



MIDI-Merger



Measuring in Word and Excel

MP3 Basics and Chipsets

staging a DIY MP3 player

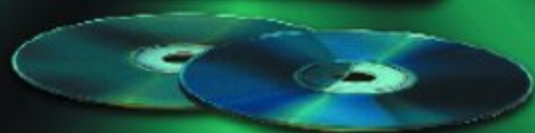


MP3

ECG Simulator

Lead-free Soldering

Working with Surface Mount Devices

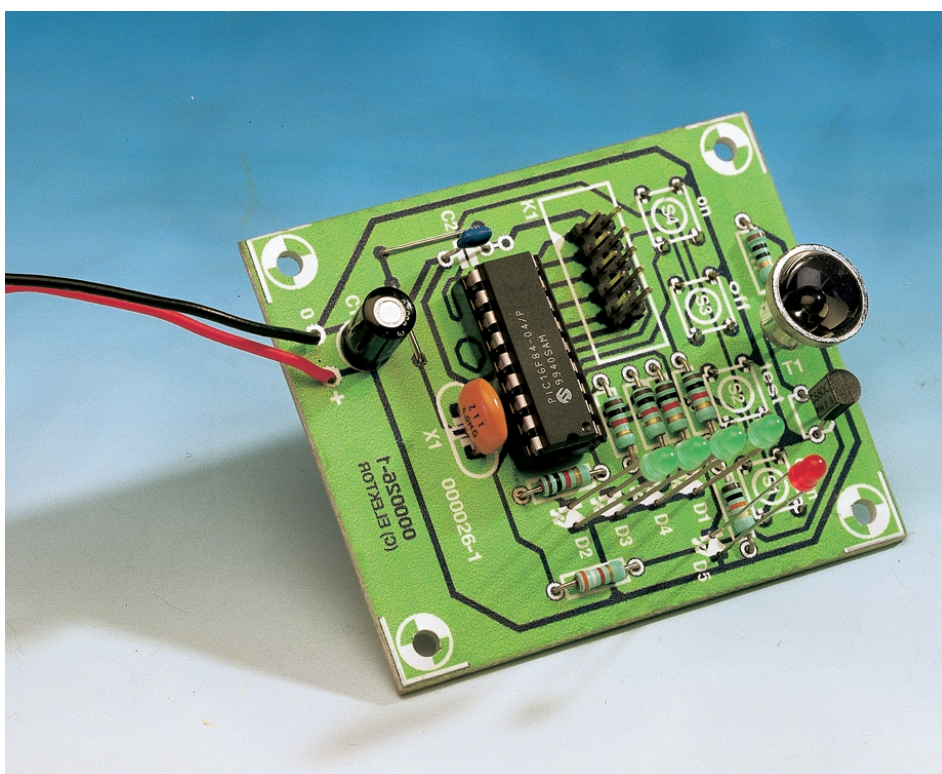


RC5 Sleep Timer

Everything off!

Design by U. Reiser

The well-known 'sleep' function in clock radios and television sets switches off the equipment after a preselected time. However, what good does it do to put the television into standby mode while the stereo set or DVD player that is connected to it remains unaffected? The sleep timer described here sends standby codes to several RC5-compatible devices at the same time.



Function and operation

The circuit shown in **Figure 1** allows you to select the equipment that will be switched on or off as well as the sleep time, which might better be called the delay time. The sleep timer is operated using four pushbutton switches. The current state of the timer is indicated by four LEDs, each of which corre-

sponds to 30 minutes of time delay. In normal operation, these diodes are enabled for only one second out of every ten, in order to save energy.

When the ON button is pressed, pin 4 (MCLR) is pulled from a high level to a low level. This resets the processor, which consequently

wakes from the sleep mode. After the switch-on pulse, the series of LEDs runs through all possible display states and finally remains in the state corresponding to a delay of two hours. The sleep time countdown starts at this point.

The operating status indicator D6 is active as long as switch S4 is pressed. The weaker the light from this LED, the lower the battery voltage. Red LEDs should be used for D1 through D4, but D6 should be a green or yellow LED. The higher voltage drop of the latter type makes it considerably easier to recognise a drop in the battery voltage than with the red LEDs used for the time scale display.

Pressing the DOWN button (S1) activates the LED scale, which shows the current delay time for slightly less than three seconds. If this button is pressed for longer than 0.75 second, the delay time is reduced by half an hour every 0.75 second. If it reaches the minimum time, it jumps back to two hours. When the DOWN button is released, the time delay begins, and the display scale remains lit for another two seconds.

Naturally, the sleep timer can control equipment only if it is pointed at the infrared receiver(s) of equipment in question. In order to ascertain the

best location for the sleep timer, you can press the TEST button (S2), which causes the selected standby signals to be transmitted. This also interrupts the sleep time counter.

Pressing the OFF button (S3) puts the PIC controller into the sleep mode (not to be confused with the sleep delay time of the circuit!). At first the display scale will show the current delay time, and then it will count down to zero at an interval of 0.3 second. Following this, the half-hour LED blinks ten times at a rate of 5.5 Hz, and the timer then switches off.

Any desired combination of equipment that should be switched off by the sleep timer can be selected using five jumpers. The television set is always included in the group to be switched off.

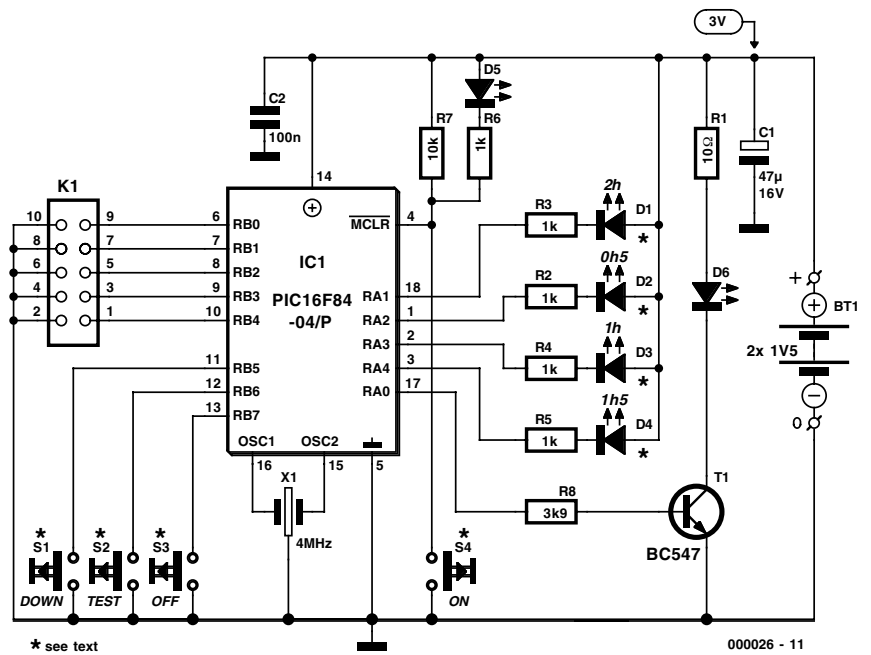


Figure 1. Circuit diagram of the RC5 sleep timer.

Generating the RC5 codes

The RC5 signal is generated by means of several timing loops that set or clear RA0. Since the shortest timing interval (one instruction time) is 1 µs with a 4 MHz clock, the timing differs slightly from the RC5 standard. The times generated by the PIC are marked on the timing diagram shown in Figure 2. Every RC5 instruction consists of 14 bits. A logic 1 (rising edge) is generated by the calling CALL LO and then CALL HI in sequence, while a logic 0 (falling edge) is generated by reversing the calling sequence. Bits 6 through 10 form the device address. In addition to the two Start bits, the Control bit is always a logic 1. The Control bit is used to distinguish between multiple presses of a button (or contact bounce) and an optical interruption of the light beam. It changes its logical state each time a button is pressed, for which reason it is also called the toggle bit. However, since the equipment is switched on by the 'normal' remote control and switched off by the sleep timer, it is not possible to correctly specify the value of the Control bit in the sleep timer. This does not hurt anything, as long as the last instruction sent by the normal remote control unit was not 'switch on from standby'. Even in this case, the chance of failure is only 50%, since this only happens if the Control bit

was a 1 the last time it was sent. By the way, this is also the reason why a RC5 receiver sometimes cannot recognise 11, 12 and so on when the instruction comes from an adaptive remote control unit.

Software description

The sleep timer is controlled by the program SLEEP.ASM. This is available via the Internet from www.elektor-electronics.co.uk, from our Readers Services on a diskette (number

000026-11), or as a ready-programmed PIC (number 000026-41). The program flow is shown in Figure 3. The subroutine named INITIALISATION sets the five bits of Port A as outputs and the eight bits of Port B as inputs, sets the prescaler ratio to 1:256 and connects it in front of the RTCC. At the same time, the pull-up resistors for all leads of Port B are activated. Immediately after the power supply is switched on or a reset occurs, the routine POWER-ON-SELF-TEST drives LEDs D1 through D4 sequentially for 0.3 s each. This process is intended to indicate that the circuit is basically in good work-

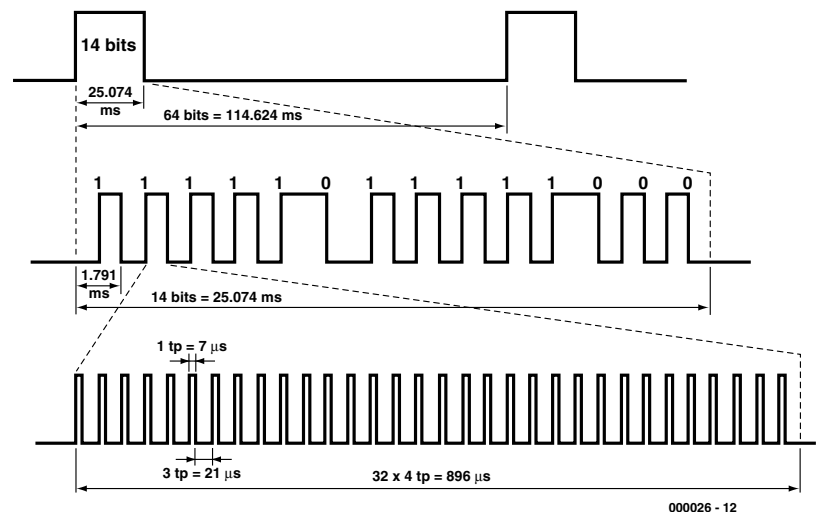
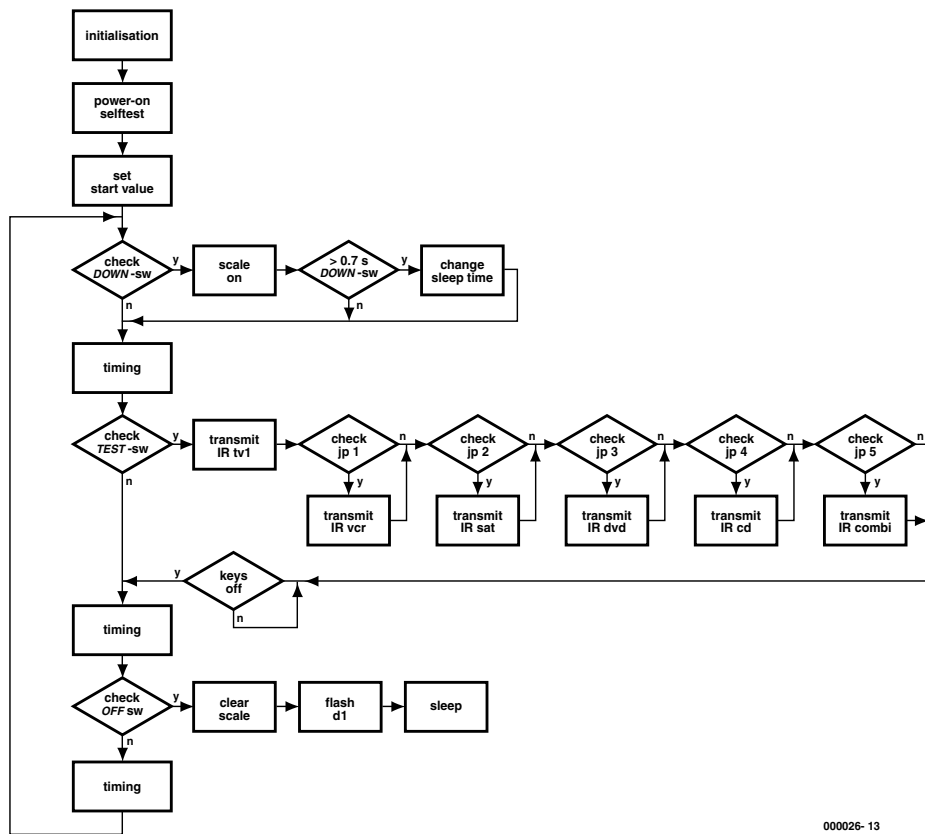


Figure 2. Timing diagram of the RC5 signals generated by the PIC.



000026-13

Figure 3. Flow chart of the RC5 sleep timer software.

ing order. The routine SET-START-VALUES loads the starting values into a series of counter registers that are used for blinking the delay time scale at a 10-second interval and for the 4 hour to half an hour time delay process. After this comes the main program, in

the form of an endless loop consisting of six other routines. The first action is to poll the DOWN switch. If it is set, the delay time scale is illuminated for two seconds. If the scale is already on, the time that it stays

on is extended by two seconds. If this button is held for longer than 0.75 second, the program jumps to the subroutine CHANGE-SLEEP-TIME. This routine reduces the sleep time by half an hour every 0.75 second, or changes it from 0.5 hour to 2 hours. This process continues until the DOWN button is released.

The TIMING routine, which is located next and in two subsequent places, decrements the counter that controls switching the delay time scale LEDs on and off. In addition, it counts down the counters for the seconds, minutes and half hours of the overall running time. If the scale

COMPONENTS LIST

Resistors:

- R1 = 10Ω
- R2-R6 = 1kΩ
- R7 = 10kΩ
- R8 = 3kΩ

Capacitors:

- C1 = 47μF 16V radial
- C2 = 100nF

Semiconductors:

- D1-D4 = low-current LED, red
- D5 = low-current LED, green
- D6 = LD271 or SFH485 with reflector
- T1 = BC547
- IC1 = PIC16F84-04/P, programmed, order code **000026-4 I**

Miscellaneous:

- X1 = 4MHz ceramic resonator (Conrad Electronic #50 31 69)
 - S1-S4 = miniature pushbutton, 1 make contact, 6·6 mm² for board mounting (Conrad Electronic #70 04 60, Bourns #7906H-001-000, Farnell #535-916)
 - 10-way pinheader, plus up to 5 jumpers
 - Toko handheld transmitter case (Conrad Electronics #52 43 44)
 - Battery holder for 2 'Micro' batteries
 - PCB, order code **000026-1***
 - Disk, order code **000026-11***
- * Price and ordering information on the Readers Services pages elsewhere in this issue.

Conrad Electronics are at <http://www.conrad-electronic.com>

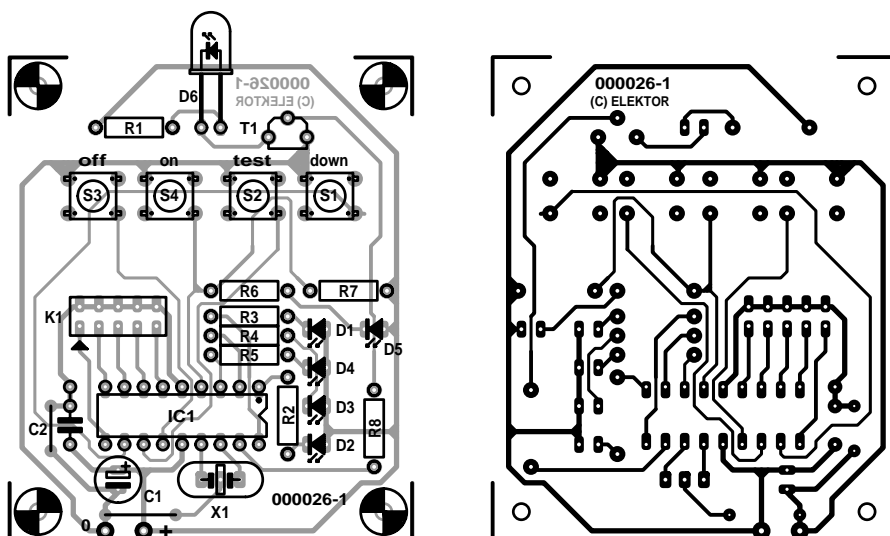


Figure 4. Circuit board track and component layouts for a circuit board that fits in the recommended remote control enclosure.

register has timed out, the program generates the RC5 codes and the processor finishes its job with a Sleep instruction.

If the overall running time has not timed out, the TEST button is next polled. If it is pressed, the RC5 code for TV1 is sent first. After this, jumper JP1 is polled. The code for VCR1 may then be sent, depending on the jumper setting. The same process is repeated for the other four jumpers.

The TEST routine can exit via the KEYSOFF subroutine only after S2 has been released. This means that only one infrared signal output can occur each time the button is pressed, which increases the life of the batteries. The TIMING subroutine is now executed once again.

The following routine, CHECK-OFF-SWITCH, monitors the state of the OFF switch S3. If this is pressed, the delay time scale is visually decreased from its present value to 0.5 hour, and LED D1 then blinks ten times. After this the program stops early with a Sleep instruction.

If the STOP button is not pressed, the TIMING routine is executed once again, and the program then jumps back to testing the DOWN button.

Hardware

With the use of a PIC processor, the number of components for the circuit is kept to an absolute minimum. A 4-MHz resonator with integrated capacitors is used to control the clock frequency of the processor. The reset input of IC1 is connected to the positive supply line via resistor R7. The ON button (S4) generates a processor reset. LED D6 also receives its negative supply voltage via S4. Buttons S1 through S3 and all the jumpers (see **Table 1**) are connected to Port B, which provides internal pull-up resistors. The indicator scale LEDs are driven via RA1 through RA4. Red low-current LEDs are used to reduce the current to

1.5 mA. The pulse code of the RC5 signal is amplified by transistor T1 and passed to the IR LED. Two 1.5-V batteries are used as the power source. According to the manufacturer, the PIC will work down to a voltage of 2 V, but in our tests it still worked at a voltage of 1.8 V. This means that you can milk the very last milliwatt-second out of the batteries. With a supply voltage of 2.5 V, the current consumption of the RC5 sleep timer is 1.22 mA with the scale diodes on and 0.4 mA when they are dark. In the PIC sleep mode, it is only 30 μ A.

Packaging

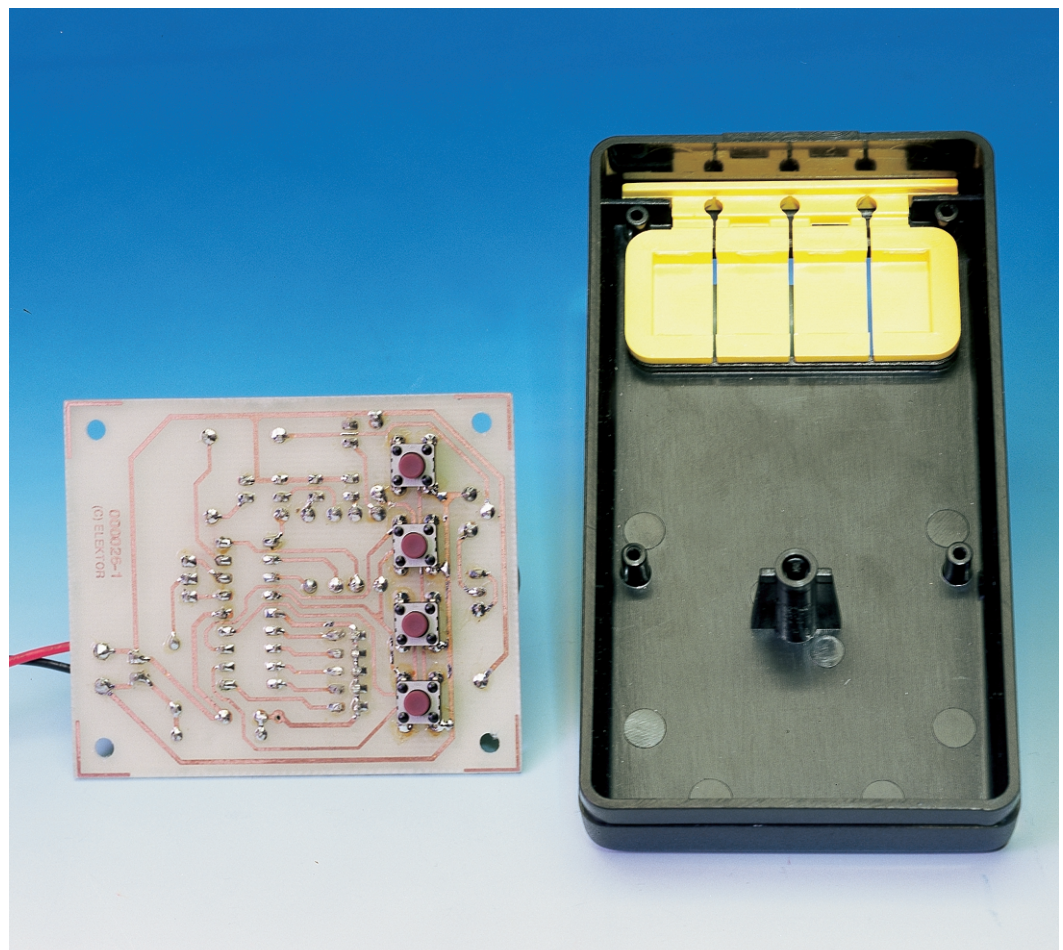
Although the printed circuit board for the sleep timer shown in **Figure 4** is one-sided, switches S1 through S4 and LEDs D1 through D5 are mounted on the copper side of the board, so that that the controls and indicators are all on one side of the board. The remote control enclosure suggested in the components list already includes four key caps. The

Table 1. Equipment codes

JP	Device
1	VCR1 (video recorder 1)
2	CD (compact disc player)
3	DVD (compact video disc player)
4	SAT1 (satellite TV receiver 1)
5	Combi (stereo set)

mounting height of the pushbutton switches should be adjusted to match the key caps. Five holes must be drilled in the enclosure for the 3-mm LEDs. Their mounting height is also important. The 5-mm IR LED protrudes through a hole at the top of the enclosure and is connected to the circuit board by flexible wire. In the lower part of the enclosure, there is a battery compartment that can hold two penlight cells (AAA) with a battery clip. You can also use mignon cells (AA), but without a clip.

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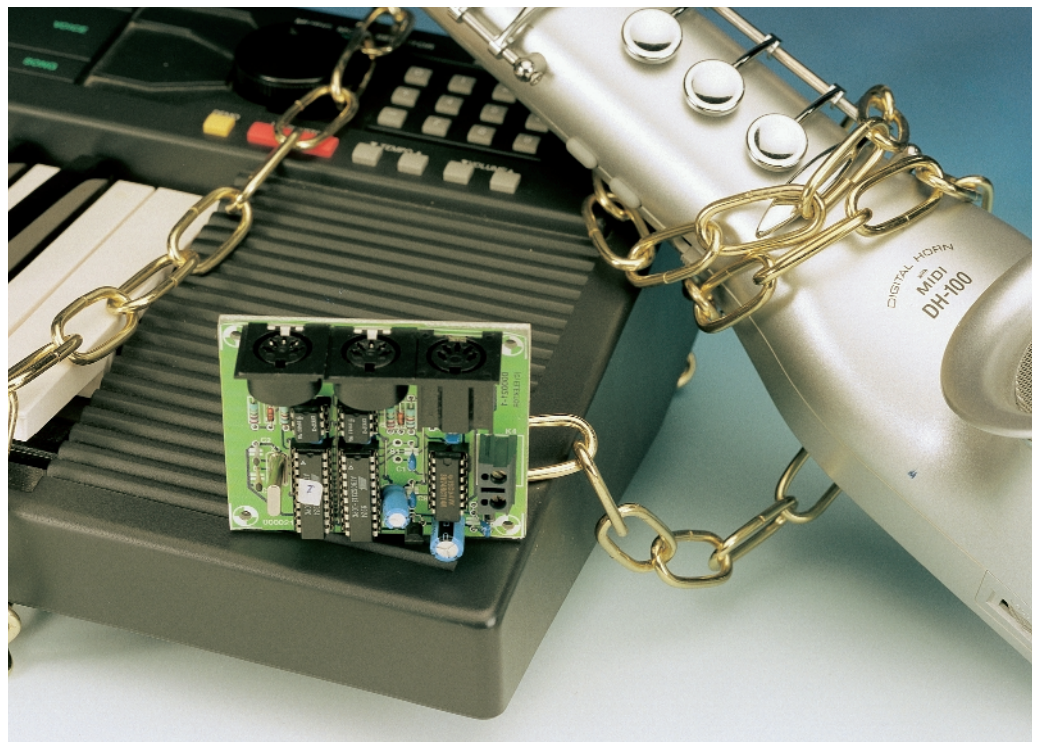
MIDI Merger

Two signals for one receiver

Design by F. H. Splittgerber

Whenever two MIDI signals have to be combined to drive a receiver, you need a MIDI merger. In the design presented here, two coupled microcontrollers merge the data.

Since the MIDI signal is unidirectional and sequential, the data are transmitted without any feedback from the receiver. This means that it is not easy to simultaneously combine the signals from two MIDI sources. However, it can be desirable to combine the data streams from two input devices in order to drive a single destination device (such as an expander). This function is performed by a device called a 'MIDI merger'. It produces a meaningful signal from the combination of several data streams from different sources. This is not a simple task, since the data can range in length from a single byte for a control instruction up to several hundred bytes for SysEx instructions, and the tone information can vary considerably (it is frequently sent as 'running status', occasionally interrupted by SysEx instructions). Supplementary control data must be correctly merged into the data stream. Problems can occur with real-time system requests and timing signals. It is necessary to buffer the data for both channels, and if necessary to resolve the running status (see the box). In principle, this problem can be solved using a microcontroller and a UART, or by using two microcontrollers.



Coupled microcontrollers

In this case, the solution that has been chosen is to use two coupled Atmel AT90S2313 microcontrollers. Since each of these devices has a built-in programmable serial interface and 128 bytes of RAM, no additional logic components are necessary. The only other components used for the MIDI Merger are a pair of optocouplers for the signal inputs,

an output driver, a clock crystal and a few passive components. The MIDI Merger automatically sets itself up to work with MIDI sources that emit an Active Sensing signal, and it in turn outputs the same signal according to the standard specification. After the MIDI Merger is switched on, the software first runs through a learning cycle. If the Active Sensing signal is detected within 300 ms, the software sets up the MIDI Merger

according to this signal. If any of the input signals is interrupted, which happens very easily on stage, a Reset is output after at most 300 ms in order to switch off the active tone. Anyone who has ever heard what happens when a MIDI synthesizer or other MIDI output device 'hangs', will certainly appreciate this feature! A reset is also generated if the buffer overflows, which is very unlikely. Due to the initial learning cycle, it is necessary to connect inputs of the MIDI Merger to the already switched on data sources before switching on the MIDI Merger itself.

The UART inputs of the two Atmel controllers (pin 2) receive the signals from the MIDI input channels. The data that arrive via input K1 are processed by microcontroller IC4. The two microcontrollers are interconnected via their control lines and an 8-bit bus (pins 12 – 19) that carries MIDI data that have been converted into parallel form by IC4. IC5 allows the MIDI Merger to be manually reset. The capacitor connected in parallel with the reset switch (S1) effectively suppresses contact bounces. The software resets the second microcontroller as necessary by sending a signal to its reset input via pin 8 of IC5. The shared control lines synchronise the two controllers when the system starts up and during data communications. The main job of IC4 is to convert the serial data arriving at pin 2 to parallel form and pass them on to microcontroller IC5, which in turn receives serial MIDI data from the K2 input via its UART input. The software in IC5 looks after combining the serial data received by IC5 with the parallel data received from IC4. The UART output signal from pin 3 of IC2 is buffered by two gates and output to the current loop via R1 and R2.

Pin 7 of IC5 must always remain open, since it is used for a software interrupt. When the software recognises a Real Time signal, it forces a level change at this bi-directional port and thus triggers interrupt 1 (INT 1). This is the only way in which Real Time signals can achieve the required priority. Timing Clock signals at the K1 input are suppressed, but they are passed through at the K2 input.

Two MIDI Mergers can easily be chained in series. This makes a third input available, which for example can be used to insert computer-generated control signals (SysExclusive) into the data stream. When the MIDI Merger is switched on, it sets the destination device to a neutral state by issuing a MIDI Reset, in order to avoid any conflicts with the new data.

Operating both microcontrollers from the 4-MHz crystal oscillator of one of the ICs has not been documented by Atmel, but it is based on

And the rest

The type of optocoupler used for the inputs is relatively critical. Of the types that were tested, only the recommended CNY17-2 achieved the required data transfer rate of 31,250 baud. Resistors R5 and R6 should have values between 1 kΩ and 3 kΩ.

A 9-V mains adapter is employed to supply power to the unit. Its output is stabilised at +5 V by IC6 to provide the operating voltage. Diode D3 prevents any damage to the unit in case of a reverse-polarity connection. The circuit draws around 19 mA.

There's not a lot to say about the con-

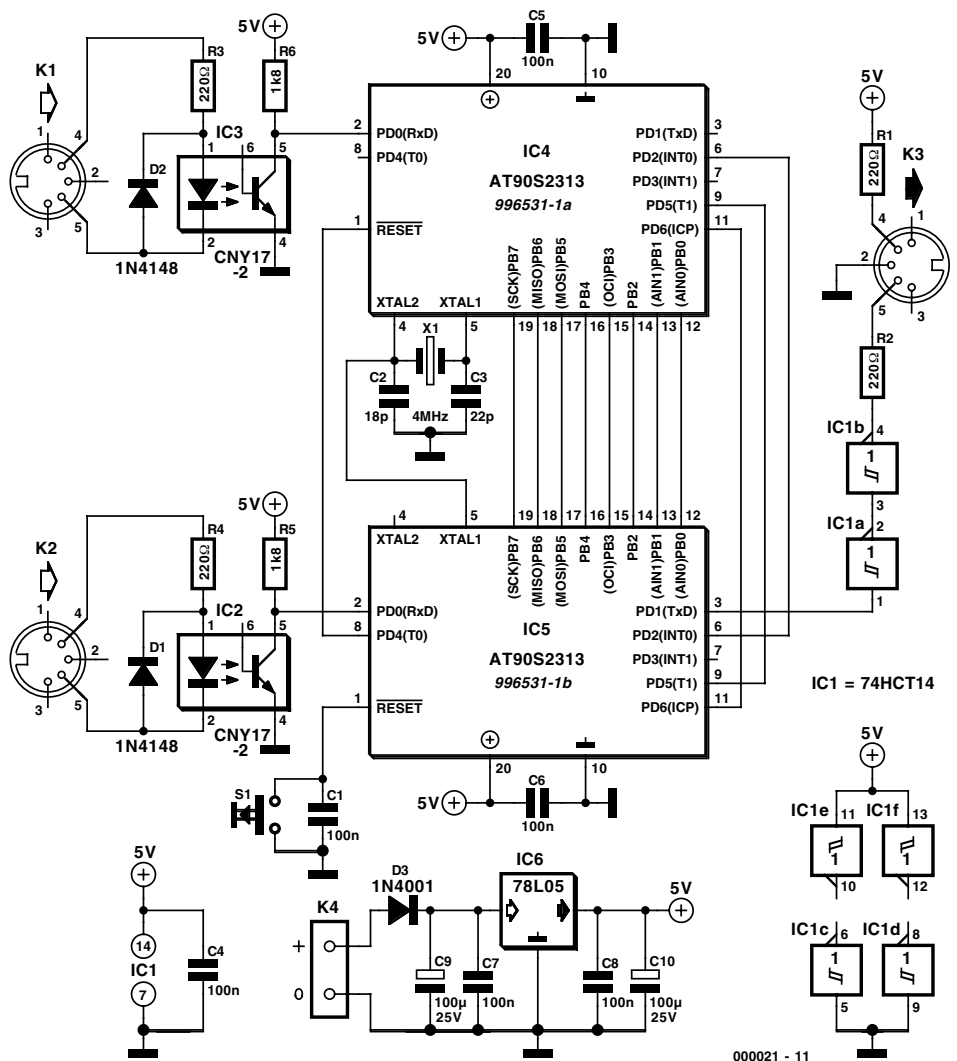


Figure 1. The circuit consists of a pair of microcontrollers, a power supply, two optically isolated inputs and one output.

a discussion with the Atmel engineer Arild Rodl in Norway. C2 is somewhat smaller than C1 in order to compensate for the extra capacitive load of the clock input of IC5.

struction of the circuit on the printed circuit board shown in **Figure 2**. The microcontroller software (source code) is available on a diskette from Readers Services, or from our website at www.elektor-electronics.co.uk. If

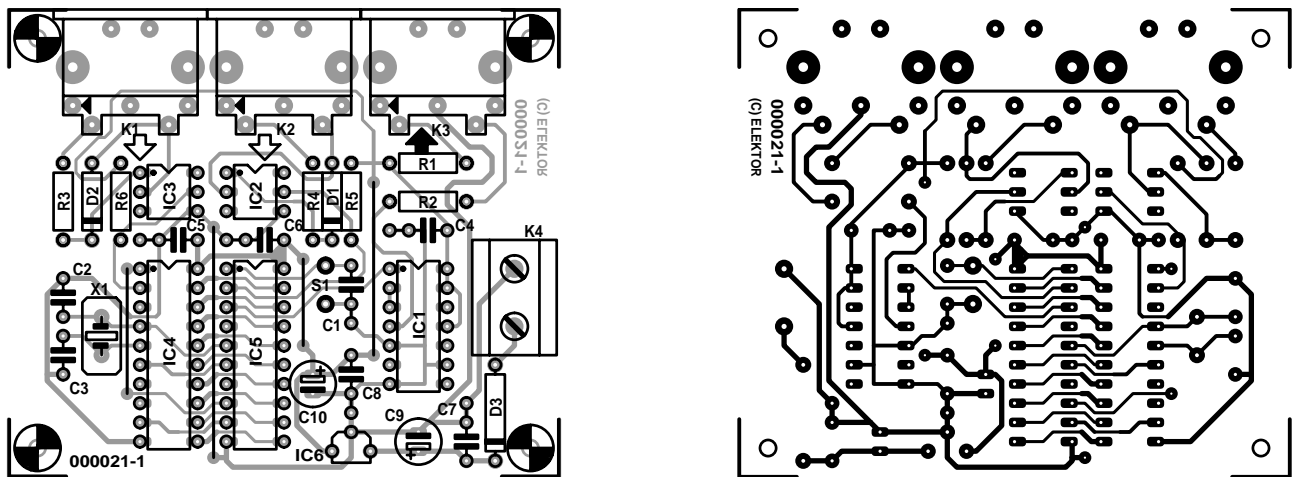


Figure 2. This printed circuit board can be used to build the MIDI Merger in a very compact form.

MIDI and the MIDI Merger

Version 1.0 of the MIDI (Musical Instrument Digital Interface) standard was first published by the MIDI Manufacturers Association in 1983. Since then, MIDI has become the predominant communications protocol between data sources (such as keyboards, MIDI instruments and drum machines) and destination devices (such as expanders, sequencers and computers). MIDI data are unidirectional and serial. They are carried by a 5-mA current loop. The transmitter device expects that the receiving device will continuously accept the data stream. There is no provision for acknowledging or temporarily halting the data transfer. Merging the data streams from two different MIDI sources is not a simple task, since it is not easy to synchronise the source devices.

The data are carried by a screened two-lead cable that may be up to 15 metres long. Five-pin 180-degree DIN connectors are used at each end of the cable. Pin 2 is connected to the cable screen, while pins 4 and 5 are connected to the optocouplers at the device inputs to close the current loops. The other pins are not used. Many devices have MIDI In, MIDI Out and MIDI Thru connectors, but in spite of what you might think the MIDI signal produced by the device itself is not combined with the MIDI In signal. All that is present at the MIDI Thru connector is a copy of the signal applied to MIDI In, while the signal produced by the device appears at the MIDI Out connector.

Data are transferred as individual bytes transmitted at 31,250 baud along with start and stop bits. Each instruction starts with a status byte, which is unambiguously identified by having its msb set to 1. All data bytes that are not status bytes have the msb set to 0. This means that 127 (2⁷) different values can be assigned to a non-status byte. *Channel* and *system* instructions can be used to distinguish two higher-level types of MIDI signals. The two channel commands are *Channel Voice* and *Channel Mode*, while the system commands are *System Exclusive*, *System Real Time* and *System Common*. In a channel command, the status byte is followed by two or three other bytes. The upper four bits (upper nibble) of the status byte may have a value between 8_H and E_H, while lower nibble of the status byte specifies the MIDI channel. The channels are designated as 1 through 16, so a 0 in the lower nibble of the status byte means channel 1 and a F_H means channel 16.

At a data transfer rate of 31,250 baud, each bit is 32 μs long, and it thus takes 320 μs to send one byte. An instruction to switch a tone on or off consists of three bytes, so it takes somewhat less than 1 ms to transfer this information. Since the MIDI data are transferred serially, the available bandwidth limits how fast the data can be transferred. For example, when ten tones are activated it takes 9 ms until the final tone is produced, which is an audible delay. Nevertheless, MIDI can manage to transfer polyphonic data without audible errors, even with very long control sequences, by using a data coding technique called 'running status' to recover some additional bandwidth.

you don't want to be bothered with programming your own devices, you can obtain ready-programmed microcontrollers through our Readers Services.

As usual, the programmed controllers may be installed in sockets, which markedly sim-

plifies the job of soldering everything in. If you use the items recommended in the components list, pay attention to the polarity and above all do not mix up the two controllers, which are programmed differently, you should

COMPONENTS LIST

Resistors:
R1-R4 = 220Ω
R5,R6 = 1kΩ8

Capacitors:
C1,C4-C8 = 100nF
C2 = 18pF
C3 = 22pF
C9,C10 = 100μF 25V radial

Semiconductors:
D1,D2 = 1N4148
D3 = 1N4001
IC1 = 74HCT14
IC2,IC3 = CNY17-2
IC4 = Atmel AT90S2313
(programmed, order code **996531-1a**)*
IC5 = Atmel AT90S2313
(programmed, order code **996531-1b**)*
IC6 = 78L05

Miscellaneous:
K1,K2,K3 = 5-way DIN sockets, pins arranged at 180°, PCB mount
K4 = mains adaptor socket
PCB, order code **000021-1***
Disk (project source code file), order code **996038-1***

* Price and ordering information on Readers Services page elsewhere in this issue.

have no trouble assembling the board in a few minutes and installing it in the recommended enclosure. After that, it's ready for use!

(000021-1)

MP3 Basics and Chipsets

Staging a DiY Stand-Alone MP3 Player

By Prof. F. P. Volpe and P. Elsesser



Traditionally, an MP3 player requires a semi-conductor memory to store MP3 data. MP3 players capable of reading data directly from a CD and without 'help' from a PC are few and far between. That may change, however, with the home-brew MP3 player described in this short series of articles.

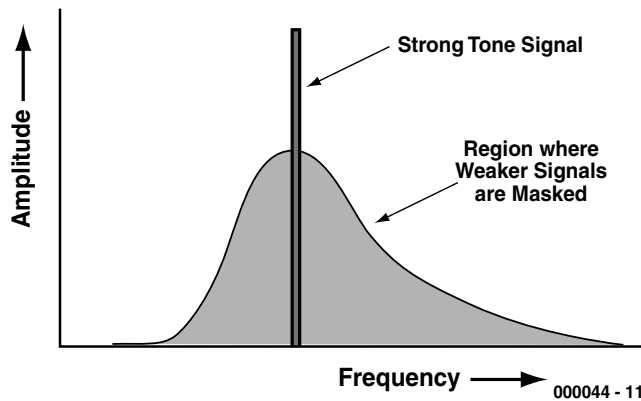


Figure 1. A frequency range is masked (obliterated) by a loud signal.

Music programme material disguised as MP3 files have become big business on the Internet. However, before you can actually play a music-CD with your own selection of MP3 titles you typically have to provide a link between your stereo and your PC, by way of the sound-card. Arguably, a stand-alone MP3 player with an internal standard CD-ROM drive and a hardware MP3 decoder, ready for connection to your stereo, represents a much better solution because it avoids the tedious process of having to 'boot' your PC every time you want to play some music. Also, the often objectionable noise level added by

the PC, and its very presence in the living room, should be considered.

Such an MP3 player will be described in the July/August 2000 issue of *Elektor Electronics*, and the present article is intended as an introduction to it. This month we will describe the outlines and basics of MP3 compression, as well as some frequently seen chip sets for MP3 decoding. We will also gaze into the crystal ball for a bit in relation to future audio compression technologies.

The follow-up article, to be published in our annual Summer Circuits issue (i.e., July/August 2000),

will cover 'hands-on' matters like the construction of the MP3 decoder board, the ATAPI support by a microcontroller and the link to a CD-ROM drive.

Why compression?

A digital audio signal typically consists of samples with a size of 16 bits. According to the sampling theorem, at a given bandwidth, a sample has to be taken at a rate that equals at least twice the frequency of the programme material. If CD quality is required in respect of bandwidth (44.1 kHz), then a data rate of about 1.35 Mbit/s is needed to convey an audio signal. In other words, one minute of music requires about 10 Mbytes of data to be conveyed or stored on a data carrier. Unfortunately, that is not practicable even with the huge capacity of today's hard disks. Obviously, the resultant transmission (=download) times using media like the Internet, Internet-Radio or Music On Demand systems would be very long and therefore prohibitive. In this case, the only solution is to find a way to reduce the immense size of the relevant data, the 'real-world' aim being to convey a stereo music signal across an ISDN link with a capacity of 64-kbit/s per channel. In view of the required compression rate of 1:12, that would seem to be possible only if losses are accepted. Over a relatively short period, a system called MPEG-1 Layer 3 has established itself as the *de facto* standard for audio transmission via the Internet. MP3 employs compression algorithms that take the real-life response of the human ear into account. The resultant quality of reproduced sound is so good that even trained experts are unable to hear the difference between a copy and its original. MP3 is also clearly superior as compared to other MPEG Layers such as the Digital Compact Cassette (MP1), Digital Audio Broadcasting, the Video-CD (MP2) and simpler systems like CELP, μ -Law or ADPCM.

The essential point about MP3 is that the system is based on a psycho-acoustic model whose elementary structure will be discussed below. A far more extensive tutorial about MPEG and audio compression techniques is available in the form of a downloadable file ([mpeg-tutorial.pdf](http://www.elektor-electronics.co.uk/mpeg-tutorial.pdf)) from the Download Area on the Elektor Electronics website at

<http://www.elektor-electronics.co.uk> (document reproduced courtesy IEEE).

Fortunately, this document does not rely on higher mathematics to explain the underlying principles!

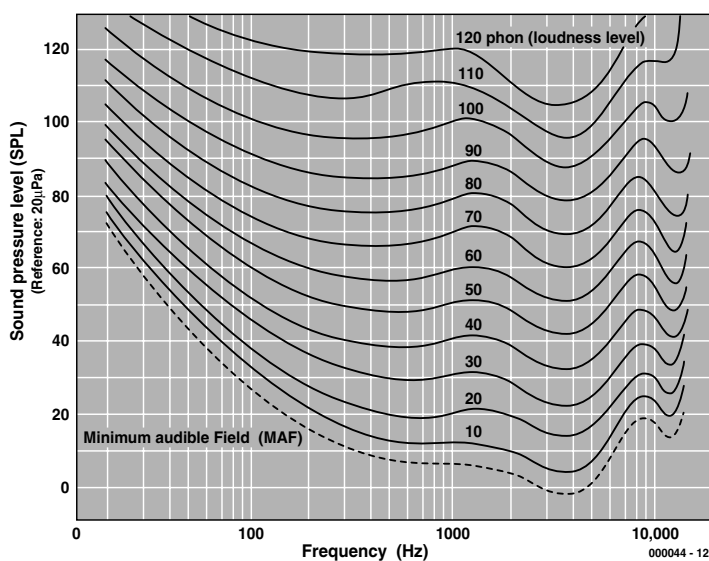


Figure 2. The human ear is particularly sensitive to speech signals.

Psycho-acoustics

The science of Psycho-Acoustics studies the behaviour of the human hearing system in relation to processing of acoustic information in the brain. Psycho-acoustic principles have been extensively used in the development of MP3 and indeed many other compression techniques.

The audible spectrum may be thought of as consisting of 26 frequency bands.

The frequency range below 500 Hz is subdivided into five bands of 100 Hz each. Above this range, the bandwidth is about 1/5th of the centre frequency. In the human hearing system, soft sounds become less distinct and even inaudible when loud, discrete sound levels occur within these 'critical' bands. As an aside, you should note that the frequency resolving capacity of the human hearing system is much more accurate than the critical bands.

The above phenomenon is a condition to allow *masking* of a soft sound by a loud sound which occurs at a nearby frequency and/or instant. The spectral masking range of an individual loud sound is shown in **Figure 1**. The masking (or, if you like, obliterating) sound may occur simultaneously with the soft sound or even after it.

The actual effect of the masking depends not only on the spectral and time-related arrangement of the masking and masked sound, but also on its *tonality*. Noise is far easier to mask than a discrete frequency. Conversely, a discrete frequency is a much better mask than noise.

The starting point for a psycho-acoustic model is the frequency-dependent characteristic of the human hearing system. The curves in **Figure 2** illustrate that sounds within the frequency range of human speech are perceived with greater resolution than very high or very low sounds. The lower, dashed, curve represent the *absolute hearing threshold*, below which no sounds are perceived by most of us. A masking operation is applied to raise the absolute threshold to the so-called *co-hearing threshold*, as it appears three times as dashed lines in **Figure 3** for three different masking signals.

A psycho-acoustic model analyses the audio signal and employs complex algorithms to compute the usability of masking sounds in the relevant frequency range. The closer the model gets to reality, the higher the compression rate that can be achieved at a given quality level of the output signal. However, the rules of the model are 'relaxed' to an extent required by the transmission rate and

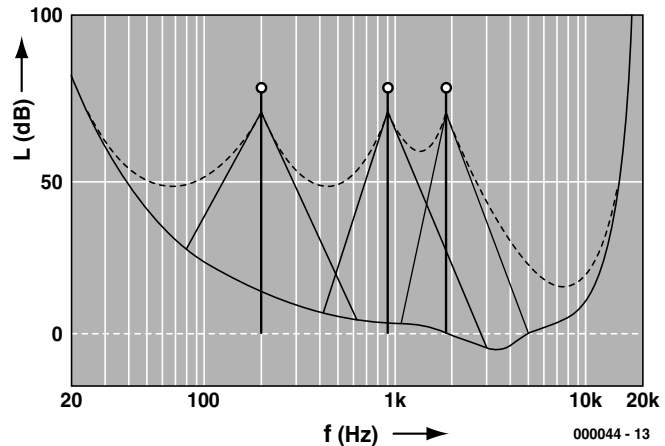


Figure 3. Three masks are applied to raise the co-hearing threshold.

the signal quality. In cases where no compression is required, this is even switched off completely.

Functional blocks

The elementary architecture of an MPEG audio encoder is illustrated in **Figure 4**. Decompression is the reverse operation or encoding. To be able to apply the psycho-acoustic model to the digital audio input signal (a PCM datastream arriving at 768 kBit/s), the signal first has to be transposed to the frequency domain. A fast Fourier transformation with 1024 coefficients is employed as part of the computation of the psycho-acoustic model. Fully synchronous with this

process, a filter bank divides the audible spectrum into 32 sub-bands of equal width (750 Hz at a sampling rate of 48 kHz). Next, 32-times sub-sampling is applied to each sub-band of the input signal, resulting in 32 PCM input data in a sub-band sample. The filter bands equal the previously mentioned critical frequency bands of the human hearing system, with three differences. Firstly, the constant width of the sub-bands is unlike that of the human example, secondly, the filter bank and its complementary function in the decoder are not loss-free, and thirdly, an individual frequency may affect the output signals because of a certain overlap of the sub-bands. Fortunately, the errors

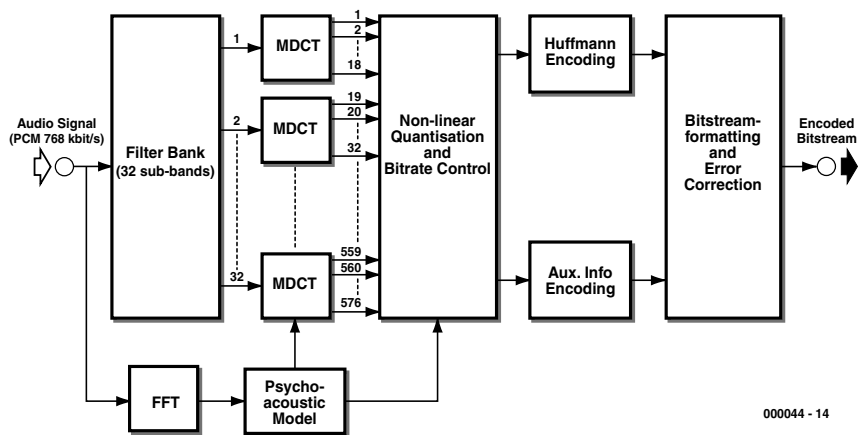


Figure 4. Block diagram of an encoder to MPEG 2.5 Layer III.

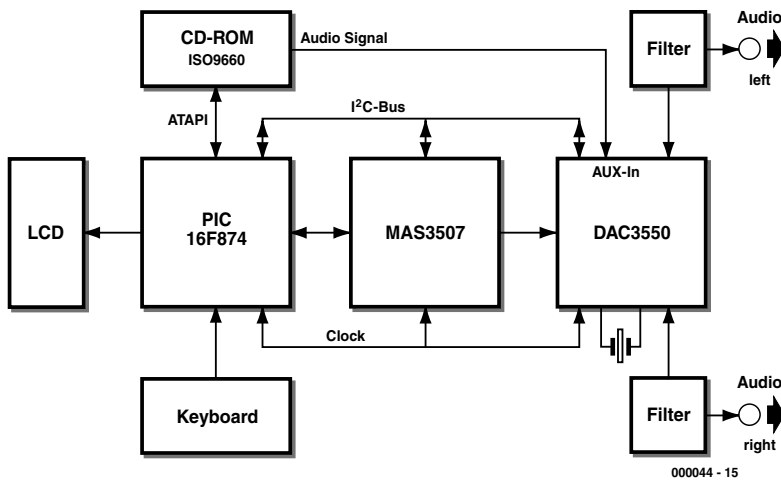


Figure 5. MP3 CD-player based on the MAS3507D decoder and DAC3550 digital-to-analogue converter, both from Micronas Intermetall. The setup is controlled by a PIC17C756.

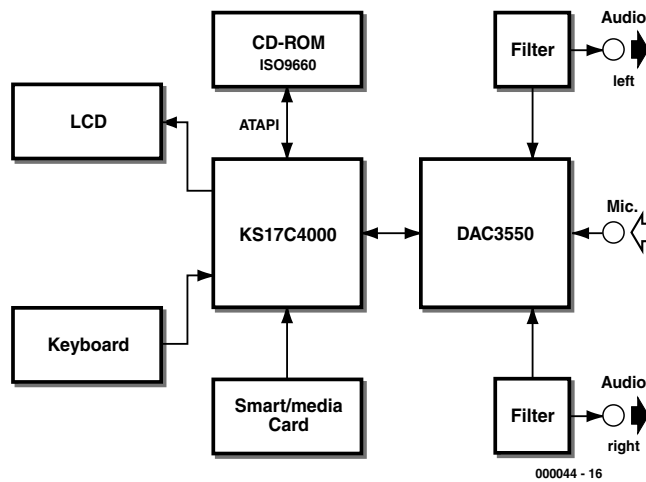


Figure 6. MP3 CD player using the Samsung TL723 IMD decoder. Besides decoding MP3 data this chip also handles ADPCM-based audio signal compression.

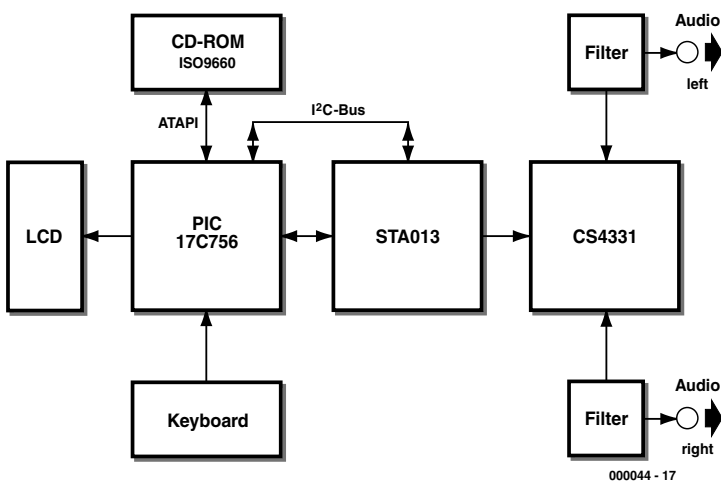


Figure 7. MP3 CD player based on the STA013 decoder from STMicroelectronics and the CS4331 DAC from Crystal Semiconductor.

introduced by the filter bank are small enough to be inaudible (<0.07 dB).

This is mainly caused by the final MDCT (Modified Discrete Cosine Transformation) which divides each of these 32 sub-bands into 18 sub-sub-bands. In the end we have $32 \times 18 = 576$ sub-bands of 42 Hz each (at a sampling rate of 48 kHz).

In the next operation, noise allocation, the ratio of the quantisation noise and the co-hearing threshold is recovered from the difference of the signal-to-noise ratio (filter bank) and the signal-to-mask ratio of the psycho-acoustic model. The number of bits available in the output datastream is then determined (depending on the selected overall data rate minus data on scaling factor, headers and other auxiliary data). The encoder varies the quantisation in a certain sequence, weighs the spectral values, counts the number of bits required for the output signal (the number being further reduced by Huffmann encoding). The outcome is used to compute the permissible quantisation noise level. If, after quantisation, bands are found with unacceptably high distortion, the encoder amplifies these bands and so raises the size of their quantisation stages. The operation is repeated until distortion levels are below the acceptable level. MP3 works with a variable transmission rate and so creates a kind of 'buffer' for the duration of signals that require a few bits only. The buffer is employed for 'difficult' encoding operations, at which the data rate is fully exhausted.

The block diagram of the encoder is completed with a formatting unit that serves to add the auxiliary data, and pack the lot into frames ready for sending to the decoder.

From chipset to MP3 player

Different chipsets are currently available for the purpose of decoding MP3 signals. In this article, three options are discussed for realizing a stand-alone CD player for MP3 and audio data, based on three different chip sets from different manufacturers. The data source is invariably a standard ATAPI-compatible CD-ROM drive. A microcontroller is used to look after the ATAPI protocol and supply the data for the MP3 decoder. The same controller also drives an LCD, and scans keys for navigation within the CD directory structure. A digital-to-analogue converter converts decompressed data supplied by the MP3 decoder into plain audio signals.

At the time of writing, MP3 chipsets are offered by three companies. **Figure 5** shows an MP3 player based on a chipset supplied by Micronas. This player is controlled by a PIC17C756 which reads the MP3 data from a

CD-ROM drive and transmits them serially to a decoder chip type **MAS3507D**. You can browse the CD contents and navigate by means of a keyboard and a readout (LCD). The display also indicates the ID-3 tag (data information). Decoded data are applied to a digital-to-analogue converter (DAC) type **DAC3550**, which supplies the analogue audio signals. After cleaning in a third-order low-pass filter, the audio signals are allowed to leave the decoder.

Besides a digital input, the converter also sports an analogue input. An I²C command is used to select between these inputs. If the microcontroller detects a music CD in the CD-ROM drive, the DAC is 'ordered' to switch to its analogue input.

Another chipset is shown in **Figure 6**. Here, the Samsung **TL7231** is used as the MP3 decoder. Because this chip integrates a digital-to-analogue converter, the number of components is drastically reduced. In addition to the MP3 decoder function, the TL7231MD also has an ADPCM Codec. Using this chip it is possible to store audio signals in compressed form, and play them back again.

If PCB space is at a premium, the solution is to employ the **STA013** from STMicroelectronics (**Figure 7**). This chip comes in a SO-28 case. The CS4331 digital-to-analogue converter from Crystal Semiconductor comes in a SO-8 enclosure. It should be noted that this MP3 decoder wants a configuration file after every reset. This file is supplied by the ST7 central controller in the system.

(000044-1)

Note:

The construction of a Stand-Alone MP3 Player will be discussed in the July/August 2000 issue of Elektor Electronics.

Literature

- Micronas Intermetall: MAS 3507D MPEG 1/2 Layer 2/3 Audio Decoder. Preliminary Data Sheet, Edition Oct. 21, 1998.
- Micronas Intermetall: DAC 3550 Stereo Audio DAC. Preliminary Data Sheet, Edition April 23, 1999.
- Samsung Semiconductor: TL7231MD Full Layer-III ISO/IEC 11172-3 Audio Decoder. Data Sheet.
- STMicroelectronics: STA013/STA013T MPEG 2.5 Layer III Audio Decoder. Data Sheet, September 1999.

Compression and the future

A number of other audio compression methods exist besides MPEG Layer III. These are partly well established, partly 'being designed'. At least for the near future MP3 seems to have won the battle for dominance on the Internet. However, Sony's AC-3 system has pushed MPEG aside in the DVD market.

MPEG-2

allows 'low' sampling frequencies like 16 kHz, 22.05 kHz and 24 kHz besides the more usual 32 kHz, 44.1 kHz and 48 kHz standards. It also supports 5.1-Surround as well as multi-language broadcasts. Otherwise downwards compatible with MPEG-1.

MPEG-2.5

again halves the sampling rates, allowing bit rates up to 8 kbit/s to be achieved. Otherwise this standard is downwards compatible with MPEG-1. The Micronas chipset used in the Stand-Alone MP3 Player is designed for MPEG-2.5.

MPEG-2-AAC (Advanced Audio Coding)

is not downwards compatible. It allows sampling frequencies of 32 kHz, 44.1 kHz and 48 kHz as well as single-channel, dual-channel 5.1-Surround and multi-language broadcasts. Provision is made for error detection/correction. AAC is increasingly used by broadcast stations and, interestingly, for a new satellite radio station covering the southern hemisphere. In Japan, HDTV and all broadcast systems are to employ AAC.

MPEG-4

allows acoustic events in a room to be described. This is of particular interest to multimedia applications because a 'speed control' enables different media to be synchronized.

ATRAC

is used in MiniDisc systems and supplies a data rate of 140 kbit/s/channel. The main difference with MPEG-1 is that the filter bank uses a different method to resolve the spectrum. In higher frequency bands, the frequency resolution is reduced and the time-resolution is increased. (the 'higher' filter sections operate faster).

Dolby AC-3

is MPEG's biggest competitor and extensively applied with DVD and HDTV. AC-3 supports various formats including 5.1-Surround. The bitrate may lie between 32 kbit/s and 640 kbit/s. The quality is about the same as MPEG-2, however it is below that of AAC with 5.1-Surround.

MS Audio

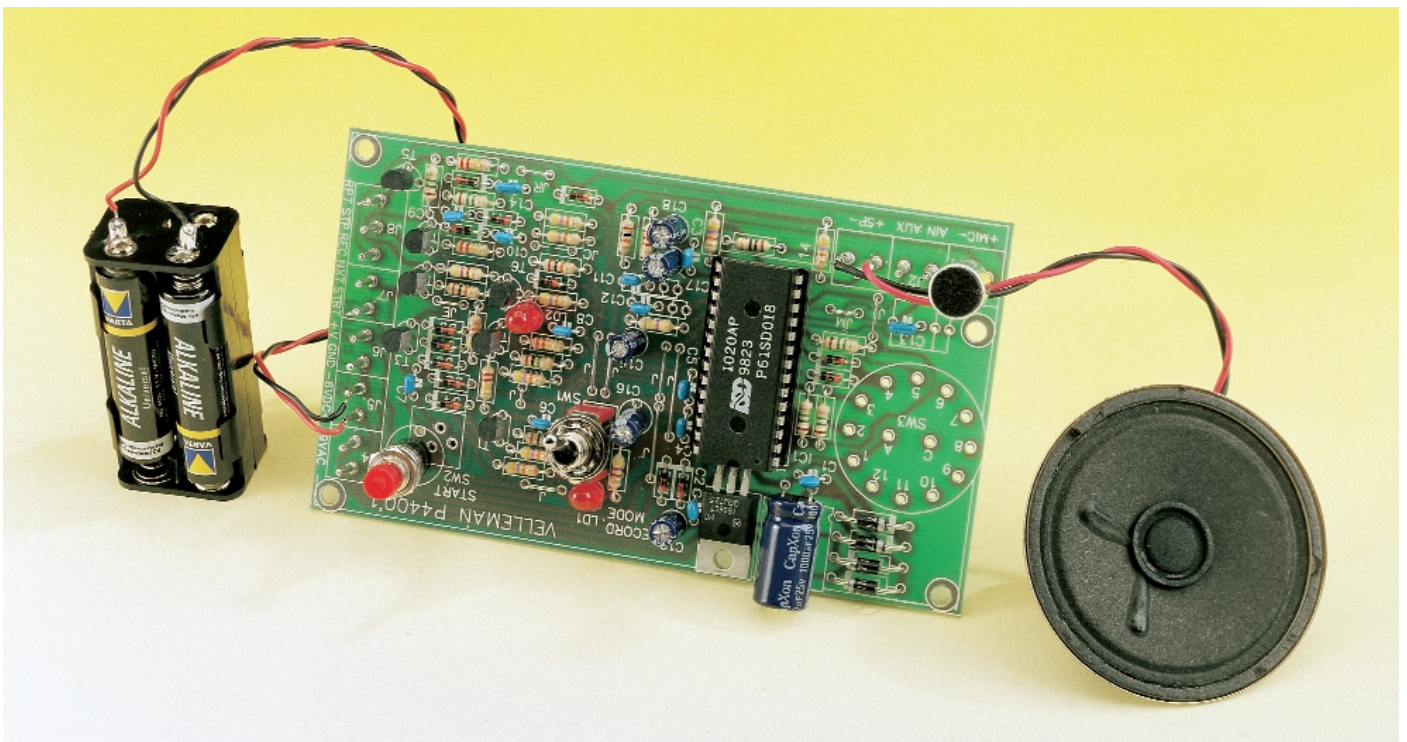
Impossible compression system devised by Microsoft.

- STMicroelectronics: AN1090 STA013 MPEG 2.5 Layer III Source Decoder. Application Note, March 1999.
- Draft ISO/IEC 9660: Information technology – Volume and file structure of CD-ROM for information interchange.
- A Tutorial on MPEG/Audio Compression, published in IEEE Multimedia Journal, Summer 1995

Record/Playback Module

A solid-state recorder

This device is an outstanding choice for a talking doorbell or any other application in which a short text of your own choice must be repeated. The length of the message is naturally limited, but it can be increased by coupling several modules in series.



This type of record/playback unit always has a special kind of fascination. After all, it's not that long ago that the recording and playback of speech or music without the aid of moving parts was only possible in science fiction stories. However, in the past few years these 'solid-state' recorders have become familiar objects. Since there are innumerable possible applications for such a device, both commercially and in the household, Velleman have included one in their catalogue of construction kits, and at a reasonable price. In order to give

our readers an idea of the features of this record/playback module, we assembled one in the Elektor labs.

Only one IC

For several years now, the firm ISD has been marketing a series of ICs that contain a complete solid-state recorder. This consists of the ISDD10XX, ISD14XX and ISD25XX series of components. The last two

digits of the part number indicate the number of seconds' worth of information that can be stored in the IC. The IC used in the Velleman kit is a rather old version, the ISD1020, with a storage time of 20 seconds.

All of these voice recorder ICs have non-volatile analogue memories that can hold the stored audio for at least ten years without power. In addition, the chip includes a microphone preamplifier and an out-

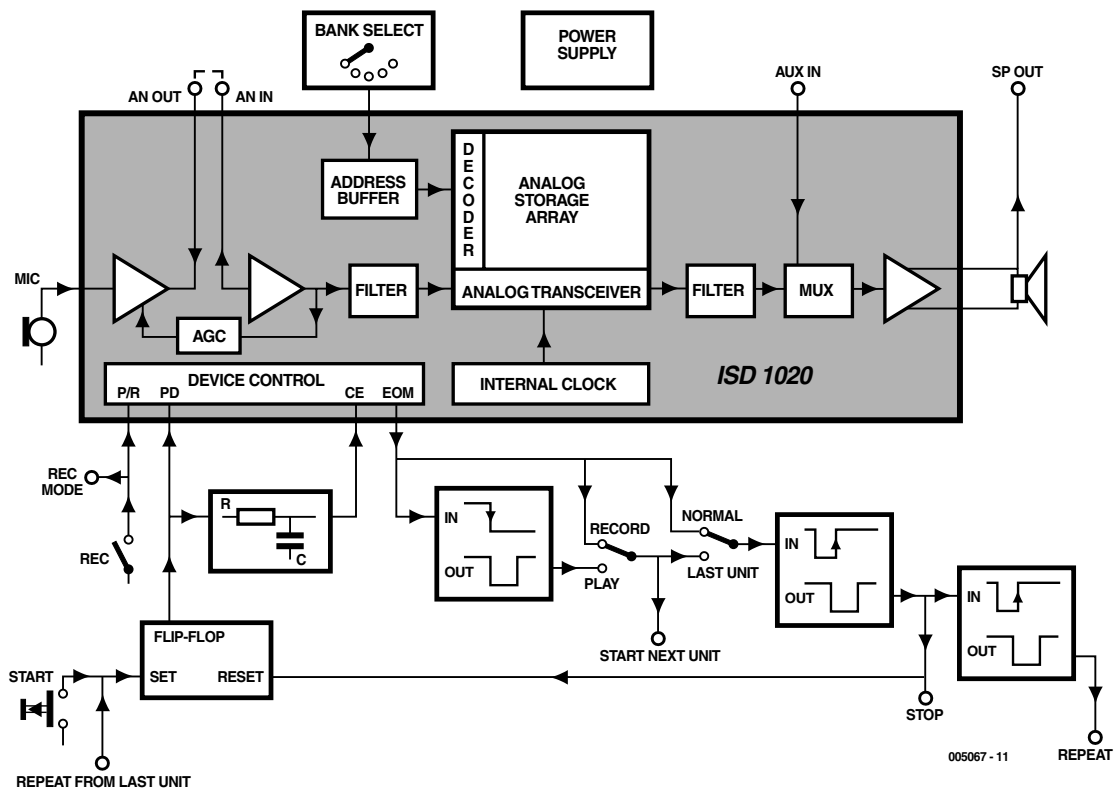


Figure 1. Block diagram of the record/playback module built around the ISD 1020 IC.

put amplifier, so a microphone and a (small) loudspeaker can be connected directly to the IC. The external components are thus limited to a few resistors and capacitors, plus two switches.

In the Velleman kit you will also find a number of transistors, since a few extra functions have been added. These allow several modules to be connected in cascade, allow the message to automatically be repeated periodically, and allow five different sections of the recording to be selected ('bank selection'). The block diagram in **Figure 1** shows how the device can be set up for the various types of playback.

The circuit can be powered from batteries (6 V) or from a standard mains adapter (9 - 12 V_{AC}). The current consumption is only a few tens of milliamps. In the standby mode, the current consumption is negligible.

Construction and operation

The kit includes an extensive set of instructions for putting it together, which makes assembling the circuit

child's play. The printed circuit board is clearly laid out and fortunately not all too small, so even the less experienced solder artist should not have any problems with it. An electret microphone is supplied with the kit, but remarkably enough there is no loudspeaker, so you will have to supply your own. Fortunately, these miniature Japanese loudspeakers are available for next to nothing.

Once we put together the circuit and connected the power source, it started to work right away. This is of course the way things should be, but experience teaches that it is not always the case.

Using the record/playback module is simplicity itself.

Recording:

- Set the record/playback switch to the 'record' position.
- Press and hold the Start button, and speak your message into the microphone. A LED shows when the maximum recording time is reached.

Playback:

- Set the switch to the 'playback'

position.

- Briefly press the Start button. The recorded message is played back. The playback stops automatically at the end of the message.

It's thus just as easy to use the circuit as it is to build it. If you are looking for a way to give your doorbell or some toy an original and 'expressive' character, this is exactly what you need.

You shouldn't expect too much in terms of sound quality, which is around the level of that of a telephone. However, this is easily adequate for most applications.

(005067-1)

Text (Dutch original): S. van Rooij

A complete construction kit for the Record/Playback module can be obtained from Velleman, Belgium. The kit, part number K4400, is priced at US\$59.95 and available from electronics retail shops). In the UK, a selection of Velleman kits is stocked by Maplin.

Velleman contact information:

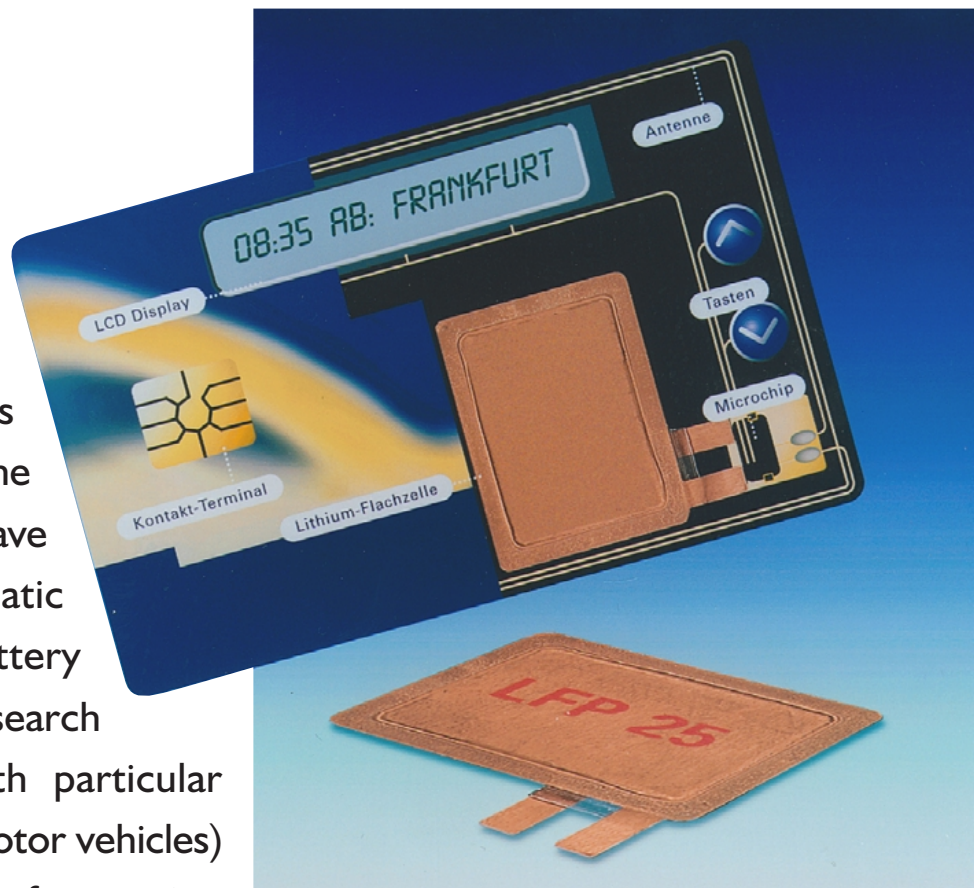
Velleman Components, Legen Heirweg 33, B-9890 Gavere, Belgium. Fax: (+32) 9 384 6702.
Email: order@velleman.be
Internet: <http://www.velleman.be>

Battery technology today ...

...and tomorrow

By E. Krempelsauer

Since the introduction onto the world markets of the Li-ion battery in the early/mid 1990s, there have been no dramatic developments in battery technology, although research on the fuel cell (with particular emphasis on its use in motor vehicles) has been the centre of attention during the past few years. Other interesting future developments are concerned with the proposal to alter the power source in motor vehicles to 42 V, the introduction of the lithium-polymer battery for mobile radios and telephones, and the demise of the nickel-cadmium (NiCd) battery.



Secondary lithium-ion (Li-ion) batteries were introduced commercially in the early 1990s (Ref. 1). A detailed report on their properties, applications, and suitable chargers may be found in Ref. 4. Since then, their use has increased greatly, particularly in laptop and palmtop computers and camcorders. World production grew from 140 million in 1996 to 385 million in 1999. This kind of growth, however, is not experienced in the mobile telephone markets.

Since its introduction, the technology has not changed other than in minute detail. The anode is usually made from graphite or manganese, and the cathode from a lithium-cobalt oxide or lithium-manganese oxide compound. The electrolyte is invariably an organic liquid containing lithium sulphate.

The highest energy density and longest life are provided by a graphite/ lithium-cobalt oxide combination, which is, therefore, the most frequently encountered. The battery capacity is somewhat smaller when a lithium-manganese oxide cathode is used, but this type of battery is slightly cheaper and offers environmental advantages, which makes a greater use in the future a certainty.

Batteries with a lithium-nickel oxide cathode have properties somewhere between those using lithium-cobalt oxide and lithium-manganese cathodes.

Small is beautiful

In the past few years physically very small secondary Li-ion batteries have come on the market. Their construction is normally button-shaped as shown in **Figure 1**. These batteries find application especially in computers. No fewer than 120 million of them are produced annually for use in real-time clocks alone. Compared with previously used nickel-cadmium (NiCd) and current nickel metal hydride (NiMH) button cells, Li-ion batteries have several important advantages, such as a



Figure 1. Rechargeable Li-ion button cells have a bright future in the memory/buffer battery market. Some of their advantages are low self-discharge and an e.m.f. of 3.6 V.

significantly longer useful life (owing to the much smaller self-discharge) and the fact that a single 3.6–3.8 V Li-ion button cell can replace three NiCd or NiMH button cells (1.2 V each). Another important aspect is that when the cathode is made from manganese oxide the

battery is much more environmentally friendly than batteries that use nickel, cobalt, or cadmium.

In an amazingly short time, Li-ion batteries have also found application in small electrically powered or hybrid road vehicles. Peugeot, for instance, have available their 'Vedelic' 106 which, powered by Li-ion bat-

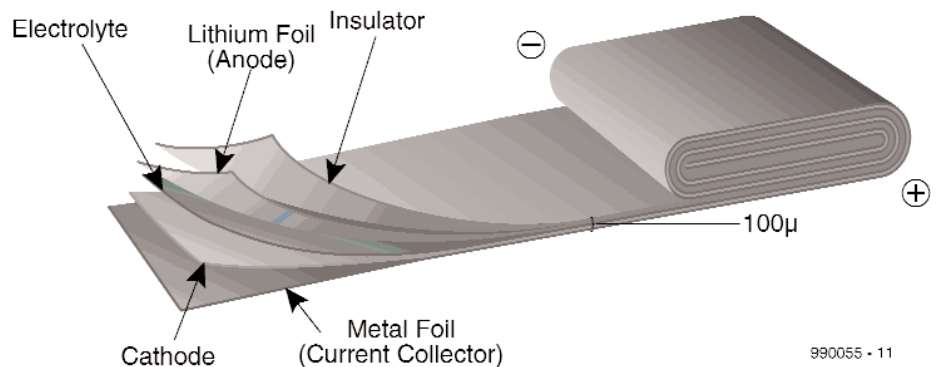


Figure 2. Basic construction of a lithium-polymer battery. When a single film of polymer is used, a battery can be formed that is thin enough to be integrated in a chip card.

* Lithium, a rare element, is a soft, silvery metal that reacts with oxygen and water at room temperature; at higher temperatures, it also reacts with nitrogen and hydrogen.

Polymer is a substance having large molecules consisting of repeated units (monomers). There are a number of natural polymers, but synthetic polymers are used extensively in plastics.

teries from SAFT, has a range of 120 miles between charges and a top speed of 65 MPH.

The latest type of lithium battery, the lithium-polymer battery, is showing good results in experimental road vehicles. Producers such as 3-M-Hydro-Quebec have high hopes for a bright future of these batteries.

Lithium-polymer*

Research has been going for a number of years to produce a solid polymer electrolyte for lithium cells and batteries. The currently used micro-porous polymer film between anode and cathode serves merely as a separator. A solid polymer electrolyte would be able to serve both as electrolyte and separator.

The problem in pure polymer electrolyte lies in the low conductivity of lithium ions at room temperature (which limits the permissible loading of the cell): only at temperatures exceeding 100 °C does the conductivity become a practical proposition.

Current lithium-polymer batteries use a polymer electrolyte in which it is not the polymer but a liquid electrolyte that provides the ion conduction. In these batteries, the electrolyte is totally contained in the polymer film which therefore appears to have the mechanical properties of a plastic film.

If the anode and cathode were also constructed as thin films, it would be possible to manufacture thin, flat cells which could be made into a variety of shapes of battery—see **Figure 2**.

The aim of current research is to increase the energy output of the cell by the use of metallic lithium for making the anode. Once this is possible, and the anode is used in combination with a pure polymer electrolyte, an electronic protection layer becomes superfluous, which improves the possible energy density. Commercial production of 0.5–0.7 mm thick secondary lithium-polymer cells is already possible.

Lithium-polymer batteries currently used in mobile telephones are 3–7 mm thick and have capacities varying from 450 to 700 mAh. A typical model has a capacity of 500 mAh, an e.m.f. of 3.7 V, weighs 15 grammes, and measures only 50×33×4 mm. Apart from their higher energy density and improved reliability (leak-proof; short-circuit proof thanks to the polymer), they offer much greater flexibility in their construction. For

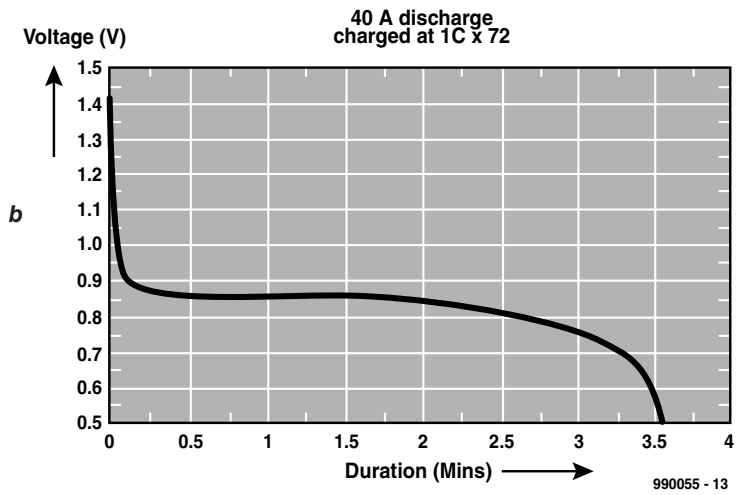
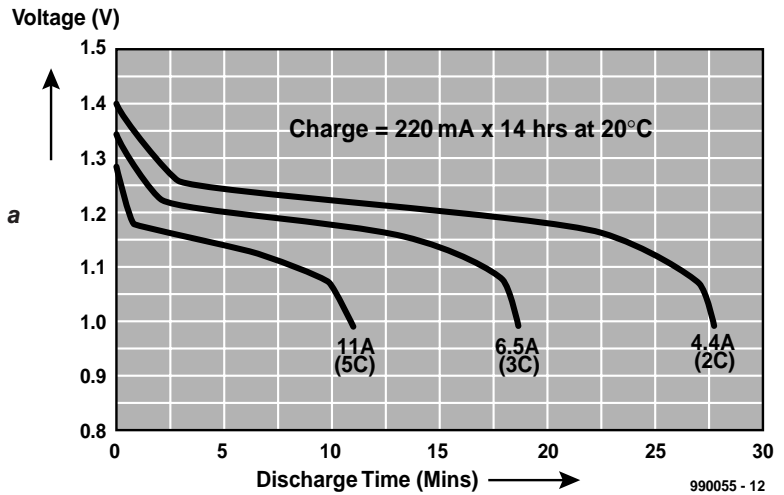


Figure 3. Discharge curves of a sub-C size NiMH battery at high output currents (a) and at a virtually short-circuit current of 40 A (b).



Figure 4. The 600 mAh NiCd battery in certain mobile telephones can readily be replaced by an 1100 mAh NiMH battery.

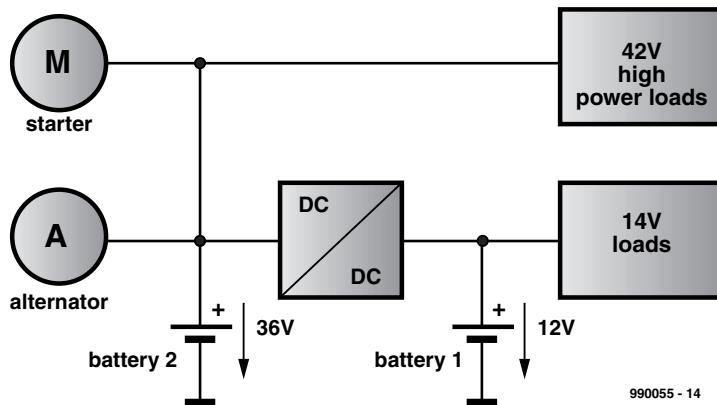


Figure 5. Future private motor cars may have 36 V batteries. The onboard supply may then be 14 V and 42 V.

instance, they may be integrated in equipment, such as the back of the display in a notebook computer.

Another application of thin-film lithium-polymer batteries (but only primary ones) is as current source for smartcards.

The end of nickel-cadmium

Within the electronics industry it has been known for some time, but it is not generally realized, that the days of the nickel-cadmium (NiCd) battery are numbered. A European Directive prohibits the use of NiCd

batteries from 2008. This does not affect the European or American battery industries much since most of these batteries are manufactured in Asia.

However, the demise of the NiCd battery is not so much caused by environmental considerations as by the fact that they are largely being superseded by nickel-metal-hydride (NiMH) batteries, not only in emergency power supplies, but also in radio telephones, portable electric drills and other tools, model constructions, and others.

The widely used round sub-C NiMH battery (23 mm dia; 42.6 mm

overall length) allows peak currents of up to 40 A to be drawn, and has a typical capacity of 3 Ah (see Figure 3). However, research aimed at increasing the capacity continues unabated. Until recently AA size batteries had a capacity of 1200–1300 mAh, but this has grown to 1500–1600 mAh, and is expected to reach 1800 mAh within a year. In other words, all things being equal, NiMH batteries have roughly double the capacity of a NiCd battery. Moreover, the differences between rechargeable NiMH and primary alkaline batteries for use in small to medium current applications are becoming smaller and smaller. At higher currents, the life per charge of NiMH batteries is greater than the overall life of primary alkaline batteries.

It should be noted, however, that there is a price to be paid for the high nominal capacity of high-power NiMH batteries in the form of a smaller life per charge and a less robust construction. For that reason, lower-capacity, more robust NiMH batteries should be used in applications where standby charging and frequent deep discharge are encountered, as in mobile telephones. For instance, the AA size NiMH battery specially developed by Varta for replacing the NiCd battery in certain mobile telephones has a capacity of only 1100 mAh. See Figure 4.

The rapid growth in capacity and the steadily falling price of NiMH batteries is the reason that Li-ion batteries have (as yet) made little inroad into the GSM market. There are even special voltage converter ICs available that enable a 3.6 V lithium cell in a mobile telephone to be replaced by two 2.4 V NiMH cells.

The development of high-current NiMH batteries makes these batteries suitable for use in hybrid-drive road vehicles. For instance, a 250 V, 10 A model produced by Varta lasted more than 30,000 miles without any problems. Varta has also developed a NiMH battery for the long-distance, electrically driven racing car 'Panoz Q9' that weighs only 100 kg (220 lb), yet delivers 90 kW of electrical power.

Fuel cells

Today, most of the industries that have a stake in vehicle engineering and production (oil industries, car makers) are far more interested in the fuel cell than in the NiMH or lithium battery. Ford, for instance, believe that fuel cells are the only basis for the clean propulsion systems of the future. Daimler-Chrysler and several of their competitors plan to launch commercial fuel-cell powered cars in America and Europe by 2004-2005. This is, no doubt, in response to a Californ-

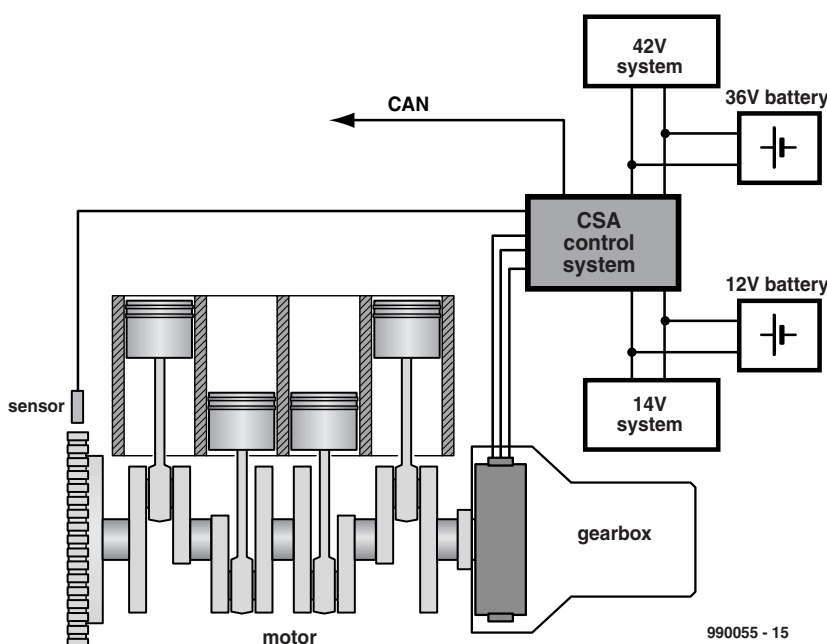


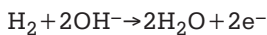
Figure 6. Future motor vehicles may have a Combined Starter-motor/Alternator (CSA) as shown here diagrammatically in a dual-voltage onboard supply system.

ian decree that by 2004 a tenth of all cars sold in the state must not produce any emission whatever. The European Union, too, is committed to drastically reduce harmful emissions from road vehicles. Iceland has pledged to become the world's first hydrogen-powered economy.

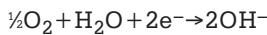
The simplest fuel-cell is one in which hydrogen is combined with oxygen from the air to generate electric power: the only by-products are water and heat.

A supply of gaseous hydrogen is fed to a compartment containing a porous sintered nickel cathode, while a supply of oxygen is fed to another compartment containing a porous sintered nickel anode. The electrodes are separated by a third compartment containing a hot alkaline electrolyte.

The electrodes are porous to enable the hydrogen and oxygen to react with the electrolyte: the nickel in the electrodes acts as a catalyst. At the cathode, the hydrogen reacts with ions in the electrolyte to form water, with the release of two electrons per hydrogen molecule:



At the anode, the oxygen reacts with the water, taking up electrons with the aid of a platinum catalyst to form hydroxide ions:



The electrons flow from the cathode to the anode through an external circuit as an electric current.

Although it is generally agreed that the fuel cell is the power source of the future, not everyone agrees what fuel it will use. Clearly, there is unlikely to be a market for hydrogen for some time. Initially, it seems likely that methanol or petrol will be used in cars, and natural gas or propane for power generation.

There are a number of constructions possible, but currently the most likely is the proton-exchange fuel cell. This is a sandwich of a cathode and an anode separated by a polymer membrane (containing the electrolyte).

An experimental small fuel cell developed by Germany's Fraunhofer Institute for Solar Energy Systems for powering a laptop computer rated at 25 W has a storage tank holding 130 litres of hydrogen. The fuel-cell proper and the hydrogen store are together about the same size as the original laptop battery. However, where the original battery had a cycle life of 2-3 hours, the fuel cell gives 10 hours of operation without the need for replenishing. This means that the fuel cell has a higher energy density than current Li-ion batteries while having a better life per charge.

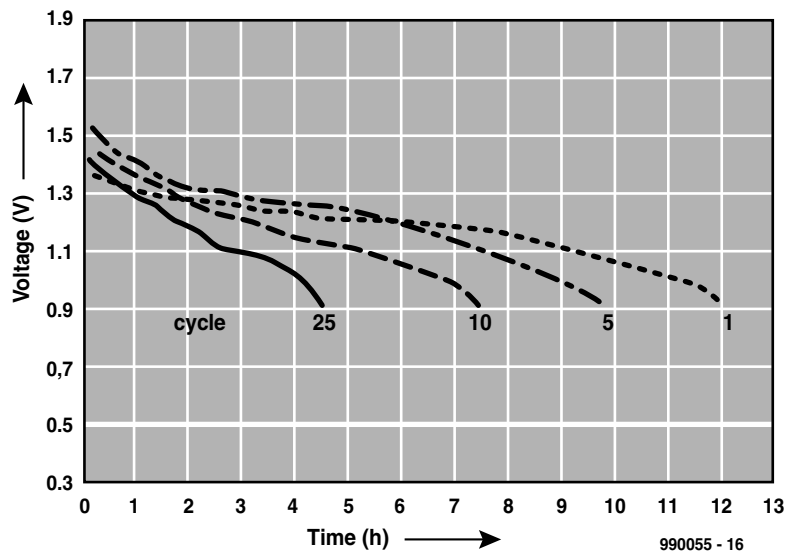


Figure 7. Voltage characteristics of an alkaline manganese secondary battery at a discharge current of 125 mA and up to 25 charge/discharge cycles.

42 v vehicles

After the Second World War, the battery voltage of private motor vehicles was standardized at 12 V (commercial vehicles 24 V, while motorcycles remained at 6 V for many years thereafter). Almost twenty years later, a start was made with equipping cars with an a.c. alternator instead of a d.c. dynamo. Today, it is planned to raise the battery voltage in private motor cars from 12 V to 36 V. This will probably be accompanied by the introduction of the combined starter

motor/alternator (CSA) now in the development stages.

As far as the onboard power supply is concerned, this will probably be changed from 12 V to 42 V. It is almost certain, however, that there will be two supplies onboard: 14 V for the car electronics and other equipment requiring a low-voltage supply, and 42 V for units requiring higher powers (see Figure 5). There are very good reasons for a dual system, the most important of which are the increased power require-

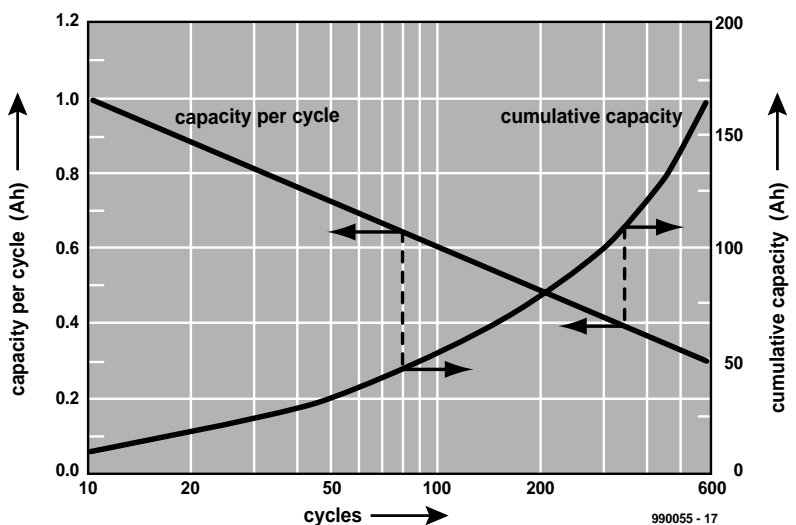


Figure 8. Correlation of depth of discharge, number of charge/discharge cycles, and cumulative capacity of an AA size alkaline manganese secondary battery. At a discharge current giving a capacity of 1000 mAh, the battery has a life of only 10 charge/discharge cycles.

ments owing to the greater use of electrical and electronic equipment; improvement of the efficiency of the electrical system; and a reduction in weight.

A higher voltage improves the efficiency, while a dual voltage system using two batteries enables the optimization of the different applications. It is likely that the 36 V battery, but almost certainly the 12 V battery, will be lead-acid versions of the so-called Absorbent Glass Mat (AGM) type. In this, an absorbent separator between the plates immobilizes the electrolyte. This construction makes the battery eminently suitable for use in cyclic or float applications, insensitive to orientation. The 36 V battery may also be a NiMH or Li-ion model.

The dual voltage concept, in conjunction with the combined starter motor/alternator, is an interesting and forward-looking means of saving energy and reducing weight.

The CSA, a compact 3-phase asynchronous machine that functions as starter motor and alternator, is fitted between the engine and the gearbox—see **Figure 6**. Electronic circuits assume all control and regulation functions, including rectification of the alternator output (rated at 68 kVA), alternator control, charging control of both batteries, and a 3 kW bidirectional 42/14 V DC/DC converter.

When the unit functions as alternator, it has an efficiency of more than 90% in the power range up to 4.2 kW. Used as starter motor, it can provide power bursts of more than 20 kW.

Optionally, when the vehicle is in motion, the CSA may be controlled to compensate any irregularities in engine output and to dampen any vibrations of the drive shaft. Provided the battery rating is adequate, the CSA may also aid the engine during stopping and acceleration manoeuvres. In this sense, it may be seen as an early part of a hybrid drive system.

Alkaline batteries, primary and secondary

A new generation of alkaline manganese primary batteries with higher capacity and permitting much

improved high current operation has recently come onto the market. These batteries, available from all the usual manufacturers, are clearly better than their predecessors, particularly as far as their life at high-current output is concerned. For instance, when a current of 1 A is drawn from an AA size, the battery life is 1.5 hours (compared with one hour from earlier models). At a current of 600 mA, battery life is greater than 2 hours; at 150 mA, 14 hours, and at 120 mA, more than 18 hours.

This improved performance is due to a number of factors, such as a much reduced internal resistance. This is achieved by using fine, highly conductive graphite as an additive to the manganese dioxide cathode and highly refined, high-surface-area zinc powder for the anode. The new design gives a high-current density per unit volume, low internal resistance and impedance, and a relatively constant capacity over a range of current drawing and discharge schedules.

Alkaline manganese secondary batteries, in contrast to the latest NiMH batteries, cannot offer such high output currents. The 1.5 V e.m.f. quoted by most manufacturers drops fairly rapidly to 1.2 V when the battery is loaded. The internal resistance is quite high, so that the capacity at high output currents drops rapidly. For instance, the nominal capacity of a rechargeable AA size model rated at 1800 mAh is attained only if the output current is ≤ 30 mA; at 125 mA, it drops to 1500 mAh, and at 300 mA to 1200 mAh (all figures apply to a discharge down to 0.9 V).

The quoted capacities apply only to the first discharge of the battery; they are further reduced in proportion to the number of charge/discharge cycles—see **Figure 7**. These curves apply to a discharge current of 125 mA. The cycle-life of the battery can be improved only by not discharging the battery to a voltage as low as 0.9 V. When the battery is discharged below 0.9 V, its cycle-life is reduced significantly.

An important advantage over an NiMH battery is the much lower self-discharge. However, its greater environmental friendliness is arguable. Although a single alkaline

manganese secondary battery has the advantage over a single NiMH battery, the NiMH comes out much better when energy consumption is considered. This is because of the following.

An alkaline manganese secondary battery (AA size) has a cumulative capacity of about 75 Ah when it is discharged at only 0.5 Ah per charge/discharge cycle. However, a NiMH battery has a cumulative capacity of at least 500 Ah, and normally 700 Ah. This means that in practical use a single NiMH battery is equivalent to 8–10 alkaline manganese secondary batteries or 100–500 alkaline manganese primary batteries. It is clear which is the more environmentally friendly battery.

[990055-1]

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2. Rechargeable alkaline manganese batteries. Elektor Electronics, May 1995.
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6. Refreshing alkaline manganese batteries. Elektor Electronics, December 1996.
7. Charger for alkaline batteries and new cells. Elektor Electronics, January 1997.
8. Capacity meter for lithium-ion batteries. Elektor Electronics, July/August 1997.
9. Switch-mode lithium-ion battery charger. Elektor Electronics, July/August 1999.

Some relevant websites:

www.varta.de
www.saft.fr
www.ise.fhg.de
www.conti.de
www.lithiumpolymerbattery.com
www.valence-tech.com
www.gايا.akku.com
www.electrochem.org
www.energyrelateddevices.com
www.eveready.com
www.accucell.de
www.bticalcorp.htm
www.rayovac.com

Do more with your BASIC Stamp

Hundreds of applications from L.O.S.A.

After last month's final instalment of the BASIC Stamp enthused programmers may want to do more with their mini controller systems. If you know where to look, the Internet is a vast resource of courses and application lists to suit every requirement.

Confident with your own constructions on the BASIC stamp prototyping board and the associated robot, you may want to consider widening your horizon. Most active followers of our course, we are sure, will have come to appreciate the simplicity of programming the BASIC Stamp II module. No wonder they may have future applications in mind. The good news is obviously that venturing out in this fascinating area is relatively easy for every with Internet access.

To begin with, the manufacturer, Parallax, has extensive technical data on the Stamp available on a web site at

<http://www.parallaxinc.com>

Most relevant documents are available as Acrobat pdf files for easy downloading and browsing or printing.

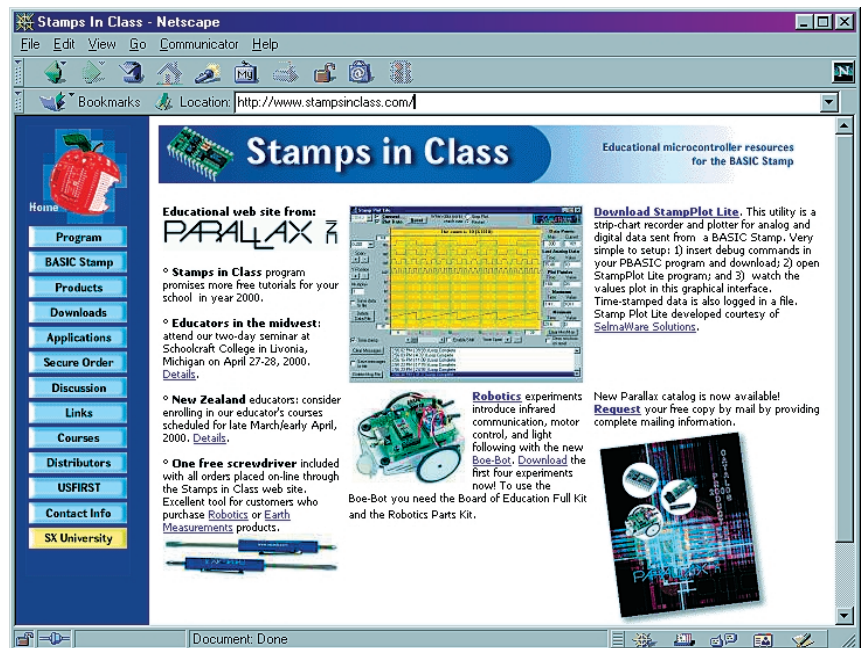
Of course Parallax on their BASIC Stamp site have not forgotten to include an overview of all courses and additional information on the Stamp, see

<http://www.stampsinclass.com>

At first blush, the purpose of this site is to spread the various courses on colleges. However, many lessons are equally of interest to hobbyists because they contain valuable information and allow your knowledge of microprocessor programming to be given a serious boost. *Stampsinclass* provides these complete courses:

- **What's a microcontroller?**
- **Earth measurements experiments**
- **Robotics experiments**
- **Basic analog and digital experiments**

What's more the site also offers the complete Parallax documentation and software for the Stamp series.



If you are keen on applying the Stamp in many different situations then do not forget to pop in at L.O.S.A. (List of Stamp Applications):

<http://www.hth.com/filelibrary/txtfiles/losa.txt>

This list is maintained by High Tech Horizon, the Swedish Parallax distributor. Currently it contains some 180 BASIC Stamp applications, each consisting of a short description, name and e-mail address of the author, plus, in many cases, a program listing with the design. Anyone is free and invited to contribute

to this list!

Our last tip this month is the American magazine *Nuts&Volts* which frequently contains Stamp-based circuits. Most of these designs are available on the website run by this magazine:

<http://www.nutsvolts.com/stmpindx.htm>

The articles may be downloaded free of charge and come as pdf documents.

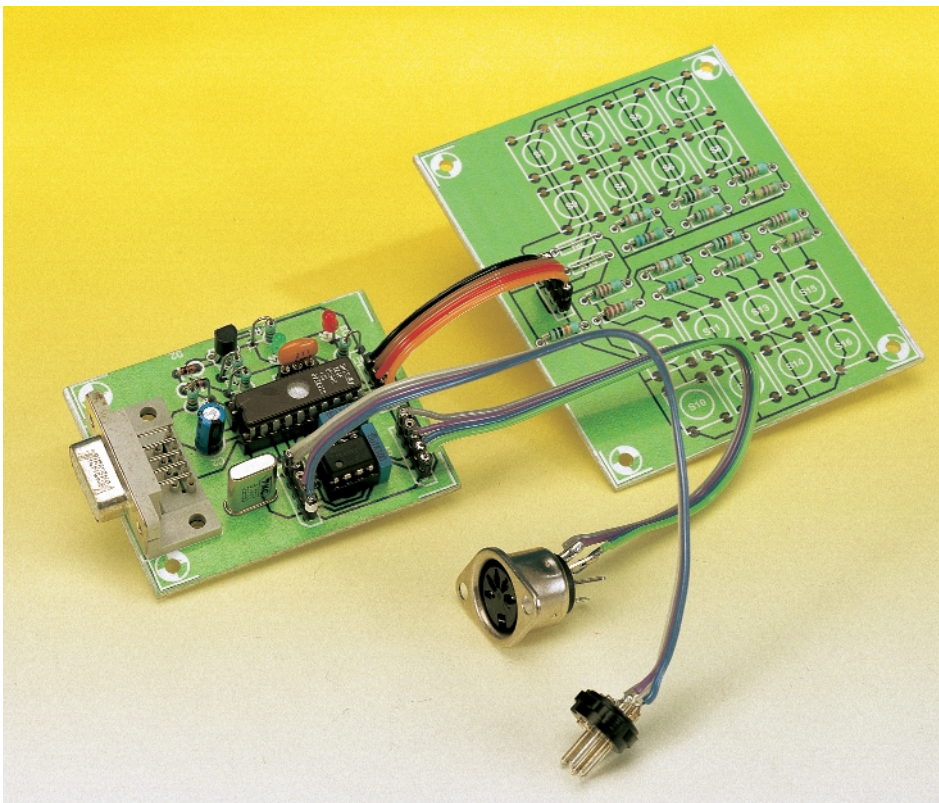
005040-1

Hotkeys keyboard

part 2: construction, software and a few tips

Design by B. Stuurman

Last month we described the features and the operation of this handy extra keyboard. Now it's time to look at the hardware and the construction of the circuit.



The schematic diagram of the hotkeys circuit is shown in **Figure 6**. All pins of the connector for the PC keyboard (K1) are connected through to the connector for the PC (K4), with the qualification that there is a pair of analogue switches inserted in the clock and data lines. These allow the hotkeys keyboard to open these lines. Power for the circuit is taken from K4. In addition, you can see a connector for the RS-232 interface (K2). Resistor R5 and diodes D1 and D2 limit the incoming signal to levels of approximately 0 V and +5 V. The outgoing RS232 signal is directly connected to PB1 of the microcontroller. Although the

signal levels here do not comply with the RS232 specification, they prove to work with nearly all PCs, and this simplified interface has been used in several *Elektor Electronics* designs.

A passive buzzer (Bz1) that is connected to port PB0 allows an acoustic feedback signal to be generated when a key is pressed, or in certain command situations. The 8-MHz ceramic resonator has built-in capacitors. Decoupling is provided by capacitors C1, C2 and C3.

The reset circuit is a little unusual. LED D4 is not used here as a light source (although it does emit light), but rather as a 'Zener' diode with a voltage of around 1.9 V. A real zener diode has too high a leakage current to function properly in this circuit. The LED and the voltage divider (R3 and R4) cause transistor T1 to start to conduct when the supply voltage reaches approximately 4.2 V, and to conduct fully at around 4.5 V. At a clock frequency of 8 MHz, correct operation of the microcontroller is guaranteed for a supply voltage of at least 4.5 V. Here we ensure that the microcontroller can never destroy the contents of the EEPROM by going amok due to an excessively low supply voltage. The voltage drop of the LED can vary from device to device, so it is recommended to check the supply voltage at which the reset signal is released. You can adjust the value of R3 if necessary.

Three outputs and three inputs are necessary for communication with the PC and the PC keyboard. Since port line PC4 cannot be used, as it is automatically connected to the Serial Peripheral Interface (SPI) of the microcontroller in the chosen configuration, two other inputs must be used for the connections to the hotkeys keyboard, namely PA3 and PC3. These are connected to K3, along with 0 V and +5 V.

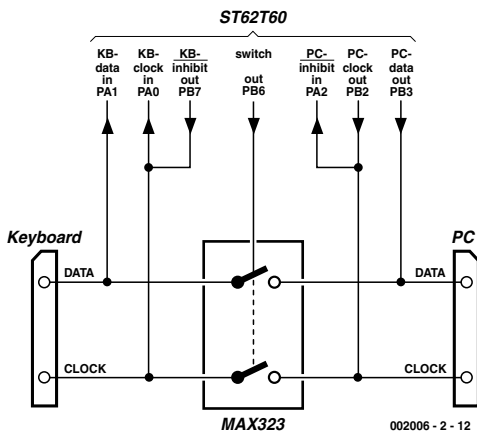


Figure 7. A clear illustration of the switchover mechanism.

accounted for, the second part is also transferred to the EEPROM and the circuit sends an acknowledge signal in order to end the transfer. The CRC number is not tested.

The keyboard

We have already mentioned that two controller inputs (PA3 and PC3) are used for connecting to the keyboard portion of the circuit. To make things simple, we use the letter 'A' for everything relating to PA3 and the letter 'C' for everything relating to PC3.

It is very easy to connect a micro-controller input to the built-in analogue to digital converter (ADC).

R14 is the upper resistor for the A group. The lower resistors for the C group are R7 through R13 (for keys S2 through S8), while the lower resistors for the A group are R15 through R21 (for keys S10 through S16). The keys are arranged such that S1 and S9 are next to each other on the lower left, while S2 and S10 are next to each other of the lower right. Since the two keys of each of these pairs do not belong to the same group, it is always possible to measure whether S1, S9 or both are pressed, and likewise for S2 and S10.

The keys are scanned by the routine 'getvolt', with PA and PC alternatingly selected as the analogue input. The subroutine 'getvolt' can return a maximum value of '8FH', which means that no key is pressed. With the selected resistor values, the upper nibble matches the code of each of the pressed keys 1 through 8. In order to arrive at the correct key code for the A group, 8 must be added to his value to obtain 8_H through F_H (note that this means that keys 1, 2, 9 and 10 are special cases).

The 'rtest' command

Table 1 shows the 1% resistance values that can be used to obtain the most nearly ideal voltage values for the keys, in order to obtain the associated hexadecimal codes. It is however not necessary for the hexadecimal value to fall exactly in the middle of the range. The tolerance is so large that 5% resistors can be used, but in this case you should check whether the values of the keys are not critically close to the boundaries. The 'rtest' command allows this to be easily done. After this command has been activated, the hex value of each key of the chosen group (except for hotkey 1) is displayed on the screen when the key is pressed. The value of the lower nibble may lie between 4_H and A_H. If you type 'rtest a', group A will be displayed, while 'rtest c' looks at group C. For example, if you type 'rtest c' and then press hotkey 4, the displayed hex value should lie between 44_H and 4A_H. If it is outside this range, the divider resistor belonging to this key must be adjusted, but this will not be necessary very often.

Hotkeys behaviour

When you communicate with the hotkeys keyboard using Hyperterminal or some other terminal emulator program, the hotkeys may not behave exactly as you expect them to. This is not so surprising. When a key is pressed while Hyperterminal is running, the keypress is received by Hyperterminal as a keyboard key. After this, the keypress is sent to the hotkeys keyboard via the RS232 interface. The hotkeys keyboard stores the keypress in its buffer and then sends it via the RS232 interface back to Hyperterminal, which displays the associated character on the screen (if it is printable). This is why keys are not repeated, even if this option is enabled. It is thus recommended that you try out the hotkeys in the program in which you intend to use them.

store the received bytes in the EEPROM. RAM page 2 is thus used for temporary storage. However, this is only 64 bytes long, while an Xmodem data block is 128 bytes. Consequently, the remainder of the block is ignored after the first 64 bytes have been received, and these 64 bytes are then transferred to the EEPROM. After this, the micro-controller sends an error message, which causes the entire block to be sent again. This time data bytes 65 through 128 are extracted from the block and stored in RAM page 2. Once the entire block has been

The ADC can measure from 00_H to FF_H, where 00_H corresponds to 0 V and FF_H to 5 V. The keyboard is divided into two groups of keys. The eight keys at the top of the schematic form the C group (left half of the keyboard), while the lower set of eight keys forms the A group (right half). Each key forms a particular voltage divider, so that a particular voltage corresponds to each pressed key. Resistor R6 is the upper resistor for the C group, and

Table I. Theoretical resistance values for the keys.

key	S1	S2	S3	S4	S5	S6	S7	S8
1% resistor value	0	2k00	3k92	6k49	10k2	16k2	26k1	49k9
potential (volt)	0.00	0.85	1.41	1.97	2.54	3.09	3.61	4.17
hex value	00	17	27	37	47	57	67	77
5% resistor value	0	2k2	3k9	6k8	10k	15k	27k	47k
open: 5.00 V = 8F _H								

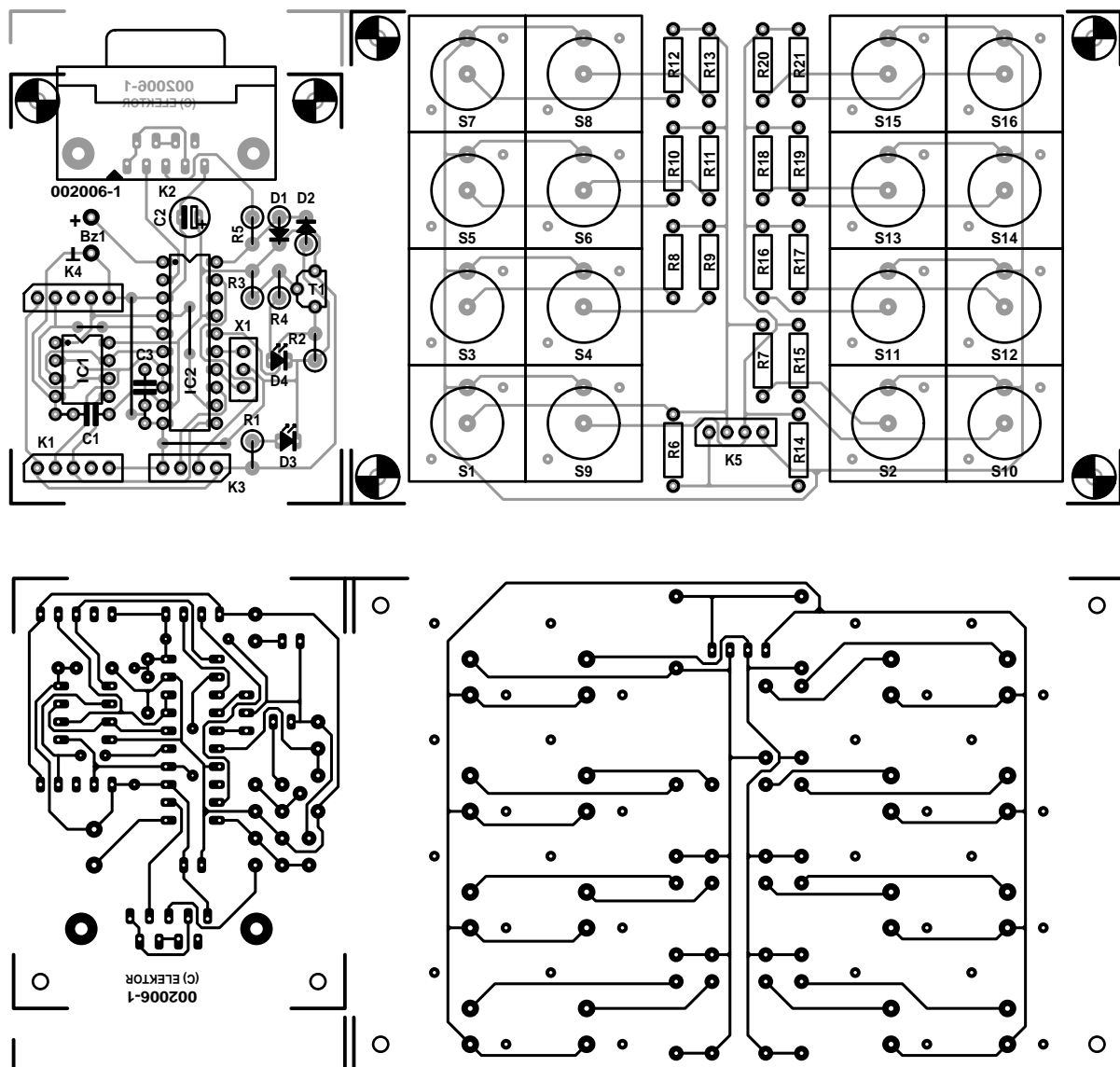


Figure 8. Circuit board track layout and component layout for the processor board and the keyboard.

Construction

The layout of the two circuit boards is shown in **Figure 8**, along with the associated component layouts. You can make the single-sided board yourself, but it is also available ready made through our Readers Services.

Start with assembling the processor board. As usual, mount the wire bridges first (four pieces). After this come the rest of the components, starting with the IC sockets and connectors K1, K3 and K4. These are lengths of board-mounted male headers that are available in strips. With K1 and K4, one pin is removed in order to ensure that the mating connectors can only be fitted in one way (after a pin has been inserted in

the unused position). This is not necessary for K3, since the connections correspond to those on the hotkeys circuit board. Mount K2 after all the other components. Once this is done, you can press IC1 and IC2 into their sockets (make sure that IC2 is first programmed!).

For the keyboard, we have chosen Marquard keys in place of the more common (and less expensive) D6 keys. The size and touch of the Marquard keys are a much better match to the keys on a PC keyboard. They also contain real microswitches and are self-cleaning.

Now you have to make the three interconnecting cables. We used two lengths of 4-conductor screened

cable for the connections to the PC and the PC keyboard. The cable to the PC is around 1.5 m long, while the one to the PC keyboard is around 50 cm long. Each cable has a mating DIN plug at one end and a 5-pin female circuit board header at the other end (and don't forget the polarisation pins). The pin assignments for the various cables can be seen in **Figure 6**. The keyboard circuit board is connected to the processor board by a 10-cm length of 4-way flat cable with a 4-pin male header at one end and a 4-pin female header at the other end. All wire connections to the header contacts can be covered with short pieces of heatshrink tubing.

The hotkeys keyboard can now be connected between the PC and the PC keyboard. When the PC is switched on, the hotkeys circuit emits a short beep, and the 'key name'

COMPONENTS LIST

Resistors:

- R1,R2,R4 = 1kΩ
- R3 = 330Ω
- R5,R6,R10,R14,R18 = 10kΩ
- R7,R15 = 2kΩ
- R8,R16 = 3kΩ
- R9,R17 = 6kΩ
- R11,R19 = 15kΩ
- R12,R20 = 27kΩ
- R13,R21 = 47kΩ

Capacitors:

- C1,C3 = 100nF
- C2 = 10μF 16V radial

Semiconductors:

- D1,D2 = BAT85
- D3 = LED, red, high efficiency
- D4 = LED, green, high efficiency
- T1 = BC557
- IC1 = MAX323CPA or MAX323EPA
- IC2 = ST62T60 (programmed, order code **002006-41**)

Miscellaneous:

- K1,K4 = 5-way SIL pinheader
- K2 = 9-way sub-D socket (female), PCB mount
- K3,K5 = 4-way SIL pinheader
- S1-S16 = pushbutton, e.g. Marquardt (Conrad Electronic o/n 70 68 92-55, with cap 70 08 60-55)
- Bz1 = 5-V piezo-ceramic buzzer (passive)
- X1 = 8 MHz ceramic resonator
- 5-way DIN plug, pins arranged at 180 degrees
- 5-way DIN socket, receptacles arranged at 180 degrees
- 10 cm 5-way flatcable
- PCB, order code **002006-1** (see Readers Services pages)
- Package: PCB and programmed controller, order code **002006-C**

must appear on the screen when a hotkey is pressed. In order to communicate with the circuit, you will have to connect the RS232 interfaces and run a terminal emulator program. The hotkeys can now be programmed, and the result can be stored as a file on the hard disk. A stored programming file can also be downloaded to the hotkeys keyboard, in order to assign a new set of functions to the keys.

A console-style enclosure (such as the Teko type 365) can be used to house the keyboard, or you can make your own enclosure from sheet aluminium.

(002006-2)

Design editing: Luc Lemmens.

Entering special characters

Many characters cannot be directly entered from the keyboard using a single key. Some familiar examples are the characters from 128 to 255 in the ASCII table. These are entered by holding down the Alt key and entering the decimal value using the numeric keypad. If you work with PostScript or TrueType characters, not all characters match the ASCII set (since Windows works with an ANSI character set). You can get a complete overview using the utility program 'Charmap', which also displays the 4-digit character codes. With some codes, the same numeral occurs twice in succession. Normally, this would mean that it is not possible to assign such a code to a hotkey (except as a free format string), since the key would have to be actually pressed and released twice (rather than repeated). The hotkeys output routine tests for double characters, and if they are present it first sends the break code of the first character before sending the make code of the second identical character.

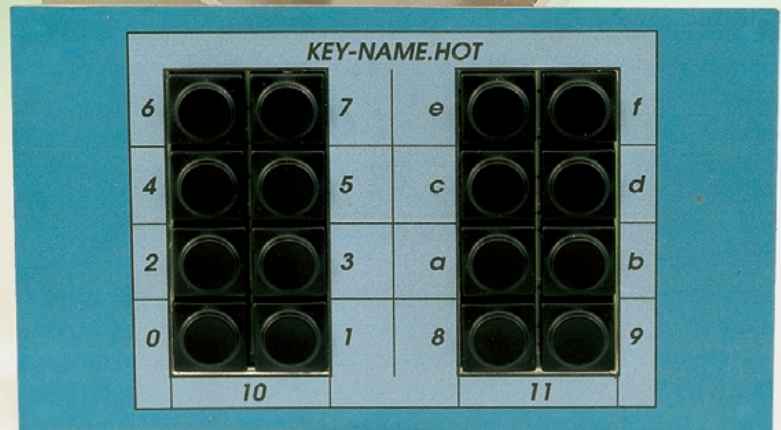
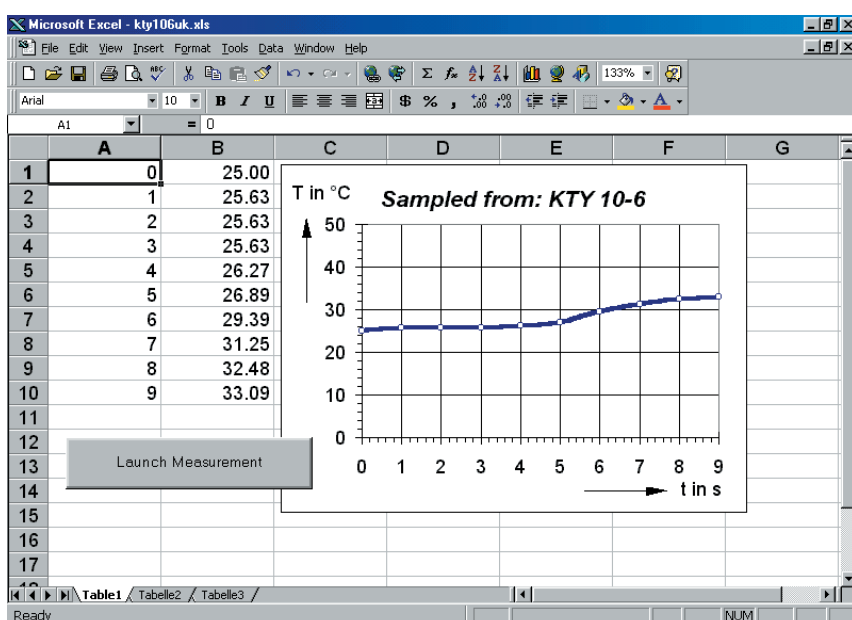


Figure 9. One way in which the boards can be fitted into an enclosure. If a metallic enclosure is used, the cable screens can be connected to the enclosure.

Measuring in Word and Excel

using Visual BASIC for Applications

By H.-J. Berndt



Nowadays, an RS232 interface is a standard feature of any better than average multimeter. However, the accompanying software can usually only display a series of measurements on the PC monitor or save the data as a text file. If you want to further process and evaluate the measurements, this tabular text file must be laboriously transformed using a statistical program or imported into a word processor.

However, Microsoft delivers the Visual BASIC for Applications interpreter as part of the Office package. This interpreter makes it possible to have direct communication between Word or Excel and the measuring

equipment. We can illustrate this with an example.

The document template shown in **Figure 1** contains a small sample program that reads data into Word from a digital multimeter connected to the COM1 serial interface. A temperature-dependent resistor sensor (type KTY10-6) is connected to the multimeter. The resistance value can be converted into a temperature using a formula provided by the manufacturer of the temperature sensor. The temperature can then be displayed in a VBA form. If you click on the Measure button, the current temperature will be displayed (assuming that the RSMINI.DLL file

Microsoft Office 97 includes a complete programming language called Visual BASIC for Applications (VBA). With this interpreter, which is largely compatible with Visual BASIC, it is possible to perform measurements directly in Word or Excel. The full power of the Office applications is then available for analysing the measured values. Since VBA can address external routines in dynamic link libraries, it is possible to directly import measurement values.

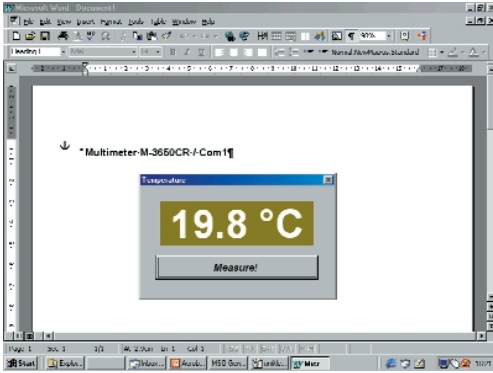


Figure 1. A Word document template can serve as a measurement program.

is present in the Windows directory). The document template (KTY.DOT) and RSMINI.DLL can be freely copied and can be downloaded from the Elektor Electronics homepage (www.elektor-electronics.co.uk). If you do not have Internet access, you may order diskette # 000053-11 from our Readers Services.

Sensors and measurement equipment

The semiconductor temperature sensor KTY10-6 is a temperature-sensitive resistor. Unfortunately, it has slightly parabolic non-linear characteristic (see **Figure 2**). This characteristic curve can be described using the formula

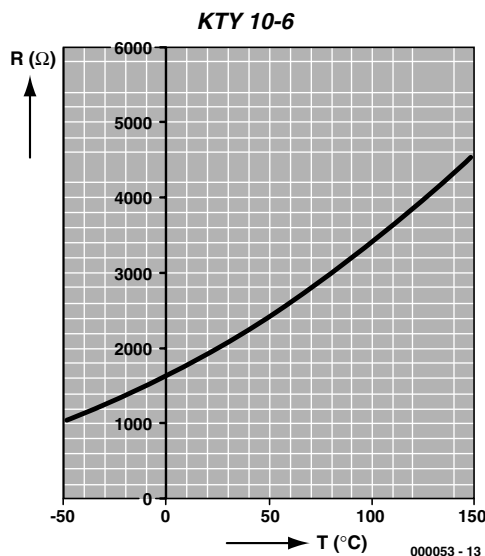


Figure 2. Characteristic curve of the KTY10-6 sensor.

$$R_T = R_{25} (1 + \alpha \cdot \Delta T_A + \beta \cdot \Delta T_A^2) = f(T_A)$$

where

$$\alpha = 7.88 \cdot 10^{-3} \text{ K}^{-1}$$

$$\beta = 1.937 \cdot 10^{-5} \text{ K}^{-2}$$

This formula can be inverted to calculate the temperature, as follows:

$$T = 25 + \sqrt{(\alpha^2 - 4 \cdot \beta + 4 \cdot \beta \cdot k_T) - \alpha} / 2 \cdot \beta$$

where $k_T = R_T / R_{25}$

For our example, we measure the resistance of the KTY10-6 using a Metax M-3650CR digital multimeter with an RS232 connector. This is a widely used type of meter, but any compatible type of DVM could be used. The resistance value is imported into Word or Excel and converted directly into a temperature.

The DVM is connected to a free COM port of the PC using a special cable. Optocouplers in the meter provide electrical isolation between the meter and the PC. They draw their power from the RS232 lines, which means that the RTS and DTR lines must be set appropriately after the interface is opened.

The multimeter sends the measured value as a 14-byte ASCII character string, using transfer parameters of 1200 baud, no parity, 7 data bits and two stop bits. The last character transferred is a CR character (byte value 13). A 'D' must be sent from the PC to the multimeter to initiate a transfer, but in practice almost any character will do the job.

Dynamic link library

The multimeter that is connected to the COM interface of the PC is directly addressed and read from Excel via a small dynamic link library (DLL). A few lines of program code filter the received resistance value, and a suitable equation is used to convert the non-linear resistance function of the sensor into a displayed temperature value.

The DLL that has been specially developed for this project (RSMINI.DLL) supports basic access to the multimeter. It can be down-

loaded along with the sample programs used in this article from the Elektor home page.

This small DLL provides all the essential functions for communication via the RS232 interface under Windows 95/98. The following DLL calls are needed to read out the displayed value from the multimeter:

OPENCOM	open the serial interface
CLOSECOM	close the interface
SENDBYTE	send a character from the PC
READBYTE	receive a character in the PC
RTS	switch the RTS line
DTR	switch the DTR line
DELAY	delay in milliseconds

A new module

After starting Word 97 or Excel 97, you can open the VBA editor by pressing Alt+F11. Here you can insert a new module using the Insert/Module menu. The first thing in the DLL is a declaration of the external functions of the DLL. In this regard, it is important to use upper-case letters for the names of all DLL functions.

```

Declare Function OPENCOM Lib "rsmini" (ByVal A%) As Integer
Declare Sub CLOSECOM Lib "rsmini" ()
Declare Sub SENDBYTE Lib "rsmini" (ByVal b%)
Declare Sub RTS Lib "rsmini" (ByVal b%)
Declare Sub DTR Lib "rsmini" (ByVal onoff%)
Declare Function READBYTE Lib "rsmini" () As Integer
Declare Sub DELAY Lib "rsmini" (ByVal ms%)
    
```

All parameters must be transferred by values (ByVal), rather than as reference parameters (presets). The DLL should be located in the Windows or System directory. Other pos-

sible locations for the DLL are the directory for spreadsheets or the templates directory.

The declarations are followed by the individual routines for reading the multimeter:

```
Function ComOpen() As Integer
    ComOpen =
    OPENCOM("COM1:1200,N,7,2"):
    RTS 0: DTR 1
End Function
```

```
Function GetString() As String
    Dim A$
    SENDBYTE 33
    A$ = ""
    Do
        e = READBYTE
        If e > 13 Then A$ = A$
        + Chr$(e)
    Loop Until e < 0
    GetString = A$
End Function
```

Opening the interface

ComOpen expects a character string containing the interface parameters. These open COM1 with 1200 baud, 7 data bits, no parity and 2 stop bits. If the interface cannot be opened, ComOpen returns a null value.

Read in a character string

The request for a measurement value is initiated by the character 'D'. After this, characters are received and packed into the character string A\$ until READBYTE provides the value -1, which indicates that the waiting time has expired. All 14 bytes should have been received within this interval.

These two functions can be tested using a small test routine:

```
Sub Test
    If ComOpen>0 then MsgBox
    (GetString)
End Sub
```

Parse a character string

The resistance of the sensor is initially contained in a character string, such as:

```
" 01.98 kOhm"
```

This is now converted into a double-precision floating-point variable. Five characters are extracted from the character string, starting from the

fourth position ("01.98"). Before the extraction takes place, the validity of the string is tested by checking the value of the decimal point character at position 6. Finally, the result is converted to ohms and the result is assigned to the function name:

```
Function StringToOhm(ByVal A$) As Double
    StringToOhm = 0
    If Mid$(A$, 6, 1) <> "."
    Then Exit Function
    b$ = Mid$(A$, 4, 5)
    StringToOhm = Val(b$) *
    1000
End Function
```

Calculate the temperature

The above mentioned formula for calculating the temperature from the resistance of the sensor is formulated as a VBA function as follows:

```
Function Temp(ByVal r As Double) As Double
    Const Alpha = 0.00788, Beta
    = 0.00001937, R25 = 2000
    If r <= 0 Then r = R25
    kt = r / R25
    Temp = 25+(Sqr(Alpha ^ 2 -
    4 * Beta + 4 * Beta *
    kt)-Alpha) / (2 * Beta)
End Function
```

This function receives the resistance in ohms and delivers the temperature in °C as a result. This formula can also be entered into a spreadsheet and then used to generate a suitable graphic, as shown in the illustration at the beginning of this article.

Measurement series in Excel and Word

A small program loop can be used to input a series of measurements. The subroutine 'Get10' takes in ten measurement values. It use DELAY 1000 to wait 1000 ms between successive measurements. The time is entered in column 1 and the temperature in column 2.

```
Sub Get10()
    Const Interval = 1000
    If ComOpen > 0 Then
        For i = 1 To 10
            Cells(i, 1) = i - 1
```

```
            Cells(i, 2) =
            Temp(StringToOhm(GetString))
            DELAY 1000
        Next i
    CLOSECOM
    End If
End Sub
```

If you do not have Excel available, you can also carry out the measurements using Word. The VBA macros will run in the word processing program almost unchanged. The routine 'Get10' must naturally be modified, since there are no cells in Word. In order to insert letters and text into the currently open document in Word 97, you can use

```
Selection.TypeText Text:="Hello".
```

All declarations and functions are the same as those previously presented. The new 'Get10' routine for Word inserts the measurement data into the current document:

```
Sub Get10()
    If ComOpen > 0 Then
        For i = 1 To 10
            Selection.TypeText
            Text:=Str$(i)
            Selection.TypeText
            Text:=vbTab
            Selection.TypeText
            Text:=Str$(Temp(StringToOhm(Get-
            String)))
            Selection.TypeParagraph
            DELAY 1000
        Next i
    CLOSECOM
    End If
End Sub
```

You can use the control element toolbox to assign a command button to the document. A double-click on the button opens the VBA editor and shows the subroutine that is executed when this button is pressed. If you enter 'Get10' here, a measurement will be made when the button is clicked.

```
Private Sub
    CommandButton1_Click()
        Get10
    End Sub
```

Naturally, you must exit the design mode before you can make a measurement.

(000053-1)

Lego Robotics Invention System

Part 2: working with sensors

By H. Steeman (text) and L. Lemmens (technical)

In the first part of this series of articles, we looked at the philosophy behind the Lego Robotics Invention System, the features of the system and the power of the RCX block. In this second part, we give our attention to the manner in which the RCX block works with sensors, which are the eyes and ears of a robot. In addition, we reveal how you can build your own sensors.

The RCX block, which is the key component of the Robotics Invention System, contains a complete microcontroller system. Up to three sensors can be connected to this block. These sensors enable the robot, to perceive 'sensations' from its environment. There are several types of ready-made sensors, including switches, reflective sensors, temperature pickups, rotation pickups and so on. Although the range of available sensors is fairly complete, Elektor readers will surely see the RCX interface as a challenge to develop their own, new sensors. As you will see, this is also possible. In addition, you will see that it is possible to connect more than one sensor to a single input.

Possibilities

The microcontroller that is used in the RCX communicates with the outside world via analogue inputs. The measured quantity is converted into a 10-bit variable. The sensor values are sampled more or less periodically and converted into digital values. These values, which are called RAW inside the microcontroller, range from 0 to 1023. It does not matter which input a sensor is connected to, since the software adapts the sensor input to the type of sensor that is connected.

The RCX has non-polarised, two-wire analogue inputs for measuring external quanti-

ties. This approach has both advantages and disadvantages. The fact that the interface is not polarised and uses two wires means that the

user can connect the sensor in the manner that suits him best. On the other hand, the entire sensor must be supplied with power via the same

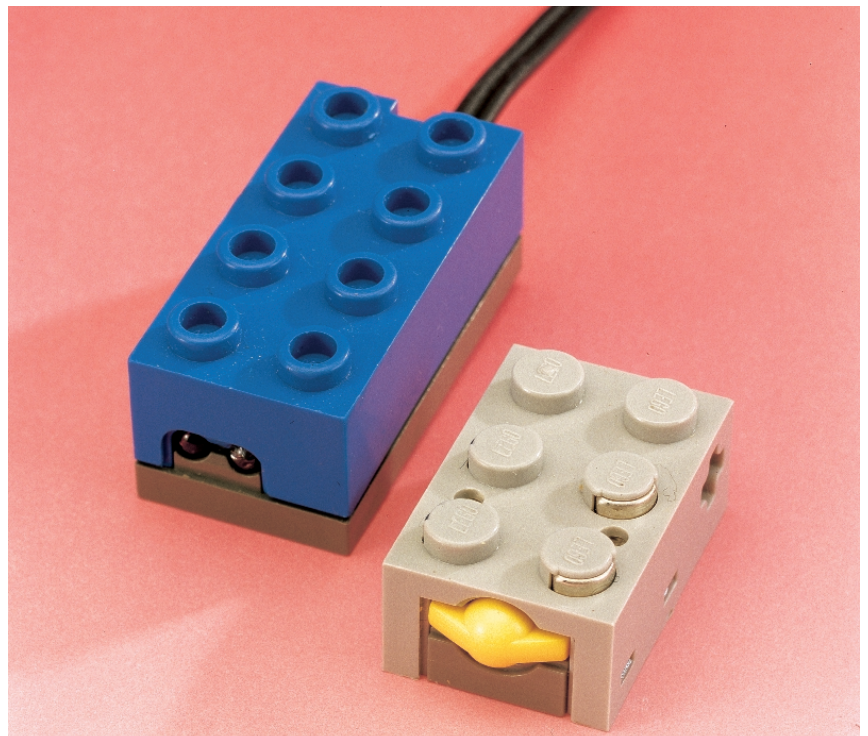


Figure 1. A number of sensors available from Lego for use with the RCX block.

Checking the RAW measurement value

The theory described in this article can be checked using standard software provided by Lego. For this experiment, it is important that the firmware has already been loaded into the RCX.

Start the programming software, select the 'Program RCX' option and go to 'RCX Code'. Activate the test panel in the menu, at the lower right of the screen. Now configure sensor 1 as 'Touch' and leave the other two outputs unused. Next, click on 'Get Sensor Values' and check that the value '0' is given for sensor 1. This means that the switch is open. On the RCX module, you must now press the button labelled 'View' twice in succession. This selects the second sensor input. The measurement value '1023' will appear on the LCD screen; this is the value of RAW when the switch is open. Since we know that the value of the pull-up resistor is 10 k Ω , we can use a second resistor to make a voltage divider. Connect a 10-k Ω resistor between the two terminals of the sensor input. The value of RAW will drop to 512. With a resistance of 4.7k Ω , the measurement value is 327, and with a short circuit it is 0.

two wires that are also used send measured values back to the RCX. In electrical terms, this means that the analogue inputs are connected to the stabilised 5-V RCX power supply via internal pull-up resistors. A simple measurement shows that the value of the pull-up resistor is 10 k Ω .

In summary, one lead of the sensor is connected to the earth of the RCX, while the other lead is connected to the analogue input of the microcontroller and also to the 5-V supply via a pull-up resistor.

Lego presently supports a number of sensors. The RCX knows what type of sensor is connected from settings in the software. The manner in which the measurement result is handled is the determining factor for the result of the measurement.

Switches — if a switch sensor is connected to an input, the following rules apply: (a) if the value of RAW after a measurement is less than 450, the result is '1' (switch closed); (b) if the value is greater than 565, the value is '0' (switch open).

Light sensor — when a light sensor is used, the RCX produces a measurement value that ranges from 0 to 100. Later on we will see how this value can be controlled. The result of the measurement is equal to $(1023 - \text{RAW}) \div 7$.

Temperature sensor — with this type of sensor, the measurement value is converted to degrees Celsius or degrees Fahrenheit. The con-

version formula for degrees Celsius is:

$$\text{temp} = (785 - \text{RAW}) \div 8$$

Table 1 shows how the voltage on the analogue input varies as a function of the value of the resistance connected to the input. The value RAW is a direct translation of the input voltage (within the range of 0 to 5 V) to a 10-bit digital value. In the remaining three columns, you can see how the environmental variables (light, temperature and switch open/closed) affect the sensor resistance.

If necessary (for experimental purposes, for example), you can use a potentiometer to emulate a temperature sensor. Configure a 47-k Ω potentiometer as a variable resistor and connect it in series with a 4k7 Ω resistor between the two terminals. If the input in question is configured for a temperature sensor, the measurement value will vary between approximately -10°C and $+60^\circ\text{C}$ when you rotate the shaft of the potentiometer. A certain amount of variation in this range can occur, depending on component tolerances.

If you use the Lego light sensor, it is apparent that the sensor has two externally accessible components. One of these is a red 3-mm LED, while the other is the actual light sensor, which is a phototransistor. A special protocol is used on the input for this sensor in order to cause the LED to illuminate. In this case, the RCX enables a 120- Ω pull-up resistor to the unregulated supply voltage, which is around 8 V. The LED is switched on by a 3-ms pulse, after which the light intensity is read out for 0.1 ms via the phototransistor. The sensor behaves like a light-dependent resistor while the light intensity is being read out. An internal voltage buffer keeps the LED illuminated while the phototransistor is being read out.

Now we know how the RCX works with sensors, how the measured quantities are converted into the measurement value RAW and the quantities that are derived from this value. Unfortunately, you can't do anything with RAW within the standard Lego software, since the processing of the measurement values takes place inside closed software modules. In a later instalment of this series, we will see that it is however possible to use these quantities with the help of a high-level language, such as Visual BASIC, in combination with the Lego 'spirit.ocx' module.

Two sensors on one input

Since each input of the RCX actually only looks for a resistance value, it is possible to

NQC: a different approach

The software developed by Lego that is provided with the kit has a strongly graphical user interface. However, 'real' programming fanatics find this too restrictive, and they have developed alternative programming environments. One example of such an alternative system is NQC, which stands for 'not quite C'.

This was developed by Dave Baum and Mark Overmars of the computing science department of the University of Utrecht has written an extensive user's guide.

NQC was developed especially for use with the RCX, and it has a syntax that closely resembles that of C. The NQC environment can be used under Windows 95/98 and NT. It provides a graphical user interface that allows the user to program the RCX block via the TCX Command Center. This programming environment can be downloaded free of charge via the Internet, and it comes complete with an extensive user's guide. If you are interested, you can find the latest version at <http://www.cs.uu.nl/people/markov/lego>. You can also find more information about NQC at <http://www.enteract.com/~dbaum/lego/nqc>.

Even if you do not plan to use NQC, it is very interesting to read the user's guide. It gives a good insight into how you can use the RCX block in different environments.

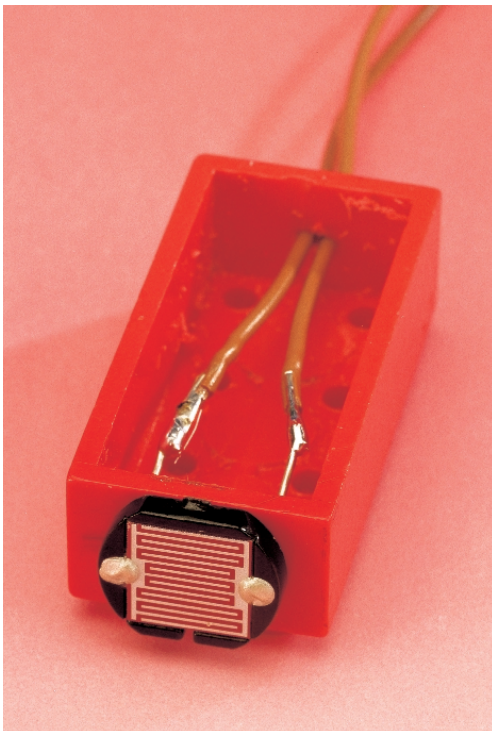


Figure 2. It is not especially difficult to make a real DIY sensor by fitting a standard LDR to a Lego block.

combine sensors. An input that is used for a contact sensor can in principle also be used to read out several contact sensors connected in parallel. When the sensors are arranged this way, they form part of an OR circuit. A prerequisite for this approach is that the response to the closure of a contact sensor is not much more than reversing the current direction of rotation of a motor. After all, if only one sensor input is used, it is not possible to derive any directional information from the sensors.

It is also possible to connect a temperature sensor and a contact sensor to one common set of terminals. The temperature sensor can be read out as long as the contact sensor is not activated. When the contact sensor switch is closed, the temperature sensor is temporarily disabled. As soon as the switch is again open, measuring the temperature can continue as usual.

Non-contacting object detector

Using the two switches that are provided in the experimenters' kit, a robot can mechanically determine whether there is an obstacle in its path. As soon as an object is touched by the feeler of the contact sensor, the switch closes and the object is sensed.

In the Elektor labs, we have developed a sensor that can detect objects without touching them. **Figure 3** shows the schematic diagram of this small sensor. It is connected to the RCX block via the two connector pins PC1 and PC2. Diodes D1 through D4 rectify the voltage applied to these pins by the RCX block, and C1 buffers the voltage. This DC voltage feeds a Sharp IS417F sensor. This contains a complete modulator/demodulator circuit, and it drives an external infrared LED (D7) via pin 4. As soon as an object appears in front of the sensor, it reflects part of the light that is emitted by the LED. The pulsed infrared light is detected by the sensor and demodulated. The use of modulated light makes the sensor relatively insensitive to interference. If the received signal is strong enough, the sensor output (pin 2) goes low. Resistor R1 is pulled low via diode D5 or D6, and the RCX sees a resistance of around 1 kΩ at the terminals. The distance at which the sensor reacts can be adjusted using trimpot P1. The lower its resistance, the more intense is the light emitted by D7, and thus the greater the distance at which an object is detected.

The main advantage of this solution, in comparison to the Lego light sensor, is that it is much less sensitive to interference from visible light, which is of course always present. The synchronous modulator and detector protect against 'random' responses. There is also a second major difference between the two sensors. Although the Sharp sensor is configured as a light sensor, it gives only the value '100' if an object is in its path or '0' if there is nothing in the way. The Lego light sensor

DIY!

The simplest sensor that you can make yourself is a light sensor using a light-dependent resistor (LDR). If no light shines on the sensor, its resistance is practically infinite. If the sensor is strongly illuminated, its resistance drops to a few ohms. The sensor can easily be made using a standard 2 × 2 or 8 × 2 Lego brick. Drill two small holes in one side (around 1 mm diameter) and pass the leads of the sensor through these holes. Fasten the sensor to the outside of the block using a bit of epoxy glue. On the other side of the block, make a small notch in the bottom edge that is wide enough to fit the cable used to connect motors and sensors. Buy a separate interconnection cable (Lego part number 5041 for 9 cm or 5311 for 25.6 cm) and cut off the connector at one end of the cable (note: if you buy a long cable and cut it in the middle, you will have two new cables, each around 12.5 cm long). Make a knot in the cable 1 cm from the loose end. Then solder the cable ends to the leads of the LDR, and fasten the cable to the inside of the Lego block with a drop of glue. The knot provides an adequate strain relief. The photo in **Figure 2** shows the construction of our prototype.

The LDR reacts to a broader range of the light spectrum than the phototransistor used in the Lego sensor. A phototransistor is normally sensitive in the infrared region. In addition, with the Lego sensor there is a risk of mutual interference, since the light source is located very close to the phototransistor. Although the sensitivity curve of our homemade sensor differs from that of the Lego sensor, it is a perfect and inexpensive alternative. The input to which the LDR is connected should be con-

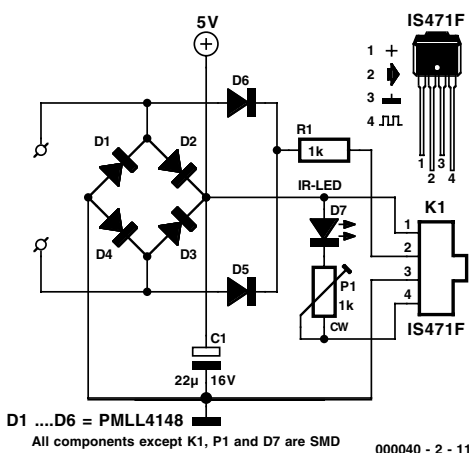


Figure 3. The schematic diagram of the DIY non-contacting object detector.

COMPONENTS LIST

Resistors:

R1 = 1kΩ, SMD
P1 = 1kΩ preset, SMD

Capacitors:

C1 = 22μF/16 V SMD or tantalum

Semiconductors:

D1-D6 = IN4148 SMD = PMLL4148 (or BAT82)
D7 = IR-LED, 3 mm (wavelength 950 nm), e.g., TSIP4400 (Farnell #178-545) or SFH409 (Conrad Electronics # 183776-33)
IC1 = IS471F (Sharp, Conrad Electronics #185094-33)

Miscellaneous:

Lego-block, type 2x4
Connecting wire + blocks:
Lego-cable, length 26.6 cm (order # 5311)
Lego-cable, length 9 cm (order # 5041)
PCB, order code **000040-1** (see Readers Services page)

SMDs. It should also be possible to use normal components, with a bit of cutting and trying. In this case, however, the trimpot will have to be replaced by a fixed resistor (first adjust the distance with a trimpot, then measure its resistance) and you will have to look for an electrolytic capacitor that is small enough to fit into the Lego block (use a small tantalum type). BAT82s make a good substitute for the diodes, if you bend their leads closely around the ends of the packages. Don't forget that there must be enough open space inside the bottom of the block to allow the sensor block to be snapped on top of another block!

The sensor and the LED are mounted on the copper side of the board. This keeps the upper surface of the board nice and flat, so that it can be fully pressed into the Lego block.

The trimpot can be adjusted only after the circuit is fitted into the block. Usually you will find that the sensor right away 'sees itself', so that you will have to make the LED opaque to infrared light on the sides and to the rear. In the prototype, we spread a thick coating of Tippex on the LED, but this proved to be inadequate, probably because the plastic of the Lego block transmits enough light to trigger the sensor. Consequently, the inner surface of the block and even the edge of the hole must also be painted.

Pay careful attention to the position of the sensor when making the sight hole for it in the block. According to the data sheet, the centre of the detector element is located 1.8 mm above the centre of a small recess on the front surface of the

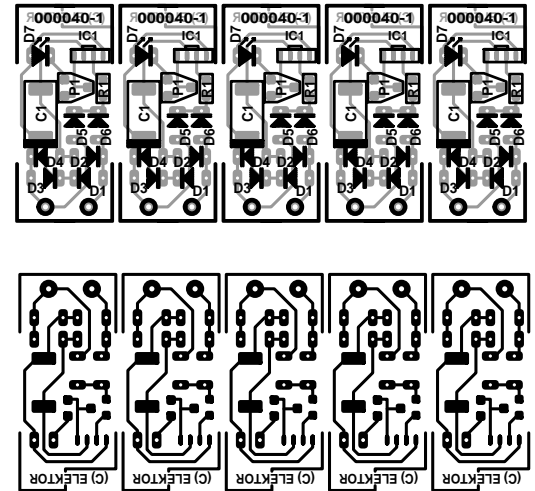


Figure 4. Copper track layout and component layout of the printed circuit board for the object detector.

sensor. Naturally, the sensor is most sensitive if the opening in the block is located exactly in front of this point.

Figure 4 shows the printed circuit board and component layouts for building this circuit. It is so compact that it can be fitted into a standard 8 × 2 Lego block. Openings for the diode and the sensor must be made on the front side of the block, and an opening for the cable can be made on the other side as already described.

This sensor can be connected to any of the three RCX inputs in place of the existing light sensor. The measurement value switches between 0 and 100, with no intermediate values. If P1 is set to midrange, objects are detected at a distance of around 50 cm. The detector has a viewing angle of approximately 80 degrees.

One final remark: the LED emits a strong infrared light signal. This can disturb the communications between the PC and the RCX when software is being downloaded to the RCX. You should therefore avoid aiming the DIY object detector at the IR sensor of the RCX or the Lego transceiver while software is being downloaded, or else simply disconnect the sensor for the duration.

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Table I. Analogue input voltage and associated results.

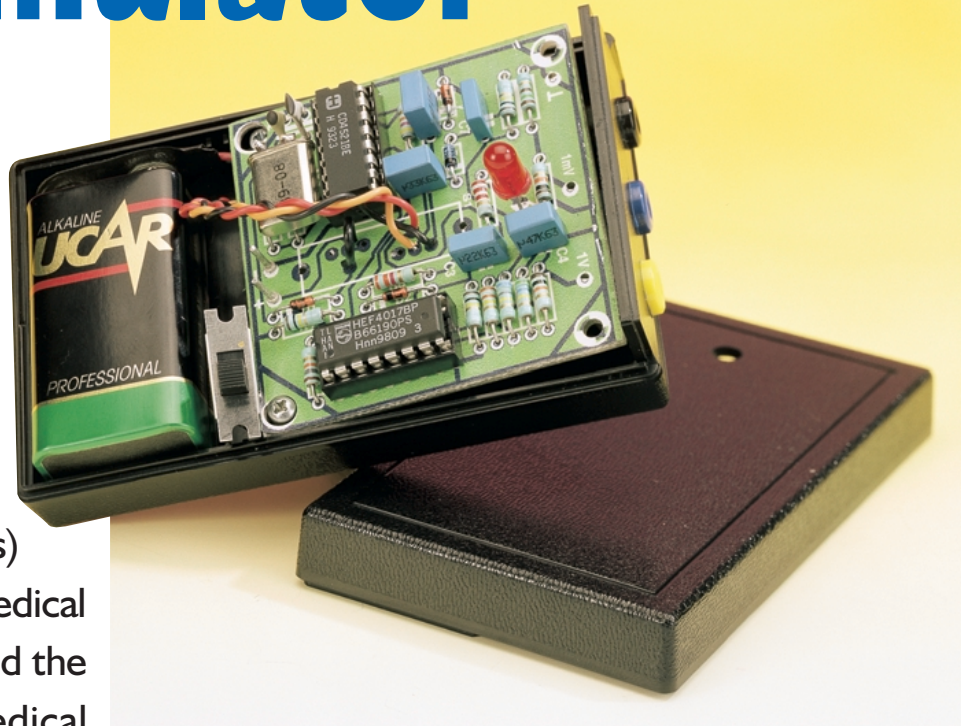
Voltage	RAW	Sensor resistance	Light	Temp (°C)	Contact sensor
0.0	0	0	-	-	1
1.1	225	2k8	-	70	1
1.6	322	4k6	100	58	1
2.2	450	7k8	82	42	1
2.8	565	12k3	65	28	0
3.8	785	32k8	34	0	0
4.6	945	120k	11	-20	0
5.0	1023	∞	0	-	0

ECG simulator

an analogue
waveform
generator

Design by J. Holzhauser

Electrocardiograms (ECGs) are used very often for medical examinations, research and the development of biomedical equipment. An ECG simulator thus has a large variety of potential applications.



Warning!

The ECG simulator described in this article should be used only for testing and repair purposes. It must never be connected to any equipment that is at the same time connected to a patient. Neither the author nor Elektor Electronics assumes any responsibility for injury or damage that may result from the use of the ECG generator.

An artificial signal that corresponds to an actual ECG signal is needed for the development and servicing of ECG equipment. This makes it unnecessary to make measurements on people, and in particular with research and repair activities it eliminates a potential risk to the test subject. The simulator described here produces a suitable signal. Since this signal is crystal controlled, it can also be used for the calibration of pulse rate displays.

From the heart

In order to make an electrocardiogram, electrodes are attached to specific locations on the body, such as the forearm, calf, and breast cage. The electrical potentials produced by the activity of the heart, as measured between these electrodes, are then recorded.

The source of the voltage for the heart muscle, the sinus node, emits a pulse that branches into two main parts (temporal and spatial). The pulse, and the progression of the excitation, can be measured on the surface of the body. The shapes of the resulting waveforms and their progression over time provide doctors with important information regarding diseases of the heart and circulatory system.

The ECG can be either continuously displayed on a monitor (for intensive supervision) or traced by a pen on paper for documentation. In the later case, several different versions of the signal, measured at different points, are often recorded at the same time. With this type of

ECG, which is called a surface ECG, the measured potentials lie around 1 mV. The heart rate can lie between 40 Hz (rest rate) and 150 Hz (with strong exertion).

Medical specialists use the letters P through U to refer to the various curves and spikes of the ECG, as shown in **Figure 1**. Modern ECG recorders and monitors verify and evaluate the input signal and are able to filter out artefacts and foreign signals, such as pacemaker signals. This means that a simple square-wave generator is not satisfactory as an ECG simulator, since the ECG equipment would simply ignore such a signal. The signal produced by the simulator described here has been successfully tested on several different ECG recorders and monitors.

A discrete circuit

A microcontroller system is normally used to generate the test signal in industrial ECG test equipment, which is consequently rather expensive. However, you will look in vain

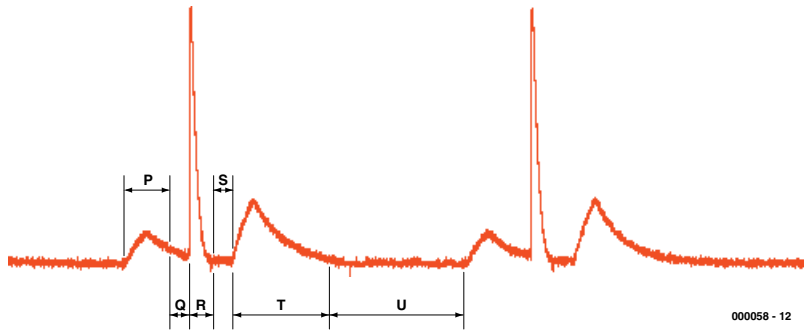


Figure 1. A heartbeat in detail: the waveform for each contraction can be broken down into various parts, identified using the letters P through U.

for a microcontroller in the schematic diagram of this ECG simulator, which is shown in **Figure 2**. Only two standard logic ICs and a few passive components are used. IC1 is a 24-stage binary counter with an integrated oscillator and divider. With the indicated crystal frequency of 4,194,304 Hz, a 16-Hz squarewave signal appears at the Q18 output (pin 10). Switch S1b picks up a second signal (2 Hz or 1 Hz). The 16-Hz signal clocks IC2, which is a decimal counter with ten outputs. The second signal is differentiated by the combination of C3 and R3. Needle-shaped pulses are present at pin 15 of the decimal counter (IC2), as indicated on the schematic diagram. These pulses reset the counter to zero at the appropriate times. The job of diode D2 is to block the negative portion of the pulses.

The decimal counter repeatedly reaches a count of 9 and holds this state, since pin 11 is connected to the /Enable input (pin 13). It is only reset when the reset pulse occurs. The setting of the switch thus influences the duration of the U interval, which ultimately results in a simulated heart rate of either 60 Hz or 120 Hz. If necessary, a 4-MHz crystal can be used. This will reduce the heart rate of the signal to 57.2 Hz or 114.4 Hz, respectively.

The ECG signal is generated in a remarkably simple manner using a dozen discrete components. Time-displaced square wave signals appear at the Q1, Q4 and Q6 outputs. The first pulse (from pin 2) is converted into the P wave by the integrator R6/C4. The value of R6 is chosen such that C4 charges exponentially from 0 V to around 1 V. The

T wave is generated by a second integrator (R7/C4). Since R7 has less than half the resistance of R6, the pulse from Q6 charges C4 to more than twice the voltage (2.2 V) of the P wave.

The differentiator C5/R10 inserts the R pulse between these two waves. Resistor R8 limits the charge current for C5, while D5 ensures that the peak value of the pulse does not exceed approximately 3.8 V. The negative portion of the pulse (on the falling edge of the input pulse) is shorted out by D4, so that all that remains is a good -0.7 V due to the voltage drop of D4. This produces a very pretty S component. Diode D3, with its series resistor R9, flashes during the R spike.

The signals from both integrators and the differentiator are summed by R11 and R12 (with different weightings). Capacitor C7 smoothes out excessively spiky pulse components. The final waveform is also shown on the schematic diagram. The voltage divider provides output signals with amplitudes of 1 mV (for connection to the input of ECG equipment) and 1 V. Insensitive equipment that normally works with signals that have already been amplified, such as secondary monitors, can be connected to the second output.

A 9-V battery can be used as the power source. The circuit draws only around 2.5 mA, so the battery should last quite a while. The circuit can be assembled in a few minutes using the printed circuit board shown in **Figure 3**. The ICs may be mounted in sockets. If you cannot obtain the slide switch, you can use two separate, single-pole toggle switches, one for the operating voltage and

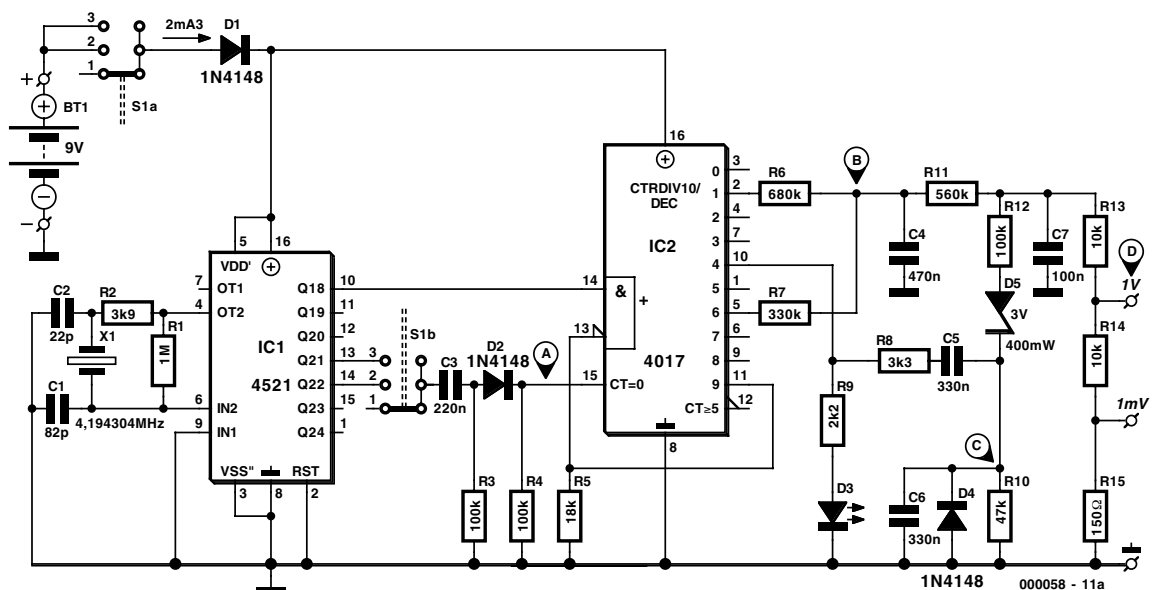


Figure 2. An analogue arbitrary signal generator using discrete components.

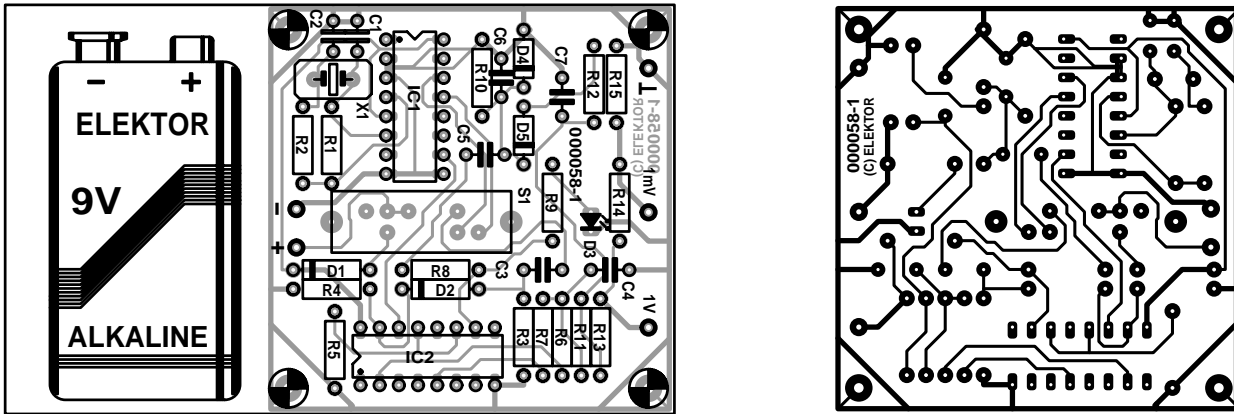


Figure 3. The ECG tester fits in a small plastic enclosure.

COMPONENTS LIST

Resistors:

R1 = 1M Ω
 R2 = 3k Ω
 R3,R4,R12 = 100k Ω
 R5 = 18k Ω
 R6 = 680k Ω
 R7 = 330k Ω
 R8 = 3k Ω
 R9 = 2k Ω
 R10 = 47k Ω
 R11 = 560k Ω

R13,R14 = 10k Ω
 R15 = 150 Ω

Capacitors:

C1 = 82pF
 C2 = 22pF
 C3 = 220nF 5mm pitch
 C4 = 470nF 5mm pitch
 C5,C6 = 330nF 5mm pitch
 C7 = 100nF 5mm pitch

Semiconductors:

D1,D2,D4 = 1N4148

D3 = LED, high efficiency
 D5 = zener diode 3 V / 400 mW
 IC1 = 4521
 IC2 = 4017

Miscellaneous:

S1 = slide switch, 2-pole changeover (Conrad Electronic o/n 708097)
 BT1 = 9-V PP3 battery with clip-on leads
 X1 = 4.194304 MHz quartz crystal
 Enclosure 60x95x23 mm (Conrad Electronic o/n 522864)
 3 wander (banana) sockets (2 mm or 2.6 mm)

the other for switching the pulse rate. The assembled circuit board fits in the suggested ABS enclosure, which also provides room for

the battery. Miniature banana jacks (2.0 mm or 2.5 mm) are an excellent choice for output connectors.

Design editing: Karel Walraven.

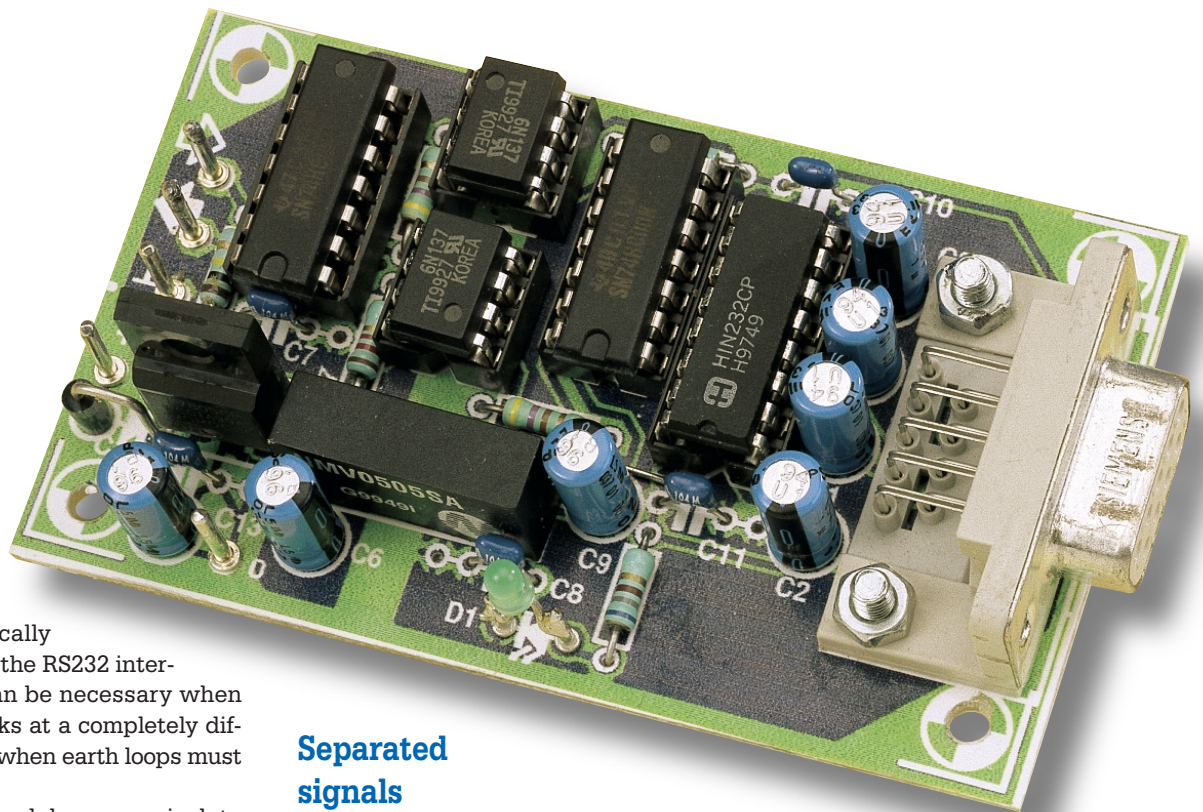
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Serial transceiver

Electrically isolated RS232

Design by A. Müller

This transceiver electrically isolates the TxD and RxD lines from the PC, provides an isolated power supply and also looks after the bi-directional conversion between TTL levels and symmetric RS232 levels.



Frequently, a microcontroller system should or must have an electrically isolated connection to the RS232 interface of the PC. This can be necessary when the target system works at a completely different voltage level, or when earth loops must be avoided.

The circuit described here can isolate potentials up to 2500 Veff or 3000 Vdc, depending on the type of optocoupler used. It uses only relatively easily obtained components, and it does not include any homemade inductors. Power for the circuit is provided by a mains adapter. A Maxim MAX232 interface driver is incorporated into the circuit to convert signals to the PC from TTL to RS232 levels (± 12 V), and signals to the microcontroller system from RS232 to TTL levels. All other lines of the RS232 interface that would be needed to support handshaking are not supported, but they can be added on without great difficulty.

Separated signals

A simple glance at the schematic diagram in **Figure 1** shows how the electrical isolation is achieved. Two optocouplers are used, along with a DC/DC converter for the power supply. A fourth component, or better said an isolating measure, can be clearly seen in the circuit board layout. A 5-mm wide copper-free strip is located between the two voltage regimes and underneath both optocouplers and the voltage converter. This prevents leakage currents as well as possible arcing with high

potential differences.

The Toshiba 6N137 optocoupler used here (which are also available from other suppliers) consists of an infrared transmitter diode and a photo-IC, which is made up of a receiver diode, a Schmitt trigger and a NAND gate with an open-collector output (see **Figure 2**). The externally available gate input (Enable) is permanently connected to +5 V in this circuit, so that the optocoupler is always enabled.

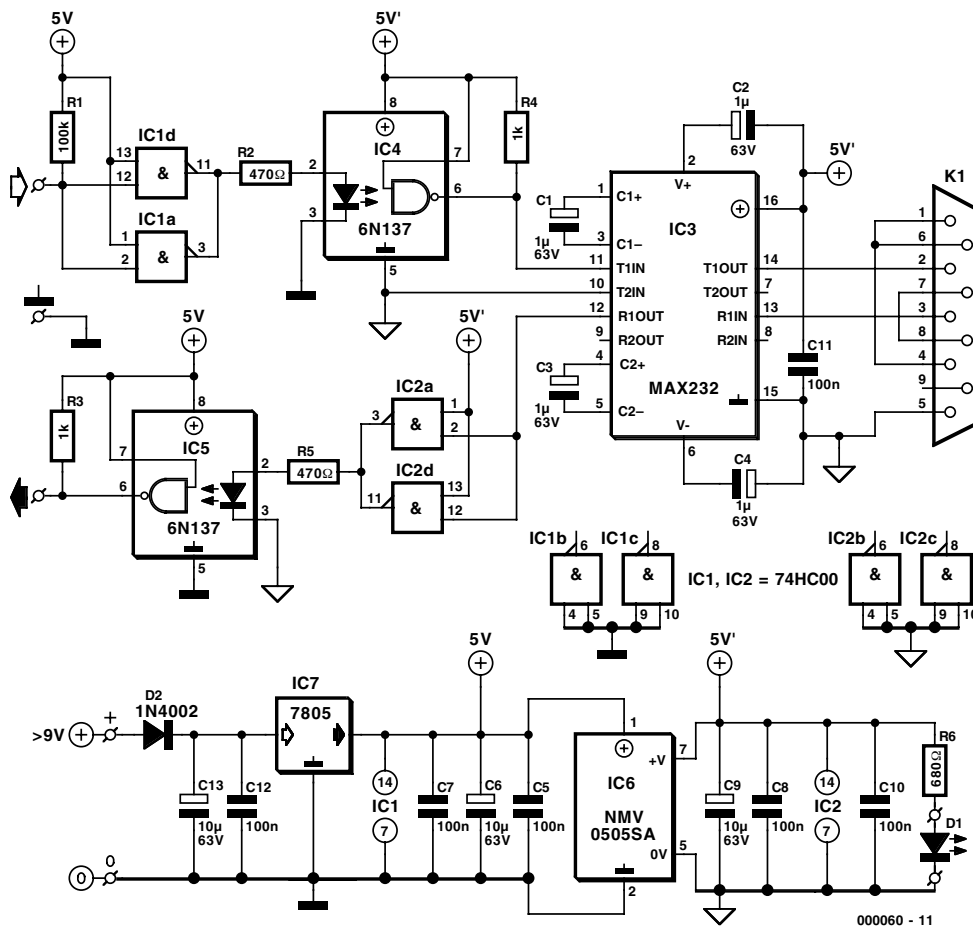


Figure 1. Two optocouplers and an integrated DC/DC converter provide the electrical isolation.

Both optocouplers are wired in nearly the same manner. The output of the microcontroller (TxD) is terminated by resistor R1 and amplified by two parallel HC NAND gates, which provide the drive current to the LED (limited by R2). Resistor R4 is the collector pull-up resistor. In the other direction (RxD), the picture is nearly the same, with the only exception being that the termination resistor is omitted. The gates and optocouplers allow a data transfer rate of more than 1 MHz.

The MAX232CPE interface driver (IC3) limits the bandwidth to 115 kbit/s. If a higher level of input protection against electrostatic discharges is necessary, you should use the MAX232ECPE instead. It guarantees protection up to ±15 kV.

DC/DC converter

Power is provided by a mains adapter (>9 V at 250 mA). A +5-V

voltage regulator (IC7, a 7805), in combination with the reservoir and decoupling capacitors C12 and C13, provides a stable operating voltage. Diode D2 provides reverse-polarity protection. The primary operating voltage is filtered by C6 and used to supply IC1, while the output side of IC5 and the cathodes of the IR diodes are powered by IC4.

The primary and secondary supply voltages are isolated by an integrated DC/DC voltage regulator, which is a Newport NMV0505SA (available from Farnell, among others). This component is a member of a family of 100-kHz switch-mode DC voltage converters that can be used to convert a DC input voltage of 5 V, 12 V 24 V or 48 V to a DC output voltage of 5 V, 9 V, 12 V or 15 V (suffix A), or ±5 V, ±9 V, ±12 V or ±15 V (no suffix). The input voltage is indicated by the first two digits of the part number, while the output voltage is indicated by the second pair. All con-

verters are available in DIL (suffix D) or SIL (suffix S) packages. The output power capacity is 1 watt per output for all models. The DC isolation voltage is 3 kV for all models. The conversion efficiency is typically 70 to 80% at full load.

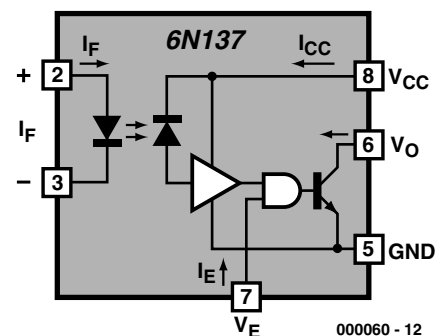


Figure 2. The internals of a 6N137 optocoupler.

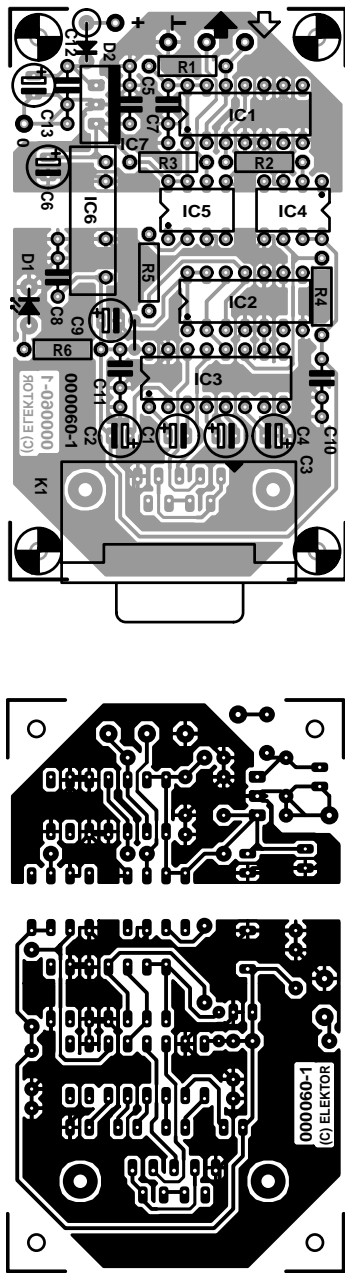


Figure 3. The electronics on the two sides is separated by a 5-mm wide copper-free strip.

We thus have the following brief specifications for the model NMV0505SA converter used here:

- input voltage: +5 V
- output voltage: +5 V
- output current: 200 mA
- package: SIL

On the secondary side we find IC2, the output side of IC4, the cathode of the transmit IR diode of IC5 and the MAX232 interface con-

verter. The two electrolytic buffer capacitors C6 and C9 support the voltage converter. Each IC also has an additional 100-nF local decoupling capacitor. LED D1 shows that the serial transceiver is operational.

Construction, testing and more

The printed circuit board layout shown in **Figure 3** is designed for a 9-pin sub-D connector (K1). A simple, standard RS232 cable can be used to connect K1 to the COM port of a PC. On the microcontroller side, we have done without this or any other sort of connector, in favour of simple solder terminals. This makes for flexibility as far as the connections to the microcontroller and the power source are concerned. If the transceiver is to be powered by a mains adapter, fitting a low-voltage connector to the enclosure is a good idea.

When inserting the components into the board, you should use only sockets that explicitly have an isolation voltage of 3 kV (1 TΩ isolation resistance) for at least IC4, IC5 and IC6. You cannot automatically assume that inexpensive sockets will meet this requirement. Pay attention to the component silkscreen markings and don't forget the small wire bridge next to C9.

After visually inspecting the finished board, you can perform a functional test. For this test, connect the two TTL pins of the transceiver to each other and then connect the transceiver via an RS232 cable to either COM12 or COM2 of a PC. Start the HyperTerminal program under Windows 95/98, disable local echo and handshaking, and check whether arbitrarily entered text is displayed in the receive window.

If you do not want to do without RTS/CTS handshaking, you can naturally add another pair of optocouplers to the circuit. There are sufficient unused NAND gates and two unused channels in the MAX232. Of course, this will require a completely new circuit board layout, which must retain the generous earth planes and the 5-mm wide separation between the two sides as found on the original board. The handshake pins of the RS232 jack (pin 7:

COMPONENTS LIST

Resistors:

- R1 = 100kΩ
- R2,R5 = 470Ω
- R3,R4 = 1kΩ
- R6 = 680Ω

Capacitors:

- C1...C4 = 1μF 63V radial
- C5,C7,C8,C10,C11,C12 = 100nF ceramic
- C6,C9,C13 = 10μF 63V radial

Semiconductors:

- D1 = LED, high efficiency
- D2 = 1N4002
- IC1,IC2 = 74HC00
- IC3 = MAX232
- IC4,IC5 = 6N137
- IC6 = NMV0505SA (Newport, Farnell)
- IC7 = 7805

Miscellaneous:

- K1 = 9-way sub-D socket, PCB mount, angled pins

RTS, pin 8: CTS) must not be connected to each other. The current consumption on the secondary side must not exceed 200 mA.

Finally, there is one (superfluous?) tip: you naturally cannot connect the transceiver to any microcontroller system that already includes a RS232 converter (such as the MAX232). The TTL logic at the input and output can only handle TTL signals (0/5 V)!

(000060-1)

Working with a Touch Screen

Touch point computed by a microcontroller

Design by W. Couzijn

Everyone nowadays is familiar with screens with which you can draw or type by touching a finger or a pen to the screen. How do such screens work, and how is the point of contact read out?



since these are inexpensive and can easily be read out. The screen consists of two plastic sheets placed one on top of the other. These have a conductive coating with a relatively high specific resistance. Tiny discs between the two sheets keep them separated. The top sheet has highly conductive strips along the two edges in the vertical direction of the screen, while the bottom sheet has similar strips along the two edges in the horizontal direction. Each of the two sheets thus represents a sort of potentiometer, one aligned to the height of the screen and the other to its width. The 'wipers' of these two potentiometers make contact with each other when the screen is pressed. The settings of the two potentiometers are then directly related to the location where the screen is pressed. The four strips that form the outer ends of the two potentiometers are accessible to the user via a small cable. This allows the position where the screen is touched to be measured.

The circuit presented in this article makes it very easy to use a touch screen in your own projects. All that you need is a single IC, which is a standard microcontroller costing only a few pounds. The circuit is self-calibrating and very energy efficient.

There are several different types of touch screens. Some are based on capacitance or resistance, while others use optical effects or guided waves. The circuit described here is limited to resistive touch screens,

The circuit: a single-chip solution

The circuit for reading out the touch screen is shown in **Figure 2**. It contains essentially only one IC, which

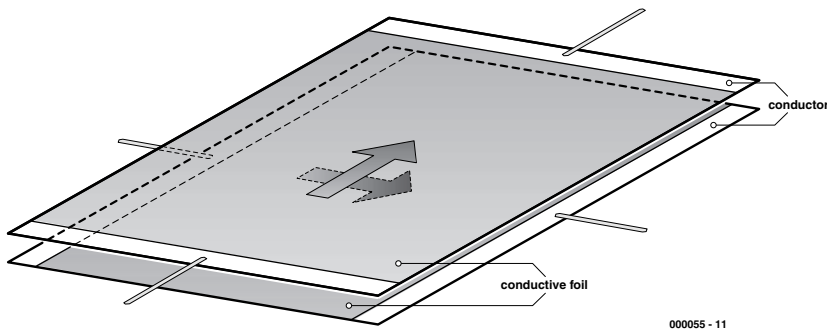


Figure 1. Construction of a resistive touch screen.

is a Microchip PIC12C671 microcontroller. This attractively priced 8-pin controller IC has an on-board 8-bit A/D converter and an internal RC oscillator that runs at approximately 4 MHz.

The remaining components are two transistors, three resistors, a diode, a voltage regulator and two capacitors. These are not necessary for reading the actual screen, but they provide power to the microcontroller and support communication with the PC. Since a serial PC port works with voltages that are significantly higher than 5 V, voltage conversion is necessary. The port is driven by software such that a voltage of around 18 V is produced between pins 4 and 7 of the 9-pin RS232 connection. This is rectified and reduced to a stable level of 5 V for the microcontroller. Pins 2 and 3 are the data channels Rx and Tx of the COM port.

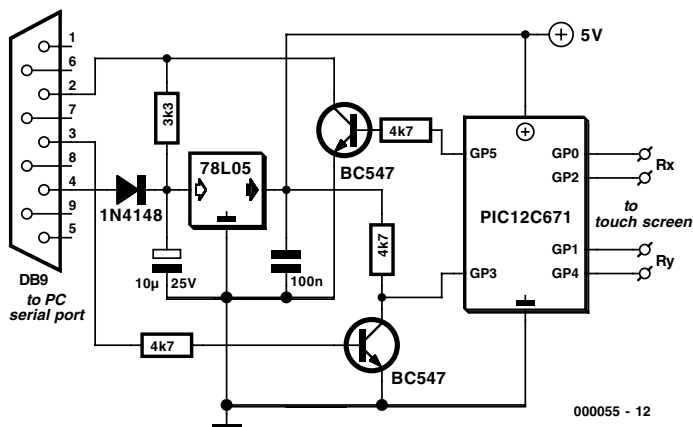


Figure 2. Schematic diagram of the touch screen circuit.

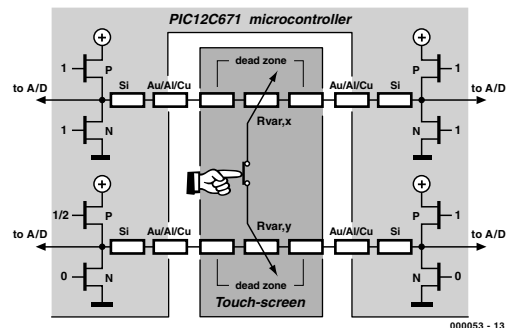
Position detection

If you want to know where the screen is being touched, the first thing you have to do is to determine whether the screen is actually being touched (see **Figure 3a**). The microcontroller does this by configuring pins GP0 and GP2 as outputs and pins GP1 and GP4 as inputs, for measuring the X axis. Pins GP0 and GP2 have low (earth) levels, while pin GP1 has an internal pull-up resistor. If the screen is being pressed, there will be a conductive path from GP1 to earth, and the level on GP1 will thus be low. If the screen is not being pressed, there will be no conductive path from GP1 to earth, and it will be held at a high level by the internal pull-up resistor.

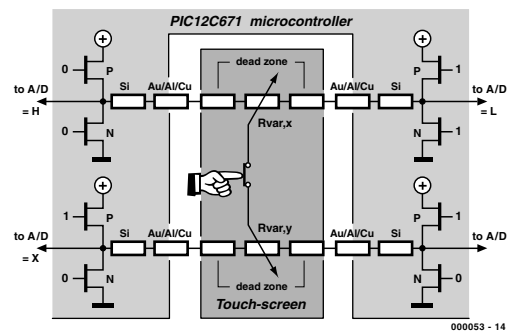
Determining the X position

The position in the X direction can now be determined as shown in **Figure 3b**. The microcontroller sets GP0

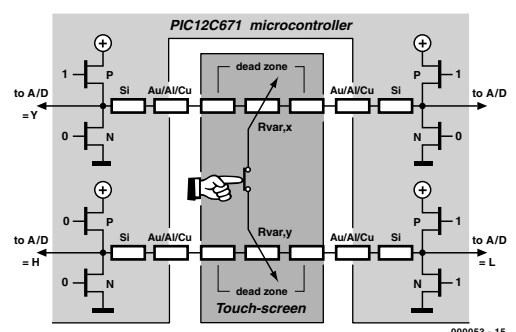
high, which causes a current to flow through the X-axis potentiometer. The internal pull-up resistor is disconnected, since it would otherwise disturb the measurement. Since GP1 and GP4 are configured as inputs, they should have sufficiently high impedance that the position of the 'wiper' of the potentiometer can be read via these pins, as the result of a simple voltage divider circuit. The microcontroller now makes A/D measurements of the voltages on the two outputs (GP0 and GP2) and the input GP1. The voltages on GP0 and GP2 represent offsets that must be used to correct the measured value of the voltage on GP1. This is necessary because the A/D con-



a) Is the screen being pressed?



b) Determine the X position.



c) Determine the Y position.

Figure 3. The three successive stages of determining the X-Y position:

verter is never perfect, and in addition a fairly strong current flows through the digital outputs GP0 and GP2, which consequently do not supply exactly 0 V and 5 V. After these offset voltages have been taken into account, the calculation of the X position is completely independent of the value of the supply voltage, the voltage drops at the outputs, the offset of the A/D converter and the range of the A/D converter. The formula for this is:

$$X_{\text{pos}} = S \frac{128(X-L)-T(H-L)}{(H-L)(128-T-B)}$$

S = size (0 - 127)

X, L, H = A/D converter values

T, B = offsets (100%/128)

This formula has also been extended to include three variables that can be specified by the user. These are the two offset values for the left and right sides of the screen, plus a scale factor. These are not calibration factors! With these variables, the user can set the location of the (0,0) pixel and specify how many pixels must be placed in each of the two directions. This allows a sort of virtual screen to be superimposed on the physical touch screen, as illustrated in **Figure 4**. For example, if there are only two touch areas in the underlying LCD screen, the user can make two pixels that represent these two areas, and crop the edges of the screen by adjusting the offset values.

Determining the Y position

You can easily guess how the Y position is determined. As shown in **Figure 3c**, pins GP0 and GP2 are now configured as inputs, while pins GP1 and GP4 are configured as low-level and high-level outputs, respectively. After the voltages on pins GP1, GP4 and GP0 have been measured, the same formula as before can be used to calculate the Y position in pixels:

$$Y_{\text{pos}} = S \frac{128(Y-L)-T(H-L)}{(H-L)(128-T-B)}$$

S = size (0 - 127)

Y, L, H = A/D converter values

T, B = offsets (100%/128)

In order to save energy, the voltage is removed from the touch screen after the position has been measured.

Measurement resolution

The built-in A/D converter of the PIC12C671 is 8 bits wide. Unfortunately, the

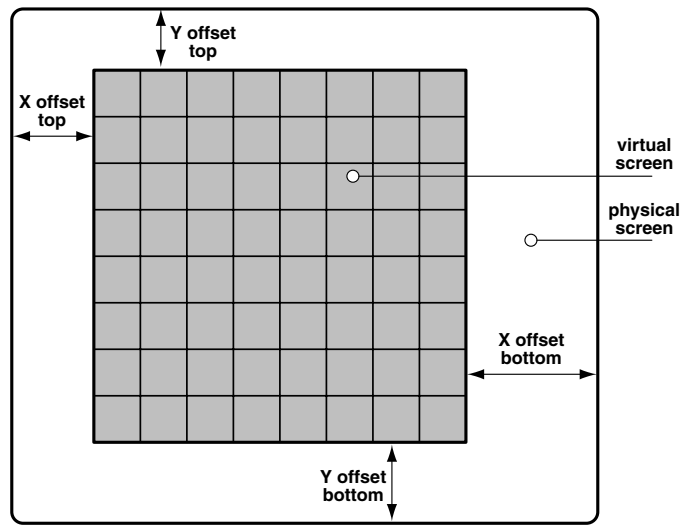


Figure 4. A virtual screen is superimposed on the physical screen.

resolution with which the touch position can ultimately be calculated is not this fine, due to non-linearity of the A/D converter and a loss of resolution caused by the offset corrections in the two formulas. However, a resolution of 6 bits is definitely achievable. It is possible to obtain even higher resolution than this by using a few tricks that work very well. For example, in place of applying a continuous 5-V level to the potentiometer while the analogue signal is being acquired, which takes several clock cycles, the level can be set to 0 V for 50% of the time and 5 V for the remainder of the time. If this process is repeated for several measurement cycles, the resolution can be increased to 8 bits.

There is also a small amount of hysteresis built into the microcontroller software, in order to prevent jitter in the measurement value

when the position lies on the boundary between two pixels.

Serial communication with the PC

A number of commands have been defined for requesting the touch position and setting the offset and scale factors. These are sent to the microcontroller using the normal serial data protocol: 8 data bits with 1 start bit and 1 stop bit, no parity, and 9600 baud. As already noted, the IC has an internal RC oscillator that runs at approximately 4 MHz. The exact frequency of the oscillator depends on a number of factors, such as temperature, supply voltage, production variables and ageing. The resulting deviations in the oscillator frequency can be large enough to cause bit errors and framing errors in the serial communication with the PC, which is naturally undesirable. To

Contents of floppy disk # 000055-II

Contents.txt	contents list
Copyright.txt	copyright notice
Egavga.bgi	auxiliary file for Test.exe
Test.exe	test program
Touch.asm	source code
Touch.hex	Intel hex file for programming the microcontroller
Tst.tpe	auxiliary file for Test.exe
Tst.tpr	auxiliary file for Test.exe

avoid such problems, the microcontroller carefully analyses the pulses that it receives from the PC, and then adjusts its internal oscillator based on timing measurements on the start bit. In this way, the communications never end up in limbo.

Commands

The touch position is requested by sending the hexadecimal code 'EF' to the microcontroller. The response is a 7-bit X position with the 8th bit low, followed by a 7-bit Y position with the 8th bit high. The 8th bit is thus used to distinguish the two data bytes (bit 7 of the final byte is always high).

The codes '0F', '2F' and '8F' are used to set the upper offset, lower offset and scale factor for the X direction. The scale factor specifies the number of pixels in the virtual screen, while the two offset values

specify the sizes of the upper and lower borders that are not allowed to be used. Each command byte must be followed by a byte containing a 7-bit value for the factor to be set, with the 8th bit high. The set value is returned (echoed) to the PC as confirmation of its correction reception. Commands '4F', '6F' en 'AF' function in the same manner for setting the offsets and scale factor in the Y direction.

Finally, the command 'CF' can be used to read out all settings, along with the version number of the microcontroller software and the result of the software self-test. The software version number is sent first as a BCD value, followed by the two X offset values, the two Y offset values, the X scale factor and the Y scale factor. The response concludes with a byte for the result of the self-test, which normally has a value of zero. If the horizontal-axis sheet is

not conductive, which indicates a broken contact, bit 0 is set high. Bit 1 has the same significance with regard to the vertical-axis sheet. Bit 2 is set if the horizontal-axis sheet is shorted, and bit 3 indicates the same situation for the vertical-axis sheet.

Construction and software

The software for this circuit consists of an assembly-language program for the microcontroller (provided as source code and a compiled hex file) and a DOS program for the PC. The latter program allows the functions of the circuit to be tested. The software is available from Readers Services on a floppy disk (order number 000055-11) and from the Elektor Internet site. There is no ready-made printed circuit board available for this project, but the circuit is so simple that it can easily be built on a piece of prototyping board. If you're handy, you should even be able to fit everything into a DB-9 connector.

(000055-1)

Lead-free soldering

Silver and copper instead of lead

In order to prevent heavy metals from being released into the environment, it's best to simply avoid the use of mercury, cadmium and lead. However, what happens to the soldering of electronic components if lead is prohibited?



The harmful environmental effects of heavy metals have been known for a long time, but only recently have any effective and publicly visible measures been taken against them. Mercury-free batteries, rechargeable batteries without cadmium and lead-free petrol are the most well known examples. There have also been changes in the composition of solder, which normally is an alloy of lead and tin. For example, the use of solders containing lead has been prohibited for food containers for quite a while already, and lead-free solders must now be used for domestic water lines as well. In these two cases the critical factor was the direct risk of lead poisoning, but in

the case of lead-based solders used in the fabrication of electronic equipment, the primary issue is the environmental effects of a steadily increasing volume of electronic products.

Electronic scrap

Revision 3 of the European guidelines for electronic scrap puts an end to the use of heavy metals and other environmentally questionable materials in the fabrication of electronic equipment. From the January 1, 2004

onwards, the guidelines prohibit not only the use of lead, mercury and cadmium, but also compounds of valence-six chromium and halogenated flame retardants. This makes it impossible to use solders containing lead after this date.

The changeover has already started in industry. The most commonly used soldering processes are reflow soldering (used primarily with SMD components) and wave soldering. Lead-free alloys can be used in both processes. However, this causes changes to essential process parameters, so a certain amount of fine tuning is necessary in order to obtain the best results when the new alloys are used.

Lead-free alloys

Up to now, soft solder containing around 60% tin (Sn) and 40% lead (Pb) has almost always been used for soldering electronic components. Small amounts of copper and silver are sometimes also present. With an eutectic tin-lead alloy, which contains 62% tin and 38% lead, the melting point lies at the relatively low value of 183 °C. 'Eutectic' means that the melting and solidification points are the same, which causes the solder to change directly from the liquid to the solid state (or the other way around). With non-eutectic alloys, there is a certain range between the melting and solidification temperatures, within which the solder has a 'pasty' or viscous consistency.

Possibly replacements for lead in tin solder alloys are copper (Cu), silver (Ag), bismuth (Bi), antimony (Sb), indium (In) and zinc (Zn). Although a eutectic tin-bismuth alloy has the lowest percentage of tin of all the lead-free alloys, and is thus not significantly more expensive than tin/lead solders, it has the disadvantage that its melting temperature is too low (138 °C). All other substitute alloys have a much higher percentage of tin (more than 90%), which means that they not only have higher melting temperatures but are also more costly. Consequently, lead-free solder is around twice as expensive as conventional lead/tin solder.

Most lead-free solders are alloys of tin with copper, silver or copper plus silver. Of this group, a eutectic tin/silver/copper alloy has the lowest melting temperature. This alloy is 95.5% tin, 3.8% silver and 0.7% copper, and it melts at 217 °C. This is still 34 °C higher than the melting point of the usual tin/lead solder. This relatively expensive alloy, which goes by the designation Sn95.5Ag3.8Cu0.7, appears to be on its way to becoming the standard for lead-free soldering.

There is also a whole series of other tin/silver/copper alloys with either a higher or lower percentage of silver, ranging from 5% silver down to 2% silver (in the latter case, with 0.8% copper plus 0.5% bismuth). The melting temperatures of these alloys range from 221 to 240 °C. Pure tin/silver alloys have a very high proportion of tin (the eutectic alloy is 99.3 Sn/0.7 Cu), and the melting point (227 °C) is nearly as high as that of pure tin (232 °C).

Lead-free soldering

Changing over to lead-free soldering presents the fewest problems with hand soldering. Lead-free wire solder made from Sn/Ag/Cu or Sn/Cu alloys is also suitable for touch-up soldering and repairing conventional tin/lead solder joints. The somewhat higher melting temperature (217 °C) of the eutectic Sn/Ag/Cu alloy, which is most commonly used, is hardly noticeable in practice. What is noticeable is that the solder joint is not shiny after it cools off, but immediately turns a dull grey. No matter

how nicely you make your solder joints, they always look like 'cold' joints.

More serious problems occur in switching over to lead-free tin/copper or tin/silver alloys for wave soldering. In this case, any sort of contamination of the solder bath by lead must be very carefully avoided. Otherwise there will be problems with the durability of the solder joints. With tin/silver alloys, the composition of the alloy changes over time, due to copper enrichment from the circuit board tracks. An additional problem relates to the wetting characteristics, which are better with tin/silver alloys than with tin/copper alloys. The temperature of the solder bath, at 260 °C, is only around 10 °C higher than that of a conventional tin/lead bath.

In the case of reflow soldering (for boards fitted with SMD components), the higher temperature is a more critical problem, since the circuit boards remain in the hot area for a longer time. However, the use of lead-free alloys does not increase the marginal cost as strongly, since the cost of the solder alloy is a relatively small part of the overall cost of manufacturing soldering powders and pastes. The lower melting point and better wetting characteristics of the Sn/Ag/Cu alloy, as compared to other alloys, are also advantages for reflow soldering.

Summary

Changing over to lead-free solder is without doubt ecologically worthwhile, and it is in principle possible. The fewest problems occur with hand soldering, since the only thing that changes is that lead-free wire solder is more expensive.

For industrial fabrication of electronic equipment, changing over to lead-free solder involves not only a higher materials cost, but also modifications to the soldering process when the new alloy is introduced. These can be time-consuming and expensive. The main areas of concern are temperature and contamination problems, as well as the wetting characteristics of the alloy.

(000057-1)

Text (German original): Ernst Krempelsauer

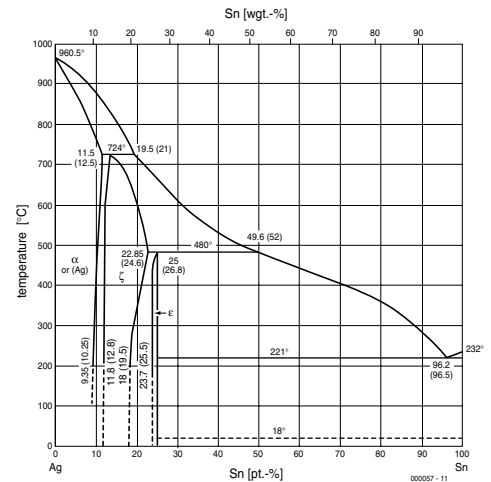


Figure 1. Melting point diagram of a tin/silver alloy.

Suppliers:

Most mail-order distributors, such as Conrad, Farnell, RS Components, Maplin and so on, already offer lead-free solders. In the UK, Multicore is the best known brand.

Internet addresses:

- www.alphametals.com/products/leadfree.html
- www.lead-free.org
- www.solderworld.com
- www.multicore.com



Figure 2. A few samples: the large rolls hold wire solder made from the eutectic tin/silver/copper alloy Sn95.5Ag3.8Cu0.7. They differ only in the flux content (3.5% for normal use and 1% for SMD soldering). The smaller rolls hold wire solder made from tin/silver (Sn95Ag5) and tin/copper (Sn99Cu1) alloys. The smallest roll is once again a tin/silver/copper alloy.

PC-hosted test equipments

Oscilloscope, generator and frequency counter

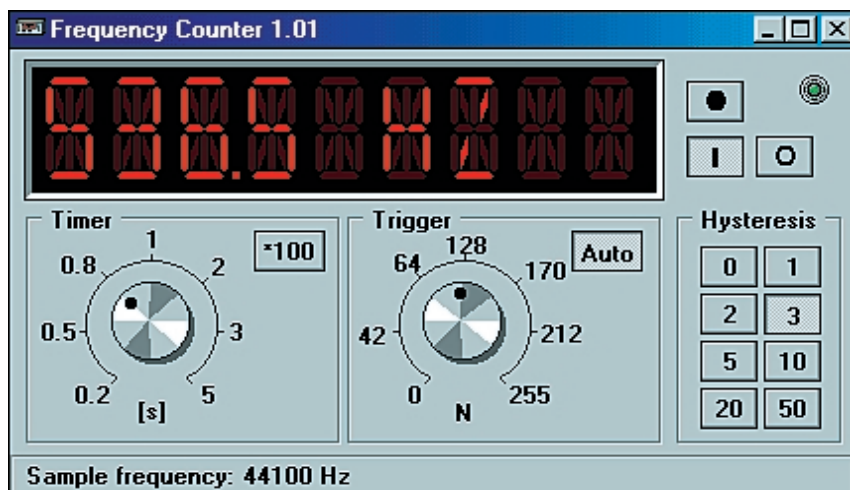
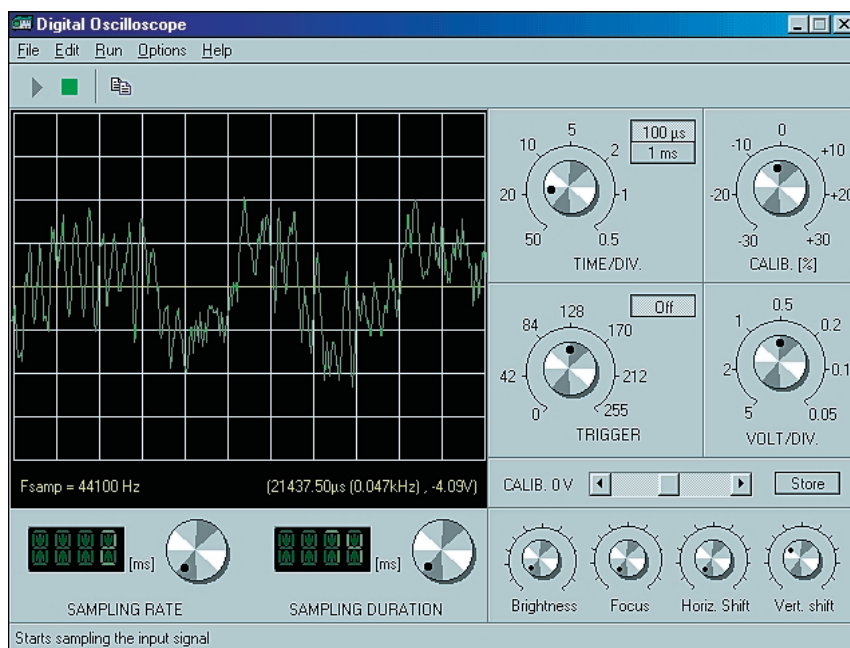
If you are occasionally involved in electronics, you'll know that for most experiments and repairs you won't get very far without the required test equipment. Luckily, a portion of the equipment doesn't have to be physically present any longer, since that task can be taken over by a computer.

A technician carrying out a practical experiment as part of his job or hobby always requires a number of test instruments to observe the effects of any adjustments. You soon build up a pile of equipment, like a function generator, power supply, multimeter and oscilloscope. It is not worth the effort and expense to acquire all those expensive instruments if they are only to be used occasionally. With the aid of the correct software, any PC with a soundcard can take over many of the tasks of the instruments just mentioned, as long as it involves fairly low frequency signals (up to about 20kHz). Extra hardware is absolutely not required.

There are a number of companies that produce software that can be used for measurements and reproduction of signals via the sound card. What we propose has the benefit of zero expenditure and excellent results.

The Dutchman Marcel Veldhuijzen wrote a few years ago a number of programs for measurement with a PC, an oscilloscope (Scope), a signal generator (Sinewave) and a frequency counter (Counter), that can be downloaded free of charge from the Internet. We are talking here about real 'freeware', fully functional programs without any restrictions.

After running the **Scope** program, you are confronted with the fascia of an oscilloscope on your monitor screen, complete with all the dials and switches. Because the hardware on the soundcard is used, the sampling frequency is limited to 44 or 48 kHz. But for the most elementary measurements this is more than enough. The user can 'turn' the knobs with the aid of the mouse pointer. Besides the regular adjustments like sensitivity, frequency and trigger level, there are also knobs for



focus and brightness. They aren't really necessary, but it creates the impression of a real test equipment. The sampled signal can be fixed and copied to the clipboard, with or without raster. There are separate adjustments for the sampling time and duration.

The **frequency meter** is especially simple to set up. There are only two dials present for selection of measuring time (timer) and trigger level. There are a further eight push-buttons to set up the hysteresis. Even here we see another trick: there is a knob to stop the measurement. If you do that, the brightness of the 'display' is reduced. The highest measurable frequency is decided by the maximum sampling frequency of the sound card.

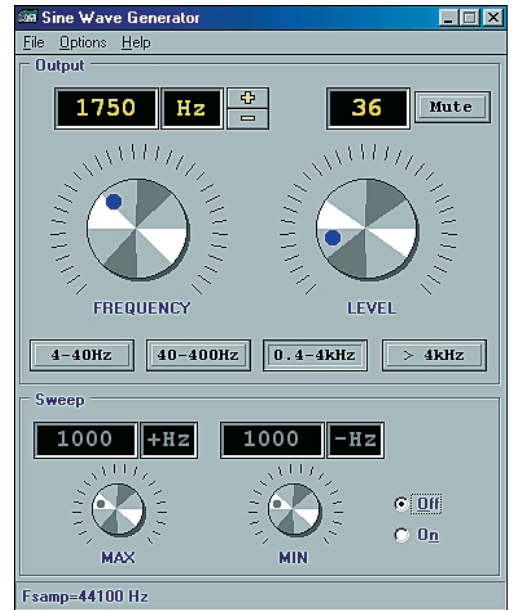
The signal generator, **Sinewave**, has also acquired the 'look and feel' of a real measuring equipment. Here the operator can set up the frequency range with the aid of four pushbuttons, after which the exact

output frequency can be set with a rotary dial or two pushbuttons. A separate knob is available for adjusting the output level, supported by a mute switch. A separate sweep section makes it possible to produce a sweep with the generator, and two rotary knobs allow for the selection of the top and bottom frequency swing with respect to the centre frequency. The nicety of such a PC-hosted signal generator is the accuracy with which the frequencies are reproduced. If for instance you select 488 Hz on the display, you also get a true output at this frequency. Try that with the dial on a real generator...

The three instruments are highly recommended to any technician with a PC.

The files can be found on the Internet at:

<http://w3.pca.net/~cpclark/SBTESTEQU.html>



They can also be found on the recently released CD-ROM 'Freeware & Shareware 2000' from Elektor.

(000049-1)

text (Dutch original): Harry Baggen

CONSTRUCTION GUIDELINES

Elektor Electronics (Publishing) does not provide **parts and components other than** PCBs, front panel foils and software on diskette or IC (not necessarily for all projects). Components are usually available from a number of retailers – see the adverts in the magazine.

Large and small values of components are indicated by means of one of the following prefixes:

E (exa) = 10 ¹⁸	a (atto) = 10 ⁻¹⁸
P (peta) = 10 ¹⁵	f (femto) = 10 ⁻¹⁵
T (tera) = 10 ¹²	p (pico) = 10 ⁻¹²
G (giga) = 10 ⁹	n (nano) = 10 ⁻⁹
M (mega) = 10 ⁶	μ (micro) = 10 ⁻⁶
k (kilo) = 10 ³	m (milli) = 10 ⁻³
h (hecto) = 10 ²	c (centi) = 10 ⁻²
da (deca) = 10 ¹	d (deci) = 10 ⁻¹

In some circuit diagrams, to avoid confusion, but contrary to IEC and BS recommendations, the value of components is given by substituting the relevant prefix for the decimal point. For example,

$$3k9 = 3.9 \text{ k}\Omega \qquad 4\mu7 = 4.7 \mu\text{F}$$

Unless otherwise indicated, the tolerance of resistors is $\pm 5\%$ and their rating is $\frac{1}{2}$ - $\frac{1}{2}$ watt. The working voltage of capacitors is $\geq 50 \text{ V}$.

In populating a PCB, always start with the smallest passive components, that is, wire bridges, resistors and small capacitors; and then IC sockets, relays, electrolytic and other large capacitors, and connectors. Vulnerable semiconductors and ICs should be done last.

Soldering. Use a 15–30 W soldering iron with a fine tip and tin with a resin core (60/40). Insert the terminals of components in the board, bend them slightly, cut them short, and solder: wait 1–2 seconds for the tin to flow smoothly and remove the iron. Do not overheat, particularly when soldering ICs and semiconductors. Unsoldering is best done with a suction iron or special unsoldering braid.

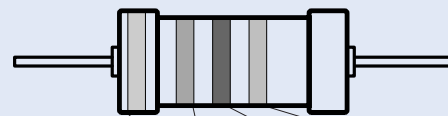
Faultfinding. If the circuit does not work, carefully compare the populated board with the published component layout and parts list. Are all the com-

ponents in the correct position? Has correct polarity been observed? Have the powerlines been reversed? Are all solder joints sound? Have any wire bridges been forgotten?

If voltage levels have been given on the circuit diagram, do those measured on the board match them – note that deviations up to $\pm 10\%$ from the specified values are acceptable.

Possible corrections to published projects are published from time to time in this magazine. Also, the readers letters column often contains useful comments/additions to the published projects.

The value of a resistor is indicated by a **colour code** as follows.



color	1st digit	2nd digit	mult. factor	tolerance
black	–	0	–	–
brown	1	1	$\times 10^1$	$\pm 1\%$
red	2	2	$\times 10^2$	$\pm 2\%$
orange	3	3	$\times 10^3$	–
yellow	4	4	$\times 10^4$	–
green	5	5	$\times 10^5$	$\pm 0.5\%$
blue	6	6	$\times 10^6$	–
violet	7	7	–	–
grey	8	8	–	–
white	9	9	–	–
gold	–	–	$\times 10^{-1}$	$\pm 5\%$
silver	–	–	$\times 10^{-2}$	$\pm 10\%$
none	–	–	–	$\pm 20\%$

Examples:
brown-red-brown-gold = 120 Ω , 5%
yellow-violet-orange-gold = 47 k Ω , 5%

The content of this note is based on information received from manufacturers in the electrical and electronics industries or their representatives and does not imply practical experience by Elektor Electronics or its consultants.

MAX807 watchdog for microcontroller systems

provides operational safeguards

Design by Prof B vom Berg and P Groppe

Microcontrollers are used in ever-increasing numbers, not only in technical and engineering applications, but also in domestic products and motor vehicles. This proliferation makes increased demands on the operational safety of microcontroller systems. After all, their failure may damage or even destroy the equipment they are used in. Even worse, such failure may create a danger to the health or the life of the operator.

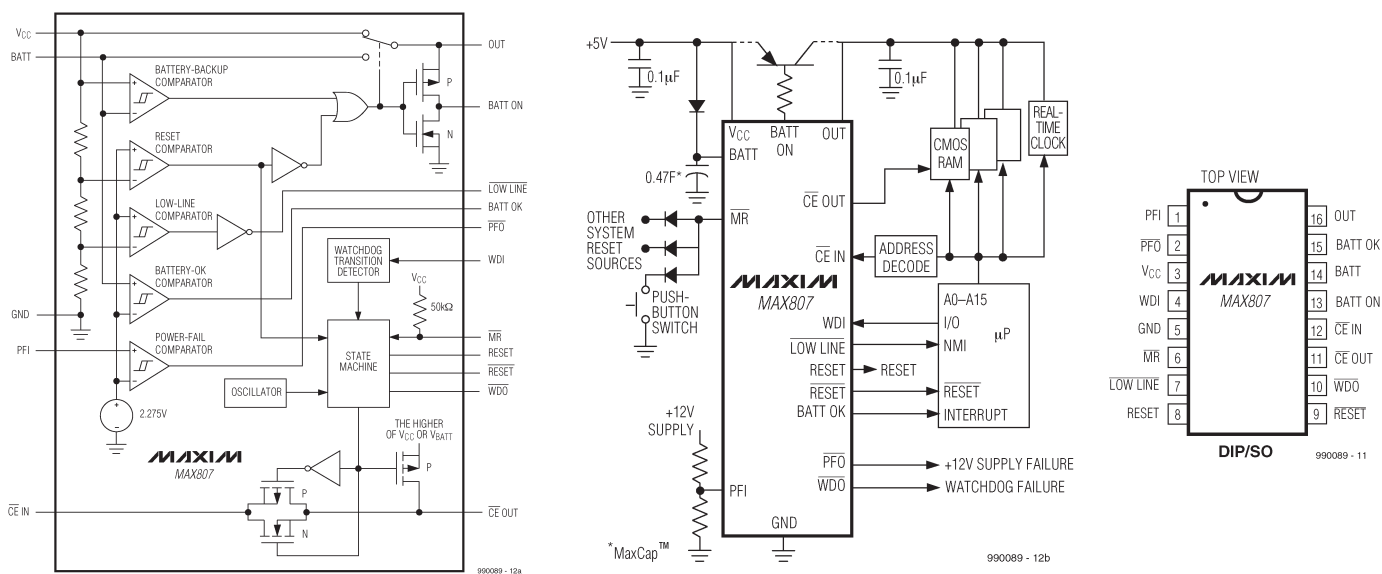


Figure 1. Block diagram, typical operating circuit and pin configuration of the MAX807.

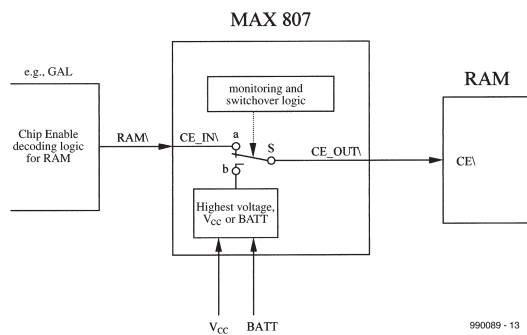


Figure 2. Switching arrangement of the RAM supply.

Two examples serve to illustrate the risks ensuing in an equipment against which the microcontroller must be protected.

Semiconductor producers guarantee error-free operation of their microcontrollers when the supply voltage is $5\text{ V} \pm 10\%$. Overvoltages are readily negated by the use of appropriate regulation of the supply lines. When, however, for whatever reason the supply voltage drops below 4.5 V , the reaction of the microcontroller cannot be foreseen. Relays may open and close at random; data memories may be adversely affected, and so on. It is obvious that in the case of undervoltages the microcontroller must be disabled by a reset for as long as the supply voltage is below par.

It happens frequently that important data are held in RAM that must be saved when the supply voltage fails. To ensure that this happens, it must be impossible for the microcontroller to access the RAM module in the write mode when the supply voltage falls out, and at the same time, the RAM must be powered by a standby buffer battery.

The MAX807 Supervisory Circuit from Maxim provides power-supply monitoring, back-up battery switch-over, and program execution watchdog functions in microprocessor systems—see block diagram in **Figure 1**. Use of BICMOS technology results in 1.5% reset-threshold precision while keeping the supply current typically below $70\ \mu\text{A}$.

The $70\ \mu\text{A}$ supply current makes the device ideal for use in battery-powered applications that require high reset-threshold precision, allowing a wide power-supply operating range, while preventing the system from operating below its specified voltage range. Moreover, a 2 ns chip-enable propagation delay and 250 mA output current capability (20 mA in battery-

backup mode) make it suitable for use in larger, higher-performance equipment.

The MAX807, which comes in 16-pin DIP and SO packages, provides the following functions:

- automatic power-on-reset;
- manual reset input;
- watchdog;
- chip-enable protection when the overall system voltage fails;
- monitoring the system voltage;
- monitoring the supply voltage;
- backup-battery switch-over for RAM, real-time clocks, or other low-power logic.

Automatic power-on-reset

The MAX807 $\overline{\text{RESET}}$ output ensures that the microprocessor powers up in a known state, and prevents code execution errors during power-down and brownout conditions. It accomplishes this by resetting the microprocessor, terminating program execution when V_{CC} dips below the reset threshold or mr is pulled low.

Each time $\overline{\text{RESET}}$ is asserted, it stays low for the 200 ms reset time-out period, which is set by an internal timer to ensure the microprocessor has adequate time to return to an initial state.

Any time V_{CC} goes below the reset threshold before the reset time-out period is completed, the internal timer restarts. The watchdog timer can also initiate a reset if $\overline{\text{WDO}}$ is connected to $\overline{\text{MR}}$.

When V_{CC} drops below the reset threshold of 4.675 V (in the case of the MAX807L), the reset output is pulled to earth, so that the microcontroller connected to it is pulled to the reset state. The controller can then no longer perform random actions at the critical instant when the supply voltage drops below the absolute limit of 4.5 V .

It is only 200 ms after the system voltage is restored to $\geq 4.675\text{ V}$ that the reset

pin is pulled high, whereupon the microcontroller restarts its program execution.

Manual reset

A reset may be generated manually by a push-button operated switch connected between the $\overline{\text{MR}}$ input and ground (GND). When this switch is closed, the reset output is pulled low, whereupon the microcontroller is reset.

Watchdog

The internal watchdog may be used for intelligent monitoring of the correct program execution. It is started by applying a high or low logic level to the wdi (watchdog in) pin. When the level at this pin remains constant (high or low) for longer than 1.6 s , output $\overline{\text{WDO}}$ (watchdog out) changes from high to low and remains so until the level at wdi changes state.

When the $\overline{\text{WDI}}$ pin is linked to a microcontroller output and $\overline{\text{WDO}}$, say, to the mr pin of the MAX807, the microcontroller program must change the level at the wdi input at intervals not exceeding 1.6 s to prevent the wdo pin being pulled to low which results in the microcontroller being reset.

The insertion of regular level-change instructions for $\overline{\text{WDI}}$ into the program ensures that there is no forced reset when the program runs correctly. When the program crashes, for instance, because of an error in an endless loop program and the control instruction for $\overline{\text{WDI}}$ is absent, the microcontroller is forcibly reset and restarts the program execution error-free from the beginning.

The watchdog can be disabled only by leaving $\overline{\text{WDI}}$ open when the supply voltage is being switched on.

Chip enable protection

A critical situation arises in a microcontroller system when the system voltage fails, whether by intentional switching off or by interference. At the instant this happens, the microcontroller may randomly access the RAM and mutilate or even destroy important data. Obviously, this situation must be avoided at all costs.

Similarly, when a system contains a real-time clock (RTC), this should not be affected in any way when the supply voltage fails.

It is clear that the RAM and RTC must be switched instantaneously to a buffer battery when the system voltage fails.

Switching the RAM from the normal supply lines to a buffer battery is not straightforward and will be described with reference to **Figure 2**.

The RAM is enabled for access by the microcontroller by the level at CE IN . When this level is high, the RAM is disabled, irrespective of any other signals from the microcontroller. When the level goes low, the RAM is enabled. The enable signal is provided by the MAX807.

The signal at CE IN that normally enables the

RAM is generated by the \overline{CE} decoder. With the use of the supervisory circuit, however, the RAM is actuated by the signal at the \overline{CE} OUT pin.

Internal monitoring and switching logic in the MAX807 ensure the correct setting of switch S. When the system voltage, V_{CC} , is correct (+5 V), and there is no reset, the switch is in position a. The RAM is then enabled via \overline{CE} OUT and driven as normal by the microcontroller.

When the system voltage fails, or a reset is initiated, the MAX807 senses this immediately – well before the microcontroller can react – and sets switch S to position b. The \overline{CE} OUT pin is then isolated from the RAM; its level is either that of the positive supply voltage, V_{CC} , or of the buffer battery voltage, BATT, whichever is the higher. This arrangement precludes uncontrolled driving of the RAM by the microcontroller, and ensures that the RAM is powered by the battery (although it cannot be accessed).

Only when the system voltage has returned to normal and there is no manual reset initiated, is switch S returned to position a, whereupon the microcontroller can once again access the RAM.

Monitoring the system voltage

It is a frequent requirement in a system that the microcontroller carries out some important tasks before the system voltage breaks down. This presupposes that the controller is made aware of an imminent breakdown. This is effected by a low-line comparator in the MAX807, which monitors the system voltage. When this voltage drops to a level 52 mV above the reset level, that is, below 4.727 V, the comparator pulls the $\overline{LOW_LINE}$ output of the MAX807 from high to low, which, for instance, initiates a non-maskable interrupt (NMI) of the microcontroller.

The microcontroller then instantly abandons its usual program routine and initiates the interrupt service routine to stabilize the system before the system voltage breaks down entirely. An internal switching hysteresis of 13 mV prevents the $\overline{LOW_LINE}$ output from fluttering.

Monitoring the supply voltage

In certain cases, it may be necessary for the microcontroller to be warned of an imminent break-down of the system or supply voltage. This is made possible by the power fail comparator (PFI) in the MAX807. This comparator monitors the overall supply voltage to the microcontroller system, for instance, the 12 V mains adaptor output preceding the +5 V regulator.

When the potential at the PFI input drops below 2.265 V, the level at the \overline{PFO} output is switched from high to low, whereupon the microcontroller initiates an interrupt. This interrupt actuates the program of the early warning stage in the supply failure monitor. In this way, the microcontroller is given more time before the final warning threshold of

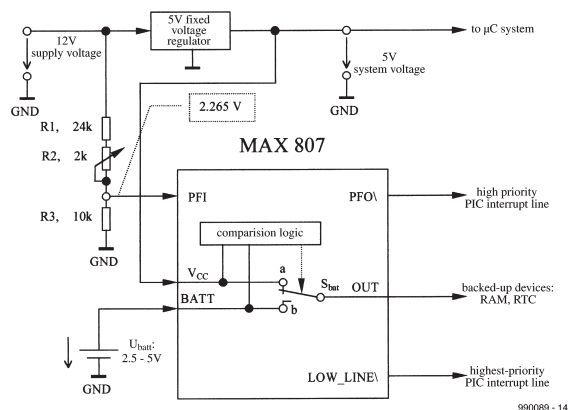


Figure 4. Arrangement of the two-stage monitoring of the supply and system voltages, including the integrated buffer battery.

4.727 V is reached, so that it can initiate a non-maskable interrupt (NMI) at an early stage. As a further safeguard, PFI is internally provided with a 20 mV hysteresis.

When the supply voltage fails, a three-stage warning procedure is initiated.

1. Initial warning (high priority interrupt) when the supply voltage drops to below, say, 8 V.
2. Second warning (non-maskable interrupt – NMI), when the system voltage drops below 4.727 V.
3. A microcontroller reset that disables the whole system when the system voltage drops below 4.675 V.

If this procedure is not needed, the PFI pin must be linked to earth (GND) to ensure that \overline{PFO} is not switched.

Buffer battery management

To ensure that important data in the RAM and, where applicable, the correct action of an RTC are retained, the RAM and RTC must be powered by a buffer battery when the normal supply fails. The instantaneous switch-over from the normal supply to the battery is carried out by the MAX807—see Figure 3.

The battery, preferably a 2.5–5 V lithium type, is connected between BATT and GND. The supply to the RAM and, where applicable, the RTC, is taken from the OUT pin.

The logic circuits in the MAX807 constantly compare the two external voltages, V_{CC} and BATT, and recognize the following situations.

- $V_{CC} > \text{reset threshold}$, or
- $V_{CC} > \text{BATT}$.

In these situations, switch S_{bat} is in position a and V_{CC} is linked to OUT, so that

the RAM and RTC are powered by the normal system voltage.

- $V_{CC} < \text{reset threshold}$, and
- $V_{CC} < \text{BATT}$.

In these situations, switch S_{bat} is in position b, so that the battery voltage is linked to OUT, that is, the RAM and RTC are powered by the battery.

The maximum current drawn from the battery should not exceed 20 mA, which is more than adequate for all current RAMs and RTCs.

During battery operation, the level at \overline{CE} OUT is high (provided the battery voltage > 2 V) so that the RAM cannot be accessed by any external signal or combination of signals.

If battery operation is not needed, the BATT pin must be strapped to GND and the V_{CC} pin to OUT.

Finally

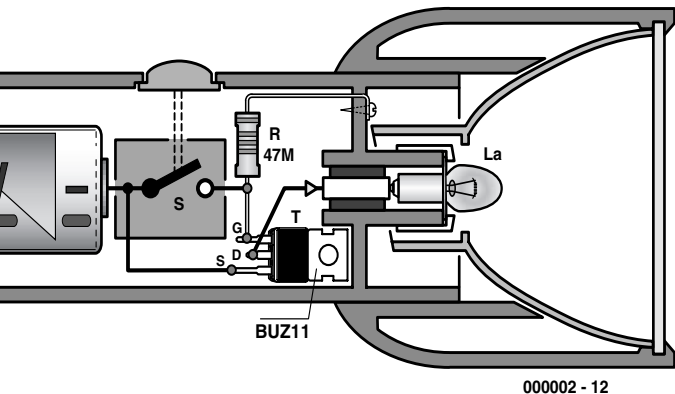
The level at the BATT ON pin indicates which voltage source supplies the OUT pin: when it is high, the buffer battery, and when it is low, V_{CC} . It is therefore possible to connect some kind of indicator to this pin to display which source is being used.

The level at the BATT OK output indicates whether the battery voltage is normal, in which case it is high. When the level is low, that is, when the battery voltage < 2.265 V, it is high time to replace the battery by a fresh one.

[990089]

See also the MSAX807 data sheet, which may be downloaded from: <http://www.maxim.ic.com>

Soft start for torch



Increases the life of torch bulbs

Design by K. Viernickel

The halogen or krypton bulbs in modern torches (USA and Canada: flashlights) have a limited life and are not particularly cheap. A simple modification in the torch lengthens the life appreciably.

It is a fact of nature that any incandescent bulb has a finite life. However, the bulbs in modern torches (US and Canada: flashlight) have a less-than-average life. The reason for this is that the halogen or krypton bulbs used are operated at overvoltage to give as bright a light as feasible.

The life of these bulbs may be extended simply by connecting a resistor in series with the bulb. For instance, when the battery voltage is 6 V and the bulb is a 500 mA type, a series resistor of 1 Ω will reduce the voltage across the bulb by about 0.5 V. This will certainly lengthen the life of the bulb, but it will also cause a reduction in the available brightness. Also, energy is wasted in the resistor (evinced by heat production). Clearly, this is not a very good solution to the problem. A better one is shunting the bulb with a transistor in series with a resistor.

Mosfet

Another well-known fact is that incandescent bulbs normally burn out when they are being switched on. This is because the resistance of the cold filament is significantly lower than that during normal operation. This results in a switch-on current that is much higher than the normal operating current. Clearly, much is to be gained by damping the switch-on current.

The switch-on current may be limited by a simple circuit that is small enough to allow it to be built into most types of torch. As the diagram shows, such a circuit consists of nothing more than a metal-on-silicon-field-effect-transistor, or MOSFET, and a resistor. The transistor may be almost any current n-channel type that can handle the requisite power. The popular BUZ11 or BUZ10 is eminently suitable for the present application.

The requisite limiting of the start-up current is provided by the internal gate capacitance of the

transistor in conjunction with the large gate resistor. If needed, a small capacitor may be added between gate and drain.

Once the transistor is conducting hard, the remaining losses are negligible. This is true also when the torch is switched off: the quiescent current flowing through the transistor is much smaller than that caused by the self-discharge of the batteries.

Finally

Since it is much simpler to break into the positive supply line of a torch than into the negative line, the addition of the limiting circuit makes it necessary for the batteries to be inserted into the torch the other way around from normal (as indicated by the manufacturer). Also, the

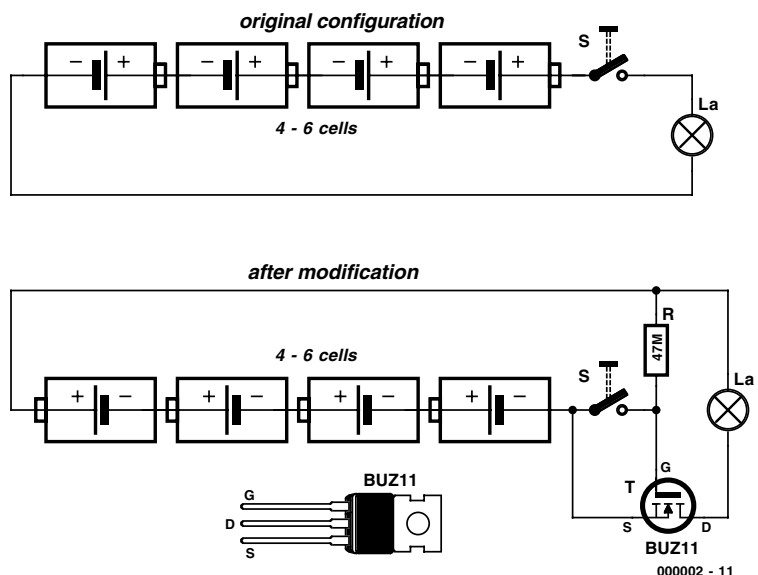
on/off switch of a modified torch works the other way around from normal.

Fitting the modification in some of the popular Mag-Lite torches is fairly straightforward. After the rubber cover of the on/off switch has been removed, the entire push-button switch mechanism may be removed by releasing a central hexagonal bolt. The switch terminals may serve as soldering supports for the transistor-resistor series network.

If it proves impossible to obtain a 47 MΩ resistor, four or five surface-mount-technology (SMT) resistors of 10 MΩ may be linked in series. Such a link works just as well and is almost as small as a normal 47 MΩ resistor.

[000002-1]

Text (Dutch original): S. van Rooij



DAC 3550A

Integrated Circuits
Special Functions - Digital Audio

ELEKTOR ELECTRONICS

DATASHEET 5/2000

Standard Mode

– without I²C

In standard mode, sample rates from 48 kHz to 32 kHz are handled without I²C control automatically. The setting for this range is the default setting.

– with I²C

Sample rates below 32 kHz require an I²C control to set the PLL divider. This ensures that even at low sample rates, the DAC 3550A runs at a high clock rate. This avoids audible effects due to the noise-shaping technique of the DAC 3550A. Sample rate range is continuous from 8 to 50 kHz. The I²C setting of low sample rates must follow.

An additional mode allows automatic sample rate detection. In this case, the clock oscillator is required and must run at frequencies between 13.3 MHz to 17 MHz. This mode, however, does not support continuous sample rates. Only the following sample rates are allowed: 8 kHz, 11.025 kHz, 12 kHz, 16 kHz, 22.05 kHz, 24 kHz, 32 kHz, 44.1 kHz, 48 kHz.

The sample rate detection allows a tolerance of ± 200 ppm at WSI.

If the oscillator is not used for automatic sample rate

detection, it can be used as a general-purpose clock for the application. The frequency range in this case is 10 MHz to 25 MHz.

MPEG Mode

This mode should be used in conjunction with MAS 3507D in MPEG player applications. In this case a 14.725 MHz signal is needed to provide a clock for the MAS 3507D and to allow an automatic sample rate detection in the DAC 3550A. All MPEG sample rates from 8 to 48 kHz can be detected. The internal processing and the DAC itself are automatically adjusted to keep constant performance throughout the entire range. I²C control for sample rate adjustment is not needed in this case. Register SR_REG[0:2] is locked to SRC_A.

The MPEG sample rates: 8 kHz, 11.025 kHz, 12 kHz, 16 kHz, 22.05 kHz, 24 kHz, 32 kHz, 44.1 kHz, 48 kHz.

As in standard mode, the sample rate detection allows a tolerance of ± 200 ppm at WSI.

Subaddressing is not possible in MPEG mode; this means, in multi-DAC systems, only one DAC 3550A can run in MPEG mode.

Recommended Operating Conditions

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit
Temperature Ranges and Supply Voltages						
T _A	Ambient Temperature range ¹⁾		0		70	°C
V _{SUPA} I	Analog Audio Supply Voltage	AVDD0/I	3.0 ²⁾	3.3	5.5	V
V _{SUPD}	Digital Audio Supply Voltage	VDD	2.7	3.3	5.5	V
Relative Supply Voltages						
V _{SUPA}	Analog Audio Supply Voltage in relation to the Digital Supply Voltage	AVDD0/I	V _{SUPD} -0.25 V		5.5 V	V
Analog Reference						
C _{AGNDC1}	Analog Reference Capacitor	AGNDC	1.0	3.3		μF
C _{AGNDC2}	Analog Reference Capacitor	AGNDC		10		nF
Analog Audio Inputs						
V _{AI}	Analog Input Voltage AC, SEL_53V = 0	AUXnL/R ³⁾		0.35	0.7	V _{rms}
V _{AI}	Analog Input Voltage AC, SEL_53V = 0	AUXnL/R ³⁾		0.525	1.05	V _{rms}

DAC 3550A

Integrated Circuits
Special Functions - Digital Audio

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DATASHEET 5/2000

DAC3550A
Stereo Audio DAC

Manufacturer

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Hans-Bunte-Strasse 19,
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Internet: http://www.intermetall.de



Example Application

MP3 Player, Elektor Electronics July/August 2000.

Description

The DAC 3550A is a single-chip, high-precision, dual digital-to-analog converter designed for audio applications. The employed conversion technique is based on oversampling with noise-shaping. With MICRONAS INTERMETALL's unique multibit sigma-delta technique, less sensitivity to clock jitter, high linearity, and a superior S/N ratio has been achieved. The DAC 3550A is controlled via I²C bus. Digital audio input data is received by a versatile I²S interface. The analog back-end consists of internal analog filters and op amps for cost-effective additional external sound processing. The DAC 3550A provides

line-out, headphone/speaker amplifiers, and volume control. Moreover, mixing additional analog audio sources to the D/A-converted signal is supported. The DAC 3550A is designed for all kinds of applications in the audio and multimedia field, such as: MPEG players, CD players, DVD players, CD-ROM players, etc. The DAC 3550A ideally complements the MPEG 1/2 layer 2/3 audio decoder MAS 3507D. **No crystal required for standard applications with sample rates from 32 to 48 kHz.** Crystal required only for automatic sample rate detection below 32 kHz, MPEG mode, and use of clock output CLKOUT.

Main Features

- no master main input clock required
- integrated stereo headphone amplifier and mono speaker amplifier
- SNR of 103dBa
- I²C bus, I²S bus
- internal clock oscillator
- full-feature mode by I²C control (three selectable subaddresses)
- reduced feature mode for non-I²C applications
- continuous sample rates from 8 kHz to 50 kHz
- analog de-emphasis for 44.1 kHz
- analog volume and balance: +18 to -75 dB and mute
- oversampling and multibit noise-shaping technique
- THD better than 0.01 %
- two additional analog stereo inputs (AUX) with source selection and mixing
- supply range: 2.7 V to 5.5 V
- low-power mode
- additional line-out
- on-chip op amps for cost-effective external analog sound processing

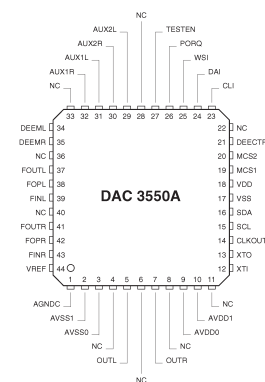
Pin Descriptions

I. Power Supply Pins

The DAC 3550A combines various analog and digital functions which may be used in different modes. For optimized performance, major parts have their own power supply pins. All VSS power supply pins must be connected.

VDD (18), VSS (17)

The VDD and VSS power supply pair are connected internally



44-pin PMQFP package.

DAC 3550A

Integrated Circuits
Special Functions - Digital Audio



DATASHEET 5/2000

with all digital parts of the DAC 3550A.

AVDD0 (9), AVSS0 (3)

AVDD0 and AVSS0 are separate power supply pins that are exclusively used for the on-chip headphone/loudspeaker amplifiers.

AVDD1 (10), AVSS1 (2)

The AVDD1 and AVSS1 pins supply the analog audio processing parts, except for the headphone/loud-speaker amplifiers.

2. Analog Audio Pins

AGNDC (1)

Reference for analog audio signals. This pin is used as reference for the internal op amps. This pin must be blocked against VREF with a 3.3 μ F capacitor.

Note: The pin has a typical DC-level of 1.5/2.25 V. It can be used as reference input for external op amps when no current load is applied.

VREF (44)

Reference ground for the internal band-gap and biasing circuits. This pin should be connected to a clean ground potential. Any external distortions on this pin will affect the analog performance of the DAC 3550A.

AUX1L (31), AUX1R (32), AUX2L (29), AUX2R (30)

The AUX pins provide two analog stereo inputs. Auxiliary input signals, e.g. the output of a conventional receiver circuit or the output of a tape recorder can be connected with these inputs. The input signals have to be connected by capacitive coupling.

FOUTL (37), FOPL (38), FINL (39), FOUTR (41), FOPR (42), FINR (43)

Filter op amps are provided in the analog baseband signal paths. These inverting op amps are freely accessible for external use by these pins.

The FOUTL/R pins are connected with the buffered output of the internal switch matrix. The FOPL/R-pins are directly connected with the inverting inputs of the filter op amps. The FINL/R pins are connected with the outputs of the op amps.

The driving capability of the FOUTL/R pins is not sufficient for standard line output signals. Only the FINL/R pins are suitable for line output.

OUTL (5), OUTR (7)

The OUTL/R pins are connected to the internal output amplifiers. They can be used for either stereo head-phones or a mono loudspeaker. The signal of the right channel amplifier can be inverted for mono loud-speaker operation.

Caution: A short circuit at these pins for more than a momentary period may result in destruction of the internal circuits.

3. Oscillator and Clock Pins

XTI (12), XTO (13)

The XTI pin is connected to the input of the internal crystal oscillator, the XTO pin to its output. Both pins should be directly connected to the crystal and two ground-connected capacitors.

CLKOUT (14)

The CLKOUT pin provides a buffered output of the crystal oscillator.

Caution: Power dissipation limit may be exceeded in case of short to VSS or VDD.

CLI (23), DAI (24), WSI (25)

These three pins are inputs for the digital audio data DAI, frame indication signal WSI, and bit clock CLI. The digital audio data is transmitted in an I²S-compatible format. Audio word lengths of 16 and 32 bits are supported, as well as SONY and Philips I²S protocol.

SCL (15), SDA (16)

SCL (serial clock) and SDA (serial data) provide the connection to the serial control interface (I²C).

4. Other Pins

TESTEN (27)

Test enable. This pin is for test purposes only and must always be connected to VSS.

PORQ (26)

This pin may be used to reset the chip. If not used, this pin must be connected to VDD.

DEEML (34), DEEMR (35)

These pins connect an external analog de-emphasis network to the signal path in the analog back-end. This connection can be switched on and off by an internal switch which is controlled either by I²C or the DEECTRL pin.

DEECTRL (21)

If no I²C control is used, de-emphasis can be switched on and off with this pin.

MCS1 (19), MCS2 (20)

Mode select pins to select MPEG, Standard Mode, and I²C subaddress.

Operation Modes

MCS1	MCS2	Mode	Sub-address	Default Sample Rate
0	0	Standard	ADR0	32-48 kHz
0	1	Standard	ADR1	32-48 kHz
1	0	Standard	ADR2	32-48 kHz
1	1	MPEG	ADR3	Automatic

DAC 3550A

Integrated Circuits
Special Functions - Digital Audio



DATASHEET 5/2000

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit
Analog Filter Input and Output						
Z _{AFLO}	Analog Filter Load Output ⁴⁾	FOUTL/R	7.5		6.0	k Ω pF
Z _{AFLI}	Analog Filter Load Input ⁴⁾	FINL/R	5.0		7.5	k Ω pF
Analog Audio Output						
Z _{LO}	Audio Line Output ⁵⁾ (680 Ω series resistor required)	FINL/R	10		1.0	k Ω nF
Z _{AOL_HP}	Analog Output Load HP (47 Ω series resistor required)	OUTL/R		32	400	Ω pF
Z _{AOL_SP}	Analog Output Load SP (bridged) Analog Output Load SP (stereo)	OUTL/R		32		Ω
				50		pF
				16		Ω
			100			pF
I²C Input						
f _{I2C1}	I ² C Clock Frequency, I ² S active	SCL		400		kHz
f _{I2C2}	I ² C Clock Frequency, I ² S inactive			100		kHz
Digital Inputs						
V _{IH}	Input High Voltage	CLI, WSI, DAI, PORQ, SCL, SDA	0.5 \times DD			V
V _{IL}	Input Low Voltage				0.2 \times DD	V
Quartz Characteristics						
F _p	Load Resonance frequency at C _l = 20pF		13.3	14.725	17	MHz
R _{EQ}	Equivalent Series Resistance			12	30	Ω
C ₀	Shunt (parallel) Capacitance			3	5	pF
Load at CLKOUT Output						
C _{load}	Capacitance	CLKOUT	0		50	pF

1) =standard temperature range, DAC 3550A tested in extended temperature range on request

2) typically operable down to 2.7 V, without loss in performance

3) n = 1 or 2

4) Please refer to Section 4.2. "Recommended Low-Pass Filters for Analog Outputs" on page 25 of Micronas datasheets.

5) Please refer to Section 4.1. "Line Output Details" on page 25 of Micronas datasheets.

Working with SMDs

It's just a matter of practice

By K. Walraven

Although surface-mounted devices (SMDs) have been a fact of life for a while already, even in DIY electronics, many hobbyists are still reluctant to use them. A few good tips and a bit of practice should help overcome any initial inhibitions.



SMDs, with their minuscule dimensions and absence of pins, are still not particularly popular with DIY constructors. It must be admitted that they are considerably more difficult to work with than conventional components. On the other hand, they have the unique advantage that they allow extremely compact circuits to be built. And as for soldering SMDs — let's just say that it's like a lot of other things: once you've done it a few times, you'll find that it's not all that bad. Try practising with a few spare components after you have read this article. You will see that it's not as difficult as you first thought.

Tools

What do you need? A small soldering course, or one that you have adapted for the purpose with a piece of copper wire, as shown in **Figure 1**. In addition, you will need a small tweezers, fine wire solder with a resin

core and possibly solder paste — and naturally you should not overlook desoldering braid (see the article in the April issue). A steady hand, good light and good eyes are also just as indispensable. If necessary, you can help your eyes with a loupe or an inexpensive pair of reading glasses. A magnifying light can also be quite handy.

The circuit board

In commercial production, soldering paste is applied to the solder pads, and a bit of glue is often applied to the space between the pads. A machine then places the SMD components, which are held in place by the soldering paste and the glue. The entire circuit board is next pre-warmed and then passed through an

oven for a few seconds for soldering. The solder particles in the paste melt and join the contact surfaces of the components to the copper of the circuit board tracks. Capillary attraction causes the solder to nicely fill all the little gaps. The solder pads on the board are usually just about as large as the contact surfaces of the corresponding components (see **Figure 2**). This helps to hold the components properly in place, even when no glue is used.

However, for hand soldering it's better to have the pads somewhat larger, in order to provide a place to touch the tip of the soldering iron (see **Figure 3**). This is why the solder pads on the circuit boards for Elektor projects are intentionally made larger than usual, to the extent that this is possible.

Soldering

Components with only a few contacts, such as resistors, capacitors and transistors, are the easiest to solder. Work as follows:

- First tin the solder pads — not too much, but also not too little.
- Grasp the component with the tweezers and hold it in the proper position on the circuit board.
- Heat one of the connections with the soldering iron until the solder melts and flows. It does not matter if the joint is not pretty, since that can be fixed later on. All that is intended is to secure the component.
- Check that the component is properly positioned.
- Take the soldering iron in one hand a length of solder in the other hand, and then solder the other contact(s) of the component.
- If the first joint is not good, remove as much solder as possible with the desoldering braid, and then resolder the joint.

It's even easier to work with SMDs if you use solder paste. This is not limited to industrial use, since you can also obtain it in a sort of syringe dispenser for personal use (see the photo of the tools). This is actually solder in the form of a viscous paste, which has the advantage that it tends to hold the components in place. If you use solder paste, work as follows:

- Tin the pads with as little solder as possible (remove any extra solder using desoldering braid), and then apply solder paste to each of the pads.

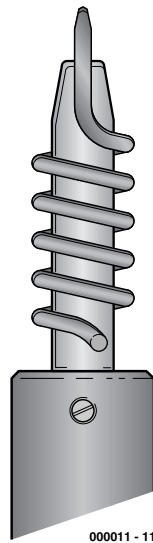


Figure 1. A soldering iron tip adapted for working with SMD components. First wind a few turns of copper wire (1.5 mm or 2.5 mm diameter) around the tip, then heat the iron and solder the wire to the tip. This optimises the heat transfer. You can now solder with the fine tip of the wire.

- Grasp the component with the tweezers and hold it in the proper position.
- Heat one of the leads with the soldering iron until the solder paste melts and flows.
- Check that the component is properly positioned.
- Solder the remaining lead(s) of the component.
- If there is too much solder on any joint, remove the extra solder using desoldering braid. If there is too little solder, touch up the joint using a bit of fresh solder.

Since only a very small mass has to be soldered, it is in practice best to apply the soldering iron and the solder to the surface of the SMD contact to be soldered at nearly the same time. It is not a good idea to first warm up the joint a bit before applying the solder. In fact, the reverse order gives very good results: place the end of the solder against the

component and then press the tip of the soldering iron against the solder so that it melts and flows underneath the component. The advantage of this technique is that less flux is lost, which means that the solder wets the surfaces optimally.

Working with ICs

It takes a bit more skill to solder integrated circuits in SMD packages, simply because they have a lot of leads. The leads are frequently placed with a pitch of 1/20 or 1/30 inch, which means that they are very close together. However, in principle you go about soldering an IC in the same way as a component with only two or three leads. Work as follows:

- Carefully tin all the solder pads, and make sure that none of them are shorted together by solder bridges.
- Place the component in position, either by hand or with tweezers.
- Solder two leads on opposite sides of the IC.
- Check that the IC is properly positioned.
- Now solder all the other leads. With very closely spaced leads, it is inevitable that several leads will be connected together by solder bridges (see **Figure 4**), but you can take care of this later. Stop soldering for a little while every so often, to avoid overheating the IC.
- Remove the excess solder from between the leads using desoldering braid. Here again, stop occasionally for a short time to avoid overheating the IC.
- Carefully inspect your work. If necessary,

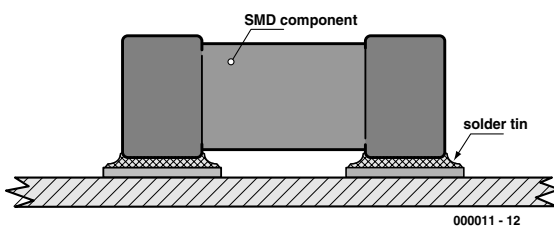


Figure 2. With industrial soldering, the gaps between the contact surfaces of the components and the solder pads are nicely filled with solder.

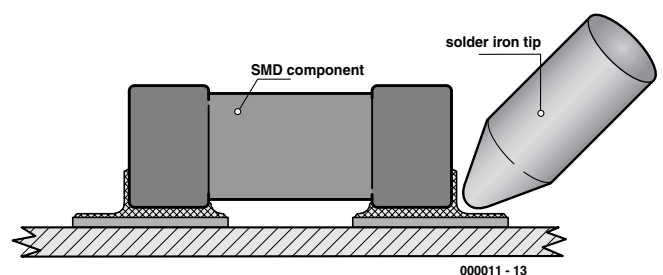


Figure 3. On Elektor circuit boards, the solder pads for SMD components are usually made a bit larger than normal in order to provide a touch surface for the soldering tip.

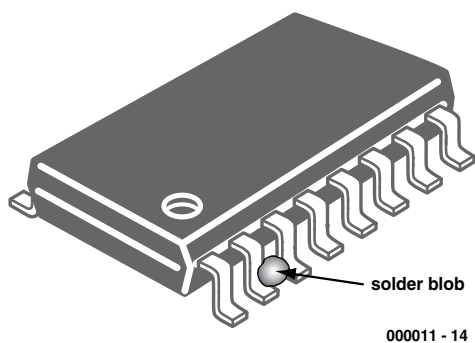
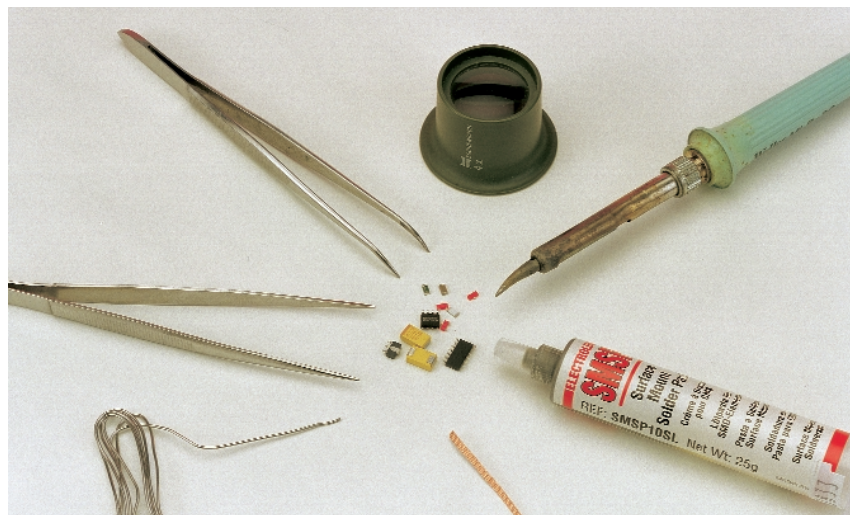


Figure 4. When you solder an IC, it's not uncommon for a solder blob to remain between the leads.

use an ohmmeter to check for unintentional shorts between the leads.

Desoldering

Whenever you have to remove a (possibly defective) SMD IC from a circuit board, the simplest method is usually to cut through each of its leads and then desolder the remaining bits of lead wire one at a time. The IC is of course useless after this, but it is by



far the fastest method. You cannot use this technique with resistors and capacitors, since they do not have leads. You may also not wish to destroy the resistor or capacitor. Here you can try the following:

- Remove as much solder as possible using desoldering braid.
- Push a thin piece of wire underneath the component (0.1 to 0.2-

mm enamelled copper wire).

- Heat one of the joints and pull the wire out sideways, through the joint.
- With an IC, you can pull the wire out through the joints of several leads at a time.

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