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# ELEKTOR ELECTRONICS

THE INTERNATIONAL  
ELECTRONICS MAGAZINE

Focus on:  
The World of  
Radio & TV Amateurs

## FUNCTION GENERATOR

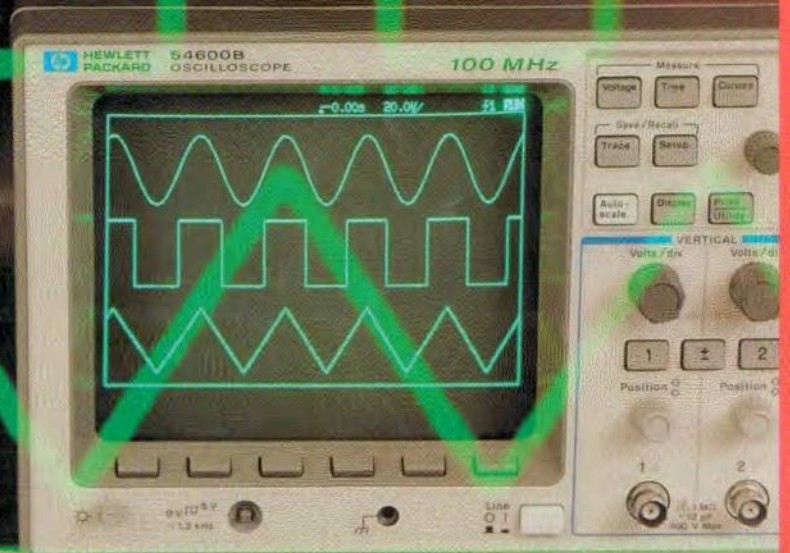
Current-sense  
amplifier

DC-DC converter

Internet: what is it?

Insulated Gate  
Bipolar  
Transistors  
(IGBTs)

Electronic  
sandglass



AUDIO & HI-FI • COMPUTERS & MICROPROCESSORS • DESIGN IDEAS • RADIO, TELEVISION & COMMUNICATIONS • SCIENCE & TECHNOLOGY • TEST & MEASUREMENT



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plus

- 50+ small construction projects

plus

- Marconi – The father of radio
- Differential voltage measurement
- Fast charger for NiCd batteries
- Simple RF signal generator
- Active mini subwoofer
- Fault-tolerant CMOS multiplexers
- and others for your continued interest.

### Front cover

The waveform generator described on pp. 30–36 is based on a MAX038 chip. The IC is an integrated, high-frequency, precision function generator whose output frequency can be controlled over a frequency range of 0.1 Hz to 20 MHz by an internal 2.5 V bandgap voltage reference and an external resistor and capacitor. Its duty factor can be varied over a wide range by applying a 2.3 V control signal, facilitating pulse-width modulation and the generation of sawtooth waveforms.

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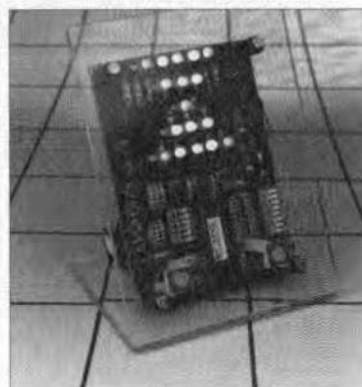
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# From the World of Electronics

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## YOUNG ELECTRONIC DESIGNERS SHOW THEIR PACES AT THE SCIENCE MUSEUM

Highly creative uses of electronics were on show in London's Science Museum in April when the finals of the annual Young Electronic Designer Awards (YEDA) competition took place.

Twenty finalists, whose ages ranged from 14 to 25, were showing their electronic innovations, which ranged from a drive alert to keep drowsy drivers awake to an electronic gadget to check the degree of Raynaud's disease\*.

The annual competition, which began in 1985, is open to students in full-time education at universities, colleges and secondary schools.

YEDA's aim is to encourage students to blend electronics know-how with business skills and so design products that stand a real chance of commercial success. Business realism is emphasized because YEDA trustees firmly believe that an understanding of true commercial demands is an essential preparation for any career.

Co-sponsored this year by Texas Instruments and Mercury Communications, the YEDA competition once again attracted high-quality entries.

Seventeen year old Martin Johnstone of Kingussie High School in Highland won the Texas Instruments Prize of £ 2,500 for the most commercially viable project with his 'MJ Switch', which is a device for indicating the turning and braking of a vehicle while carrying bicycles at the rear. Martin told *Elektor Electronics*: "I was driving with my dad one day on a tourist road when we noticed how many of them did not have a correct method of signalling as the cycles they were carrying at the rear of their vehicles were obscuring their vehicles' rear lights".

Martin, who is taking Higher Craft Design in Scotland, began thinking of how to solve this problem electronically and designed the 'MJ Switch', which comprises four light-dependent resistors (LDRs) and an electronic circuit. The device is plugged into the cigar lighter of the car, while the four LDR sensors are located at the vehicle's rear lights, brake lights and

turning indicators.

Sharing the Mercury Planet awards of £ 2,500 for the most socially or environmentally aware project were 16-year-old Sarah Preson from Blyth Ridley High School in Blyth, Northumberland, for her 'Poor Circulation Monitor - PCM', and 17-year-old Steven Mather from Cheltenham College, one of the oldest public schools in the UK, for his 'Asepsimeter' - an improved digital peak expiratory-flow meter. Both successful finalists developed their devices to deal with the ailments they suffer from - Sarah from Raynaud's disease and Steven from asthma.

In addition, the overall winner in each age group received a Texas Instruments TravelMate notebook computer for their school or college, a cash awards, and a YEDA trophy, sculpted by Sir David Hughes, using solid bronze and silver.

In the senior category (18-25), Martin Foley (22) of Brunel University in Egham won a prize of £ 1,000 for his 'Freeboard' - a multi-access computer keyboard emulator for disabled PC users. Christopher Kirkham (24), also from Brunel, won the second prize of £ 500 for his 'Nautilus', a sailboat racing starting aid for race officials. Alison Chappell (24), again from Brunel, won the third prize of £ 250 for her card-operated street condom vending machine.

In the intermediate category (15-17), Steven Maher (17) from Cheltenham College took the first prize of £ 750 for his 'Asepsimeter'. David Wilson (16) of Merchiston Castle School, Edinburgh, won the second prize of £ 400 for his RAPP (remotely activating power points) device. The third prize of £ 200 was shared by Mark Edgerton (16) of Colston's College, Bristol, with his 'Peak Charge', a new design of NiCd Battery Charger, and Timothy Munn (16) of Sandown High School, Sandown, Isle of Wight, with his foghorn operation system for small boats.

In the junior category (under 15), Lars Blackmore (14) of Sevenoaks School, Sevenoaks, Kent, won the first prize of £ 500 for his low-cost reversing indicator for cars using ultrasound. The second prize of £ 250 went to Ross Adams (14) of Coleraine Boys' School, Coleraine, Northern Ireland, for a device that deters able-bodied drivers from parking in spaces allocated to disabled drivers. Third prize of £ 150 went to Colin Miskelly (14) of St. Mac Nissis College, Carnlough, Northern Ireland, for 'Velerouse', an electronic board game based

on house building.

All finalists were presented with certificates and Texas Instruments calculators, while their schools or colleges received Mercury compatible telephones.

The YEDA awards were presented by His Royal Highness, the Duke of York, patron of The YEDA Trust, which governs the competition, and the names of the winners and runners-up were announced by Miss Moira Stuart of BBC Television News.

## SPEED UP PACE OF INFORMATION SUPERHIGHWAY

At a recent international conference\* in Brussels, Sir Iain Vallance, chairman of British Telecom, said that firm and practical action was now essential to make the Information Superhighway a reality. He told the conference that the political will and general recognition of the need for change were no longer enough. The G7 countries should agree a plan for the convergence of timescales for a fully open and consistently regulated communications market.

Sir Iain continued to say that "there is little - if any - sign of early movement in the two largest markets in continental Europa (Germany and France). We have to ask whether there is a place in this competitive market for companies or alliances who continue to enjoy protected status in their home markets."

Sir Iain called on governments and regulators to allow competition to flourish. He endorsed the idea of a European regulatory body to set and enforce policy guidelines for the communications industries and which would ensure consistency of rules and rule-making throughout Europe. It would form a link with national regulatory bodies as implementors to embrace broadcasting, cable TV and the electronic publishing industries, and be in a position to reduce regulation where there was established competition and market access.

\*The Telecommunications Superhighway - Accelerating the Pace in Europe.

## "MICROELECTRONICS IN BUSINESS" EXTENDED

The Department of Trade and Industry has announced that its "Microelectronics in Business" technology transfer programme is to be extended with the addition of a £ 1 million Programmable Microelectronics module.

The decision to widen the scope of the original programme has been taken as a result of surveys pointing to a general lack of awareness and knowledge of the technology and its benefits amongst UK

\* A paroxysmal disorder of the arteries of the fingers and toes characterized by attacks of pain in them, the fingers or toes going white and then blue, usually after exposure to cold or stress.



industry.

In particular, a recent survey commissioned by *New Electronics* of UK companies that use electronics in their products concludes that only 25% of those not using microcontroller could supply a positive reason for not adopting the technology. Even companies currently using microcontrollers were found to be unaware of recent advances.

Nevertheless, "The first year results of the *Microelectronics in Business* programme are very encouraging", said Industry and Energy Minister Tim Eggar on the occasion of the programme's first anniversary. "UK industry clearly needs the competitive advantages of custom circuit - ASIC - technology."

The programme was established last year in response to survey results indicating that many firms were either not aware of the relevance of custom circuit technology to their business or overestimated the cost and difficulty of designing custom circuit devices.

"*Microelectronics in Business* aims to alter this perception through a structured programme of education and practical help. The programme is also proving beneficial to the microelectronics industry by creating a more receptive market for its products", said Mr Eggar.

"In the first year every mainland UK company that uses electronics, and a further 10,000 companies in related activities, have been sent information on the business benefits to be derived from using microelectronics; the first two support centres established under the scheme (Bournemouth University and Bolton Institute) have alone responded to more than 700 enquiries about the programme;

105 companies have now become *Microelectronics in Business* customers and received demonstrations of leading-edge, industry-standard tools and support capabilities. Half of them have subsequently modified or upgraded their original plans."

#### 1995 TOP TECHNICIAN IN INDUSTRIAL ELECTRONICS

Twenty-one-year-old Matthew Swift, a computer integrated manufacture engineer with the Dynamics Division of British Aerospace in Lostock, is this year's winner of the Top Technician in Industrial Electronics competition. The announcement of the winner was the culmination of a four-day national final held recently at the Training Centre of EEV Limited, Europe's largest Electron Tube manufacturer, in Chelmsford, UK. In presenting the prize of a colour notebook computer, Sir John Cassels, Chairman of UK Skills, expressed his pleasure at the high standard of competitors, who had been chosen for the final from regional events held last year. He thanked the organizers of the event and congratulated Matthew Swift on his impressive achievement. All eight finalists were set theory and draughting papers and were required to undertake a practical test.

The competition, jointly organized by the Institution of Electronics and Electrical Incorporated Engineers (IEEIE) and The Institution of Electrical Engineers (IEE), aims to enhance and improve the skills of electronics technicians in the UK. The 1995 event has the backing of US Skills and was sponsored by a number of leading companies.

Later this year, the winner will travel to Lyon, France, to compete on behalf of the UK in the International Youth Skill Olympics, an event held every two years in one of the member countries of the International Organization for the promotion of Vocational Training.

The runner-up, Alastair Brady, aged 20, was presented with a black-and-white notebook computer. Alastair is a software engineer with British Aerospace Defence Military Aircraft Ltd, Preston.

The other six finalists in the competition were Geoffrey Garland (GEC Marconi Avionics, Basildon, Essex); Jimmy King and Ian Saunders (British Aerospace Defence Ltd, Stevenage, Herts); Darren Oram (Racal Radar Defence Systems, New Malden, Surrey); and Steven Smethurst and Darren Taylor, British Aerospace Defence, Lostock, Bolton.

#### DISK WARS

All is not well in the big world of video disks. Sony of Japan and Philips of the Netherlands are going ahead with their digital video disk. However, they are up against formidable opposition from Toshiba, Pioneer and Matsushita, all of Japan, who have developed their own version.

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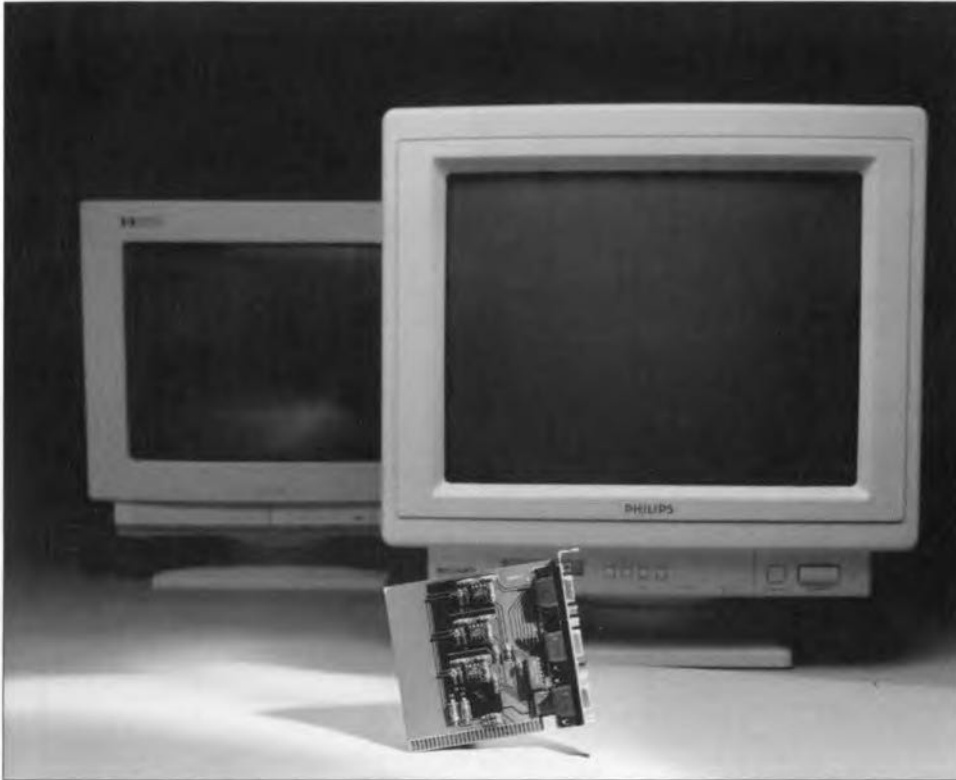
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# VGA DISTRIBUTION AMPLIFIER

This article describes a distribution amplifier for VGA cards which allows you to do, for instance, a small presentation running on one PC, with the video output routed to a local and a remote monitor. Alternatively, the distribution amplifier may help to drive long cables when the monitor is located at a considerable distance from the PC.



Source: Sontronic, design by K. Walraven

IT all seems so simple: insert the DB15 plug at the end of the monitor cable into the socket on the VGA card in the PC, and the monitor displays the video signal. In a number of cases, however, things are not so simple. Problems are sure to arise, for instance, if you want to connect more than one display to a VGA card, or if a very long cable (with a length of more than 10 m) is to be used. To make sure that the quality of the displayed picture is above reproach, the analogue video signal must have the proper level (0.75 V<sub>pp</sub> to 1.0 V<sub>pp</sub>); it must be free from induced noise, and, finally, its pulse edges should retain their original steepness. In addition to the three analogue video signals, R(ed), G(reen) and B(lue), the connector also carries one or two digital synchronization signals. These signals have TTL levels.

The synchronization signal received by the monitor has a much lower frequency than the video signals, and will rarely be higher than 100 kHz or so.

While most VGA monitors are satisfied with a combined synchronization signal, a few require separate horizontal and vertical synchronization signals. Many VGA cards supply a combined synchronization signal at the horizontal sync output pin.

## In practice

The video output stage of an ordinary PC video card (VGA or SVGA) supplies an electrical signal which normally meets all requirements without the slightest problem. When two monitors are connected in parallel to such a card, however, the signal level will drop appreciably owing to the low load

impedance. The actual remaining signal level at each monitor input is then only two-thirds of the nominal level. When long cables are used, the steepness of the signal edges is reduced by stray capacitance, the signal level drops, and the risk of noise degrading the picture quality increases.

Today's video cards are capable of supplying signals with a frequency of well over 100 MHz to produce crisp (S)VGA images on a monitor. Nor surprisingly, the cable between the video card and the monitor input has a strong effect on the picture quality. The VGA distribution amplifier described in this article ensures proper buffering of the video signals, and enables the above mentioned negative effects to be kept to a minimum.

Video signals with such high frequencies make high demands on the connection between the monitor and the video card. Aspects to be taken into account include the proper termination impedance for the video amplifier, the right type of connecting cable, and proper impedance matching between the output on the video card and the monitor input.

In order to satisfy all these requirements, a fast wideband opamp type LT1227 is used to process the RGB signals. The LT1227 is a current feedback amplifier manufactured by Linear Technology. A feature of this opamp is that its bandwidth is almost gain-independent. The LT1227 sports a bandwidth of at least 140 MHz. A cheaper, lower-spec, variety, the LT1252, still achieves an impressive bandwidth of 100 MHz. A short backgrounder to current feedback opamp technology is given in an inset further on in this article.

## The circuit

The circuit diagram of the video distribution amplifier is given in **Fig. 1**. Because the card will normally be used with an IBM-PC or compatible, it takes the form of a PC insertion card. The advantages of doing so are (1) to avoid external cables; (2) to economize on a power supply; (3) to make sure that the amplifier is always co-sited with the PC. Those of you who use a non-IBM type of computer will have to build the card into a small enclosure, which should also contain a dedicated power supply.

With reference to the circuit diagram, the video signal supplied by the VGA insertion card is connected to K<sub>4</sub>. The monitor which remains close to



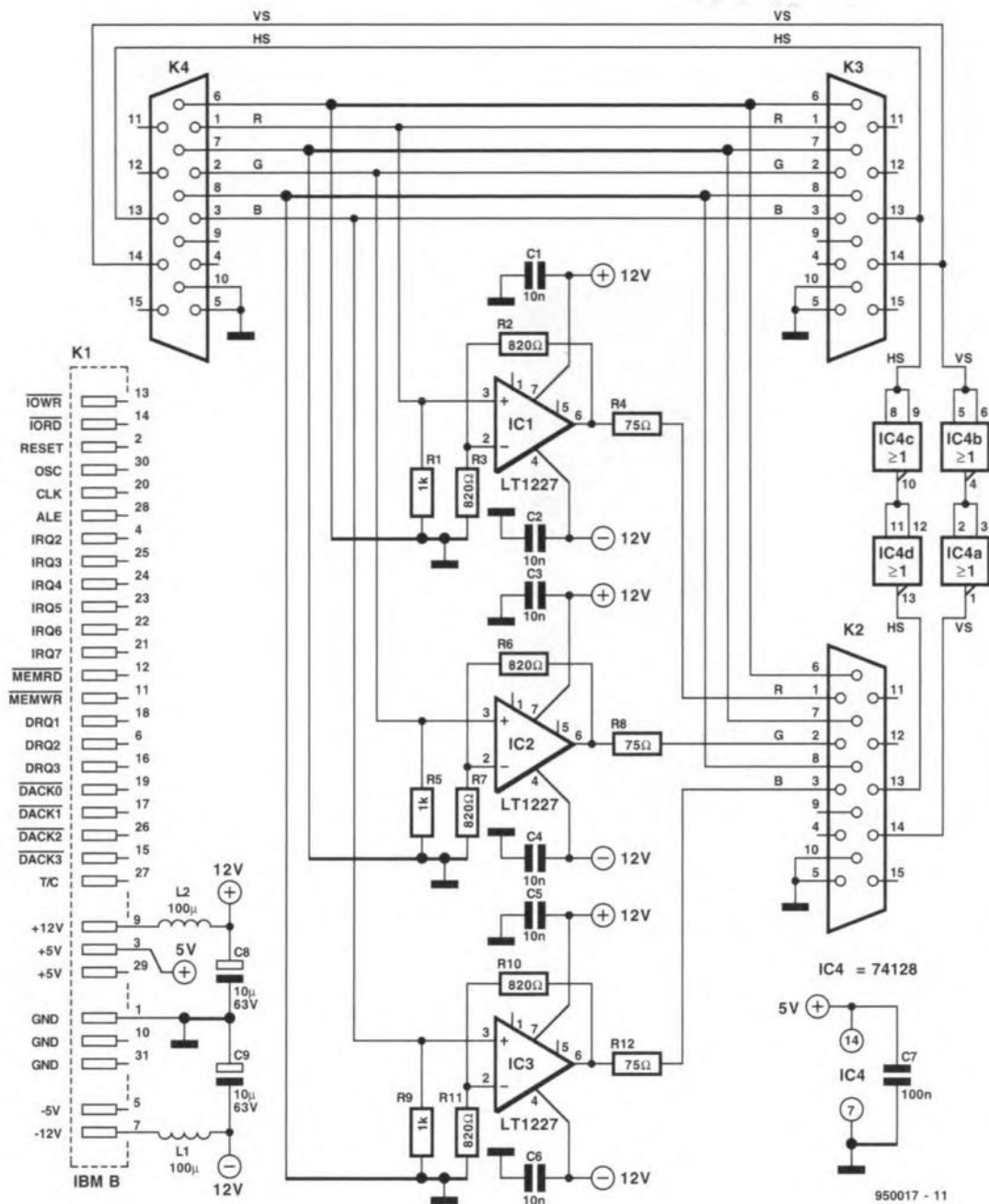


Fig. 1. This circuit allows you to connect more than one monitor to a PC.

the PC is connected to K<sub>3</sub>. K<sub>3</sub> must always be used. Connector K<sub>2</sub> is intended for the extra monitor. This output supplies the buffered video signal.

The digital synchronization signals, HS and VS, are connected directly to the corresponding outputs on connector K<sub>3</sub>. The HS (horizontal synchronization) signal is buffered by gates IC<sub>4c</sub> and IC<sub>4d</sub> (74128) and subsequently applied to pin 13 of K<sub>2</sub>. The other sync signal, VS (vertical synchronization) is buffered by IC<sub>4b</sub> and IC<sub>4a</sub> before it is applied to pin 14 of connector K<sub>2</sub>. The buffers contained in the 74128 are capable of driving loads with an impedance of 75 Ω directly.

Because the sync inputs on most monitors have a relatively high input impedance, the low source impedance of the buffers ensures a proper signal level at all times.

The video signals, R, G and B, are cleaned and shaped up with the aid of the previously mentioned current feedback opamps. The three colour signals are processed identically. The R(ed) signal furnished by the computer is applied to pin 1 of K<sub>4</sub>. This signal is passed directly to connector K<sub>3</sub>. The monitor on this connector ensures the proper termination of this video line. In order to change the impedance as little as possible, the video amplifier is wired to present a relatively high input

impedance of about 1 kΩ. This value hardly affects the line impedance while ensuring a proper connection to ground. This is necessary because output K<sub>3</sub> may be connected to an AC-coupled monitor, when the level at the input of the video opamp is not defined without the 1-kΩ resistor.

Opamp IC<sub>1</sub> is wired as a non-inverting amplifier with a voltage gain of ×2. The gain is determined by resistors R<sub>2</sub> and R<sub>3</sub>. The values used ensure an effective bandwidth of 75 MHz when an LT1227 is used, or 66 MHz when an LT1252 is used. Within this bandwidth, the gain response of the amplifier has a ripple of only 1 dB.

The output of the opamp is con-



nected to a series resistor of  $75\ \Omega$  to make sure that it supplies the same signal level as that presented on connector  $K_4$ . Remember, the opamp has a gain of  $\times 2$ , while the series resistor effectively halves the output voltage again when a monitor with an nominal input impedance of  $75\ \Omega$  is connected.

Capacitors  $C_1$  and  $C_2$  serve to decouple the supply voltage.

The amplifiers are powered via connector  $K_1$ , which is inserted into a free expansion slot in the PC. Two LC networks,  $L_1-C_9$  and  $L_2-C_8$ , are inserted in the  $+12\text{-V}$  and  $-12\text{-V}$  supply lines to divert noise and spurious pulses.

## Construction

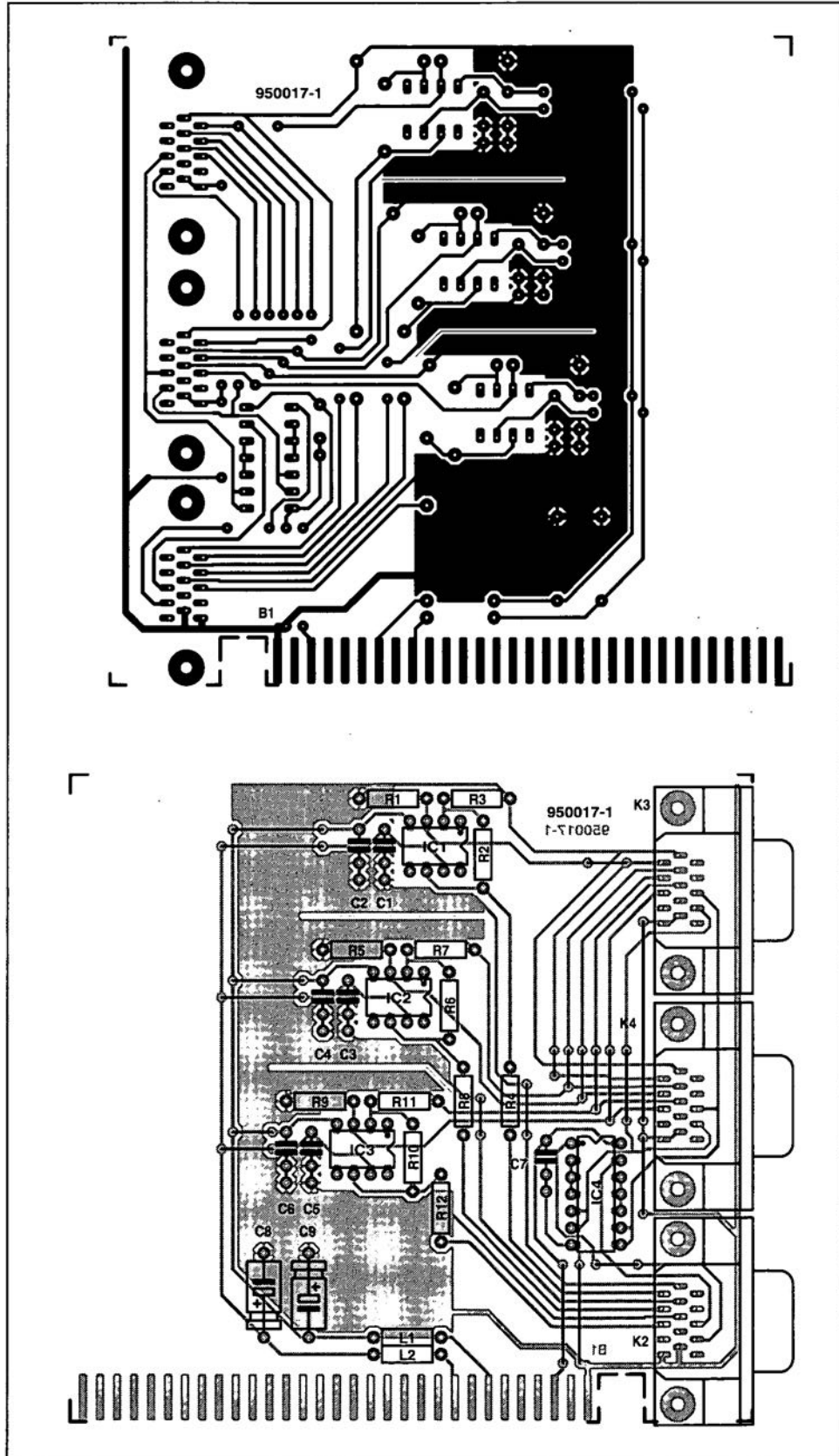
The VGA distribution amplifier is best built on the single-sided printed circuit board whose artwork is shown in **Fig. 2**. This board is available ready-made through the Readers Services, and comes with pre-tinned contact fingers ( $K_1$ ). The PC card bracket mentioned in the parts list comes ready-drilled with three holes for the respective connectors,  $K_2$ ,  $K_3$  and  $K_4$ . If you want to use a 'blank' card bracket, you will have to cut the holes yourself with the aid of the template shown in **Fig. 4**.

Before you start soldering away, make sure the insertion card fits in your computer, especially if you are using an older brand of PC which may not have enough room between expansion bus slots.

Start the construction by fitting the wire links and the connectors on to the board. You will notice that there are quite a few wire links, but that is hard to avoid on a single-sided printed circuit board.

Unfortunately, the 74128 may be hard to obtain locally. The more common 74LS02 may then be used as a reasonable alternative. Do not use HC or HCT versions of this IC.

Once all components have been fitted on to the board, and the solder



**Fig. 2.** Track layout and component mounting plan of the single-sided printed circuit board designed for the VGA distribution amplifier (board available ready-made, see page 70).

## COMPONENTS LIST

### Resistors:

$R_1, R_5, R_9 = 1\text{ k}\Omega$   
 $R_2, R_3, R_6, R_7, R_{10}, R_{11} = 820\ \Omega$   
 $R_4, R_8, R_{12} = 75\ \Omega$

### Capacitors:

$C_1-C_6 = 10\text{ nF}$   
 $C_7 = 100\text{ nF}$   
 $C_8, C_9 = 10\ \mu\text{F } 63\text{V}$

### Inductors:

$L_1, L_2 = 100\ \mu\text{H}$

### Semiconductors:

$IC_1, IC_2, IC_3 = \text{LT1227 (Linear Technology*)}$   
 $IC_4 = 74128 \text{ or } 74LS02$

### Miscellaneous:

$K_2, K_3, K_4 = 15\text{-way sub-D socket, angled, for PCB mounting.}$   
 One PC insertion card bracket KHPC-O-071 (Fischer\*\*).  
 Printed circuit board, order code 950017-1 (see page 70).

\* MicroCall (01844) 261678.

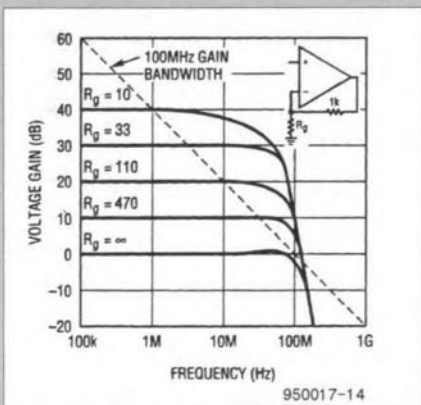
\*\* Dau Components (01243) 553031.



### CURRENT FEEDBACK AMPLIFIERS

Current feedback amplifiers are often presented as the latest technology with perfect characteristics. And yet, the technology is not at all new. Indeed, there is evidence which suggest that current feedback is even older than voltage feedback. The principle of current feedback has existed for more than 55 years. It was first applied by William R. Hewlett while developing phase his famous sinewave oscillator which dates from 1939. Cathode feedback, the valve-era equivalent of current feedback, was a well established technique in RF circuits dating from the 1930s, 40s and 50s, the simple reason being that there was no other electrode on the valve to which feedback could be applied.

The differences between voltage feedback and current feedback are very small. Indeed, it is hard to tell them apart in many circuits. The symbols of the opamps used are the same, and the calculations to define the response of the amplifier are based on virtually identical equations. The differences between a voltage feedback opamp and a current feedback opamp are, however, immediately evident by looking at the bandwidth of the amplifiers and their response to large input signals. With current feedback amplifiers, the bandwidth is not proportional to the voltage gain. The drawing shows the characteristics of a voltage feedback opamp and a current feedback opamp. With the voltage feedback type, the effective bandwidth drops linearly when the



closed-loop gain is increased. Current feedback opamps are virtually free from this disadvantage. Recently, a number of current feedback opamps for general use have appeared on the electronics market, allowing this interesting device to be used for many applications without running into high cost. However, current feedback opamps also have an important disadvantage: their d.c. behaviour is rather poor as compared with regular opamps. Fortunately, that is immaterial for many applications, where they can be used to great advantage.

work has passed a thorough inspection, the card is ready to be plugged into your PC. Connect the video output on the video card to socket K<sub>4</sub> on the VGA distribution amplifier. This should be a pin-for-pin connection consisting of a short piece of cable with a plug at both ends. Such cables are available ready-made. The monitor which belongs to the computer is connected to socket K<sub>3</sub>, while the 'remote' monitor is connected to K<sub>2</sub>. To make sure that the VGA card in your PC can read the 3-bit (but more usually 2-bit) monitor identification code, link pins 4, 11 and 12 of connectors K<sub>3</sub> and K<sub>4</sub>. That is easily done with the aid of three short insulated wires. The monitor connected to K<sub>3</sub> then determines the video mode. After switching on the computer, both monitors should produce a clear and stable image.

If you want to connect up more than two monitors, that can be achieved by building more distribution amplifiers. Socket K<sub>4</sub> is then looped through to K<sub>3</sub> on the next distribution card. The 'local' monitor is connected to socket K<sub>3</sub> on the last card in the chain. Cascading the cards in this way allows you to connect one additional monitor per card.

If you can live with some loss of quality, a second monitor can be connected to the card. That can be achieved by connecting a resistor of 75 Ω to each video amplifier output (pin 6) to create an extra output, and then collecting the R, G B and sync

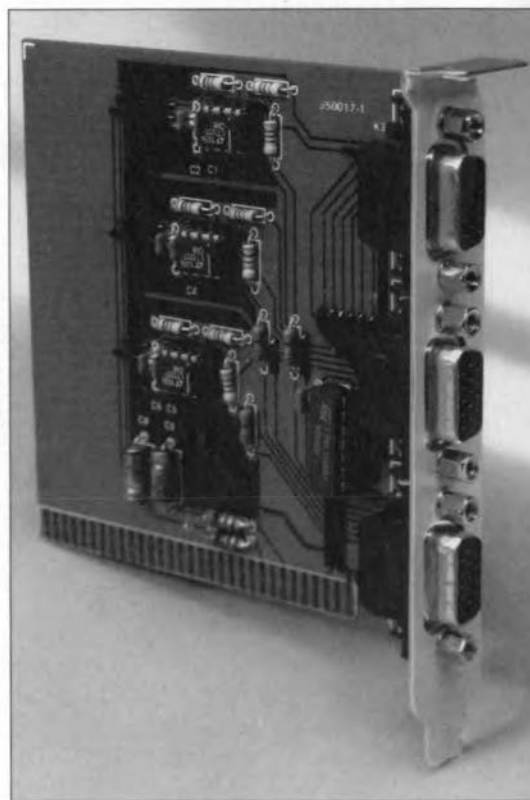


Fig. 3. Finished prototype of the distribution amplifier. The three sockets are secured on a PC insertion card bracket from Fischer.

outputs on an extra socket. This solution roughly halves the video bandwidth. Fortunately, the picture quality will still be adequate for a regular VGA monitor.

The distribution amplifier draws a current of about 30 mA. The opamps run slightly warm after a while — this is normal and no cause for alarm.

(950017)

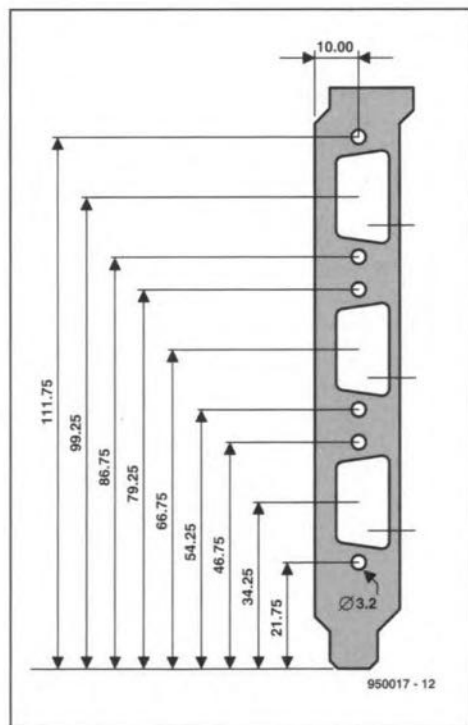
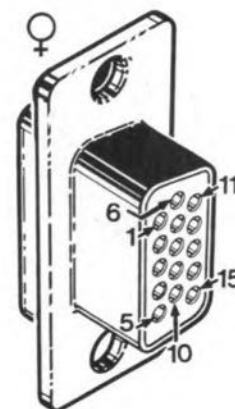


Fig. 4. If you can not get hold of the pre-drilled insertion card bracket from Fischer, make your own from a blank plate with the aid of these measurements.



PIN #	ASSIGNMENT	PIN #	ASSIGNMENT
1	Red (0 - 0.7V)	9	N / A
2	Green (0 - 0.7V)	10	Sync return
3	Blue (0 - 0.7V)	11	Mon ID (0) (in)
4	Mon ID (2) (in)	12	Mon ID (1) (in)
5	Ground	13	Horizontal Sync (out)
6	Red return	14	Vertical Sync (out)
7	Green return	15	(reserved)
8	Blue return		

950017 - 13

Fig. 5. VGA/SVGA socket pinout.



# FOCUS ON: THE WORLD OF RADIO AND TV AMATEURS

If there is a sub-field of electronics which is never boring or totally foreign to the man in the street, it is radio. Radio will continue to be important because it is inevitably tied up with the basic human need to communicate. Radio amateurs, for instance, communicated by satellite long before you could even watch satellite TV programmes. Similarly, their packet radio networks were in existence ten years before the breakthrough of Internet, and they pioneered microwave communication decades before you could walk in the street talking into your mobile phone.

This article aims at giving the radio bug to those of you with just a general interest in electronics. In addition, some of the recent developments in this ever so lively pastime are discussed.

By our editorial staff

THE great thing about being a licenced radio amateur (of any class) is that you are never stuck for ideas, helpful suggestions or even components when it comes to solving a problem related to electronics project construction. The radio amateur is never a lone battler because he can reach his allies via a variety of media, including telephony, television or even computer mail by air (free of charge, as opposed to any link by telephone). So, if you have ever had the desultory feeling of being the only electronics enthusiast for miles around, and have no one to assist you, consider seriously becoming a radio amateur. The hobby will put you in touch with hundreds of electronics enthusiasts of a wide diversity of educational levels. Many radio amateurs are friends for life although they live thousands of miles apart, and have never actually met each other in person. In the UK, the Radio Communications Agency (RCA) and the Radio Society of Great Britain (RSGB) will be pleased to show you the ropes to this highly interesting and educational pastime.

After a decline during the past five years or so, the number of licenced radio amateurs is on the rise again, witness the latest reports of the IARU (International Amateur Radio Union). The temporary drop in active amateurs is probably owing to the growing popularity, at the same time, of the personal computer. Now, the two hobbies are linked by the tremendous interest in

packet radio, and even those who once gave up the tuning dial for the PC keyboard are now back on the air again as enthusiastic 'packeteers'. Also, home construction is back on the rise again, with many amateurs becoming aware of the educational value of building a project,

as compared to buying off the shelf and never knowing how it actually works. This goes for simple projects, like power supplies, to more complex stuff like a DTMF-over-air controlled digital heart for the local repeater station.

## A mode for everyone

Radio amateurs, after having been licenced for a while, typically tend to pick up a specialisation within the hobby. This is partly brought about by the licencing system, which allows you to do the RAE (Radio Amateurs' Examination) only, and take a 'B' licence for 50-MHz (6-m band) and up only. For the 'full' or 'A' licence you have to pass a 12-wpm morse proficiency test as well, which on passing allows you to use all radio bands, including those below 50 MHz. Although the full licence gives you many more bands to work on, many 'B' licensees remain B's forever because they are not interested in the extremely crowded shortwave bands. Similarly, many 'A' licensees are never heard on the VHF and UHF bands. A special category is formed by the 'Novice' licensees, who take a simplified exam (also 'A' or 'B'). Unfortunately, the Novice licence is not (yet) commonplace in all countries, at



Fig. 1. Going mobile? This is the PRC-2250-MIL special ruggedized 150-watt 1 to 30-MHz AM/CW/SSB transceiver from SGC. The rig features 100 user programmable channels, plus 644 factory programmed ITU channels for voice and data. Also suitable for RTTY, ARQ, FEC and Packet.



least not in those in which amateur radio is regulated by CEPT Recommendation T/R 61-01 (see Table 3). The Novice licence was first used in the UK.

A distinction is also often made between amateurs who build their own equipment, and those who use off-the-shelf rigs and antennas only. That distinction does not exist because (1) it is impossible to make everything yourself cheaper than you can buy it ready-made, and (2) there is some home-brew item in any radio amateur's shack.

Still on the subject of diversification, some general points will be made on the most popular specialisms available to radio amateurs.

**RTTY.** Plain telexing seems to have disappeared nowadays, being replaced by more intelligent systems like AMTOR (amateur telex over radio) and PACTOR. AMTOR is a synchronous 100-baud system which has two primary operating modes: ARQ (automatic repeat request) and FEC (forward error correction). Most long-distance RTTY traffic is found in the shortwave bands, particularly, in the 80-m (3.5 MHz) and 20-m (14 MHz) bands. Most radio amateurs have now got rid of old mechanical telex machines, and have taken to using PCs and special interface cards.

**CW.** Morse (CW) still has its staunch supporters but is definitely on the decline, being inherently slow as compared with almost any digital communication protocol. Interestingly, this mode was officially abandoned for coastguard communications not so long ago. None the less, there are still many radio amateurs who love to make very long distance contacts using their morse key and a very low power transmitter.

**SSTV.** Slow-scan television (J2F), too, will never be the same since the PC arrived. These days, computer-generated pictures are exchanged in colour mainly via the 20-m band, sometimes in two-way links using error-correcting systems.

**Fax.** Mechanical systems are rapidly being replaced by computers. A special area is formed by weather fax reception, which uses terrestrial transmitters, low-orbiting satellites (NOAA, GOES) as well as the geostationary Meteosat at about 1.7 GHz. No licence is required to receive weather fax signals, which are of great interest to amateur meteorologists. Here, as in many other areas, radio amateurs have been in the forefront of modern developments.

**Amateur satellites.** Radio amateurs have pioneered communication by satellite, indeed, they have for many years built and operated their own satellites. The best known 'ham sats' are those in AMSAT's 'OSCAR' (Orbiting Satellite



Fig. 2. Many radio amateurs, including those who have receiving equipment only, enjoy scouring the radio spectrum for exotic utility stations *anywhere* on and above the globe (extraterrestrial signals? well, no, they are just satellites). Worldwide, there are thousands of these stations for weather fax, telex, press information, maritime and aircraft use, together with beacons, frequency standards, time standards and many more. Klingenfuss Publications supply a range of books, and, recently, a CD-ROM, which provide a wealth of information on this fascinating aspect of the radio hobby. Remarkably, the information contained in these publications is compiled and updated on the basis of the publishers' own radio monitoring expeditions.

Carrying Amateur Radio) series, which became popular through their 2-m band transponders. A recent development is

the use of satellites totally geared to packet radio communication (PACSAT). This will undoubtedly lead the way to-



Fig. 3. The shorter the waves, the longer the faces? Certainly not! People interested in communication at frequencies from VHF and up towards daylight (well, 144 GHz, for instance) have traditionally formed a separate interest group within the amateur radio fraternity. Any frequency below 430 MHz is d.c. to the real microwave enthusiast, who has no QSL cards, no morse key and no shortwave receiver, except, perhaps, one that functions as an SSB demodulator only. In his pockets are pieces of waveguide, Gunn diodes, maps of mountainous areas, a micrometer and, of course, his very own magazine called *VHF Communications*.

wards Microsoft's initiative to commission satellites for computer communication. When these plans get off the ground (hi) radio amateurs with experience in working via satellite will have a great technical advantage. In general, the equipment needed to communicate via satellite in the 2-m band is very simple indeed, and antenna tracking is not always necessary.

**Fast-scan television.** ATV (amateur television), mode C3F, is among the most exciting modes, simply because 'live' or recorded pictures can be made to appear on a normal 'telly'. Invariably, a demonstration of a two-way ATV contact with pictures in colour, accompanying sound and sometimes even Teletext never fails to impress 'outsiders'. On many amateur radio shows where various modes are demonstrated to the public, the ATV corner is sure to draw a large crowd. Nearly all ATV equipment is home-made, commercial products being relatively rare (not including kits). As a result of considerable pressure from 'voice' amateurs and other (professional) users, there is a tendency among ATV-ers to move their wide-band signals (up to 8 MHz) out of the trusty 70-cm (435 MHz) band, and into the 24-cm band (1250 MHz). The 24-cm band has far more space, and even allows the advantageous FM mode to be used, when the bandwidth goes up to about 15 MHz. On the down side, propagation is slightly less advantageous, and the path loss is higher, so that the range of an ATV transmitter with a certain output power will be smaller than in the 70 cm band. The use of the 24-cm band is promoted by (1) the availability of easily converted surplus satellite TV tuners like the Amstrad SRX100/200 which currently go at prices of £10 and less, and (2) an increasing number of ATV repeater stations at high locations. Another band which is very popular among ATV users is 10 GHz (3 cm), where small dishes are

Frequency band (MHz)	The Amateur Service	The Amateur Satellite Service	Max. power level (PEP)	Permitted types of transmission	
1.810-1.830	Primary. Note (A)	(Not allocated)	26 dBW	Morse Telephony RTTY Data Facsimile SSTV	
1.830-1.850	Primary		15 dBW		
1.850-2.00	Note (B)				
3.500-3.800	Primary. Shared with other Services				
7.000-7.100	Primary	Primary			
10.100-10.150	Secondary	(Not Allocated)			
14.000-14.250	Primary	Primary	26 dBW		
14.250-14.350		(Not Allocated)			
18.068-18.168		Primary			
21.000-21.450					
24.890-24.990					
28.000-29.700					
50.00-51.00	Primary. Note (A)	(Not Allocated)	20 dBW		
51.00-52.00	Secondary. Note (B)		22 dBW		
70.00-70.50	Secondary. Note (A)		26 dBW		
144.0-146.0	Primary	Primary			
430.0-431.0	Secondary	(Not Allocated)	16 dBW erp	Morse Telephony RTTY Data Facsimile SSTV FSTV	
431.0-432.0	Secondary. Note (C)				
432.0-435.0	Secondary				
435.0-438.0			Secondary		
438.0-440.0			(Not Allocated)		
1240-1260			(Not Allocated)		
1260-1270			Secondary. Space to Earth only		
1270-1325			(Not Allocated)		
2310-2400					
2400-2450			Secondary. Users must accept interference from ISM users		Secondary. Users must accept interference from ISM users
3400-3475	Secondary	(Not Allocated)	26 dBW		
5650-5670		Secondary. Earth to Space only			
5670-5680					
5755-5765		(Not Allocated)			
5820-5830	Secondary. Users must accept interference from ISM users				
5830-5850		Secondary. Users must accept interference from ISM users. Space to Earth only.			
10000-10450	Secondary	(Not Allocated)			
10450-10500		Secondary			
24000-24050	Primary. Users must accept interference from ISM users	Primary. Users must accept interference from ISM users			
24050-24150	Secondary. Note (D). Users must accept interference from ISM users	(Not Allocated)			
24150-24250	Secondary				
47000-47200	Primary	Primary			
75500-76000					
142000-144000					
248000-250000					

**Table 1. Overview of band limits, status of allocations in the United Kingdom, maximum power level and permitted types of transmission. Reproduced from: Amateur Radio Licence (A) or (B), terms, provisions and Limitations booklet BR68. Issued by the Radiocommunications Agency, July 1994.**

#### Notes

- (A) Available on the basis of non-interference to other services outside the United Kingdom.  
 (B) Available on the basis of non-interference to other services inside or outside the United Kingdom.  
 (C) Not available for use within a 100km radius of Charing Cross, London (51°30'30"N, 00°07'24"W).  
 (D) May only be used with the written consent of the Secretary of State.

#### Abbreviations

ISM = Industrial, Scientific and Medical.  
 erp = effective radiated power



used. Mind you, this is not always short-range communications, as distances up to 100 km have been covered using 3-cm ATV. In the UK, the BATC (British Amateur Television Club) co-ordinates the activity of many ATV-ers and repeater groups around the country. The BATC club magazine is called *CQ-TV*.

**Digital communication.** Of the many digital communication modes available to the licenced radio amateur, Packet Radio has rapidly become by far the most popular. Packet is in many ways comparable to Internet for the 'general' computer user, allowing, in principle,

stations all over the world to exchange messages. In as far as the systems can be compared, the main differences are that Packet is free of charge, run on a non-profit basis by amateurs, and much slower than Internet. Because of the great importance of Packet to amateur radio in general, this mode will be discussed separately further on.

**Other specialized modes.** Some highly specialized modes are practiced by relatively few amateurs only. *EME* (earth-moon-earth, or *moonbounce*) uses extremely high power levels and huge antenna arrays.

*Meteor-scatter* is fascinating because signals ('pings') are reflected way beyond their normal range by meteor fragments which enter the earth's atmosphere as a meteor shower passes by (for instance, the Perseids).

*Tropo-scatter* allows VHF/UHF signals to travel extremely large distances (thousands of miles) via certain layers in the atmosphere.

*QRP* operators make an issue of running as little power as possible from all-home brew transmitters to get in touch with other QRP stations. Contacts around the globe with as much power as a bicycle rear light are not uncommon.

<b>Telephony (speech):</b>	
Single sideband, suppressed carrier (SSB)	J3E
Frequency modulation (FM)	F3E
Phase modulation (PM)	G3E
Amplitude modulation	A3E
<b>Packet/Data:</b>	
Direct frequency shift keying of the carrier	F1D
Frequency shift keyed audio tone (FM transmitter)	F2B
Frequency shift keyed audio tone (SSB transmitter)	J2B
<b>Television:</b>	
Slow scan television (SSB transmitter)	J2F
Vestigial sideband (AM transmitter)	C3F
<b>Facsimile:</b>	
Frequency shift keyed audio tone (SSB transmitter)	J2C

Table 2. Under the Telecommunication Convention, classes of emissions are designated by groups of three characters. Above are some examples for the most popular modes. The full set of symbols used is listed in the Radio Regulations, available from the RCA, London.

Albania	A1
Austria	A
Belgium	B
Bosnia and Herzegovina	BH
Bulgaria	BG
Croatia	HR
Cyprus	CY
Czech Republic	CZ
Denmark	DK
Estonia	EST
Finland	FI
France	F
Germany	D
Greece	GR
Hungary	H
Iceland	IS
Ireland	IRL
Italy	I
Latvia	
Liechtenstein	FL
Lithuania	LT
Luxembourg	L
Malta	M
Moldova	MLD
Monaco	MC
Netherlands	NL
Norway	N
Poland	PL
Portugal	P
Romania	RO
Russian Federation	
San Marino	RSM
Slovakia	SK
Slovenia	SLO
Spain	E
Sweden	S
Switzerland	CH
Turkey	TR
United Kingdom of Great Britain and Northern Ireland	GB
Vatican City	SCV

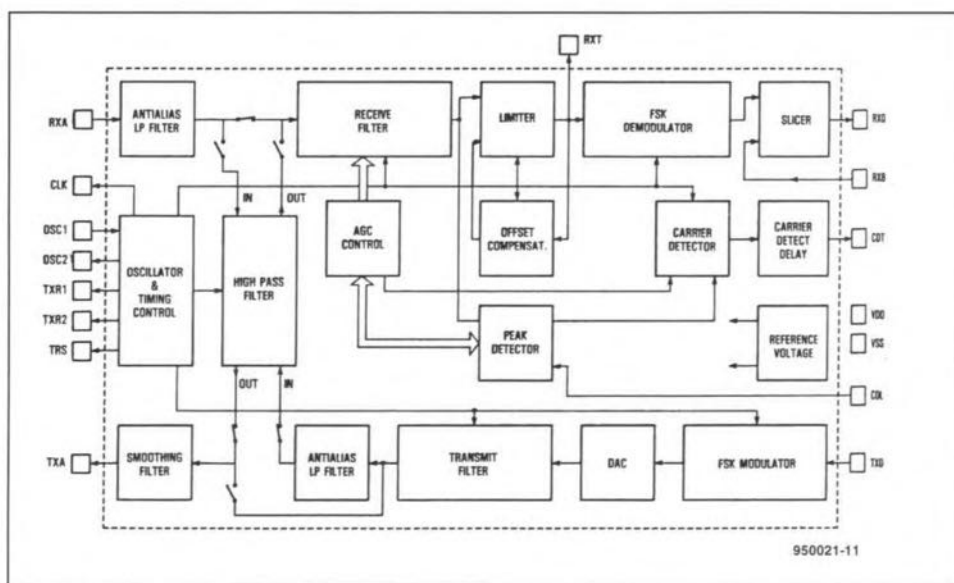


Fig. 4. Block diagram of the TCM3105 modem chip from Texas Instruments. Thousands of radio amateurs 'on packet' are using this low-cost chip in simple modems to exchange digital data by air. Probably the best known modem design based on the TCM3105 is that from Baycom, who also initiated the distribution of the shareware program to run packet radio on a shoestring, using any PC equipped with an RS232 port. Amateur radio has never been the same since.

Table 3. Countries involved in the CEPT T/R 61-01 harmonisation of regulations applicable to radio amateurs. For the most up-to-date information, contact the RCA.



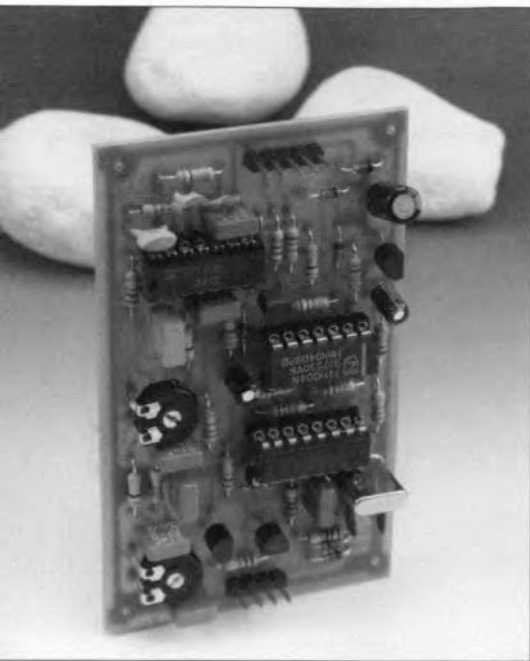


Fig. 5. Typical low-end (1200-baud) packet radio modem. Very easy to build and operate, this one is based on the famous TCM3105, and has one extra: a PLL type XR2211 for DCD (data carrier detect) control to eliminate digital noise if the radio has a slow squelch. This type of modem is compatible with many shareware packet radio programs, including BayCom and PK88. The modem is connected to the PC's serial port and to the transceiver, and will get you 'on packet' in one afternoon. Its supply power is 'stolen' from the RS232 port.



Fig. 6. Radio is invariably linked to nostalgia. If you do not believe this, pay a visit to one of the many hamfests, conventions, car boot sales and radio amateur rallies held in your area. *Radio Bygones* magazine, published by G.C. Arnold Partners, covers all historical aspects of radio and related topics, including amateur radio. The magazine is claimed to be the only publication of its type and class anywhere in the world. Also shown is Book 5, one of a series of reprints of the famous *Radio Valve Guides* originally published by Barnards' in the 1950s and 1960s.

*Very-low frequency communications* can be very funny because of the unexpectedly large range of sub-milliwatt (erp) signals, and all kinds of effects related to the earth's magnetic field. In the USA, the 1,750 m band is used (under strict regulations) as a kind of citizen's band. The people using this band are called 'lowfers'. In most CEPT countries, the 160-m band (1.8 MHz or 'top' band) is the lowest band which may be used.

*Amateur Radio Direction Finding* (ARDF) is better known as 'fox hunting'. A very popular, sportive and sociable out-of-doors hobby, which does not require a licence (as far as the contestants are concerned; the transmitter must be licensed!). The main bands used for ARDF are 2 m and, to a lesser extent, 80 m. The bands have totally different characteristics. Strange as it may sound, 80-m fox hunting is probably the best choice for the uninitiated because there are fewer problems with reflections by buildings, trees, etc. Receivers for 2-m and 80-m ARDF can often be borrowed from the local amateur radio club.

## The revolution - Packet Radio

Thanks to the pioneering work of the Tucson Amateur Packet Radio (TAPR) group, packet radio has caused a revolution in amateur digital mode operations. Packet radio is based on AX.25, a modification of the widely used ANSI X.25 protocol.

Packet data is sent in bursts called 'data packets'. Data is encoded in 8-bit bytes, and the ASCII code may be sent and received directly (as well as 8-bit binary data). The start of a packet includes callsign identifiers and allows a repeater path to be specified. The data packet ends with a CRC (cyclic redundancy check) number. The receiving station computes its own CRC, and compares it with the received CRC. If the two do not match, a repeat is requested.

Packets usually contain 32, 64 or 80 characters (bytes), but may have up to 255. Unfortunately, owing to the principle of CSMA (carrier sense, multiple access), packet traffic slows down and eventually bogs down completely if a lot of stations (say, 10 or more) attempt to use the same frequency. On HF, where there is the additional problem of noise, static, etc., AX.25 packet has not been very successful. On VHF and UHF, however, the number of packet radio stations, packet BBSs and digipeaters have seen an explosive growth.

The most popular packet radio mode is on 2-m FM where 1,200-baud, 1000-Hz shift AFSK is used, based on 1200/2200-Hz tones and the Bell 202 modem standard. Software is available in the shareware domain. In the USA alone, there are over half a million packet radio stations.



Fig. 7. Protect your valuable equipment from surges up to 5,000 ampères with a Cushcraft constant-impedance LAC4 arrester. The LAC-4 has a replaceable gas discharge tube which clamps voltage surges to less than 50 volts in about 100 nanoseconds, much quicker than the voltage rise time of lightning.



Fig. 8. The Blitz Bug from Cushcraft is based on a patented three-point static discharge design. The device features a sealed air chamber, constant static drain, and controlled voltage discharge. The Blitz Bug is rated at 2 kW PEP to 500 MHz with negligible insertion loss. Shown here is the LAC-1 version with UHF PL-259 and SO-239 connectors.

## Packet - the next generation

A packet radio modem differs from its more extensive 'big brother', the TNC (terminal node controller), by the absence of a built-in memory to store messages received over the radio. Also, a TNC is often capable of operating at higher speeds than just 1,200 baud. Most TNCs are microprocessor-controlled, run AX.25 superset according to the K9NG/GB3RUH standard, and come with extensive control software. They are used increasingly by individual station operators and operators of so-called digipeaters, which are packet radio BBSs capable of doing their own 'mail sorting', and linking to other digipeaters via UHF frequencies (for instance, 70 cm or 23 cm) using higher data speeds (9,600 baud for the so-called 'back-bones'). These fre-



## Some useful addresses



**AKD**, Unit 5, Parsons Green Estate, Boulton Road, Stevenage, Herts SG1 4QG, England. Tel. (01438) 351710, fax (01438) 357591.

**American Radio Relay League (ARRL)**, 225 Main Street, Newington, CT 06111-1494, U.S.A. Tel. (+1) 203 666 1541, fax (+1) 203 665-1166.

**Amsat**, 850 Sligo Avenue, Suite 600, Silver Spring, MD 20910-4703, U.S.A. Tel. (+1) 301 589-6062, fax (+1) 301 608-3410. In the UK, contact, Ron Broadbent G3AAJ, 94 Herongate Road, Wanstead park, London E12 5EQ. Tel. (0181) 989 6741, fax (0181) 939 3430.

**BayCom Team**, Rudi Dussmann DK5RQ, Otto Hahn Str. 9, D-8400 Regensburg, Germany. UK Distributor: Siskin Electronics Ltd.

**British Amateur Television Club (BATC)**, Dave Lawton G0ANO, Grenehurst, Pinewood Road, High Wycombe, Bucks HP12 4DD, England.

**CQ-TV magazine**, see BATC.

**Cushcraft Corp.**, P.O. Box 4680, 48 Perimeter Road, Manchester, NH 03108, U.S.A. Tel. (+1) 603 627-7877, fax (+1) 603 627-1764.

**Icom (UK) Ltd.**, Herne Bay West Industrial Estate, Sea Street, Herne Bay, Kent CT6 8LD. Tel. (01227) 741741, fax (01227) 741742.

**Klingenfuss Publications**, Hagenloher Str. 14, D-72070 Tuebingen, Germany. Tel. (+49) 7071 62830, fax (+49) 7071 600849.

**Nevada**, 189 London Road, North End, Portsmouth, Hants PO2 9AE, England. Tel. (01705) 662145/613900, fax (01705) 690626.

**Radio Bygones magazine**, published by G. C. Arnold Partners, 9 Wetherby Close, Broadstone, Dorset BH18 8JB, England. Tel./fax (01202) 65847.

**The Radio Communications Agency**, Waterloo Bridge House, Waterloo Road, London SE1 8UA. Tel. (0171) 215 5000.

**The Radio Society of Great Britain (RGSB)**, Lambda House, Cranborne Road, Potters Bar, Herts EN6 3JE, England. Tel. (01707) 659015, fax (01707) 645105.

**Remote Imaging Group**, The Membership Secretary, Ray Godden, Rig-Sub, P.O. Box 142, Rickmansworth, Herts WD3 4RQ, England.

**SGC**, The SGC Building, 13737 SE 26th St., P.O. Box 3526, Bellevue, WA 98009, U.S.A. Tel. (+1) 206 746-6310, fax (+1) 206 746-6384.

**Siskin Electronics Ltd.**, PC House, 2 South Street, Hythe, Southampton SO45 6EB. Tel. (01703) 207155, fax (01703) 847754.

**Timewave Technology Inc.**, 2401 Pilot Knob Road, St. Paul, MN 55120, U.S.A. Tel. (+1) 612 452-5939, fax (+1) 612 452-4571. UK distributor: Nevada.

**VHF Communications magazine**, published by KM Publications, 5 Ware Orchard, Barby, Rugby CV23 8UF, England. Tel. (01788) 890365, fax (01788) 891883.

**Vine Antenna Products**, The Vine, Llandrinio, Powys SY22 6SH. Tel. (01691) 831111, fax (01691) 831386. For KLM, Gem Quad, Cushcraft, Hygain and Force 12 antennas.

quencies are not normally accessible to low-level users. Similarly, other frequencies have been proposed and reserved for different types of packet radio usage: experimental, DX spotting, BBS interlink, keyboard-to-keyboard chatting, and backbones. Terms like nodes, trunking, sysops and electronic mail have been in use for many years among packet radio users.

Containing the addressee's callsign and a repeater search path, a message sent by packet radio only reaches the radio amateur you want. Possibly conveyed via any number of backbones and digipeaters, the message may take a few days, and quite a few miles, to reach the addressee's 'mailbox'. Until the ad-

dressee fetches his or her mail, this remains in the memory of the TNC at the repeater he/she 'subscribes to'. Many radio amateurs have a simple transceiver and an old PC on standby just for the purpose of collecting mail from their local digipeater. By contrast, there are also 70-cm rigs (like the Azden PCS-9600D) totally geared to packet radio at 9,600 baud.

It should be noted that special licencing conditions exist for unmanned stations like digipeaters and backbones. In all cases, the relevant authorities will insist on (1) a responsible, licenced radio amateur; (2) electrical safety; (3) provisions for switching the station off in the event of an emergency.

9,600-baud packet no longer uses tone shift keying but direct keying of the carrier (F1D instead of F2B). Currently, there is talk of 38.4 or even 57.6 kbaud packet radio via satellite. As already mentioned, this will form a nice step-up platform for the days when computer users will start to discover the advantages of communication by satellite instead of by telephone. Again, radio amateurs will have the edge on others. Still on the subject of future developments, packet radio nodes will soon be coupled to the Internet!

Back on earth again, low-speed packet radio 'on a shoestring' is possible using a low-cost TCM3105-based modem (see Fig. 5), some shareware software and any old PC XT or AT with at least a floppy drive and one serial port.

## More digital stuff — DSP!

Digital signal processing (DSP) can help to recover very weak signals from what sounds like a lot of noise only. DSP-based 'noise killers' such as the Timewave DSP9+ (Fig. 10) or MFJ's model 784, have filters that can be shaped as required, even down to bandwidths of 1 kHz for SSB. Similarly, a DSP filter enables CW stations to be resolved which are only 80 Hz apart. The advantages of DSP are the total absence of filter ringing, and the best possible subtraction of band-noise (by means of anti-noise). The disadvantage is that very high transmitter frequency stability is required. DSP processors like the DSP9+ are adaptive, i.e., they can be 'trained' to extract even the weakest signals, and require no modifications to your receiver. DSP is totally



Fig. 10. The Timewave DSP-9+ is a highly intelligent and technically very advanced 'noise killer' for a multitude of radio modes including SSB, CW, RTTY, AMTOR, PACTOR, HF packet and G-TOR. Based on a digital signal processor (DSP), the unit is simply connected to the earphones socket of your receiver or transceiver.



# TELNET

8, Cavans Way, Binley Ind. Estate, Coventry, CV3 2SF  
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 (Premises situated close to Eastern Bypass in Coventry with easy access to M1, M6, M40, M42, M69, M45.)

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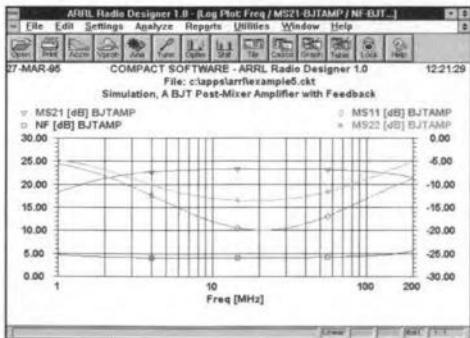


Fig. 9a. Report created by ARRL Radio Designer on a transistor amplifier intended to be used after a double-balanced diode mixer.

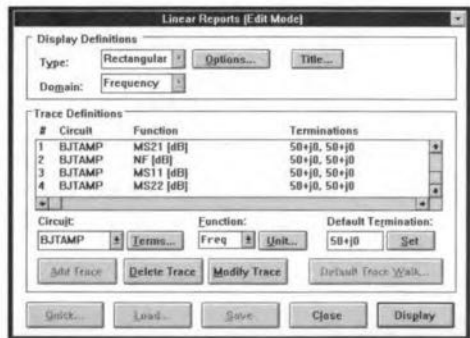


Fig. 9b. Linear Reports (Edit mode) window for the post-mixer amplifier.



Fig. 9c. Circuit editor and all three (pre-defined) reports on a simple JFET preamplifier (example).

different from traditional analogue filtering, and is said to work better than even the best auto-tracking and double-notch analogue filters in use with shortwave DXers. Not surprisingly, the military use DSP, too!

Says Timewave: "the noise reduction functions of the DSP9+ operate by examining a characteristic of signals and noise called 'correlation', and dynamically filtering out the undesired noise (using bandpass filters with steep skirts and linear phase response). The degree of cor-

relation is relative. Random noise such as a white noise or static is uncorrelated. Speech is moderately correlated. Pure tones such as heterodynes are highly correlated. The DSP9+ measures correlation and automatically filters out noise that is outside its correlation thresholds".

The computer has taken hold of the radio hobby in more than one way. Today, the PC is also used for circuit design and simulation, and not just for d.c. or audio applications! An increasing number of (Windows compatible) pro-

grams is becoming available to the radio amateur, for instance, the ARRL Radio Designer package (Fig. 9), or WISP, Amsat's bundle of utilities to operate through digital satellites (PacSats), plus 'tracking' software. Many hams are also using their PC to log radio contacts. The latest versions of these programs run under Windows and are capable of semi-automatic logging. During contests in particular such programs are very useful. (950021)

# THE DIGITAL SOLUTION

## Part 7 – Digital filters

By Owen Bishop

In this series we look closely at digital electronics, what it is, what it does, how it works, and its promise for the future.

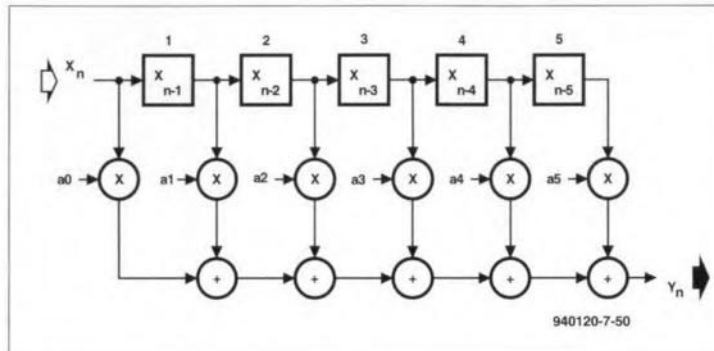


Fig. 51

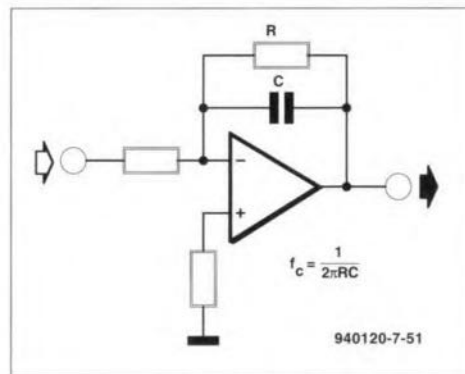


Fig. 52

In almost all electronic circuits there is a need for filtering to remove unwanted frequencies from the signals. In analogue circuits, filtering is achieved by using combinations of resistors, capacitors and (sometimes) inductors. The filters may include operational amplifiers (op amps), too. Filtering is a kind of mathematical operation. A low-pass filter has the properties of an *integrator*. It averages out signals levels over a period of time, thus removing, or at least attenuating, the rapid changes of voltages due to high frequencies. By contrast, a high-pass filter has the properties of a *differentiator*, responding strongly to rapid changes in signal level and thus attenuating the slowly changing voltages of the lower frequencies. As well as using integration and differentiation, analogue filtering uses addition and subtraction of signals, especially in band-pass filters.

Similarly, a digital filter performs mathematical operations on the digital samples that constitute a digital signal. The operations are performed in real time at very high speed and the filtered signals reach the output of the filter with an imperceptible delay. But, in digital filters, the operations are directly mathematical, being performed by microprocessors or special-purpose ICs with built-in mathematical functions, known as digital signal processor. As an example, we describe how a digital low-pass filter works.

### Low-pass digital filter

The structure of a low-pass filter is shown in Fig. 51. The drawing is a block diagram of a digital IC with registers, multiplying sub-circuits and summing sub-circuits. It could also be taken as a flow chart of a mathematical operation. As such, it could be executed by hand on paper or by using

a computer program. The computer program could be written in machine code or in a high-level language such as C or BASIC. This underlines the fact that digital filters are essentially *software*, whereas analogue filters are essentially *hardware*. Of course, hardware is required in the implementation of a digital filter (including paper and pencil as hardware for the brain-powered form of filter), but the result of filtering depends much more on the sequence of actions and the coefficients introduced into the calculation than it does on the structure of the hardware.

A digital filter consists of a number of registers in which

digital samples are stored as they arrive. The registers are arranged in a chain and, as each new sample  $x_n$  arrives, the other samples are passed along the chain at the sampling frequency. For this reason, the chain is known as a *delay chain*. Each register is an array of bistables (flip-flops), one for each bit of the sample, which is typically 16 bits long. The diagram shows five registers, but there may be fewer or more than this number. Typically, a digital signal processor may have a hundred or more registers, though the processor may be programmed to use only a few of them, perhaps only the first one. In the figure, sample  $x_n$

has just arrived, perhaps from an analogue-to-digital converter (ADC). At this instant, the previous samples are moved one step along the delay chain. The sample in register 5 (the sample taken longest ago) is overwritten by the sample from register 4, so is lost from the filter. The sample in register 4 is now overwritten by the sample from register 3. In this way the samples are shifted along the chain and the present sample  $x_n$  is transferred to register 1.

The present sample and the output from each register (the five previous samples) are each fed to multiplier units, which multiply them by one series of coefficients,  $a_0$  to  $a_5$ . These coefficients weight the samples in a way that gives the filter its characteristics. The array of multipliers is referred to as *taps*, since they tap the signal as it proceeds along the chain. The filter in Fig. 51 is a 6-tap filter.

The weighted outputs are summed by an array of summing circuits, and their total is the output  $y_n$  of the filter. If the six coefficients were all made equal to  $1/6$ , then  $y_n$  would be a *moving average* based on the present sample and the five previous samples. A moving average, by its nature, averages out any particularly large or small values. Given a high-frequency signal, in which the signal level is rapidly changing, making five consecutive samples range widely in value, the extremes are averaged out. In other words, rapid changes, or high-frequency changes, are attenuated. This is a low-pass filter, and its averaging effect is greater if we include more registers in the chain.

Note that the output of the filter is obtained by *summation*. The action is similar to that of a low-pass active filter as shown in Fig. 52, in which the charge accumulating on the capacitor is the sum of currents recently arriving. In



general, the most recently arrived current has the biggest effect. To produce an equivalent effect, we must weight the coefficients so that  $a_0$  is the largest and  $a_5$  is the smallest. This modifies the moving average calculation, but the effect is still that of a low-pass filter. It is the nature of the weighting that largely determines the exact shape of the filter's response curve and the type of phase changes it exhibits. Later we shall look at other patterns of weighting.

### Filter action

To see how the filter operates, here is a numerical example. The filter in Fig. 51 has six taps and its output at any instant is represented by this equation

$$y_n = a_0x_0 + a_1x_{n-1} + a_2x_{n-2} + a_3x_{n-3} + a_4x_{n-4} + a_5x_{n-5}$$

Suppose that seven consecutive samples, in order of arrival at the input, are 11, 13, 15, 17, 14, 12, and 10. Suppose also that the coefficients are 0.3, 0.25, 0.2, 0.15, 0.1, and 0.05. When the first six samples have arrived, the output is

$$0.3 \times 12 + 0.25 \times 14 + 0.2 \times 17 + 0.15 \times 15 + 0.1 \times 13 + 0.05 \times 11 = 14.6$$

Note that the *first* sample to arrive is now in register 5; the samples are in the reverse of their order of arrival. An instant later, the seventh sample (10) arrives, and the others are shifted along the chain. The first sample (11) is lost. Now the output is

$$0.3 \times 10 + 0.25 \times 12 + 0.2 \times 14 + 0.15 \times 17 + 0.1 \times 15 + 0.05 \times 13 = 13.5$$

Between the 6th and 7th samples, the input signal falls by 2. The output falls by 1.1. The filter is smoothing out the signal, as required in a low-pass filter.

We could continue to analyse the filter in this way but, obviously, operating a pencil-and-paper digital filter is a lengthy business. A simple BASIC program gives results more quickly.

### BASIC simulation

**Figure 53** lists a GWBASIC program that simulates digital filters of the type illustrated in Fig. 51. It is easily converted into other dialects

```

10 REM *** FIR DIGITAL FILTER ***
20 DIM X(100), A(100)
30 CLS:INPUT"Number of taps";T
40 INPUT"Number of samples";N
50 PRINT"Select waveform"
60 PRINT TAB(10)"1 Square
70 PRINT TAB(10)"2 Sawtooth
80 PRINT TAB(10)"3 Triangle"
90 PRINT TAB(10)"4 Sine"
100 PRINT TAB(10)"5 Pulse"
110 INPUT"Key 1 to 5";W
120 INPUT"Period";P
130 FOR J=0 TO T-1
140 PRINT"Coefficient ";J;:INPUT"=" ;A(J)
150 NEXT
160 FOR SAMPLE=0 TO N STEP 1
170 XS=SAMPLE MOD P
180 ON W GOTO 190, 220, 230, 250, 260
190 XS=SGN(XS-P/2)
200 X=0:IF XS>0 THEN X=255
210 GOTO 270
220 X=INT(XS*255/P):GOTO 270
230 X=INT(XS*255/P):IF X>127 THEN X=255-X
240 GOTO 270
250 X=INT((SIN(XS*6.283/P))*127+127):GOTO 270
260 X=0:IF SAMPLE<=P THEN X=255
270 FOR J=T-1 TO 1 STEP -1
280 X(J)=X(J-1)
290 NEXT
300 X(0)=INT(X)
310 Y=0
320 FOR J=0 TO T-1
330 Y=INT(Y+X(J)*A(J))
340 NEXT
350 PRINT X; Y;" ";
360 NEXT

```

Fig. 53

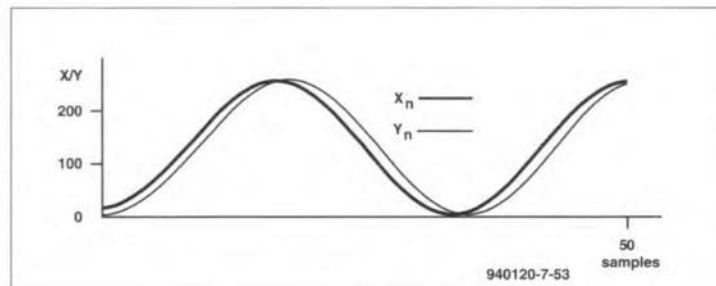


Fig. 54.

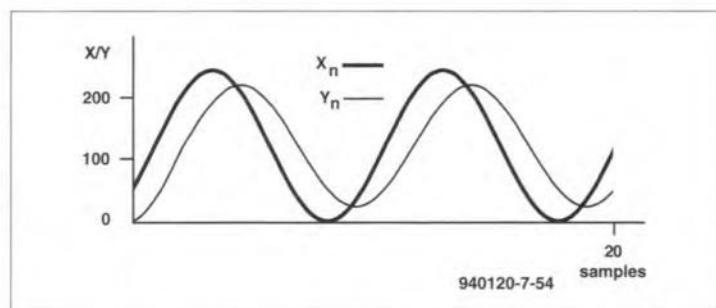


Fig. 55.

of BASIC. The program allows the user to decide on the number of taps, the number of samples, the waveform, the period (the number of samples per cycle of the waveform or the length of the single pulse), and the coefficients for each tap. The waveforms all have an amplitude and offset of

127, so they are equivalent to having 8-bit registers in the filter. Actual filters usually have 16-bit registers, giving a precision of 1 in 65536 or 0.0015%, provided that the amplitude of the waveform is sufficiently great to *almost* saturate the registers. Incidentally, this factor is impor-

tant in all kinds of digital circuit. The precision of a digital value is usually  $\pm 1$  bit, so the precision with which a value is represented digitally depends on its magnitude. Values in the region of 60 000 have a precision of 0.0015%, but values in the region of 100 (with 7 bits) have a precision of only 0.01%. For optimum precision, registers should be used near their full capacity, provided that they do not become over-full. Usually, the most significant digit of a register that is filled beyond its full capacity changes from 1 to 0, with a dramatic fall in the value stored. This would seriously upset the action of the filter. Many DSPs have registers that minimize the error by making the register fill with 1s when there is overflow. The error passes along the chain and is eventually lost (not so in another filter type yet to be described). Similarly, if a register underflows, it is made to hold all 0s. This feature could be added to the BASIC program.

The results of filtering a sine wave are shown in **Fig. 54**. The program was set to provide three taps with coefficients  $a_0 = 0.25$ ,  $a_1 = 0.5$ , and  $a_2 = 0.25$ . The period of the sine wave is 40 samples. The magnitude of the coefficients affects the 'gain' of the filter; for a 'gain' of 1, the coefficients should total about 1. The graph shows a transient response for the first three samples as they are shifted through to occupy both taps. From then on, the filtered waveform is a sine wave of the same frequency and almost the same amplitude as the input signal. There is a very slight phase delay of one sampling period. In a real digital filter in which the sampling rate is higher in comparison with the signal frequency, this delay is negligible. Note that in this filter we have allocated the middle tap the largest coefficient, and that  $a_0$  and  $a_2$  are equal. This symmetrical pattern of coefficients has the effect of giving the filter a linear phase response, a characteristic of Bessel filters in the analogue world. Unfortunately, this advantageous feature of analogue Bessel filters is counter-balanced by their poor roll-off. With digital fil-

ters we can have linear phase response and good roll-off, too.

**Figure 55** shows the result of filtering a sine wave of four times the frequency (period = 10 samples), but leaving the number of taps and the coefficients unchanged. The output is a sine wave of the same frequency, lagging one sample period behind the input, as before. But the amplitude of the output is less than that in the previous example, indicating that the filter is behaving as a low-pass filter. With more taps, the effect would be greater.

The low-pass action is more apparent in **Fig. 56** in which a single pulse is filtered. In this example, the filter has 11 taps with coefficients 0.19, 0.17, 0.15, 0.13, 0.11, 0.09, 0.07, 0.05, 0.03, 0.01 and 0.005. The 'exponential' rise and fall at the beginning and end of the pulse are indicative of a low-pass filter. By contrast, **Fig. 57** shows behaviour associated with a high-pass filter. Analogue high-pass filters are differentiators, so we might expect to use *differences* between successive samples to represent rate of change and thus produce a high-pass filter. Figure 57 was produced with a 5-tap filter with coefficients 0.1, 0.25, 0.4, -0.25, and 0.1. Typical upward and downward spikes occur at the beginning and end of each pulse of this square wave.

The mathematics of digital filters is highly involved and any discussion of this is not appropriate to this series. The coefficients for the foregoing examples were arrived at by intuition rather than by calculation. But enough has been said to illustrate the principles behind digital filtering. The reader is left to investigate further, using the BASIC program.

### Another digital filter

The filter described above is known as a *finite impulse response* or FIR filter. Each sample is considered to be an impulse. Each sample passes along the row of taps and is eventually lost. Thus, each impulse exerts its effect for a finite number of sample periods. **Figure 58** shows a different type of digital filter. The

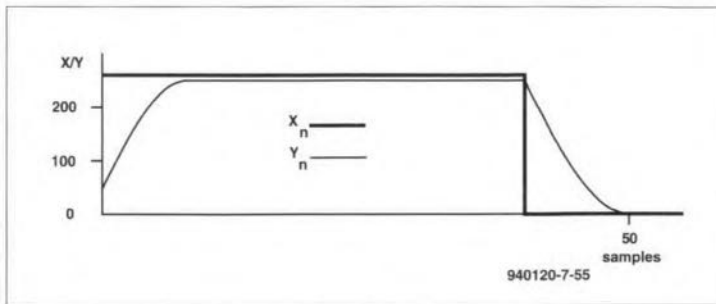


Fig. 56.

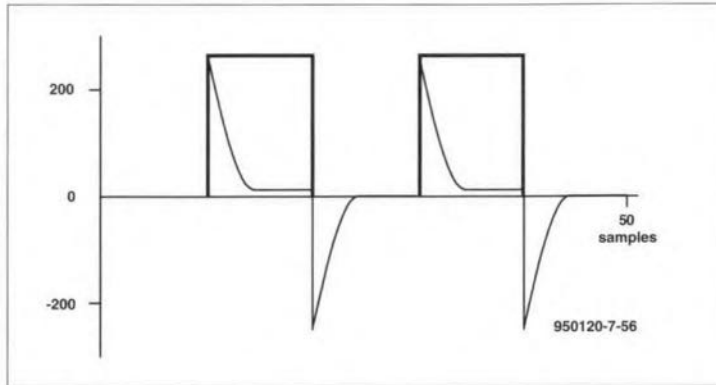


Fig. 57.

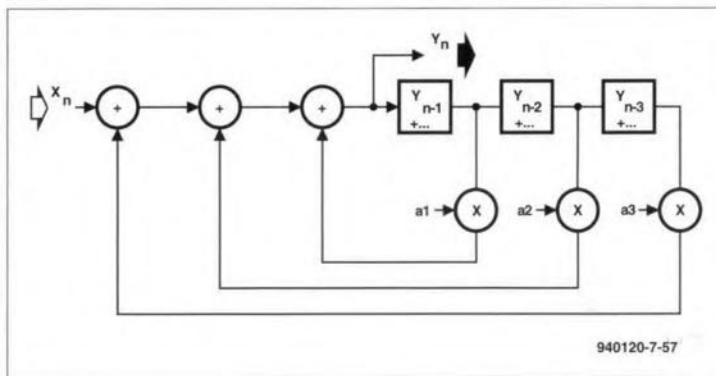


Fig. 58

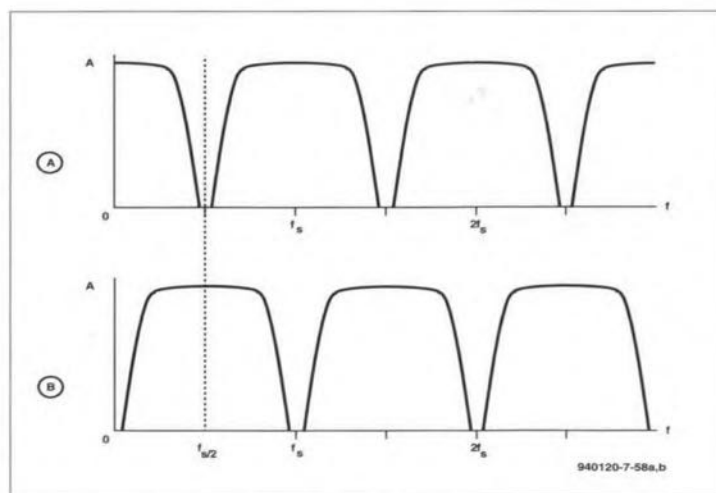


Fig. 59.

value in each tap, multiplied by the corresponding coefficient, is fed back to the input side, to be summed with the products from subsequent samples. Each sample, multi-

plied by the coefficients, thus circulates indefinitely in the filter. The filter is described as an *infinite impulse response* or IIR filter. For a given number of taps, an IIR filter has a faster roll-off at the extremes of the passband, which is an advantage. However, in contrast with an FIR filter, which is always stable, an IIR filter may become unstable in certain circumstances. This is because the IIR filter has an element of feedback in its action and, where there is feedback, there is always the possibility of the system going into permanent oscillation. For this reason, IIR filters need much more careful design.

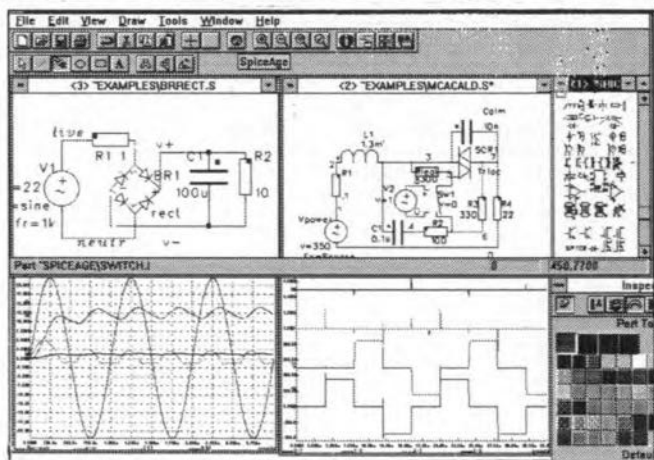
The FIR and IIR filters are the two basic configurations of digital filters, but it is possible to combine both types. The simplest of these is a filter in which the output from each register is summed and sent to the filter output, as in an FIR filter and, at the same time, the output of each register is also fed back to the input side as in an IIR filter. It is possible to cascade these filters or connect them in parallel to give filters of higher order. There are very many ways in which filters can be built, leading to a wide range of responses that can be engineered. The digital filter is a flexible device and is capable of realizing filter functions that are not possible with analogue filters.

We have shown that digital filters may be implemented in several different ways. The BASIC program is one such way which, though quick enough as a demonstration, is not fast enough to filter, say, an audio signal. Increased speed is obtained by programming the computer in machine code, but this falls short of the speed that can be achieved with a dedicated digital signal processor. Multiplication is an essential stage in filtering and, on a microprocessor acts as a bottleneck. It takes a microprocessor several machine cycles to perform a multiplication. In contrast, DSPs have multiplication circuits built in, and can multiply in a single cycle. A DSP, such as one of the Texas TMS320C5x series, operating as a 50-tap filter, can



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- *Geswin* automatically invokes (or switches to) *SpiceAge*; you can also invoke *Geswin* from *SpiceAge*.



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\*upgrade price from *GESECA*; £295 + VAT new

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accept and filter signals at frequencies up to 250 kHz. In contrast, a typical microprocessor, working at 33 MHz and programmed as a 50-tap filter, can filter signals with a maximum frequency of only 25 kHz.

### Frequency response

It is a consequence of the mathematics that the frequency response of digital filters is repeated at multiples of the sampling frequency. Whether a filter is considered to be low-pass, high-pass, band-pass or band-stop depends on the relationship between the location of the multiple pass-bands in the frequency spectrum. In Fig. 59a, the first pass-band extends from zero frequency (0) to a value less than  $f_s/2$ , where  $f_s$  is the sampling frequency. The band is repeated at  $f_s, 2f_s, \dots$ . The sampling frequency is chosen so that it is at least double the frequency of any signal that is of interest. This is why, in digital audio, for which 20 kHz is the highest frequency that the human ear can detect, the sampling frequency is at least 40 kHz. The

result is that the low-pass filter passes all the lower frequencies that can be heard (to the left of the dashed line) and also higher frequencies that can not be heard. In Fig. 58b, the pass-bands are shifted up the frequency spectrum. The band within the range of interest provides a high-pass function. Suitably located combs of bands can provide band-pass and band-stop filters.

### The digital solution

Digital filters operate by calculating and produce an output to any reasonably required level of precision. In addition, filters of widely differing characteristics can all be realized with a general-purpose DSP device. There is no need of high-precision (and expensive) resistors, capacitors (possibly ganged), inductors or op amps as there is for an analogue filter. There is no need for special layouts on the PCB. Discrete components, particularly inductors, are relatively bulky and take circuit-board space. A digital filter is built from minute devices on a silicon chip and takes up little

space. No matter how precise the components in an analogue filter, they introduce parasitic capacitance and inductance into the circuit with consequent distortion. Trimmers to adjust the capacitances and inductances are often required in precision analogue filters, adding more to cost and board space.

Even when an analogue filter has been built from high-precision components and carefully trimmed, its behaviour is subject to changes in component values resulting from age or temperature. Digital filters work precisely according to the response designed into them and are entirely stable. This is a reminder that it is possible to program a digital filter with frequency and phase responses that are just not possible with analogue techniques.

Finally, there is the advantage that the response of a digital filter can be altered, possibly quite drastically, simply by changing the values of the coefficients. A few small changes in the coefficients can even change a low-pass filter into a high-pass filter. Ana-

logue filters need complete rewiring to effect such a change. The ability to program the filter by changing the coefficients opens up the possibility of altering the response of the filter while it is running. This means that the filter can be altered to suit the signal that it is currently receiving. Filters of this type are known as *adaptive filters*. The incoming signal is monitored and the coefficients altered accordingly. Taking all these points into consideration, it is not surprising that the digital solution has been so widely adopted.

**Reference:** Craig, Marvin and Ewers, Gillian: *A simple approach to digital signal processing*; Texas Instruments, 1993.

### Test yourself

The IIR filter in Fig. 58 has coefficients  $a_0 = 0.2$ ,  $a_1 = 0.4$ , and  $a_2 = 0.2$ . A single ramp pulse is fed into it, having values 2, 4, 6, 8, 10. Find the output of the filter for 10 consecutive sample times, rounding to four decimal places.

[940120-VII]



# FUNCTION GENERATOR

Design by H. Bonekamp

A generator is described that, based on the MAX038, provides triangle, sawtooth, sine, rectangular and pulse waveforms.

The MAX038, on which the present generator is based, is an integrated, high-frequency, precision function generator whose output frequency can be controlled over a frequency range of 0.1 Hz to 20 MHz by an internal 2.5 V bandgap voltage reference and an external resistor and capacitor. Its duty factor can be varied over a wide range by applying a  $\pm 2.3$  V control signal, facilitating pulse-width modulation and the generation of sawtooth waveforms. Frequency modulation and frequency sweeping are achieved in the same way. The duty factor and frequency controls are independent.

## Circuit description

The circuit diagram of the generator proper is shown in **Fig. 1** and that of the liquid crystal display, LCD, in **Fig. 2**.

The frequency of the MAX038, IC<sub>1</sub>, is determined by C<sub>1</sub>-C<sub>7</sub> which are linked to pin 5 via S<sub>1a</sub>. The highest frequency is governed by C<sub>5</sub>-C<sub>7</sub>, an arrangement that eliminates the effect of parasitic capacitances (about 20 pF). Switch section S<sub>1b</sub> sets the decimal point on the display.

The waveform is selected with S<sub>2</sub>, one of whose sections (a) is linked to selection input pins 3 and 4 of IC<sub>1</sub>. The second section (b) is used to set the duty factor and symmetry of relevant output signals (triangle, sine and rectangular).

The symmetry is set with an auxiliary voltage derived from the reference potential,  $U_{ref} = 2.5$  V, which is generated internally by IC<sub>1</sub>. The duty factor must be adjusted with a symmetrical reference voltage, which is obtained by inverting  $U_{ref}$  in IC<sub>3a</sub>, that is, amplified by -1. The op amp is stabilized by an RC network. The control range of P<sub>1</sub> then extends from  $-U_{ref}$  to  $+U_{ref}$ .

The signal at the wiper of P<sub>1</sub> is applied to duty factor adjust pin 7 of IC<sub>1</sub> via IC<sub>2b</sub> when S<sub>2</sub> is set to position sine, triangle or rectangular. In positions triangle and pulse, the potential at pin 7 is set with P<sub>2</sub>. Although this potentiometer also has a control range of  $-U_{ref}$  to  $+U_{ref}$ , this is reduced to about 40%. This diminution is required since all control inputs, with the exception of sweep, are normalized to a range based on a control voltage of  $\pm 1$  V.

The signal frequency can be varied via voltage-controlled frequency adjust input pin 8 and via current-controlled frequency control current input pin 10 of IC<sub>1</sub>.

A voltage is applied to pin 8 when an external signal is to provide frequency modulation. The control voltage, taken from K<sub>4</sub>, is applied via S<sub>3a</sub> to IC<sub>2a</sub>, in which it is raised  $\times 2.4$  to normalize it to  $\pm 1$  V.

With switch S<sub>3</sub> in position 1, the input at pin 10 of IC<sub>1</sub> enables the frequency to be set manually so that the generator can be used in the traditional way. Pin 8 is then low (via IC<sub>2a</sub>). The current sunk via pin 10 varies between 16  $\mu$ A and 250  $\mu$ A.

With S<sub>3</sub> in position 3, the central frequency can be set with P<sub>5</sub>, whereupon the frequency sweep around this frequency is arranged by a voltage at K<sub>4</sub>.

With S<sub>3</sub> in position 2, op amp IC<sub>6b</sub> raises the external sweep signal at K<sub>4</sub>  $\times 7.5$ , whereupon the signal is passed to IC<sub>6a</sub> via S<sub>3b</sub>. Op amp IC<sub>6a</sub> is connected as a voltage follower, whose output is converted into a current to pin 10 of IC<sub>1</sub> by R<sub>30</sub>. Here again, pin 8 is made low.

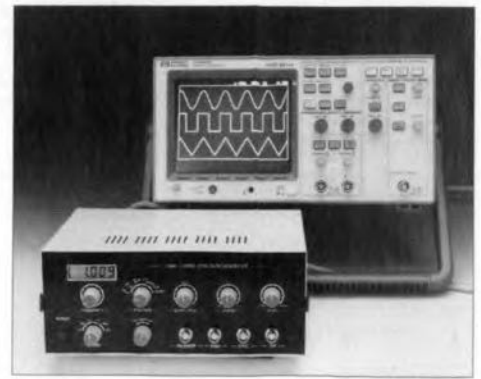
The output signal is available at OUT (pin 19) of IC<sub>1</sub>. Since this is not sufficient, it is applied to buffer amplifier IC<sub>4</sub>. This op amp has a slew rate of 1000 V  $\mu$ s<sup>-1</sup> and a peak output current of 150 mA. It amplifies the output of IC<sub>1</sub>  $\times 10$  and, at the same time, ensures correct compensation of the offset voltage (in conjunction with IC<sub>3b</sub>). The output voltage at K<sub>3</sub> can be preset between 0.5 V<sub>pp</sub> and 22 V<sub>pp</sub>. Resistors R<sub>22</sub>, R<sub>23</sub>, R<sub>24</sub>, and R<sub>25</sub> ensure an output impedance of 50  $\Omega$ , and at the same time that the output resistance can dissipate sufficient power.

The junction R<sub>18</sub>-R<sub>19</sub>-R<sub>20</sub> is at ground potential for a.c. via C<sub>18</sub>, C<sub>19</sub> and C<sub>20</sub>, but direct voltages at the output of IC<sub>3b</sub> are applied to IC<sub>4</sub>. Since IC<sub>3</sub> does not work well with a capacitive load, a compensating network, R<sub>18</sub>-R<sub>19</sub>-C<sub>17</sub> is provided at its pin 7. In this way, the offset of the output signal can be adjusted by  $\pm 5$  V.

The SYNC output (pin 14 of IC<sub>1</sub>) is buffered by TTL gate IC<sub>5e</sub> and then applied to K<sub>1</sub>. The signal is at TTL level. The impedance at K<sub>1</sub> is 50  $\Omega$ .

All op amps in the circuit, in which signals at frequencies up to 100 MHz can occur, are decoupled extensively.

The power supply is straightforward and traditional. The rectified symmetri-



## Brief specification

Output waveform: sine, triangle, pulse, rectangular, sawtooth  
 Rectangular wave:  $t_r, t_f \ll 15$  ns  
 Duty factor: variable 15-85%  
 Sine wave: frequency range: 10 Hz-10 MHz;  
 THD  $\ll 1\%$   
 Number of ranges: 6  
 Frequency stability:  $df/f \ll 0.1\%$   
 Output level (sync): TTL  
 Output level (analogue): 20 V peak to peak  
 Offset compensation:  $\pm 5$  V  
 Display: 4 $\frac{1}{2}$  digit  
 FM modulation:  $f_o \pm 70\%$   
 FM sensitivity:  $\pm 1$  V  
 FM bandwidth: 2 MHz ( $R_{in} = 100$  k $\Omega$ )  
 Sweep range: 25:1  
 Sweep sensitivity: 0-1 V  
 Sweep bandwidth: 10 kHz ( $R_{in} = 100$  k $\Omega$ )

cal voltage is regulated by IC<sub>7</sub> and IC<sub>8</sub> to  $\pm 15$  V and by IC<sub>9</sub> and IC<sub>10</sub> to  $\pm 5$  V.

The display is coupled to K<sub>6</sub> on the generator via K<sub>1</sub>. Pin 5 of this connector carries the SYNC signal (which has the same frequency as the output of the MAX038. Unfortunately, there is no possibility of the display showing whether the frequency is in Hz, kHz or MHz. However, a solution to this has been found: if the display shows only digits, the frequency is in Hz; if the digits are separated by a decimal point, the frequency is in kHz, and when the digits are separated by a decimal point and preceded by a colon, the frequency is in MHz.

The time base of the display circuit is provided by IC<sub>7</sub> (note that this must be the A version of the ICM7207). The IC also generates all control signals for the counter proper and display driver IC<sub>8</sub>. The combination of these two ICs forms a frequency-independent counter. Depending on the level at pin 11 of IC<sub>7</sub>, a measuring period of 0.1 s for the three highest frequency ranges or 1 s for the three lowest ranges is used. This gives measuring cycles of 0.2 s and 2 s respectively. This is too long for the highest frequencies, so that the times are scaled down by 100 and 10 respectively. This is done in IC<sub>6</sub>. The final measuring result is displayed on LCD<sub>1</sub>.

Power-up network R<sub>3</sub>-C<sub>3</sub> arranges for



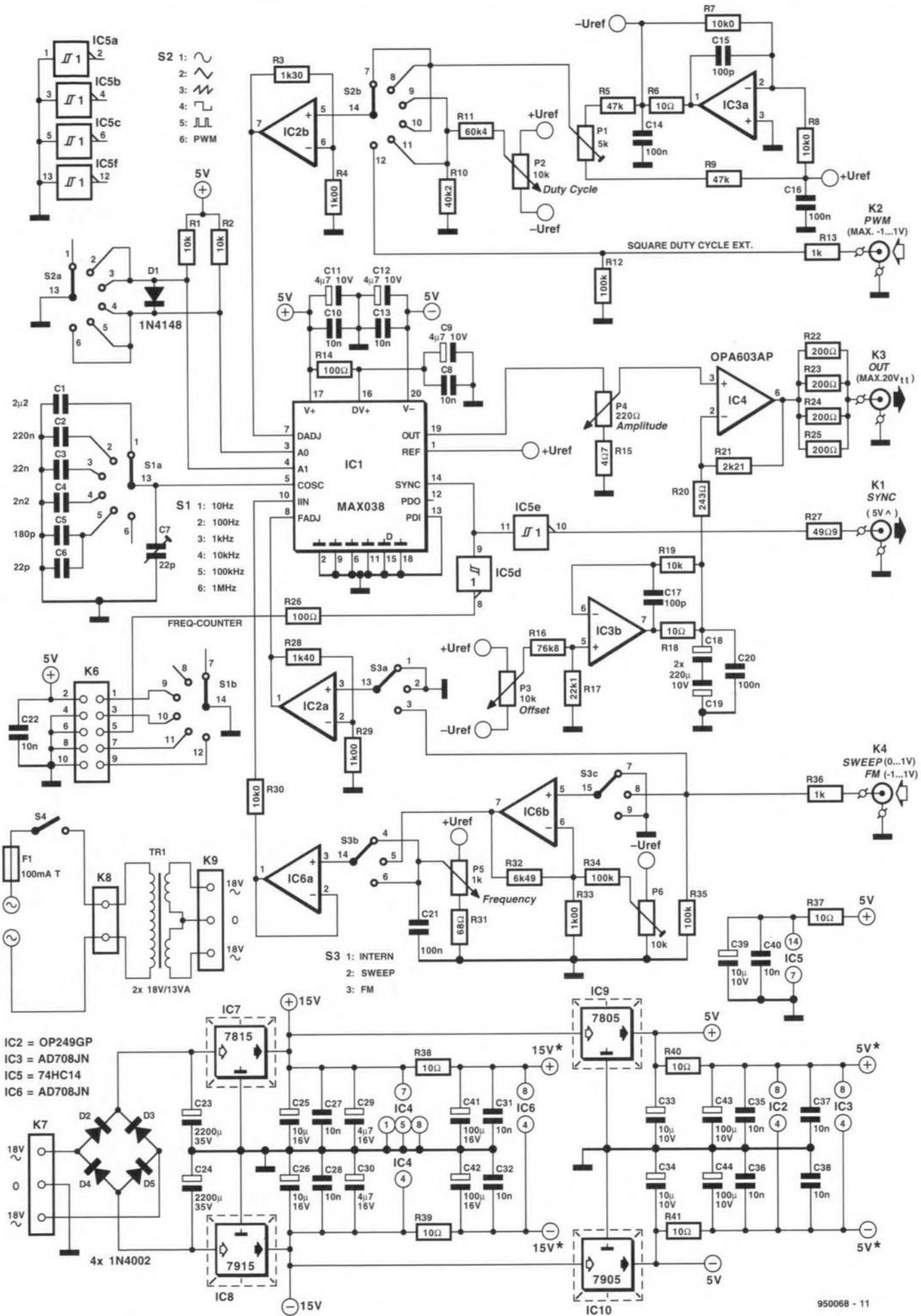


Fig. 1. Circuit diagram of the waveform generator.

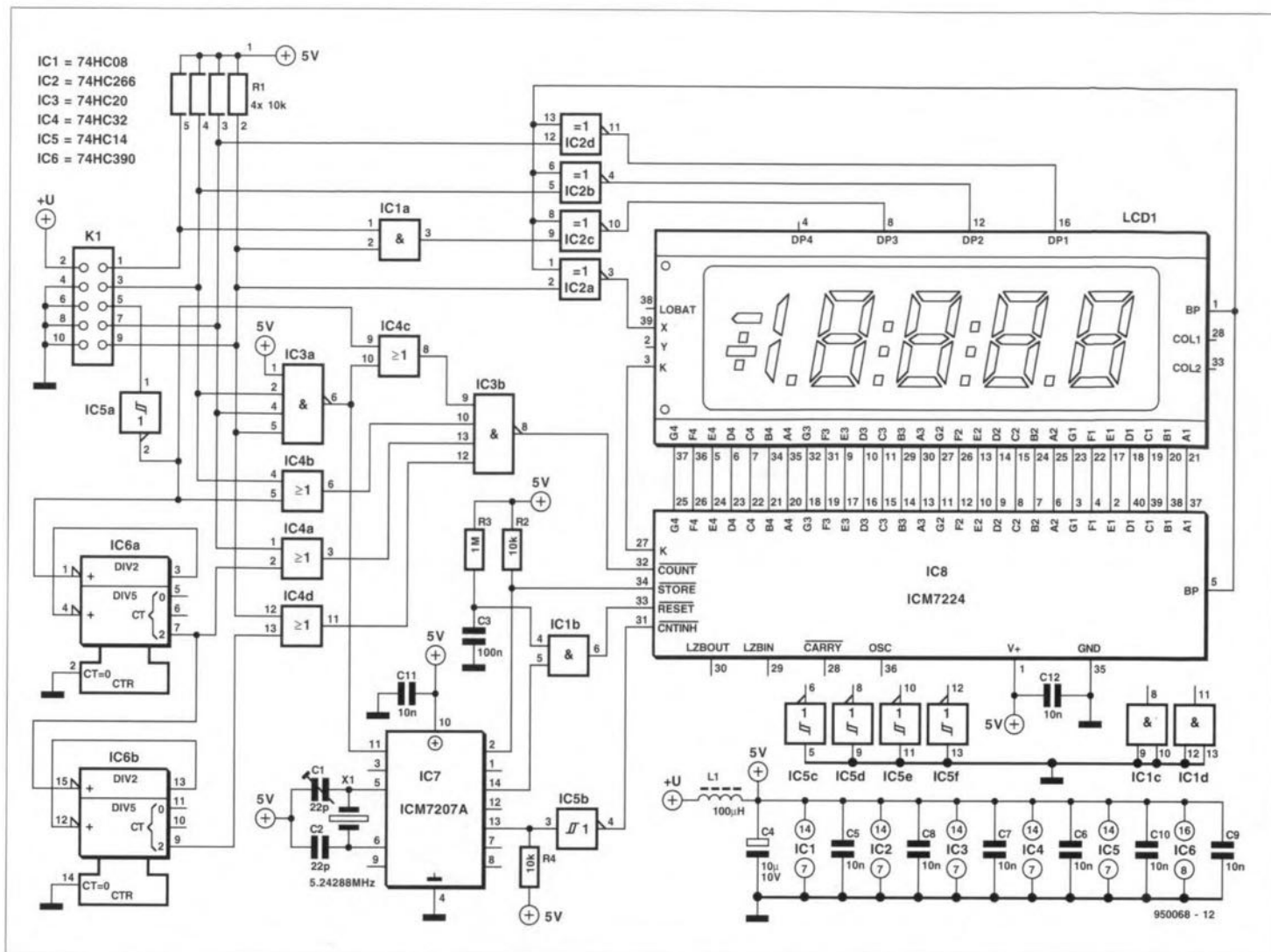


Fig. 2. Circuit diagram of the display unit.

the display to be set to a defined readout after the supply has been switched on. This prevents the appearance of undefined characters on the screen on power up.

The signal at pin 1 (BP) of the LCD ensures that the display is always driven by a.c. Driving it with d.c. would cause irreparable damage.

## Construction

The function generator is intended to be built on the double-side, through-plated printed-circuit board shown in Fig. 4. This board consists of three parts, mother board, display board and transformer board, which should be separated from each other before any other work is done.

It is best to start with the mother board: fit four spacers in the fixing holes near the corners—see Fig. 3. Use sockets for all ICs, except IC<sub>1</sub> and IC<sub>4</sub>, which should be soldered directly to the board. (Sockets create too much spurious inductance). Note that IC<sub>4</sub> uses the copper pad on the board as heat sink, for which three special pins are provided on the device. Use adequate solder to ensure good thermal coupling with the copper. When the board has been completed, fix a small heat sink on

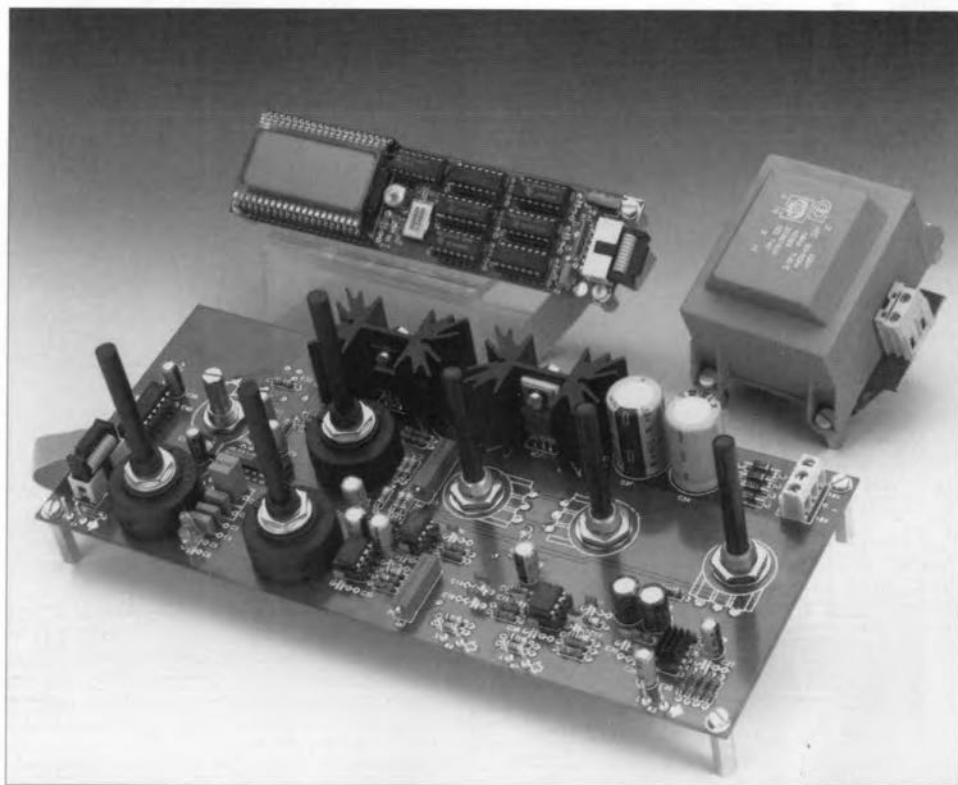


Fig. 3. The three boards that constitute the function generator.



to IC<sub>4</sub> as shown in Fig. 5: use a small drop of superglue for this.

A few points to note in the construction of this board: trimmer capacitor C<sub>7</sub> is fitted at the track side as are the four presets—see Fig. 6. The heat sinks for IC<sub>7</sub>-IC<sub>8</sub> and IC<sub>9</sub>-IC<sub>10</sub> are fitted at the component side. Make sure that the regulators mounted on a common heat sink are well insulated from one another: use ceramic washers and plastic tubing in each of the screw holes.

The mains transformer is mounted on a dedicated, small board, which has, however, no mechanical function: it merely provides the necessary connection points and makes the required link between the two secondary windings. The assembly is fitted in the enclosure by the eyelets in the transformer housing.

The display board is, of course, not essential, but it is very useful. An external frequency meter may also be used: if so, it must be connected to the SYNC output.

In the prototype, all ICs are fitted in sockets; the LCD in two single-row 20-pin sockets. Note that other than the specified LCD may be used.

The flatcable should be laid well away from IC<sub>1</sub>, since the high-frequency digital signals carried by it may adversely affect the operation of the IC.

Finally, note that capacitor C<sub>4</sub> is a radial type that must be fitted axially.

## Setting up

Link the display board to the mother board via a short length of flatcable. Connect the mains transformer to K<sub>7</sub> on the mother board and switch on the mains. Take care not to touch anything at the primary side of the transformer.

To adjust the symmetry of the signal, set S<sub>2</sub> to position 4: rectangular wave. Select a frequency of about 10 kHz and turn P<sub>4</sub> fully anticlockwise. Connect a multimeter, set to direct voltage to the output, whose level should be minimal. Vary P<sub>3</sub> (offset) until the multimeter reads 0 V.

Place an RC network, consisting of a 10 kΩ resistor in series with a 1 μF polypropylene capacitor, in series with one of the multimeter leads and the output. Turn P<sub>4</sub> fully clockwise and vary P<sub>1</sub> until the d.c. component is 0 V.

Users fortunate enough to have access to a spectrum analyser can do the following. On the function generator, select a sine wave output and adjust the level of the second harmonic to a minimum with P<sub>1</sub>.

To set the lower limit of the sweep range, note that the IC works optimally when the lower limit is set to one tenth of the value of the lower limit indicated by the range selector. Set S<sub>3</sub> to position 1, S<sub>1</sub> to position 3 or 4, and vary P<sub>5</sub> until the display shows a series of numbers. Set S<sub>3</sub> to position 2 and adjust P<sub>6</sub> until the value read on the display is one

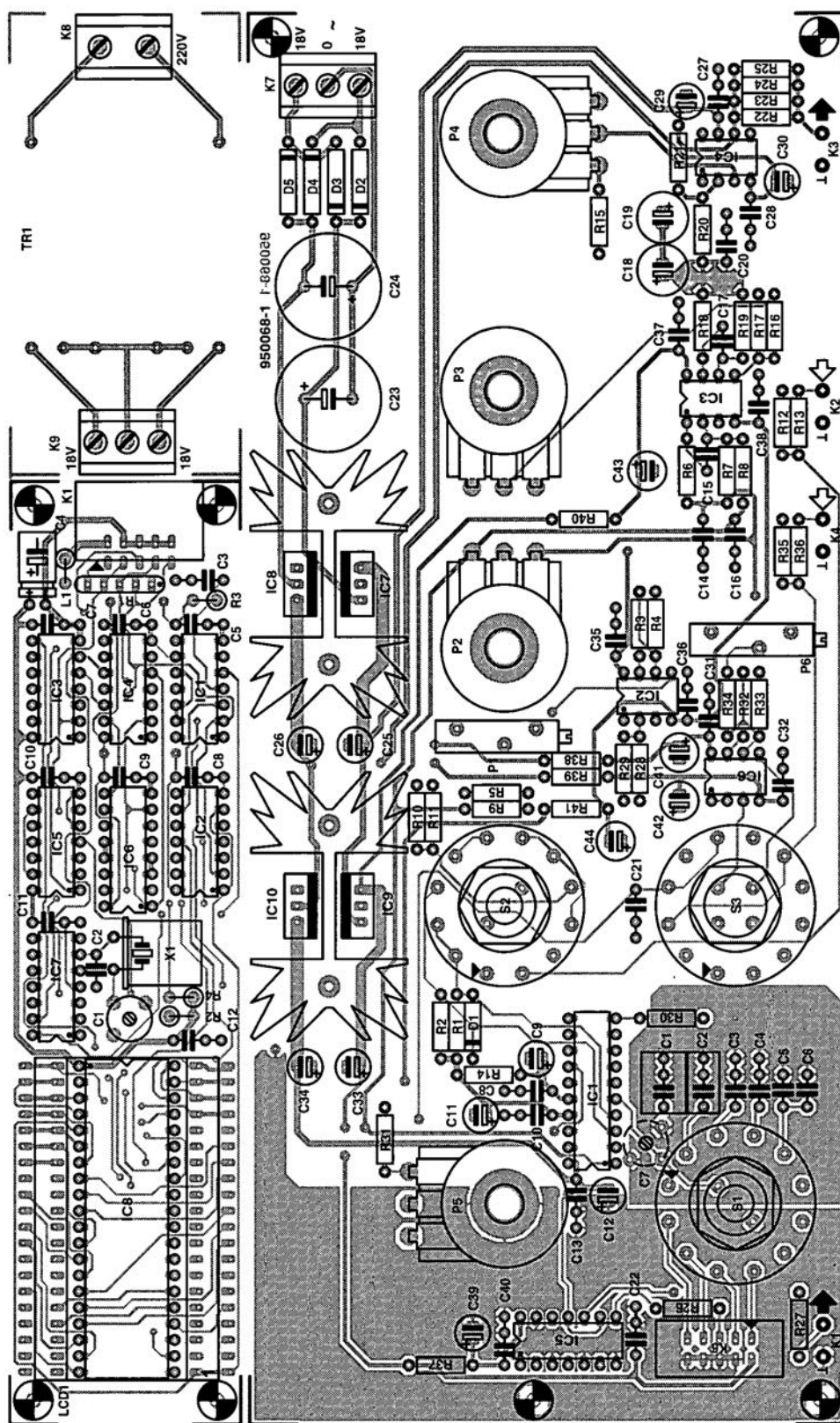


Fig. 4. Component side of the double-sided, through-plated PCB.

tenth of that when S<sub>3</sub> was in position 1.

To set the upper limit of the sweep range, set S<sub>1</sub> to position 6, turn P<sub>5</sub> fully clockwise and vary C<sub>7</sub> until the display reads 10 MHz.

To set up the display board, retain switch S<sub>1</sub> in position 6 and place the function generator in the vicinity of a medium wave radio receiver. Connect a short length of bare circuit wire to the out-

put of the function generator and tune the receiver to a station whose frequency is known, but which should be near the top end of the band above 1 MHz. Vary P<sub>5</sub> until the station is wholly suppressed and adjust C<sub>1</sub> (display board) until the display reads the frequency of the radio station.

The display module is, of course, best calibrated with a standard frequency

meter.

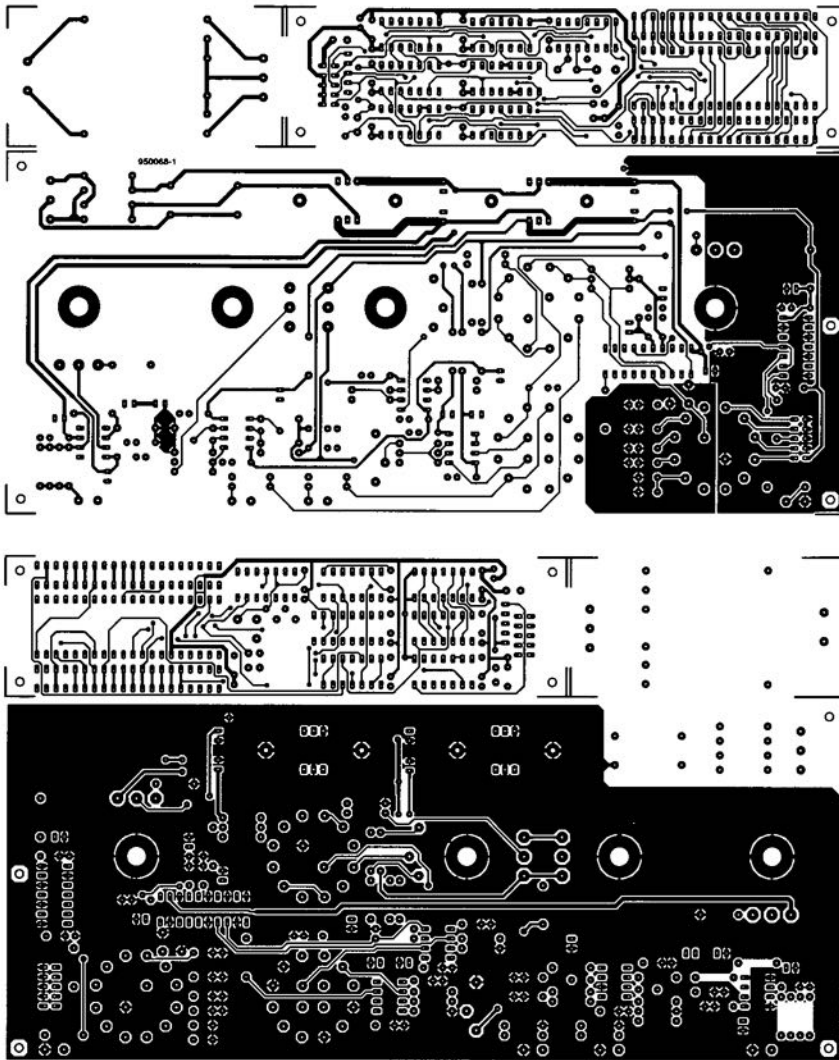
## Assembling the generator

When the generator has been set up and

works correctly, it should be assembled in a suitable enclosure, for instance, as shown in **Fig. 7**. The enclosure should be sturdy and be screened to minimize electromagnetic radiation.

Mount the transformer at the right of the rear panel and the other two boards close behind the front panel. A possible front panel layout is given in **Fig. 8**: note that a ready-made foil for this is available. A photocopy of Fig. 8 can be used as a drilling template for the front panel.

Wiring from the mains entry (with integrated fuse holder) at the rear panel to the mains transformer should be as short as possible and be kept well away from C<sub>1</sub>-C<sub>7</sub>.



**Fig. 4b.** Track side and third foil of the PCB (scale 1:2).

## Parts list

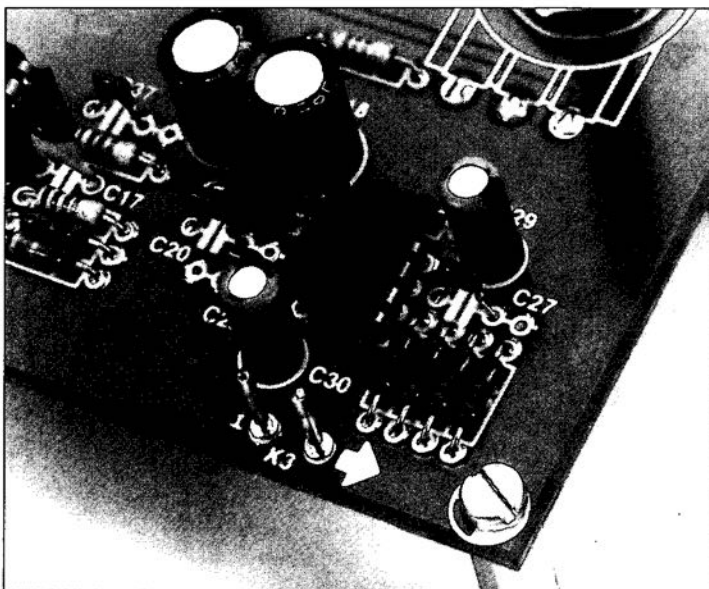
### MOTHER BOARD

#### Resistors:

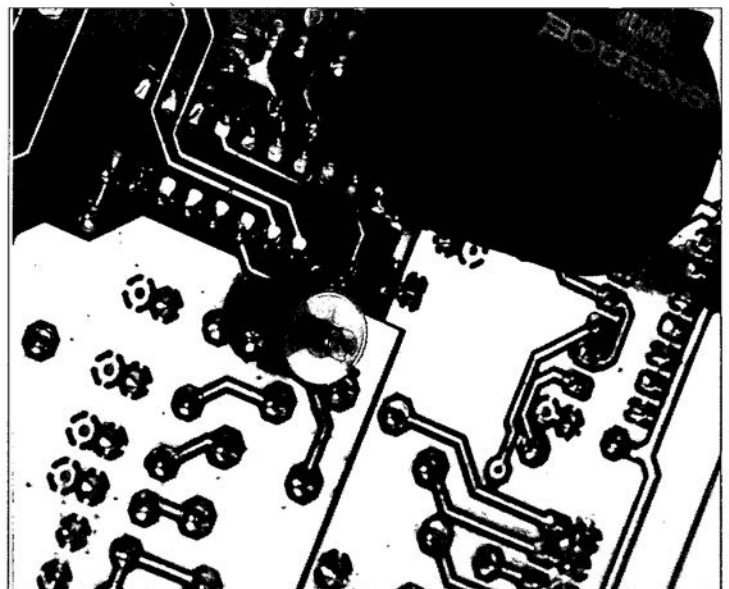
- R<sub>1</sub>, R<sub>2</sub>, R<sub>19</sub> = 10 k $\Omega$
  - R<sub>3</sub> = 1.30 k $\Omega$ \*
  - R<sub>4</sub>, R<sub>29</sub>, R<sub>33</sub> = 1.0 k $\Omega$ \*
  - R<sub>5</sub>, R<sub>9</sub> = 47 k $\Omega$
  - R<sub>6</sub>, R<sub>18</sub>, R<sub>37</sub>-R<sub>41</sub> = 10  $\Omega$
  - R<sub>7</sub>, R<sub>8</sub>, R<sub>30</sub> = 10.0 k $\Omega$ \*
  - R<sub>10</sub> = 40.2 k $\Omega$ \*
  - R<sub>11</sub> = 60.4 k $\Omega$ \*
  - R<sub>12</sub>, R<sub>34</sub>, R<sub>35</sub> = 100 k $\Omega$
  - R<sub>13</sub>, R<sub>36</sub> = 1 k $\Omega$
  - R<sub>14</sub>, R<sub>26</sub> = 100  $\Omega$
  - R<sub>15</sub> = 4.7  $\Omega$
  - R<sub>16</sub> = 76.8 k $\Omega$ \*
  - R<sub>17</sub> = 22.1 k $\Omega$ \*
  - R<sub>20</sub> = 243  $\Omega$ \*
  - R<sub>21</sub> = 2.21 k $\Omega$ \*
  - R<sub>22</sub>-R<sub>25</sub> = 200  $\Omega$ \*
  - R<sub>27</sub> = 49.9  $\Omega$ \*
  - R<sub>28</sub> = 1.40 k $\Omega$ \*
  - R<sub>31</sub> = 68  $\Omega$
  - R<sub>32</sub> = 6.49 k $\Omega$ \*
- \* = 1%

#### Potentiometers

- P<sub>1</sub> = 5 k $\Omega$  (4.7 k $\Omega$ ) multiturn preset
- P<sub>2</sub>, P<sub>3</sub> = 10 k $\Omega$  linear
- P<sub>4</sub> = 220  $\Omega$  (250  $\Omega$ ) linear
- P<sub>5</sub> = 1 k $\Omega$  multiturn, linear (e.g. Bourns Type 3590S-002-102)
- P<sub>6</sub> = 10 k $\Omega$  multiturn preset



**Fig. 5.** Detail of how to fix a small heat sink on to IC<sub>4</sub> with a drop of superglue.



**Fig. 6.** Detail showing how trimmer C<sub>7</sub> is fitted at the trackside of the mother board.



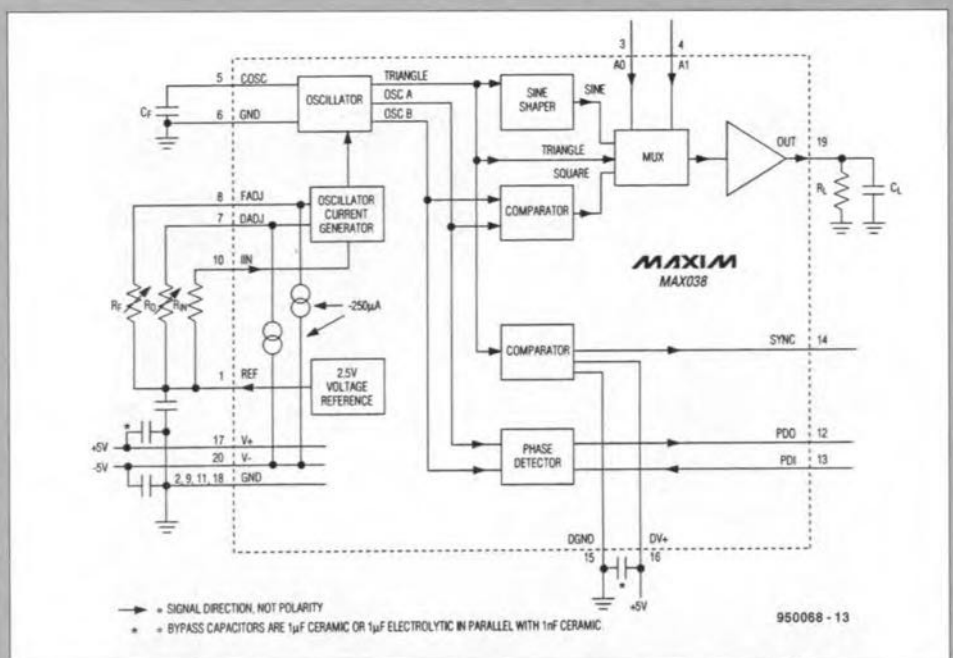
### High-frequency waveform generator MAX038

The MAX038 is a high-frequency function generator that produces low-distortion sine, triangle, sawtooth or rectangular (pulse) waveforms at frequencies from less than 1 Hz to 20 MHz or more, using a minimum of external components. Frequency and duty factor can be independently controlled by programming the current, voltage or resistance. The desired output waveform is selected under logic control by setting the appropriate code at the  $A_0$  and  $A_1$  inputs. A SYNC output and phase detector are included to simplify designs requiring tracking to an external signal source.

The MAX038 operates with  $\pm 5\text{ V} \pm 5\%$  power supplies. The basic oscillator is a relaxation type that operates by alternately charging and discharging a capacitor,  $C_F$ , with constant currents, simultaneously producing a triangle wave and a rectangular wave. The charging and discharge currents are controlled by the current flowing into IIN, and are modulated by the voltages applied to FADJ and DADJ. The current into IIN can be varied from  $2\ \mu\text{A}$  to  $750\ \mu\text{A}$ , producing more than two decades of frequency for any value of  $C_F$ . Applying  $\pm 2.4\text{ V}$  to FADJ changes the nominal frequency (with  $U_{FADJ} = 0\text{ V}$ ) by  $\pm 70\%$ ; this procedure can be used for fine control.

The duty factor (the percentage of time that the output waveform is positive) can be controlled from 10% to 90% by applying  $\pm 2.3\text{ V}$  to DADJ. This voltage changes the  $C_F$  charging and discharge current ratio while nearly constant frequency is maintained.

A stable 2.5 V reference voltage, REF, allows simple determination of IIN, FADJ,



or DADJ with fixed resistors, and permits adjustable operation when potentiometers are connected from each of these inputs to REF. FADJ and/or DADJ can be grounded, producing the nominal frequency with a 50% duty factor.

The output frequency is inversely proportional to  $C_F$ ; values can be selected for this capacitor to produce frequencies above 20 MHz.

A sine-shaping circuit converts the oscillator triangle wave into a low-distortion sine wave with constant amplitude. The triangle, rectangular and sine waves are input to a multiplexer. Two address lines,  $A_0$  and  $A_1$ , control which of the three waveforms is selected. The output amplifier produces a constant  $2\text{ V}_{pp}$

amplitude ( $\pm 1\text{ V}$ ), regardless of wave shape or frequency.

The triangle is also sent to a comparator that produces a high-speed rectangular-wave SYNC waveform that can be used to synchronize other oscillators. The SYNC circuit has separate power-supply leads and can be disabled.

Two other phase-quadrature rectangular waves are generated in the basic oscillator and sent to one side of an XOR phase detector. The other side of the phase detector input, PDI, can be connected to an external oscillator. The phase detector output, PDO, is a current source that can be connected directly to FADJ to synchronize the MAX038 with the external oscillator.

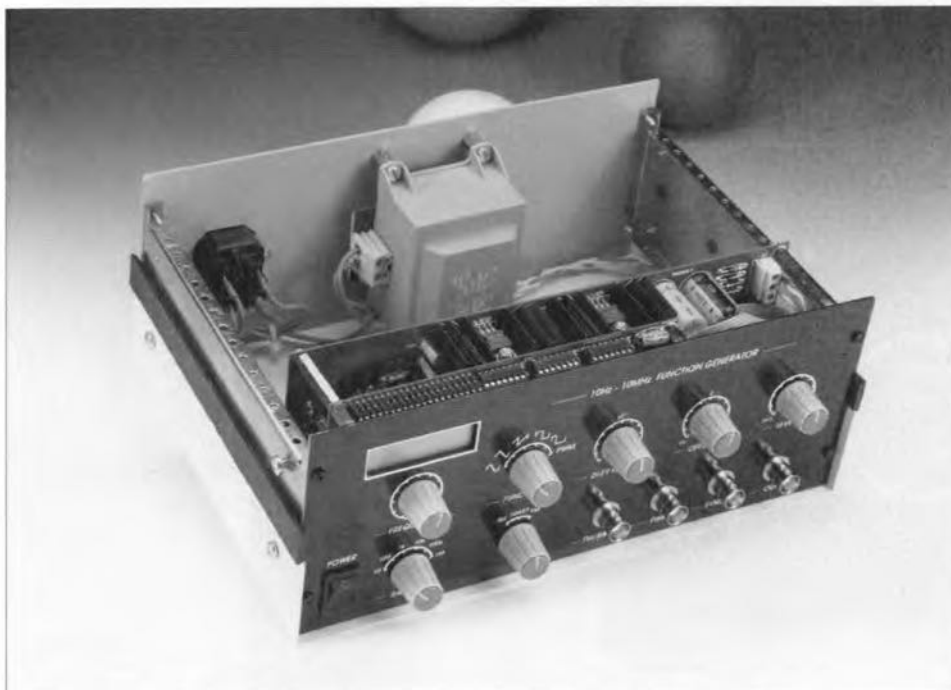


Fig. 7. The completed function generator with top of enclosure removed.

#### Capacitors:

- $C_1 = 2.2\ \mu\text{F}$ , polypropylene\*, 10%
- $C_2 = 220\ \text{nF}$ , polypropylene\*, 5%
- $C_3 = 22\ \text{nF}$ , polypropylene\*, 5%
- $C_4 = 2.2\ \text{nF}$ , polypropylene\*
- $C_5 = 180\ \text{pF}$ , polyester, 2%
- $C_6 = 22\ \text{pF}$ , polyester, 2%
- $C_7 = 22\ \text{pF}$  foil trimmer
- $C_8, C_{10}, C_{13}, C_{22}, C_{27}, C_{28}, C_{31}, C_{32}, C_{35}-C_{38}, C_{40} = 10\ \text{nF}$
- $C_9, C_{11}, C_{12} = 4.7\ \mu\text{F}$ , 10 V, radial
- $C_{14}, C_{16}, C_{20}, C_{21} = 100\ \text{nF}$
- $C_{15}, C_{17} = 100\ \text{pF}$  ceramic
- $C_{18}, C_{19} = 220\ \mu\text{F}$ , 10 V, radial
- $C_{23}, C_{24} = 2200\ \mu\text{F}$ , 35 V, radial
- $C_{25}, C_{26} = 10\ \mu\text{F}$ , 16 V, radial
- $C_{29}, C_{30} = 4.7\ \mu\text{F}$ , 16 V, radial
- $C_{33}, C_{34}, C_{39} = 10\ \mu\text{F}$ , 10 V, radial
- $C_{41}, C_{42} = 100\ \mu\text{F}$ , 16 V, radial
- $C_{43}, C_{44} = 100\ \mu\text{F}$ , 10 V, radial

#### Semiconductors:

- $D_1 = 1\text{N}4148$
- $D_2-D_5 = 1\text{N}4002$

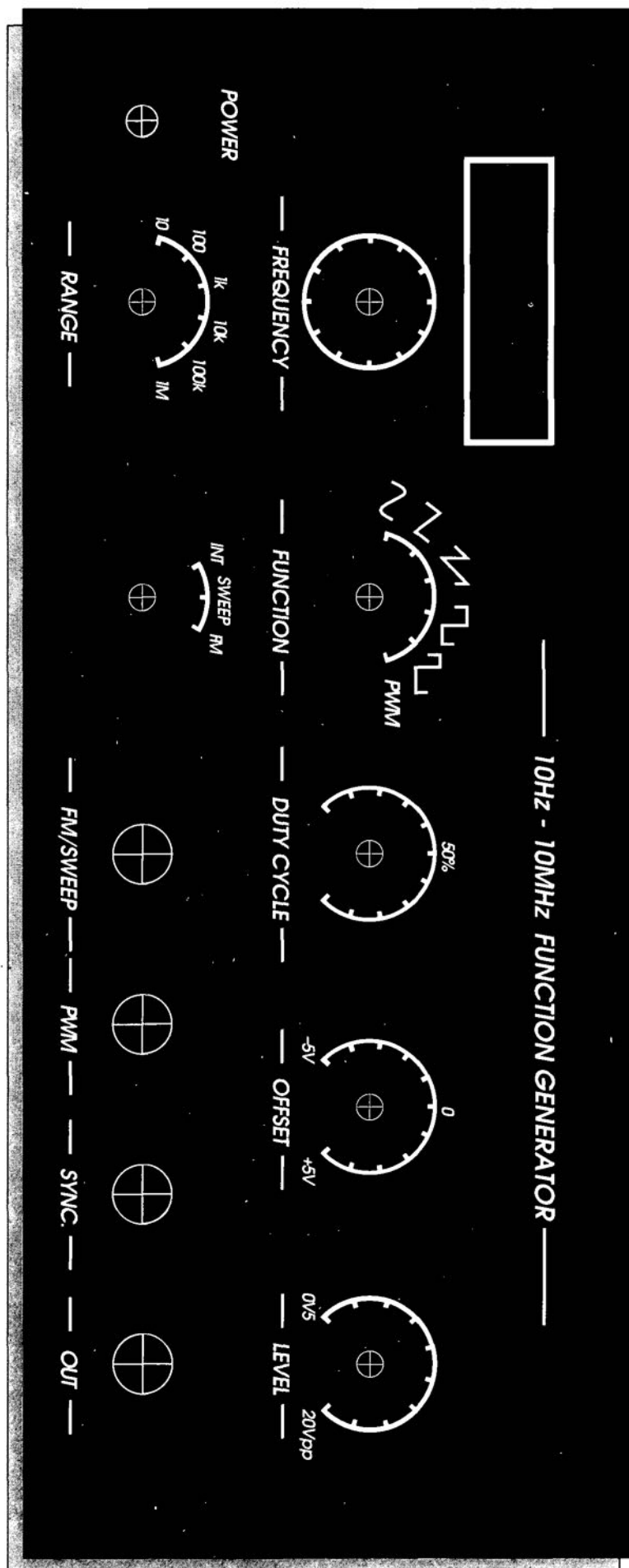


Fig. 8. Suggested front panel layout for the function generator (scale 1:1). A self-adhesive foil is available - see p. 70

#### Integrated circuits:

IC<sub>1</sub> = MAX038CPP (Maxim)  
 IC<sub>2</sub> = OP249GP (Analog Devices)  
 IC<sub>3</sub>, IC<sub>6</sub> = AD708JN (Analog Devices)  
 IC<sub>4</sub> = OPA603AP (Burr Brown)  
 IC<sub>5</sub> = 74HC14  
 IC<sub>7</sub> = 7815  
 IC<sub>8</sub> = 7915  
 IC<sub>9</sub> = 7805  
 I<sub>10</sub> = 7905

#### Miscellaneous:

K<sub>1</sub>-K<sub>4</sub> = BNC socket (board fitting)  
 K<sub>6</sub> = 10-way box header  
 K<sub>7</sub>, K<sub>9</sub> = 3-way terminal block, 5 mm pitch  
 K<sub>8</sub> = 2-way terminal block, 7.5 mm pitch  
 S<sub>1</sub>, S<sub>2</sub> = 2-pole, 6-position rotary switch  
 S<sub>3</sub> = 4-pole, 3-position rotary switch  
 S<sub>4</sub> = double-pole on/off switch  
 F<sub>1</sub> = fuse, 100 mA, slow  
 Tr<sub>1</sub> = mains transformer, secondary  
 2 × 18 V, 13 VA  
 2 off heat sink, 6.5 K W<sup>-1</sup> (e.g. SK129/25\*)  
 1 off heat sink, 83 K W<sup>-1</sup> (e.g. ICK6/8L)  
 for DIP-8 case  
 4 off ceramic washers  
 Screened cable as required  
 Enclosure to individual requirements  
 (prototype = LC960 from LTP)  
 PCB Ref. No. 950068 (see p. 70)  
 Front panel foil Ref. No. 950068-F  
 (see p. 70)  
 \* Dau (UK) Ltd, Phone (01243) 553031

#### DISPLAY BOARD

##### Resistors:

R<sub>1</sub> = array of 4 × 10 kΩ  
 R<sub>2</sub>, R<sub>4</sub> = 10 kΩ  
 R<sub>3</sub> = 1 MΩ

##### Capacitors:

C<sub>1</sub> = 22 pF foil trimmer  
 C<sub>2</sub> = 22 pF ceramic  
 C<sub>3</sub> = 100 nF, polypropylene  
 C<sub>4</sub> = 10 μF, 10 V, radial  
 C<sub>5</sub>-C<sub>12</sub> = 10 nF

##### Inductors:

L<sub>1</sub> = 100 μH

#### Integrated circuits:

IC<sub>1</sub> = 74HC08  
 IC<sub>2</sub> = 74HC266  
 IC<sub>3</sub> = 74HC20  
 IC<sub>4</sub> = 74HC32  
 IC<sub>5</sub> = 74HC14  
 IC<sub>6</sub> = 74HC390  
 IC<sub>7</sub> = ICM7207A  
 IC<sub>8</sub> = ICM7224

#### Miscellaneous:

K<sub>1</sub> = 10-way box header  
 LCD<sub>1</sub> = 4.5 digit liquid crystal display  
 (prototype Seiko SP516P)  
 X<sub>1</sub> = crystal, 5.24288 MHz  
 2 off 10-way socket  
 10-core flatcable as required.

[950068]



# ***CORRECTIONS & UPDATES***

## **4-way serial port switch**

*October 1997 - 970057*

*The correct value for capacitors C4 and C5 is 10 $\mu$ F, 25V, not 4.7 $\mu$ F, 25V as stated in the Components List on page 31.*

## **PIC-controlled home alarm system**

*April 1997 - 970022*

*In some cases, D7 starts to flash*

*rapidly although the alarm should go off. Normally, rapid flashing of D7 indicates an alternating-voltage fault. The problem may be solved by increasing the value of C2 to 33 $\mu$ F.*

## **Function Generator**

*June 1995 - 950068*

*If the decimal point and the colon (:) are not displayed cor-*

*rectly, IC2 (in the frequency meter section) has to be replaced by a type 74HC7266.*

## **ADC for Centronics port**

*July/August 1997 - 974088*

*Lines 130 and 140 in the program printed with this design generate a clock pulse too early. Once CS has dropped low, D7 is available on D-out (IC2). Lines 130 and 140 however cause D7*

*to be overwritten by D6, thus killing the MSB. This happens again in line 150 as a result of the assignment  $i=1$ .*

*The recommended remedy is to (1) delete lines 130 and 140 from the program, and (2) change line 150 to read: FOR  $i = 0$  to 7.*

# ASTRA DIGITAL RADIO (ADR) - 2

In this second and final instalment we look at the channel encoding principles and the signal processing at the transmitter and receiver side of the ADR link.

By G. Kleine

THE signal processing blocks required at the transmitter side of the ADR links are shown in Fig. 1. The A-to-D conversion in the stereo ADC with subsequent Musicam data reduction was described in part 1 of this article. In the Musicam coder, audio data is formatted into ADR frames containing packets with a length of 576 bytes. This principle was also described in part 1. The data packets contain 32 words of ancillary data (for instance, RDS). These words are transmitted as 7 bits. Because the channel interleaving encoder (described further on) does not afford sufficient protection for the ancillary data, another channel encoding operation is performed with the aid of a (7,4)-block code. This means that four original bits (= one 'nibble') are extended to give a 7-bit code word. This is done by adding parity bits which are formed according to a certain standard [1]. Further protection against burst errors, i.e., corruption of several successive bits by a relatively long noise burst, is provided by interleaving (Fig. 2). Since 36 code words of 7 bits each yield only 252 bits, while a total space of  $32 \times 8 = 256$  bits is available in the ancillary data section, four non-functional bits are transmitted at the end (compare

Figs. 2 and 3 in part 1). These bits are reserved for future applications.

## Channel encoding

The output of the Musicam audio coder then supplies the digital signal to be transmitted (i.e., music and ancillary data). The subsequent stages serve to encode the data such that high speed transmission can be applied, and also to modulate the data on to a carrier which can be accommodated in the baseband together with the video signal and any (analogue) stereo TV sound programmes. The first stage is a differential encoder which supplies the difference information between any two successive bits. This is done to eliminate the risk of ambivalence at the receiver side. To prevent a pile of non-correctable errors as a result of relatively long noise bursts on the downlink path, the bitstream is interleaved according to a fixed pattern (Fig. 2). By applying the reverse, i.e. de-interleaving, at the receiver side, the bit errors are distributed such that error correction is possible in most cases. Next, FEC channel encoding is achieved by taking the signal through a rate-1/2-convolutional encoder. Here, quasi-redu-

ndant information is added the bitstream to enable the receiver to perform error correction operations when necessary. Next the convolutional encoder doubles the data rate to 384 Kbit/s, and splits the signal into two datastreams, C0 and C1, each with a bitrate of 192 Kbit/s. The operation of the interleaving encoder is illustrated in Fig. 3. First, the input data is applied to a 7-stage shift register, certain outputs of which are then added to create the datastreams C0 and C1. Next, modulo-2 addition is applied, i.e., carry-overs into the second binary position are ignored and not processed further. The error protection required for the satellite link is achieved by means of accurately defined take-off points on the shift register.

The data rate may be reduced, without seriously affecting the error protection, by combining certain bits in the datastreams C0 and C1 according to a symbol puncture logic arrangement shown in Fig. 4. This function is carried out by the puncture logic block (Fig. 1), which forms two 128-Kbit/s datastreams, I and Q, from C0 and C1 plus the remaining bits. Overall, the data rate at the output of the Musicam encoder increases from 192 Kbit/s to 256 Kbit/s, in other words, by a factor 4/3 (whence rate-3/4). Finally, the signals are fed into a QPSK modulator which is held at the required subcarrier frequency by a synthesizer. Each I+Q bit-pair ('di-bit') selects one of four possible phase positions of the RF output signal.

The ADR signal described so far is added to other ADR subcarriers and the

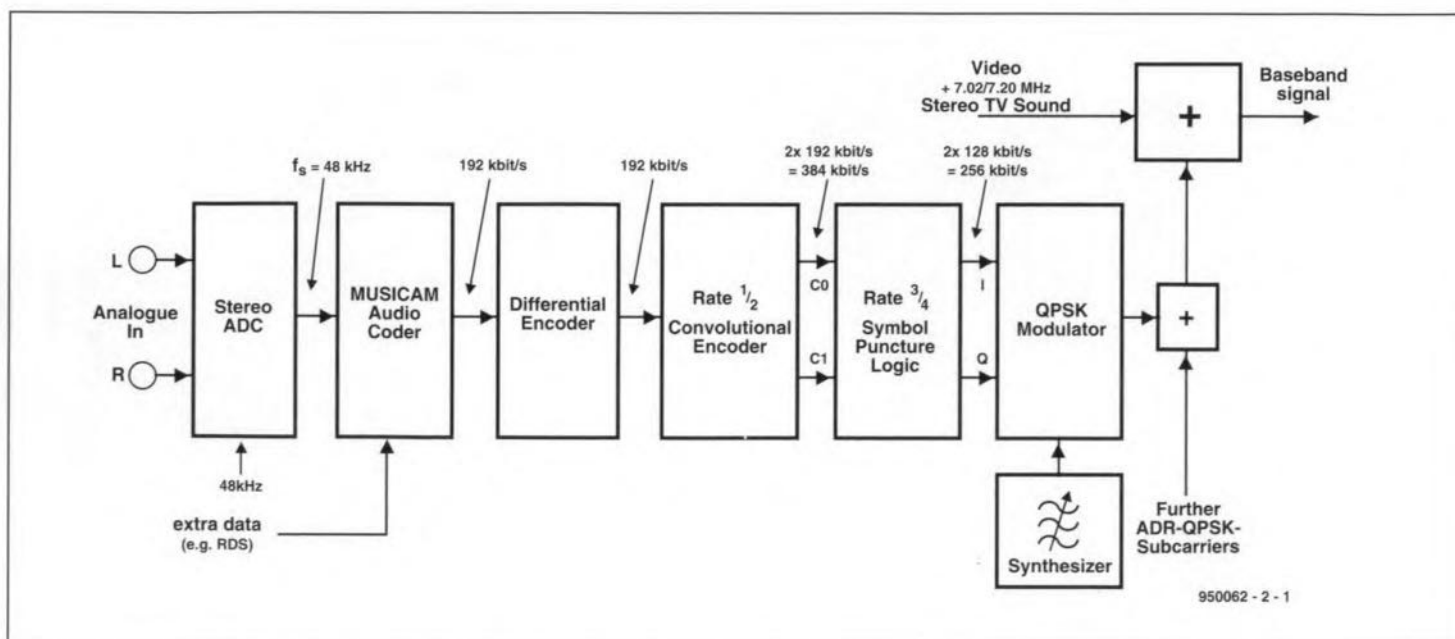


Fig. 1. Block diagrammatical representation of the functions at the ADR transmitter side.



**ABBREVIATIONS**

ADC	analogue-to-digital converter
ADR	Astra digital radio
DAC	digital-to-analogue converter
DMX	digital music express
DSR	digital satellite radio
EBU	European Broadcasting Union
FSK	frequency shift keying
CVBS	colour, video, blanking, synchronisation
FEC	forward error correction
FM	frequency modulation
IEC	International Electrotechnical Committee
ISO	International Standardisation Organisation
IR	infrared
LNC	low-noise converter
Musicam	masking-pattern adapted universal sub-band integrated coding and multiplexing
MPEG	moving pictures experts group
QPSK	quadrature phase shift keying
RDS	radio data system
TV	television
IF	intermediate frequency

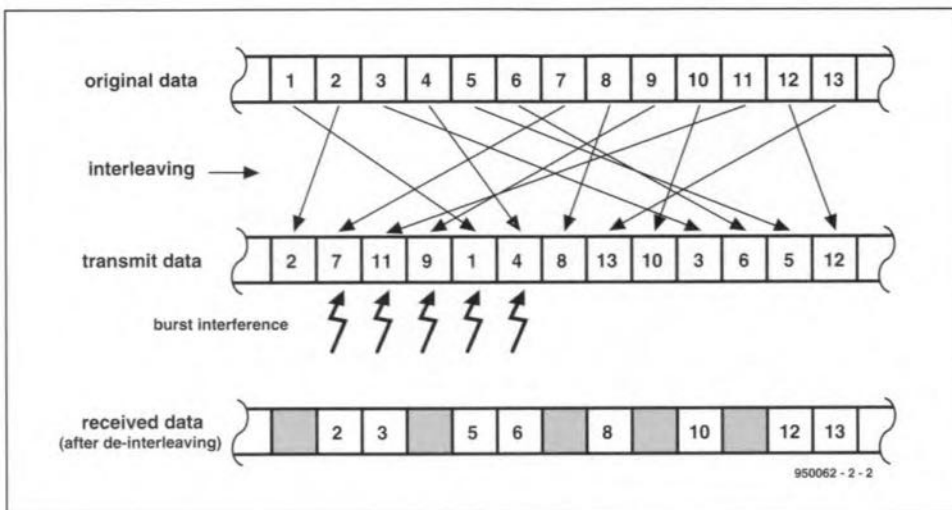


Fig. 2. How interleaving is applied to minimise the effects of noise bursts.

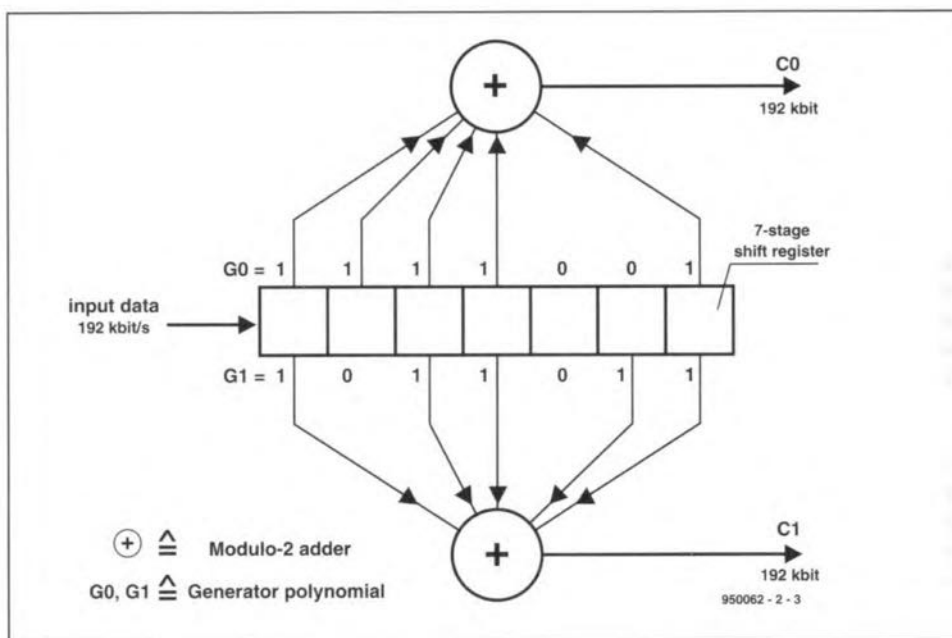


Fig. 3. Principle of 1/2 convolutional encoding using a shift register and polynomials.

video signal plus associated sound sub-carriers, to give a baseband which can be uplinked to the satellite via a frequency in the 14-GHz band.

Table 1 once more summarizes the Astra transmission parameters.

**At the receiving side**

To be able to recover the ADR information from the baseband, the baseband itself must first be obtained by FM demodulation of the 11 GHz signal received from the satellite transponder. Not surprisingly, stand-alone ADR receivers contain roughly the same front end as a regular Astra receiver. Second-generation receivers, however, will avoid this duplication of functions by integrating an ADR decoder into the Astra receiver.

The block diagram of an ADR receiver is shown in Fig. 6. To be able to demodulate different subcarriers, signals are usually mixed down to a fixed intermediate frequency of, for instance, 10.7 MHz. This means that only one IF bandpass filter is required whose frequency and phase response is accurately tuned to QPSK demodulation. Furthermore, a 'flat' group delay response is required to avoid distortion of the demodulator input

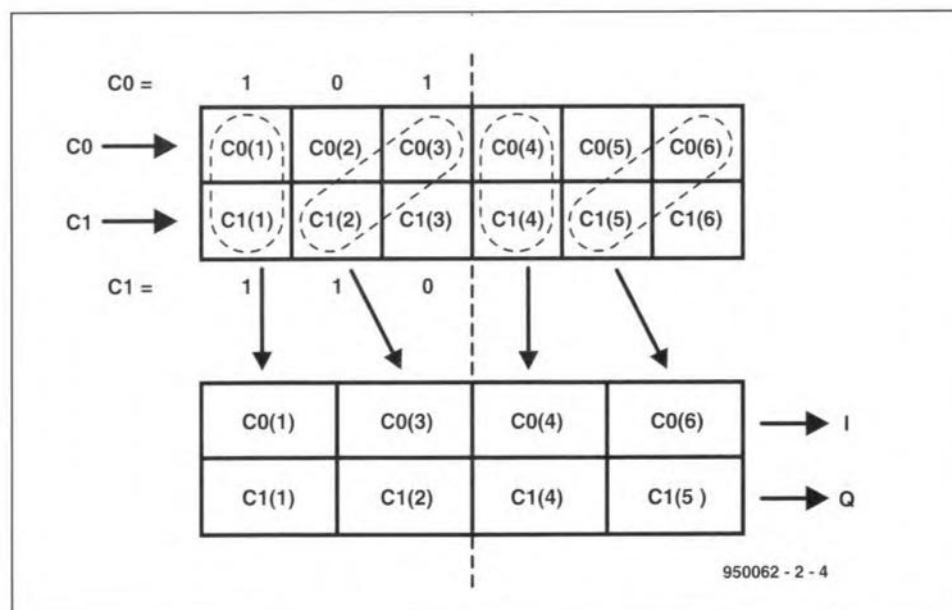


Fig. 4. The convolutional encoder data are 'punctured' to achieve data reduction.

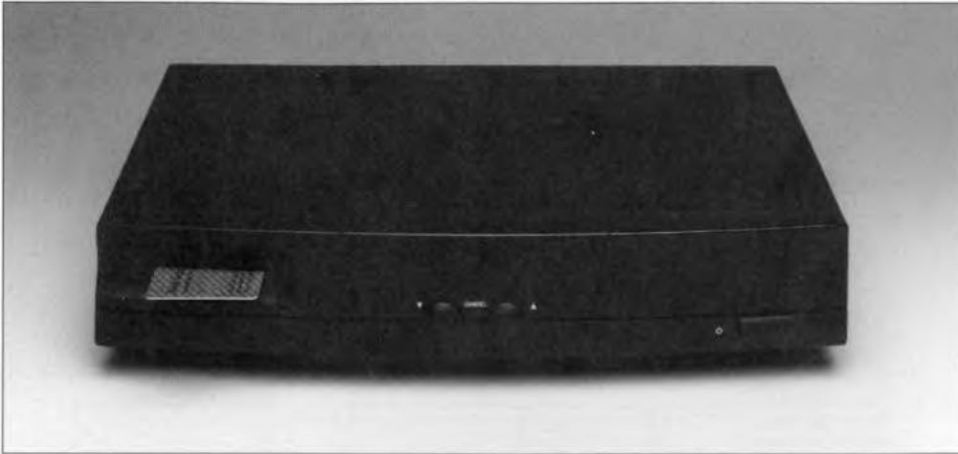


Fig. 5. Prototype ADR/DMX receiver (courtesy Kathrein Germany).

signal. The QPSK demodulator outputs two datastreams, I' and Q', which may have errors caused by noise on the satellite-to-earth link. The QPSK demodulator also recovers the clock of the I' and Q'

signals. This clock is used for the subsequent signal processing stages.

The demodulator is followed by a Viterbi decoder, which forms the counterpart of the interleaving encoder from

Fig. 3. It processes the redundant bits in the datastream to establish the most probable bit order. The Viterbi decoder contains a very complex integrated circuit which is capable of high-level number crunching to process and correct the datastream received from the de-interleaver. It also processes the redundant bits in the datastream, and establishes the bit order with the highest probability, all in real time. A complete description of the operation of the Viterbi decoder is, unfortunately, beyond the scope of this article, and also requires some knowledge of mathematics applied to digital signal processing. For the purpose of this article it is sufficient to know that the Viterbi decoder is capable of eliminating nearly all errors in the I' and Q' datastreams, and yields a 'net' bit rate of 192 Kbit/s for use by the subsequent stages.

The Viterbi decoder is followed by a decryption block for DMX reception (optional), which requires a Smartcard

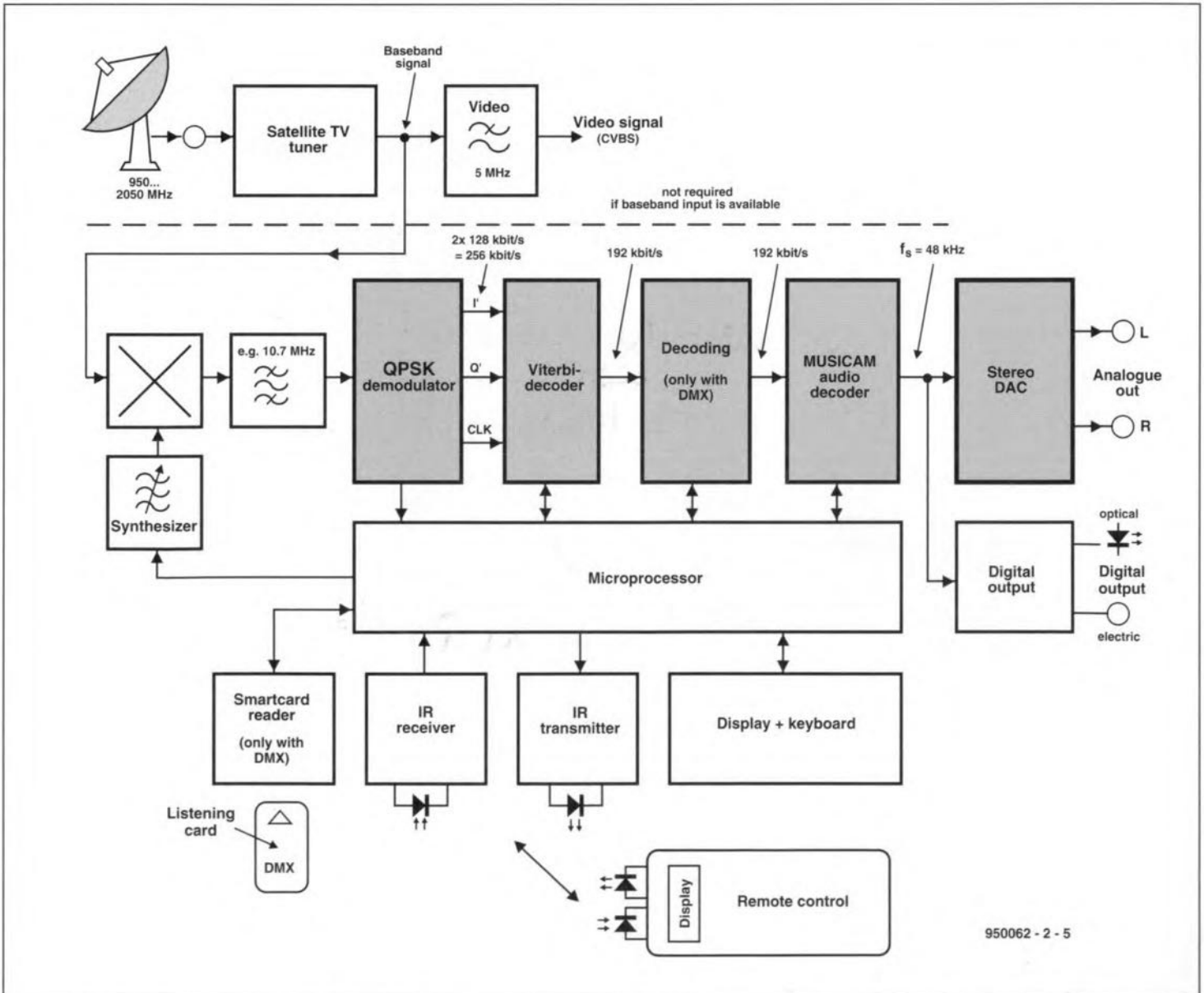


Fig. 6. Block diagram of a stand-alone ADR receiver.



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## ADR TRANSMISSION SPECIFICATION [1]

Audio encoding:	ISO/IEC 11172-3 Layer-2 (Musicam)
Audio modes:	two-channel (mono), stereo, joint stereo
Preemphasis:	50µs, 15 µs, or none
Audio frequency range:	20 Hz to 20 kHz
Audio sampling rate:	48 kHz
Audio quantisation:	16 bits
Audio S/N:	>90 dB
Modulation type:	differential QPSK
Net bit rate:	192 Kbit/s
Gross bit rate:	256 Kbit/s
Interleaving:	CCITT V.35
Interleave factor:	3/4 with k=7
Generator polynomials:	G0 = 1111001; G1 = 1011011 (cf Fig. 3)
Symbol puncture logic:	C0 = 101; C1 = 110 (cf Fig. 4)
C/N (26 MHz bandwidth)	9.5 dB for BER 1x10E-5
Frequency range:	6.12 MHz to 8.14 MHz (with video signal) 0.18 MHz to 9.00 MHz (entire transponder for ADR)
Channel raster:	180 kHz
Channel bandwidth:	130 kHz (-3dB)
Stereo channels:	12 (with video signal) 48 (entire transponder for ADR)

[1] ADR Specification, October 1994, SES-Astra, Betzdorf, Luxembourg.

reader to be built into the receiver. The microprocessor in the ADR receiver checks if the listening card inserted by the user is valid. If so, the DMX decoder is enabled.

To return to an analogue signal, a Musicam decoder is first required which accepts the data-reduced audio part of the 192-Kbit/s datastream, and feeds the ancillary data to the microcontroller. The Musicam decoder uses a set of scaling factors to reconstruct the timing of the left and right hand channels, and outputs sampling values at a rate of 48 kHz to a stereo DAC. Some ADR receivers also have an electrical and/or optical digital output which is connected to the output of the Musicam decoder.

A central microcontroller checks and controls the receiver electronics, and arranges for all relevant data to be shown on a display. Provision is made for a special bidirectional infrared link between the ADR receiver and the remote control. This allows additional information to be displayed on a small LCD screen on the remote control. The display could show, for example, the title of the song or music piece being received, the artist(s), and, possibly, also the title of the CD on which the track may be found.

(950062-2)



# INTERNET: WHAT IS IT?

No other subject has caused such commotion in the telecommunications world as Internet. Although this network has been in use for more than a decade, everybody is suddenly enthusiastic about the digital highway. In fact, you can't open a computer magazine these days without hitting on a story about the hype of hypes, Internet.

By our editorial staff

THE roots of the Internet are, as in so many cases, found in the military. The net was first set up in the nineteen-sixties within the framework of military and scientific research at the U.S. Ministry of Defence. Since then, the National Science Foundation (NSF) has been responsible for the Internet, which originally served to offer technicians nationwide a means of exchanging research information quickly and efficiently. The Internet being an inherently strategic project, the importance of protecting its structure against link failures was soon recognized. Consequently, no central server was used on the network. Today, the structure of the Internet allows com-

puter systems to communicate at high speeds via an infrastructure which can expand by itself to literally any size. In the early days of the Internet, only four computers were linked via the network. Any time a new information supplier expressed a wish to participate, his computer was connected up to the network. In the course of more than twenty-five years, the number of links grew to form the extensive, worldwide network as we know it today.

In theory, because there is no central computer or authority, the participants rule on the network, and they are able to jointly determine the standards to be used. This has come true in practice. The

most recent estimates indicate that there are currently about 3 million computers worldwide connected to the Internet, allowing about 30 million users to exchange information. The number of users increases every day.

## The possibilities

The Internet offers a number of services to its users. For instance, they can communicate with each other by electronic mail (e-mail). In practice, the distribution of the mail is not tied up with just the Internet. Users of other e-mail systems such as CompuServe and FidoNet, may be reached via the same system.

In view of the current explosion of interest in the Internet, experts expect e-mail to take over the function of today's fax within a few years. Whereas the fax only allows a printout on paper to be transmitted, e-mail gives you the opportunity to transmit original documents, enabling the receiver to do further processing on these documents.

Another interesting way of communication is via news groups such as Netnews and Usenet. Each Internet user is free to join such a newsgroup. A newsgroup functions as a kind of BBS (bulletin board service) within the Internet. Every time a user who is a member of a certain newsgroup links to the Internet, he or she is able to receive the latest messages which circulate within his or her newsgroup(s), free of charge. Meanwhile, the number of newsgroups has risen to several thousands, each having its own, special, interest. If there is no newsgroup for a specific subject, one is easily set up.

A well-known newsgroup is, for instance, *comp*, which stands for computers. Within this group there are sub-groups, for instance, *comp.lang.prolog* for prolog programmers, or *comp.lang.C++* for C++ users. Likewise, scientists involved in, for instance, astronautics are found in the sub-group *sci.space*. Biotechnology is discussed by members of the *sci.bio.technology* sub-group. Should you be interested in the social background of Chinese culture, it is recommended to consult with the newsgroup 'social sciences', more in particular, the sub-group *soc.culture.china*. Riveting stuff!

Direct communication between Internet users is also possible by means of the Internet Relay Chat (IRC), which enables contact via the keyboard and the screen.

Using advanced graphics-based search programs like Gopher and Archie, the user gains direct access to databases, libraries and other information suppliers.

## THE DIGITAL HIGHWAY FOR WORLDWIDE COMMUNICATION



Fig. 1. Welcome screen presented by the Internet link facility of CompuServe.



## The organisation

Currently, an organisation called Internet Society (ISOC) is responsible for the Internet. This organisation was founded in 1992, and has taken up the responsibility for the future developments of the net. Their main areas of attention are:

- standardising the protocols used;
- promoting the Internet;
- development and enhancement of the technology.

The ISOC itself has long since lost its all-American face. In the course of time it has become a worldwide organisation in which representatives of companies and institutions work together. Within the ISOC, an number of workgroups are active. The best known of these are:

- **The Internet Architecture Board (IAB)**, whose main focus is on standardisation of the technology used;
- **The Internet Engineering Task Force (IETF)** which concentrates on solving current problems;
- **The Internet Research Task Force (IRTF)** which deals with long-term research.

The most pressing problems related to the Internet are the protection of the user's privacy, the use of the available bandwidth, and the administration of all names. Each Internet user must have a unique name. The president of the United States, for instance, can be reached at the address *president@whitehouse.gov*. Thanks to the unique name, information can be exchanged between two users. Fixing a name for a certain user involves a procedure marked by a lot of debating.

## Communicating with the Internet

The Internet is a public network, which means that it is accessible to everyone. Connecting to the network is possible in a number of ways, as indicated by the large number of advertisements in computer magazines. Internet service providers such as CompuServe, Euronet, XS4All and Surfnet function as an intermediary between the Internet and the user, in other words, they offer access to the Internet to anyone with a computer and the appropriate software. As might be expected, the charges for this service depend strongly on the services offered. In most cases, a basic rate per month applies, plus the cost of the time one is actually connected to the network. The most obvious services are:

### e-mail

In many cases, it is only possible to 'purchase' so-called e-mail services. The provider then assigns a kind of mailbox to the user. This mailbox is connected to the Internet.

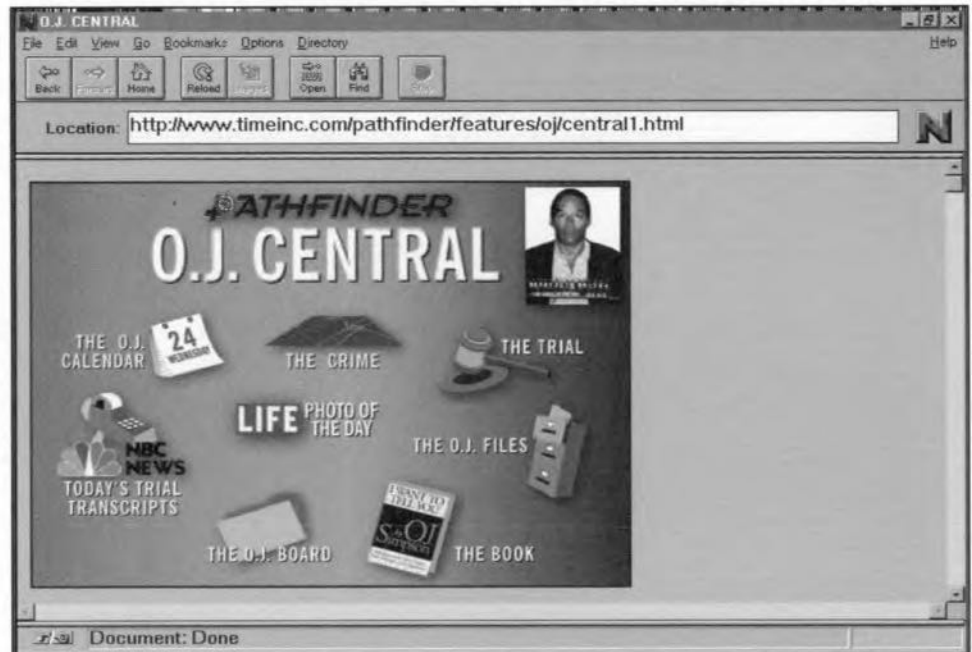


Fig. 2. As illustrated by this picture of the O.J. Simpson trial, the WWW enables the user to communicate graphically with the Internet. For Windows, Netscape is an excellent piece of software.

### Log-in access

With this type of access, the user has his computer ring up the service provider. The only software required to do so is a terminal emulation program. The provider's computer has all the software necessary to put the user through to the Internet.

### IP access

This is one of the most flexible types of access to the Internet. The computer is permanently connected to the Internet, and so forms a physical part of the network. The telephone line is then usually a special data line, hired from the relevant telecom provider. These data lines are in general too expensive for most small users.

### Quasi-permanent IP access

This type of connection is a combination of the two types mentioned above. The data link between the user and the provider is not made until it is required. The link is automatically broken as soon as it is not used for a certain time.

### IP access via a network

Most universities and other large institutes use their own network as a direct gateway to the Internet.

## The connection

You do not have to fork out large sums to get going with the Internet. Any reasonably fast (386 and up) PC with a fast modem (14.4 KBaud or 28.8 KBaud) may be used plus, of course, the appropriate software. A number of programs are in the public domain, or are shareware, and

available against a nominal charge only. Apart from that, suppliers of operating systems make their own contribution. IBM's OS/2 Warp package, for instance, comes complete with software to link to the Internet, while IBM also acts as a service provider, arranging access to the net for any user of OS2 Warp.

Microsoft reportedly intends to do the same with the Windows 95 operating system, the successor of Windows 3.1. Microsoft is also to offer network services at competitive prices via the Microsoft network (MSN) which is due to start as this article is being written. The MSN itself also provides access to the Internet. As soon as Windows 95 is on the market (reportedly around August 1995), computer users in about 35 countries will have direct access to the MSN.

## The main protocols

The Internet is so versatile that it is hardly possible for a single program to give access to all facilities, although that can be expected to change rapidly by new developments in the field of software. Many different auxiliary programs ('tools') in the shareware and public domain are offered for most types of computer system. Internet providers often offer a software package with the relevant functions and support for the protocols required.

The **Telnet** protocol is used to connect a terminal to a remote host computer via the Internet. The terminal then allows the computer to be used just as if the system was connected directly. Setting up a Telnet connection with a host computer is possible on the Internet once you know

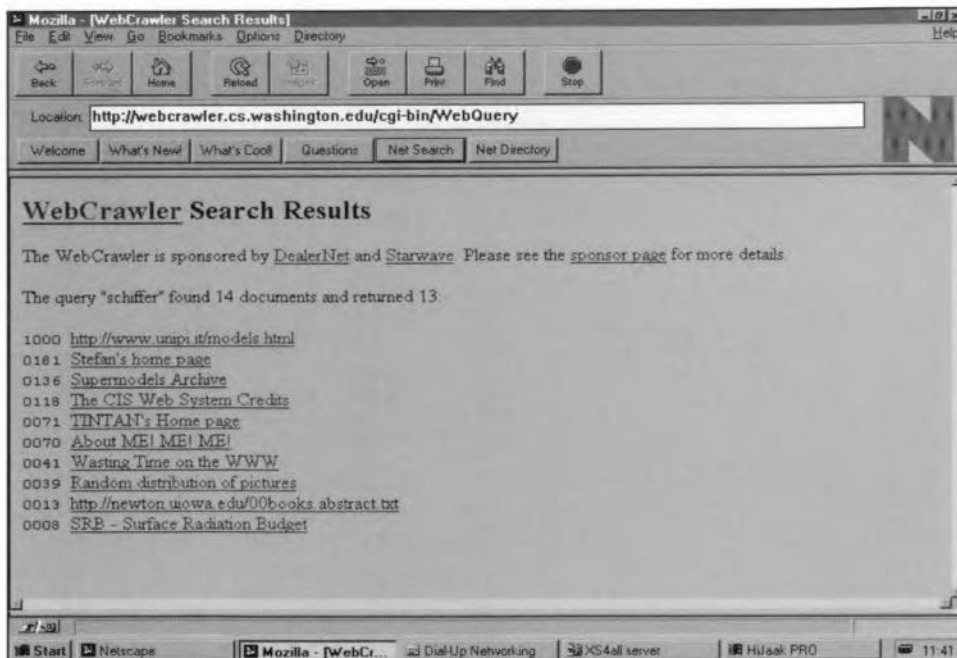


Fig. 3. A key word enables you to find information on the Internet in a simple way. Here, we are scouring for information on top model Claudia Schiffer.

the computer's name. To prevent anybody who knows the name from getting direct access to the system, a password is requested after you enter your user name. In most cases, Telnet users obtain only limited access to a system, certain sections being 'screened'. This is called 'anonymous Telnet'. Thanks to this function, any user is allowed to obtain 'public' information from a system, for instance, by consulting a database, without interfering with the operation of the host computer.

**FTP sessions** (File Transfer Protocol) are available to exchange data between two computers. The FTP tool allows computer users to download files and store these on their own hard disk. The files may be any type of data, i.e., programs, text, drawings, photographs, etc. The efficiency of the data exchange is increased by the use of data compression systems. The FTP function also offers an anonymous mode, which, however, restricts the type of software which may be downloaded to shareware and public domain only.

**Archie** is an archiving system which is frequently updated. Using this system, an index may be created which contains the names of the many thousands of servers on the Internet. Archie offers three options to the user:

- establish a Telnet connection with the server;
- if Archie is on the Internet server, it can be run from there;
- make use of e-mail.

Archie has two important limitations. Because it works via anonymous FTP, the archive is restricted to files which

can be requested anonymously. All files are indexed by name. Because there are no descriptors, the names are pretty cryptic at times. The Archie system was developed by McGill University in Canada.

**Netnews** has a key function in the exchange of information between newsgroups. Netnews is just a different name for the entire collection of newsgroups. The Internet provider decides which newsgroups are accessible to the client.

**Usenet** is related to Newsnet in that it embraces all computers which exchange

information via Newsnet. This makes Usenet a cluster of users. The computers which are active within Usenet exchange information according to a schedule. All computers active at one time in the exchange together form a 'site'. Such a site may comprise of many thousands of computers.

**IRC** (Inter Relay Chat) is a protocol that enables several users to communicate with each other via the keyboard and the screen. The applications of this function are fairly limited.

**E-mail** is the electronic mail function which is employed by virtually all Internet users. Many programs are capable of handling e-mail. Moreover, access to a mail address is not restricted to users of the Internet — all other networks connected to the Internet may be reached directly. That makes e-mail eminently suited to sending electronic information around the globe in a very short time, and at low cost.

**Gopher** is really your guide on the Internet. This program, developed by the University of Minnesota, makes information sources more easily accessible via a menu structure. Gopher reduces uploading and downloading programs to a single keystroke, while it is also suitable for running an FTP or Telnet session. The only condition for the Gopher user is that the computer which is logged on has the required supporting software.

**Veronica** goes one step further. Developed by the University of Nevada, the Very Easy Rodent Oriented Netwide Index to Computerized Archives enables you to use key words to search in Gopher title indexes.

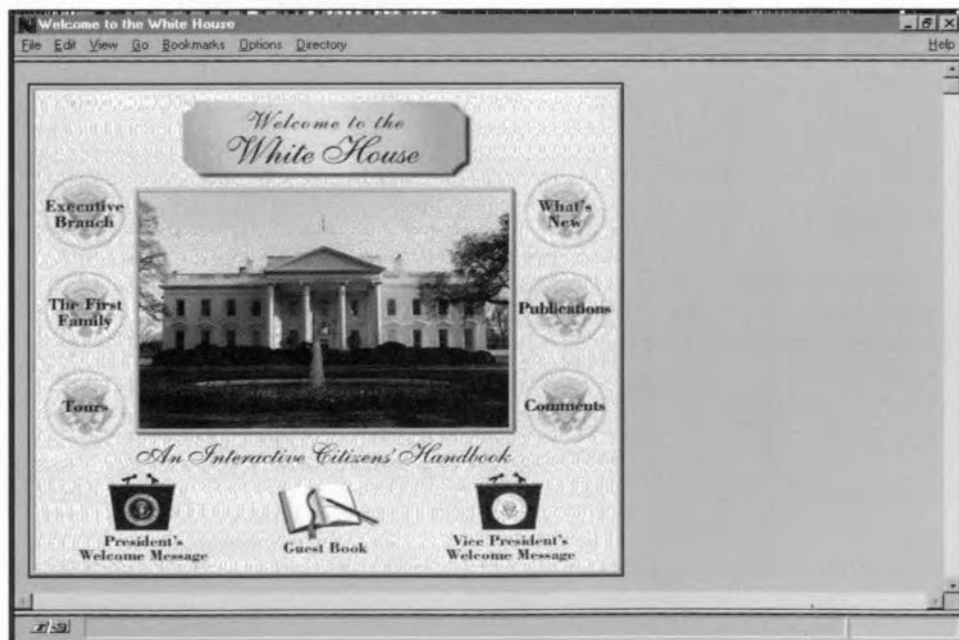


Fig. 4. The White House is just a phone call away.



## INTERNET SURFSPEAK

<b>Archie</b>	System to locate files stored on FTP servers.
<b>Backbone</b>	Fast central network which links smaller networks.
<b>DNS</b>	Domain Name Structure, a system which translates Internet addresses into comprehensible names.
<b>Finger</b>	Auxiliary program to find out whether or not a specific user is actually connected to the network. Also used to look up an e-mail address.
<b>FTP</b>	File Transfer Protocol, describes the way in which files may be exchanged between a host system and a computer.
<b>Gopher</b>	Auxiliary program which provides information on the hierarchical structure of the net.
<b>HTTP</b>	Hypertext Transfer Protocol, used mainly for the distribution of documents via the World Wide Web.
<b>HTML</b>	Hypertext Markup Language, an encoding system which allows text, graphics and sound to be linked by hyperlinks in documents.
<b>IP</b>	Internet Protocol, a standard which describes the way data packets are transmitted over the network.
<b>IRC</b>	Internet Relay Chat, a protocol to enable keyboard-to-keyboard communication between users.
<b>NDIS</b>	Network Driver Interface Specification, a Microsoft specification which enables the use of different protocols on a single network.
<b>Newsgroup</b>	Bulletin board system containing information on a particular subject.
<b>MNTP</b>	Network News Transport Protocol, an extension of the TCP/IP protocol which describes how messages from newsgroups may be exchanged between compatible servers.
<b>ODI</b>	Open Datalink Interface, a standard data interface designed by Apple and Novell, with features compatible with those of NDIS.
<b>PING</b>	Packet Internet Groper, a TCP/IP utility for transmitting data packets to a computer over a network. PING may be used to check if a computer is connected to the network.
<b>Protocol</b>	a set of rules which describe how a certain action must be executed.
<b>Router</b>	a combination of hardware and software which arranges the direction of the data flow.
<b>URL</b>	Uniform Resource Locator, a name given to the location of objects. Names are used which are easy to remember.
<b>SLIP/PPP</b>	Serial Line IP/Point-to-Point Protocol, two protocols used to get in touch with the Internet via a serial link. Most Internet software support both protocols.
<b>SMTP</b>	Simple Mail Transfer Protocol, a simple protocol which describes how e-mail messages may be transmitted via a TCP/IP network.
<b>SNMP</b>	Simple Network Management Protocol, this describes how information may be exchanged between display systems and databases.
<b>TCP/IP</b>	Transmission Control Protocol/Internet Protocol, a collection of network and transport protocols for the communication between several PCs via a network.
<b>Usenet</b>	User Network, a public network formed by many thousands of newsgroups.
<b>UUCP</b>	Unix-to-Unix Copy, originally a Unix program which enables two PCs running Unix to exchange data.
<b>Veronica</b>	Very Easy Rodent Oriented Network index to Computerized Archives, a software utility which looks for text in Gopher menus.
<b>WAIS</b>	Wide Area Information Server, software used to index large text files on servers.
<b>WHOIS</b>	TCP/IP utility which may be used to gather information on other Internet users.
<b>Winsock</b>	Windows Socket, an Application Programming Interface (API) to make Windows programs run via a TCP/IP network.
<b>WWW</b>	World Wide Web, a network of servers which use hypertext documents. Many Web even allows the use of sound and video.

**WAIS** is a program which makes databases accessible, provided these databases have a so-called WAIS index.

**WWW** stands for World Wide Web. Just like Gopher, this is a utility to locate information in a quick and efficient way. WWW was developed by the European Particle Physics Research Centre (CERN). The key word with WWW is hypertext, which refers to a system in which information is presented using 'multimedia' (sound and vision). Documents are then a combination of text and graphics, plus a description of how these elements are linked. Special programs are available, such as WWW, Lynx and Mosaic, to process the graphics information.

Recently introduced software such as Netscape integrate all protocols in one program. No doubt the rapidly growing interest in Internet will boost the availability of clever and efficient software for all protocols.

### Name assignment for e-mail

Within the IP (Internet Protocol), a structure has been devised to make sure that each user has a unique address. Addressing on the Internet is based on number sequences separated by points. A translation system was set up for the average user to make sure that an easily understandable name is assigned. Within the very extensive network, so-called domains are used. The Domain Name System (DNS) uses a structured way to assign names. All domains in the United Kingdom, for instance, end with '.uk'. An overview of all currently used country codes may be found in the newsgroup alt.internet.services where an article circulates about this matter ('International E-mail Accessibility').

Each domain usually has a number of sub-domains. In the UK, for instance, such a sub-domain is formed by Keele University (Staffs). Anyone connected to the university's computer has an address which ends with 'keele.ac.uk'. Within the university itself, there may be further sub-domains for certain departments. Since any user should be able to find his or her mail in his or her own mailbox, the name is also included in the address, using the '@' (at) separator to indicate the exact location of the addressee. For instance, janet@cc.keele.ac.uk.

A different addressing system is used in the United States, where the subdivision in domains is based on application areas. Addresses in the USA end with letter combinations such as 'com' (for commercial organisations), 'mil' (for the military), 'gov' (for government bodies), 'edu' (for educational institutes) or 'org' (for other organisations).



Fig. 5. The Internet offers an immense variety of information. Playboy magazine, for example, has its own 'corner' where playmates are presented, and interviews with celebrities may be found.

## Cheaper phone calls via Internet?

Telephone line providers worldwide who once rubbed their hands as Internet became popular now face unexpected competition. Internet Phone offers users the possibility to telephone worldwide at the rate of a local call! An Israeli company, Vocaltec, recently introduced a program called 'The Internet Phone' which enables

users of a PC equipped with a sound card to establish a voice connection. The sound card in the PC digitizes the signal picked up by a small microphone. Next, the data is heavily compressed and then exchanged with the other party via a high-speed modem and, of course, the Internet. At the receiving end, the data is decompressed and made audible again via the sound card and a set of loudspeakers. Such a speech link is inherently simplex

(one-way), and the software shows an icon to tell you that you are allowed to speak. It's a bit like talking into a handheld radio transceiver, but one with a very long range indeed!

The cost of a telephone call made in this way (at either end) is that of the call to the relevant Internet provider(s). Particularly with international calls, these costs can work out much lower than those of a 'traditional' overseas call charged by, say, BT or others. The Internet Phone program costs US\$50, and may be found at [ftp.vocaltec.com](ftp://ftp.vocaltec.com), or [www.vocaltec.com](http://www.vocaltec.com). This location also contains a demo version of the program. The minimum system requirements are: 486 PC, 25 MHz, 8 MByte RAM, sound card with microphone and loud-speaker(s). A modem is required with a minimum data speed of 14.4 Kbaud.

## The future

The National Science Foundation recently announced that it will no longer maintain the Internet. Meanwhile, other organisations have expressed their willingness to keep the network running within the United States. Furthermore, the American company International Discount Telecommunications has stepped in to ensure the Internet remains accessible to every country in the world. IDT's founder and President, Howard Jonas, expressed the company's firm intention "to make the Internet more accessible than ever before". A joint effort with companies from Switzerland and Korea has already resulted in new nodes in these countries. The aim of IDT is to create local points of connection in over 50 countries by the end of 1995. To do so, they are looking for well-established companies throughout the world to enter into a venture with IDT to bring Internet to their country. (950073)

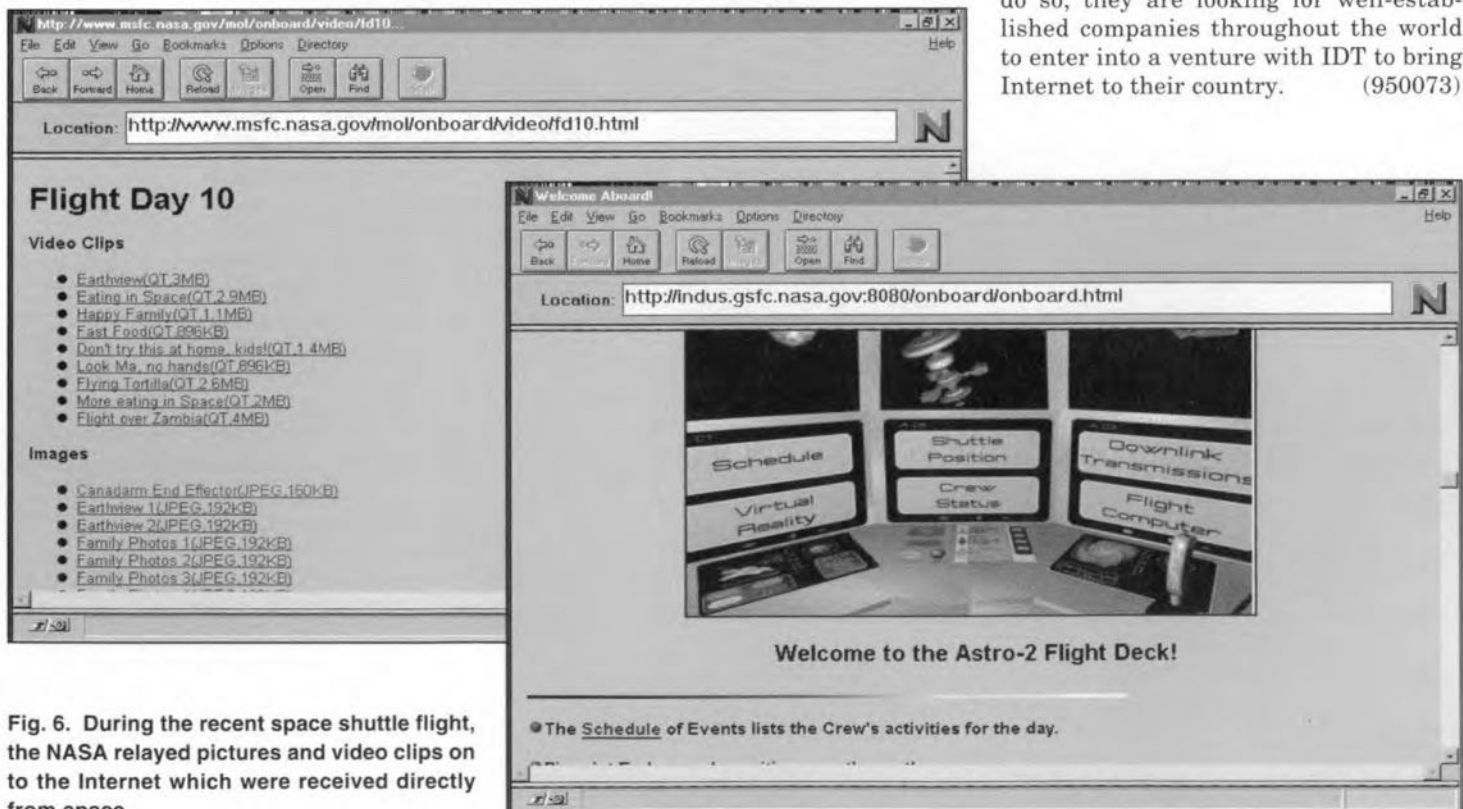


Fig. 6. During the recent space shuttle flight, the NASA relayed pictures and video clips on to the Internet which were received directly from space.



# APPLICATION NOTE

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.

## Current-sense amplifiers Max 471/472

By G. Kleine, based on a Maxim application

The MAX471/472 are complete, bidirectional, high-side current-sense amplifiers for portable PCs, telephones, and other systems where battery/d.c. power-line monitoring is required. High-side power-line monitoring is especially useful in battery-powered systems, since it does not interfere with the ground paths of the battery chargers or monitors often found in 'smart' batteries.

The MAX471 has an internal  $35\text{ m}\Omega$  current-sense resistor and measures battery currents up to  $\pm 3\text{ A}$ . For applications requiring higher current or increased flexibility, the MAX472 functions with external sense and gain-setting resistors. Both devices have a current output that can be converted to a ground-referred voltage with a single resistor, allowing a wide range of battery voltages and currents. Both devices operate from  $3\text{ V}$  to  $36\text{ V}$ , draw less than  $100\text{ }\mu\text{A}$  over temperature, and include a  $5\text{ }\mu\text{A}$  max. shutdown mode.

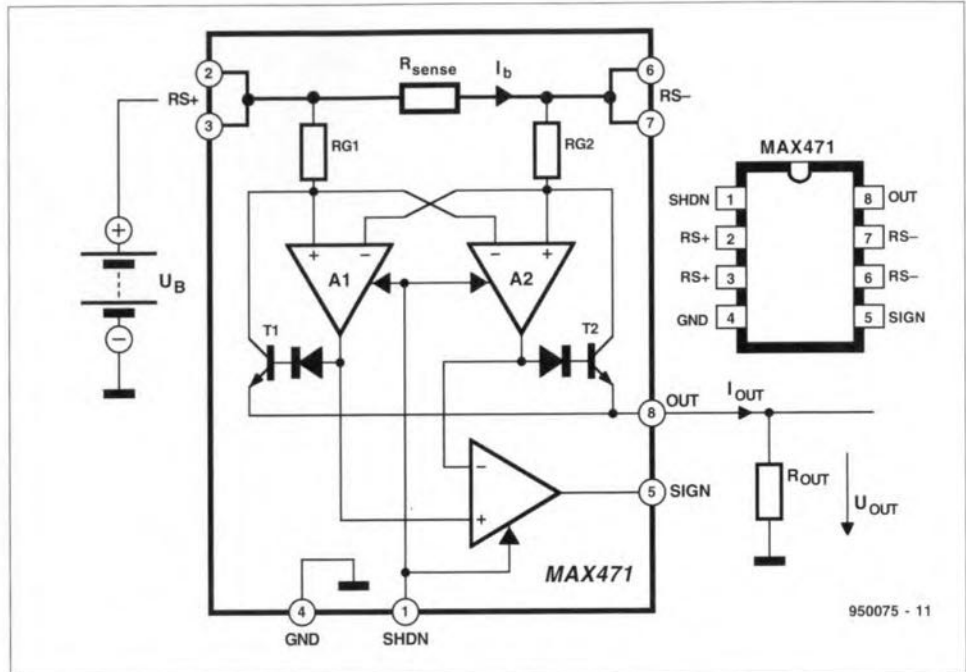


Fig. 1. Functional diagram of the MAX471.

### Function

The MAX471 provides an output current that is proportional to the measured current. The output current is independent of the direction of the monitored current, so that, in the case of batteries, both the charging and the discharge currents can be measured. The SIGN output indicates which is which.

Figure 1 shows a simplified functional diagram of the MAX471 with internal  $R_{\text{sense}}$ . With the MAX472,  $R_{\text{sense}}$  and resistors  $R_{G1}$  and  $R_{G2}$  must be added externally.

Assume that current flows from  $RS+$  through  $R_{\text{sense}}$  to  $RS-$ , which is, for instance, the case when a battery is being discharged. In this case, amplifier  $A_1$  is active and output current  $I_0$  flows from the emitter of  $Q_1$ . Since no current flows through  $R_{G2}$  ( $Q_2$  is off), the negative input of  $A_1$  is equal to  $V_{\text{source}} - (I_{\text{load}} \cdot R_{\text{sense}})$ . The open-loop gain of  $A_1$  forces its positive input to essentially the same level as the nega-

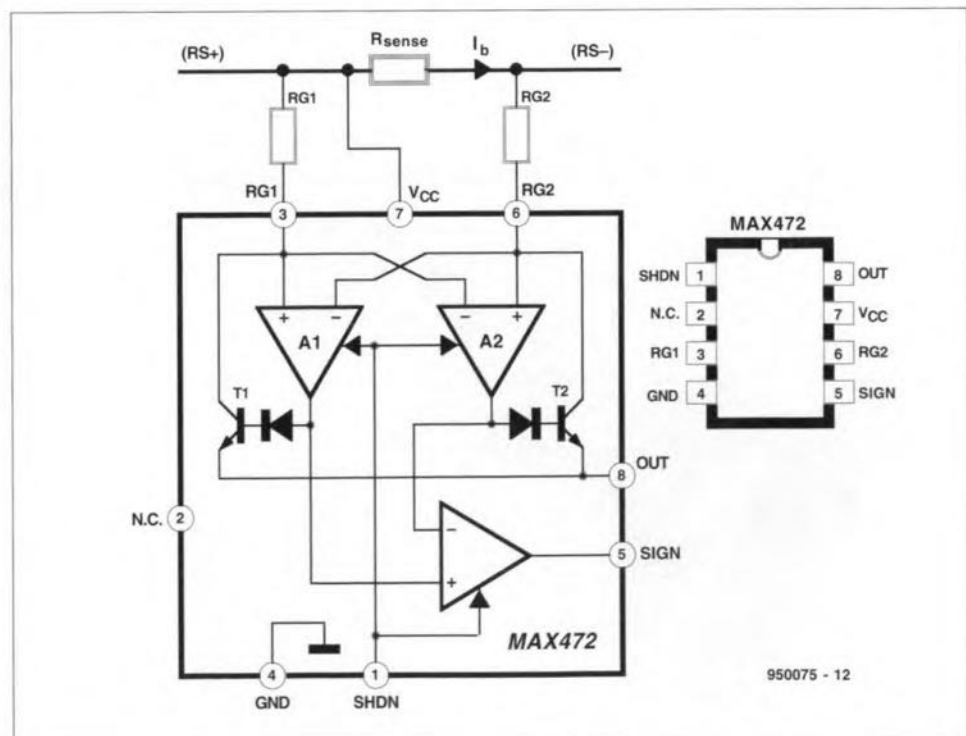


Fig. 2. Functional diagram of the MAX472

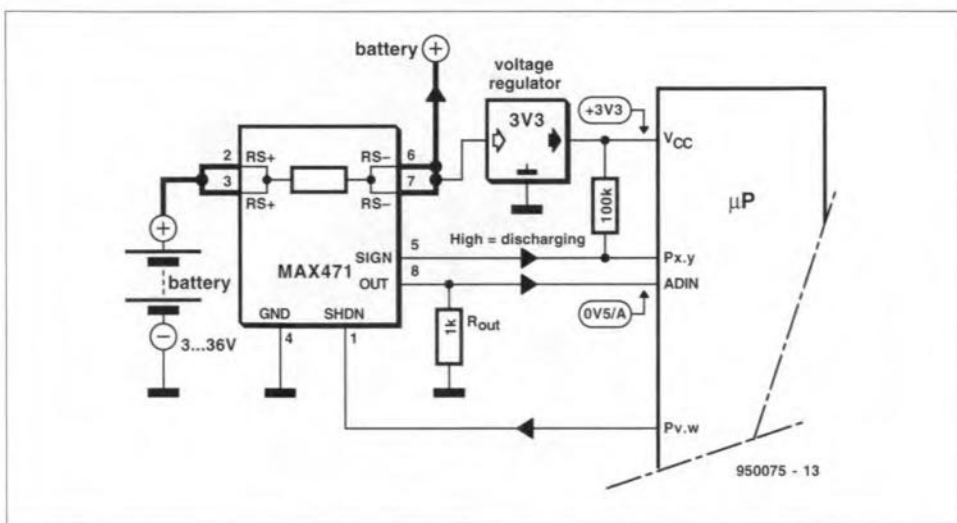


Fig. 3. MAX471 as battery monitor in a microprocessor-controlled system.

tive input. Therefore, the drop across  $RG_1$  equals  $I_{load} \cdot R_{sense}$ . Then, since  $I_0$  flows through  $Q_1$  and  $RG$  (ignoring the very low base currents),

$$I_0 \cdot RG_1 = I_{load} \cdot R_{sense},$$

or

$$I_0 = (I_{load} \cdot R_{sense}) / RG_1.$$

The output current is converted into voltage  $V_{out}$  by a resistor between pin 8 (OUT) and ground. In the MAX471, the current-gain ratio has been preset during manufacture to  $500 \mu A/A$ , so that an output resistor,  $R_{out}$ , of  $2 \text{ k}\Omega$  provides  $1 \text{ V A}^{-1}$  for a full-scale value of  $+3 \text{ V}$  at  $\pm 3 \text{ A}$ . Other full-scale values can be set with different  $R_{out}$  values, but the output voltage can be no greater than  $V_{RS+} - 1.5 \text{ V}$  for the MAX471 or  $V_{RG-} - 1.5 \text{ V}$  for the MAX472.

$$V_{out} = (R_{sense} \times R_{out} \times I_{load}) / RG,$$

where  $V_{out}$  is the desired full-scale output voltage,  $I_{load}$  is the full-scale current being sensed,  $R_{sense}$  is the current-sense resistor,  $R_{out}$  is the voltage-setting resistor, and  $RG$  is the gain-setting resistor ( $RG = RG_1 = RG_2$ ).

When the current is a charging current, which flows through  $R_{sense}$  in the opposite direction,  $A_2$  and  $T_2$  are actuated by the polarity logic. Since, in the MAX471,  $RG_1 = RG_2$ , the formulas just given apply for charging and discharge currents. With the MAX472, the designer is free to give the two resistors a different value, so that the scales for the two conditions are dissimilar.

The current at OUT indicates magnitude. The SIGN output indicates the current's direction. Operation of the SIGN comparator is straightforward.

When  $Q_1$  in Fig. 1 and 2 conducts, the output of  $A_1$  is high, while that of  $A_2$  is zero. Under this condition, a high SIGN output indicates positive current flow (from  $RS+$  to  $RS-$ ). In battery-operated systems, this is useful for determining whether the battery is being charged or discharged. The SIGN output may not correctly indicate if the load current is such that  $I_{out}$  is less than  $3.5 \mu A$ . The MAX471's SIGN output accurately indicates the direction of current flow for load currents greater than  $7 \text{ mA}$ .

SIGN is an open-collector output (sinks current only), allowing easy interface with logic circuits powered from any voltage. Connect a  $100 \text{ k}\Omega$  pull-up resistor from SIGN to the logic supply. The convention chosen for the polarity of the SIGN output ensures that it draws no current when the battery is being discharged. If current direction is not needed, float the SIGN pin.

The MAX471/MAX472 are shut down by making SHDN high; the devices then draw a current  $< 5 \mu A$ . In the shutdown mode, SIGN is high impedance and OUT turns off.

Power supply to the MAX471 is via  $RS-$  (pins 6, 7), and to the MAX472 via  $V_{CC}$  (pin 7), which may be connected to either side of  $R_{sense}$  (because of the tiny voltage drop across this resistance, which side does not matter).

## MAX471 application

Figure 3 shows how the MAX471 is used in a microprocessor system to monitor the charging and discharge currents of a battery. The microprocessor and logic circuits operate from a regulated  $3.3 \text{ V}$  supply derived from the battery, whereas other parts of the sys-

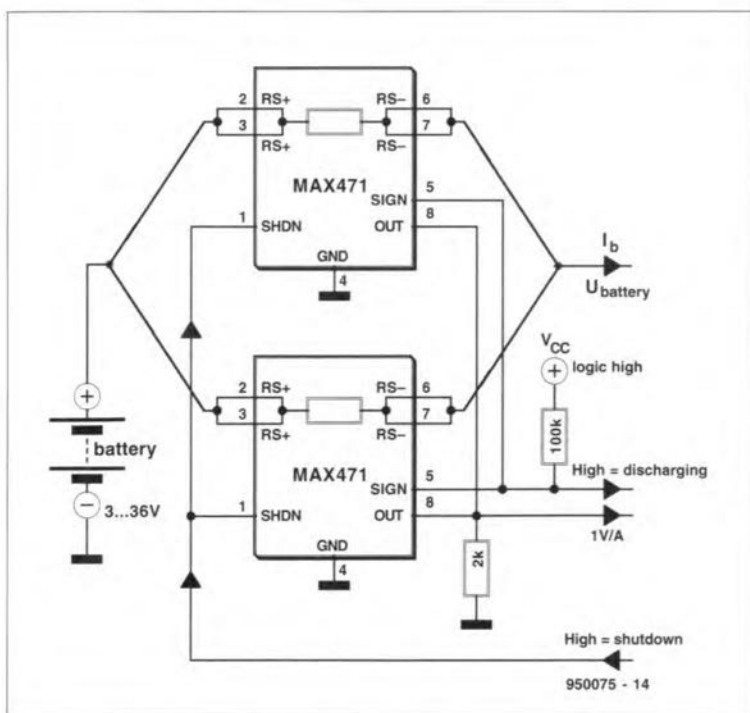


Fig. 4. Two MAX471s connected in parallel.

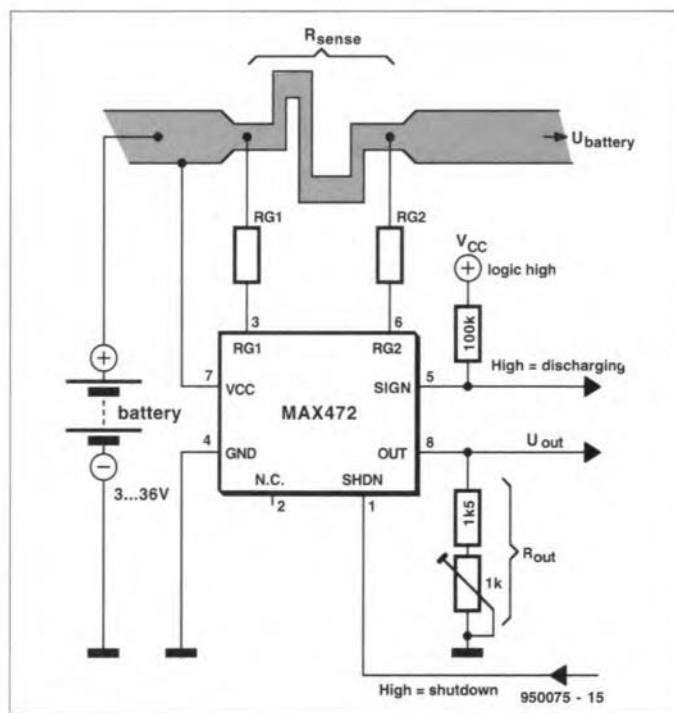
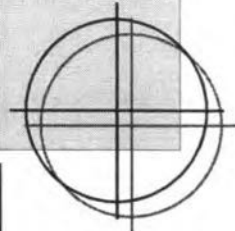


Fig. 5. PCB track used as sense-resistor for MAX472.



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tem operate directly from the battery.

The current drawn by the system is measured by connecting pin 8 (OUT) of the MAX471 to the input (ADIN) of an analogue-to-digital converter (ADC) in the microprocessor. Resistor  $R_{out}$  converts the output current of the MAX471 into a voltage. Its value has been chosen such that when the system draws maximum current, the voltage applied to the ADC input is near to maximum requirement. Care must be taken to ensure that the input resistance of the ADC is large enough to prevent the voltage at OUT is not loaded excessively (a value  $>10 R_{out}$  is recommended).

The SIGN output is made high via a 100 k $\Omega$  pull-up resistance and linked to the Px.y input of the processor. From this input, the processor can determine whether, for instance, the battery is being charged during operation.

The shutdown input of the MAX471 is driven by the Pv.w output of the

processor so as to sink the current during standby. Note that during standby only the measuring stage of the MAX471 is disabled; in no circumstances is the supply line from the battery interrupted.

### High-current measurement

Since pin 8, OUT, is high impedance, several MAX471s may be connected in parallel as shown in Fig. 4. Care must be taken to ensure that the branches have the same resistance. If this were not so, the output currents would not be equal, whereupon one of the MAX471s would be overloaded.

### When to use MAX472?

The MAX472 should be used when the long-term maximum load current is expected to be greater than  $\pm 3$  A, but it can, of course, also be used when

the full-scale load current is smaller than  $\pm 3$  A. The table shows suggested component values and indicates the resulting scale factors for various applications required to sense current from 100 mA to 10 A. Higher or lower sense-current circuits can also be built.

If the cost of  $R_{sense}$  becomes an issue, part of a PCB track may be used to create a sense resistor as shown in Fig. 5. Owing to the inaccuracies of such a 'resistor', it will be necessary to adjust the full-scale current value with a potentiometer. Also, the resistance temperature coefficient of copper is fairly high (about 0.4%  $^{\circ}\text{C}^{-1}$ ), so in systems that experience wide temperature variance this aspect should be taken into account.

**Reference:** Maxim Precision, high-side current-sense amplifiers (19-0335; Rev 0; 11/94). [950075]

Full-scale load current $I_{sense}$ (A)	Current-sense resistor $R_{sense}$ (m $\Omega$ )	Gain-setting resistors $RG_1 = RG_2$ ( $\Omega$ )	Output resistor $R_{out}$ (k $\Omega$ )	Full-scale output voltage $V_{out}$ (V)	Scale factor $V_{out}/I_{sense}$ V A <sup>-1</sup>
0.1	500	200	10	2.5	25
1	50	200	10	2.5	2.5
5	10	100	5	2.5	0.5
10	5	50	2	2	0.2

# ELECTRONIC SANDGLASS

Here is a microprocessor-based version of the original silicon-powered sandglass. More versatile than the original 3-minute only version, this sandglass, though still based on silicon, can be set to run from 1 to 99 minutes. Great for children!

**Design by Andrew Woodfield**

**Y**OUNG children find it hard to read the time. The long-hand and the short-hand on the clock are frequently mixed up. Digital clocks can be even more confusing for children, with numbers being read back-to-front, even upside-down! Curiously, the difficulty with reading the right time seems to rise to a peak around bedtime, or when something important has to be done.

An ordinary sandglass is a great solution, since it clearly shows how much time has elapsed, and how much is left. But for avid readers of books, especially the author's children, the typical 3-minute sandglass was not nearly long enough.

The Electronic Sandglass was the solution I came up with to solve the problem. It is programmable, allowing for timed durations of up to 99 min-

utes. It is also very colourful. Even when not in use, it serves as a useful 'night-light' for children who need some help in getting off to sleep. In operation, it simulates the falling sand-grains of the original, and allows children to quickly judge how long it has to run before the lights go out. Or, to be truthful, the time to run until the next appeal for more time to higher authorities.

To keep the project as simple as possible, the sandglass only uses one chip. The 87C751 is one of the smallest and most powerful single-chip microcontrollers available. The chip drives the display, reads the switches, sounds the alarm, and counts the time. With only a few parts required to this busy little chip, the sandglass is also quick and easy to make.

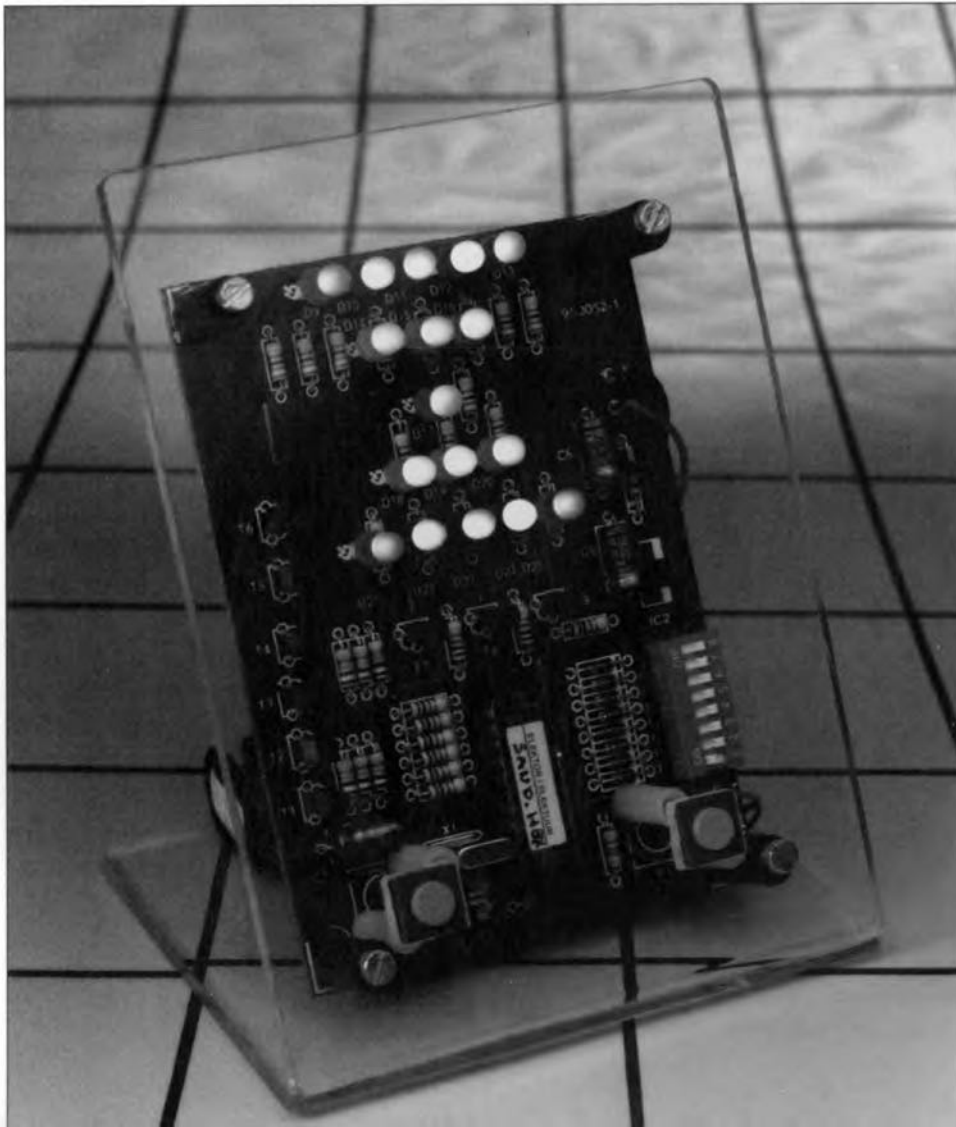
## The 87C751 microcontroller

The microcontroller used in the timer is one from the 8051 family. Originally developed by Intel, the device is also made by a number of other companies. One of these, Philips Semiconductors, produce a range of 8051 variants to meet different applications, and the sandglass uses one of the smallest family members, the 87C751.

As for almost all single-chip microcontrollers, the 87C751 includes EPROM (erasable programmable read-only memory), RAM (random access memory), CPU (central processing unit) functions and I/O (input/output) pins. The micro has three ports with a total of 16 I/O lines, two interrupt pins, several special timer input pins, in addition to two versatile internal timers. The Philips I<sup>2</sup>C special serial control bus is also implemented on the chip, for use with the wide variety of external interface chips available in the I<sup>2</sup>C family.

Manufactured in CMOS technology, the 87C751 has a low current consumption and heat dissipation. The chip can be placed in several idle modes, where it waits for some signal requiring it to act. In this quasi-sleep mode, it only draws a few micro-amps of current.

The I/O pins can be programmed into a variety of modes. Some pins share functions, and may be used either for direct I/O or for some interrupt-driven function. The I<sup>2</sup>C serial bus system pins on the device may be used to drive specialized chips for use as infra-red remote control, analogue







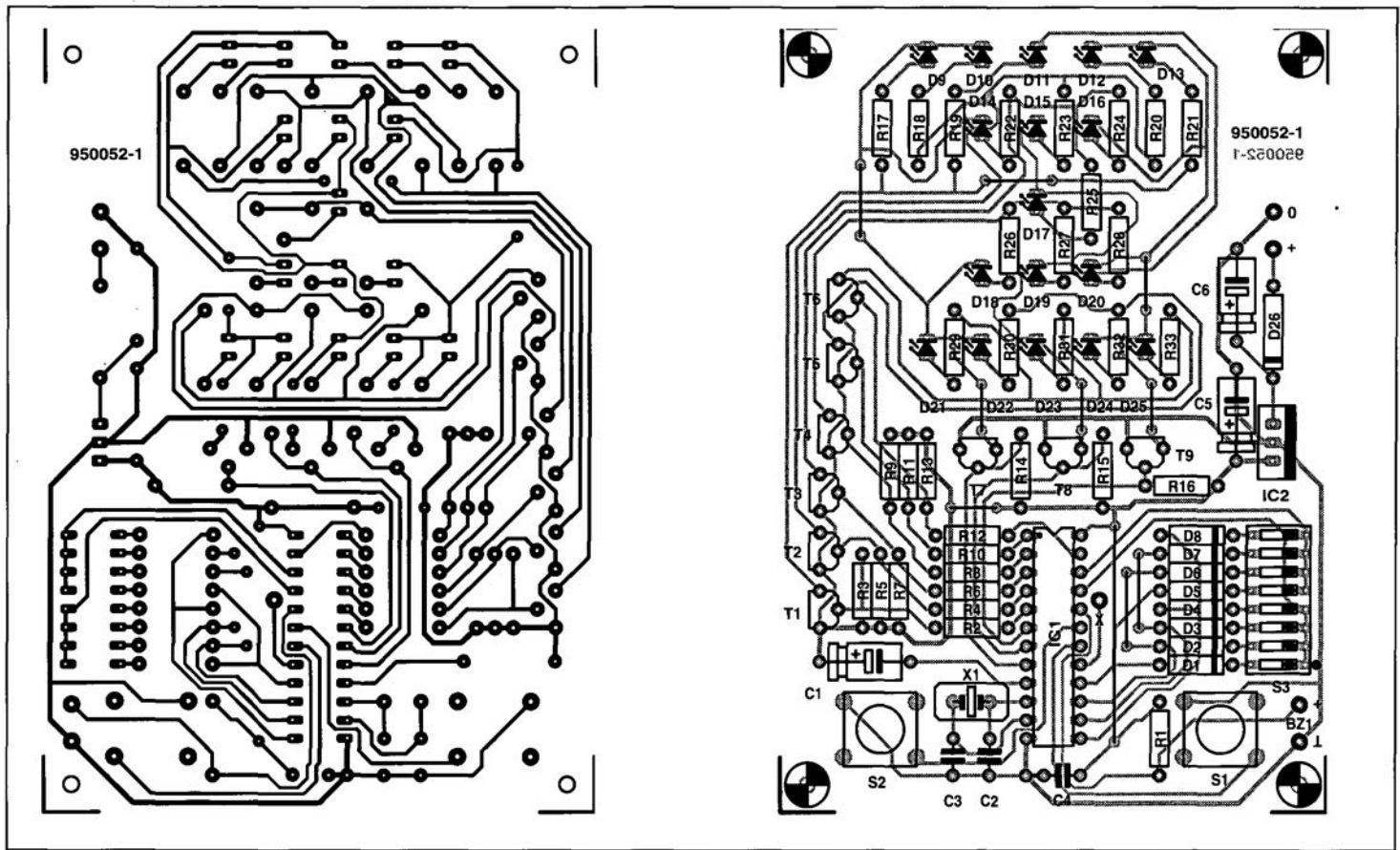


Fig. 2. Track layout and component mounting plan of the PCB designed for the sandglass (board available ready-made, see page 70).

## COMPONENTS LIST

### Resistors:

$R_1 = 47k\Omega$   
 $R_2; R_4; R_6; R_8; R_{10}; R_{12}; R_{14}; R_{15}; R_{16} = 10k\Omega$   
 $R_3; R_5; R_7; R_9; R_{11}; R_{13} = 100k\Omega$   
 $R_{17}-R_{33} = 680\Omega$

### Capacitors:

$C_1; C_5; C_6 = 10\mu F$  63V  
 $C_2; C_3 = 22pF$   
 $C_4 = 100nF$

### Semiconductors:

$D_1-D_8 = 1N4148$   
 $D_9; D_{13}; D_{17}; D_{21}; D_{25} = \text{LED, green}$   
 $D_{10}; D_{11}; D_{12}; D_{22}; D_{23}; D_{24} = \text{LED, red}$   
 $D_{14}; D_{15}; D_{16}; D_{18}; D_{19}; D_{20} = \text{LED, yellow}$   
 $D_{26} = 1N4002$   
 $T_1-T_6 = BC557B$   
 $T_7; T_8; T_9 = BC547B$   
 $IC_1 = 87C571$  (order code 946647-1)  
 $IC_2 = 7805$

### Miscellaneous:

$S_1; S_2 = \text{PCB mount presskey, e.g., MultiMec CTL3.}$   
 $S_3 = 8\text{-way DIP switch.}$   
 $BZ_1 = \text{piezo buzzer, passive.}$   
 $X_1 = 11.0592\text{MHz crystal.}$   
 Printed circuit board and programmed 87C571: order code 950052-C (see page 70).

## Construction

The design of the printed circuit board is shown in Fig. 2. This board is available ready-made together with the programmed microcontroller. Start by fitting the wire links on to the board. Check your work very carefully, because if you forget to fit one, the timer is not likely to work, even if you do fit the other parts in the correct way. Next, add the capacitors, the resistors, the diodes and the DIP switch. Check the polarity of the electrolytic capacitors and the diodes.

Insert the socket for the micro. If you can not get hold of a 'narrow' (0.3-in. wide) 24-pin IC socket, use three 8-pin sockets instead. Make sure the notch is at the side indicated on the component overlay. Then carefully solder the crystal. While using the 11.0592-MHz crystal suggested will produce the best timer accuracy, any crystal within 250 kHz from that frequency will be acceptable. For example, if you have an 11 MHz crystal available, that will be suitably accurate.

Install the transistors for the display, and then the LEDs. Since the display uses three n-p-n transistors (BC547B) and six p-n-p transistors (BC557B), there is room for confusion here. Check before soldering. The LEDs must be mounted at a height of

about 6 mm. The simplest way to do this is to get hold of some drinking straws, and cut off pieces with a length of 6 mm. Insert one of the LED legs through it, and then solder them into the PCB. Again, watch to make sure you install them the correct way

tens →	S3(1)	S3(2)	S3(3)	S3(4)
units →	S3(5)	S3(6)	S3(7)	S3(8)
0	off	off	off	off
1	off	off	off	on
2	off	off	on	off
3	off	off	on	on
4	off	on	off	off
5	off	on	off	on
6	off	on	on	off
7	off	on	on	on
8	on	off	off	off
9	on	off	off	on

Table 1. The DIP switch allows you to change the preset timeout period.



around. The two push-buttons should be mounted a little higher than the LEDs. Plastic PCB spacers are suitable for that purpose.

Mount the 78(L)05 voltage regulator next. Add the battery wires, and once more check that all the components are fitted correctly, in the right place, and the right way around. **Do not insert the microcontroller yet!**

Connect a 9-V battery and measure the voltage between pin 24 (positive) and pin 12 (negative or common) of the microcontroller socket. The meter should display between 4.5 V and 5.5 V. If the voltage is too high or too low, check and fix the fault. The fault is likely to be either a poorly soldered joint, or the regulator has been fitted the wrong way around. Do not proceed until your timer passes this test. Disconnect the battery.

The next test checks the display to make sure that the LEDs are connected correctly, and the driver transistors are functioning. Temporarily connect pin 5 of the microcontroller socket to ground. Reconnect the battery. LEDs D<sub>9</sub>, D<sub>11</sub> and D<sub>13</sub> should light. Temporarily link, one at a time, pins 6, 7 and 8 to ground. This should turn each of the LEDs off in turn.

Disconnect the ground link from pin 5, and connect it to pin 4 to test the next row. Then repeat this test again for subsequent rows, using pins 3, 2, 1 and 23. If any individual LED does not light, check to see that it has been inserted into the PCB correctly. If an entire column or row of LEDs does not function correctly, check the relevant buffer transistor. Note that one row only has two LEDs.

Now set the DIP switches in accordance with the preset timeout period you want. The switches in block S3 are programmed in BCD (binary coded decimal) to represent the tens and units of the desired time. If the switch is omitted, the timer will initialise itself with a default period of 10 minutes. **Table 1** indicates the switch settings.

For example, to program a timeout period of 15 minutes you require a binary pattern 0001 0101. This is achieved by leaving switches S<sub>3(1)</sub>, S<sub>3(2)</sub>, S<sub>3(3)</sub>, S<sub>3(5)</sub> and S<sub>3(7)</sub> open, and closing S<sub>3(4)</sub>, S<sub>3(6)</sub> and S<sub>3(8)</sub>. The pattern on the DIP switch then looks as follows:

S <sub>3(1)</sub>	S <sub>3(2)</sub>	S <sub>3(3)</sub>	S <sub>3(4)</sub>	S <sub>3(5)</sub>	S <sub>3(6)</sub>	S <sub>3(7)</sub>	S <sub>3(8)</sub>
off	off	off	on	off	on	off	on

To help you with the orientation, switch S<sub>3(1)</sub> is connected to diode D<sub>1</sub>, and S<sub>3(8)</sub> to diode D<sub>8</sub>.

It should be noted that the timer reads the switches at power-on only. If you want to change the preset value, you have to disconnect the power first and then change the switch settings.

Next, install the 87C751, observing

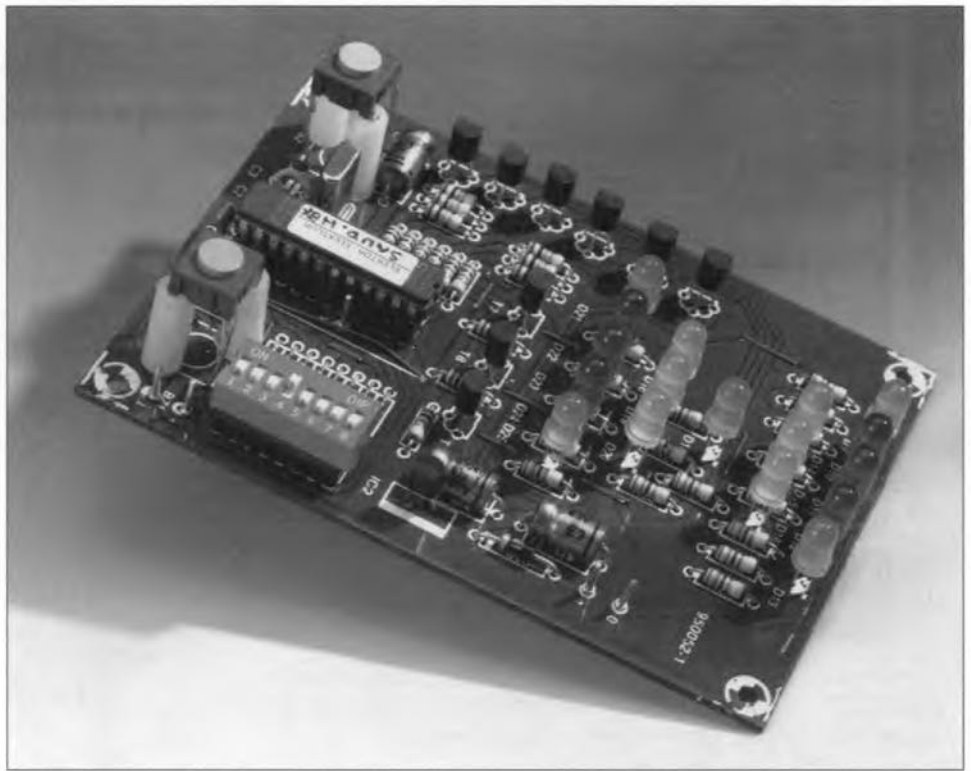


Fig. 3. Fully populated board before it is fitted on to the perspex stand.

precautions against static electricity discharges which may damage the device. Also make sure the chip is fitted the right way around on the board. The micro has a notch at the top which should be at the same end as the notch printed on the PCB overlay and the notch on the socket.

Attach the battery. The display will remain blank for about half a second before bursting into life with the random light display. This will run as long as power is connected, and the timer is not running.

### Using the sandglass

Press the SetTime button, and release it. The display will briefly change to show the preset time you encoded with the DIP switch. If you did not fit the switch, the timer will display the default time of 10 minutes. If you continue to hold the SetTime button, the timer will slowly increment the Alarm Time, displaying each number in turn, and starting at the preset value read from the DIP switch. After displaying 99 minutes, the timer will start again at 1 minute. A timer setting of '0' or greater than 99 minutes is not possible.

Once the time has been set, the timer can be started. Press and release the Start/Stop button. The timer display will change again, this time to the simulation of the sandglass. The 'sand grains' will fall bit by bit, changing periodically. The display changes at a rate of 2.5 seconds per minute of alarm time. For example, if the alarm

time is two minutes, the display will change every five seconds. For an alarm time of 15 minutes, the display will change every 37.5 seconds.

If the Start/Stop button is pressed during this mode, the timer display will flash and revert to random mode, halting and resetting the timer. Pressing the SetTime button has no effect in this mode. You must stop the timer to reset the alarm time.

At the end of the preset time, the alarm starts. This consists of repeated display flashing and rising beeps of sound from the piezo speaker. They will continue for about a minute, or until the Start/Stop button is pressed. This resets the timer back to the random mode.

All of this may sound a little complex, but in fact the operation of the timer is quite straightforward. A few minutes of experimentation will demonstrate all the functions and clarify any confusion.

### Making the timer's plastic stand

The timer can be mounted into a suitable enclosure, or on to the little perspex stand shown in the photographs. This is made from a single sheet of 2 mm or 3 mm thick smoked perspex which has been bent to form the stand. The best way to bend it is to use a hot-air gun or electric paint stripper, which is probably the safest and best controllable. You will need to experiment to see how long to heat up your





# WHISTLE-CONTROLLED SWITCH

This circuit switches two electrical loads on and off under the control of an acoustic signal. The remote control operates reliably up to a distance of about four metres (15 feet) and is well protected against interference. The system does not require a transmitter because control signals are generated physically rather than electronically. The only proviso is that you are fairly proficient in ... whistling!



Design by H. Bärnthaler

THE circuit is an acoustic switch for two loads which are controlled by whistle signals. Such a switch can be very useful in locations where the light switch is difficult to find in the dark, such as in the cellar or on the loft. Another application is as a protective device, for instance, to prevent unauthorized use of your computer system or stereo equipment. As long as unauthorized users remain unaware of your very personal switching signal, they will be unable to get your equipment to work. So, plenty of applications.

The acoustic switch is fairly sensitive, so you do not have to follow a crash-course in power whistling to be

able to use it. Additionally, the built-in interference suppressor affords a good degree of protection against triggering by random signals.

## From microphone to relay

The whistle-controlled switch is in essence an acoustic receiver with switching outputs. If you look ahead at the circuit diagram, the circuit proper sits between an electret microphone element at the input and two relays at the output. The (mainly digital) electronics in between ensures that the relays are switched on and off in response to an accurately defined

whistling signal only. The relays respond to two different signal frequencies, so you may have to practice a bit to be able to whistle the 'high' and 'low' tones with sufficient volume and accuracy as regards frequency.

So far, it all seems fairly simple, but the question is, of course, how the circuit converts the whistle tones into reliable switching signals. Before going into detail as regards the operation of the circuit, it may be useful to give a broad outline of the way the signals are processed.

The acoustic signal picked up by the microphone is first amplified and then taken through a band filter whose pass-band is 'tuned' to human whistling signals. This effectively blocks signals with vastly deviating frequencies. Next, the signal is converted into a square wave whose period is compared with that of an adjustable 'reference block'. This operation actually forms a kind of 'channel filter', because it allows the circuit to determine whether the 'high' or 'low' whistle was detected. Once the whistle tone has been translated into a corresponding logic level, the output section of the circuit changes the state (on/off) of one of the relays.

The circuit also contains an effective noise suppression filter, which tells the digital section whether the whistle tone has sufficient volume and duration. If so, a kind of 'o.k.' signal is generated which enables the output section. So, no switching takes place until the proper whistle signal is recognised.

## Practical circuit

The complete circuit diagram of the whistle-controlled switch is given in **Fig. 1**. The diagram is so clear that a block schematic is really superfluous. From the previous description, it is clear already that the circuit consists of five blocks: input amplifier, bandfilter, channel filter, power driver(s) and noise filter. All of these sub-circuits are easily recognized in the circuit diagram. Let's have a look at how they work.

### Input amplifier and bandfilter

The pick-up device is, evidently, a microphone. This may be a dynamic microphone, although it is much more likely that an electret (also called 'condenser') element is used. That is why a phantom supply is provided with the aid of resistor  $R_1$ . The signal picked up by the microphone arrives at transis-

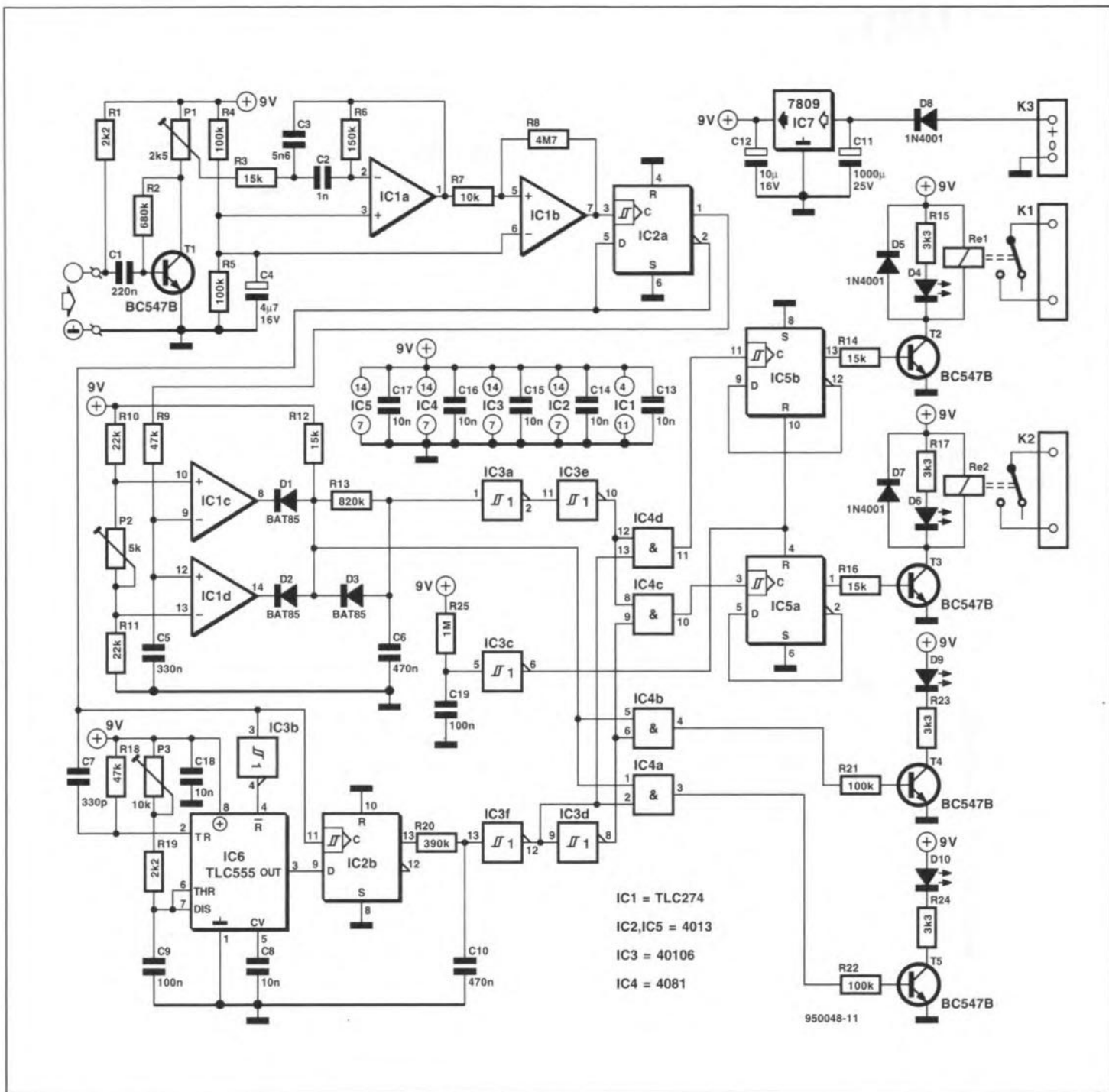


Fig. 1. The main functions in this circuit are a bandfilter (IC1a), a channel filter (IC2b; IC6), switching stages with memories (T2; T3; IC5) and a noise suppressor (IC1c; IC1d).

tor  $T_1$  via capacitor  $C_1$ .  $T_1$  acts as an amplifier and provides a gain of about  $\times 50$ . Preset  $P_1$  allows the gain of the amplifier (and thus the sensitivity of the switch) to be matched to the voltage produced by the microphone used.

From the wiper of  $P_1$ , the signal arrives in the circuit around opamp  $IC_{1a}$ . This forms an active band filter whose frequency determining components,  $C_2$ ,  $C_3$ ,  $R_3$  and  $R_6$ , have values which cause the 'low' and 'high'  $-3$ -dB roll-off points to lie at 775 Hz and 2 kHz respectively. This corresponds reasonably well to the frequency range of the art of whistling. The slope of the filter

is about 6 dB per octave. This gives a sufficiently narrow band for the present application. The voltage gain of the filter is set to  $\times 1.5$ .

The sine wave shaped signal at the output of  $IC_{1a}$  is then fed to opamp  $IC_{1b}$ , which acts as a comparator with a hysteresis of about 20 mV. Consequently, a minimum input level of 0.3 mV<sub>pp</sub> is required for the comparator to respond. The frequency of the output signal produced by  $IC_{1b}$  is halved by bistable  $IC_{2a}$ , which supplies a symmetrical square wave at its output. Although the bistable already forms part of the noise filter, it is more

convenient to mention it here because of the layout of the circuit diagram.

#### Channel filter and relay drivers

The square wave signal produced by  $IC_{2a}$  is fed to the clock input of  $IC_{2b}$ . This bistable, helped by timer  $IC_6$ , acts as the channel filter. The timer IC is wired as an astable multivibrator whose mono time is adjusted with preset  $P_3$ . When the half period time of the square wave is shorter than the mono-time of  $IC_6$ , the D input of  $IC_{2b}$  will be high on the positive-going edge of the clock signal. Consequently, the  $Q$  output is then high after the positive-



going clock edge. Only when the half period time exceeds the monotime, the D-input will be low during the clock, and the Q output changes state. The 'changeover' frequency of the channel filter is adjusted by changing the monotime of P<sub>3</sub> with the aid of preset P<sub>3</sub>. Above this frequency, whistle signals are recognized as 'high', and below this frequency, as 'low'.

RC network R<sub>20</sub>-C<sub>10</sub> gives just enough delay to prevent spurious toggling of IC<sub>2b</sub>. Since Schmitt trigger IC<sub>3f</sub> inverts the signal, its output is at '0' for the 'high' whistle, and at '1' for the 'low' whistle.

The output section consists of two switching stages, each of which with its own memory in the form of a bistable (IC<sub>5a</sub>; IC<sub>5b</sub>).

The logic level at the output of IC<sub>3f</sub> corresponds to the whistle frequency, and is fed to AND gates IC<sub>4d</sub> and IC<sub>4c</sub> (the latter via inverter IC<sub>3d</sub>). From the output of IC<sub>3e</sub>, a '1' is applied to the other inputs of the AND gates if the input signal meets the requirements demanded by the noise filter — more about this further on. Depending on the frequency of the received whistle signal, the output of either IC<sub>4d</sub> or IC<sub>4c</sub> goes high. At that instant, either IC<sub>5a</sub> or IC<sub>5b</sub> receives a clock pulse, so that the relevant bistable changes state. These D-type bistables thus provide a kind of memory function. IC<sub>5a</sub> and IC<sub>5b</sub> each drive a relay via a transistor, T<sub>2</sub> or T<sub>3</sub>. These relays control loads, such as lamps, via connectors K<sub>1</sub> and K<sub>2</sub>. To make sure that the relays are not actuated at power-on, IC<sub>5</sub> is endowed with a power-on reset circuit, consisting of IC<sub>3c</sub>, R<sub>25</sub> and C<sub>19</sub>.

### Noise filter

To make sure that the circuit does not respond to random beeps and whistles whose frequency may fall inside the pass-band of the band filter, a sub-circuit has been added which is, strictly speaking, not a filter although it does act like one. Most noise will consist of signals which, although they may briefly have the right frequency, are too short to be recognized as a 'valid' whistle. Signals with strong modulation or interruptions, too, are too short, overall, to be recognized as a valid switching signal. In short, the circuit must be capable of detecting the right tone frequency, and in addition set up a minimum limit as regards the duration of the tone.

This is achieved in the first instance by adding network R<sub>9</sub>-C<sub>5</sub>. As already mentioned, the received whistle signal is converted into a square wave with the aid of IC<sub>1b</sub> and IC<sub>2a</sub>. This square wave is averaged by the previously mentioned RC network. Provided the input signal is sufficiently long, the symmetrical character of the square

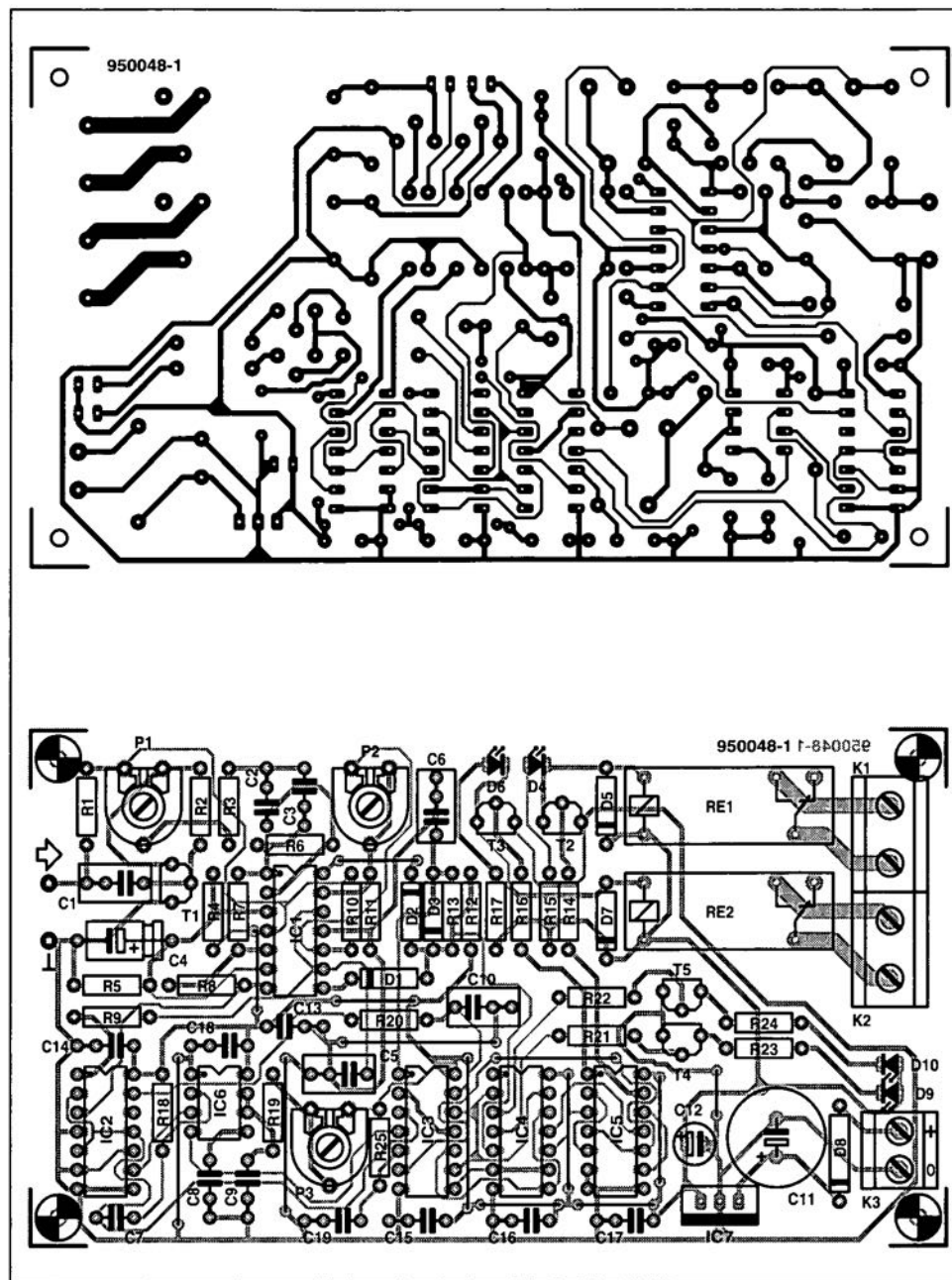


Fig. 2. The PCB design is well laid out and compact. Terminal blocks K<sub>1</sub> and K<sub>2</sub> are connected in series with one of the supply lines of the relevant load (board not available ready-made through the Readers Services).

wave ensures that the voltage across C<sub>5</sub> is about half the supply voltage. As soon as there is something amiss with the input signal, that will be reflected by the voltage across C<sub>5</sub>. Thus, any deviation of this voltage from a pure square wave (duty factor 0.5; mark space ratio 1:1) can be used to detect an 'error' condition for the noise filter to act on.

The function of accurate voltage comparator necessary to implement the error detector is carried out by a window comparator. This consists of opamps IC<sub>1c</sub> and IC<sub>1d</sub>. The 'width' of the detection range is adjustable with preset P<sub>2</sub>. Only if the whistle signal meets the previously mentioned requirements, and the voltage across C<sub>5</sub> has the right level and minimum dura-

tion, will the output of comparator charge capacitor C<sub>6</sub> to a level which is high enough for the input of IC<sub>3a</sub> to recognize a logic '1'. If the conditions are no longer satisfied, C<sub>6</sub> is discharged rapidly via D<sub>1</sub>/D<sub>3</sub> or D<sub>2</sub>/D<sub>3</sub>. Schottky diodes are used in these positions to enable C<sub>6</sub> to be fully discharged and so achieve the widest noise margin.

Summarizing, a logic '1' is copied to AND gates IC<sub>4c</sub> and IC<sub>4d</sub> only if the right whistle signal is received. Only then, the channel filter is able to make bistable IC<sub>5a</sub> or IC<sub>5b</sub> toggle.

### Adjustment

The circuit contains three presets, which have to be adjusted intuitively

## COMPONENTS LIST

## Resistors:

$R_1, R_{19} = 2k\Omega$   
 $R_2 = 680k\Omega$   
 $R_3, R_{12}, R_{14}, R_{16} = 15k\Omega$   
 $R_4, R_5, R_{21}, R_{22} = 100k\Omega$   
 $R_6 = 150k\Omega$   
 $R_7 = 10k\Omega$   
 $R_8 = 4M\Omega$   
 $R_9, R_{18} = 47k\Omega$   
 $R_{10}, R_{11} = 22k\Omega$   
 $R_{13} = 820k\Omega$   
 $R_{15}, R_{17}, R_{23}, R_{24} = 3k\Omega$   
 $R_{20} = 390k\Omega$   
 $R_{25} = 1M\Omega$   
 $P_1 = 2k\Omega$  preset  
 $P_3 = 10k\Omega$  preset  
 $P_2 = 5k\Omega$  preset

## Capacitors:

$C_1 = 220nF$   
 $C_2 = 1nF$   
 $C_3 = 5nF$   
 $C_4 = 4\mu F$  16V  
 $C_5 = 330nF$   
 $C_6, C_{10} = 470nF$   
 $C_7 = 330pF$   
 $C_8, C_{13}-C_{18} = 10nF$   
 $C_9, C_{19} = 100nF$   
 $C_{11} = 1000\mu F$  25V radial  
 $C_{12} = 10\mu F$  16V radial

## Semiconductors:

$D_1, D_2, D_3 = BAT85$   
 $D_4, D_6, D_9, D_{10} = LED$ , red, 3 mm, low current  
 $D_5, D_7, D_8 = 1N4001$   
 $T_1-T_5 = BC547B$   
 $IC_1 = TLC274$   
 $IC_2, IC_5 = 4013$   
 $IC_3 = 40106$   
 $IC_4 = 4081$   
 $IC_6 = TLC555$   
 $IC_7 = 7809$

## Miscellaneous:

$K_1, K_2 = PCB$  terminal block, 2-way, pitch 7.5 mm.  
 $K_3 = PCB$  terminal block, 2-way, pitch 5 mm.  
 $Re_1, Re_2 = PCB$  relay 12 V/5 A (e.g., Siemens V23057-B0002-A101).  
 Electret microphone element.

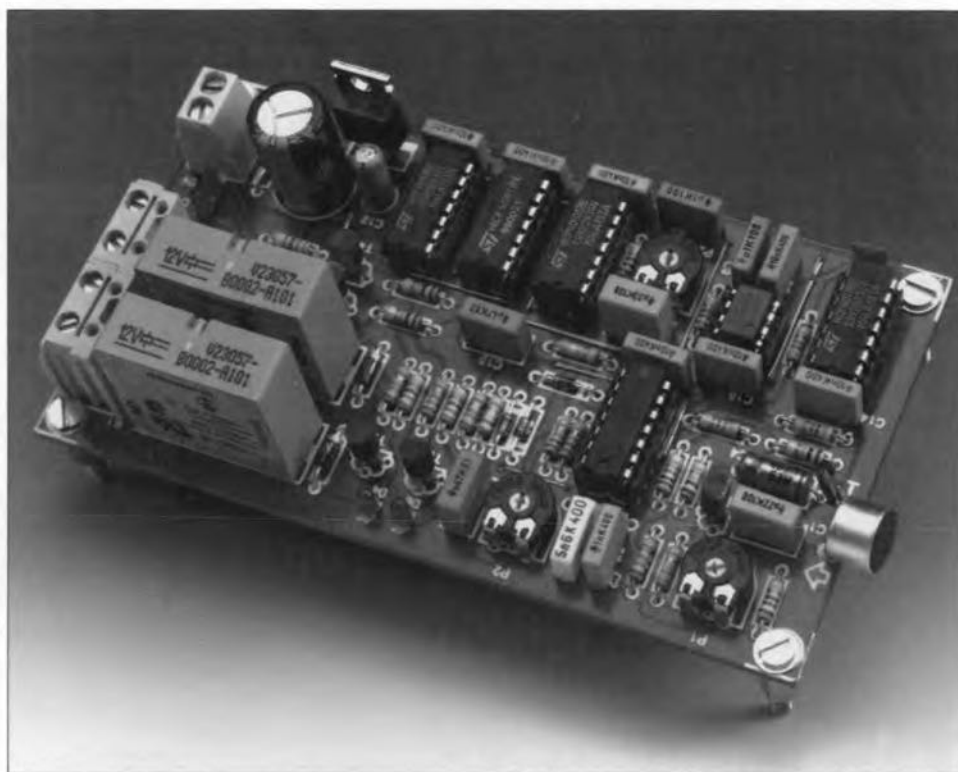


Fig. 3. Use this photograph to check your own construction work.

rower, the chances of a wrong signal being recognized as 'o.k.' become smaller. At the same time, the demands on the whistling ability of the user increase. Finding the right setting of this adjustment is therefore bound to require quite some whistling.

The changeover frequency of the channel filter is set with the aid of preset  $P_3$ . The best value is, again, dependent on you, the whistler, and can only be found by trial and error adjustment.

Two monitor LEDs,  $D_9$  and  $D_{10}$ , are available to help you adjust the circuit. These LEDs are driven by AND gates  $IC_{4a}$  and  $IC_{4b}$ , and signal the state of the noise filter and the channel filter outputs, without the delaying action of  $R_{13}-C_6$ . In addition, two LEDs show the state of the relays, so that you do not have to connect a load while adjusting the circuit.

## Construction

The printed circuit board design for the whistle controlled switch is shown in Fig. 2. Unfortunately this PCB is not available ready-made through the Readers Services, so you have to make it yourself. Construction is all plain sailing if you stick to the parts list and the indications on the component mounting plan. The relays mentioned in the parts list are capable of switching currents up to 5 A, which will be more than sufficient for most applications. The load connections are clearly marked on the PCB.

The microphone is connected to the pins marked with the 'input' arrow. Observe the polarity of the microphone element. Sockets  $K_1$  and  $K_2$  are connected in series with the supply wires of the relevant loads. The power supply is connected to  $K_3$ .

Since the relays need only 30 mA or so, and the LEDs are high efficiency types, the circuit is pretty economical. Consequently, it can be powered by an ordinary mains adaptor capable of supplying 12 V d.c. at 100-odd milliamps. This voltage need not be regulated, because the circuit has its own, on-board, 9-V regulator,  $IC_7$ .

The photograph in Fig. 3 shows the fully populated circuit board. The board may be fitted in any suitable all-plastic case. Because of its relatively small size, the choice of a suitable case will not be too difficult. Pay attention to electrical safety, and be sure to use properly rated wiring to connect to  $K_1$  and  $K_2$ . Particularly if you want to switch mains-operated loads, the use of heavy duty insulated wire, strain reliefs and grommets is a must.

The microphone must be mounted such that it has a 'free view' of the area. Although their function is not strictly required once the circuit is adjusted, LEDs  $D_9$  and  $D_{10}$  may be mounted visibly to help you hit the right whistle frequency.

(950048)

and by trial and error.

Preset  $P_1$  determines the gain of the preamplifier, and thus the 'hearing range' of the switch. The maximum range of the prototype was just over four metres.

Preset  $P_2$  sets the size of the comparator's window, or the speed at which a deviation is recognized as a fault. As the window becomes nar-



# AUTO LIGHT CONTROL

Design by K. Walraven

**A circuit is described that automatically adjusts the flux from a light source (incandescent or fluorescent) in accordance with the ambient conditions. Thus, it will increase the luminous intensity when daylight diminishes owing to the hour of day or heavy cloud blotting out the sun and decrease it when daylight becomes brighter.**

Strictly speaking, the auto lights control is a phase-angle control unit in which the usual potentiometer has been replaced by light-dependent circuit.

## Pulse-width control

The principle of operation may be seen from the block diagram of the unit in Fig. 1. A sawtooth voltage, derived from, and synchronous with, the mains voltage, is applied to the non-inverting input of a comparator. As long as the inverting input of the comparator is low, its output will be a rectangular pulse. This pulse, which is invariably logic high, is used to trigger a triac.

The pulse width of the comparator output may be changed by a direct voltage at the inverting input. The comparator will then change state when the leading edge of the sawtooth rises above the level of this direct voltage. This means that the higher the level of the direct voltage at the inverting input, the narrower will be the comparator output pulses and the shorter the phase (fraction) of each 50 Hz period during which the triac is on. The light flux of the lamp in series with the triac will then decrease.

A variable direct-voltage source is formed by a metering bridge, one leg of which is a light-dependent resistor (LDR), and a comparator. The direct voltage is directly proportional to the illuminance on the LDR.

Note that the LDR should not be replaced by a photodiode or phototransistor, because these are too sensitive and too fast. In the present application, high sensitivity is not required, while high speed would make the circuit react too fast to short-duration changes in the illumination.

## Circuit description

In the circuit in Fig. 3,  $T_1$ - $T_4$  form a zero-crossing detector:  $T_1$  reacts to the positive half period and  $T_2$  to the negative half. Both transistors are off, how-

ever, when the mains voltage is near the zero crossing. Since  $T_2$ , in contrast to  $T_1$ , is driven via its emitter,  $T_3$  is necessary to ensure that the sensitivity for both periods is the same.

The switching of the three transistors results in junction  $R_3$ - $R_6$  becoming high only when the mains voltage is at or near a zero crossing. The level at the junction is inverted by  $T_4$ , so that  $C_2$  is charged via  $R_5$  during the larger part of each and every half period. The capacitor is, however, discharged rapidly when the mains passes through a zero crossing. Consequently, the potential across  $C_2$  is a sawtooth, which is synchronous with the mains voltage. Although the leading edge of the sawtooth is determined by a power of  $e$ , which normally is not ideal, in the present circuit it is fine, because it makes the circuit act faster when the mains is at or near a zero crossing.

The sawtooth voltage is applied to the non-inverting input of comparator  $IC_{1a}$ . The inverting input is fed with the light-dependent direct voltage generated by the circuit around  $IC_{1b}$ . The value of  $R_7$  should be about 1 k $\Omega$  in op-

eration. This value is not too important as the range of  $P_1$  is fairly large.

As long as the bridge is in equilibrium, the output voltage of  $IC_{1b}$  remains constant. If the illuminance on  $R_7$  changes, the equilibrium will be broken: an increase results in a rise, and a reduction in a drop, of the output voltage of  $IC_{1b}$ . Network  $R_8$ - $C_3$  causes  $IC_{1b}$  to function as an integrator; the time constant ensures that changes in the output voltage occur gradually.

## Triggering the triac

Owing to the simplicity of the power supply,  $IC_{1a}$  can not provide the 5 mA current required by the gate of the triac during the entire length of its output pulses. This is remedied by astable  $IC_2$ . Basically, the triac can be triggered by a fairly small pulse. Since the pulse-width information in the output of  $IC_{1a}$  is contained in the onset of the leading edge, it would seem possible to convert the leading edges to needle pulses to trigger the triac. After all, the triac is switched off automatically every time the mains passes through a zero crossing.

The difficulty with this is that single gate pulses work fine with ohmic loads, but the transformer of a halogen lamp, or the choke of a neon light, is an inductive load. This means that the current lags the voltage and it may happen, therefore, that the triac is switched off immediately after it has been triggered, since the current has not had the time to reach the level of the holding current. This would lead to asymmetric switching, which would sooner or later result in such a large direct current through the transformer, or choke, that (at best) the relevant fuse blows.

Because of this difficulty, the triac is triggered for as long as it has to conduct. This is not done with a single,

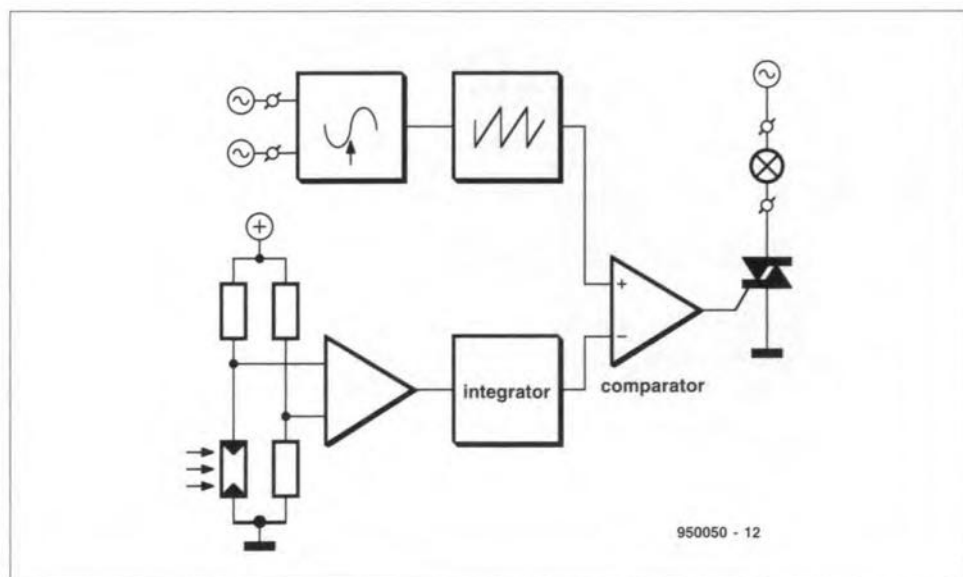


Fig. 1. Block diagram of the auto light control.

long, pulse, but with a series of short, discrete pulses, which require far less current. These pulses (duty factor 10%) are generated by IC<sub>2</sub> as long as the output signal of IC<sub>1a</sub> is high.

Any triac whose gate current need not exceed 5 mA may be used. The prototype uses a TIC206D. Network R<sub>19</sub>-C<sub>8</sub> suppresses any voltage peaks. Many modern triacs, which are particularly suitable for use with inductive loads, do not need this network.

**Power supply**

As usual in this type of circuit, power is derived directly from the mains, that is, without a mains transformer. Instead of this, C<sub>6</sub> functions as a sort of a.c. series resistance. During each positive half period, C<sub>7</sub> is charged via C<sub>6</sub> and D<sub>3</sub>. Zener diode D<sub>2</sub> limits the voltage to 5.6 V and ensures that nothing untoward happens during the negative half periods. Resistors R<sub>15</sub> and R<sub>16</sub> ensure that C<sub>7</sub> is discharged rapidly when the mains is switched off to prevent dangerous situations occurring. Resistor R<sub>13</sub> limits the current at switch-on. Inductor L<sub>1</sub> and capacitor C<sub>6</sub> form an effective noise suppressor.

The value of fuse F<sub>1</sub>, which is a must, depends on the wattage of the lamp connected to K<sub>2</sub>. The maximum

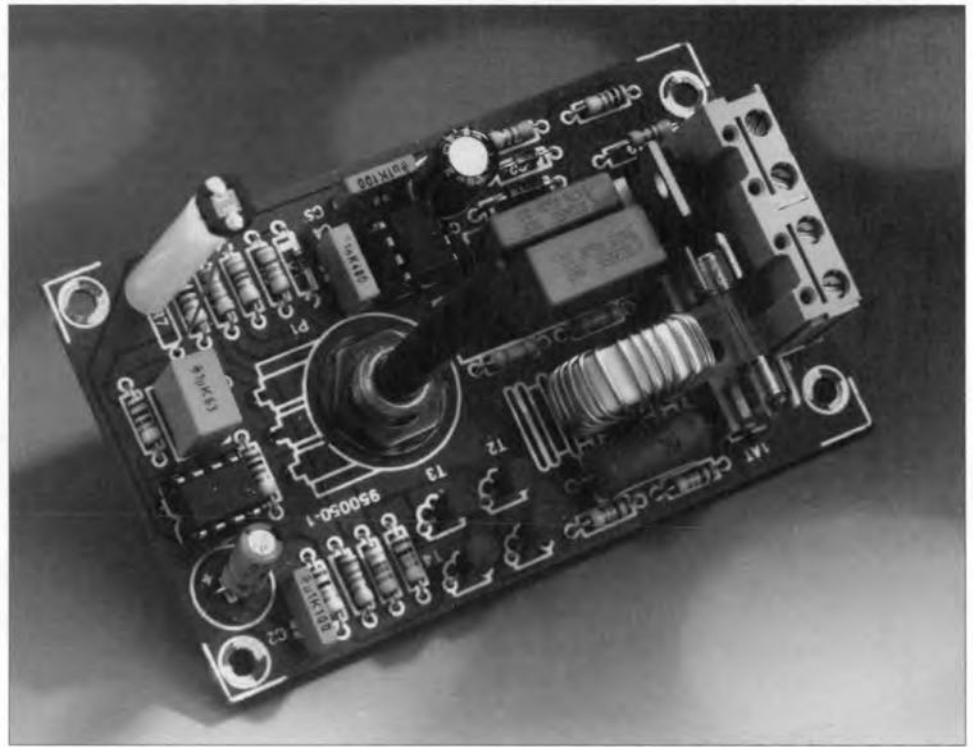


Fig. 2. Completed prototype printed-circuit board.

permissible load is 250 W. The rating of the fuse is obtained by multiplying the nominal current by 1.25. Thus, if a

lamp of 100 W is used, the fuse should be rated at 500 mA  $[(100/240) \times 1.25]$ . The maximum fuse rating should not exceed 1.25 A. It is advisable to use a delayed action fuse.

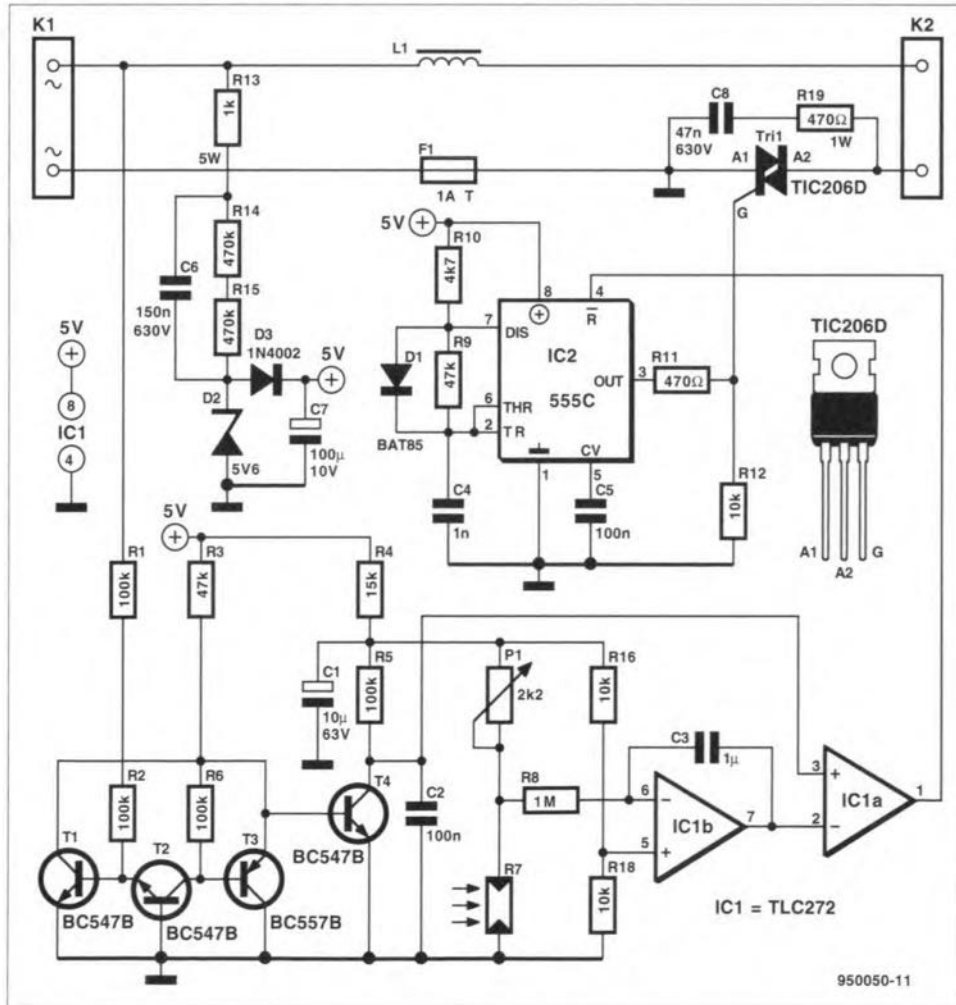


Fig. 3. Circuit diagram of the auto lights control.

**Construction and use**

The control is intended to be built on the printed-circuit board in Fig. 4. The completed prototype model is shown in Fig. 2. Populating the board should not present any difficulties. NEVER work on the board when the mains is switched on: this could be fatal. When it is finished, it should be fitted in a strong plastic, or preferably high-impact ABS, box. In most cases, a mains on/off switch will not be needed, but if it is, a slightly higher box must be used as specified in the parts list.

For safety reasons, the spindle of the potentiometer must be of man-made fibre (polythene), and this must be the only part that protrudes through the front panel.

It is recommended that strain reliefs are fitted to the cables connected to K<sub>1</sub> and K<sub>2</sub>.

The LDR should be fitted in a position where it is well exposed to the ambient light through a small hole. For safety reasons, this hole should not be so large that a finger or even screwdriver can be pushed through it. The best way is to cover the hole with a round piece of perspex.

The equilibrium of the metering bridge (when the luminous intensity is exactly as desired), is set with P<sub>1</sub>. Two points should be noted. The first is that the light emitted by the controlled



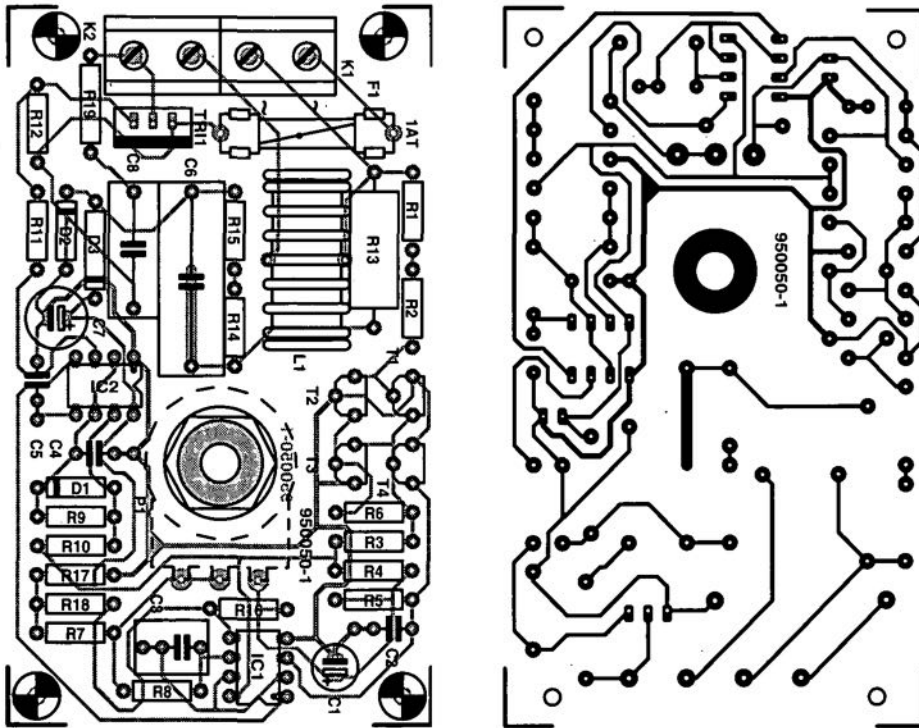


Fig. 4. Printed-circuit board for the auto light control unit.

lamp must be included in the control and it must, therefore, also fall on to the LDR. The second is that patience is required when setting  $P_1$  since, owing to the large time constant of the integrator, it takes a while before the effect of adjusting the preset becomes noticeable. If this is unacceptable, the time constant may be shortened by (temporarily) replacing  $C_3$  by a 100 nF capacitor. Once the correct setting has been found, mark the front panel accordingly and replace the 100 nF ca-

pacitor by the original 1  $\mu$ F.

### Parts list

#### Resistors:

$R_1, R_2, R_5, R_6 = 100 \text{ k}\Omega$   
 $R_3, R_9 = 47 \text{ k}\Omega$   
 $R_4 = 15 \text{ k}\Omega$   
 $R_7 = \text{LDR (see text)}$   
 $R_8 = 1 \text{ M}\Omega$   
 $R_{10} = 4.7 \text{ k}\Omega$   
 $R_{11} = 470 \Omega$   
 $R_{12}, R_{16}, R_{18} = 10 \text{ k}\Omega$

$R_{13} = 1 \text{ k}\Omega, 5 \text{ W}$   
 $R_{14}, R_{15} = 470 \text{ k}\Omega$   
 $R_{17} = 68 \text{ k}\Omega$   
 $R_{19} = 470 \Omega, 1 \text{ W}$   
 $P_1 = 2.2 \text{ k}\Omega$  linear potentiometer, with polythene or similar spindle (see text)

#### Capacitors:

$C_1 = 10 \mu\text{F}, 63 \text{ V}, \text{radial}$   
 $C_2, C_5 = 100 \text{ nF}$   
 $C_3 = 1 \mu\text{F}, \text{MKT (polypropylene)}$   
 $C_4 = 1 \text{ nF}$   
 $C_6 = 150 \text{ nF}, 630 \text{ V}$   
 $C_7 = 100 \mu\text{F}, 10 \text{ V}, \text{radial}$   
 $C_8 = 47 \text{ nF}, 630 \text{ V}$

#### Semiconductors:

$D_1 = \text{BAT85}$   
 $D_2 = 5.6 \text{ V}, 400 \text{ mW zener}$   
 $D_3 = 1\text{N}4002$   
 $T_1, T_2, T_4 = \text{BC547B}$   
 $T_3 = \text{BC557}$   
 $\text{Tri}_1 = \text{TIC206D; BTA04-600T (see text)}$

#### Integrated circuits:

$\text{IC}_1 = \text{TLC272}$   
 $\text{IC}_2 = 555\text{C (CMOS type)}$

#### Miscellaneous:

$L_1 = \text{triac choke, 3 A}$   
 $K_1, K_2 = \text{two terminal strip for board mounting, pitch 7.5 mm}$   
 $F_1 = \text{fuse with holder (see text)}$   
 Enclosure: 120x65x40 mm (if mains switch not used) or 120x65x65 mm (if mains switch used)  
 PCB Order No. 950050 (see p. 70)  
 [950050]

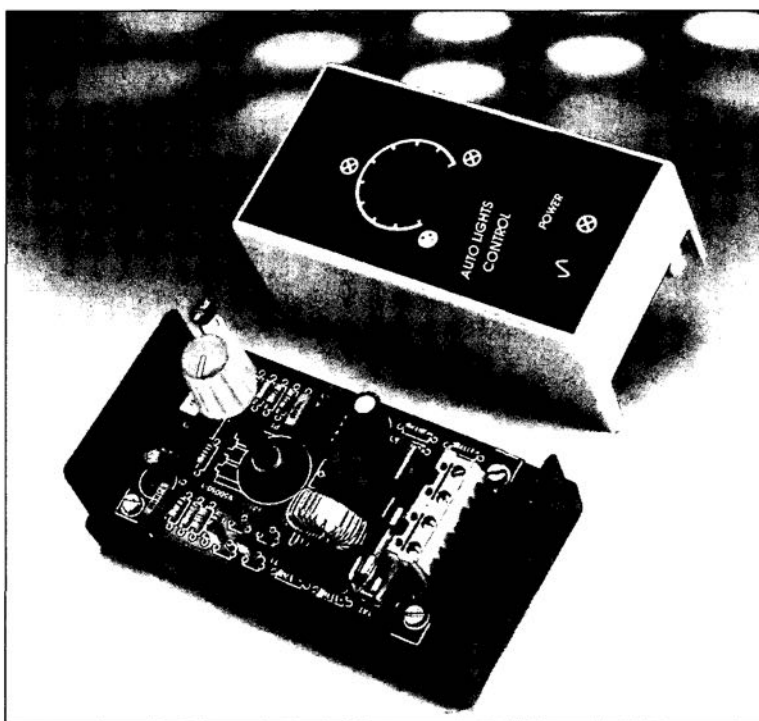


Fig. 5. The completed control unit with top cover removed.

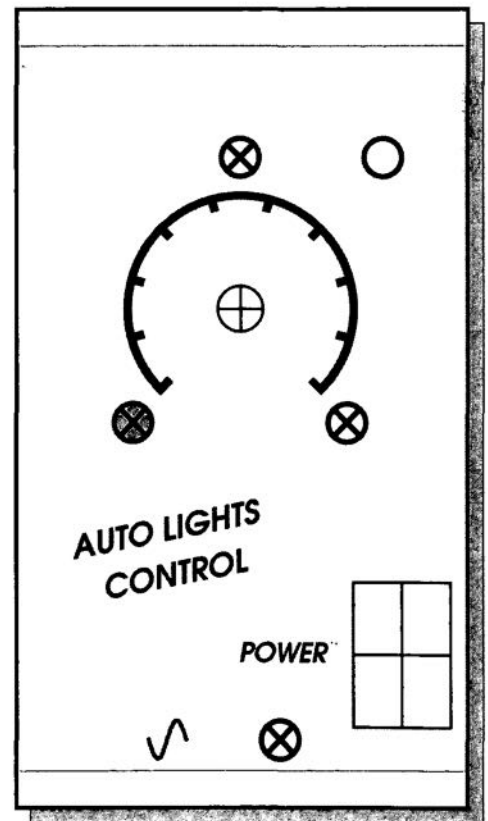


Fig. 6. Suggested front panel (not available ready made).

# INSULATED GATE BIPOLAR TRANSISTORS (IGBTs)

## By our Editorial Staff

Insulated Gate Bipolar Transistors are being used more and more widely. Modern drive system engineering would not be the same without these devices.

IGBTs are ideally suited to applications where high voltages coupled with high currents must be switched. They are found in voltage converters, heavy-duty control circuits and audio power amplifiers. The first project that used IGBTs was published in this magazine in December 1994 (1-to-3 phase converter).

Noteworthy properties of IGBTs are the ease of voltage control and the low losses at high voltages. These characteristics make one think of power MOSFETs. However, the effective on-resistance of IGBTs is significantly lower than that of MOSFETs. The relevant symbols and equivalent circuits of n-doped and p-doped IGBTs are shown in **Fig. 1**. Note, however, that the symbols are (not yet) world-standardized, so that others may be encountered.

When the gate-emitter potential exceeds the threshold,  $V_{GE(th)}$ , a collector current flows. The current amplification,  $I_C/I_G$ , of an IGBT, is very high:  $10^9$ , which is possible because the gate current only needs to charge the effective input capacitance (ignoring the tiny leakage currents through the gate oxide). Perhaps more appropriate is the transconductance,  $\Delta I_C/\Delta V_{GE}$  (see **Fig. 2**). The definitions of

saturation and linear range are the same as for standard bipolar transistors.

## Construction of IGBT

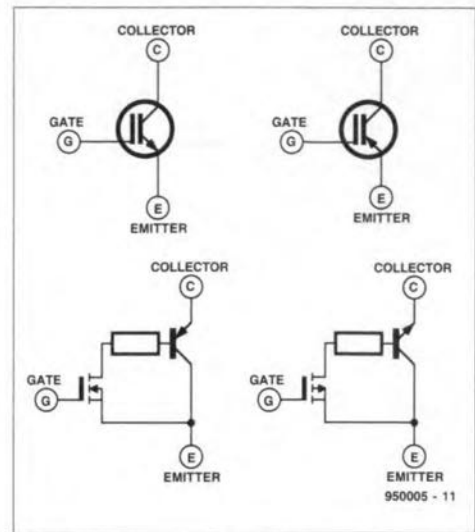
An IGBT consists of a heavily boron-doped substrate (p+), which is fused on to the collector, on which a phosphorus-doped n-epitaxial layer is deposited. The gate and emitter are epitaxial layers formed by a high-resolution n-channel DMOS process. Since the transistor therefore obtains an n-p-n-p structure, like a silicon-controlled rectifier (SCR), a p+ diffusion layer is inserted into the centre of the device. This layer reduces the current amplification of the upper n-p-n transistor and prevents any latch-up effects of the SCR. Without it, the IGBT would cut off at high currents owing to the breakdown of the gate control.

A separate p-base region permits independent control of the threshold voltage at the gate during the onset of conduction.

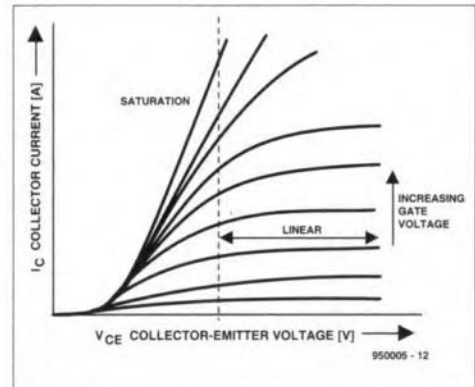
The maximum permitted reverse voltage is determined by the thickness and resistance of the n-epitaxial layer, which is optimized for a minimum forward voltage.

## Switching characteristics

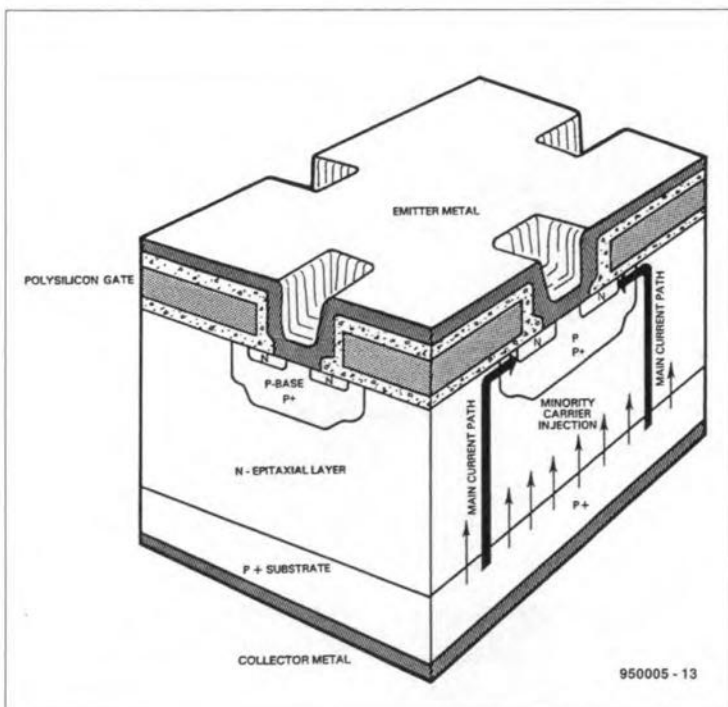
IGBTs (and power MOSFETs) have a gate-emitter threshold potential,  $V_{GE(th)}$ , and a capacitive reactance. To make these devices conduct, that is, before a collector current can flow, it is necessary for the input capacitance to be charged to a



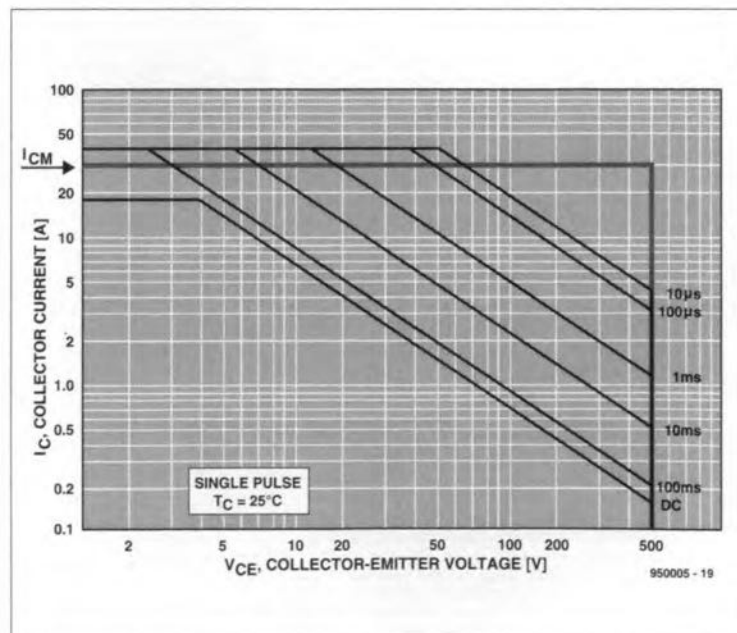
**Fig. 1.** Graphical symbol and equivalent circuit of n-IGBTs and p-IGBTs.



**Fig. 2.** Output characteristics of an IGBT.



**Fig. 3.** Construction of an Insulated Gate Bipolar Transistor.



**Fig. 4.** Safe Operating Area (SOA) during normal operation and when the IGBT gets switched off. (peak values of  $I_C$  and  $V_{CE}$  shown).



voltage that exceeds  $V_{GE(th)}$ . To switch off an IGBT, a resistor,  $R_{GE}$ , between gate and emitter is required, via which the input

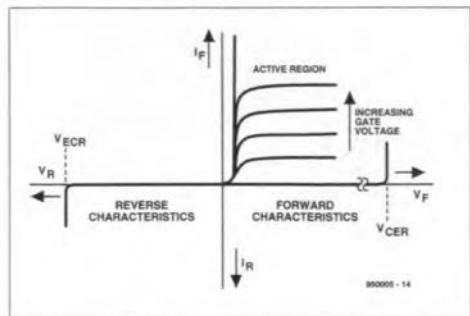


Fig. 5. Parameters of the collector characteristics.

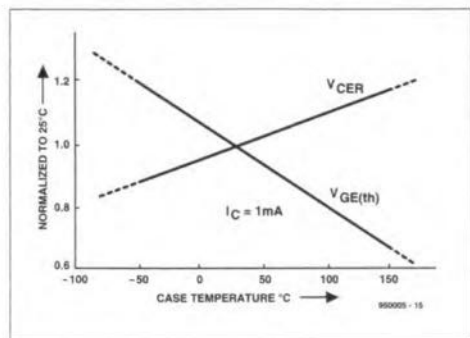


Fig. 6. Temperature dependence of  $V_{CE}$  and  $V_{GE(th)}$ .

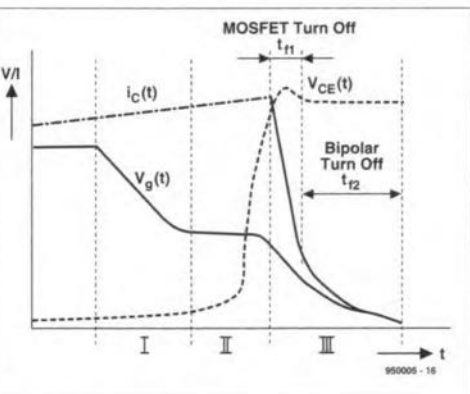


Fig. 7. Various phases in the switching off of an IGBT.

capacitance can be discharged. The minimum value of  $R_{GE}$  is specified in the data sheet of the relevant IGBT.

An IGBT has a peak controllable collector current that is dependent on the gate-emitter  $dv/dt$  transient. The higher this ratio, the lower the controllable collector current.

Because of its construction, the switch on and switch off times of an IGBT are influenced by the gate-emitter impedance. This impedance is much lower as that of a power MOSFET handling comparable voltages and currents. An IGBT is switched on by a positive potential on the gate and emitter terminals. When  $V_{GE}$  is greater than  $V_{GE(th)}$ , (which in switching applications is always the case), a collector current flows.

The switch-off behaviour of an IGBT is a mixture of that of a standard bipolar transistor and that of a power MOSFET. The switch-off time is determined by three different stages: I, II, and III, in Fig. 7. During the first phase, the gate-emitter voltage drops until the onset of the Miller effect (gate-collector capacitance) and  $V_{CE}$  rises. The second phase is typified by a constant gate potential (Miller effect). During this phase, the rising collector-emitter voltage causes a diminishing gate capacitance and a reversal of the gate polarity. Thereupon, the emitter voltage rises to a peak value, which is determined by the drive circuit. The final phase consists itself of stages: (a) the (very short) switch-off time,  $t_{f1}$ , of the MOSFET, and (b) the rather longer switch-off time,  $t_{f2}$ , of the bipolar transistor. The latter time does not commence until the MOS channel is off and the base of the p-n-p transistor is open.

Owing to the various phases of the switch-off time, it is difficult to put a value on the losses on the basis of the 10–90% switch-off time given in the data sheet. Instead, the equivalent switch-off time,  $t_{f[eq]}$  is taken which assumes a linear decay of the collector current; however, the following expression gives the actual decay time:

$$t_f = 2 / I \int_{I_0}^{\infty} i(t) dt$$

If inductive loads are switched, the switch-off losses are given by

$$1/2 \cdot V_{CE} \cdot I_C \cdot f \cdot t_{f[eq]}$$

Since the switch-off period of the bipolar transistor part of the IGBT is really constant, the duration of the switch-off period of the MOSFET part can be influenced by the correct choice of  $R_{GE}$ . The higher the value of this, the longer the switch-off period. In case of an inductive load, the period may be protracted to such an extent that operation without a snubber network becomes possible.

There are slow and fast IGBTs. For applications of slow types (d.c. and a.f.), the minimum switch-off current is of prime importance, whereas with fast types the switch-off characteristics should be as linear as possible (Fig. 9). For high-frequency applications, fast IGBTs with small  $R_{GE}$  should be used; this ensures that switching losses are kept to a minimum.

The typical Safe Operating Area (SOA) of an IGBT is shown in Fig. 4. The device can handle peak currents direct exceeding the maximum collector direct current; this current is limited only by the thermal threshold and the thickness of the connecting leads.

Sources: 'IGBT Driver'; Toshiba, March 1993.

SGS Thomson: Technical Note 1/5. [950005]

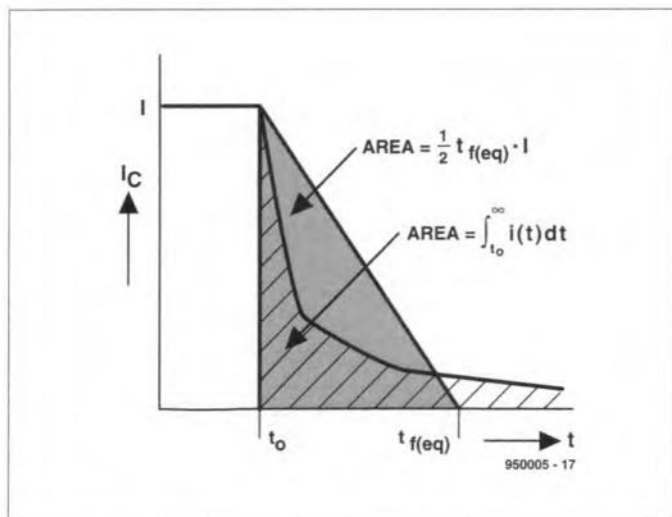


Fig. 8. Power losses at switch-off can be assessed from the equivalent decay times.

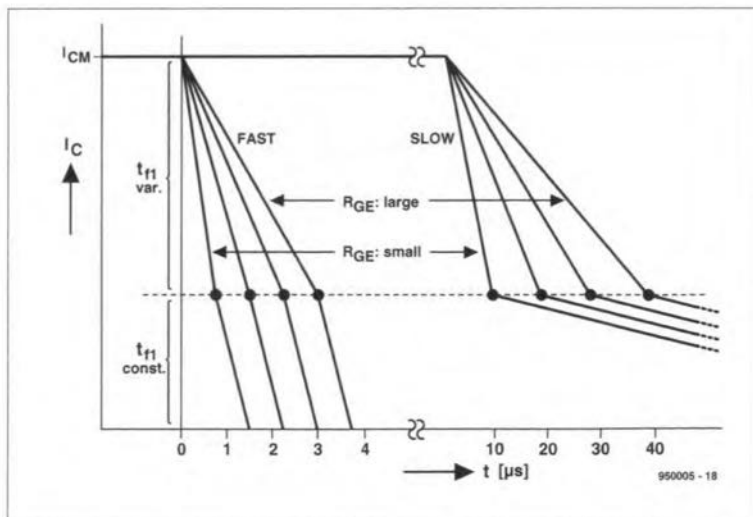


Fig. 9. Switching off of fast and slow IGBTs with various values of gate-emitter resistance.

# DC-DC CONVERTER

Design by W. Zeiller

**There are often occasions when a higher direct voltage is required than an available battery can provide. In many such cases, the circuit described can offer the solution. It can raise 6 V to 12 V or 12 V to 24 V.**



There are several special ICs on the market for use in d.c. to d.c. converters. The present circuit, however, uses a standard device: a stereo a.f. amplifier from SGS Thomson, which is arranged rather differently from its usual application.

The circuit diagram of the present converter is given in Fig. 1. The available direct voltage is applied to plug K<sub>2</sub>. The doubled direct voltage is available at socket K<sub>1</sub>. Whereas one of the prime requirements of an audio design is total freedom of any tendency to oscillate, in the present application this does not matter at all. The two amplifiers contained in the IC are arranged as a multivibrator, which provides a rectangular voltage at a frequency of about 5 kHz. The frequency and duty factor are determined by the values of C<sub>1</sub>-C<sub>4</sub>.

Operation is straightforward: when the output of one of the amplifiers, say, pin 10, is low, capacitor C<sub>5</sub> is charged to virtually the level of the supply voltage via D<sub>1</sub>. When the multivibrator changes state, pin 10 goes high, which results in the output voltage (i.e., nearly supply voltage level) of the amplifier being added to the potential across C<sub>5</sub>. This raised voltage is used to charge C<sub>6</sub> via D<sub>2</sub>. This means that the potential across C<sub>6</sub> is a pulsating direct voltage with a peak value of very nearly double the supply voltage. Of course, every time pin 10 goes low, the potential drops sharply.

The second multivibrator acts in the same way, but in 'antiphase' as it were. This means that when pin 10 goes low, pin 8 goes high. Therefore, when the potential across C<sub>5</sub> begins to drop, C<sub>7</sub> is being charged to almost double the supply voltage. Since the potential across C<sub>7</sub> is also used to charge C<sub>6</sub> (via D<sub>3</sub>), the voltage across C<sub>6</sub> is thus nicely 'ironed out'.

The aim of the circuit has been reached: the potential across C<sub>6</sub> is constantly at a level of double the supply voltage (or very nearly so) and no longer shows a pulsating character.

There is, of course, some voltage loss in diodes D<sub>1</sub>-D<sub>4</sub>, and also owing to the saturation voltage of the output

transistors in IC<sub>1</sub>, but these combined losses do not amount to much.

Networks R<sub>1</sub>-C<sub>9</sub> and R<sub>2</sub>-C<sub>10</sub> are Boucherot networks that are indispensable for maintaining stability in a.f. amplifiers.

## Construction

The converter is intended to be built on the printed-circuit board shown in Fig. 2, which is, unfortunately, not available ready made. The construction of the board is straightforward. Note, however, that, although Schottky diodes are specified for D<sub>1</sub>-D<sub>4</sub>, standard 5 A types may also be used. These will, however, lead to a greater difference between double the input and output. If, therefore, the output should be as nearly as possible double the input, Schottky diodes must be used.

Depending on the output current, the temperature of IC<sub>1</sub> may rise quite appreciably. This is natural, because when the output voltage is 24 V and the output current is 1 A, the power output is well above 20 W. Even as-

suming an efficiency of 80%, which is, of course, very good, the IC dissipates at least 4 W. It can not handle this without a heat sink (rated at 5 K W<sup>-1</sup>).

If the fixing hole of the IC is carefully drilled out from 3.7 mm to 4 mm, the device can be fastened with a brass M4 bolt, which conducts heat much better than the usual iron M3 bolt and is, moreover, insensitive to magnetic influences.

The introductory photograph shows the completed prototype board.

The choice of enclosure will depend to a very large extent on the envisaged application. There is no restriction on any type, as long as the cooling of the IC is not jeopardized. Note that if the temperature of the IC rises unduly, its protection circuits become active with the result that the voltage plummets. It is, of course, also possible in some applications to build the converter into an existing appliance.

Some results measured on the prototype operating from a 12 V battery are as follows. With load currents not exceeding 200 mA, the output voltage

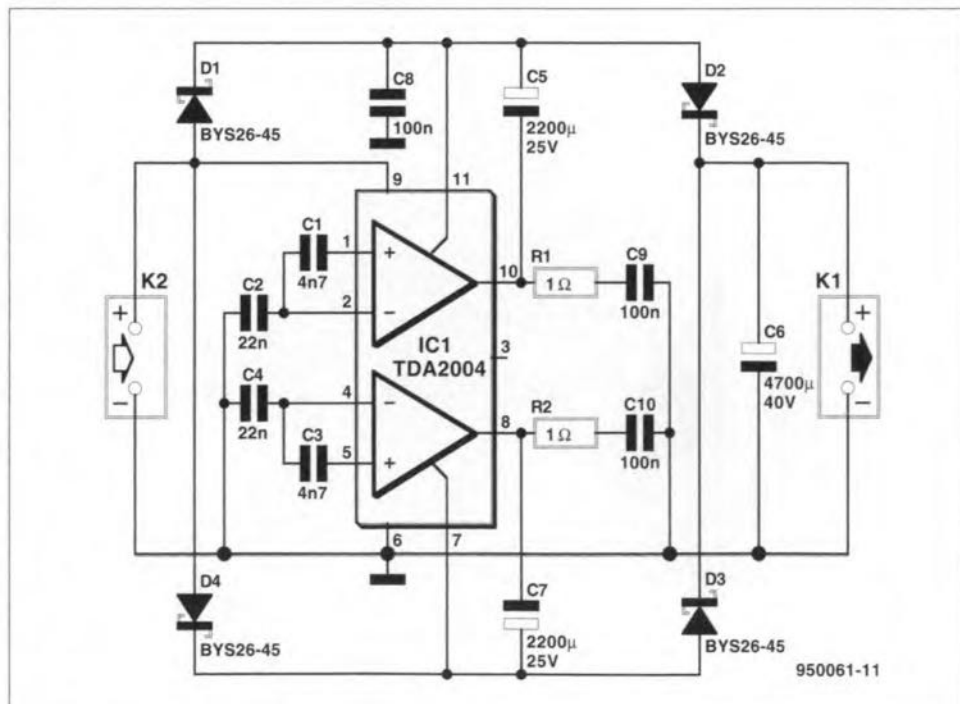


Fig. 1. Circuit diagram of the step-up d.c. to d.c. converter.



remained very close to the theoretical value of 24 V; actual 23.5 V. When the current increased, the output voltage dropped slowly: to 22.3 V at 1 A and to 20.7 V at 1.4 A. The latter figures are about the maximum, because output power is then 29 W. The efficiency of the converter remained in all case above 80%: with an output current of 1 A, it was 85.5%.

With 12 V input, the quiescent current of the prototype was about 130 mA. With a dry or small rechargeable battery, this needs to be taken into account; with a car battery it is not worth mentioning.

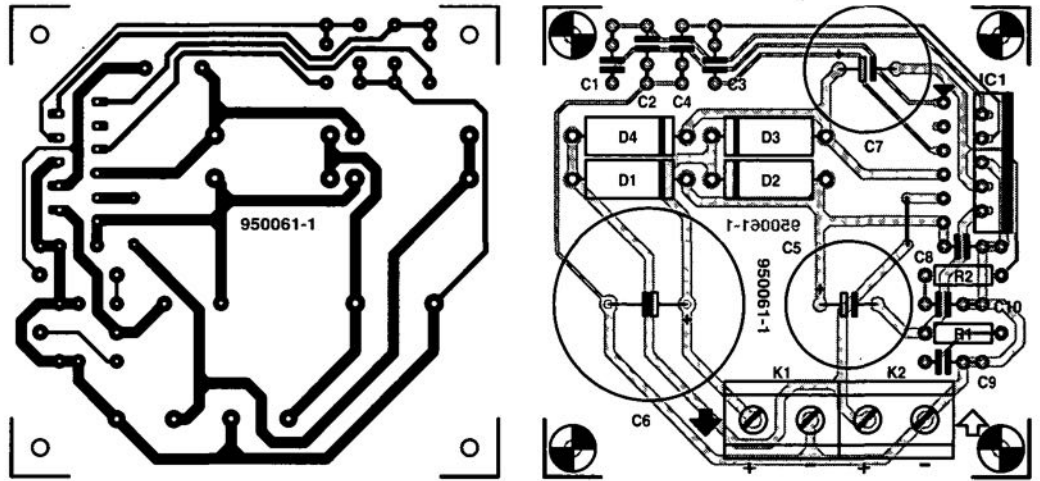


Fig. 2. Printed-circuit board for the d.c. to d.c. converter.

## Parts list

### Resistors:

$R_1, R_2 = 1 \Omega$

### Capacitors:

$C_2, C_4 = 22 \text{ nF}$

$C_5, C_7 = 2200 \mu\text{F}, 25 \text{ V}, \text{ radial}$

$C_6 = 4700 \mu\text{F}, 40 \text{ V}, \text{ radial}$

$C_8, C_9, C_{10} = 100 \text{ nF}$

$C_1, C_3 = 4.7 \text{ nF}$

### Semiconductors:

$D_1\text{--}D_4 = \text{BYS26-45 (Schottky)}$

### Integrated circuits:

$IC_1 = \text{TDA2004 (SGS Thomson)}$

### Miscellaneous:

$K_1, K_2 = 2\text{-way terminal block}, 7.5 \text{ mm pitch}$

Heat sink  $5 \text{ K W}^{-1}$  (e.g. SK106)

[950061]

### Power IC Type TDA2004

The IC used in the converter is a Type TDA2004 integrated Class B stereo power amplifier, developed primarily for use in motor vehicles. Operating from a 12 V battery, it can deliver an output power of  $2 \times 10 \text{ W}$ . It needs few external components, can provide a current of up to 3.5 A, and can work into loads as low as  $1.6 \Omega$ .

The IC is housed in an 11-pin Multiwatt case that does not need to be isolated from a heat sink (if used). It is known for its robustness and is provided with a host of protection facilities, which make it proof against short-circuits, inductive loads, too high temperatures, and

so on.

The diagram shows the pinout as well as a typical application circuit: a complete amplifier for car radios, which can deliver  $2 \times 10 \text{ W}$  into  $2 \Omega$ .

The more important parameters are:

Peak supply voltage: 18 V

Quiescent current: typically 65 mA,

peak 120 mA (for  $U_b = 13.2\text{--}14.4 \text{ V}$ )

Power output:  $2 \times 6.5 \text{ W}$  into  $4 \Omega$ ;  $2 \times 10 \text{ W}$  into  $2 \Omega$  (for  $U_b = 14.4 \text{ V}$ )

Distortion: typically 0.2%, peak 1% (for  $U_b = 14.4 \text{ V}$  and  $R_L = 4 \Omega$ )

Bandwidth ( $-3 \text{ dB}$ ): 35 Hz to 15 kHz ( $R_L = 4 \Omega$ )

Peak output current: 3.5 A

Peak power dissipation: 30 W

