sockets.

All constructors are advised not to scrimp on the components. A fair number of 1% resistors, as well as quite a few close-tolerance polystyrene (not cheap) capacitors, are used. Furthermore, high-quality types of socket must be used for K_1–K_3.

Output transformer Tr_1 is a **DIY** component, wound on a toroidal core Type G2/3FT12. Wind the primary, consisting of 20 turns of 0.7 mm dia. enamelled copper wire, evenly spread over the core, first. Leave some space at the centre of the winding, where the two-turn secondary (same wire) is laid. This is exactly the same transformer as used in the 'sampling rate converter' published in the October 1996 issue of this magazine.

Using heavy-duty wire, short-circuit

Figure 2. The double-sided, through-plated printed-circuit board consists of two sections: one for the power supply and the other for the digital and analogue circuits. The board is intended to be cut into two.

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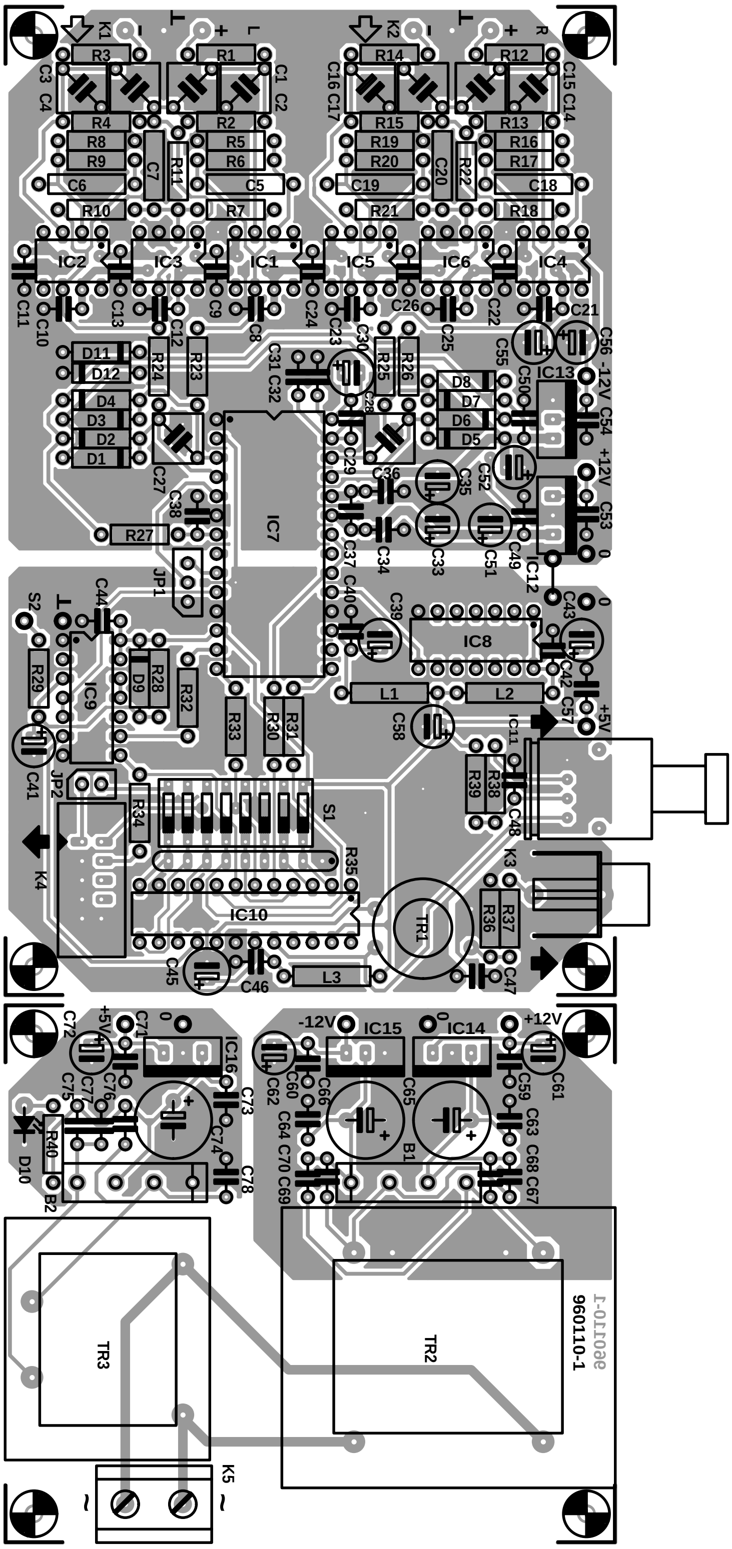


the two terminals of wire bridge JP_3.

With JP_1 in the right-hand position (pin 5 of IC_7 to ground), the offset of the input amplifiers is measured during the automatic calibration; with JP_1 in the left-hand position (pin 5 linked to pin 9), this is not done.

If the equipment connected to K_4 can be powered by the converter (current drawn by it no more than a few mA), the +5 V line is linked to K_4 via wire bridge JP_2.

When both boards have been completed, a thorough check (consulting the circuit as well as the parts list) is recommended. Also, compare the boards with the photograph of the completed prototype in **Figure 3**.

INITIAL TEST

Connect 2.2 kΩ resistors to each of the outputs of the supply board.

Connect the mains to terminal block K_5 via a suitable mains cable, whereupon on/off indicator D_{10} should light.

Using a good multimeter, check the output voltages of the power supply. If all potentials are what they should be, the 2.2 kΩ resistors must be removed from the supply board outputs, which should then be linked to the relevant terminals on the converter board.

ENCLOSURE

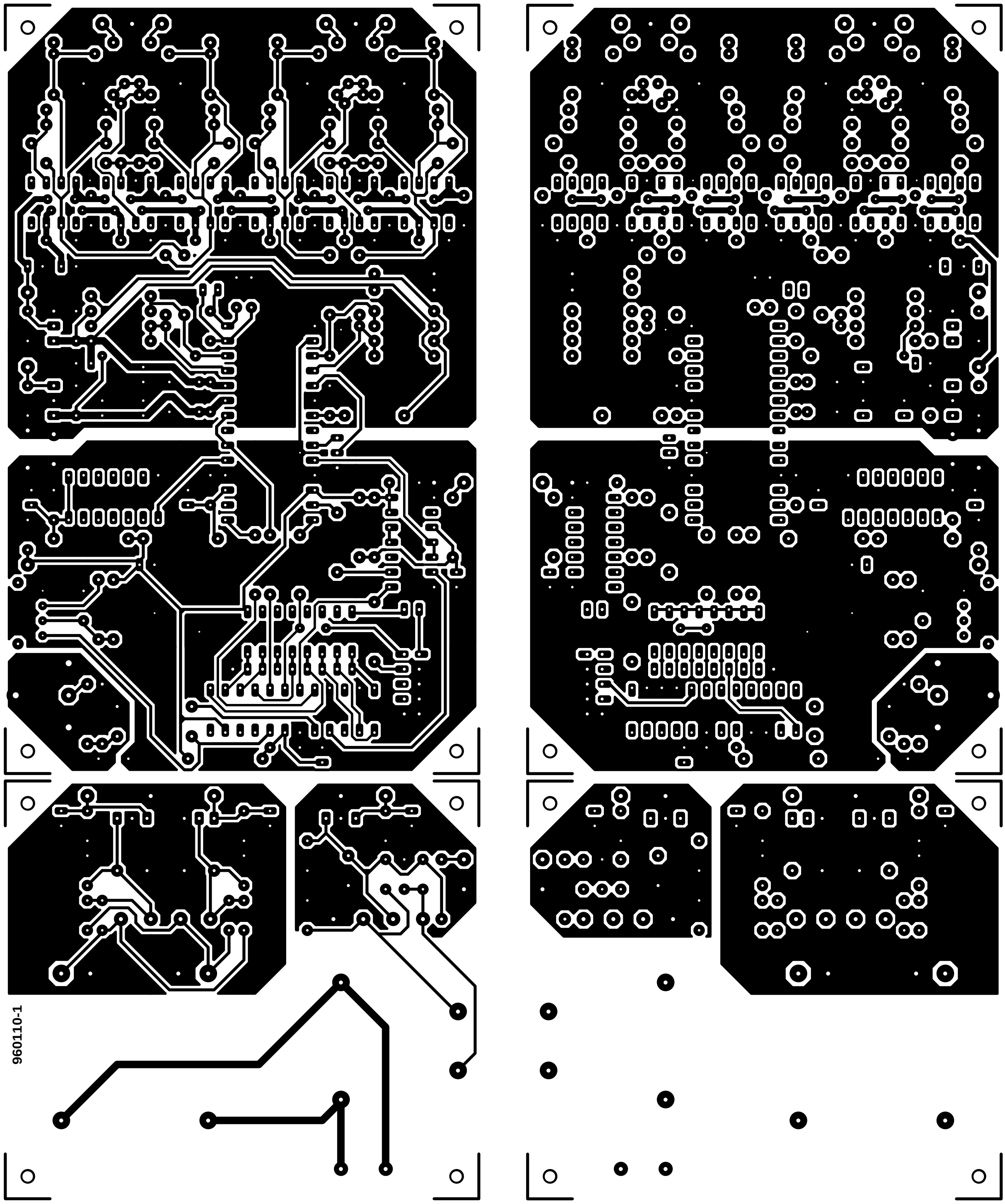
When all has been found in order, the converter should be fitted in a suitable enclosure. The only restrictions on the choice of this are that it must be of metal and large enough to house the converter and its power supplies.

Parts list

Resistors:
R_1–R_4, R_{12}–R_{15} = 7.87 kΩ, 1%
R_5, R_8, R_{16}, R_{19} = 1.10 kΩ, 1%
R_6, R_7, R_9, R_{10}, R_{17}, R_{18}, R_{20}, R_{21} = 10.0 kΩ, 1%
R_{11}, R_{22} = 100 kΩ
R_{23}–R_{26} = 39.2 Ω, 1%
R_{27} = 51.1 Ω
R_{28} = 120 kΩ
R_{29} = 100 Ω
R_{30}–R_{34} = 47 Ω
R_{35} = 10 kΩ octal array
R_{36} = 270 Ω
R_{37} = 75 Ω
R_{38} = 8.2 kΩ
R_{39} = 4.7 Ω
R_{40} = 2.2 kΩ

nductors:
L_1–L_3 = 47 µH

Capacitors:
C_1–C_4, C_{14}–C_{17} = 100 pF, 63 V, polystyrene, radial, pitch 7.5 mm
C_5, C_6, C_{18}, C_{19} = 47 pF, 160 V, polystyrene
C_7, C_{20} = 120 pF, 160 V, polystyrene
C_8–C_{13}, C_{21}–C_{26}, C_{29}, C_{31}, C_{32}, C_{34}, C_{36}–C_{38}, C_{40}, C_{452}, C_{44}, C_{46}, C_{48}–C_{50}, C_{53}, C_{54}, C_{57}, C_{59}, C_{60}, C_{63}, C_{64}, C_{71}, C_{73} = 100 nF, ceramic
C_{27}, C_{28} = 6.8 nF, 63 V, 1%, polystyrene, radial, pitch 7.5 mm
C_{30} = 100 µF, 25 V, radial
C_{33}, C_{35}, C_{39}, C_{43} = 1 µF, 35 V, tantalum
C_{41}, C_{51}, C_{52}, C_{55}, C_{56}, C_{58}, C_{61}, C_{62}, C_{72} = 10 µF, 63 V, radial
C_{45} = 47 µF, 25 V, radial
C_{47}, C_{67}–C_{70}, C_{75}–C_{78} = 47 nF, ceramic
C_{65}, C_{66} = 470 µF, 25 V, radial



C_{74} = 1000 µF, 16 V, radial

ISemiconductors:

D_1–D_9 = BAT85

D_{10} = LED, low current

D_{11}, D_{12} = zener diode 5.6 V, 1.3 W

B_1, B_2 = B80C1500 right-angled bridge rectifier

Integrated Circuits:

IC_1, IC_2, IC_4, IC_5 = AD711JN (Analog Devices)

IC_3, IC_6 = TL071CP (see text)

IC_7 = CS5390-KP (Crystal)

IC_8 = oscillator module, 12.288 MHz (Seiko Epson Type SG51P)

IC_9 = 74HC14

IC_{10} = CS8402A (Crystal)

IC_{11} = TOTX173 (Toshiba)

IC_{12}, IC_{16} = 7805

IC_{13} = 7905

IC_{14} = 7812

IC_{15} = 7912

Miscellaneous:

JP_1 = 3-way pin header and jumper

JP_2 = 2-way pin header and jumper

JP_3 = wire bridge

K_1, K_2, K_3 = phono socket for board mounting

K_4 = 10-way box header

K_5 = 3-way terminal block (for accepting 3-wire mains cable), pitch 7.5 mm

S_1 = octal DIP switch

S_2 = single-pole push-button switch

Tr_1 = see text

Tr_2 = mains transformer 2×15 V, 4.5 VA

Tr_3 = mains transformer 1×9 V, 1.5 VA

PCB, Order no. 960110

3

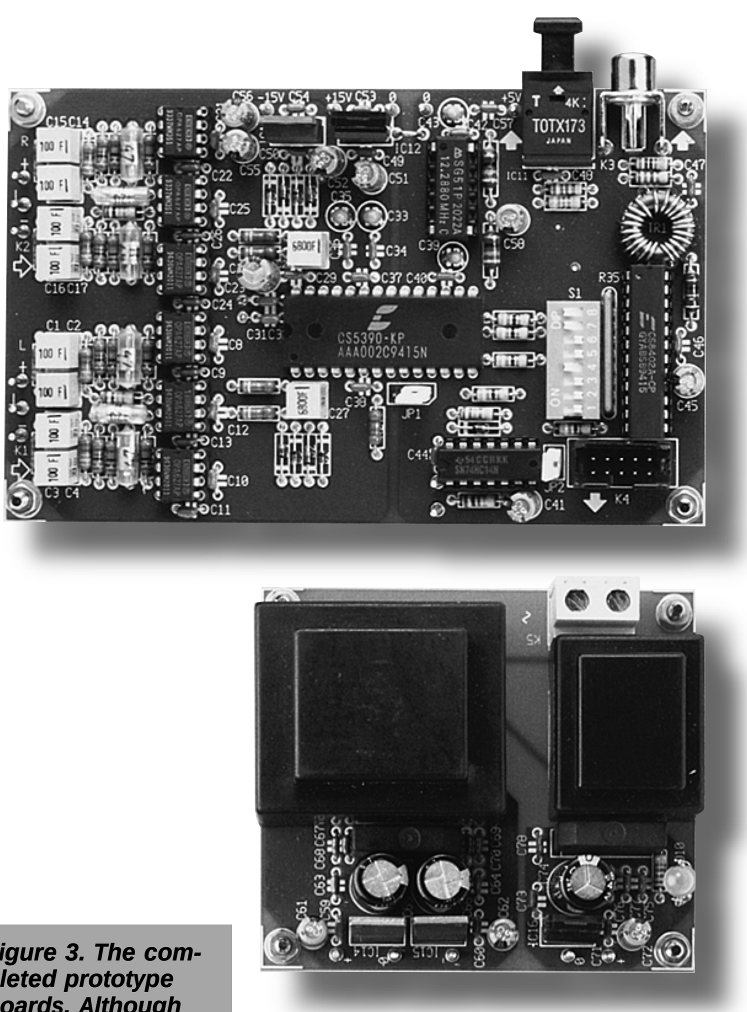


Figure 3. The completed prototype boards. Although the photograph is small, it may be seen that Type OPA627 circuits are used in the IC_1–IC_6 positions.

Wiring up the unit is simple, but the best way is to fix the converter in such a way that output sockets K_3 and IC_{11} protrude through the rear panel of the case.

Next, fit sockets K_1 and K_2 and link these with screened cable to the input terminals of the converter board.

Fit a mains entry, preferably with integral on/off switch, to the rear panel of the case and link this via a length of suitable mains cable to K_5. If the on/off switch is preferred on the front panel, insert it in series with the mains entry and K_5.

The only other operating controls on the front panel are on/off indicator D_{10} and reset push-button switch S_2.

To obtain maximum benefit of the screening of the metal enclosure, it should be linked at a single point to the ground of the converter and power supplies and to the mains earth. This is best done with a small bolt, nut, washer and solder tags fitted to a suitably drilled hole in the bottom of the enclosure. Wire bridge JP_3 may also be used for commoning the earths.

Finally, consult the Safety Guidelines elsewhere in this issue.

APPLICATIONS

The converter is suitable for use in a wide range of applications in which analogue-to-digital conversion of the highest quality is needed. One possible application is its use as an upgrade for a DAT recorder (no longer in production), which is straightforward thanks to its symmetric inputs. Where the necessary equipment exists for mixing at digital level, several converters may be used to make a master recording with only one DAT recorder.

Another use is in combination with the ‘sampling rate converter’ mentioned before. Such a combination would make it possible, for instance, to make analogue recordings with a sampling rate adapted to the CD standard. In principle, that may also be done without a sampling rate converter, but then the clock of IC_7 must be altered to 11.2896 MHz: this would give a sampling rate of 44.1 kHz. However, the published ‘sampling rate converter’ offers the possibility of converting the 20-bit data into a 16-bit format, whereby, through psycho-acoustic noise shaping, a resolution of 18 bits is attained.

[960110]

In passing ...

What progress?

After much discussion, we had finally convinced our managing director that we urgently needed a new, faster computer for communicating over the Internet. The 386 unit to be replaced was, in spite of the Windows 95, a lame duck.

When the new 150 MHz pentium computer finally arrived, we coud not wait to get going on it. Alas, our joy did not last very long. After all connections were made and the mains switched on, all that worked was the internal fan. The computer itself remained dead. Now what? Of course, there is such a thing as a guarantee, but as engineers ourselves, we wanted to find out what was wrong. So, the case was opened and what did we find? The VGA card was suspended somewhere above the PCI connector it should mate with. A further check revealed that the cover of the card was not in the correct position, so that the card could not be pushed far enough into the PCI connector. When all this was righted, hurray! The PC worked.

The supplier had installed Windows 95 on to the hard disc, but he had probably never heard of cluster sizes. The entire 1.6 GB hard disc consisted of one partition! So, we arranged the disc in three partitions and reinstalled the software. After Windows had been reinstalled, the drivers for the VGA card also had to be reinstalled. Not so difficult, you might think, since there was an installation for Windows 95. This worked all right, but the utility for setting the image frequency (which was there originally) could not be found. But we had selected the correct video processor according to the manual and the floppy. So, we installed the DOS utilities, which, strangely enough, were on another floppy that was, according to the instructions, intended for OS/2. The utitlity we wanted could not be found. By now very suspicious, we looked again and found the Windows drivers for this card on a CD-ROM containing all sorts of demo for the VGA card. When these were tried, they proved to be for a different video processor than the present one. Oh, well, you can only try! And, lo and behold, they were the correct drivers with the associated Windows utilities. If you can understand all this, we cannot.

Browsing through the said CD-ROM, we had seen MPEG-player software, and this we had to try, of course. This did not prove to be a success, either. The program worked all right, but every time the film was run, the start menu for Windows disappeared after a second or so, so that there was no time to start the program. By then it was time to go home.

We shall sleep over it. Tomorrow, with fresh suspicions, we shall try the sound card.

Harry Baggen