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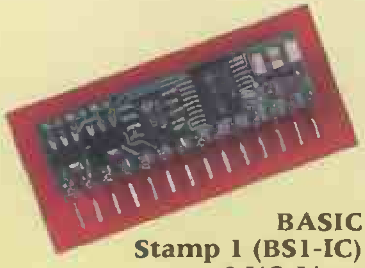

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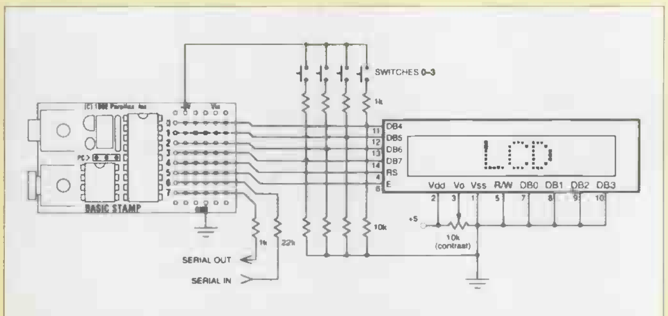

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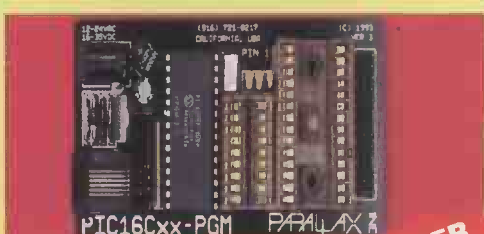

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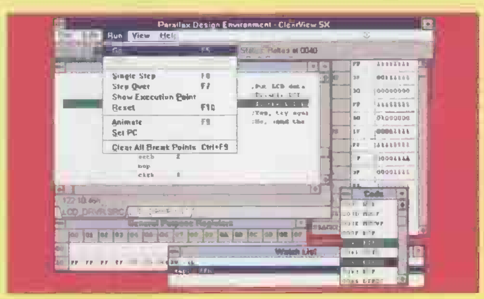

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Cover – Jamel Akib

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Spectacular view of the full northern auroral oval in ultraviolet light – Research Notes, p. 641.

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ISSN 0959-8332

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REED BUSINESS PUBLISHING

Pricing versus rationing

Karl Marx rejected capitalism and free markets in favour of public ownership of the means of production and distribution. He did this on the premise that people would work better for the common good than for their own profit But he – or at least his followers in the USSR – went further than that. They virtually eliminated the operation of any price mechanism and substituted the command economy, which was a euphemism for rationing by central bureaucrats.

Those two issues – private versus public ownership and pricing versus rationing – should not be confused. There is now widespread acceptance in this country that private ownership generally leads to more prosperity in peace time than public ownership, but that there are exceptions. On the other hand, the price mechanism has an engineering function which is indispensable under either kind of ownership. It does not stem from any judgment of human motivation.

For example, power station designers invest in improving their stations' thermal efficiencies because fuel is generally expensive. Where fuel is cheap, they are correspondingly less concerned. In any case, they use large quantities of excess air for combustion because air is plentiful and free. They apply that principle of balancing costs against benefits to all their decisions, and so do their consumers, fuel suppliers and so on. It has produced a web of interlocking prices which co-ordinate the efforts of engineers across the whole economy.

Prices are often disdained as a sordid necessity in a vulgar world, but in truth they are the life blood of engineering, quite apart from their role in free markets. By removing them, the communists reduced their engineers to copying – as best as they could with inadequate information – the designs of their opposite numbers in non-communist countries. That was what doomed communism and would have done so even if the people and their leaders had been altruistic beyond belief.

Within our pricing web, telecommunication engineers have invested in increasing the information transmission rates of cables because cables are expensive to manufacture and lay. But they have paid much less attention to economising with radio spectrum because the supply has seemed to be plentiful. Spectrum has been freely allocated (except for administration charges) on the principle of first come first served But it is a finite resource and serious congestion appeared in the 1970s in the private mobile radio bands.

The Merriman Report recognised the problem in

Power station designers use large quantities of excess air for combustion because air is plentiful and free.

1983 and included a pricing scheme for the whole spectrum, proposed by the Department of Transport to reflect the scarcity values of the various bands. But the engineering function of pricing was not understood and the large established users, notably in broadcasting, civil telecommunications and defence, opposed spectrum pricing.

Some consultants proposed instead to deregulate the congested bands but *EW+WW* exposed the irrelevance and failings of that idea in September 1987. The central regulators were left to ration out spectrum in the congested bands without knowing which users could make the most cost-effective use of it. The congestion worsened.

Now a DTI white paper on 'Spectrum Management into the 21st Century' (Cm 3252) proclaims a welcome change of government policy, albeit with some reservations. It proposes legislation to introduce spectrum pricing on the lines proposed by the Department of Transport thirteen years ago. The congestion is worse now than it was then, so the cure will be correspondingly more painful but, if they really mean what they say, the DTI will extend the pricing web across that part of our economy, which badly needs to be strengthened there. The white paper and some implications of those reservations will be reviewed next month.

David Rudd, independent engineering and economics consultant.

Electronics World is published monthly. By post, current issue £2.35, back issues (if available £2.50. Orders, payments and general correspondence to L333, Electronics World, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. Tlx:892984 REED BP G. Cheques should be made payable to Reed Business Publishing Group
Newstrade: Distributed by Marketforce (UK) Ltd, 247 Tottenham Court Road London W1P OAU 0171 261-5108.
Subscriptions: Quadrant Subscription Services, Oakfield House Perrymount Road, Haywards Heath, Sussex RH16 3DH. Telephone 01444 445566. Please notify change of address. Subscription rates 1 year £30 UK 2 years £48.00 3 years £70.00. Surface mail 1 year £35.00 2 years £56 00 3 years £80.00 Air mail Europe/Eu 1 year £43.00 2 years £68.00 ROW 1 year £52.00 2 years £83.00
Overseas advertising agents: France and Belgium: Pierre Mussard, 18-20 Place de la Madeleine, Paris 75008. United States of America: Ray Barnes, Reed Business Publishing Ltd, 475 Park Avenue South, 2nd Fl New York, NY 10016 Tel; (212) 679 8888 Fax; (212) 679 9455
USA mailing agents: Mercury Airfreight International Ltd Inc, 10(b) Englehard Ave, Avenel NJ 07001. 2nd class postage paid at Rahway NJ Postmaster. Send address changes to above. Printed by BPCC Magazines (Carlisle) Ltd, Newtown Trading Estate Carlisle. Cumbria, CA2 7NR
Typeset by Wace Publication Imaging 2-4 Powerscroft Road, Sidcup, Kent DA14 5DT ,
Reed Business Publishing Ltd 1995 ISSN 0959 8332

Copyright protection delays DVD

More non-technical wrangling over the digital video disk specifications is further delaying the introduction of the format. Previously, the debate was over which audio format to use with DVD video, now it is over intellectual property protection, again, predominantly with video.

Frank Carrubba, chief technical officer of Philips Electronics, said: "Some companies say they are bringing out DVD products this September. Don't believe it; they can not. There will be no products this year."

Philips is one of the companies intending to make DVD players and also owns a record label.

Six bodies dominate the group discussing the specification. These represent: equipment makers, film makers, the computer industry, record companies, business software sellers and CD-ROM publishers.

Research and development investment fell in '95

Electronics companies' investment in research and development (r&d) in the UK fell significantly last year, a DTI report has shown. The UK r&d Scoreboard reveals that within the electronic and industrial equipment sector, the r&d expenditure as a percentage of turnover fell from 4.2% in 1994 to just 3.2% in 1995.

Although r&d expenditure worldwide also fell in the same period, the average remained higher than that of the UK.

The amount spent on r&d is far greater among foreign-owned companies than their UK rivals. The top five spenders in the global electronics industry were, in order, Siemens, Hitachi, Matsushita, IBM and Toshiba. Toshiba spent £1.89bn on r&d, while GEC, which headed the UK electronics rankings, spent just £412m.

Mike Pilbeam, managing director of Cray Communications (part of Cray Electronics), pointed out that, to compete in R&D spending with US firms, UK electronics companies must recognise Europe as their home market.

"The biggest problem is the UK home market is only a fraction of the American home market," he said. "Consequently the sales turnover spent on r&d is much less."

For the first time the scoreboard includes foreign-owned companies based in the UK.

"Much of the electronics industry in the UK is owned by international companies," said Peter Jones, seconded from Thorn EMI to the DTI's Innovations Unit. Jones explained that including UK based arms of international companies "gives a much fairer representation of the UK electronics industry."

Richard Freeman, chief economist at ICI, said increasing r&d spending does not automatically lead to commercial success.

Jon Mainwaring
Electronics Weekly

EMC effects of Police radio

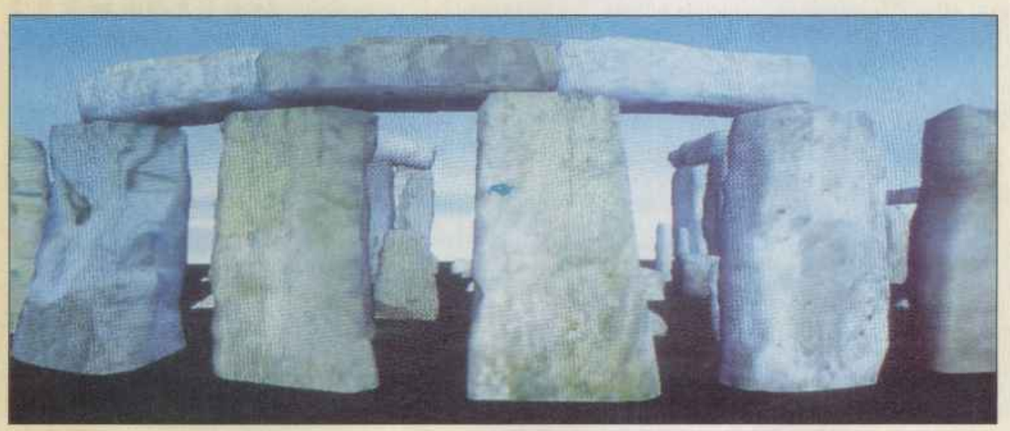
Concerns over the effects of stray electromagnetic radiation have surfaced again. Following a recent report that electromagnetic interference is causing motorists to be locked out of their cars, the latest scare is that 'police radio system can trigger bombs'.

This headline reported in a national newspaper recently, while sensationalist, does highlight an emc issue: users of radio transmitting equipment, including mobile phones, should not use them without regard to the situation and location.

There are police guidelines against transmitting from its its handsets in hospitals, computer rooms and other places with electronic equipment. In addition, a police spokeswoman said: "There is a longstanding guideline from the Association of Chief Police Officers that radio handsets should not be used within 25m of a suspected explosive device."

The police radio handset in the report is the Motorola *MTS2000* which forms part of the Metropolitan Police's new cellular Metradio system. The uhf handset produces 1W effective radiated power, less than most mobile phones and slightly more than the older vhf police handsets which radiate around 0.7W.

A spokesman for Motorola said: "There is nothing magic about our handset. The police guidelines are precautions that could easily apply to mobile phones. Indeed, airlines will not allow mobile phones to be used on their aircraft and mobile phone instructions carry similar warnings not to operate them in petrol stations."



Virtual Stonehenge
A virtual reality model of Stonehenge is available on the Internet. Developed by Intel, Superscape and English Heritage, the model can be navigated in ten different eras from 8500BC to 2000AD by pc users. A photo realistic model has also been developed, on a 200MHz Pentium Pro processor, by VR Solutions Limited of Salford, who worked with English Heritage archaeologists to generate it. The Internet-based Stonehenge can be accessed on Intel's website: http://www.intel.com/

Tethered satellite investigation report is released

NASA and the Italian Space Agency (ASI) have released the report of the investigative board appointed to determine factors which resulted in the Feb 25 tether break and loss of the Tethered Satellite during the STS-75 Space Shuttle mission.

"The tether failed as a result of arcing and burning of the tether, leading to a tensile failure after a significant portion of the tether had burned away," the report concludes.

Arcing occurred because of either external foreign object penetration (but not orbital debris or micrometeoroids) or a defect in the tether caused a breach in the layer of insulation surrounding the tether conductor. The insulation breach provided a path for the current to jump, or arc, from the copper wire in the tether to a nearby electrical ground.

The break occurred when approximately 12.2miles (19.7km) of tether was unreeled, in a period when the tether was experiencing normal stresses of approximately 15pounds (65newtons).

● Scientific papers recently presented at an American Geophysical Union conference reported that currents generated by the tether were three times higher than theoretical models had predicted prior to the flight.

The system was generating 3,500Vdc and up to 0.5A of current during satellite deployment. That high level of electrical energy resulted from the length of conducting tether extending from the Shuttle, coupled with the 17,500mile/h speed at which the Shuttle and tether were cutting through Earth's magnetic field lines.

"This arcing produced significant burning of most of the tether material in the area of the arc," the board found. The tether was designed to carry up to 15,000Vdc and handle tensile forces of up to 400pounds (1780newtons). It used super-strong strands of Kevlar as a strength-providing member, wound around the copper and insulation.

Software that summarises

BT's research centre at Martlesham has developed a text summarising program that can reduce pages of text into paragraphs, or sentences. The program, called 'Netsumm', is currently being trialed on the Internet, but BT plans a stand-alone version, for use with Microsoft Windows, soon.

The software has come about because of the modern complaint of information bombardment. Keith Preston manager of BT's intelligent systems group, explained that people now "have so much information available that they won't make any use of it."

This textual intimidation can be overcome using Netsumm, which uses statistical methods to summarise a piece of text. The summariser program accepts any plain-text document and automatically picks out sentences it considers to be the most relevant part of the text.

At present, Netsumm exists only as a prototype and will be demonstrated in the coming months to City dealers. Netsumm would be used by dealers to draw out key elements from detailed company reports.

The 'Dealing Room' will feature other technologies including speech-to-text conversion and videoconferencing, as well as improved presentation of market information. The overall aim is to improve the speed and efficiency of City dealers.

Dawn of the Solar Age

Solar electric power will soon be seen in all parts of the country as part of a Government programme to support important British technologies needed in the next 10 years.

Children who already study solar electricity (photovoltaics) in theory will be able to experience it working in reality in 100 schools and colleges. Although the technology is made in Britain, it is still virtually unknown and most of the panels are exported abroad. The scheme is aiming for maximum impact as all the systems will be linked via the Internet to reach a wider national and international audience.

The Scolar Programme is part of the government's Foresight Initiative and is the brain-child of Philip Wolfe.

"This is excellent news for Britain," commented Philip. "The Foresight Award means we can bring the technology faster to a whole generation. By using photovoltaics on a bigger scale today we are also helping to avoid the energy problems of the future."

Dick Tracy arrives

A wristwatch phone weighing just 70 grams has been developed by Nippon Telegraph and Telephone (NTT) in Japan. The prototype personal handyphone system (PHS) is said to weigh 20% less and be 50% more compact than existing handsets.

This level of miniaturisation is achieved through the use of voice recognition for dialling, removing the need for a keypad. The voice recognition software is located in the base unit, reducing the PHS's software requirements.

Users can either say a number or a previously recorded name. The system transforms the instruction into a telephone number.

Flat antenna for satellite tv

Anntech has developed a satellite receiving antenna halfway between the BSB 'squarial' and a dish – the panel is flat but a feedhorn projects.

The panel is plastic, 5-8mm thick, incorporating a metal element to focus the satellite signal onto the feedhorn by diffraction.

This allows it to be flush mounted on any wall or roof with an unobstructed view of the satellite. Installation is similar to that of a dish but, because the electrical axes are offset, an additional pair of angles (focus and rotation) must be determined from a set of tables. Four panel type numbers will be produced to cover all installation possibilities, with fine-tuning by adjustment of the feedhorn position. The sensitivity is about 60%, which is comparable to an average dish.

60-70cm panels will be launched at the end of August, with prices 'very competitive'. Any size is possible, using multiple panels for those over 1.2m, with the cost advantage increasing along with the size.

The panels will not only minimise 'unsightliness' in suburbia and help to spread satellite tv to poorer areas of the world, but will also reduce the time and cost of temporary installations and find uses for non-satellite microwave applications. ■

Jonathan Campbell

Nanotubes get wired up

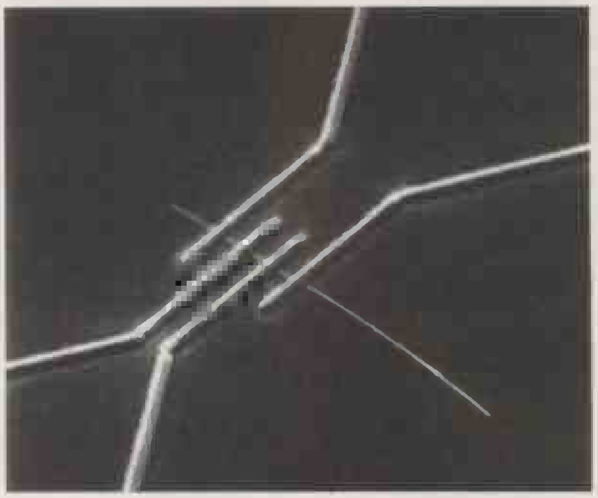
Carbon nanotubes – hollow tubes manufactured on the atomic scale – could offer an attractive method of connecting together circuits in tomorrow's highly miniaturised nanocircuits. Now, researchers at NEC and Micrion Europe have taken a step forward to exploitation of nanotube technology with the first detailed electrical measurements of individual tubes.

Various types of nanotubes have already been produced, but precise data on their properties has been scarce. However, the NEC/Micrion research is showing that each nanotube has unique electronic properties, including both metallic and non-metallic behaviour. It is also becoming clear that the differences between nanotubes are far greater than expected. And the results confirm that, at this scale, geometry and electronic properties are closely linked.

The method used for the investigation has been to attach four 80nm-wide tungsten leads directly to individual nanotubes, enabling accurate evaluation of their electronic properties, using a focused ion beam system. The experiment has shown that the current carrying capacity of the nanotubes is very high and also that the temperature dependence of the conductivity differs greatly between nanotubes. Also revealed is that different segments of a nanotube may have different temperature profiles and that nanotubes in general show significant variations in resistivities.

Early data suggests that nanotubes can be fabricated with a wide range of electronic properties. Interest has been greatly stimulated by theoretical predictions that their electronic properties would be strongly modulated by small structural variations. In particular, the diameter and helicity of carbon atoms in the nanotube are believed to determine whether the nanotube is metallic or semiconductor. The beguiling prospect for researchers is that if they can be accurately characterised, they offer the possibility of being used as wires, with diameters about 1% the line width used in current 16Mb memory chips.

Contact William Gear, NEC Research Institute, Princeton, New Jersey, USA.



Nanotubes could dramatically reduce memory cell size. Here, four 80nm leads help reveal a tube's electrical properties.

Extreme chip production

Working microelectronic devices, with electrical gate widths of 0.1µm, have been fabricated at Sandia National Laboratories in California. The tiny dimension is more than three times smaller than that used for devices found on current chips, and has been made possible using extreme ultraviolet light as part of the lithographic process. The device is a field effect transistor, a common building block of all integrated circuits.

Current leading edge chip patterns are printed with the photographic-like optical lithography, creating features that are 0.35µm wide. But, optical lithography is reaching physical limits. The shorter wavelengths of extreme ultraviolet light enable printing smaller features at high resolution.

Lithography has been targeted as a key technology for semiconductors as they continue to be made smaller, faster and more powerful. The Semiconductor Industry Association aims for commercial production of microchips with 0.1µm features in the year 2007.

Contact Sandia National Laboratories, Albuquerque, USA.

__Crowning achievement:__ A spectacular view of the full northern auroral oval in ultraviolet light, just released by Goddard Space Flight Center, is a testament to the work of University of Iowa scientists who have developed the visible imaging system on the Polar spacecraft. The Earth is imaged from an altitude of 25,740km over the southern border of Alaska, and the auroral oval is seen as a 'crown' in the top portion of the image. Advances in technology for the construction of the cameras has allowed the auroral light to be extracted from the sunlit atmosphere with unprecedented clarity, as amply demonstrated by this picture of a complete auroral oval that extends well into the sunlit atmosphere. An extended region of light in the centre and bottom of the image is the glow from the Sun's illumination of Earth's upper atmosphere. The filter for this image passes ultraviolet emissions that are not directly visible to the human eye. Intensities of this light from atomic oxygen in Earth's atmosphere at altitudes in the range of about 100 to 500km are colour coded in the image with dark red as lowest intensities and whitish yellow as the brightest. A coastline superposed on the image shows that the aurora is positioned just north of the Great Lakes on the dayside of the Earth and over the Scandinavian peninsula on the far nightside of the Earth. Principal investigator for the visible imaging system instrument is Louis Frank and the instrument scientist and manager is John Sigwarth, both from The University of Iowa.
Goddard Space Flight Centre, Greenbelt, MD.

Smart needle helps tumour treatments

More effective curing of cancerous tumours could be the result of work being carried out at MIT into development of a prototype sensor needle that contains integral microchips. The electronics give medics direct feedback on the progress of hyperthermic treatment in a cost-effective and simple manner so improving control. MIT's special needles could replace several of the probes currently used by doctors to characterise tissues, and should be less expensive than current probes while being 30% smaller in diameter.

The researchers, led by Research Affiliate Kenneth Szajda of the Harvard-MIT Division of Health Sciences and Technology (HST), have so far built a device that measures temperature. But the ultimate goal is a needle that measures a variety of parameters, such as pH, oxygen concentration, and radiation dosage.

Effectiveness of hyperthermic treatment of tumours is critically dependent on temperature control and is why it is so important to be able to measure temperature precisely during treatment.

In the prototype device, eight microchips are embedded in a channel milled down the length of the needle. Each smart chip not only senses temperature, but also processes and digitises the temperature signals so they can later be read by a computer. A separate chip near the head of the needle coordinates data flow between the microchip sensors and a personal computer.

The entire system consists of a series of 7mm long, 600µm wide integrated circuits mounted in the channel milled into a 22 gauge solid stainless steel needle. At its core is a low-noise, high resolution diode-based sensing circuit. The output of this sensor is then buffered by pre-amplifier, using correlated double sampling to maintain integrity of the signal. An oversampled modulator digitally transmits the analogue temperature signal from the needle, and further digital signal processing is performed to complete the analogue to digital conversion. The process eliminates signal corruption caused by sensitive analogue signals travelling off chip.

A custom digital controller chip coordinates transactions between the sensors and a personal computer that processes and displays the data. The circuits are fabricated using a specially developed (2-poly, 2-metal) biocmos process, a non-optimised bicmos extension of the ccd/cmos process developed at MIT.

A silicon nitride passivation process is incorporated into the biocmos process to prevent cross contamination between the circuits and the patient since the devices will be operated in a hostile physiologic environment.

Purpose of this project is not only to measure temperature but also to demonstrate the feasibility of 'active needle' techniques.

The researchers say the system approach used for the project can easily be extended to other types of sensors, including – but not limited to – oxygen, radiation, and pH sensors, and Szajda is currently working on radiation and oxygen sensors with Thermal Technologies of Cambridge.

Other advantages of the needle include its size and potential cost. Use of microelectronic technology could reduce costs because, among other things, the sensors could be mass-produced.

In addition to the continuing development of radiation and oxygen sensors, the researchers are also working on the next generation of the temperature-sensor microchip, and the team has recently succeeded in cutting the length of each chip in half to about 4mm. This means that more chips can be packed into each needle, increasing the spatial resolution of the system.

Targeting diesel engine pollution

Technology that only a few years ago was being developed to knock enemy missiles out of the sky is being refined at the University of Southern California to repel an even more insidious air-borne invader – vehicle pollution.

US researcher Martin Gundersen and Russian scientist Victor Puchkarev are working on a high energy plasma system fitted to a diesel engine that will do to pollutants what it was once hoped it could do to satellites.

Missile technology helps clean up car exhausts.

Current experimental test bed for the trial is an elderly green Volkswagen Golf wired up in a USC basement. A special prototype chamber attached to the car's exhaust contains a mechanism that, each second, sends between 100 and 1000 100ns extremely high-voltage spikes of electrical energy through the stream of exhaust gases.

The electrical emissions create a high-density flux of energetic, fast-moving electrons. These don't heat the gas. Rather, they set off a cascade of chemical changes in the exhaust, which breaks down one of the main raw materials that cause smog – the oxides of nitrogen – into harmless pure nitrogen and pure oxygen.

The new system is already working. But a crucial measure of its potential is going to be the efficiency by which the process is achieved.

As Gundersen puts it: "How much engine power does it take to remove how much pollutant?."

To be economical, less than 5% of the engine's output should be used for pollution control. Gundersen and Puchkarev believe this goal is feasible.

Diesel engines are highly fuel efficient. Unfortunately their exhaust contains more nitrogen oxides (NO_x) and other pollutants than conventional engines, and strategies that control emissions in non-diesel, automobile engines either don't work as well for diesels or considerably depress the diesel engine's efficiency.

Working under contract with the US Navy – which operates large fleets of diesel-driven ships and is under pressure to conform to environmental emission standards – the researchers are hoping to devise a simple unit that can be attached to the exhaust of any diesel-driven vehicle and bring it into compliance.

"A plasma system would allow continued use of existing efficient designs, and also permit cost-effective clean up of dirty older trucks and ships," says Gundersen.

Several problems remain to be solved before their electron plasma method can live up to its potential. First, there's some theoretical evidence that the device would be more efficient if the pulse were even shorter – about 20ns. That interval is beyond the reach of existing devices, but the researchers are working on a way to reduce the pulse time.

Second, the reactions produced by the high speed electrons need further study. While scientists have a general idea of the chemistry that takes place when a plasma hits exhaust gases, detailed data on the subject is virtually non-existent and the theoretical foundations for studying these reactions are not well developed. So hard data needed for modelling is not available and is extremely difficult to predict.

Nonetheless, Gundersen and Puchkarev have made enough progress that they will be testing a version of their system on a stationary diesel engine at Port Hueneme, in Ventura County, California later this year.

More information from Martin Gundersen, University of Southern California, Los Angeles CA 90089-2538, USA.

Fuel cells get 100% power boost

Researchers at Ernest Orlando Lawrence Berkeley National Laboratory have developed a thin-film electrolyte that both doubles the power output and significantly reduces the cost of solid oxide fuel cells (sofcs).

Fuel cells, which transform hydrocarbons into electricity without combustion, are highly fuel-efficient and almost non-polluting. But, until now, sofcs have been most fuel-efficient operating at 1000°C – increasing the cost of materials and decreasing the lifetime of cells.

In fact, as sofcs are solid-state devices, researchers know how to drop their operating temperature, but the problem has been that when the temperature is dropped, electrolyte conductivity is lost. One way to deal with this is by making the electrolyte thinner, and scientists around the world have looked for a way to thin down the electrolyte, from a 100μm film down to about 10μm.

But now the Berkeley team says it has devised a technique that doesn't just preserve performance at a lower temperature of 800° but, with a new, ultra-thin ceramic electrolyte, actually doubles the power output to 2W/cm^2 of cell surface area.

Berkeley electrolyte, a yttria-stabilised zirconia film, starts out as a ceramic powder suspended in solution and is painted onto the anode and then fired. What has held back development is that the paint tends to fill in the pores and can crack during sintering due to thermal stresses. The Berkeley researchers say they have simply got the processing of both the anode and the electrolyte right.

More information from Steve Visco, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California.

Looking into a dark future

At night, driving at speed, how far ahead can you see with your headlights? A system currently being tested in the US promises to reveal the road ahead for three to five times further, using thermal imaging cameras and heads-up display (hud) technology to project a picture of the road ahead into the driver's field of view.

NightSight, under development by Texas Instruments, uses a Delco Electronics hud to project real-time thermal images onto the lower section of the car's windscreen. In this way the image, created by a thermal array which translates infrared heat into stark, high-contrast video images, is displayed in the same perspective as the driver's own vision, so is superimposed on the view through the screen.

Differences in heat emitted by objects are recorded and used to generate a real-time black-and-white video picture of the scene.

For automotive applications, thermal imaging has the advantage of separating people, hazards and other objects from cluttered backgrounds in full daylight or total darkness.

The energy being sensed is heat and not light, so the system should work even in total darkness, and will not 'bloom' or shut down when hit directly by visible light. So it will not be affected by oncoming headlights, and will help reduce glare and distraction of oncoming traffic.

Texas Instruments has high hopes for the system, and says that feedback from automobile manufacturers suggests that the technology will prove to be as important to vehicle and driver safety as the air bag has been.

The motivation for the work has been the US statistics that show that though only 28% of driving takes place at night, 55% of all driving fatalities occur in darkness.

The military routinely use thermal systems and the police are also evaluating them. Could they become as common on the family car as air bags?

The route to pcb cad

Thinking of buying PC software for making your own pcbs? Rod Cooper's comprehensive – and possibly unique – run down of ten medium, low and no-cost packages will help you make the right choice. Part 1 covers *PIA*, *Easytrax* and *PCB Designer*.

Although the multi-thousand pound CAD system for designing pcbs has been in use by larger companies and specialist electronics firms for many years, the combined cost of hardware and software has undoubtedly deterred most small firms, many of whose core activities may not even be directly in electronics but who still use pcbs, designed by outside contractors.

Also deterred have been individual designers who would dearly have liked to get their hands on these design aids but who could not justify the expense. In addition, stories of program bugs and especially user unfriendliness have prompted others to hold back deliberately from buying a software package – not just until the price became more affordable, but also until performance had improved. This review is for these people.

Review scope

The range covered here is restricted to so-called 'budget' or entry-level systems, defined by an arbitrary limit of around £500 for a system. This review is only intended as a guide which will, in conjunction with the appropriate evaluation disk, point the way to the system that's right for you.

When choosing your first CAD package, bear in mind that some makers produce a low-cost, entry-level package that can be upgraded later. Suppliers often offer generous upgrading allowances.

To assess a pcb-design CAD program takes a lot of time. Engineers are often reluctant to spend time on a wide-ranging assessment. Time spent learning about systems that are not going to be purchased is naturally almost completely wasted. Also, you do not accumulate much general knowledge of operating CAD because each maker has its own way of doing things.

On the other hand, a quick scan of a few chosen programs can give a completely false impression. I found that a good deal of time was required not just for working the computer but for reading through the manual and making sense of it. And after that, you need to go through the steps of converting a schematic into a real board. To make assessment even more difficult, program manufacturers often have different terminology for the same thing.

It is symptomatic of the pcb CAD makers that they cannot even agree on a common name for the area on screen that holds the symbols that are about to be used – ie a parts bin. In *Quickroute*, it is called the parts bin, but in *Ranger2* it is called the tray, while in *Isis* it is called the object selector. Similarly, the area on screen where you put your drawing is called variously the edit window, main design window, the sheet or the drawing area.

In some cases, the description of the program glosses over or omits to mention shortcomings or over-emphasises the product's supposed superiority. All this disinformation takes time to sort out.

Big discrepancies

Products from the USA, the Continent and the UK – shareware, freeware and evaluation versions – were collected for this review. What I found was astonishing; big discrepancies in value for money, wide and unexpected variations in the time taken to learn the program, a large spectrum of user-friendliness and an even wider spectrum of features provided. There was not a lot of correlation between cost and benefit.

This collection was then pared down to those that I thought would be of most interest to the intended audience. Each program was checked on a variety of computers ranging from an IBM 286, 12MHz, with just 2Mb of ram, through a couple of Compaq 386 machines, 20MHz with 4 and 8Mb ram, and a 'brand x' 486DX, 66MHz with 16Mb ram.

The computer chosen for a particular program was the one thought most suitable for testing the producer's stated minimum requirements. Outputs were checked on dot-matrix, bubble jet printers and a pen plotter.

In compiling this review, I omitted those programs that did not offer either shareware or usable evaluation disks. It is vital for the prospective purchaser not simply to watch a demonstration or to read about the features, but to try out the process of making a small pcb from start to finish for themselves.

Most of the program producers offer a working version of their product which is either limited by having the library files cut down, or by restricting the number of components in a diagram. In some cases the limitation is by preventing the artwork from being printed.

Some so-called evaluation disks are so cut-down that they almost refuse to work. I believe the disparaging buzz-word for these is 'crippleware'. If you cannot try out a program – and by this I mean produce a real pcb – my advice is to avoid it. It is inviting disaster to watch a slide-show demonstration disk, read the manufacturers claims, and then buy.

There are no long lists of every feature for the programs in this review, as this method would make very dull reading. Instead, as all the programs had strengths and weaknesses, these have been highlighted together with salient features. For example, no mention is made of how easy or difficult installation of the programs is, unless there is something out of the ordinary about it. Therefore if any special feature is required for a specific need, you will best find this feature by operating the evaluation program.

The review is not intended to enable the reader to choose one program to suit his or her particular requirements, but to point the way to a shortlist, and so avoid having to plough through numerous evaluation disks, sales leaflets, and operating manuals.

Do you really want CAD?

Firstly, you should ask yourself why you want CAD. There are four reasons or categories as far I can see. In the first category, if you merely want to present a smart-looking schematic to a prospective purchaser of your design, or if you want to publish the circuit, then a schematic drawing program may not be what you want.

You could be better off with a general CAD drawing program. KeyCad for Windows*, for instance, is only £20. It has a library of electronic symbols which can be added to as required and gives excellent drawing quality. A big advantage is that you can also use it for simple 2D engineering drawing, for example designing the case or rack system, which you won't be able to do with a specialised electronic program.

In the second category, if you only want to test your circuit by means of a simulator, and have no interest in pcb artwork generation, then a schematic computer-aided design package with schematic capture and a netlist output in at least a couple of recognised formats can be the answer. Some have a built-in simulator. Such packages need not be very expensive.

In the third category, you may simply want to get that circuit diagram you scribbled down changed into a pcb without having to go to the trouble of re-drawing the whole thing again as a schematic on a computer screen. In this case, a manual pcb drawing program without schematic drawing will give you the precision and professional appearance that the computer offers. You will also be able to cut out the time-wasting ultra-violet exposure and development if you follow the suggestions that I make at the end of this review.

In the last, and probably largest category, are those who want to short-cut the whole tedious business of making a pcb design altogether. In this case, a schematic drawing program with schematic capture and an integrated autorouter may be the solution. But there are many snags to this last CAD alternative. An autorouter can be a big time-saver, but it can just as easily turn out to be exactly the opposite.

And if so, which type?

Before deciding on which CAD type to go for, you should analyse your motives for acquiring CAD. The advantages are that in laying the pads and tracks with CAD it is easy to get the precision that previously only a skilled draughtsman could achieve. Another advantage of those systems with a built-in library of components is that you may no longer need numerous component data books on your desk. Pin-out information is often included.

In addition, it is very easy to make a change to a board layout on the computer. With the conventional 'hard' artwork method, it was difficult to rip up and re-lay a track. There was a chance of destroying your whole artwork in the process. With CAD it can be quicker to get from schematic to finished board once you are familiar with the program you have selected, although reaching this stage may take longer than you think.

CAD certainly circumvents all the man-power usually needed to turn your circuit into a board. And light-boxes, multi-layer transparencies, transfers, fragile stick-on component outlines, and all the other paraphernalia of the conventional process can be thrown out. There is no need for careful storage of the finished artwork.

Review 1 – *PCB Designer*

This is a small and inexpensive Windows program for purely manual design of pcbs. It is about as basic as it is possible to get. Nevertheless it will still competently handle single-sided and double-sided boards. In effect, it is the computer equivalent of the conventional light-box and transfer method.

Most of the information needed to run *Designer* is in a tutorial on the disk. I found that there was really no need for anything else. The package has a good on-screen Help, and the system is very intuitive.

This product was obviously written from scratch as a Windows program – not as a conversion from DOS. It needs Windows 3.0 or 3.1 and MS-DOS 3.3 or above, or the equivalent, so you will need at least a 286 and 2MB of RAM minimum.

Screen area available is good at about 9.5in by 5.5in. At the top is the usual Windows menu bar, and underneath a button bar with 27 buttons. Button coverage of the functions is sufficiently extensive that you will rarely have to resort to the menu system. Most of the pad outlines and tracks are directly available from the button bar, with an small extra library in reserve.

A pop-up reminder of all the button functions appears on selection, and these are reinforced by a longer explanation of functions at the bottom of the screen. With this system you should be able to switch on *Designer* even after a long absence from CAD and still be

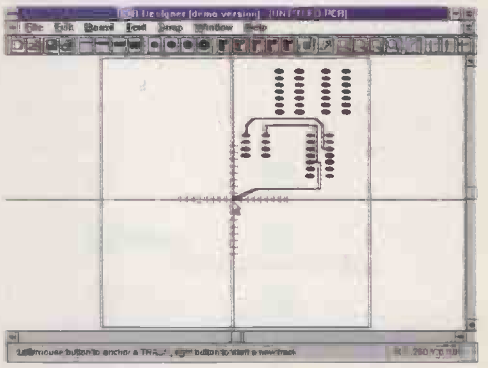
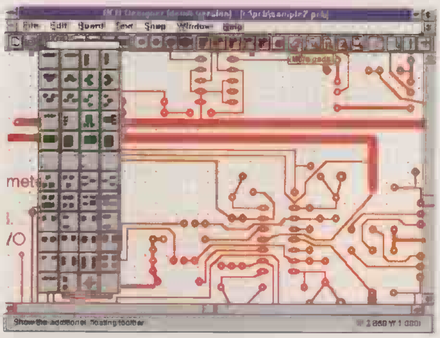


Fig. 1. Note unusual cross-hair cursor with PCB Designer.



Typical PCB Designer screen with grid on. Note extra pad library on lhs and text at button bar.

able to work it straight away. You cannot claim that for many CAD programs. There are no endless, meaningless, DOS commands to forget – its all there for you read on screen.

Surprisingly for such a small program, it has autosave, and its supplier, Niche, is to be commended for including it. Equally surprising is the absence of a grid system until the zoom is operated. I found this a little disconcerting at first. Based on three fixed levels, the zoom system is very easy to use, and there is a custom zoom feature.

Another novel feature is that when placing parts on the board with the grid off, the mouse cursor is replaced by a large graduated cross-hair arrangement. This cross-hair is moved by the mouse just as the cursor is, Fig. 1. Although I did not get on well with this system, I could envisage some people liking it. I think it is another area where personal preference reigns.

The only thing I did not like about *Designer* was the lack of a library of component outlines. Only pads are visible, and I found this was not enough to make a good layout. Also, if you are without a built-in component library you will of course need a pile of data books for the pin-out.

I feel that the lack of a library in *Designer* is not making the best use of the computer's potential. Niche should rectify this with a small library of the common outlines, with the facility for users to add their own. They would then have a thoroughly commendable product.

PCB Designer uses the standard Windows printer drivers. It has no Gerber or NC file outputs.

PCB Designer in summary

The first step away from light-boxes, transfers, tapes and transparencies and towards CAD provides the biggest gain. PCB Designer, although a small program, gives all the major advantages of using CAD at small cost and is a good introduction to pcb CAD.

Niche Software Ltd,
tel. UK 01432 355414, £49 all inclusive.

Review 2 – *PIA*

PIA is the next step up in terms of sophistication, as it has both pad and component outlines in its library and an autorouter. *PIA* is a relative newcomer, so as you would expect, it's a Windows program. It comes in three

Terms used in PCB CAD

CAD for schematics and pcbs has its own jargon, which may be unfamiliar if you have not encountered CAD before. Here is a brief glossary of commonly used terms.

Autopan. Because the screen often displays only a small part of a circuit diagram, it is necessary to pan across the drawing area with your relatively small viewing window. With an autopan system, when the mouse reaches any side of the screen, the diagram is made to move into view from that side automatically. A useful – but not essential – feature which not many programs have. Manual panning is more common and some prefer it.

Autosave. There is always a possibility that you will tie yourself up in knots – especially while you are learning – or that the system will crash. What autosave does is to save your work to the hard disk every 5–15 minutes, overwriting the previous save. When you crash, you will – with luck – only have lost the last few minutes of work. This is a valuable time-saving feature and far superior to manual saving.

Autoneck. A system in which, if a routed track goes between two adjacent pads, track width is automatically reduced to pass between and maintain the specified clearance in the drc. A feature worth having, but not as useful as Autoshave, **Fig. A**.

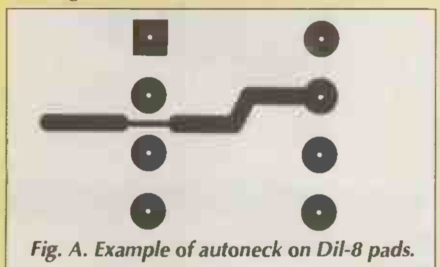


Fig. A. Example of autoneck on Dil-8 pads.

Autorouter. A program which attempts to turn netlist, via a rat's nest, into a piece of pcb artwork using various strategies. (Read Lee's Algorithm and Gridless Techniques.) Although autorouters are, by definition, automatic, you will still have to manipulate the rat's nest to get the autorouter to work properly. You will also have to draw manually any tracks left uncompleted by the autorouter.

Autoshave. A similar feature to Autoneck above, but instead of reducing the track width, the pads are reduced in the area of the track to maintain clearances specified in the drc. This feature is not often seen, but is the way I prefer to treat tracks passing between DIL pads, **Fig. B**.

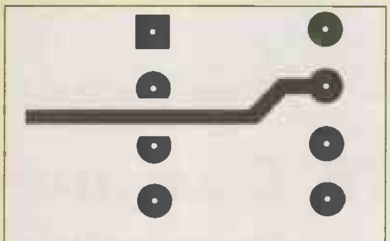


Fig. B. Example of auto shave on Dil-8 pads.

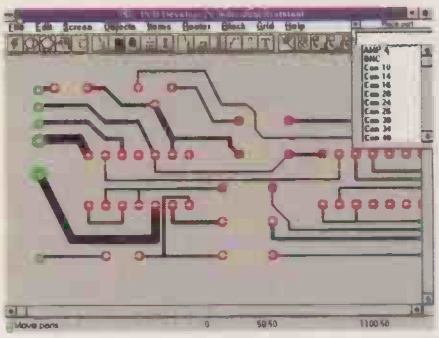
Backwards annotation. If you constantly make changes to your finished board design, this feature may interest you. With it, you can make an annotation change to the board design and the program will automatically make corresponding changes to up-date the other parts of the design e.g. the schematic. The converse of this is Forward Annotation.

Connectivity check. It may seem obvious, but you expect a track drawn between two points on the schematic to be processed by the netlist/rat's-nest/autorouter as such. Unfortunately, it is not that simple. There are many ways in which a track that appears perfectly ok, is not acceptable to the system, leading to a missed connection. Most programs allow an automatic check to ensure that the integrity, or connectivity, is kept.

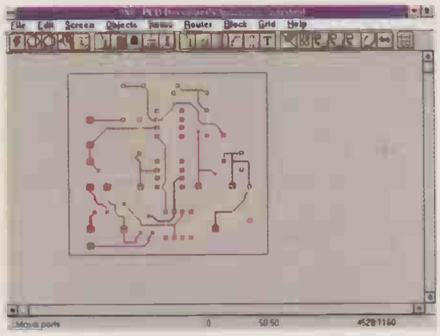
Design rule check. (drc) On most programs the designer is required to set a list of parameters for track width, spacing between tracks, distance from the edge of the board, etc. Programs have a method of checking these design rules automatically. This is vital feature when using an autorouter. Without running a check you are almost certain to have short-circuits, open tracks and burn-outs. Beware of programs with a limit on setting parameters; you are certain to want to change the specification at some time to suit your own needs.

Gate swapping. This autorouter feature concerns those ics that contain several identical gates. To ease the burden on the autorouter, it helps if the program can automatically swap the gates round to aid route-finding. This is a useful feature if large boards are involved. A similar situation occurs with pins, the feature is then called pin-swapping.

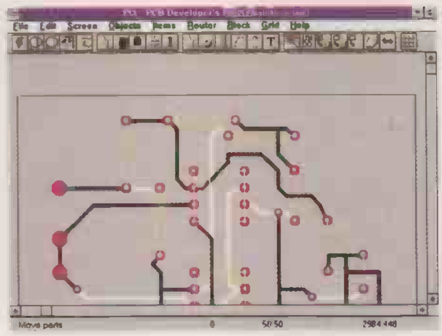
Gridless autorouteing. Most budget-priced autorouters use a grid system to fix the routes between pads. If the pads do not lie on the grid, the router may mis-route or not route them at all. This is a generalisation and gridded autorouters can route off-grid to some extent. A gridless autorouter on the other hand can route anywhere it likes, if a little more slowly, and this is useful for components whose pins do not fall naturally to any particular grid. There are more of these components around than you might think. You could instruct a gridded autorouter to use a very fine grid to make the chances of a missed



Typical manually drawn pcb on PIA showing library of connectors at top rhs.



Double-sided PIA autorouter result on test circuit board.



PIA close-up of the shot to the left.

versions. All have approximately the same engine, but differ in the size of board they can handle and in output devices available.

The standard version handles up to 1000 pads and 1400 lines while the extended version achieves 2000 pads and 3000 lines. The 32-bit version handles 8000 pads and 12000 lines. Only the 32-bit version has HPGL plotter, Gerber file and numerically-controlled-drill-file output. Both other versions use the Windows printers for artwork output.

Minimum hardware requirements for the standard and extended versions are a 386 – preferably with co-processor – and 4Mbyte of ram. Needless to say, a mouse plus and Windows 3.1 or higher are needed. For the 32-bit version, you need at least 8Mbyte of RAM and at least the WIN32S extension to Windows 3.1. Performance is enhanced if you have more ram.

Despite these requirements *PIA* is a relatively simple program. Because of this, and because of its intuitive interface, *PIA* is very easy to operate – in fact probably the easiest of all to learn.

All *PIA* versions are programs for board routing only – there is no schematic drawing

connection small. But just halving the grid spacing quadruples the grid load on the computer. Suddenly, your reasonably fast autorouter becomes very slow.

Interactive. Programmers' double-speak for do-it-yourself. For example, manual routing of tracks that the autorouter has failed to route is sometimes referred to as 'interactive routing'.

Layer. You may see that a system operates on 12 layers. This does not mean 12 layers of copper track on a multilayer board. A layer is an operating plane used by the system to store information. A typical 12 layer system may use layers 1 and 2 for information on component-side and solder-side copper track on a double-sided board, then use 3 and 4 for silk-screen information, layers 5 and 6 for solder-resist and so on. Some of the remaining layers may well contain information on internal copper tracks and buried vias, if the router is capable of making a multilayer board.

Lee router. Autorouters use not just one but several strategies for routing tracks. These strategies are often listed and explained in the program's manual. The Lee algorithm – a type of maze solver – is claimed to be the most effective at finding routes. But it is slow, so it is sometimes left as the last strategy to try, to attempt completion of the board when the other strategies have failed. Now that faster pcs are here, the slowness is less relevant, so it is worth looking for this type of router in the autorouter specification.

Memory router. This is a strategy used for regular, repeating patterns of tracks. It is normally used on a single layer only, of the sort needed for memory systems, **Fig. C**. It is not suitable for routing anything other than this type of pattern.

Net. A connection between two or more component pins resulting, for example,

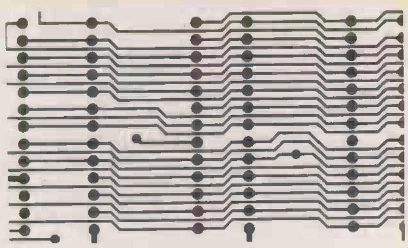


Fig. C. Example of memory routing.

from the pad-to-pad, track-to-pad, track-to-track connections made on the schematic.

Global Nets. As nets are given unique names by the program, nets with the same name are assumed to be connected even if not shown as such on the schematic. Such nets could be, for example, on a different sheet of the drawing, but still electrically connected as far as the program is concerned.

Netlist. A list of nets which can be automatically produced from a schematic or typed in by hand. The netlist describes the circuit, and is a necessary step between the schematic and automatic production of a rat's nest, or connection to a simulator. In some programs the netlist contains both the nets and components. Others produce a separate component list. Most makers have their own netlist format so there is not much opportunity for transfer of netlists between different programs. But there are exceptions. As the netlist is usually in text, it can be used to verify by eye that the connections you thought you had made in the schematic are in fact present in the netlist. This often holds a few surprises. Viewing a netlist and checking each net by eye on a large board is – as you may have guessed – a very tedious process. Some programs have methods of reducing this burden, as you will see.

Rat's nest. While most engineers will be familiar with rat's nests, those produced by the computer from the netlist may in fact be just an unrecognisable pile of what appears to be junk on the screen. Most programs need the operator to sort these out into a 'proper' rat's nest by hand, placing the components into your preferred position before the pcb routing can take place. The degree of difficulty experienced in doing this varies widely between programs.

Schematic capture. The act of turning the symbols of a schematic into a form usable by the computer for either routing, or simulation, or transfer to another system, the form being usually a netlist. Not all programs with schematic drawing combined with pcb artwork have schematic capture.

Rubber banding. A technique used in a lot of CAD drawing programs – not just electronic ones – for redrawing a line. The line appears to be stretched like a rubber band at the point where the mouse cursor is located, and stays attached for as far as you move the cursor. Corners are often added by keyboard typing. A very easy method for beginners and experts alike to tie Gordian knots.

Push-and-shove. An autorouter strategy in which tracks already routed, but causing obstruction to further routing, are re-aligned to make way – a very useful feature.

Rip-up-and-retry. Similar to push-and-shove, rip-up-and-retry allows tracks already routed to be automatically removed, completely, and rerouted. This feature and push-and-shove are only found on the more developed autorouters and are highly desirable. Together, they do a lot towards getting a near 100% routed design.

or capture. There are facilities for importing and exporting basic ASCII netlists on the 32-bit version.

The drawing area is good, at 9.5 by 5.5in on a 14in screen, and is presented in the standard Windows format. Panning is carried out with scroll bars – a very good method – and there are five fixed levels of zoom.

In all versions of *PIA*, there are two options. You can either route the board manually as in any other manual routeing program, or you can use the autorouter. With the latter, it is necessary first to generate a rat's nest.

Some reviewers have commented that if you are going to draw rat lines, you may as well draw tracks and have done with it. But, in *PIA* all you have to do to produce a rat line is click on two pads, and the ratline is drawn for you.

Because of PIA's snap-to grid system, you do not have to be accurate at the track-producing stage. In fact, you can be quite sloppy and it will still draw correct rat lines. This makes the process rapid. Drawing lines in space is inhibited so you can hardly go wrong.

With this system, if you have a design on paper that already has the pin connection information on it, you can transfer it to the screen ready to autoroute in a much shorter time than you could with a schematic drawing and capture program.

This attractive track routeing concept means that the package will appeal particularly to experimental designers. Such designers do not require a neatly drawn schematic. What they do need is to produce a working prototype pcb without hassle. In particular, the operator does not need to remember how to use the program.

There is a constraint to using this method. As any pcb draughtsman will tell you, there is a well-defined limit to how many rat lines you can put in before making a mistake. With a schematic, it is relatively easy to spot a mistake, such as an unconnected pin, even on large schematics. But with a rat's nest that has been built up to certain stage of complexity, a mistake can be readily made and not noticed.

Although this point will vary with individual designers, I think it is fair to say that this limits *PIA* to small or medium sized boards – at least in the rat's nest mode. The manufacturer of *PIA* makes no bones about this, advancing the package as a 'pcb-developer's individual assistant', rather than as an all-singing, all-dancing pcb design tool.

In keeping with the theme of simplicity, there are no autosave, autopan, autoneck, etc., features, and there is no map to locate lost drawings. There is no parts bin. Selecting parts is done direct from a basic library of pad/component outlines to the screen.

The library is presented in text in a small area on the screen and is scrolled through to reach the part required. Alternatively, you can get common parts from the button bar. Most designers would want to add their own outlines to the basic library, and this is easy to do.

Like many others, *PIA*'s autorouter is meant for doing only double-sided boards. Although it can be made to do a single-sided board, the result will contain many uncompleted tracks. The handbook specifically discourages single-sided use of the autorouter. The power of this simple autorouter is not great; it has only the standard features you would find at this price level. It does not have rip-up-and-retry or push-and-shove, for example, and only a small amount of pre-routing configuration is possible.

Some manual completion of boards has been anticipated by the unusual and welcome addition of a button on the tool-bar to provide jumpers. What a good idea. The autorouter is gridded with a choice of just three grid and track size combinations, so is quite basic. Although it would route off-grid, the autorouter did not like it, and always gave warning messages – even when it was able to give 100% routing.

The manual drawing part of the program is easy and pleasant to use and, bearing in mind the limits of the autorouter, is probably the main use to which *PIA* would be put by most users.

PIA in summary

Although the rat's-nest/autorouter method is a good way of producing a working prototype of a double-sided board quickly, I would like to see *PIA* developed further. It should be equipped with a much more powerful autorouter. Nevertheless, as it stands, *PIA* is an attractive product with an identifiable niche in a particular sector of the market.

AW Software, tel. Germany +49 89 6915352. PIA std DM99: extended DM171 32bit DM286, all inc. 15% tax.

Review 3 – Easytrax

Easytrax is a dos based pcb drawing program of medium size and complexity. It has no schematic capture or provision for importing a netlist. It will run on any IBM pc from XT upwards. The main program ran well using just conventional memory. When it came to plotting however, I needed to convert some extended memory into expanded memory in order to run the whole of some boards without receiving the 'out of memory' message.

The main attraction of *Easytrax* is that it is offered completely free to anyone who wants to use it. As such, it is an economical introduction to the world of pcb CAD. From using it you can find out which aspects are important to you and which are not. It even includes a method of automatic routing, but this is an unsophisticated semi-automatic type not a fully-fledged autorouter.

There is no written manual with *Easytrax*. It has to be extracted from the disk and is some two dozen pages long. The manual does not cover every aspect of the program – only the basic operation. You are left to discover the finer points for yourself. This may take some effort, but is well worthwhile.

As this is a free piece of software, do not expect any technical support. There is no on-screen help but the prompt system is good. Most of the control throughout is by a good, logical menu system, backed by the usual key-

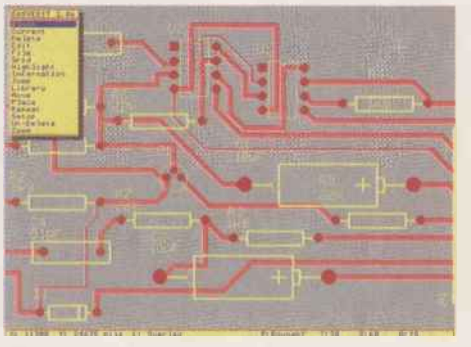


Fig. 2. Manually drawn exercise showing quality of graphics and typical menu in Easytrax.

board short-cuts. These short-cuts are mostly logical, but some alas are of the incomprehensible dos sort. For example, the asterisk key changes layers. Why not use 'L' for this?

The screen area is good at 9.5in by 6.5in when none of the menus is showing. Graphics are good, as **Fig. 2** shows. There is an adequate library of component outlines which is easy to access. As you would expect in a relatively simple dos program, the library is in text form only. Many of the text descriptions of the components may appear to be somewhat cryptic until you get used to them. RADO.4, for example, is a generalised outline for a component,

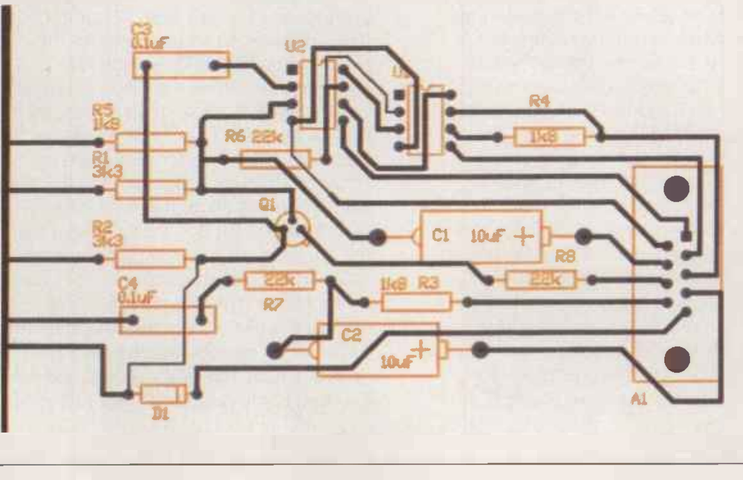


Fig. 3. Plot of exercise shown in Fig. 2 using Easytrax HPGL plotter driver, showing final artwork quality. Reproduced twice size and showing top overlay.

which could be a capacitor, resistor, etc., with radial leads on a 0.4in pitch.

Although a very straightforward program, *Easytrax* has some finer points. Examples are autopan, which can be turned on or off as you wish, adjustable autosave, and a 'jump' option which takes you to any component on the board that you specify. This could be useful on large circuits to get to a specific place on the board without panning.

It is easy to lose your work off-screen if you are not careful with the autopan. There is no map showing where you are. Beginners may find this very frustrating until they master this control.

The zoom/unzoom function has eight levels. It can be accessed via the menu system, which makes it a slow process. On the other hand, it can be accessed using page-up and page-down keys on the keyboard, which is very quick and convenient.

As you would expect with a dos program, screen redraws are fast. There is also a 'zoom-all' function which brings all the circuit to fit on the screen. This function can be used to retrieve lost circuits.

Drawing in the tracks manually was straightforward. Surprisingly, *Easytrax* is perfectly capable of making not just single-sided and double-sided, but multilayer boards too.

An alternative to manual routing is to use the automatic router. With this router, the operator selects two component pads with the mouse, which causes a track to be inserted – complete with vias. This two-layer router inserts vias far too freely, limiting its usefulness. It is essentially non-configurable. This type of semi-automatic routing is a slow method compared with a full autorouter but quicker than drawing tracks by hand and not such hard work. The results may not be what is desired or intended. As a result, be prepared for odd-looking tracks and lots of vias.

Considering this is a free program, there is a good choice of output devices for the pcb artwork. As **Fig. 3** shows it can produce high-quality artwork. The illustration was just an exercise drawn quickly on the manual system. It shows the quality of pad and track outlines and plotted on *Easytrax*'s HPGL plotter driver. The final quality and appearance of a real board depends very much on the amount of time and effort you are prepared to put into the drafting.

Note that if you try out this program, and can't find the printer/plotter drivers after installation, re-install it, putting all the various parts of the program under the '*Easytrax*' directory, and not in the default directories.

Easytrax in summary

For a dos program, *Easytrax* is not too difficult to learn. If you master it, you will find it is pleasant to use, comparatively bug-free, and practical.

Its limitations should become immediately apparent on using it to make a real pcb. The merits of the program are that it is possible to design practical basic pcbs and that it is free of charge. It is claimed in the literature that files from *Easytrax* can be transferred to Protel's higher programs, such as *Autotrax* and their Windows products.

PCB CAD review subjects

This review, continued next month, covers the following ten products.

PCB Designer: Niche Software Ltd, tel. UK 01432 355414. £49 inclusive.
PIA: AW Software, tel. Germany +49 89 6915352. PIA std 99DM: extended 171DM 32bit 286DM inc tax.
Easytrax: Protel International pty, tel. Australia 408 437 7771, UK PDSL, tel. 01892 663298. £6 copying charge.
Electronics Workshop: Robinson Marshall.
CircuitMaker: MicroCode Engineering.
Quickroute 3.5 Pro+: Quickroute Systems Ltd.
Propak: Labcenter Electronics.
Proteus: Labcenter Electronics.
Ranger2: Seetrax CAE Ltd.
EasyPC Pro XM: Number 1 Systems.

Note that although starting with a couple of smaller packages, this review is not in any order of complexity or competence.

Protel International pty, tel. Australia 408 437 7771, UK – PDSL, tel. 01892 663298. £6 copying charge.

■

**KeyCad is a product of Softkey International Ltd.*

Video inserter

Ian Polczynski's module superimposes text, together with time and date information, on any standard composite signal – whether PAL, SECAM or NTSC.

This article describes an on-screen display unit, osd, that allows date, time and text characters to be displayed on top of a background colour video signal. Devices similar to this circuit are common in security and surveillance systems. But low cost and simple construction make this unit suitable for home video processing and archive titling.

Basically this circuit is an eight-bit stand-alone microcontroller with real time clock, display and input/output facilities. It can perform virtually any task, from controlling your reticulation to titling your video tapes.

The function of this circuit is to input live video, add on-screen information, and output the result as a composite video signal. Whether the unit is powered up or not, the input video signal is permanently output. A minimum battery back up time of not less then 90 days is achieved.

Features of the *μPD6145* video insertion chip

- Numbers of character displayed: 12 lines by 24 columns
- Numbers of character types: 112(rom), 16(ram)
- Character size: 2H, 4H, 6H, and 8H per dot
- Character matrix: 6×9 dots, no inter-character space
- Interface with microprocessor: 8-bit serial input format
- Power supply: Single +5V power rail

How the video inserter operates

Figure 1 shows block diagram of the on-screen display unit. In simple terms, a composite video signal is fed to the sync separation circuit and separated into two sync signals, HSYNC and VSYNC. These two signals clock the character generator IC. The generator receives commands from the cpu via serial link and outputs the necessary information to a buffer, which adds character signal to the composite video signal.

About the on-screen display

The unit is based on the NEC *μPD6145* and its display character format is 6 × 9 dots. As there is no space between characters, the *6145* cmos IC, **Fig. 2** enables display of a combination of two or more characters, kanji characters and graphs.

The device consists of a 288-character video ram array, for 12 lines by 24 characters, a 112-character font rom, a 16-character user defined font ram, the on-screen display logic, and a video clock oscillator.

The chip logic accepts horizontal sync., HSYNC, and vertical sync., VSYNC, and provides digital video outputs for character information.

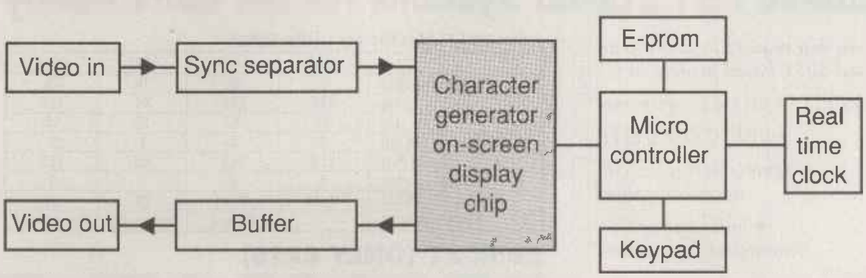


Fig. 1. Video switching is arranged so that the module can be left in circuit and by-passed transparently when not needed.

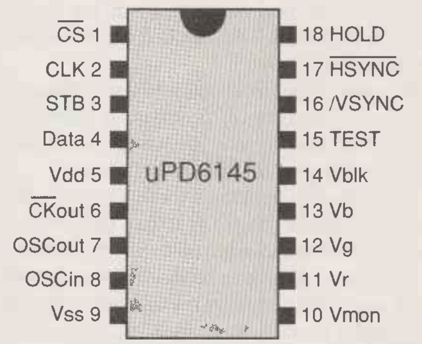


Fig. 2. Signal names for the μPD6145 video message inserter.

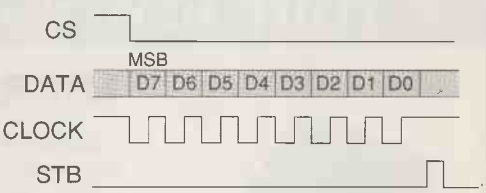


Fig. 3. Control input for the 6145 video insertion chip is clocked in serially while chip-select is low.

Timing for the character dots is provided by the video clock oscillator. In most applications, this oscillator is simply an *LC* tank circuit connected to the osc in/out pins. The frequency controls the character width.

Video ram stores the characters to be displayed on the screen along with certain attribute data pertaining to those characters. One nice feature of this IC is that once a character has been written to the on-screen display chip, no further cpu intervention is required to 'refresh' the screen.

Protocol of the display chip

Figure 3 shows the *6145* control-input format. After the CS line is set to 'L' the cpu starts to send clock impulses and data bits from msb.

The shift registers for serial interfacing with external units consist of eight bits, but the *6145* commands comprise nine bits. Because of this, instructions are divided into two banks. One of these banks is selected by one bit of the format selection command, **Fig. 4**.

Each control command is executed when a strobe pulse is input after eight-bit data has been input. To write display character data continuously without changing the character attributes only character command is to be sent. To display the sequence '012' for example, the following control commands should be transmitted: 00_{16}, 01_{16}, 02_{16}. The write address is incremented automatically at the fall of the STB pulse when display character data is input.

Separating sync

The *6145* only accepts extracted horizontal and vertical sync signals, HSYNC and VSYNC. To provide the device with this timing information from a composite video signal, a dedicated sync separator circuit is employed, based on the Gennum *GS4881* sync separator, **Fig. 5**. This IC is a drop-in replacement for the industry standard *LM1881*.

Composite video is ac coupled via an external capacitor to pin 2. The device clamps the sync tip of the input video to 1.5V and then slices at 77mV above the clamp voltage. Resultant signal, at pin 1, is the input signal with the active video portion removed.

For HSYNC timing, the BACK PORCH output, at pin 5, is used. **Figure 6** shows the difference between these two signals.

In PAL composite video, horizontal sync pulses are followed by the back porch interval. The *4881* generates a negative-going pulse on pin 5 during this time. It is delayed typically 500ns from the rising edge of sync and has a typical width of 2.5μs – just enough for the *6145* display IC.

The vertical sync interval is detected by integrating the composite sync pulses and is clocked in and out with a fixed width of 197.7μs.

No chrominance filtering is done within the device. If the input signal contains large chrominance components or has significant amounts of high-frequency noise, external filtering may be necessary. This filter can be a simple single-pole low-pass filter, having a corner frequency of approximately 500kHz, and providing an ample bandwidth for passing sync pulses with almost 18dB attenuation at 3.58MHz (NTSC colour subcarrier).

To control the source resistance seen by the sync separator, i.e. minimise the amount of attenuation, a low output impedance buffer is recommended. An NPN emitter follower works well.

Mixing video

To simplify the circuit and to make it compatible with NTSC, PAL and SECAM, a limitations need to be imposed on the project targets – colour availability. Unfortunately, the three standards use different colour encoding methods. It is impossible to produce a colour video signal that is compatible for the three standards, unless you go for vivid white only.

To envisage vivid white means, imagine a screen showing a colour video pattern from a video generator for all three colour standards and monochrome, **Fig. 7**. Displayed on screen, the video of Fig. 7 shows vivid-white dot in the middle of one of the horizontal lines, regardless which standard it is overlayed onto. The black line, 10% above white level, represents a 'white dot' overlayed on top of 'live' video signal.

Figure 8 shows the video mixer in outline, illustrating how a composite video signal passes through the on-screen display unit. A 75Ω

Bank 0 commands
Display character data
Colour/blink data for each character
Character display line address
Character display column address
Background specifications
Write sync, smoothing on/off, display on/off
Blink/oscillation control

Bank 1 commands
Video ram wrlte data
Video ram word address
Vertical display positlon address
Hoizontal display position address
Character size specification

Fig. 4. Command descriptions for codes controlling the on-screen display chip.

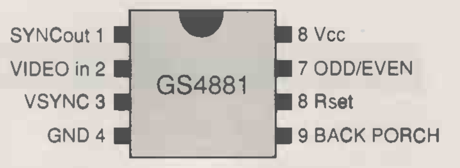


Fig. 5. Pin compatible with the industry-standard LM1881, the GS4881 extracts horizontal and vertical sync signals from composite video.

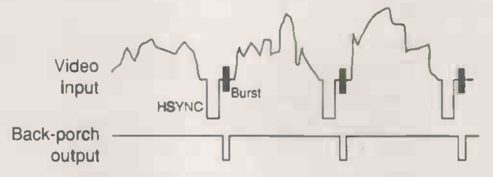


Fig. 6. For horizontal sync, the 4881's back-porch signal is used. At 2.5μs, this pulse is just wide enough for the 6145 display chip.

Video signals and standards

NTSC: National Television Standard Committee, or NTSC, is the USA agency that developed standard monochrome and composite-colour video signals for the USA. NTSC (some say this means never the same colour) standard has been adopted by countries like Japan, Canada, Mexico and many others.

PAL: An acronym for Phase-Alternate-Line, PAL is a video standard for colour tv developed by Telefunken Company in Germany and from principals point of view is similar to NTSC. It includes a line-by-line alternation in phase for one of the two colour-signal components. PAL is used by most of Western Europe, except France.

SECAM: This standard, Sequential Couleur Avec Memoire, was developed in France. Luminance signals have the same format as those of NTSC and PAL, but colour-difference signals modulate two separate carriers that are transmitted on alternate line and to restore missing colour information SECAM decoders include a one-line (1H) delay element.

Colour Burst: is a reference subcarrier window for colour identification. It is transmitted after horizontal sync impulse and before video section of the composite video signal.

Composite Video: Composite video is an analogue signal suitable for transmission on a single channel and is obtained by combining the chrominance and luminance signals with sync and blanking pulses.

RGB: This term refers to the tree electrical signals corresponding th the red, green and blue components of an image.

YUV: After correction and shaping, the RGB signals are encoded to produce chrominance (C for Colour) and luminance (Y for brightness) signals. Then, combining the chrominance and luminance with sync. and blanking signals produces a composite video signal. Video signals may pass through many stages of editing and recording. To maintain fidelity the video signal is best handled in a three-signal component format: the electrical analogous of luminance (Y) and the colour differences B-Y (U) and R-Y (V). YUV requires less bandwidth than RGB: equal amounts of picture detail reside R, G and B, but the YUV system conveys fine picture detail only in Y. Bandwidths are approximately 4MHz for Y, 500kHz for U and 1500kHz for V, resulting in a lower overall bandwidth. A VCR needs three tracks to handle RGB standard, but for YUV, the VCR requires only two tracks, one for Y and one for U and V together.

composite video signal feeds the input connector and is output to the output pin via a low-value resistor.

From the input, the signal is buffered to the sync-separation circuit. An emitter-follower type circuit switches the on-screen display circuit to the output. This transistor is switched by the on-screen display IC. While on, the transistor saturates the live video signal to white, but while off, it has no effect on the output video.

In addition to mixing a live video signal with white overlayed information, the above circuit maintains the 75Ω characteristic impedance for both input and output. The unit can be permanently connected to the video path of any video system – regardless of being used or not. The unit will not have a negative influence on the quality of the transmitted video signal.

On-screen display components

Resistors (all 1/4W metal film)

$R_{1,5,14}$		1k
$R_{2,3,10,11}$		10k
$R_{12,15,16}$		10k
R_6		75R
R_7		220R
R_8		2k2
R_9		100k
$R_{13,17}$		100R
R_{18}		680k
Resistor blocks:		
$MR_{1,4}$		8×10k, 9pin
$MR_{2,5}$		4×10k, 5pin
MR_3		5×10k, 6pin
VR_1	Variable	2k

Capacitors

$C_{1,12}$	Ceramic	1µF
C_2	Ceramic	56nF
C_3	Ceramic	10nF
$C_{4,6,7,9,10}$	Ceramic	100nF
$C_{11,13,14,18}$	Ceramic	100nF
C_5	Electrolytic	1000µF/16Vdc
C_8	Tantalum	22µF/25Vdc
$C_{15\text{-}17}$	Ceramic	22pF
C_{18}	Variable	5-30pF

Semiconductors

D_1		*UF4002*
D_2		Red led
D_3		*1N4148*
$Q_{1\text{-}3}$		*2N2369*
IC_1	OSD	*PD6145*
IC_2	Oscillator	*HA7210IP*
IC_3	Sync sep.	*GS4881*
IC_4	RTC	*6818*
IC_5	8 bit cpu	*80C39*
IC_6	E-prom	*M27C64*
IC_7	Octal latch	*74LS373*
IC_8	Voltage reg.	*L7805*

Miscellaneous

Quartz crystals

$XTAL_1$	32 768kHz
$XTAL_2$	12MHz
L_1	22H fixed inductor

Keypad push buttons

Circuit details

Circuitry for the on-screen display module is shown in **Fig. 9**. Diode D_1 provides rectification as well as reverse-polarity protection. Any ac or dc input between about 8 and 12V should suffice. Unregulated voltage is sensed via a transistor which pulls down the chip select input of IC_4.

Analogue circuits needs to have a near constant current drain with time. Since the designer has less control over the variation in digital ground currents you must be aware of the logic power requirements. Current surges can be decreased through extensive bypassing. Even though the digital logic may not need it, providing a bypass ceramic capacitor for every power pin minimises interference from the digital circuit on the analogue signal.

CPU and the program memory

Logic is built around the *80C39* microprocessor, IC_5. This controller contains a 128 byte ram, 24 i/o lines, 16 bit auto-reloaded timer, a fixed-priority interrupted structure and an on-chip oscillator.

Software resides in an external *27C64* eprom. For addressing this device, latch IC_7 is necessary to demultiplex the lower address bits from the data bits. The *80C39* is mapped in the external data memory area. To do this, external-enable pin EA is connected to 5V.

All i/o pins connect to pull-up resistor blocks. Resistor R_{15} pulls up e-prom address line 12, thus with LINK1 open the upper half of the program memory is selected. When closed, this link causes program memory to start from location zero.

LINK2 must be open to enable the cpu to fetch instructions from external program memory starting from address 0000. We have produced a pcb designed to operate with both internal rom cpus, i.e. 83xx, 87xx types, and rom-less versions in the 80xx range. With LINK2 closed, the circuit operate correctly only with internal-rom cpus.

Reading from the e-prom is carried out in two phases. First, the cpu sends out via PORT0 the lower address bits $A_{0\text{-}7}$. At the same time, the ALE line goes low and the the lower part of current address is latched in IC_7.

In the second phase of the cycle, the cpu sends out the upper address $A_{8\text{-}11}$ via PORT2 pins $P_{20\text{-}23}$ and the PSEN signal goes low. This activates e-prom data lines $D_{0\text{-}7}$ and the cpu reads a byte of data from the e-prom.

The same occurs when the cpu talks to the cmos ram and real time clock, IC_4. This device is accessible at any time because its chip select input pin is pulled down by the transistor and the RESET and PWR SENSE inputs are pulled up via resistor R_{11}.

There is no conflict on the address/data bus even though the two memories connect to the same port. The *80xx* family has separate address spaces for program and data memory. In other words, when the cpu addresses an e-prom, it uses PSEN as the chip-select output,

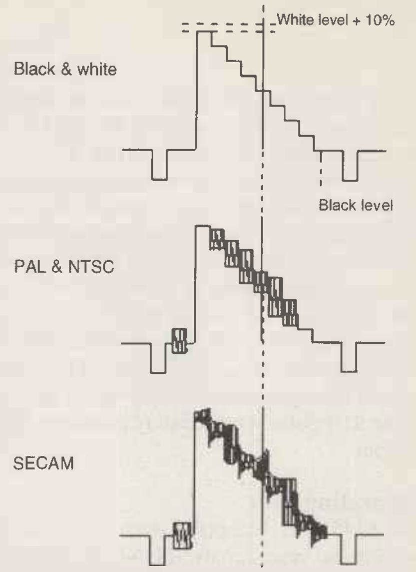


Fig. 7. Colour video patterns for the three tv colour standards and monochrome are dissimilar but it is possible to superimpose a vivid-white signal that provides the same display results with all four.

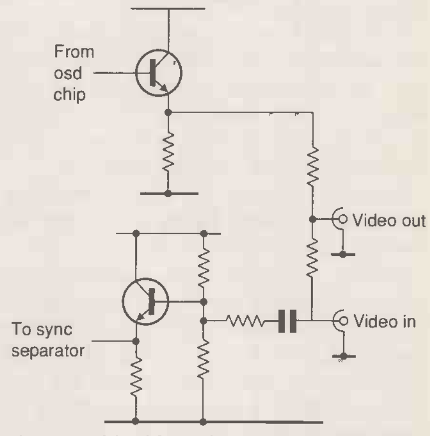


Fig. 8. In this video mixer arrangement, the top emitter follower is switched by the on-screen display unit between acting as a buffer and saturating the video to white.

whereas while addressing ram it uses RD and WR outputs to read or write.

RTC and memory with back-up

The *146818* real-time clock is a peripheral c-mos device combining three features – a complete time-of-day clock with alarm, a calendar, a programmable periodic interrupt and square-wave generator, and 50 bytes of low-power static ram. It includes a multiplexed bus interface circuit, so it can be directly connected to the *8039* cpu.

The on-chip oscillator is designed for a parallel resonant crystal at 4.194304MHz, or 1.0485765MHz, or 32.768kHz. However, if the internal oscillator is used, current con-

Technical support

Readers interested in a designer's kit incorporating the *6145* on-screen display IC, osd and keypad pcbs and a pre-programmed e-prom can obtain them from Polvision at 77 Glanton Way, Dianella, Western Australia 6062 for AU$99.

sumption of the chip is too high and battery back up time would only be about a week. The target was set up to minimum 90 days. To solve the problem an additional low-power c-mos chip IC_2 has been employed, namely the *HA7210IP*. This is a very efficient oscillator IC and brings consumption down to battery less than 30μA. As a result, 100mAh NiCd battery can easily provide more than 90 days' operation.

The battery is charged from the 5V rail via resistors R_{17} and R_{13} and diode D_3. This diode stops the battery being discharged by other components when the unit is in a standby mode.

Implementing the design

In our design, all major components of the on-screen display circuit are mounted on a single board.

A description of switch functions and software appears in a later article. ■

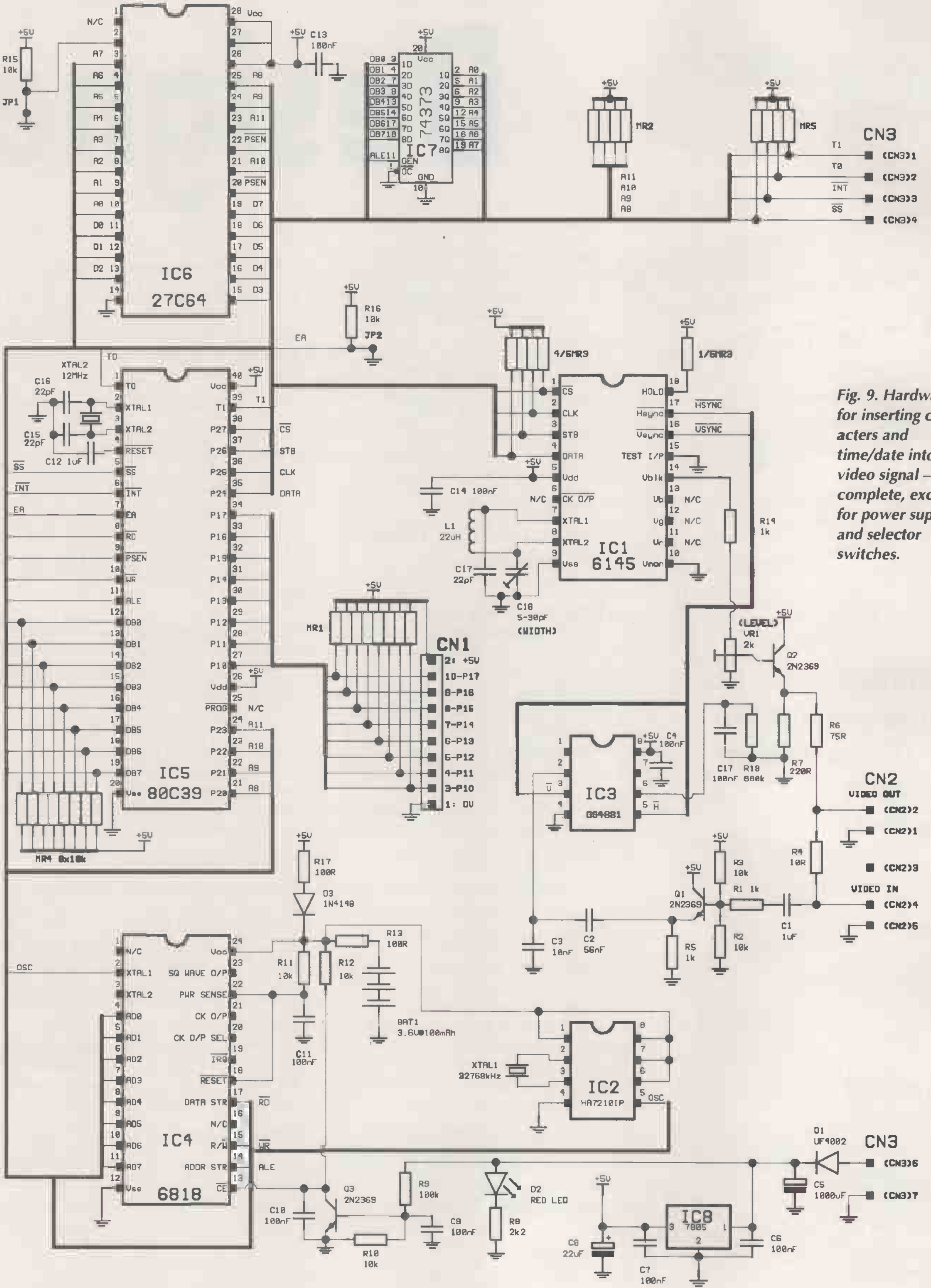
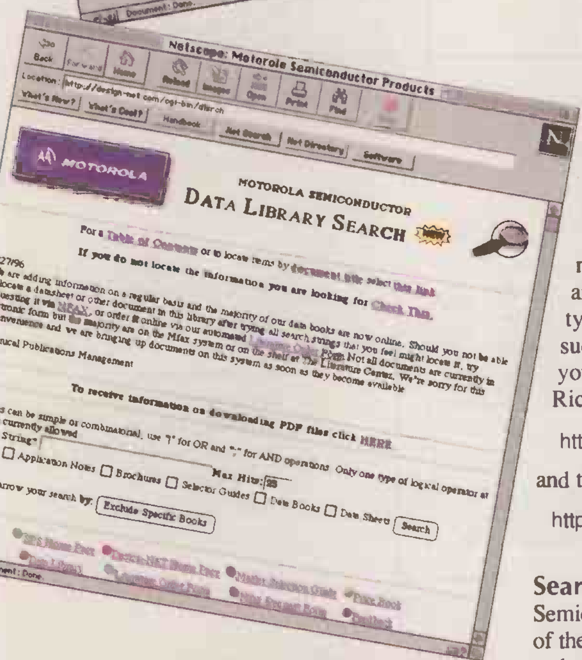
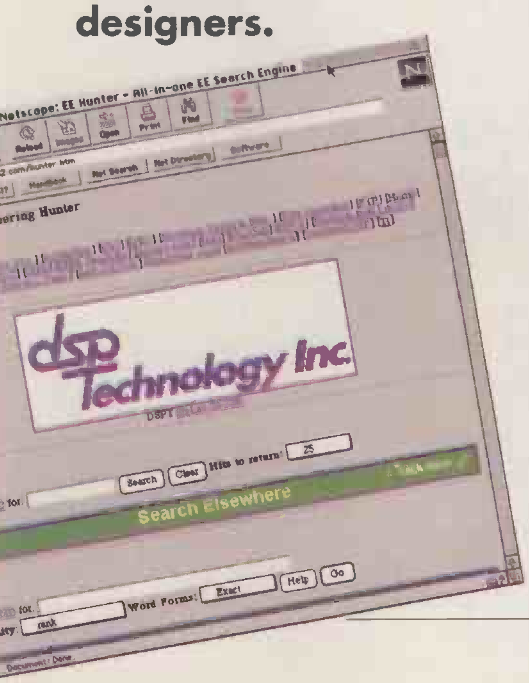


Fig. 9. Hardware for inserting characters and time/date into a video signal – complete, except for power supply and selector switches.

Designer



Jason McDonald has been searching for Web sites useful to electronics designers.



From your World Wide Web browser, you can now key in a few words, hit 'search', and presto – the Web site returns a hit list of applicable resources in seconds.

To benefit from these resources, you must have a World Wide Web browser, and a connection to the Internet. Simply type in the Uniform Resource Locator – such as http://www.search.com – and go. If you're new to the Net, useful overviews are Rice University's search report at,

http://riceinfo.rice.edu/Internet

and the Electronics Search FAQ at,

http://www.eg3.com/srcnet.htm

Search the chip companies

Semiconductor manufacturers now publish most of their data sheets, new product specifications, and other useful design information on their Web sites. The most innovative companies now offer search capabilities. These can range from simply entering a specific part number to retrieve its datasheet, to searching for useful information by keywords such as *68HC11* or real-time.

AMD, for example, has recently initiated their impressive Thunderstone search engine at,

http://www.amd.com/search.htm

Not to be outdone, Intel offers both a search engine, at,

http://www-cs.intel.com/search.htm

and a customizable Web interface. The latter means that you can customise Intel's site to display only the information you want.

Motorola has yet to make its semiconductor Web sites fully searchable. You can only search the Motorola corporate Web site. But the company does offer a search capability for its data library. The library search site is at,

http://design-net.com/cgi-bin/dlsrch

and allows you to identify Motorola data sheets or design information. Motorola's Master Selection Guide is also searchable at,

http://motserv.indirect.com/cgi-bin/msg

Like Intel, Texas Instruments offers a customisable Web interface, meaning you can customise the TI site to display only information useful to you. Texas Instruments also has search capability at,

http://www.ti.com/corp/docs/search.htm

An all-in-one interface to numerous semiconductor search sites is EE Hunter at,

http://www.cera2.com/hunter.htm

EE Hunter unifies a number of companies, such as Texas Instruments, Motorola, and Analog Devices, which allows you to easily toggle between them and quickly identify useful information.

Search non-commercial web sites

Even non-commercial Web sites now offer search capability. Don't miss the impressive Ada IC web site at,

http://sw-eng.falls-church.va.us/AdaIC/

There you can find everything you ever wanted to know about the Ada language and related topics, in seconds.

Norway's excellent contribution to Internet design information – FTP Search – is at,

http://ftpsearch.unit.no/

FTP Search is the fastest way to scan the Net for downloadable source code or files by entering key words like *68HC11* or *8051*. Looking for an *8051* compiler? Search no more – log on to the Free Compilers search engine at,

http://cuiwww.unige.ch/cgi-bin/freecomp

and quickly locate your prey.

Looking for shareware? Perhaps you need a Windows 95 add-on, or a converter from HTML to ASCII for your company's Web site. The searchable Shareware.Com is at,

http://www.shareware.com

This is an outgrowth of the Virtual Software Library.

Indiana University operates the Unified

Web files

Computer Science Technical library, searchable at,

http://www.cs.indiana.edu/cstr/search

There, you can locate computer or EE-related technical reports, though most are highly academic. CERA Research maintains a comprehensive list of searchable non-commercial sites at,

http://www.cera2.com/micro.htm

Search the world wide web

As any design engineer who surfs the net will tell you, finding the Web sites of even major vendors like Hitachi Semiconductor can be difficult. Who would think of,

http://www.halsp.hitachi.com

Fortunately, major search engines now make finding them easier than ever.

One of the most popular is Alta Vista, underwritten by Digital Electronics Corporation at,

http://altavista.digital.com

On Alta Vista, use the symbols '+' or '–' to tighten your searches for exact matches. Enter '+embedded +microcontroller', for example, to identify Web sites having both embedded and microcontroller in their text. Lycos is a great alternative, at,

http://www.lycos.com

though not as fast as Alta Vista.

Even Yahoo – formerly only a subject-tree of resources – now provides a limited search capability at,

http://www.yahoo.com

There, you can have the best of both worlds – almost. First, select a category-specific area such as,

http://www.yahoo.com/Computers/Hardware/Microprocessors/

to browse for microprocessor-related information. Then, search the subarea by entering terms in the blank field at the top, such as 68K. Alternatively, go up a level and search all of Yahoo.

Across the Net, at AT&T, don't miss the innovative new service called Phoaks – People helping one another know stuff – at,

http://weblab.research.att.com/phoaks/

Phoaks sifts through postings to USENET discussion groups, and tabulates the most popular Web sites for a particular group such as sci.electronics.components, or comp.realtime. It's a great way to identify which sites your electronics engineering peers find hot.

Search usenet

USENET discussion groups, such as sci.electronics.design, can be a wonderful yet frustrating way to obtain electronics design information. The problem is the high volume of 'noise' on groups such as comp.dsp, comp.arch.embedded, or sci.electronics.cad. The solution? Use a USENET search engine, such as Dejanews at,

http://www.dejanews.com

Dejanews will sift through postings based on key words, allow you to read postings, and you can even respond to postings of interest.

Other free search services for USENET are Alta Vista (simply select 'USENET') Infoseek at,

http://www.infoseek.com

or Excite at,

http://www.excite.com

In most cases, you can restrict your search to a specific group such as comp.dsp or sci.electronics.design. ■

About the author

Jason McDonald is an Internet and Web consultant, working in Fremont, California. He has a Ph.D. from the University of California, Berkeley, and has written for numerous trade magazines. He can be reached by email jasonm@violet.berkeley.edu or at Tel. 510-713-9493.

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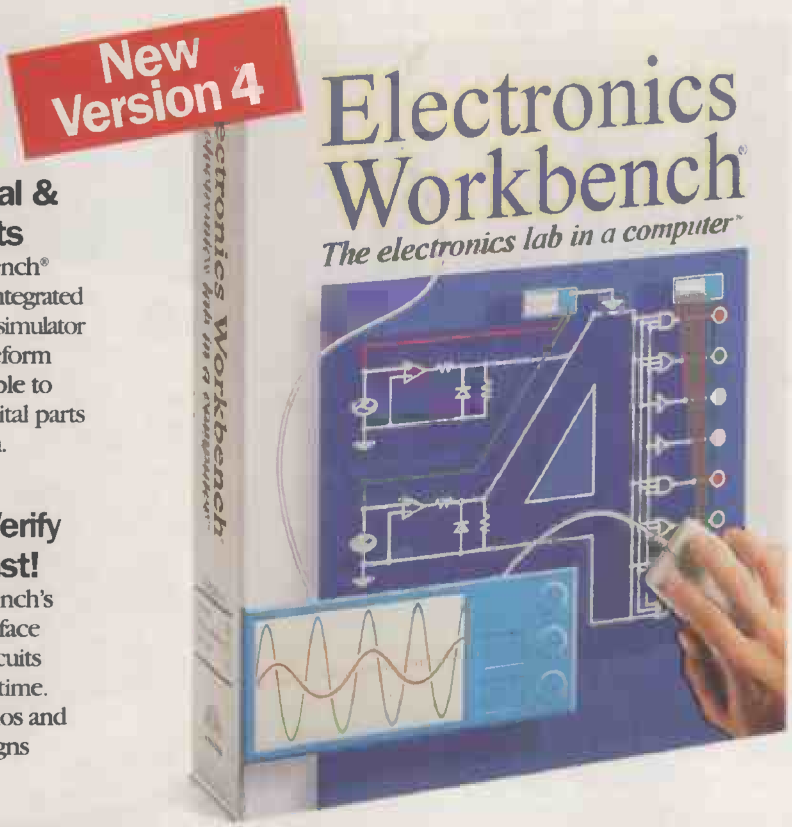

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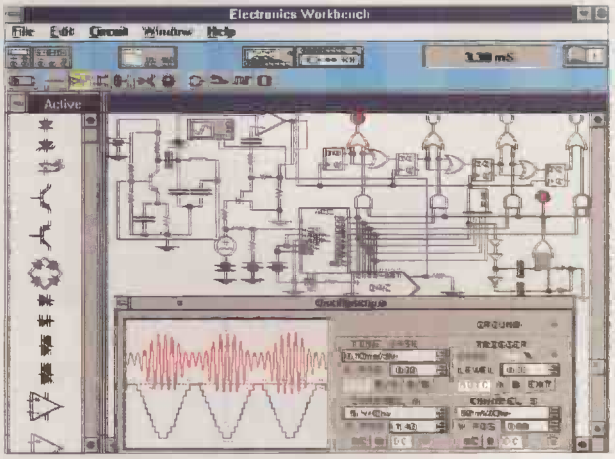

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CIRCLE NO. 114 ON REPLY CARD

A new variable *capacitor?*

Martin Grove proposes a variable capacitor that could form the basis of a variety of transducers – including a truly digitally driven loudspeaker.

Reading an overview article on digital audio, made it evident to me that digital transduction at both ends of the audio chain is still a problem. This provoked some thought, especially as far as sound reproduction was concerned. While pulse-width modulation, pwm, appears well suited to electromagnetic loudspeakers, power output circuitry is still required and does not appear to be purely digital.

In order to deal with parallel digital data, electrostatic speakers seemed to offer the best possibility of a solution, provided that the capacitance of the speaker could be altered by digital means. This implied that the surface of the plates be divided into compartments that could activated independently according to the magnitude of the byte, the final capacitance depending on the sum of the active compartments. Since the capacitance of a capacitor is expressed by

$$C=\frac{\varepsilon A}{d}$$

Physical dimensions of the capacitor would be fixed, so the only remaining variable would be the dielectric medium. If some medium could be found which would instantaneously change its dielectric properties in response to an electric current, a solution would become feasible.

At this point, inspiration struck. Two long strips of aluminium foil were attached diametrically opposite one another to a fluorescent lighting tube, held tightly with rubber bands. Leads were connected from each of the plates of the capacitor thus formed, to a capacitance measuring multimeter. The resting capacitance was measured before the tube was switched on, at which point I noticed an instantaneous increase of capacitance – by a factor of more than ten. In order to exclude possible ac interference, I repeated the procedure with a dc supply loaded by an incandescent lamp. With great delight, I noticed an even greater increase.

A better prototype

Following many abortive attempts at trying to manufacture a flat glass envelope with multiple gas discharge elements, I abandoned further experiments

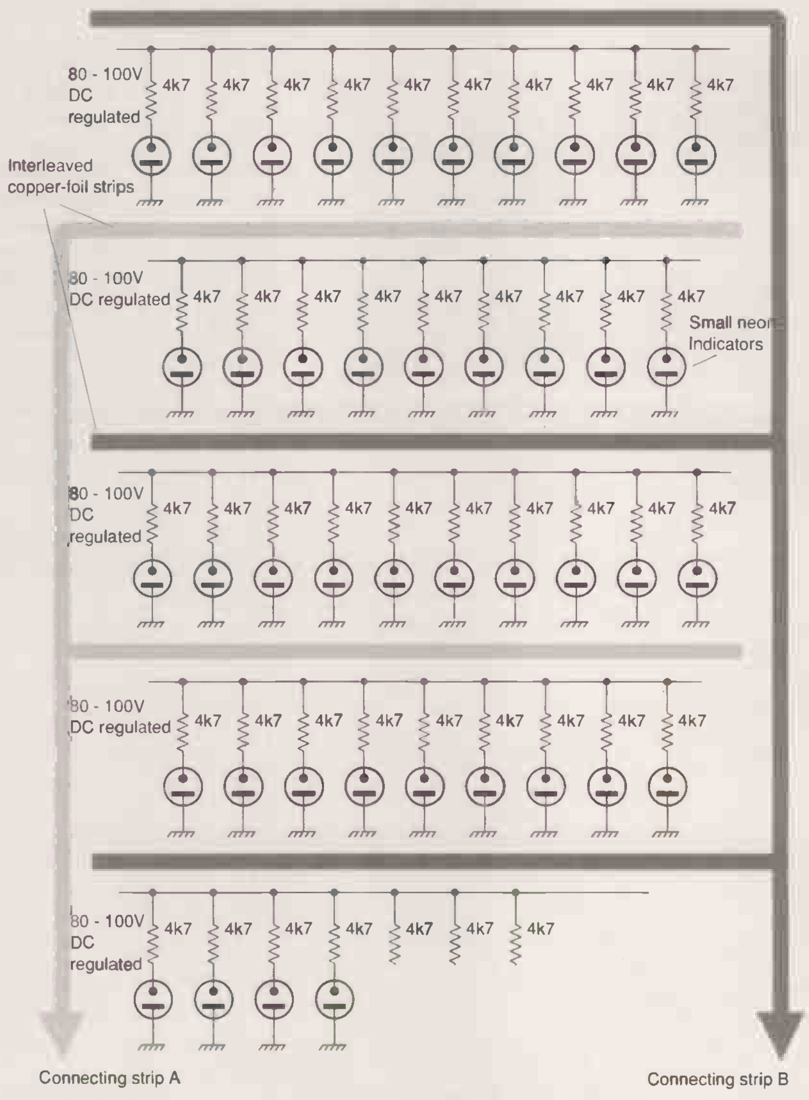


Fig. 1. In the prototype digital capacitor miniature gas discharge indicator tubes were switched to alter the capacitance between interleaved strips of copper foil. Capacitor elements were paralleled via connecting strips to alternate leaves.

until a job offer necessitated a translocation to England. With the greater availability of electronic resources here, I resumed my investigations. This work culminated in a prototype digital capacitor, illustrated in **Fig. 1**.

Figures 2 and **3** show the physical structure of the capacitor. In its resting state the capacitor recorded a reading of approximately 90pF on a digital multimeter.

I used the capacitor as a timing element in a *555* astable multivibrator circuit and took a series of measurements. As you will see from **Graph 1**, the change in apparent capacitance is clear. In addition, I repeated the experiment, measuring the reactance with a square wave. Results are shown in **Graph 2**.

Energy required to produce this effect is almost certainly provided by the dielectric phenomenon, as can readily be shown by simply connecting the oscilloscope probes across the uncharged and isolated capacitor. By switching the tubes on and off rapidly with a square wave, a replica waveform of about 35V appears at the terminals. This effect is amplified by charging the capacitor. There is no dc component.

Although the material was very basic and the test equipment anything but professional, it appears that the plasma envelope does indeed enhance the dielectric properties. I could find no mention of this effect in standard physics texts. In my prototype, the gas envelope occupied only a small percentage of the volume between the plates, of less than 10%. By miniaturising the device to obtain the closest possible packing density, an enhancement by a factor of ten should be possible.

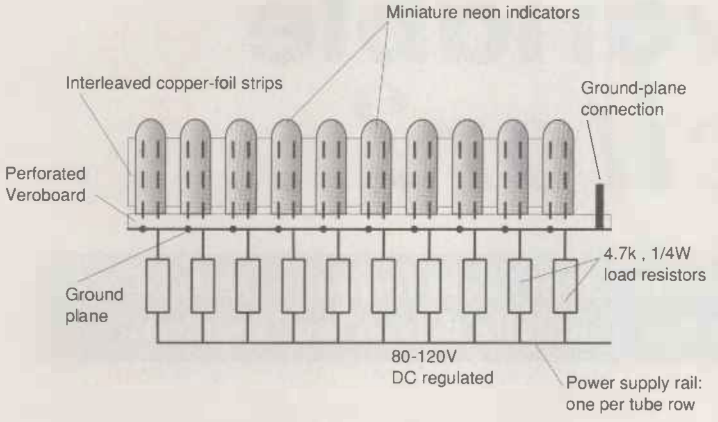


Fig. 2. Side view of the digital capacitor showing how the indicator tubes connect on one side to the Veroboard track and on the other, through the board, to current limiting resistors. There is one power supply rail per row of tubes.

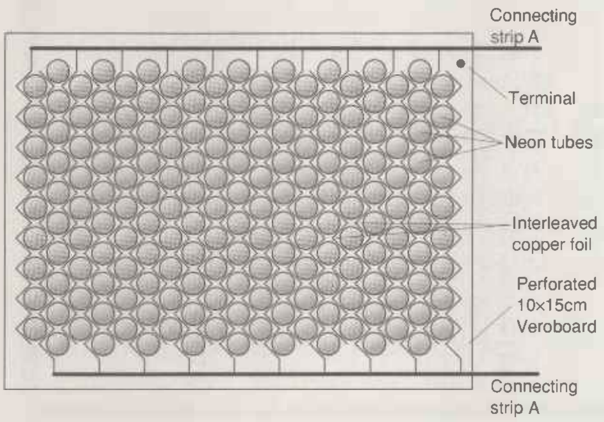


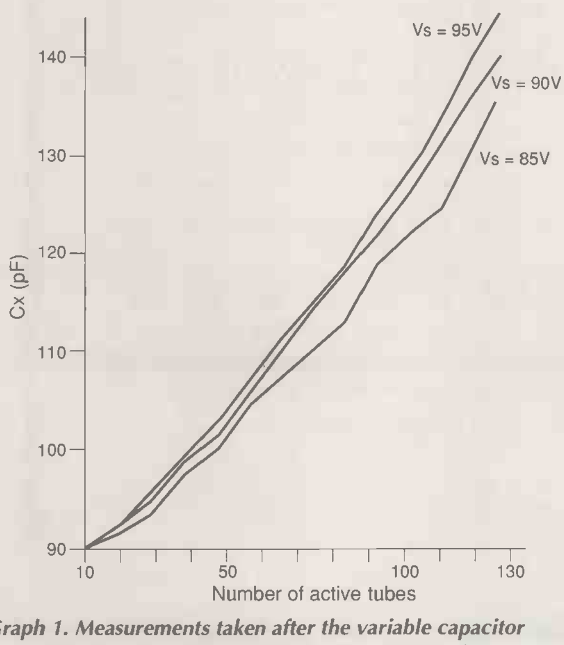
Fig. 3. Plan view of the digital capacitor's structure clearly shows how the copper strip sets form capacitor plates, between which are the neon indicators. Capacitance increases stepwise as each row of neons strikes.

A practicable digital capacitor

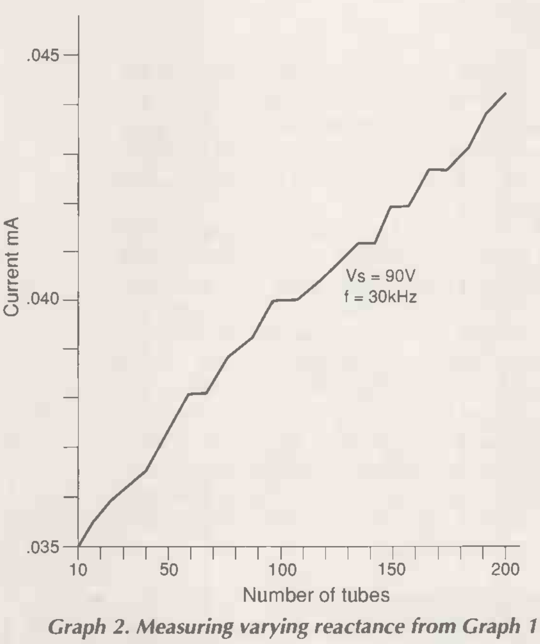
Assuming a resting dielectric constant similar to the prototype and a diameter of 1mm per tube, a capacitor containing 65536 tubes would measure 256 by 256mm and have a resting capacitance of around 25nF. Whether a practical digital loudspeaker could be realised from this remains to be seen and will require further work.

Considering the intuitively appropriate nature of this dielectric enhancing phenomenon, it would be unlikely that it has remained unreported – especially taking into account that fact that this experiment could have been conducted a hundred years ago. Your comments would be very welcome.

I would like to express my thanks to Dr. M. Divine of Cranfield University, for his kind assistance. ■



Graph 1. Measurements taken after the variable capacitor was substituted for a timing capacitor in a 555 astable multivibrator.



Graph 2. Measuring varying reactance from Graph 1 with a square wave.

Design lab bytes

Tina is a pc-based circuit design lab with virtual instrumentation including scope and spectrum analyser. Until now it has bubbled under as a DOS package, but Clive Ousbey believes that the new Windows version poses a serious threat to the competition.

Recent years have seen a greater use of simulators as an aid to electronic design. This has been due largely to easier to use graphically driven systems. While being powerful in experienced hands, older style netlist entry types of simulator where not user friendly. On the other hand, the early graphics-based programs that *were* easier to use were either expensive 'professional' systems or lacked much power or flexibility.

TINA for Windows, version 4, from DesignSoft, is the latest simulator package attempting to close this gap. An acronym for Toolkit for Interactive Network Analysis, *TINA* is a Hungarian product that has existed in a DOS form for several years. Until now, it has had quite a low profile in the UK. In order to address these problems, the makers have appointed a new distributor to market the significantly enhanced new Windows version.

TINA's graphical interface is similar in style to its main competitor *Electronics Workbench*, but offers a wider variety of output presentation, greater flexibility, optional instrumentation hardware and more extensive analysis options. The latter gives it a functionality more in line with something like PSpice.

Circuit capture facilities

The schematic editor is normally used for working on a circuit for analysis. The alternative is to import a PSpice type netlist: exporting is also a possibility. *TINA* has an editor which is easy to use and operates as you would expect a Windows program to work.

Component symbols are selected from tabbed groups on the tool bar. In some cases, a generic symbol is not appropriate. Clicking the symbol icon instead opens a list of related parts to choose from. The symbol can be rotated or mirrored and its properties modified, either while placing or at any time thereafter. Various parameters relating to the component can be edited – value or tolerance for example – via the properties window.

In addition to the usual components, there are various others to aid building and simulating a circuit. These include voltage sources, jumpers allowing separate parts of the circuit to be connected by a signal name and the ground symbol that must always be present.

Input and output can be slightly confusing due to the variety of ways it can be achieved, depending on the type of analysis required. For measuring basic signal input and output, there are voltage or current generators, various meters and voltage test pins available. A selection of signal types can be applied to the input – including the option of a user-defined waveform.

Virtual function and digital signal generators are available to provide stimulus. For more complex analysis, a

Tina's vital statistics

Editors
Schematic and netlist editors
Text and equation editors with interpreter

Presentation
Bode plots and Nyquist diagrams
Transient response plots and digital waveforms
Linear or log scales

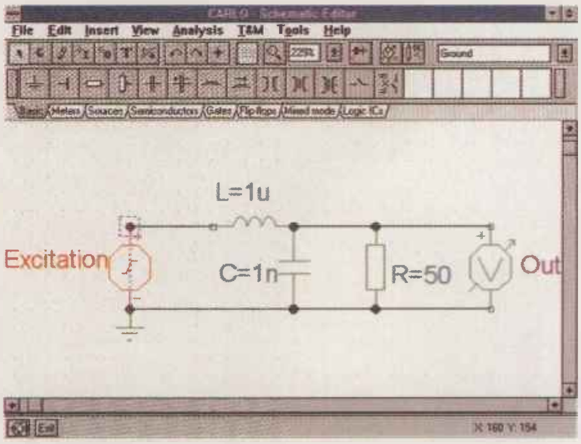
Analysis
Fourier
DC, with automatic circuit optimisation
AC, with complex *V*, *I*, *Z* and power analysis
Transient analysis for analogue *and* mixed mode
Symbolic analysis gives closed form expressions

Simulation
Analogue, digital and mixed-mode

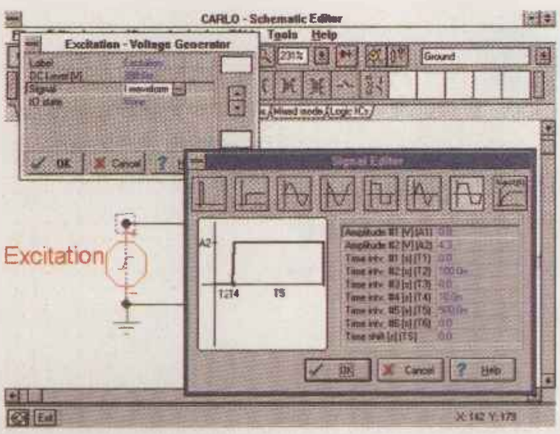
Stimulation
Standard and user-defined circuit excitation

Virtual instruments
Signal analyser
Storage oscilloscope
Function generator
Logic analyser
Digital multimeter
Digital signal generator

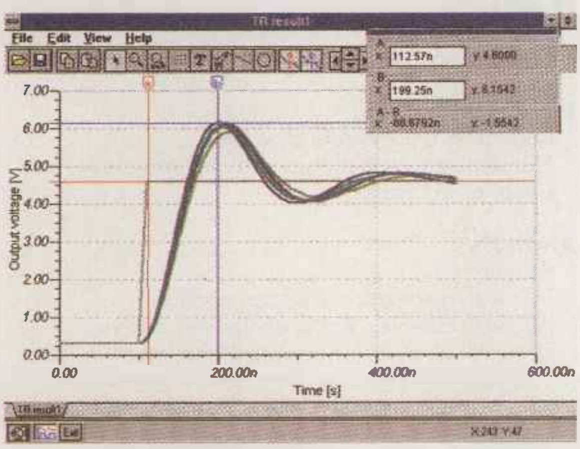
Hardware options
PC measurement expansion card
Experimenter box with plug-ins



Main editing window with example RLC circuit.



Setting up non-ideal step excitation.



Output graph showing result of transient analysis with Monte Carlo tolerance sweeping (5 runs only), the step input and the cursors can also be seen.

special input, and or output, need to be added.

To enhance presentations, teaching materials or other literature, text – including mathematical expressions – may be added to the circuit diagram. Pressing F9 automatically inserts the component value as a label on the diagram. Alternatively, the component label can be entered manually and customised.

Symbols are connected with the wiring tool and this is one of TINA's weaker features. While better than some packages, when first wiring up a circuit in the usual way, care is needed as it is reasonably easy to fail to connect things up.

DesignSoft is currently working on improvements in this area which I am told will be ready by the time the production version becomes available. Even so, using the mouse in conjunction with 'hot keys' makes wiring much easier. Also, if a circuit element is not connected, it is highlighted before analysis, and pressing DEL gets rid of any extra wires.

Wiring is made up of vertical or horizontal segments. These can start or end on any grid point – not just at pins. Segment lengths can be changed but if a mistake is made it is probably easier to delete the original and add a new segment of wire. This also means that if a component is moved the wiring stays put, unless all the wiring segments are selected as well. Moved components then have to be reconnected and the original wires deleted.

The above problem is only relevant when one component is moved. You can move whole circuits or circuit segments and the wires stay connected. DesignSoft says it is currently working on an upgrade involving rubber banding, which will solve this inelegance.

With the exception of the virtual instruments, almost all analysis is controlled from the menu. The usual Windows type dialogue/control boxes make it reasonably easy.

Analyses include mixed-mode

There are three basic types of analysis – namely digital, analogue and mixed mode. For a purely digital circuit you can choose whether or not to look at delays, but all high/low transitions are considered ideal – i.e. almost instantaneous. In analogue mode, a full simulation takes place and in mixed mode, propagation delays of the digital parts is also taken into account.

A digital-only circuit can optionally be run in mixed mode. In mixed-mode analysis, again you can choose to include delays, but in this case, rise times and slopes are calculated. In analogue modes, options include dc, ac, transient and noise. Having run a transient analysis, a Fourier series or spectrum can be obtained via the process menu.

Particular component parameters can be swept to determine their effect on a circuit. The component can also be optimised to a target or maximum/minimum value. Component tolerances can also be varied using various distributions or worst case. This is useful for seeing how sensitive a circuit will be to real component variations.

The analysis can be run at any desired temperature or swept over a range of temperatures.There is also the option of running a PSpice analysis by first generating a netlist.

Output facilities

Standard analysis output is a graph, or set of graphs, in a new window. There is also the option of using a virtual multimeter, oscilloscope, signal and logic analyser.

The graphs windows allows the placing of a moveable cursor that can track any curve to obtain the x and y values. To aid presentation, etc lines and circles can be drawn on the graph as well as text and labelling. The graphs can be rescaled and the annotation of axes can be changed before printing.

Libraries

A library catalogue compiler – running in DOS only – is available, allowing users to add their own parts into the library. This was not included in the review release.

The method as described in the manual uses a text file that contains the various component modelling details as well as symbol drawing directives. This is compiled into the binary catalogue that *TINA* uses.

Additional features include matching hardware

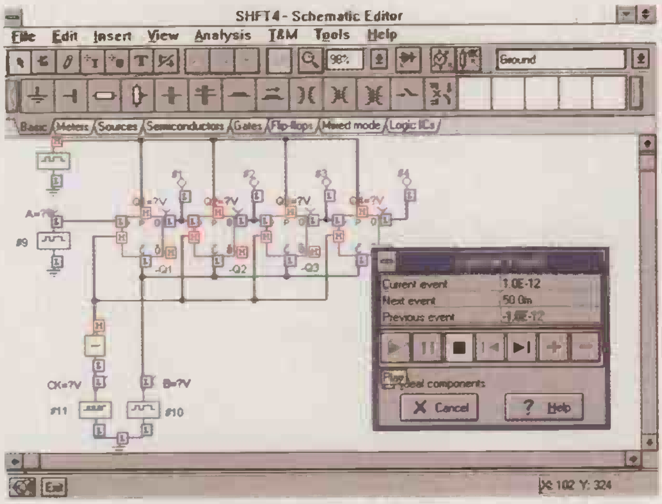
A mathematical interpreter is provided to allow the entry and evaluation of expressions and equations. Other uses include plotting results and defining arbitrary signals for circuit stimulation.

As already mentioned there are also features included that can assist in the teaching of electronics. There are modes for training and examination that provide for students' exercises pre-assigned by a lecturer. Fault simulation is also a useful feature for the teaching environment.

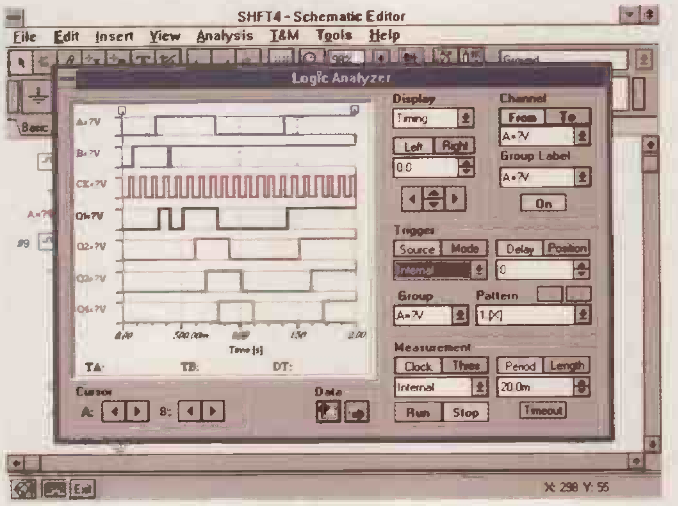
Matching hardware, for use with *TINA*, is available but was not reviewed. A plug-in instrumentation *PC* card – known as *TINAlab* – provides a multimeter, oscilloscope and signal generator under *TINA*'s control. User interfacing for these features is provided by the virtual instruments. This allows a real circuit to be built and directly compared with the simulated version.

Further available hardware includes an experimenter box with a breadboarding area that connects to *TINAlab*. This also has a slot for plug-in modules such as a fault insertion card or a digital measurement card.

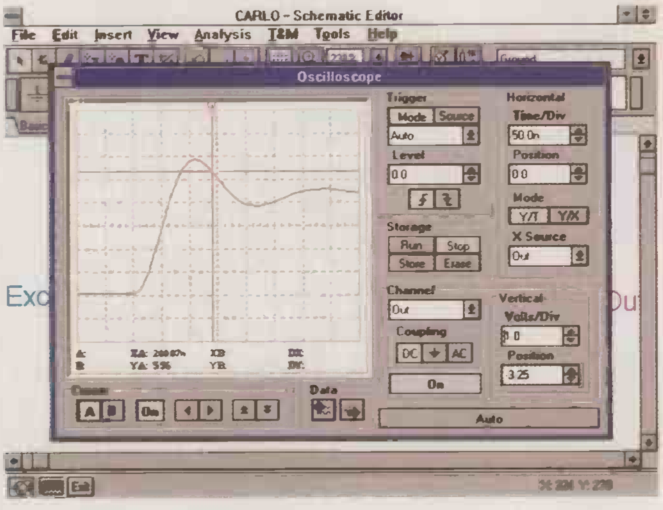
This feature of matching hardware for real world interfacing is something quite rare in simulators and provides new scope to their use.



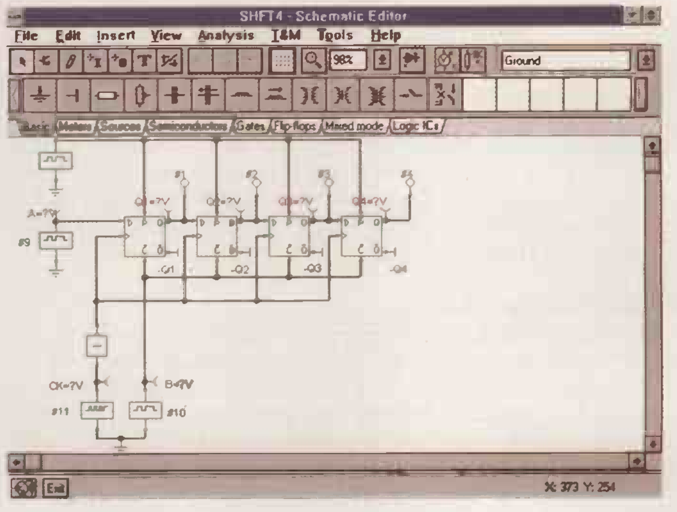
Four-stage shift register showing logic states of nodes and step-by-step analysis control control.



Virtual logic analyser showing resulting states of shift register circuit.



Virtual oscilloscope showing response of RLC circuit.



4 stage shift register.

Capabilities, requirements and manuals

TINA's capacity is stated as being 1000 components and 2000 nodes, dependent on memory. But the actual relationship between capacity and memory size is not given. The minimum specification for the package is a 386SX running, Windows 3.1.

Generally, the manuals are good, but some areas are not explained very well. For example, the different methods of input and output are not made clear. On the other hand, good attention is paid to the various components and to the simulator itself. Appendices covering the library compiler, interpreter, additional hardware and the educational aspects are also good.

I found some inconsistency in the getting started section. The screen shots did not always show what had been described in the text. For example, a meter symbol that has been placed on a circuit as instructed in the text is different from that shown in the screen shot.

In summary

Overall this is an excellent package, versatile, value for money and easy to use. It poses a serious threat to the competition. TINA scores particularly well with the ability to take into account tolerances, do parameter sweeping and being able to define new symbols as well as simulation models.

The features to aid training and presentations are very good and the additional instrumentation hardware could be very useful.

The supplier has indicated various forthcoming features which – if they don't fall into the everlasting 'coming real soon' category of upgrades – will usefully enhance *TINA*.

Top of the list must be an interface to a pcb layout tool. This is a natural progression as what often happens is that a simulated circuit has to be re-entered into the pcb system before layout can commence. Improvement to the schematic editor giving 'rubber banding' of the connections is also promised.

Macros or the ability to make sub-circuit blocks from a circuit to give a form of hierarchical design could make the handling of larger circuits easier.

Although not mentioned, the ability to have component parameters visible or not would be very useful instead of having to enter them separately as a text label or automatically via the F9 function key.

Beyond these features. what would make a very interesting application would be the ability to use the simulator itself as a sub-circuit. That is by using the hardware to take input from and provide output to the real world *TINA* would act as a virtual breadboard. ■

Free circuit design software

TINA for Windows

This month's cover disk* is a working, interactive version of TINA for Windows. Newly launched, this comprehensive package is an electronics toolkit integrating all the functions needed for the design, development and test of electronic circuits. TINA makes it easier and faster to simulate circuits with realistic characteristics.

TINA comprises a software simulation and analysis package, together with a complete range of 'virtual' test and measurement instruments for testing design theories as well as breadboards, prototypes or any other electronic product.

The demonstration version of TINA presented free with this issue of *Electronics World* allows circuits of any size to be constructed but analysis only works on a limited number of nodes. Save and print facilities are also disabled.

PSpice compatibility

Unlike many circuit design systems, TINA can save your designs as an industry standard PSpice format netlist – which means that design concepts are based on the specifications of actual components. This makes simulation more realistic and the identification of faults easier. It also simplifies 'what if' questions, and allows different components to be tested quickly, easily and without the need to build breadboards. This obviously saves considerable time, as well as the cost of components.

Comprising all the necessary hardware and software, Tina is a complete system which allows digital, analogue or mixed-mode circuits to be simulated. Tina is also a powerful analytical tool and can perform AC, DC or transient analysis as well as noise, tolerance and Fourier analysis.

Comprehensive library

A comprehensive library of components contains power supplies, resistors, capacitors, inductors, amplifiers, switches, etc. Using familiar Windows-style commends, these are simply selected, dragged and dropped into the desired circuit diagram. Component values can then be changed to create and test the feasibility of the ideal circuit.

The library features digital components, including a large selection of TTL and CMOS standard devices.

Low price

Tina, is very cost effective. A single copy of the software costs only £299 and a 20-user site licence is only £1,800, excluding hardware. Special discounts are available for educational establishments.

For further information contact: Tandem Technology Limited, Breadbare Barns, Clay Lane, Chichester, West Sussex, PO18 8DJ, telephone: 01243 576121 fax: 01243 576119, e-mail 101626.3234@compuserv.com.

*Available to UK readers only.

Virtual instruments – supplied with the Tina circuit design tool is a complete range of test and measurement 'virtual instruments' – including a function generator, multimeter, power supply and oscilloscope. These are used to analyse test circuit designs as well as providing real time test and measurement of actual circuits, prototypes and breadboards. The benefit of these 'virtual' instruments is that they operate via the PC. This makes it easy to incorporate measurement values into calculations and analyses.

£100 voucher

Until 4 October, this voucher is worth £100 off TINA's normal price of £299 excluding VAT and delivery. Simply send this voucher together with £237.93 – fully inclusive – to Tandem Technology Limited, Breadbare Barns, Clay Lane, Chichester, West Sussex, PO18 8DJ. Telephone: 01243 576121 fax: 01243 576119, e-mail 101626.3234@compuserv.com.

Loading your free software

Full instructions on loading the demonstration version of Tina are given in the README.TXT file on the disk. This file is accessed by inserting the disk in drive A and double-clicking on the file under Windows' File Manager. Once the software is installed, this read-me file appears as a Windows icon.

HART

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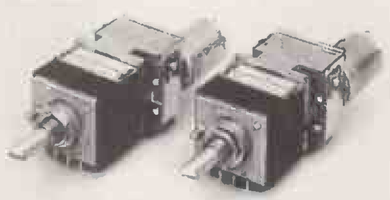

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Prescale to 1GHz

Nick Wheeler describes a low-cost prescaler designed to extend the useful range of a frequency counter to just over 1GHz.

Table 1. On the SA701 prescaler, logic levels on two pins determine the division ratio.

Divisor	SW	MC
128	Low	High
129	Low	Low
64	High	High
65	High	Low

Until recently, digital frequency meters with gigahertz capability were confined to costly laboratory models, the more affordable types generally extending up to, typically, 200MHz. Some eight years ago, and possibly even earlier, it was possible to obtain gigahertz prescalers based on emitter-coupled-logic to extend the range of these inexpensive instruments – many of which must still be in use.

While ecl-based gigahertz prescalers have been around for years they have either been expensive or only obtainable in production quantities. One of the earliest was the Philips *SAB456*, used in a tv tuner for digital frequency control, but this was discontinued in eight-pin DIL form some years ago.

More recently, the developing portable phone market has caused several manufacturers, including Philips, to produce useful low-cost parts. I used the quadruple-modulus *SA701*, which is intended for 64/65 and 128/129 division. This device is is obtainable in small quantities from RS and Macro. Note that its part number for the DIL version has an 'N' suffix.

Applying the GHz prescaler

With the exception of the Plessey *SP8680*, which is a 650MHz part, ecl prescalers have ecl output levels and limited output drive capability into capacitive loads. **Figure 1** shows how these problems are overcome.

Emitter follower Tr_1 imposes negligible load on the prescaler and the diode clamp ensures that there is a big enough positive excursion at the base of Tr_2 to bottom it. Collector swing of Tr_2 is enough to drive the high-speed c-mos divider chain which follows. Pins 3 (SW) and 6 (MC) determine the division ratio, as in the **Table 1**.

For this application, the division ratio needed is 64, so both SW and MC are high. To avoid having to use a calculator to determine

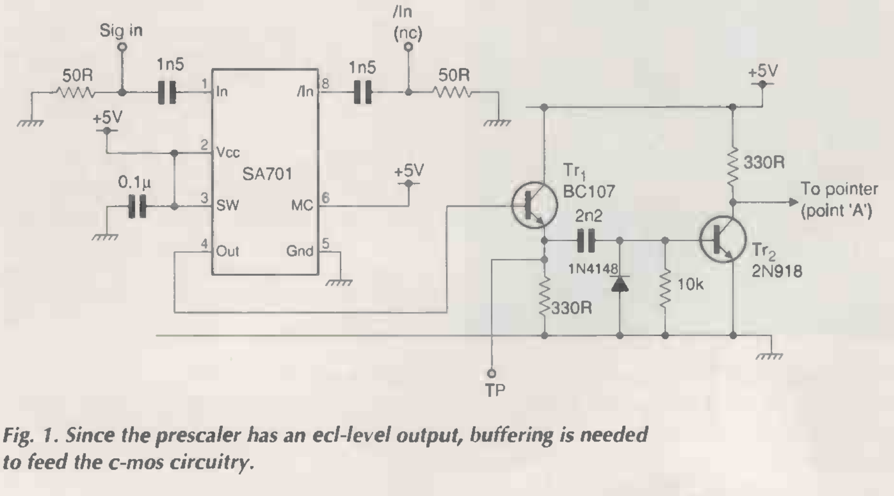

Fig. 1. Since the prescaler has an ecl-level output, buffering is needed to feed the c-mos circuitry.

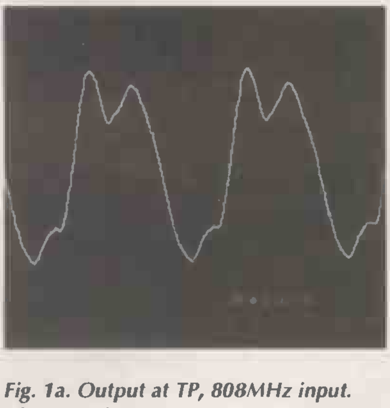

Fig. 1a. Output at TP, 808MHz input. Absence of noise or jitter characterises correct pre-scaler operation.

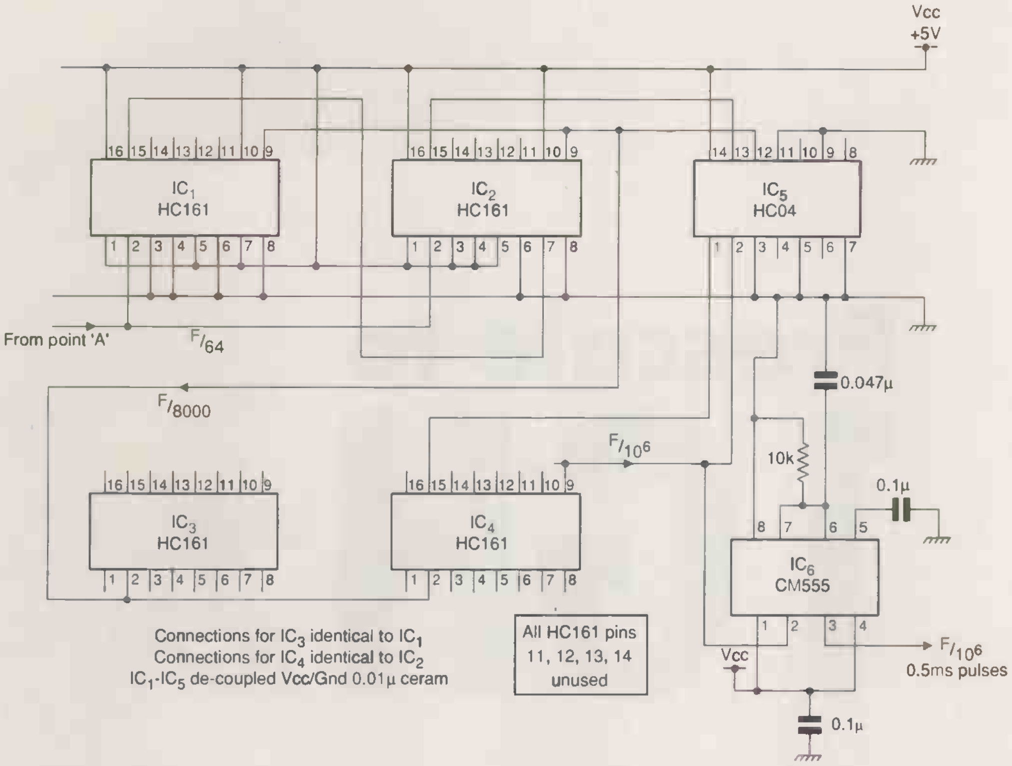

Fig. 2. Using this configuration to divide by 125 avoids glitch problems. Narrow pulses output by the divider chain could cause erratic readings so a pulse-stretching 555 is added.

the frequency being measured, the overall division ratio must be a multiple of ten. There is a way round this but it usually involves having a special crystal made for your frequency counter. Suppose the counter has provision for an external frequency standard. This will certainly be a multiple of 1MHz. However, if an external source which is an appropriate multiple of 976.5625kHz is applied, then a binary divider chain of ten stages will give a readout of kilohertz for gigahertz – which is manageable.

Fortunately, division by 2^6 (64), followed by 5^6 (15625) equates to division by 10^6. This is done by dividing twice by 125.

Dividing by 125

Figure 2 shows the divider, taken from ref. 1.

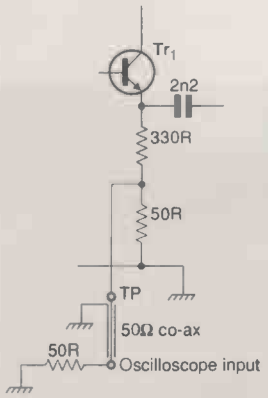

Fig. 3. To check for correct operation of the prescaler, care must be taken with loading and termination.

The timing diagram for this rather unusual ratio is complicated. It is fortunate that this ratio is not one of those which suffer from incurable glitches. Note that the quirky timing of this circuit calls for 116 to be preloaded. Follow the circuit diagram and you will arrive at the desired result.

The circuit works without problems from 20MHz down to 1MHz, representing an input signal frequency range of 1.28GHz down to 64MHz. Division in two cascaded blocks of 125 is essential as there is a possible glitch problem if three or more *HC161*s are cascaded. Texas Instruments' manual explains this.

Unlike binary division, which yields successive outputs of close to unity mark-space ratio, each of the two cascaded divide-by-125 stages yields a signal of 1:124 mark-space ratio. Thus an input signal of 1GHz produces an output of 1kHz, but with a pulse width of 8μs. Some inexpensive frequency counters respond erratically to waveforms of this sort, so the c-mos *555* monostable is included to stretch the pulses to around 0.5ms.

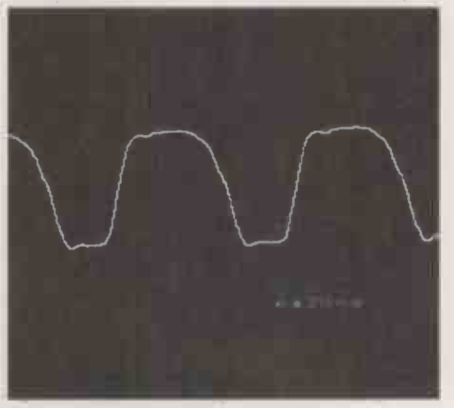

Fig. 3a. Waveform at TP viewed in properly terminated system. Absence of noise and jitter characterises correct prescaler operation. Test frequency 808MHz.

Implementation problems

It appears to be a characteristic of ecl prescalers that if no input, or too small an input, is connected, oscillation occurs around the upper frequency limit of the device. Such oscillation can be detected at the emitter of Tr_1 which, fed to a suitable rf connector, forms the output. The oscillatory mode has random time-jitter and is quite different in appearance from the waveform observable when division is occurring properly, **Fig. 3**.

This test point has another important function. Because the signal frequency is divided by 10^6 long gate times are required to make accurate frequency measurements. At 1GHz, and with 100 seconds of gate time, the display is only to five decimal places or 100kHz. Often this will be unimportant. Where greater accuracy or a quicker response is needed, the divide-by-64 point gives results at once and to the full accuracy of the frequency meter. But you will need a calculator to work out the real frequency being read.

Best results are obtained at the upper frequency end if the prescaler is mounted on PTFE based pcb, but much the same effect can be achieved by preceding the prescaler with a monolithic microwave IC such as the *MAR 6*.

Measurements at gigahertz frequencies can only be conducted remotely, and in this case remotely means at distances of more than a few cm, via properly matched transmission lines. You can seen from Fig. 1 that this is a 50Ω system.

For remote measurements, where the imposition of a 50Ω load is unacceptable, an approach on the lines of ref. 2 is appropriate. This type of circuitry still has gain well beyond 1GHz, though it has fallen off a lot compared with the flat frequency performance up to 130MHz. ■

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1. Lancaster, D., Sam's TTL Cookbook, 1988.
2. Wheeler, N., 130MHz probe, *EW+WW* Aug 1995.

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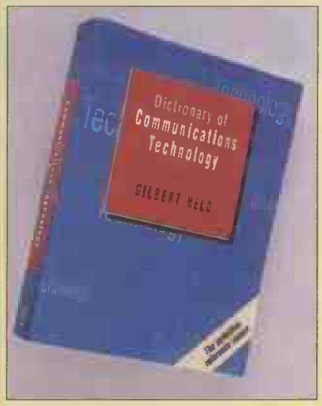

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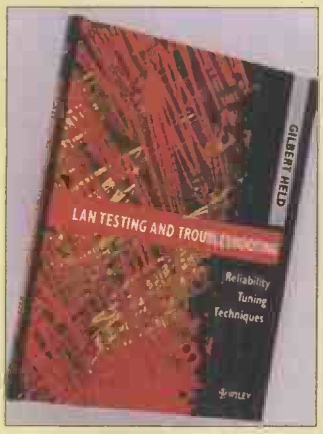

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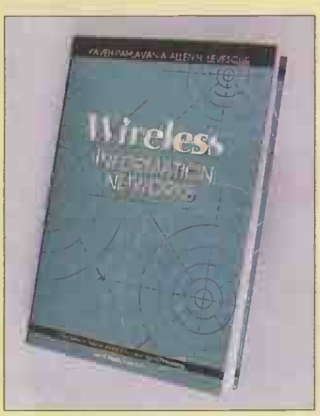

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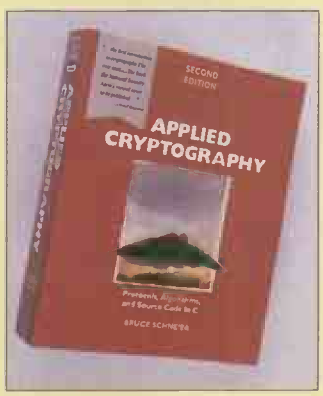

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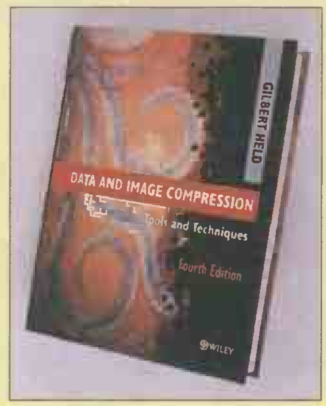

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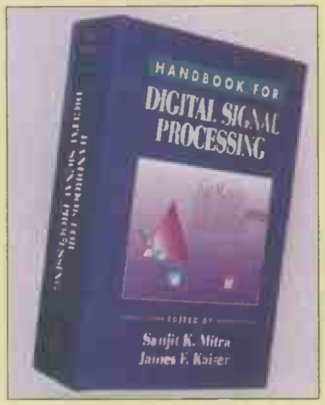

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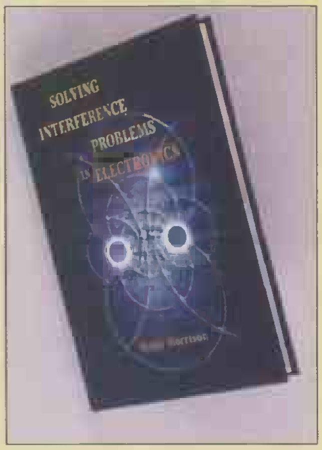

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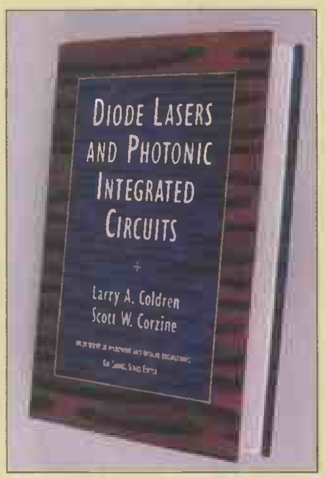

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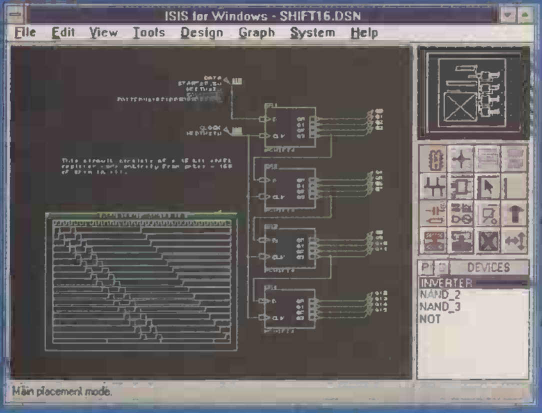

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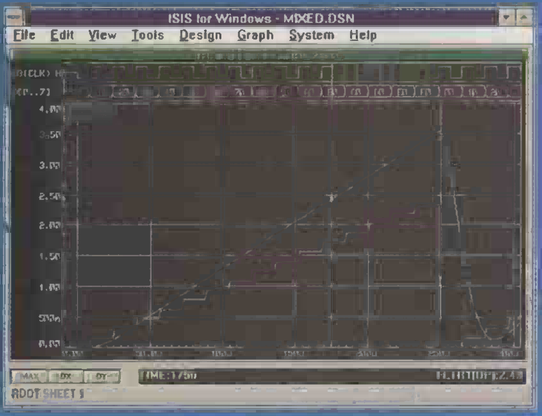

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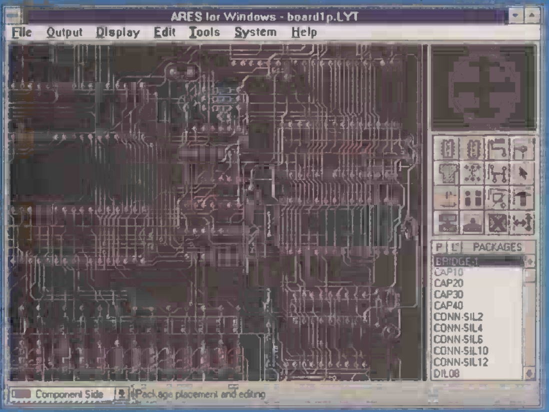

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Light update

Derek Robinson* has been looking at how Texas' light sensors are evolving. Line imagers have been added to the product range and there's emphasis on easier interfacing with increased performance.

*Derek is with TI in Freising, Germany

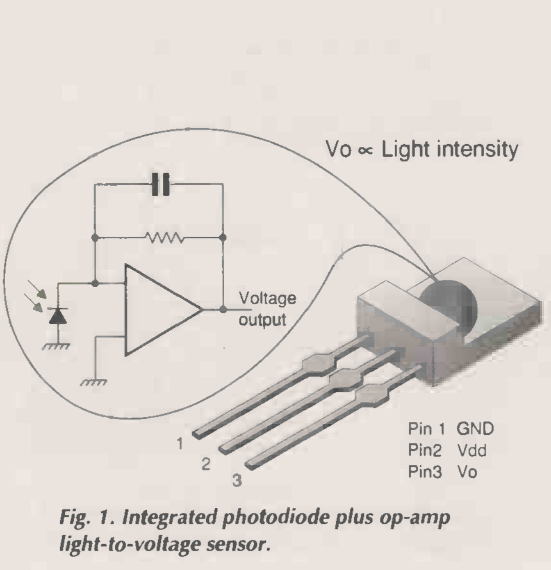


Fig. 1. Integrated photodiode plus op-amp light-to-voltage sensor.

With the predominance of digital systems in measurement and control applications, comes the increased importance of analogue-to-digital conversion, in order to interface real-world analogue signals to the system.

Light is such a real-world signal that is often measured either directly or used as an indicator of some other quantity. Most light-sensing elements convert light to an analogue signal in the form of a current or voltage, which must be further amplified and converted to a digital signal in order to be useful in such a system.

Important considerations in the conversion process are dynamic range, resolution, linearity and noise. In former times, a discrete light sensor was followed by some form of analogue signal conditioning circuitry, before being applied to an analogue-to-digital converter, which effectively interfaced it to a digital system. Now, a wide range of intelligent opto sensors are available, combining sensor and signal conditioning in a single device. Typical of these are light-to-voltage converters, light-to-frequency converters and integrated line imagers.

Light-to-voltage converters

Good examples of light-to-voltage converters are the *TSL25x* range of single-supply visible-light sensors, Fig. 1. These combine a photodiode and an op-amp connected as a transresistance amplifier, complete with frequency compensation for stability. The photodiode is used without reverse bias, and operates into a virtual earth. This results in a negligible voltage across the diode, minimising dark current.

Figure 2a) shows the sensitivity of the three members of the family to illumination on the optical axis, and **b)** shows the relative sensitivity as a function of angular displacement from it. A feature of the *TSL25x* family is a very low temperature coefficient of output voltage V_o – typically 1mV/°C. This is because the internal feedback resistor, namely 16MΩ, 8MΩ or 2MΩ for the –250, –251 or –252 types, is polycrystaline silicon. This material has a temperature coefficient which compensates for the temperature coefficient of the photo-diode.

The *TSL26x* range of sensors designed for infrared applications share the same package and circuit arrangement. **Figure 3a)** shows the on-axis sensitivity of the three members of the family – the angular displacement response is as Fig. 2b). Figure **3b)** compares the spectral response of the *TSL250* and *–260* families.

A selection of useful application circuits, which are equally applicable to the *TSL25x* family[1], is included in the data sheet for the *TSL26x* range of devices.

Light-to-frequency converter

The light-to-frequency converter is a natural solution to the problem of light intensity conversion and measurement, providing many benefits over other techniques. Light intensity can vary over many orders of magnitude, and this complicates the problem of maintaining resolution and signal-to-noise ratio over a wide input range.

Converting the light intensity to a frequency overcomes limitations imposed on dynamic range by supply voltage, noise, and a-to-d resolution. Since the conversion is performed on chip, effects of external interference such as noise and leakage currents are minimised. The resulting noise-immune frequency output is easily transmitted even from remote locations to other parts of the system.

Since the data is in serial form, interface requirements can be minimised to a single microcontroller port, counter input or interrupt line. This saves the cost of an analogue-to-digital converter. Isolation is easily accomplished with optical couplers or transformers.

The conversion process is completed by counting the frequency to the desired resolution, or period timing may be used for faster data acquisition. Integration of the signal can be performed in order to eliminate low frequency (such as 50 or 60Hz) interference, or to measure long-term exposure.

The *TSL220* is a high-sensitivity, high-resolution single-supply light-to-frequency converter. Its dynamic range is 118dB, and it has a convenient c-mos-compatible output, all housed in a clear plastic eight-pin DIL package.

Figure 4a) shows a block diagram of the device[2]. Output pulse width is determined by a single external capacitor, and the frequency of the output pulse train determined by the capacitor and the incident light intensity, as in Fig. **4b)**.

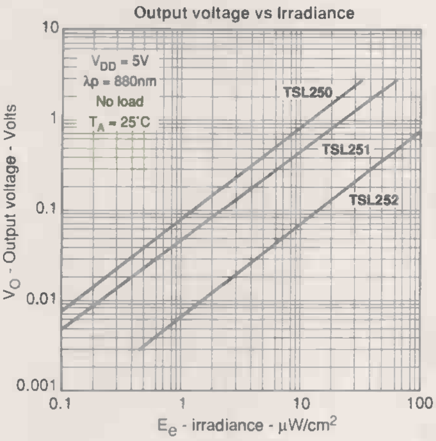
Figure **4c)** shows the output frequency as a function of the ambient temperature, normalised to that at 25°C. This indicates a need for compensation which can be easily looked after in the subsequent digital-signal processing, with the aid of a temperature sensor. Spectral response of the device is very similar to that of the *TSL25X* range shown in Fig. 3b), extending a little further into the infra-red but not quite so far into the ultra-violet.

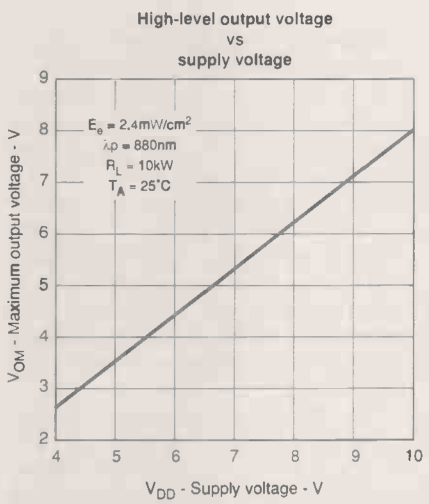
Sensors featuring frequency output

The *TSL235* and *245* are visible-light and infra-red sensors, packaged in the same three-pin encapsulations as the *TSL25x* and *26x* ranges. However, they produce a frequency output in place of a voltage output. **Figure 5a)** shows output frequency versus incident illumination for the *TSL235*, under the conditions shown.

Figure **5b)** shows how the tempco of output frequency varies with the wavelength of the incident radiation. Note the very low temperature coefficient at wavelengths shorter than 700nm. The *TSL245* is basically the same device as the *235*, but packaged in an encapsulation material which is transparent in the infra-red but opaque to visible light.

The *TSL230* programmable light-to-frequency converter also consists of a monolithic silicon photodiode and a current-to-fre-





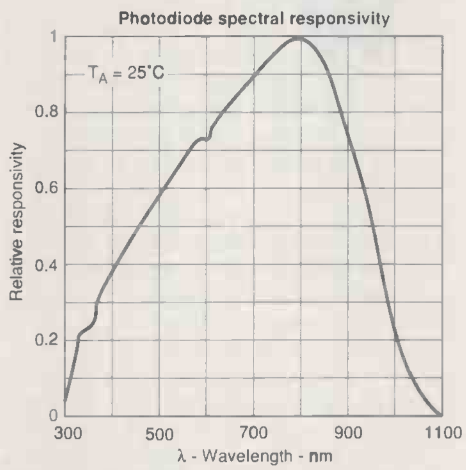


Fig. 2a). Output voltage as a function of incident illumination for the TSL25x series devices, top, with curves for maximum o/p against supply, bottom left, and spectral responsivity, right.

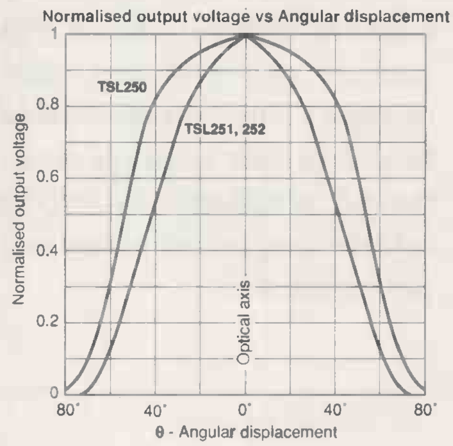


Fig. 2b). Angular response of the TSL25x devices.

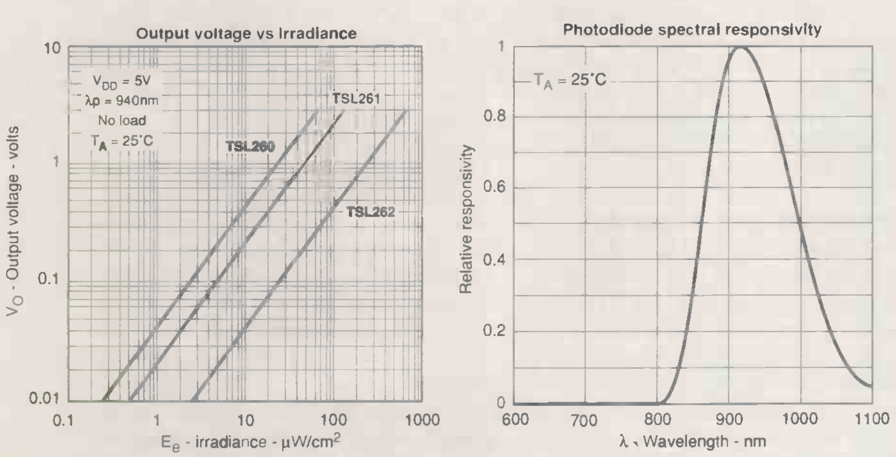


Fig. 3a). Output voltage as a function of incident illumination for the TSL26x series devices, left, together with spectral response, right.

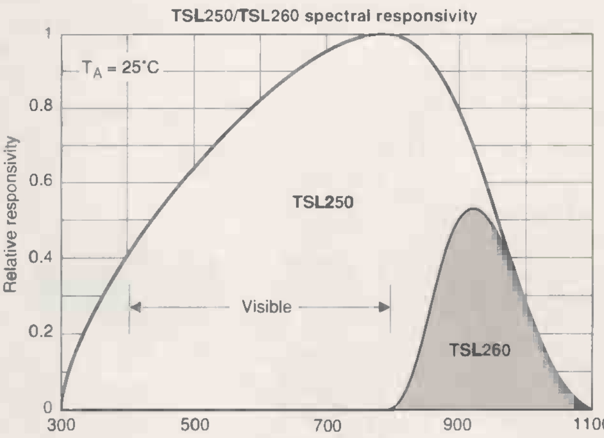


Fig. 3b). Comparing the spectral response of TSL25x and TSL26x series devices.

quency converter circuit. A simplified internal block diagram of the device is shown in Fig. 6a). Figure 6b) shows how the device simplifies interfacing with an associated microcontroller. Light sensing is accomplished by a 10-by-10 photodiode matrix. The photodiodes, or unit elements, produce photocurrent proportional to incident light.

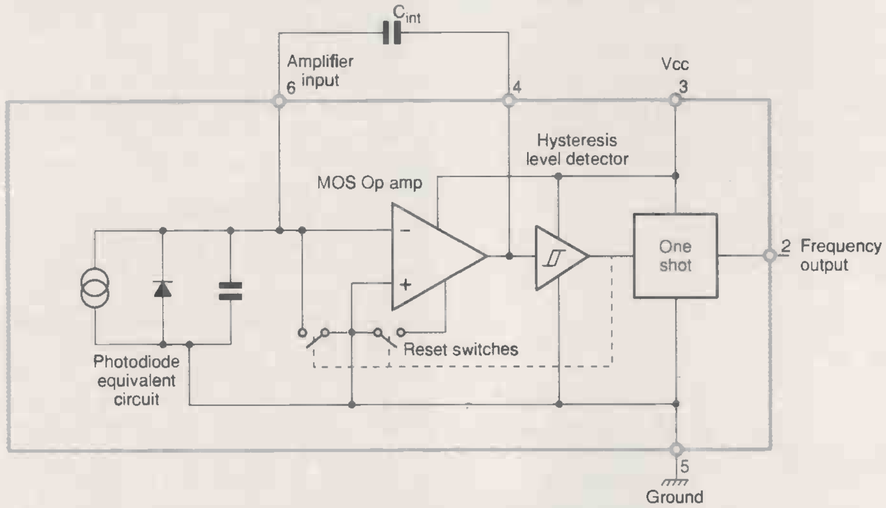


Fig. 4a). Internal workings of the TSL220. (First Figure in article, Ref. 2)

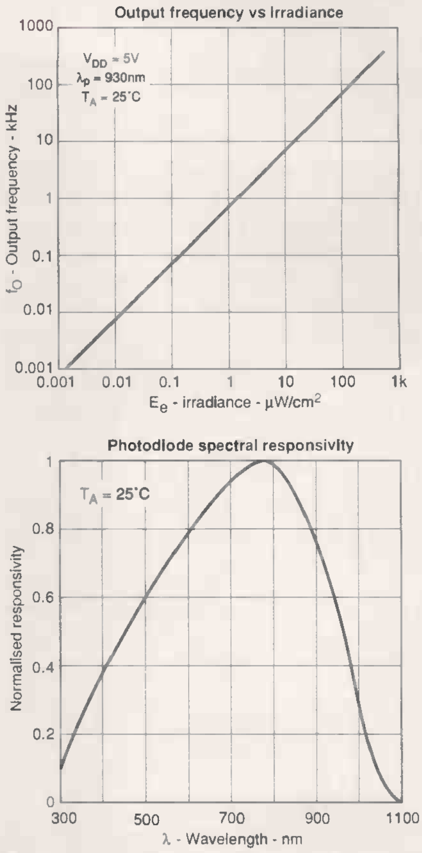
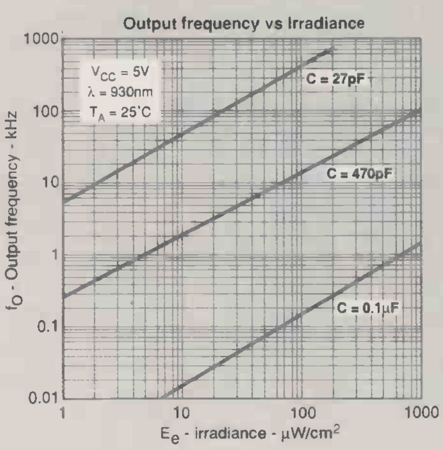
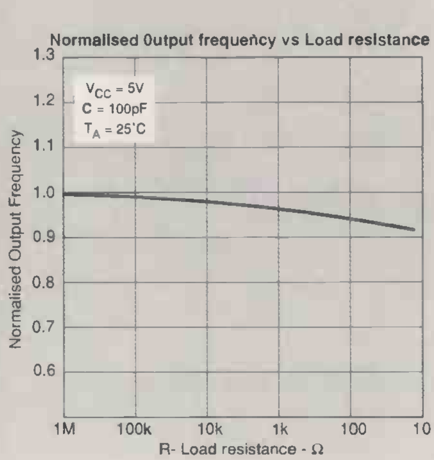


Fig. 5a). Output frequency versus incident illumination, top, and spectral response, bottom, for the TSL235 light-to-frequency converter.





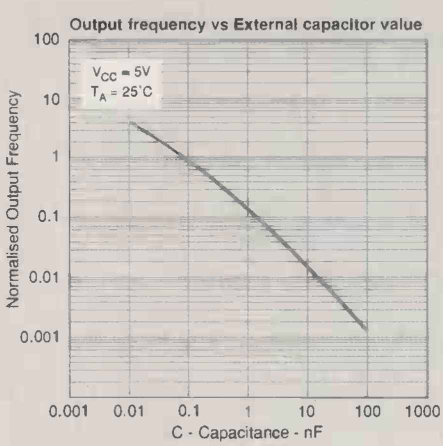


Fig. 4b). TSL220 output frequency versus illumination for various values of capacitor, top left, with load and normalised capacitance curves.

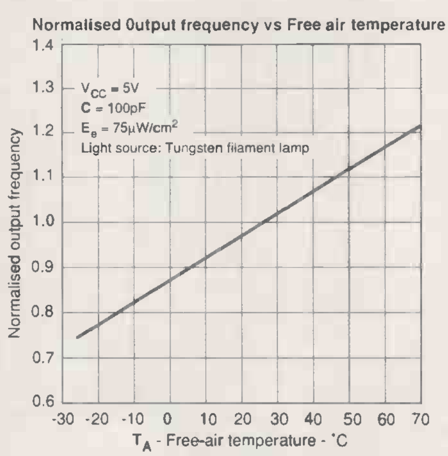


Fig. 4c). Output frequency versus temperature, normalised to 25°C, of the TSL220 under the stated conditions.

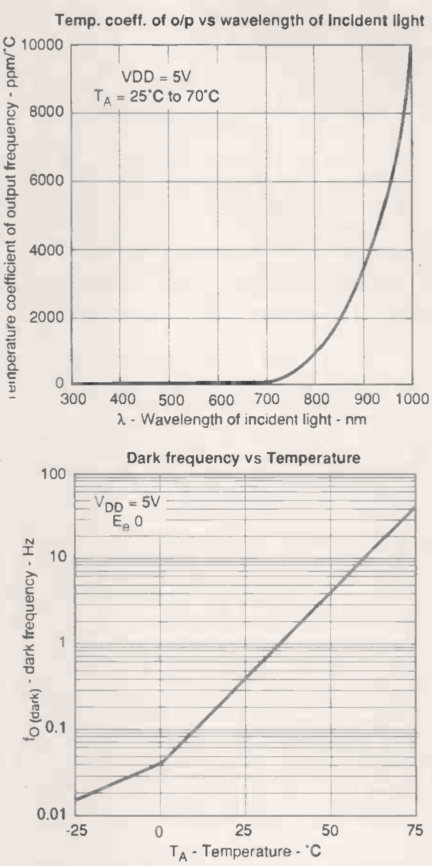
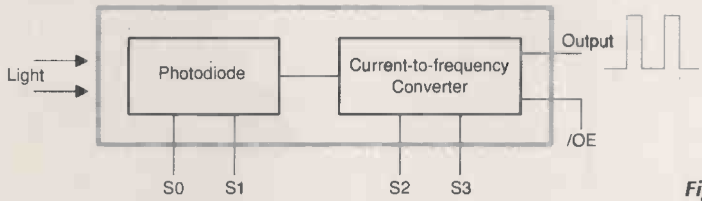


Fig. 5b). TSL235 temperature coefficient of output frequency as a function of wavelength, top, and dark frequency performance, bottom.

Sensitivity control inputs S_0 and S_1 control a multiplexer which connects either 1, 10, or 100 unit elements thereby adjusting the sensitivity proportionally, implementing a kind of 'electronic iris'. The unit elements are identical and closely matched for accurate scaling between ranges which are illustrated in Fig. **6c**). The exceedingly low dark current of the photodiode results in the dark frequency output being generally below 1Hz, Fig. **6d**).

The current-to-frequency converter utilises a unique switched capacitor charge-metering circuit to convert the photo-current to a frequency output. Output is a train of pulses which provides the input to the output scaling circuitry, and is directly output from the device in divide-by-one mode. Scaling of the output can be set via control lines S_2 and S_3 to divide the converter frequency by 2, 10, or 100, resulting in a 50:50 mark/space ratio square wave.



S1	S0	Sensitivity
L	L	Power down
L	H	1x
H	L	10x
H	H	100x

S1	S0	FO scaling (divide-by)
L	L	1
L	H	2
H	L	10
H	H	100

Fig. 6a). Functional block diagram of the TSL230 programmable light-to-frequency converter.

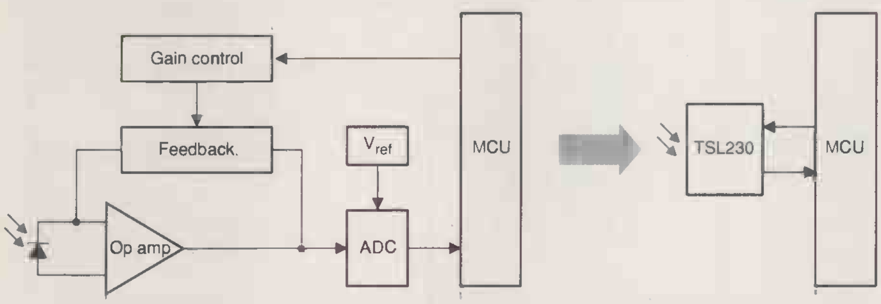


Fig. 6b). Illustrating the system simplification possible with the TSL230 Programmable Light-to-Frequency-Converter.

The *TSL230* is designed for direct interfacing to a logic-level input. It includes circuitry in its output stage to limit pulse rise and fall times, thus lowering electromagnetic radiation. Where lines longer than a 1m must be driven, a buffer or line driver is recommended. An active low output-enable line, $\overline{OE}$, is provided which, when high, places the output in a high-impedance state. This can be used when several *TSL230* or other devices are sharing a common output line.

Like other light-to-frequency converters, the *TSL230* is easily interfaced to digital control systems. But it has the added advantage of sensitivity and output frequency range adjustable over a four wire bus, S_{0-3}. Details of interfacing to a particular controller were given in a recent article in this magazine[3], but the device interfaces simply with any controller, such as the Texas Instruments *TMS370C010*, the Microchip Technology *PIC16C54HS*, or Motorola's *MC68HC11A8*[1].

Integrated line imagers

Reference 1 includes data on a number of line imagers, fabricated in LinCMOS technology. Each consists of a linear array of light sensing pixels on a 125μm pitch, together with gates and control circuitry which sequentially address and read out the pixels contents.

Voltage read out from each pixel is proportional to the accumulated charge, which is in turn proportional to the product of the incident light intensity and the period of time elapsed since the last read-out and reset.

Both *TSL213* and *214* are 64-element sensors, while the *TSL215* has 128 elements and the *TSL218* has 512. An article featuring the *TSL214* has appeared in these pages, Ref. 4, and can be found reproduced in Ref. 5. Compared with charge-coupled-device imagers, or ccds, the addressed-array line

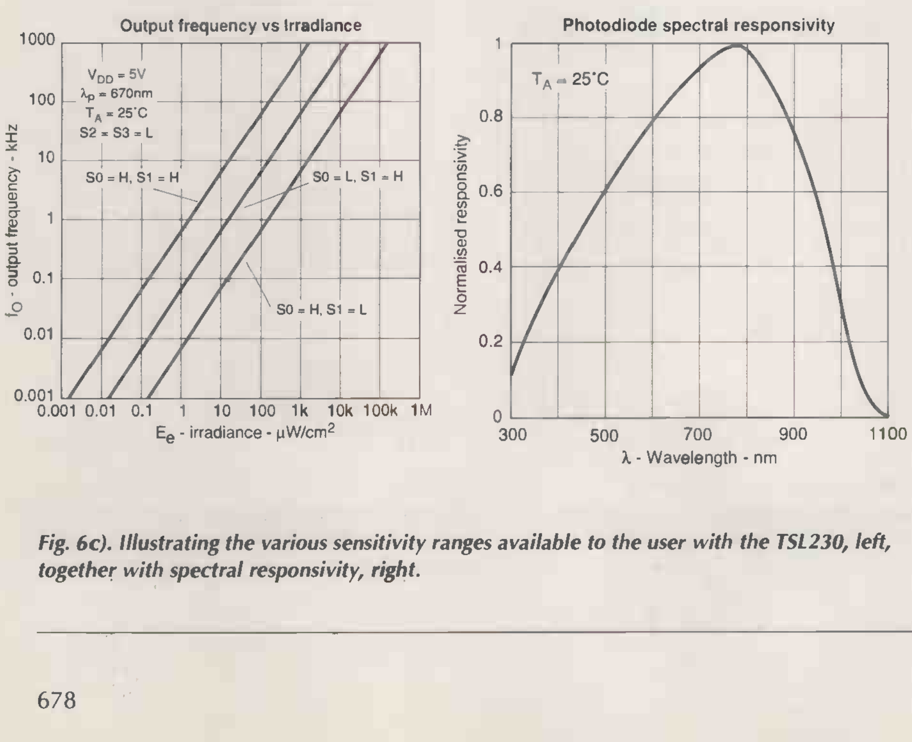


Fig. 6c). Illustrating the various sensitivity ranges available to the user with the TSL230, left, together with spectral responsivity, right.

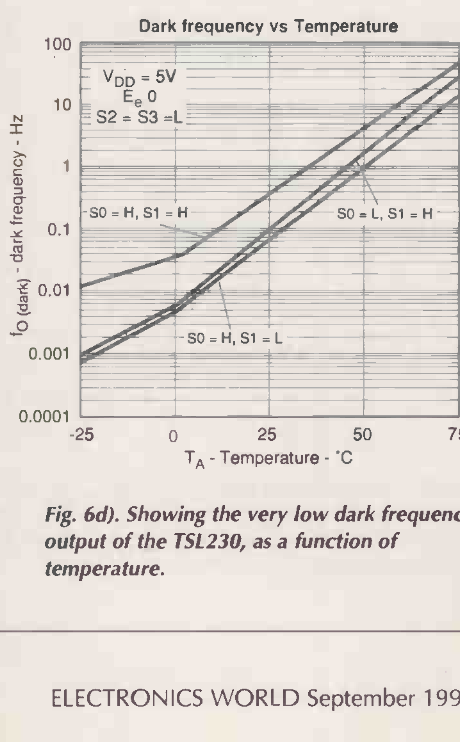


Fig. 6d). Showing the very low dark frequency output of the TSL230, as a function of temperature.

imagers offer only a 1MHz max data rate as against the ccd's 10MHz. But to set against this are a number of other advantages, resulting in a simpler and cheaper system solution, **Fig. 7a**). In particular, the wider pixel spacing of 125µm – against 12.7µm for the ccd sensor – allows the use of inexpensive plastic lenses, while in some applications a lens can be dispensed with entirely.

Figure **7b**) shows a block diagram of the internal workings of the *TSL218* 512 pixel linear array. Note that a readout sequence is initiated by a single pulse, SI, one clock pulse wide. Also, the clock frequency must be at least high enough to shift out all 512 pixel outputs before the next SI pulse, although it can be higher. Figure **7c**) shows this in a timing diagram.

During the analogue output period, all 512 pixel output voltages are presented sequentially on the AO line, with but a small glitch between each output sample's level, due to the on-chip NOCG, or non-overlapping clock generator. As it exits the last stage of the shift register, the SI pulse is output from the device as an SO pulse. This can be used as the SI pulse to another device, permitting the implementing of arrays longer than 512 pixels, all devices being fed with the same clock, with the SI pulse being applied only to the first device. ■

Fig. 7a). Comparison of 128 pixel imagers.

	TSL215 (addressed array)	**TC102 (ccd imager)**
Pitch	125µm	12.7µm
Speed	1MHz o/p data (parallel)	10MHz o/p data
Input	5V digital supply integration and readout clocks	+2V, –16V clock +16V V_{DD}, +7V ref Needs mos-drivers (ext.)
Readout	Pixels individually addressed	All pixel charges simultaneously moved.
Output conditioning	Analog video output	Needs video clamp, external sample/hold to remove clock noise.

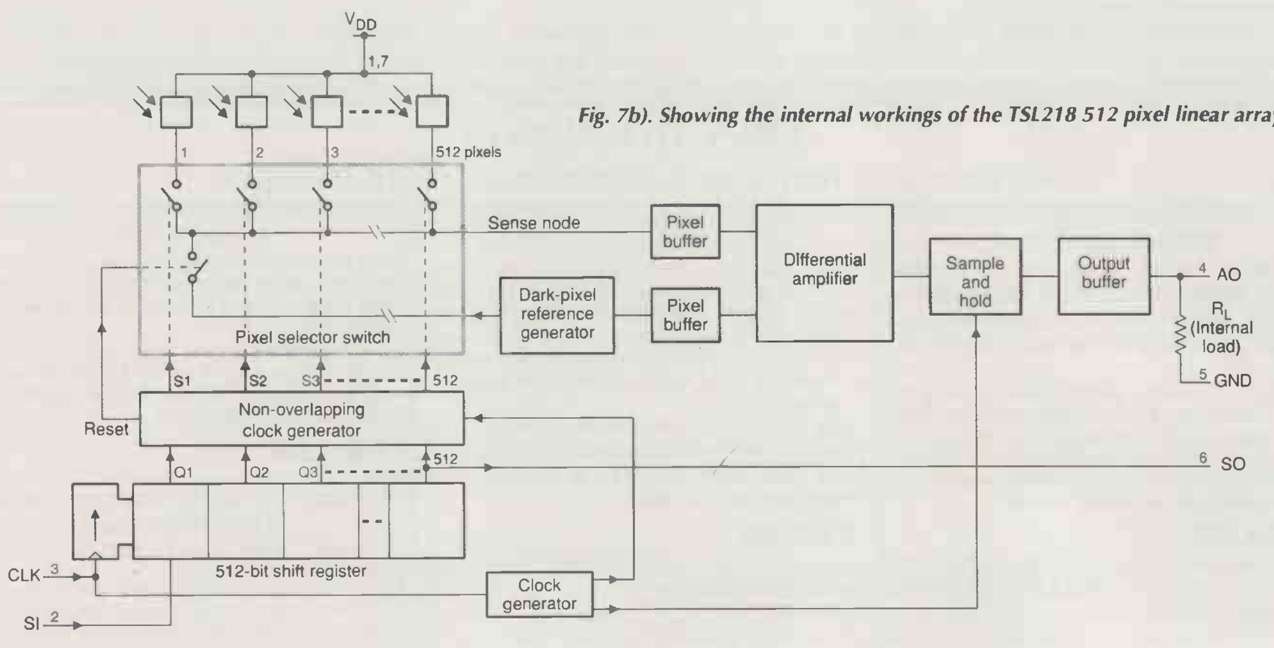


Fig. 7b). Showing the internal workings of the TSL218 512 pixel linear array.

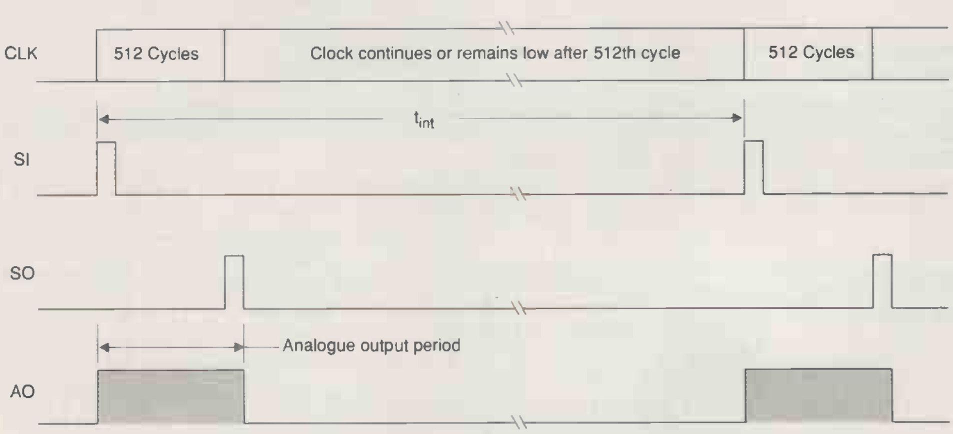


Fig. 7c). Following an SI pulse, the contents of all 512 pixels are read out serially. An SO pulse follows, which may be used as the SI pulse for a second device.

References

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2. F. Ogden, 'An Easier Route to Light Measurement', *Electronics World + Wireless World*, June 1993, pp 490, 491.
3. C Kuhnel, 'Bits of Light', *Electronics World*, January 1996, pp 68, 69.
4. Ian Hickman, 'Sensing the Position', *Electronics World + Wireless World*, November 1992, pp 955–957.
5. Ian Hickman, Analogue Circuits Cookbook, Newnes (Butterworth-Heinemann), 1995, ISBN 0 7506 2002 1.

Class-A power

After two and a half decades, John Linsley-Hood's Class-A power amp is still rated among the best. Here, John explains how to bring the design up to date, adding enhancements such as dc-coupled output.

The current debate, among some of the more reactionary of the hi-fi devotees, about the relative merits of thermionic valve operated audio amplifiers makes intriguing reading, if only because, in a sense, this is 'where I came in'. I will explain.

I have had an interest in the reproduction of music, principally from gramophone records, for a very long time. I made my first, two-valve, battery-operated, audio amplifier as a twelve year old school boy, some time before the outbreak of the 1939–1945 war.

This gave way – in the interests of economy, – to a series of mains powered audio amplifiers, which were usually combined with a radio receiver. Electricity from the mains was free, to me at least, whereas high-tension batteries had to be bought from my pocket-money.

My early work culminated, in 1951, with the assembly of a luxurious kit for the highly esteemed high-fidelity Williamson 15W amplifier design. Although, by this time, I had my first proper job – in the electronics labs of the Sellafield nuclear research establishment in Cumberland – and cash was a bit more plentiful, I still wouldn't have built that particular, rather expensive version of the hardware if I hadn't heard through the lab grapevine that one of the research chemists had bought himself a Williamson kit, but, on receiving the parcel, lacked the courage to assemble its contents. Rumour had it that he was open to offers, and I was happy when he accepted mine.

This was an excellent amplifier, and

Valves versus transistors

Not all of the considerations of valves versus transistors relate solely to performance. It is worth bearing in mind that products involving obsolete technology will be disproportionately expensive, difficult to obtain and possibly of inferior quality.

Valves can also vary in operating characteristics from sample to sample – especially where two valves of the same type are obtained from different sources. Characteristics that can vary are mutual conductance, gain, operating grid bias, anode current impedance, and even usable anode voltage.

By comparison, the performance characteristics of, say, a range of *2N3055* epitaxial base output transistor are almost identical, whether made in the Philippines or in Toulouse.

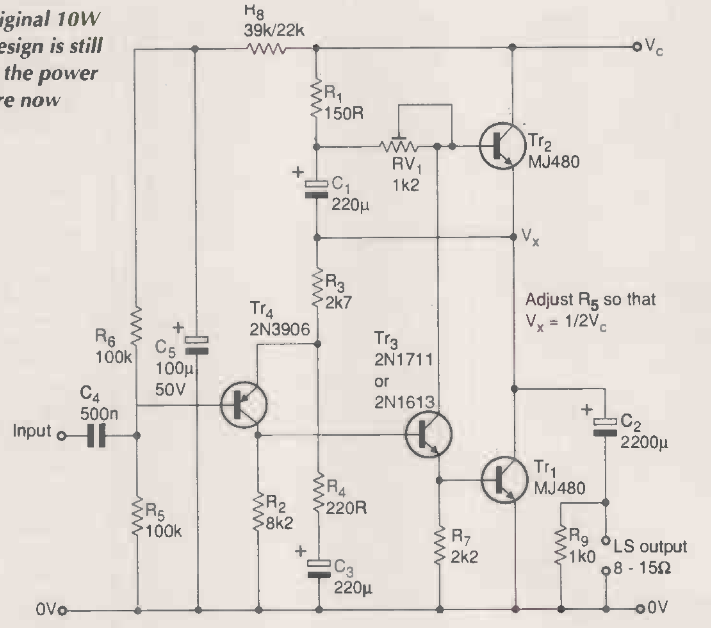
Again, all valves deteriorate in use, exhibiting a gradual loss of cathode emission over a typical 3000 hour service life. If a valve is persistently over-driven, the heating of the anode may cause the metal to out-gas. This impairs the vacuum essential to proper operation, and shortens the valve's life.

A further consideration is that valves are high voltage devices, which can be dangerous. And the need for high working voltages can lead to more rapid failure of other components in the circuit – especially capacitors.

was better, in my judgment, by a greater or lesser extent, than any of its predecessors of my own design, or, indeed, any of the other valve amplifiers, belonging to my friends, with which I had had a chance to compare it. It gave me great pleasure until early 1968, when I replaced it with a solid-state equivalent.

What I replaced it by, and the circumstances of this replacement, were described in an article in *Wireless World* in April 1969, entitled 'A simple class A amplifier'. This was a long time ago. In the light of the current debate, it seems possible that both my listening trials at the time, and an up-dated version of my original class A design, may be of interest to you. By up-dated, I mean using more modern components and delivering a bit more power output,

Fig. 1. Original 10W Class-A design is still valid, but the power devices are now obsolete.



The Williamson amplifier

In the inter-war years, with the improvement in audio quality of both gramophone records and radio broadcasts, considerable attention was paid to improving the quality of ac mains-powered audio amplifiers. A number of interesting designs were offered. These were mainly based on the use of push-pull output stage layouts. Relative to straight single ended circuits, push-pull stages would give greater output power for a given distortion level.

At that time, there were audiophiles who decried the use of push-pull output stage layouts. They claimed that the best audio quality was only obtainable from the much less efficient single ended arrangements, i.e. those in which the output valve had a simple resistor, choke or output transformer load. Interestingly, this is a claim which was examined and dismissed by Williamson at the time, but which has recently been resurrected.

Using negative feedback

Almost all valve operated audio power amplifiers require an output transformer to match the relatively high output impedance of the valve output stage to the low impedance load presented by the loudspeaker.

In general, the transformer is the most difficult and expensive part of the system to design and construct. This is because of the following conflicting demands:

- For a low leakage reactance – combining both leakage inductance and inter-winding capacitance – from the primary to the secondary windings, to avoid loss or impairment of high frequency signal components.
- For a low level of leakage inductance from one half of the primary to the other, to reduce the discontinuities due to push-pull operation, and the odd-order harmonic distortion resulting from these.
- For a high primary inductance, to give a good low-frequency response.
- For a low winding resistance, to avoid power losses.
- For a good quality grade of core laminations to ensure a low level of core-induced distortion, due to magnetic hysteresis and similar effects.

Intrinsic signal distortion of a valve amplifier stage could range from 0.5 to 10%, depending on its circuit form and operating characteristics. It had been appreciated for some time that such intrinsic distortion could be reduced significantly by applying local negative feedback. Various amplifier designs incorporating local negative feedback had been proposed. However, this still left the output transformer – however well made – as a major source of transfer and frequency response non-linearities.

At this point, D. T. N. Williamson, who was working at the time as a development engineer for the valve section of the GEC Research Laboratories, described a high-quality audio amplifier design, using the recently developed GEC 'kinkless tetrode' output valve, namely the *KT66*. In this design, a single overall negative feedback loop embraced both the whole of the amplifier and the loudspeaker output transformer.

With the exception of the output valves, which were triode connected *KT66*s, Williamson's design employed triode amplifier valves, exclusively because these had a lower intrinsic distortion figure. He also made use of extensive local negative feedback, provided by un-bypassed cathode-bias resistors. This had the additional benefit of eliminating the electrolytic bypass capacitors – a philosophy which is in accord with much of contemporary thinking.

Williamson also used non-polar rather than electrolytic high-tension reservoir and smoothing capacitors, in the interests of more consistent ac behaviour. Electrolytic capacitors were much worse at that time.

If overall negative feedback was to be applied without causing either high or low-frequency instability, careful design was essential – both in the amplifier stages and in the output transformer. These problems had frustrated earlier attempts to do this – but Williamson demonstrated that it could be done.

The performance given by his design, if his detailed specifications were carried out to the letter, was superb. The performance criteria of better than 0.1% thd, at 15W output, from 20Hz to 20kHz, and a gain bandwidth from 10kHz to 100kHz ±1dB, are at least as good as those offered by many of today's better commercial designs.

The series of articles written by Williamson, in *Wireless World* over the period 1947-1949 described the power amplifier and its ancillary units. This series had an enormous impact on audio design thinking, and if I may quote the *WW* editor of the time, in his introduction to a reprint of all of these articles.

> *"Introduced in 1947 as merely one of a series of amplifier designs, the 'Williamson' has for several years been widely accepted as the standard of design and performance wherever amplifiers and sound reproduction are discussed. Descriptions of it have been published in all the principal countries of the world, and so there are reasonable grounds for assuming that its widespread reputation is based solely on its qualities".*

All in all, the Williamson was a hard act to follow.

Alternative hardware

The world had not stood still since 1951. My equipment had remained monophonic, while the rest of the audio world was changing over to stereo.

My main interest was in music, not in circuitry, so I thought it would be prudent to ask my ears what they thought of the alternatives, before I started to replace my hardware.

To this end, I built or borrowed six well thought-of audio amplifiers, my own Williamson, a *Quad 2*, two dissimilar but recently published class AB transistor amplifiers, a commercial 30W solid-state unit, and a simple Class-A unit of my own design.

I included the Class-A design out of curiosity. If it turned out to be any good, it would be cheap and easy to build. It was not expected to offer any special merit in performance.

In the event, as I reported at the time, (*WW* April 1969, p. 152), the six amplifiers divided quite clearly into two separate tonal groups. The three class AB transistor amplifiers formed one group, while the two valve amplifiers and the simple class A amplifier formed the other.

To be fair, the differences between any of these were not very great – but they were audible. Once they were noticed, they tended to become more apparent on protracted periods of listening. Certainly, for me – and I was doing these tests for my own benefit – in these comparative trials, the two best were the Williamson and the class A. They were virtually indistinguishable. Of these two, the Williamson was vastly more massive and costly to construct.

The only remaining question was, if I replaced the 15W Williamson with the 10W Class-A design, would the output be adequate? Connecting an oscilloscope across the loudspeaker terminals showed that I seldom needed more than 2–3W from the power amplifier – even under noisy conditions.

I suppose that the final proof of my satisfaction with the class A transistor amplifier was that, a year or so later, I gave my old Williamson to a friend.

The class A design

My original design is shown in **Fig. 1**. This is still a valid design, except that the *MJ480/481* output transistors are now obsolete. However, they can be replaced by the more robust *2N3055*. In this case, the epitaxial-base version of this device should be chosen rather than the hometaxial, since the f_T of the output transistors should be 4MHz or higher.

As I commented, at the time, the design gave a somewhat lower distortion if the h_{FE} of Tr_1 was greater than that of Tr_2. This caused the output circuit to act as an amplifier with an active collector load rather than an output emitter follower with an active emitter load.

A simple modification which takes advantage of this effect is the use of a Darlington transistor such as an *MJ3001* for Tr_1. At 1kHz, this reduces the distortion level at just below the onset of clipping from about 0.1% down to nearer 0.01%. As before, residual distortion is almost exclusively second harmonic. Also, as before, it fades away into the general noise background of the measurement system as output power is reduced.

While this transistor substitution seems to be a good thing, it was not a modification whose effect I was able to check, in listening trials, against the Williamson. As a result, for the sake of historical fidelity, I would still recommend the use of epitaxial-base *3055*s as Tr_1 and Tr_2.

I have checked all the other changes which I have proposed with the exception of the power increase.

Improving performance

With regard to the original 10W design, as published, I feel the following improvements will be beneficial:

- Provide a more elegant means of controlling output transistor operating current by including a variable resistor in the base of Tr_2.
- Arrange the circuit so that it would operate between symmetrical power supply lines, allowing the amplifier to be directly coupled to the loudspeaker.
- Increase output power from 10 to 15 watts per channel.
- Up-grade the smoothed but not regulated power supply arrangement.

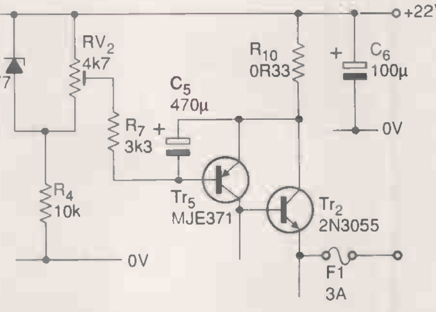


Fig. 2. Improved method of adjusting quiescent current, suggested as a postscript to the original design.

In my postscript to this design, which *WW* published in December 1970, I suggested both alternative transistor types and an improved method of adjustment and control of the output transistor current flow, Fig. 2.

Although, in theory, this layout should give a superior performance, when I changed my prototype amplifier to this arrangement, I found little change in measured thd and I couldn't hear any difference in sound quality.

Although directly coupling the amplifier to the loudspeaker will not have much effect on thd, it is still beneficial since it eliminates the output coupling capacitor. The most obvious way of doing this is to rearrange the input layout, around Tr_4, so that it becomes the input half of a 'long-tailed' pair.

I am reluctant to do this because this would alter the overall gain/phase characteristics of the amplifier. It would also require additional high-frequency stabilisation circuitry, with all

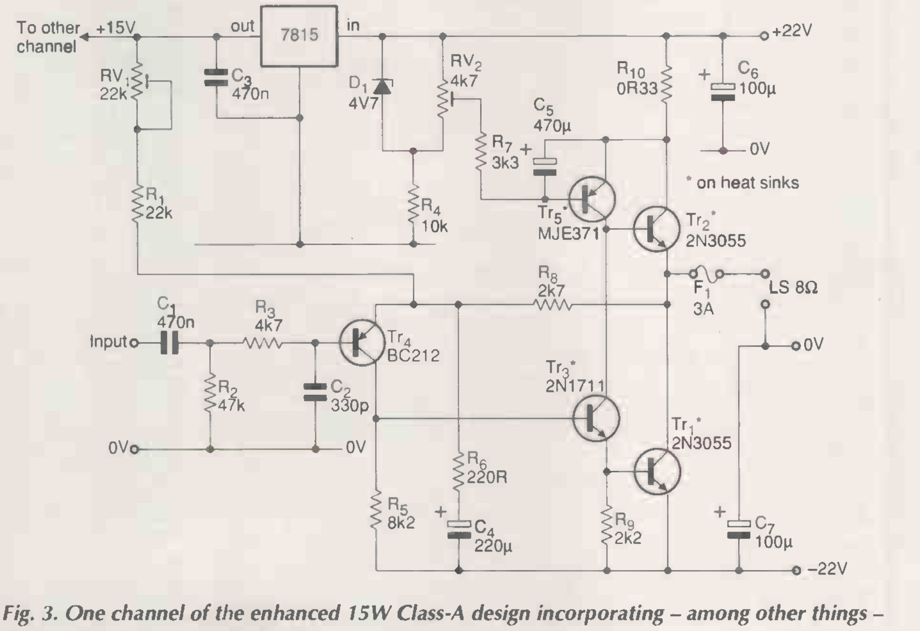


Fig. 3. One channel of the enhanced 15W Class-A design incorporating – among other things – direct loudspeaker coupling.

its incipient problems of transient intermodulation or slew-rate limiting.

Fortunately, the need to remove the dc offset at the output can be achieved without altering the good phase margins of the design, by simply injecting an appropriate amount of current into the base circuit of Tr_4.

Output power and dissipation

In essence, all that is required to increase the power output from the amplifier is to increase the rail voltages and standing current through the output devices. Restrictions are that power consumption must remain within the confines of what the mains transformer and rectifier can deliver. Also, the heat-sinks must be able to dissipate the extra heat and the output transistors must be adequately rated.

For a 15W (sinusoidal) output into an 8Ω load, an $11V_{RMS}$ drive voltage is required. This, in turn, means a $31V_{p-p}$ voltage developed across the load, and an output current into the load of $2A_p$. Since the circuit is a single-ended configuration, in which the collector current will not increase on demand, this means that the output transistor operating current must be at least 2A to allow this.

With the circuit shown, using the improved current control layout – which is rather less efficient than the boot-strapped load for Tr_3 which I originally proposed – the rail voltage needed is ±22V.

This will lead to a dissipation, in each output transistor, of 44W. Prudence suggests that a heatsink having a rating of no more than 0.6°C/W, should be used for each output pair.

Most *2N3055*s have a V_{ce} of 60V, a maximum collector current of 15A, and a maximum dissipation, on a suitable heatsink, of 115W. However, RCA's *3055*, and its complementary *MJ2955*, are rated at 150W.

Working conditions for the output transistors lie entirely within the devices safe operating area, so no specific overload protection circuitry is needed. Even so, the inclusion of a 3A fuse in the loudspeaker output line would seems prudent.

DC offset cancellation

Figure 3 shows the full circuit for one channel of the 15W Class-A audio amplifier. I have inserted a 15V three-terminal regulator ic into the positive rail to prevent any unwanted signal or hum intrusion into the emitter of Tr_4.

It is easy to set the dc offset to within ±50mV. The offset does not change greatly with time, although this assumes that Tr_5 is not allowed to warm up too much. This is because the base-emitter potential of this transistor controls the operating current, which in turn, affects output dc offset.

Small-signal bandwidth.

In the original circuit the small-signal bandwidth was 10Hz–250kHz, ±3dB, which was needlessly wide. Because of this, I have added an input high-frequency roll-off network, R_3/C_2, to the input circuit to limit the top end response to some 50kHz. This assumes an input source impedance of 10kΩ or less.

As it stands, the low-frequency –3dB point is about 7Hz. It can be lowered even further, if necessary, by making C_1 larger – say to 1μF.

Supplying power

As was shown in the 1970 postscript, it is possible to operate this amplifier from a simple rectifier/reservoir capacitor layout. **Fig. 4** is an example. The only penalty is a small 100Hz background hum, probably about 3mV in amplitude. However, I feel that, if you are seeking the best, a proper regulated power supply is preferable, **Fig. 5**.

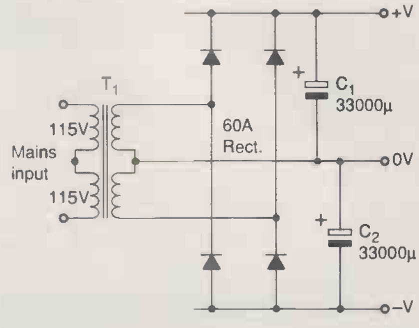


Fig. 4. Simple but adequate dual-rail supply using a single bridge.

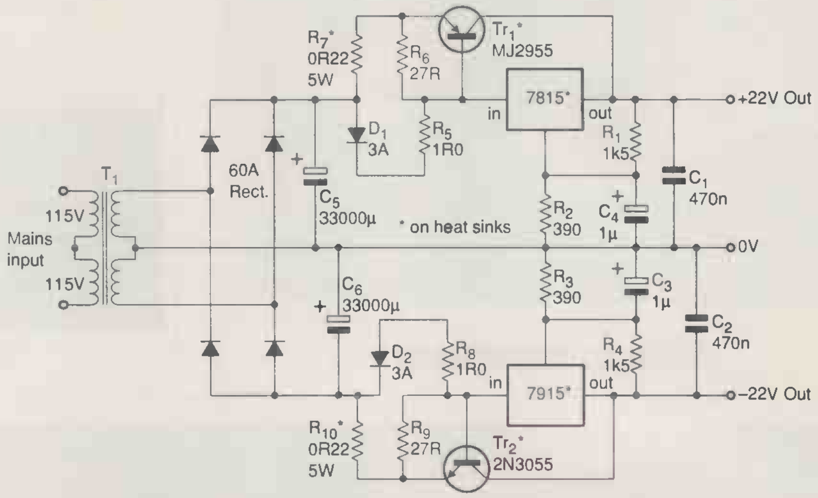


Fig. 5. Regulated power supply for the Class-A amplifier uses boosters around the three-terminal regulators. These take advantage of the regulators' current-limiting feature.

The circuit shown for the current booster pass transistors, Tr_1/Tr_2, is one suggested by National Semiconductor. It takes advantage of the internal current limiting circuitry of the *7815/7915* devices to limit the short-circuit current of these ICs to 1.2A. By choosing the correct ratios of R_5:R_7 and R_8:R_{10}, the short-circuit current drawn from Tr_1 and Tr_2 will also be limited.

For a satisfactory ripple free dc supply of ±22V, the on-load voltage supplied to the regulator circuit should be ±27V.

Performance

I prefer measurements made with appropriate instruments to judgments based on listening tests.

Measured distortion is less than 0.1% near the onset of clipping. It fades away into the background noise level of the measuring system as output power level is reduced.

For me, the fact that the distortion given by this circuit is almost pure second harmonic is more persuasive of its performance than any 'golden eared' judgment of tonal purity.

If you then add the observation that the circuit remains stable on a square-wave drive into typical reactive loads, I am not surprised that its performance was capable of equalling the Williamson on listening tests. No significant overshoot is observed on the square-wave, and stability is achieved without the need for internal high-frequency compensation arrangements.

So, as a final thought, if any of you want to find out how a top quality valve amplifier like the Williamson sounds, you can find out at a tenth of the cost of building one by making up this Class-A design. It has the additional advantage of incorporating readily available and modern components. ■

Technical support

Hart is supplying full component sets for this design. Ring 01691 652894 (24h) or find Hart in the advertisers' index at the end of this issue.

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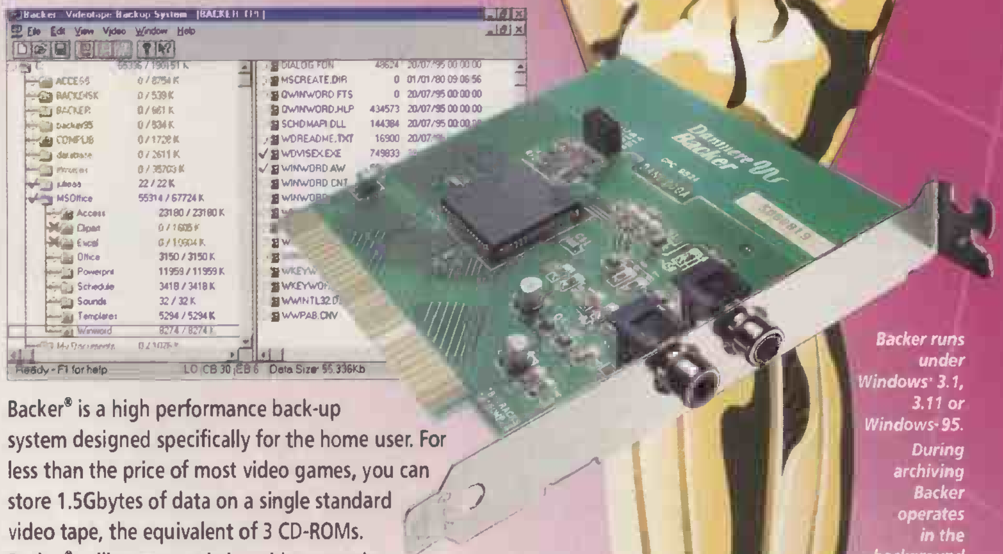

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CIRCLE NO. 137 ON REPLY CARD

Designing reliable *rectifiers*

Ray Fautley explains how to design a reliable power supply using optimum components.

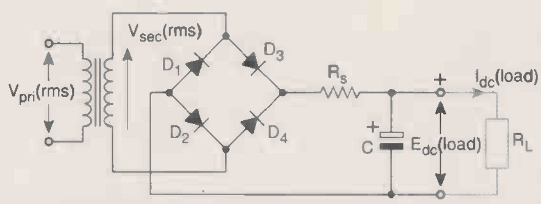

Fig. 1. The full-wave bridge rectifier is not the easiest way of producing dc from ac mains, but electrical stresses are lower than for other rectifier types.

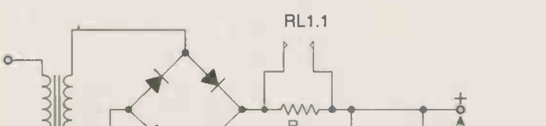

Fig. 2. At switch on, the capacitor present a short to the bridge and can cause diode failure. In this protection circuit, the relay contacts remain open until the capacitor is charged.

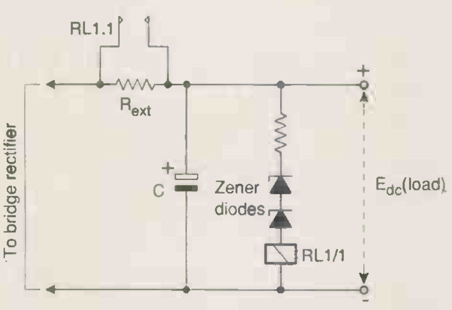

Fig. 3. Zener diodes can be used to operate the protection relay when output voltage reaches about 75% of maximum.

Reliable linear power supplies of many different types are common. But their apparent simplicity can easily lead designers to think that a few components connected to a mains transformer will produce the desired result. It can be disconcerting when at switch-on there is a bang and no output.

Main pitfalls to be avoided are breakdown of rectifier diodes due to excessive pulse current or reverse voltage, and too high voltage or ripple current causing violent demise of the reservoir capacitor.

This article and its successors cover how to design the commonest rectifier circuits, namely half-wave, full-wave centre tap, full-wave bridge and voltage doubler circuits. Design procedures presented are intended to help you design reliable linear supplies with a minimum of effort.

The source of the tabulated figures is a set of curves produced by O. H. Schade for valve type rectifiers. Although originally published over fifty years ago, these figures are still valid and useful[1].

Because the full-wave bridge is probably the commonest rectifier circuit these days, it is the subject of the first design procedure. It is not by any means the simplest way of providing dc from ac mains, but the electrical stresses on the diodes are less than for other types.

Full-wave bridges

In the full-wave bridge circuit, **Fig. 1**, alternating voltage is applied to the bridge diodes $D_{1\text{-}4}$, where it is rectified and the output smoothed by the reservoir capacitor C. The fundamental frequency of the ripple voltage superimposed on the dc output is twice that of the supply frequency. So for a 50Hz mains supply the ripple frequency is 100Hz. Resistor R_s represents the resistance of the source of the supply, and R_L the effective resistance of the dc load.

Designing a full wave bridge

To design a full-waver bridge rectifier, follow these steps.

1) Specify required dc output voltage at full load $E_{dc(load)}$ (volts).
2) Specify required maximum load current $I_{dc(load)}$ (amps).
3) Specify maximum ripple voltage acceptable $V_{r(rms)}$ (volts).
4) Specify the ac mains supply voltage $V_{pri(rms)}$ (volts).
5) Specify the frequency of the ac mains supply f (hertz).
6) Determine the value of the equivalent load resistance $R_L=E_{dc}/I_{dc(load)}$ where E_{dc} is the design value of the dc output voltage. It is the voltage drop across the load $E_{dc(load)}$ added to the voltage drop across the rectifiers: E_{dc} equals $E_{dc(load)}+2V_{rec}$ and V_{rec} is 0.9V, which is the drop across each rectifier diode. So R_L equals $[E_{dc(load)}+1.8]/I_{dc(load)}\Omega$.
7) Determine average current through each diode, I_o. As the bridge has two current branches, half the total average current will flow through each branch and thus also through each diode. Current I_o equals $I_{dc(load)}/2$.
8) Determine a value for the source resistance of the supply to the bridge rectifier, R_s.
8a) For low resistance loads, ie, low voltage high current supplies, for example 12V at 10A, diode resistance R_{rec} will probably be the largest component of R_s and so must not be forgotten. Resistance $R_{rec}=V_{rec}/I_o$, where V_{rec}=0.9V. As a result, R_s equals $R_{sec}+R_{pri}/N^2+2R_{rec}$, where N is $V_{pri(rms)}/V_{sec(rms)}$

The term for rectifier diode resistance is $2\times R_{rec}$ because in the bridge circuit there are two diodes in series across the transformer secondary winding. The term R_{pri}/N^2 represents the value of the resistance of the transformer primary winding reflected – or appearing at – the secondary winding. Resistance of the transformer secondary winding itself is R_{sec}. So R_{sec} is transformer secondary winding resistance, R_{pri} is transformer primary winding resistance and N is transformer turns ratio, ie, $N=V_{pri}/V_{sec}$ or primary-turns/secondary-turns.

If the transformer winding resistances are not known – and this is very likely as the transformer requirements haven't been defined yet – it is fairly safe to assume that $R_{sec}+R_{pri}/N^2$ is about 5% of load resistance R_L. Then R_s is $(R_L \times 5)/100+(2\times 0.9)/I_o$.

8b) For high resistance loads, i.e. high voltage, low current supplies (eg, 500V, 100mA) the resistance of the transformer windings will completely swamp the much smaller value of the rectifier resistance. So $R_s=R_{sec}+R_{pri}/N^2$.

As before, if the transformer winding resistances are not known, assume that $R_{sec}+R_{pri}/N^2$ is about 2% to 5% of R_L. Say $R_s=R_L\times 5/100$ (5% of R_L).

9) Calculate the ratio of R_s to R_L as a percentage: $R_s/R_L \times 100\%$.

10) Determine the percentage ripple voltage from the specified maximum ripple voltage and the dc output voltage, $V_r\%$, from $V_{r(rms)}/E_{dc(load)} \times 100\%$

11) From **Table 1**, determine the value of X required to provide the percentage ripple voltage, $V_r\%$, and $R_s/R_L\%$, as above.

If figures for $V_r\%$ and $R_s/R_L\%$ are not exactly the same as those found in the table headings, then the required value for X must be interpolated. A couple of examples may help.

11a) If $V_r\%=2.5$ and $R_s/R_L\%=2.0$, look for values on each side of those in the example. For $V_r\%=2$ and $R_s/R_L\%=1.0$, then $X=36$, $V_r\%=3$ and $R_s/R_L\%=3.0$, then $X=23$.

Although not absolutely theoretically correct, finding the arithmetical mean value between 22 and 36 will give a good enough approximation of the value for X. The arithmetical mean between a and b is given by $(a+b)/2$. So the arithmetical mean between 22 and 36 is: (22+36)/2, which is 58/2, or 29.

11b) If $V_r\%=15$ and $R_s/R_L\%=20$, again look for values on each side.

For $V_r\%=10$ and $R_s/R_L\%=10$, then $X=5.9$, $V_r\%=20$ and $R_s/R_L\%=30$, then $X=2.2$. The arithmetical mean between 2.2 and 5.9 is 4.05, again a good enough working approximation. This method is, of course, applicable to finding in-between values when using the other three tables.

12) Calculate the value of the reservoir capacitor C, required to provide the ripple voltage $V_{r(rms)}$ from $C=X/(2\pi f \times R_L)\times 10^6 \mu F$.

Some of you may wonder why the term used for frequency in the equation for C mentioned earlier is f and not $2f$ (the ripple frequency in a bridge rectifier being twice the supply frequency). It is simply because the figures in Table 1 were calculated to allow for the difference.

Table 1. An aid to finding the value of X

$V_r\%$	$R_s/R_L\%$						
	0.1	**0.3**	**1.0**	**3.0**	**5.0**	**10**	**30**
0.1	771	740	709	679	650	583	463
0.2	381	368	354	340	326	294	233
0.3	257	247	237	228	219	199	158
0.4	195	188	177	170	163	147	120
0.5	154	148	141	135	129	116	95
0.6	128	123	117	112	108	98	81
0.7	110	106	102	98	94	85	69
0.8	97	93	88	85	81	74	61
0.9	86	82	78	75	72	65	54
1.0	78	75	71	68	65	59	49
2	38	37	36	35	33	30	25
3	26	25	24	23	22	20	16
4	19	19	18	17	17	15	12
5	15	15	14	14	13	12	10
6	13	12	12	11.5	11.1	10	8
7	10.6	10.3	9.9	9.6	9.3	8.5	7.0
8	9.1	8.8	8.5	8.2	8.0	7.4	6.0
9	8.0	7.7	7.5	7.3	7.0	6.5	5.3
10	7.1	7.0	6.8	6.6	6.4	5.9	4.9
20	2.9	2.8	2.7	2.6	2.6	2.4	2.2
30	1.6	1.6	1.5	1.5	1.4	1.4	1.2
40	0.9	0.9	0.9	0.9	0.9	0.8	0.7

Table 2. Finding the value of Y, using X

X	$R_s/R_L\%$									
	0.05	**0.1**	**0.5**	**1.0**	**2**	**4**	**6**	**8**	**10**	**12.5**
0.1	0.64	0.64	0.64	0.63	0.62	0.61	0.60	0.57	0.57	0.56
0.2	0.64	0.64	0.64	0.63	0.62	0.62	0.60	0.58	0.57	0.57
0.3	0.64	0.64	0.64	0.63	0.63	0.62	0.61	0.59	0.58	0.57
0.4	0.64	0.64	0.64	0.63	0.63	0.62	0.61	0.60	0.58	0.58
0.5	0.65	0.64	0.64	0.63	0.63	0.62	0.61	0.60	0.59	0.58
0.6	0.65	0.65	0.64	0.64	0.64	0.63	0.62	0.60	0.59	0.58
0.7	0.66	0.65	0.65	0.65	0.64	0.63	0.62	0.61	0.60	0.59
0.8	0.66	0.66	0.66	0.65	0.65	0.64	0.63	0.62	0.60	0.59
0.9	0.67	0.66	0.66	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1.0	0.68	0.68	0.67	0.67	0.66	0.65	0.64	0.63	0.62	0.61
1.5	0.72	0.71	0.70	0.70	0.69	0.68	0.67	0.65	0.64	0.62
2.0	0.76	0.76	0.76	0.76	0.75	0.73	0.71	0.70	0.67	0.64
2.5	0.77	0.77	0.77	0.77	0.76	0.74	0.72	0.71	0.68	0.66
3.0	0.79	0.78	0.78	0.78	0.77	0.75	0.73	0.72	0.69	0.68
4.0	0.82	0.82	0.80	0.79	0.79	0.78	0.75	0.73	0.71	0.69
5.0	0.85	0.85	0.84	0.84	0.82	0.80	0.77	0.75	0.73	0.70
6.0	0.86	0.86	0.85	0.85	0.84	0.80	0.77	0.75	0.73	0.70
7.0	0.88	0.87	0.86	0.86	0.85	0.82	0.78	0.75	0.74	0.71
8.0	0.89	0.88	0.87	0.87	0.86	0.82	0.78	0.76	0.74	0.71
9.0	0.90	0.90	0.88	0.88	0.87	0.83	0.79	0.76	0.74	0.72
10	0.92	0.91	0.90	0.89	0.88	0.84	0.80	0.77	0.75	0.72
15	0.95	0.93	0.91	0.90	0.89	0.85	0.80	0.77	0.75	0.72
20	0.96	0.95	0.94	0.92	0.90	0.86	0.80	0.78	0.75	0.73
25	0.96	0.96	0.95	0.93	0.90	0.86	0.81	0.78	0.75	0.73
30	0.97	0.96	0.95	0.93	0.91	0.86	0.82	0.78	0.76	0.73
40	0.98	0.97	0.96	0.93	0.91	0.86	0.82	0.78	0.76	0.73
50	0.98	0.98	0.96	0.94	0.91	0.86	0.82	0.79	0.76	0.73
60	0.98	0.98	0.96	0.94	0.91	0.86	0.82	0.79	0.76	0.73
70	0.99	0.99	0.96	0.94	0.91	0.86	0.82	0.79	0.76	0.73
80	0.99	0.99	0.96	0.94	0.91	0.86	0.82	0.79	0.76	0.73
90	0.99	0.99	0.97	0.94	0.91	0.86	0.82	0.79	0.76	0.73
100	0.99	0.99	0.97	0.94	0.91	0.86	0.82	0.79	0.76	0.73
200	1.0	0.99	0.97	0.94	0.91	0.86	0.82	0.79	0.76	0.73
300	1.0	0.99	0.97	0.95	0.91	0.86	0.82	0.79	0.76	0.73
1000	1.0	0.99	0.97	0.95	0.91	0.86	0.82	0.79	0.76	0.73

TABLE 2 (continued)

To Find the Value of Y

X	R_s/R_L% 15	20	25	30	35	40	50	60	70	80	90	100
0.1	0.56	0.54	0.51	0.49	0.47	0.46	0.44	0.40	0.38	0.35	0.33	0.32
0.2	0.56	0.54	0.51	0.49	0.47	0.46	0.44	0.40	0.38	0.35	0.33	0.32
0.3	0.56	0.54	0.51	0.49	0.47	0.46	0.44	0.40	0.38	0.36	0.33	0.32
0.4	0.56	0.54	0.51	0.49	0.48	0.46	0.44	0.40	0.38	0.36	0.33	0.32
0.5	0.57	0.54	0.51	0.50	0.48	0.46	0.44	0.41	0.38	0.36	0.34	0.32
0.6	0.57	0.54	0.51	0.50	0.48	0.46	0.44	0.41	0.38	0.36	0.34	0.32
0.7	0.57	0.55	0.52	0.50	0.48	0.46	0.44	0.41	0.38	0.37	0.34	0.32
0.8	0.58	0.55	0.52	0.50	0.48	0.47	0.44	0.41	0.39	0.38	0.34	0.33
0.9	0.58	0.55	0.53	0.51	0.49	0.47	0.45	0.41	0.39	0.38	0.34	0.33
1.0	0.59	0.56	0.53	0.51	0.49	0.47	0.45	0.42	0.40	0.38	0.35	0.33
1.5	0.60	0.57	0.55	0.52	0.50	0.48	0.45	0.42	0.40	0.38	0.35	0.33
2.0	0.63	0.59	0.56	0.53	0.51	0.49	0.46	0.43	0.41	0.38	0.35	0.33
2.5	0.64	0.60	0.57	0.54	0.52	0.50	0.47	0.43	0.41	0.38	0.36	0.34
3.0	0.65	0.61	0.58	0.55	0.52	0.50	0.47	0.43	0.41	0.38	0.36	0.34
4	0.66	0.62	0.59	0.55	0.53	0.51	0.47	0.44	0.41	0.38	0.36	0.34
5	0.67	0.63	0.60	0.56	0.54	0.52	0.48	0.44	0.42	0.39	0.37	0.35
6	0.68	0.63	0.60	0.56	0.54	0.52	0.48	0.44	0.42	0.39	0.37	0.35
7	0.68	0.64	0.60	0.57	0.54	0.52	0.48	0.44	0.42	0.39	0.37	0.35
8	0.68	0.64	0.60	0.57	0.54	0.52	0.48	0.44	0.42	0.39	0.37	0.35
9	0.69	0.64	0.60	0.57	0.54	0.52	0.48	0.44	0.42	0.39	0.37	0.35
10	0.69	0.65	0.61	0.58	0.55	0.52	0.48	0.44	0.43	0.39	0.37	0.35
15	0.69	0.65	0.61	0.58	0.55	0.52	0.48	0.44	0.43	0.39	0.37	0.35
20	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.44	0.43	0.39	0.37	0.35
25	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.39	0.37	0.35
30	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.39	0.37	0.35
40	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.39	0.37	0.35
50	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.35
60	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.35
70	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.35
80	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.35
90	0.70	0.65	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.35
100 to 1000	0.70	0.66	0.61	0.58	0.55	0.53	0.49	0.45	0.43	0.40	0.38	0.36

13) Find the nearest standard or available value for the reservoir capacitor C, close to or preferably just above, the value calculated earlier. If the value different from the one found earlier, call it C_1 and determine a new value for X, called X_1, using $X_1=2\pi f R_L C_1$ with C_1 in µF, and $X_1=(2\pi f R_L C_1)/10^6$.

14) From the figures in **Table 2** determine the value of Y for X in (11) (or X_1 in (13) and R_s/R_L% in (9).

15) Determine the transformer secondary voltage $V_{sec(rms)}$ required, from the value for Y in (14),

$$V_{sec(rms)}=E_{dc}/(\sqrt{2}\times Y)=(0.707\times E_{dc})/Y$$

where $E_{dc}=E_{dc(load)}+2V_{rec}$.

16) Determine peak voltage or PIV, or peak inverse voltage, that each of the rectifier diodes must withstand. PIV is $V_{sec(peak)}$, which equals $\sqrt{2}\times V_{sec(rms)}$, or $1.414V_{sec(rms)}$.

17) Find the value of Z from the figures in **Table 3** for $2X$ or $2X_1$, where X was found in (11), and for $R_s/2R_L$%, where $Z=I_{(rms)}/I_o$.

18) From the values for Z found in (17) and I_o in (7), determine the current through each rectifier diode: $I_{(rms)}=I_o\times Z$.

19) Determine recurrent peak current $I_{(peak)}$ through each rectifier diode. From the figures in **Table 4** for $2X$ (or $2X_1$) and $R_s/2R_L$% find W, which is $I_{(peak)}/I_o$. Then find $I_{(peak)}=I_o\times W$

20) Determine initial switch-on current I_{on}. As C (or C_1) will be initially discharged, the load on the rectifier diodes will be nearly a short-circuit at the instant of switch-on, limited only by the source resistance R_s. As a result, I_{on} is $V_{sec(peak)}/R_s$.

This very high current flows for only a very short time, but the rectifier diodes must be capable of withstanding it. If suitable devices with such high pulse current ratings are not available, the source resistance R_s must be increased by adding an external resistor R_{ext} between the bridge rectifier and the reservoir capacitor C (or C_1). The value of R_{ext} to limit the switch-on current to an acceptable lower value $I_{on(L)}$, is determined later in (28).

21) Decide on a suitable rectifier diode type to be used. The device must have all its ratings equal to, or greater than the following:
Peak-inverse voltage or $V_{sec(peak)}$, sometimes called V_{RRM}, as in (16):
Initial switch-on current or I_{on}, sometimes called I_{FSM}, as in (20): Average current or I_o, sometimes known as $I_{F(AV)}$, as in (7).

22) Determine rms ripple current, $I_{c(rms)}$, flowing through the reservoir capacitor C (or C_1) using $\sqrt{(2[I_{(rms)}{}^2]-[I_{dc(load)}{}^2])}$.

23) Decide on the specification for the reservoir capacitor to be used. The capacitor must have ratings equal to, or greater than, the following. Capacitance C (or C_1) see (12) or (13), dc working voltage $V_{sec(peak)}$, see (16), and ripple current $I_{c(rms)}$ see (22).

24) Total transformer secondary current $I_{t(rms)}$ comprises two currents, one in each branch of the bridge, which must be summed using: $\sqrt{([I_{(rms)}{}^2]+[I_{(rms)}{}^2])}$, which is $\sqrt{2}\times I_{(rms)}$.

25) Transformer VA or volt-amp rating T_{VA} determines the size of the transformer: $V_{sec(rms)}\times I_{t(rms)}$

26) Transformer requirements are volt-Amp rating T_{VA}, see (25), primary winding voltage $V_{pri(rms)}$, see (4), secondary winding $V_{sec(rms)}$, see (15), and secondary current $I_{t(rms)}$, see (24).

27) When a suitable transformer has been chosen, measure the resistance of both windings. If measured source resistance $R_{s(m)}$, or $R_{sec}+R_{pri}/N^2+2R_{rec}$, is less than R_s calculated in (8), then an external resistor calculated using $R_{ext}=R_s-R_{s(m)}$ must be added, see (28), to limit I_{on} to the value found in (20). For low resistance loads, as in (8a), it is unlikely that any external resistance will be necessary as the diode resistance R_{rec} will tend to limit the switch-on current rather than the resistance of the transformer windings.

28) If an external resistor R_{ext} was found necessary in (20) or (27) to be fitted between the rectifiers and the reservoir capacitor C (or C_1) to limit the switch-on current to $I_{on(L)}$, see (20), its value will be $[V_{sec(peak)}/I_{on(L)}]-R_s$

29) Power P_r, dissipated in R_{ext} (if used) is given by $[I_{t(rms)}{}^2]R_{ext}$.

A suitable resistor should have a power rating of about twice the value of P_r for reliable operation.

30) If external resistor R_{ext} is used, and is of high enough resistance to degrade the supply's regulation, it could be shorted out by a switch immediately after switch-on. Either a hand operated toggle switch or, preferably an automatically operated circuit could be used.

Power switch with automatic sensing

Automatic operation could be by a circuit sensing the rise of current through a relay coil. This relay has an operating voltage just below $E_{dc(load)}$ connected and is directly across the dc output. Its contacts are normally open, and connected across R_{ext}.

At the instant of switch-on, with high current charging the reservoir capacitor, the relay contacts are open, so R_{ext} limits the current. As the capacitor charged, the voltage across it rises until it becomes high enough to operate the relay. The relay contacts then close, shorting out R_{ext}, thus reducing the series resistance of the supply and improving its regulation, **Fig. 2**.

For higher voltage supplies the relay could have a combination of resistance and zener diodes in series. This would enable operation when say, the output voltage reached about 75% of its full value, $E_{dc(load)}$, see **Fig. 3**.

Implementing the equations

Suppose you want a supply to operate a linear amplifier. Requirements are for an output voltage of 13.5V at 10A. Assume that an acceptable ripple voltage is 0.6Vrms and that the supply will operate from the standard mains supply of 240V, 50Hz. Design stages are numbered as previously.

1) $E_{dc(load)}$ is 13.5V.
2) $I_{dc(load)}$ is 10A.
3) $V_{r(rms)}$ is 0.6Vrms.
4) $V_{pri(rms)}$ is 240Vrms.
5) f is 50Hz.
6) $R_L=E_{dc}/I_{dc}$, where E_{dc} is $E_{dc(load)}+2V_{rec}$. So R_L is $[E_{dc(load)}+1.8]/I_{dc(load)}$, or (13.5+1.8)/10, giving 1.53Ω.
7) $I_o=I_{dc(load)}/2=10/2=5A$.
8) Using (8a), $R_s=(R_L\times5)/100+2R_{rec}$, where R_{rec} is $V_{rec}/I_o=0.9/5$, or 0.18Ω and R_s is (1.53×5)/100+2(0.18) or 0.437Ω.
9) $R_s/R_L\times100\%=(0.437/1.53)\times100\%$, giving 0.286×100%, or 28.6%.
10) $V_r\%$ is $V_{r(rms)}/E_{dc(load)}\times100\%$, which equals 0.6/13.5×100%, or 4.44%
11) From Table 1, the value of X for $V_r\%=4.44\%$ and $R_s/R_L\%=28.6\%$, is found to be 11.0
12) $C=X/2\pi fR_L$ is $(X\times10^6)/2\pi\times50\times1.53$µF or 22,885µF.
13) 22,000µF is a standard value for an electrolytic capacitor and would be a suitable choice.
14) The value of Y for X=11.0, and $R_s/R_L\%$=28.6% from Table 2 is 0.59.
15) $V_{sec(rms)}$ is $E_{dc}/\sqrt{2}\times Y$, which is 15.3/1.414×0.59 or 18.34V_{rms}.
16) $\sqrt{2}\times18.34$ is 25.9$V_{(peak)}$ or PIV.
17) Value of Z, for $2X$=22.0 and $R_s/R_L\%$=14.3%, from Table 3 is found to be 2.0. Here, X is 11.0 in (11) and $R_s/R_L\%$ equals 28.6% in (9).
18) $I_{(rms)}=I_o\times Z$, which is 2×5, or 10A, where Z=2.0 in (17) and I_o=5.0A in (7).
19) Value of W for $2X$=22.0 and $R_s/2R_L\%$=14.3% from Table 4 is found to be 5.0 and thus $I_{(peak)}$ is $I_o\times W$, which is 25A. Here, X=11.0 in (11) and $R_s/R_L\%$=28.6% in (9).
20) $I_{on}=V_{sec(peak)}/R_s$=25.9/0.437=59.3A.
21) Diode ratings required are PIV (or V_{RRM}) of 25.9V, I_{on} (or I_{FSM}) of 59.3A and I_o (or $I_{F(AV)}$) of 5.0A. Diode type *BYX98-300* is suitable, having a PIV (V_{RRM}) of 300V, an I_{on} (I_{FSM}) of 75A and an I_o ($I_{F(AV)}$) of 10A.
22) $I_{c(rms)}=\sqrt{(2[I_{(rms)}^2]-[I_{dc(load)}^2])}$, which gives $\sqrt{2([10^2]-[10^2])}$, or 10A.
23) Reservoir capacitor ratings are a capacitance of 22,885µF (22,000µF standard value) a $V_{sec(peak)}$ equal to $V_{DC(wkg)}$ of 25.9V and a ripple current of $I_{c(rms)}$ of 10A.
24) Current $I_{t(rms)}$ is 1.414×I_{rms} of 14.14A.
25) Transformer T_{VA} is $V_{sec(rms)}\times I_{t(rms)}$, which is 18.34×14.14, or 259.3VA.
26) Mains transformer ratings required are the T_{VA} of 259.3VA, primary winding voltage $V_{pri(rms)}$ of 240V_{rms}, secondary-winding voltage $V_{sec(rms)}$ of 18.34V_{rms} and the $I_{t(rms)}$ secondary current of 14.14A_{rms}.

Compared with guessing components, you may find this design process rather laborious – but it does provide you with an elegant and reliable power solution. ■

Further reading

Schade, O. H., 'Analysis of Rectifier Operation', Proc. IRE, Vol. 31, No. 7, July 1943.

PSU rectifier symbols used

C	Capacitance of reservoir capacitor
C_1	Alternative for C
E_{dc}	Design value for dc output voltage
$E_{dc(load)}$	DC output voltage across full Load
f	Frequency of ac mains supply
$I_{c(rms)}$	Ripple current through reservoir capacitor
$I_{dc(load)}$	Maximum current in load
$I_{F(AV)}$	Same as I_o
I_{FSM}	Same as I_{on}
I_o	Average current through each diode
I_{on}	Current at initial switch-on
$I_{on(L)}$	Reduced initial switch-on current
$I_{(peak)}$	Recurrent peak current through each diode
$I_{(rms)}$	Current through each diode (rms)
$I_{t(rms)}$	Mains transformer secondary current
N	Mains transformer ratio (V_{pri}/V_{sec})
PIV	Diode peak inverse voltage
P_r	Power dissipated in R_{ext}
R_{ext}	External resistance added to source resistance
R_L	Equivalent load resistance
R_{pri}	Resistance of mains transformer primary winding
R_{rec}	Effective resistance of each diode
R_s	Source resistance
$R_{s(m)}$	Measured source resistance
$R_s/R_L\%$	Ratio of source resistance to equivalent load as %
R_{sec}	Resistance of mains transformer secondary winding
T_{VA}	Mains transformer volt-amp rating
$V_{pri(rms)}$	Supply voltage applied to mains transformer primary
$V_r\%$	Ratio of ripple voltage to dc output voltage as %
$V_{r(rms)}$	Maximum ripple voltage acceptable
V_{rec}	Voltage drop across each rectifier diode
V_{RRM}	Same as PIV
$V_{sec(peak)}$	Mains transformer secondary voltage (peak)
$V_{sec(rms)}$	Mains transformer secondary voltage (rms)

Table 3. Finding the value for Z.

2X	$R_s/2R_L\%$										
	0.02	0.05	0.1	0.2	0.5	1.0	2	5	10	30	100
1	1.80	1.80	1.79	1.79	1.79	1.78	1.77	1.77	1.73	1.70	1.66
2	2.03	2.02	2.01	2.00	1.99	1.98	1.97	1.96	1.89	1.77	1.67
3	2.19	2.17	2.16	2.14	2.13	2.11	2.10	2.03	1.95	1.79	1.67
4	2.32	2.30	2.28	2.26	2.24	2.22	2.17	2.08	1.98	1.80	1.68
5	2.43	2.40	2.36	2.32	2.27	2.23	2.19	2.10	2.01	1.82	1.68
6	2.50	2.48	2.46	2.44	2.42	2.40	2.28	2.13	2.04	1.83	1.68
7	2.58	2.53	2.51	2.49	2.47	2.45	2.31	2.16	2.05	1.84	1.68
8	2.66	2.63	2.61	2.60	2.58	2.50	2.35	2.17	2.06	1.84	1.68
9	2.73	2.70	2.68	2.66	2.64	2.57	2.38	2.18	2.07	1.85	1.68
10	2.80	2.78	2.75	2.73	2.70	2.62	2.40	2.19	2.08	1.86	1.68
20	3.30	3.20	3.17	3.15	2.83	2.82	2.53	2.26	2.12	1.88	1.68
30	3.64	3.50	3.40	3.29	3.05	2.89	2.59	2.30	2.15	1.90	1.68
40	3.91	3.72	3.55	3.40	3.13	2.92	2.62	2.32	2.16	1.90	1.68
50	4.08	3.87	3.68	3.48	3.22	2.93	2.64	2.33	2.17	1.91	1.68
60	4.23	3.97	3.78	3.55	3.25	2.94	2.66	2.35	2.18	1.91	1.68
70	4.35	4.03	3.87	3.60	3.27	2.95	2.67	2.36	2.18	1.91	1.68
80	4.45	4.10	3.94	3.65	3.30	2.96	2.68	2.36	2.18	1.91	1.68
90	4.52	4.18	3.98	3.67	3.31	2.97	2.68	2.37	2.19	1.91	1.68
100	4.62	4.23	4.02	3.69	3.32	2.98	2.69	2.37	2.19	1.91	1.68
200	5.03	4.60	4.27	3.86	3.37	3.00	2.69	2.38	2.19	1.91	1.68
300	5.20	4.79	4.33	3.88	3.38	3.00	2.69	2.38	2.19	1.91	1.68
400	5.35	4.86	4.37	3.88	3.38	3.00	2.70	2.38	2.19	1.91	1.68
500	5.45	4.90	4.38	3.89	3.38	3.00	2.70	2.39	2.19	1.91	1.68
600	5.51	4.93	4.38	3.89	3.39	3.00	2.70	2.39	2.19	1.91	1.68
700	5.60	4.96	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
800	5.67	4.98	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
900	5.70	4.99	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68
1000	5.75	5.00	4.39	3.90	3.39	3.01	2.70	2.39	2.19	1.91	1.68

Table 4. Finding the value for W.

2X	$R_s/2R_L\%$										
	0.02	0.05	0.1	0.2	0.5	1.0	2	5	10	30	100
1	3.70	3.70	3.70	3.64	3.62	3.60	3.60	3.59	3.58	3.57	3.46
2	4.60	4.57	4.55	4.53	4.52	4.50	4.28	4.20	4.08	3.72	3.51
3	5.50	5.40	5.33	5.30	5.20	5.10	5.00	4.67	4.33	4.00	3.55
4	6.20	6.17	6.13	6.10	6.00	5.98	5.45	5.20	4.95	4.05	3.57
5	7.30	6.95	6.90	6.85	6.80	6.75	6.51	5.60	5.00	4.10	3.62
6	8.00	7.90	7.70	7.60	7.50	7.30	6.90	5.84	5.09	4.19	3.63
7	8.70	8.55	8.50	8.30	8.10	7.82	7.30	6.00	5.10	4.22	3.64
8	9.60	9.50	9.35	9.00	8.50	8.20	7.69	6.15	5.14	4.23	3.64
9	10.3	9.80	9.60	9.50	9.10	8.55	7.72	6.23	5.21	4.25	3.65
10	10.9	10.7	10.5	10.1	9.50	8.64	7.74	6.30	5.28	4.26	3.66
20	16.0	15.0	14.4	13.0	11.1	9.44	7.83	6.47	5.29	4.27	3.66
30	19.7	18.0	16.3	14.3	11.7	9.60	7.92	6.50	5.31	4.27	3.66
40	21.9	20.0	17.3	14.7	12.1	9.64	8.01	6.51	5.33	4.28	3.66
50	23.7	20.8	18.2	15.2	12.2	9.70	8.10	6.51	5.34	4.28	3.66
60	24.9	21.1	18.5	15.4	12.3	9.77	8.12	6.51	5.34	4.29	3.66
70	25.9	21.4	18.9	15.6	12.4	9.84	8.14	6.51	5.34	4.29	3.66
80	26.7	21.8	19.4	15.7	12.4	9.90	8.16	6.51	5.34	4.30	3.66
90	27.5	22.2	19.5	15.8	12.5	9.93	8.18	6.51	5.34	4.30	3.66
100	28.5	22.5	19.7	15.9	12.5	9.96	8.19	6.52	5.35	4.31	3.66
200	30.5	23.0	20.0	16.3	12.6	10.0	8.19	6.52	5.36	4.31	3.67
300	31.6	23.3	20.5	16.9	12.7	10.0	8.20	6.53	5.38	4.32	3.67
400	32.8	23.5	20.9	17.0	12.7	10.0	8.20	6.54	5.40	4.32	3.67
500	33.3	23.8	21.0	17.1	12.8	10.0	8.20	6.55	5.42	4.33	3.68
600	33.8	24.0	21.1	17.2	12.8	10.1	8.20	6.56	5.44	4.33	3.68
700	34.2	24.5	21.2	17.3	12.9	10.1	8.20	6.57	5.46	4.33	3.69
800	34.4	24.9	21.4	17.4	12.9	10.1	8.20	6.58	5.48	4.33	3.69
900	34.5	25.8	21.5	17.5	13.0	10.1	8.20	6.59	5.52	4.33	3.70
1000	34.7	27.0	21.6	17.6	13.0	10.1	8.20	6.60	5.56	4.33	3.70

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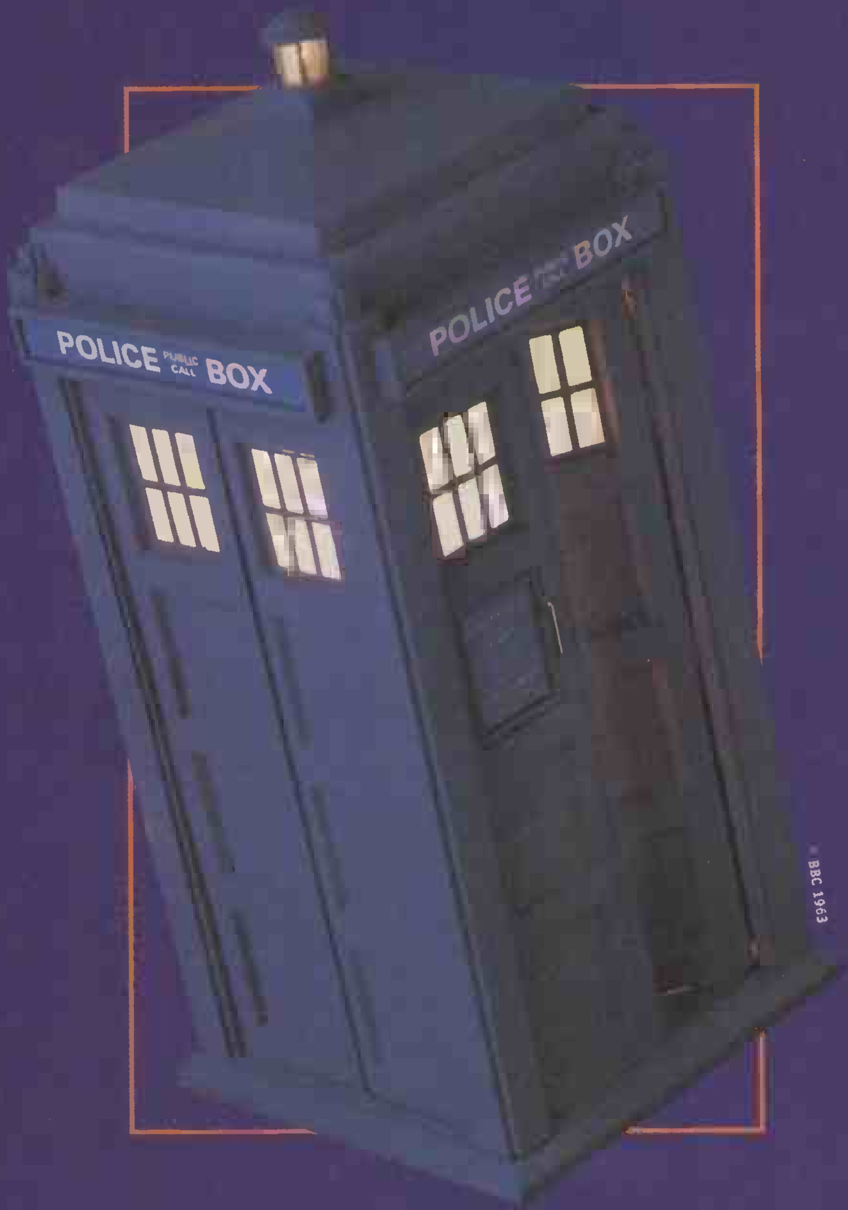

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Hands-on Internet

Cyril Bateman **discusses new search tools and looks at Spice models and hardware and software support via the World Wide Web.**

As the Web grows, so newer, more user friendly search tools become available. Last month I highlighted the 'Infoseek' search engine accessible from Netscape. This is now complemented by A2Z and Accufind[1], making a total of twenty-three search tools accessible from this page.

A development from Lycos, A2Z offers authoritative descriptions of the best Web pages, while Accufind claims its *JavaScript* search engine makes new power available to the user.

The *Java* explosion continues apace. By the time this issue is published, the first *Java* developers' conference – JavaOne – will have taken place in San Francisco 29-31 May, **Fig. 1**.

On April 25, Dun & Bradstreet Software[2], in conjunction with Sun Microsystems, announced the release in May of the first enterprise applet allowing local and remote users to complete purchase requisitions electronically.

The IBM Hursley UK port of Java to AIX[3], release 1.01, having passed Sun Microsystem's test suite, now has Java-compatibility approval. And IBM Raleigh has released its demo version of WebExplorer-with-Java[4], available by download.

Fig. 1. Web announcement of the first ever Java Developers' Conference. The rush to embrace the Java concept continues to gain pace world wide.

Security issues

Some of the concerns expressed regarding security aspects of Java have now been remedied. Netscape Navigator version 2.01 addresses three potentially vulnerable areas. These are host connection, files or document locations and mail or news postings, **Fig. 2**.

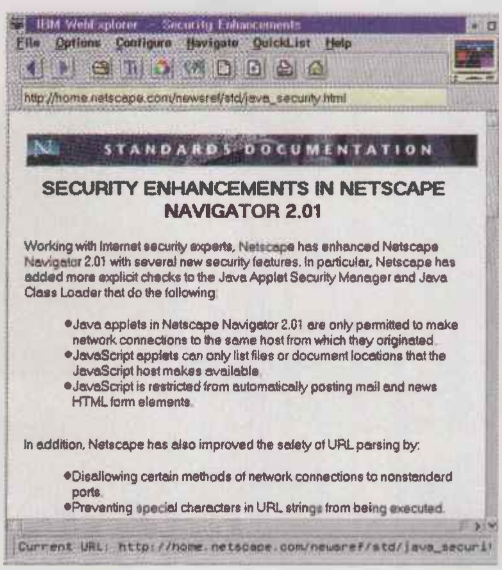

Fig. 2. The need to improve the security of Java used for Web browsers is now official. Those interested are advised to download and print out this two page announcement. Watch Java's space for future announcements.

The desktop operating system clash between IBM and Microsoft continues with both companies offering critiques of the others system, accessible via their Web pages. While the imminent demise of OS/2 Warp had been voiced by some writers, on 23 April, IBM announced that the next OS/2 upgrade – code-named Merlin[5] and due this year – will include speech recognition software, **Fig. 3**.

Also, the first low-cost Internet access boxes have arrived[6]. The British company Acorn[7] is involved, in the production of these, together with Apple, **Fig. 4**.

Software and hardware support

During a recent visit to a client with my pc, a dos and Windows whizz noticed the 'IBM-Information-Superhighway' folder on my desktop and asked why he might need Internet access. Apart from the topics already covered in this series, perhaps the most relevant for his need is to gain software and hardware support.

Support was brought forcibly to my attention recently

Fig 3. OS/2 – neither dead nor buried, but resurrected maybe under a different name? Some of the published missives from IBM and Microsoft camps reveal weakness in both their systems. Hopefully these processor and memory guzzling operating systems will pass into history.

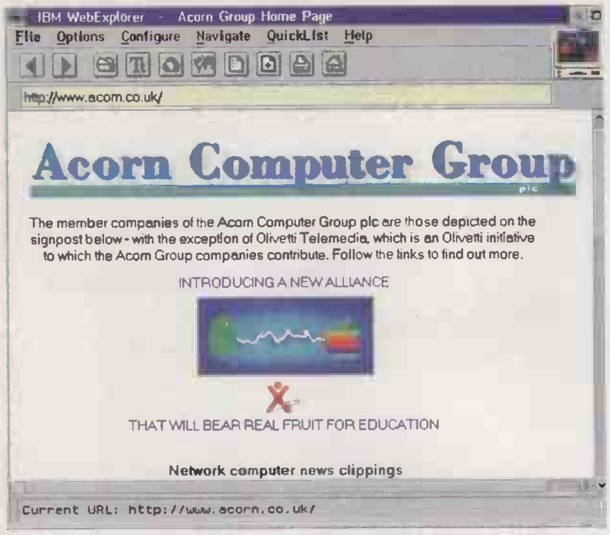

Fig. 4. This Acorn/Apple alliance for education has since been designated Xemplar. In my view, combining these two desk tops must be good for education.

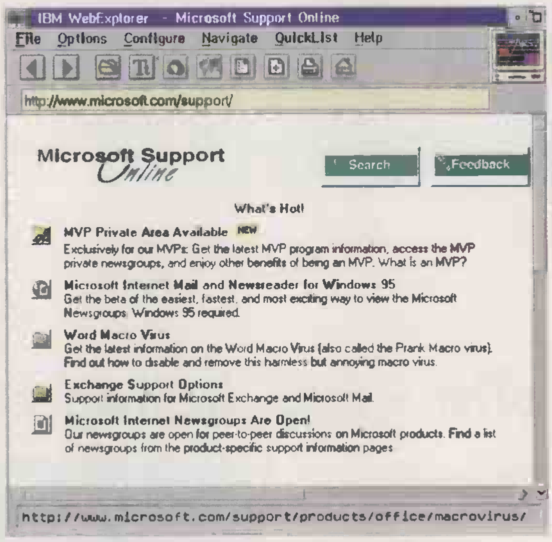

Fig. 5. Part of the Microsoft users' support system. This site's FAQ is essential reading to understand the terminology used and site structure. Not the most intuitive or user friendly, but support is there, given familiarisation. A useful area is the so-called knowledge base, unfortunately indexed by document number.

by two different incidents. Having owned and used a registered copy of *Visual Basic 3* for well over a year, I received only promotional literature from Microsoft. During this time I had not used one facet of the program – the company's much vaunted 'Set-up Wizard' – which requires a file not included in the 'packing list.

On investigation I found this failing was known prior to my purchase and had been published on the Internet. But at that time I had no modem. Microsoft considers that publication on the Internet[8] or their BBS[9] covers their obligations. To compound this error, their 'fix-pack' also failed to work when following the included instructions. The outcome was four days lost work and many harsh words.

I recently found time to install OS/2 Warp Connect 'Blue Box', replacing, the original Warp 'Red Box' which had served me well for more than a year. Unfortunately the specific version of the S3 video graphics accelerator I use was not supported by the 'shrink wrap', although the required driver was available from the IBM Web page[10], or their BBS[11].

This problem of device drivers is common to all current pc operating systems – including *Windows 95* – when using non-current hardware. For those of you still afflicted by the 'Prank' virus by the way, help to identify and remove it is available from Microsoft[8], **Fig. 5**.

Benefits of modem access

Traditional telephone support is time consuming and expensive after the initial free period. A modem and Internet or Compuserve access makes these problems addressable economically. But more importantly modem access can forewarn you of problems, easily justifying the cost of a modem for all sizes of business.

Hewlett Packard manufactures both semiconductors and simulation systems, offering Spice macro models as well as S parameters. A search on Spice models from their home page revealed more than forty reference documents for download, **Fig 6**.

Earlier this year, my verbal request for macro models to the

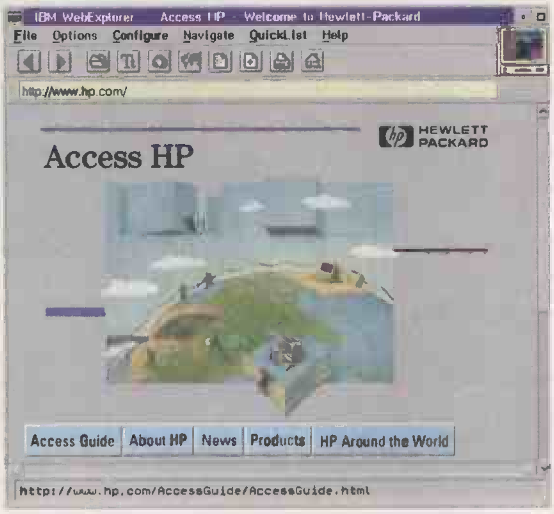

Fig. 6. As with all Hewlett Packard products, everything works, is user friendly and accessible. Well worth visiting just to view this well organised site.

Fig. 7. A month ago, this site had no Spice macro models. Things update quickly on the Internet. If a first visit to any site is unfruitful, try again shortly.

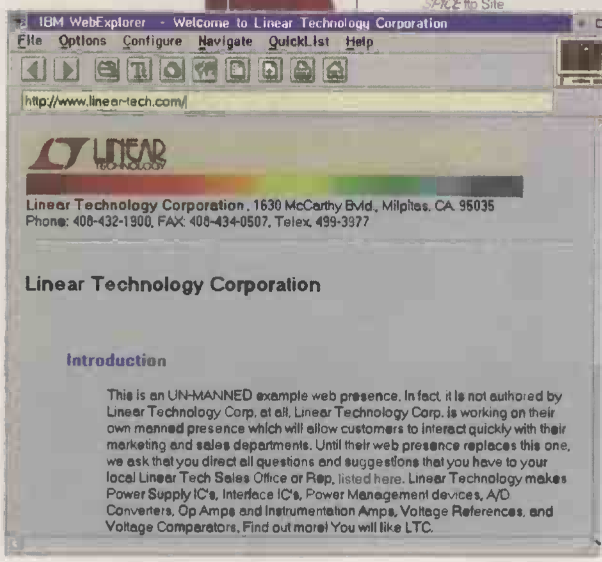

Fig. 8. While not obvious from this page, LTC can supply Spice models. In the days when 5.25in disks were standard, LTC supplied my first Spice simulator and models.

company's UK office failed. But International Rectifier now offers a zip file of all the company's current models downloadable from IR's Web page. This page also provides applications and literature, Fig 7.

At the moment, Linear Technology Corporation has only a temporary, un-manned, Web page advertisement although an interactive page is in development, Fig 8. ■

Web sites accessed

1. Netscape http://www.netscape.com/escapes/maps/escapes.map
2. Sun Microsystems Inc. http://java.sun.com/
3. IBM Hursley Park UK http://ncc.hursley.ibm.com/javainfo
4. IBM Raleigh http://www.ics.raleigh.ibm.com/ics/give3.htm
5. IBM Austin http://www.austin.ibm.com/pspinfo/merlin2.html
6. First Web PCs Arrive, *Byte* April '96 p 24,25.
7. Acorn Computer Group http://www.acorn.co.uk/
8. Microsoft Support Online http://www.microsoft.com/support
9. Microsoft BBS UK, 01734-270065
10. IBM Europe Repository http://www.europe.ibm.com/getdoc/psmemea/progserve/device
11. IBM BBS UK, 01256-811900

LETTERS

Letters to "Electronics World"
Quadrant House, The Quadrant,
Sutton, Surrey, SM2 5AS

Check it out

Your sceptical correspondent Dr Fisher (*EW*, May) will, in the near future, need to double-check his own work rather than maintain his present attitude towards those who regard anomalistic phenomena as challenges to an inquisitive intellect.

He will, for instance, be very surprised to learn that many scientists of international repute are engaged in the study of 'dowsing, ball lightning, free energy and/or anti-gravity'. The majority of these experimentalists are highly skilled mathematicians and cross-check each others' work using a variety of methodologies.

Many phenomena previously considered to be 'paranormal' are now yielding up their secrets, a process which is likely to be accelerated by the redefinition of the phase space of both thermodynamics and information theory. Dr Fisher can work this out for himself by a simple experiment using a gaming die. In this, the die is placed on a sheet of paper orthogonally gridded to match the length of each of its edges. It is then orientated with its 'six' spot in one of the central cells of the grid with its 'two' spot facing him and its 'five' spot facing north. With most dice, the 'four' spot then faces west and the 'three' spot faces east.

The die is then rolled slowly and step-wise over its edges so that the number of spots on the faces of the die which come into contact with successive cells can be recorded in those cells as a form of sequential memory. These number sequences are, in fact, representations of displaced rotations about the x, y and z axes and correspond to a spinning object in three-dimensional space which is represented in the observer's stationary frame of reference under a condition of projective geometry.

Unfortunately, even this simple procedure demonstrates several surprising errors of omission in Alan Turing's famous 1936 paper entitled 'On computable numbers, with an application to the Entscheidungsproblem' on which much of contemporary computing is based. Perhaps Dr Fisher could work out what these errors were?

Brian Clement
Powys

Proof is in the cable?

I refer to the letter '10mV diode proof?' by Allen Wright, May 1996. A little thought will show that the effect described has nothing to do with putative 10mV diode effects in the speaker cable.

Let's take some approximate figures. In the March 1996 issue, Doug Self refers to a test for the existence of these diodes carried out at 50W/8Ω (ie 20Vrms output) and measures a drop of 140mV across his speaker cable.

Allen Wright refers to a listening level of 'milliwatts'. If we assume 50mW, this implies an output voltage reduced by a factor of $\sqrt{1000}$ or approximately 660mV. The resistance of Allen Wright's RG59 braid won't be much different from Doug Self's cable so we have a voltage drop across the cable of about 5mV. If the speaker cables are newly made, with freshly soldered or crimped terminations and no broken strands, then even if the strands were insulated from each other along the length of the cable, the voltage difference between them at any point due to random variations in thickness would only be fractions of a microvolt. Clearly, even if Ben Duncan's diodes do exist, they can have nothing to do with the effect described.

What is going on, then? The resistance of 0.25mm diameter wire will be much higher than the braid, and may be helping to swamp the reactive components of the loudspeaker impedance, thus flattening the frequency response. This could easily be tested by wiring a non-inductive resistor of a few ohms in series with the braid, and seeing if the same improvement results.

Additionally, the (unspecified) amplifier will be operating almost entirely in its crossover region, and if it is not in fact free of crossover nasties, may be less able to control a reactive load. At these power levels it would be no problem to knock up a single-ended Class A amplifier to check this one out.

Chris Bulman
Bedford

Bach in time

In his article on free phasing oscillators for electronic organs, Ian Hickman suggests that one oscillator can be shared between two adjacent semitones. He may not know that this is a very old idea, actually dating back to 1730, when 'fretted' clavicords were constructed that shared one string between two or more semitones. A clavichord works by simultaneously stopping the free length of the string and exciting its vibration by striking it with a wooden tangent. The tangent is directly attached to the key, and thus two adjacent keys can stop different notes on the same string.

The system became obsolete when J. S. Bach began writing keyboard music that occasionally requires the simultaneous sounding of two adjacent semitones. In fact one does not need to look further than the first prelude of book 1 of the "Wohltemperiertes Klavier" (the set of 48 preludes and fugues written in every major and minor key) to find two examples, of a B sounded with a C, and later on, an E with an F.

If Bach found such economies restrictive, surely we should not consider reintroducing them?

Cosmo Little
Cornwall

In the real world

Ben Duncan's piece 'Modelling cable' (*EW* Feb 1996) was a fine demonstration of the capabilities of his circuit simulator. Unfortunately his modelling does not give an accurate view of the real world. Ben has not included the proximity effect in his modelling, although I doubt it would be any more significant than the skin effect – that is, not very.

Also, his assumption that loudspeaker drivers are substantially inductive at high frequencies was not borne out by measurements. I took of five loudspeakers' impedances, using an *HP 4193A* vector impedance meter. At 400kHz – the instrument's lowest working frequency – phase angles measured ranged between 38° and 56°. At 1MHz the range was –62 (capacitive) to 57°. These figures indicate that their Q probably never exceeds two. The speaker that ranged from 38° (400kHz) to –62° (1MHz) was a 10in woofer, and it was self resonant at 600kHz where its impedance was 780Ω. On the basis of this one must doubt the accuracy of Ben's models.

I first saw the idea that copper cables contained oxide diodes over five years ago in the Australian electronics press. At the time I thought the idea sounded plausible so I decided to test it. Checking the dc resistance of a piece of wire revealed it to be as linear as I could measure, so a more sophisticated method was required. I reasoned that if significant amounts of current were flowing in these oxide diodes then they would reveal their non-linear behaviour by distorting the voltage drop along the cable.

As I was not well equipped to perform a harmonic distortion test with sufficient resolution I decided to try measuring the intermodulation distortion. This way distortion components generated by the wire would not be integer multiples of the test frequencies and the harmonic distortion components from signal sources could be easily identified and ignored, leaving any intermod components sticking out like the proverbial dog's ...errrr, well easy to identify. My partner in this venture was Dr Mark Ballico, who was at the time working towards his PhD in the Dept of Plasma Physics.

A more complete description of the experiment and the results was printed in *Electronics Australia* (Oct. 1990), but briefly the wire used was RS 357-340 'tinned copper stranded 10/0.1mm conductor ...(rated at)... 0.5A'[1]. For test signals I used 1.5A 50Hz from the mains, isolated by a transformer and set with a *Variac*, and a 5kHz (approx) signal from a low distortion oscillator.

The higher frequency signal was selected not to be a harmonic of the 50Hz mains but close to 5kHz Around the high frequency signal the noise floor was at least 65dB down for over a kilohertz, and all frequency spikes that the spectrum analyser displayed were simple harmonics of the test signals – mostly harmonics of the mains. There was no evidence of any intermodulation distortion at all. I could only deduce from this that there were no such diodes, or that they were shunted by sufficiently low impedance, eg. plain metallic copper, that they had no effect.

These results need to be scaled to compare them to the circumstances that exist in an audio system. The cross-sectional area of the wire was less than 0.08mm^2 – very small and woefully underrated for connecting speakers – the current of 1.5A would generate 18W in the nominal 8Ω load. Normal speaker cables would have at least ten times the cross sectional area, and at the same current density 1.8kW would be delivered to the load, without, it would seem, significant distortion.

Further if less than 10% of the output voltage was dropped across the cable then you would expect that the cable would not produce any distortion products at the speaker greater than 84dB down from the original signal. I have not heard of a hi-fi speaker that produces less than 0.01% IMD, or THD or Doppler distortion, at 1.8kW. Most devices produce more distortion with more power.

With regard to the notion that copper cables consist of copper oxide diodes that cause audible distortion, I suspect that Ben Duncan has more closely modelled a fertile imagination than the physical universe that we live in. There are more plausible explanations for why some people believe that one type of cable sounds better than another that require no reference to electronics at all. The poor and variable frequency response of human hearing and its effects on perceived sound would be one of the strongest.

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1. RS Catalogue, 1995
2. R.A. Greiner, 'Amplifier-loudspeaker interfacing', *J. Audio Eng. Soc.*, Vol. 28, No. 5, 1980 May.
3. Fred E. Davis, 'Effects of cable, loudspeaker and amplifier interactions', *J. Audio Eng. Soc.*, Vol. 39, No. 6, 1991 June.
4. Ben Duncan, 'Modelling cable', *EW* Feb 1996.

Phil Denniss
Sydney, Australia

Did you do your homework?

I was surprised to read the article entitled 'Crossover networks made simple'. I think simple is the operative word and I would suggest that Mr Teleki should do a bit more homework before writing any further articles on loudspeaker networks.

a) Correctly designed networks are specifically designed for predetermined units in a specific cabinet. Every unit has its unique parameters. I have yet to measure differing unit types that have a sufficiently close acoustic and impedance curves to be able to use, optimally, the same crossover network. No unit I know has a flat response and impedance in a practical enclosure.

b) The network has to take into account the acoustic response and acoustic phase of the units involved, mounted in the design cabinet. Hence the electrical network has to take this into account. The thing that matters is the acoustical output of the combined electrical and acoustical signals. The network order is therefore not necessarily the same as the required acoustic order.

c) Because of the above, the acoustic responses of the units in the specified cabinet need to be known along with their impedance curves and preferably their phase response.

d) Networks are available with components ranging from cheap reversible electrolytic capacitors ±20% to ±2.5% Polypropylene, and ferrite inductors with thin copper wire to very large air-cored cores with very thick wire. We have produced air-cored inductors weighing over 1kg each. The price should take into account some design time, assembly time and component costs. Oh yes, plus hopefully some profit and 17.5% VAT.

e) Both ferrite and air-cored inductors can and should be orientated so that there is virtually no mutual coupling (magnetic interaction) between them. Toroids are not normally used due to their overload characteristics and high cost and size for sufficient power handling.

f) From the above it is obvious that a theoretical network using the nominal impedance of the unit will give nothing like an optimum response, in fact in many cases the response can be more irregular than with no network at all.

g) With regard to cascading high and low pass sections as suggested, this does not even work in theory, due to interaction between the sections. This interaction diminishes with the separation of the two crossover frequencies, but is still significant for normal three-way systems[1,2].

$$f_4=f_3(f_2/f_1-1)$$
$$f_3=\sqrt{f_1 f_2/(f_2/f_1-1)}$$

where f_1 and f_2 are the crossover frequencies and f_3 and f_4 are the calculated design frequencies.

Rather than having to buy C(++?) compilers it is simpler to construct a spreadsheet where the frequencies and impedances are in referenced boxes and the various order filter components are in the body of the sheet. Other items such as resonance tuned circuits and Zobel networks can be included.

Finally; 6 decimal places on results?

References

1. Norman Crowhurst, High Fidelity Sound Engineering.
2. M.D. Hull, Building Hi-Fi Speaker Systems.

Malcolm Jones
Norfolk

Hand-crafted Cs

I liked Vladkov's capacitance meter. For it to be of maximum use, one requires small, accurate, reference capacitors. The snag is that in the picofarad region, lead capacitance is significant. Chip capacitors are free of this but even the best ones, such as those provided by ATC, are not tightly toleranced in the pF region.

Microwave cables such as the RG 402 are made to very tight tolerances and this particular item is specified as having a capacitance of 98pF/metre.

Thus it is possible to construct capacitors of a few pF with considerable precision. The lead length can be made very small.

At measurement frequencies up to a few MHz the fact that one's capacitor is a transmission line is irrelevant, though purists may like to form the length of line into a loop and feed it at both ends in parallel.

This is an old trick, of course, but only works with this type of co-ax in short lengths. Try cutting off 2cm of braided outer co-ax accurately.

Nick Wheeler
Surrey

Historical units

When I saw the reference to 'm.s.c.' in Mr. Owen Davie's letter in the July/August 1996 issue, I recalled my early notes on the origins of logarithmic units of attenuation:

The 'standard cable' referred to, was originally an ordinary 19 AWG-conductor telephone cable, which had constants: 88Ω, 1mH, 57nF and 1μS per loop-mile[1]. The capacitance was a little different for some manufacturers. This gave; f_c=30kHz and a=0.94dB (0.106 neper) at 800Hz.

The most used measure was the '800 cycle-mile'[2]. Current or power ratios were expressed as the number of miles of standard cable which gave the same ratio at 800Hz.

Because the power attenuation of a mile of standard cable, at 886Hz, was $10^{0.1}$ and involved common logarithms; this attenuation was adopted as a standard for all frequencies and was called the 'transmission unit'.

In 1923, the American Telephone and Telegraph Company announced this new 'transmission unit' to replace the mile of standard cable. In the following year, the International Advisory Committee on Long Distance Telephony recommended the 'bel' or the 'neper' should be used.

The adoption of the decibel, as the name for the 'transmission unit', was eventually announced by the Bell System in January, 1929[3].

References – 'Electric Circuits and Wave Filters' STARR, Arthur Tisso, 1948 [Pitman] p.180.
2. 'Communication Engineering' EVERITT, William Littell, 1937, (Mc Graw-Hill) p.101,102.
3. 'Decibel'-the name for the Transmission Unit. Martin, W.H., Bell System Technical Journal, January, 1929

T.J. Wynn South Wales

Wait for me

In his response to Chris Bulman's letter in the June issue, Seggy Segaran mentioned BT's plans to enhance the Call Waiting system to allow Caller ID units to display the number of the waiting caller. This service is described in the ETSI specification ETS300-659-2 and could well be introduced in the UK this year.

Allan Edwards
Essex

Clear as a bell?

Bengt Olsson, in his July 1996 letter, says that in speaking of output stages and their devices, one must be clear. Unfortunately, he is not.

The first part of his letter claims that a bipolar transistor is highly non-linear, just because it has high gain. This is of course quite untrue when baldly stated thus. I said myself in 'FETs vs Bipolars: The Linearity Competition' (*EW* May 1995) that on the same graph, transistor collector current vanishes near vertically off the scale, exponentially increasing, before the fet has even begun to conduct. The raw transconductance (g_m) of a bjt is far higher than for any power fet, so to make the two devices even vaguely comparable one must insert 0.1Ω into the bipolar emitter as local feedback, reducing its gm to about 9A/V, equal to that of the fet at an I_d of 10A.

Adding this emitter-resistor to a bipolar device with high gm has the happy side effect of making it very linear indeed compared with the fet. The bipolar g_m is now constant over a wide range, ie the gain is linear. The fet, with no spare gain to allow the application of any local feedback, still has gm that varies linearly with I_d, so that the actual I_d/V_{gs} output characteristic is square-law rather than linear.

I must admit that I thought this was demonstrated beyond all doubt in my article; I hope this makes it clearer.

The second part of the letter seems to deal with the internal negative feedback of the complementary feedback pair output stage; how this is relevant to the linearity of single devices is not obvious to me. The gain quoted (58 dB, not 60) is wholly mysterious as it is not at all clear whether this is supposed to be voltage or current gain; either way it seems to be wrong.

I find that the reference to the linearity of borrowed plumes does little to clarify matters. I wish to reassure concerned readers that no bird products were used in the amplifier experiments I have reported.

Douglas Self
England

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ENERGY BANK KIT 100 6"x6" 6v 100mA panels, 100 diodes, connection details etc. £69.95 ref EF112.

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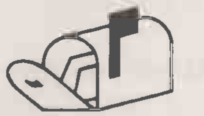

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4.6mw LASER POINTER. BRAND NEW MODEL NOW IN STOCK!, supplied in fully built form (looks like a nice pen) complete with handy pocket clip (which also acts as the on/off switch.) About 60 metres range! Runs on 2 AAA batteries. Produces thin red beam ideal for levels, gun sights, experiments etc. just £39.95 ref DEC49 TRADE PRICE £28 MIN 10 PIECES

BULL TENS UNIT Fully built and tested TENS (Transcutaneous Electrical Nerve Stimulation) unit, complete with electrodes and full instructions. TENS is used for the relief of pain etc in up to 70% of sufferers. Drug free pain relief, safe and easy to use, can be used in conjunction with analgesics etc. £49 Ref TEN/1

PC PAL VGA TO TV CONVERTER Converts a colour TV into a basic VGA screen. Complete with built in psu, lead and s/ware.. Ideal for laptops or a cheap upgrade.Supplied in kit form for home assembly. SALE PRICE £25 REF SA34

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AUTO SUNCHARGER 155x300mm solar panel with diode and 3 metre lead fitted with a cigar plug. 12v 2watt. £8.99 REF SA25.

MICRODRIVE STRIPPERS Small cased tape drives ideal for stripping, lots of useful goodies including a smart case, and lots of components. SALE PRICE JUST £4.99 FOR FIVE REF SA26

SOLAR POWER LAB SPECIAL You get TWO 6"x6" 6v 130mA solar cells, 4 LED's, wire, buzzer, switch plus 1 relay or motor. Superb value kit SALE PRICE JUST £4.99 REF SA27

RGB/CGA/EGA/TTL COLOUR MONITORS 12" in good condition. Back anodised metal case. SALE PRICE £49 REF SA16B

PLUG IN ACORN PSU 19v AC 14w , £2.99 REF MAG2P10

13.8V 1.9A PSU cased with leads. Just £9.99 REF MAG10P3

UNIVERSAL SPEED CONTROLLER KIT Designed by us for the C5 motor but ok for any 12v motor up to 30A. Complete with PCB etc. A heat sink may be required. £17.00 REF: MAG17

PHONE CABLE AND COMPUTER COMMUNICATIONS PACK Kit contains 100m of 6 core cable, 100 cable clips, 2 line drivers with RS232 interfaces and all connectors etc. Ideal low cost method of communicating between PC's over a long distance utilizing the serial ports. Complete kit £8.99. Ref comp1.

VIEWDATA SYSTEMS made by Phillips, complete with internal 1200/75 modem, keyboard, psu etc RGB and composite outputs, menu driven, autodialler etc. SALE PRICE £12.99 REF SA18

AIR RIFLES .22 As used by the Chinese army for training puposes, so there is a lot about! £39.95 Ref EF78. 500 pellets £4.50 ref EF80.

PLUG IN POWER SUPPLY SALE FROM £1.50 Plugs in to 13A socket with output lead. three types available, 9vdc 150mA £1.50 ref SA19, 9vdc 200mA £2.00 ref SA20, 6.5vdc 500mA £2 ref SA21.

VIDEO SENDER UNIT. Transmits both audio and video signals from either a video camera, video recorder, TV or Computer etc to any standard TV set in a 100' range! (tune TV to a spare channel) 12v DC op. Price is £25 REF: MAG15 12v psu is £5 extra REF: MAG5P2

***MINATURE RADIO TRANSCEIVERS** A pair of walkie talkies with a range up to 2 km in open country. Units measure 22x52x155mm. Including cases and earp'ces. 2xPP3 req'd. £30.00 pr.REF: MAG30

***FM TRANSMITTER KIT** housed in a standard working 13A adapter!! the bug runs directly off the mains so lasts forever! why pay £700? or price is £15 REF: EF62 (kit) Transmits to any FM radio.

***FM BUG BUILT AND TESTED** superior design to kit. Supplied to detective agencies. 9v battery req'd. £14 REF: MAG14

TALKING COINBOX STRIPPER COMPLETE WITH COINSLOT MECHANISMS originally made to retail at £79 each, these units are designed to convert an ordinary phone into a payphone. The units have the locks missing and sometimes broken hinges. However they can be adapted for their original use or used for something else?? SALE PRICE JUST £2.50 REF SA23

GAT AIR PISTOL PACK Complete with pistol, darts and pellets £12.95 Ref EF82B extra pellets (500) £4.50 ref EF80.

6"X12" AMORPHOUS SOLAR PANEL 12v 155x310mm 130mA. SALE PRICE £4.99 REF SA24.

FIBRE OPTIC CABLE BUMPER PACK 10 metres for £4.99 ref MAG5P13 ideal for experimenters! 30 m for £12.99 ref MAG13P1

MIXED GOODIES BOX OF MIXED COMPONENTS WEIGHING 2 KILOS YOURS FOR JUST £5.99

4X28 TELESCOPIC SIGHTS Suitable for all air rifles, ground lenses, good light gathering properties. £19.95 ref R/7.

GYROSCOPES Remember these? well we have found a company that still manufactures these popular scientific toys, perfect gift or for educational use etc. £6 ref EP70

HYPOTHERMIA SPACE BLANKET 215x150cm aluminised foil blanket, reflects more than 90% of body heat. Also suitable for the construction of two way mirrors! £3,99 each ref O/L041.

LENSTATIC RANGER COMPASS Oil filled capsule, strong metal case, large luminous points. Sight line with magnifying viewer. 50mm dia, 86gm. £10.99 ref O/K604.

RECHARGE ORDINARY BATTERIES UP TO 10 TIMES! With the Battery Wizard! Uses the latest pulse wave charge system to charge all popular brands of ordinary batteries AAA, AA, C, D, four at a time! Led system shows when batteries are charged, automatically rejects unsuitable cells, complete with mains adaptor. BS approved. Price is £21.95 ref EP31.

TALKING WATCH Yes, it actually tells you the time at the press of a button. Also features a voice alarm that wakes you up and tells you what the time is! Lithium cell included. £7.99 ref EP26.

PHOTOGRAPHIC RADAR TRAPS CAN COST YOU YOUR LICENCE! The new multiband 2000 radar detector can prevent even the most responsible of drivers from losing their licence! Adjustable audible alarm with 8 flashing leds gives instant warning of radar zones. Detects X, K, and Ka bands, 3 mile range, 'over the hill' 'around bends' and 'rear trap facilities. micro size just 4.25"x2.5"x.75". Can pay for itself in just one day! £79.95 ref EP3.

3" DISCS As used on older Amstrad machines, Spectrum plus3's etc £3 each ref BAR400.

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ACTIVE

A-to-D and D-to-A converters

11-bit sampling converter. Analog's *AD7861* four-channel simultaneous sampling a-to-d converter has a four-channel multiplexer for auxiliary inputs, a voltage reference and double-buffered output registers for reading in any sequence. Applications range from motor control and three-phase power systems to cellular telephones and data acquisition. Sample/hold acquisition time is 1.6μs and conversion time 3.2μs. Internal logic operates with a microcontroller to form a low-cost general-purpose data acquisition device. Analog Devices Ltd. Tel., 01932 266000; fax, 01932 247401.

And a 14-bit one. From Datel comes the *ADS-919* 14-bit, 2MHz sampling converter, which is guaranteed to have no missing codes to the 14-bit level over the military temperature range. Signal-to-noise ratio is 77dB and thd −74dB. It is pin-compatible with earlier Datel 1MHz and 2MHz types. Power is ±12V or ±15V and +5V, dissipation 1.8W. Datel (UK) Ltd. Tel., 01256 880444; fax, 01256 880706.

Audio a-to-d converter. From AKM, the *AK5391* 24-bit, 128 times oversampling, stereo, analogue-to-digital converter, which employs a new dual-bit technique for low distortion and wide range. It samples at a maximum rate of 54kHz and exhibits a sinad of 100dB, with a dynamic range of 115dB and s:n ratio of 115dB. Stop-band attenuation is 110dB. The device resets itself after power-up if it loses sync. DIP International Ltd. Tel., 01223 462244; fax, 01223 467316.

Linear integrated circuits

Dual cfa. A dual 250mA, 60MHz current feedback amplifier by Linear Technology, the LT1207 features a slew rate of 900V/μs, 0.02% differential gain and 0.17° typical differential phase. It has a pin for an optional compensation network for use with large capacitive loads. Micro Call Ltd. Tel., 01844 261939; fax, 01844 261678.

3-port isolated amplifiers. Burr-Brown offers the *ISO250* family of four, three-port isolated amplifiers in 28-pin dips: the *ISO253* buffer; *ISO254* programmable-gain amplifier; instrumentation amplifier *ISO255*; and the *ISO256* operational amplifier, all meant for industrial process control. Each model uses a new modulation-demodulation duty cycle technique for increased accuracy and possesses a 1500V continuous isolation rating (2500V for a minute). Burr-Brown International. Tel., 01923 233837; fax, 01923 233979.

Microprocessors and controllers

Low-cost PICs. New *PIC*s from Microchip are the *PIC16C710* and *711*, which are 8-bit, one-time-programmable microcontrollers for 8-bit a-to-d conversion in low-cost systems. The 711 has 1024word (1K by 14) of eprom and 68byte of ram for data memory; 710 has 512word of eprom and 36byte of data memory. Both include 35 single-word instructions, 200ns single-cycle instruction time, 3-6V operating voltage, four analogue inputs and in-circuit serial programming. An internal four-channel a-to-d converter and the brown-out detector help to reduce component count. The devices are supported by the *PICmaster* development system. Arizona Microchip Technology Ltd. Tel., 01628 851077; fax, 01628 850259.

Mixed-signal ICs

SCSI terminators. Both the *UCC5610/5611* 3.3V active terminators by Unitrode provide 18 lines of termination for the Small Computer Systems Interface (SCSI) parallel bus. During disconnect, channel capacitance is 1.8pF, minimising the effects on signal of disconnected channels, and supply current is 0.5μA. The devices operate on a supply of 2.75V to 7V and both can be programmed for 110Ω or 2.5kΩ termination. The 5610 is for standard logic, while the 5611 uses reverse logic disconnect. Unitrode (UK) Ltd. Tel., 0181-318 1431; fax, 0181-318 2549.

Optical devices

1550nm laser diode. Mitsubishi has the *FU-68PDF-1* distributed-feedback laser diode module, which has a polarisation-maintaining fibre pigtail from the butterfly package. The package also contains a thermal electric cooler and an optical isolator. Maximum impedance is 25Ω and spectral line width 20MHz typical. Optical output from the fibre end is 4mW at a forward current of 150mA. Mitsubishi Electric UK Ltd. Tel., 01707 276100; fax, 01707 278692.

Oscillators

Vcxo. Fordahl's new range of 14-pin, dual-in-line, voltage-controlled crystal oscillators allow a minimum of ±100ppm frequency pulling and ±10ppm stability over the 0-70°C range of temperatures. Output waveforms at 470MHz are ecl logic level and a clipped sine wave. Fordahl GB. Tel., 01703 848961; fax, 01703 846532.

Ovened crystal oscillator. Oscillator 4834 by Oak is available in versions covering 4-10MHz. Temperature stability is $\pm 3\times10^{-9}$ over −20°C to 70°C and ageing $\pm 3\times10^{-8}$ per year. At 100Hz, phase noise is −140dBc/Hz. Ginsbury (UK) Ltd. Tel., 01634 290903; fax, 01634 290904.

Power semiconductors

Hexfet/Schottky combination. Inevitably known as a Fetky, IR's *IRF7421D1/7422D2* are power mosfet/Schottky diode combinations in an SO-8 small-outline package, the impetus for the design being the recent reduction in mosfet die size and on-resistance obtained using the company's new process. The *7422D2* contains a −20V, 90mΩ p-channel Hexfet and a 30V, 3A Schottky, the other a 30V, 35mΩ n-channel Hexfet and a 30V, 1A Schottky. Fetkys used in dc-to-dc converters should, says IR, reduce battery drain and will reduce power dissipation and heat in the converters in desk-top systems. In both, board space and component counts will be smaller. International Rectifier. Tel., 01883 713215; fax, 01883 714234.

Class D industrial amplifiers. Apex's *SA Series* of hybrid amplifiers are 97% efficient and provide up to 20A continuously from 100V, or 2kW into a load. They find application in vibration cancellation, magnetic-coil controls, brush motor control and active magnetic bearings. An analogue input is converted into a variable duty cycle switched signal to the output stage, thereby reducing power dissipation in the device and allowing the use of smaller packages. *SA01*, the 20A one, is in a 10-pin package and switches at 42kHz, while *SA50* and *SA51* in TO-3 give 5A for 16-80V. *SA50* switches at 45kHz and the SA51 takes an external pwm signal under processor control up to 500kHz. METL. Tel., 01844 278781; fax, 01844 278746.

PASSIVE

Passive components

Mains-rated film capacitors. Arcotronics's *R.41* Class Y2 capacitor is designed for use across the 250V mains line or mains to ground and meets the standards to qualify for the EN132400 mark. It is self-healing and failure leads to open circuit rather than a short. Values are E6 from 0.001μF to 0.1μF. Test over 21 days at 40°C and in 90% humidity gave no breakdown or flashover at 1500Vac for 1 minute. Easby Electronics Ltd. Tel., 01748 850555; fax, 01748 850556.

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Non-polar electrolytics. Nitai Series D non-polar electrolytic capacitors are made in nine voltage ratings from 6.3V to 100V and in values from 0.47μF to 1000μF for the 6.3V range and 0.47μF to 100μF in the 100V types. Tolerances are ±20%, but ±10% units are available. Leakage current is less than 3μA. The body is pvc sleeved and fitted with tinned copper leads at one end. Europa Components & Equipment plc. Tel., 0181-953 2379; fax, 0181-207 6646.

Rectifiers. ITT has the *IN4000G* range of glass-passivated plastic rectifiers, which feature a 1V maximum forward voltage and 5μA leakage current at 25°C. Peak reverse voltage is 50V to 1000V, depending on which of the range is in use and max. repetitive peak forward current over 15Hz is 10A. Package is DO-41. ITT Semiconductors. Tel., 01932 336116; fax, 01932 33148.

3GHz baluns. Balun transformers from Toko now cover the range of frequencies used in GPS and wireless lans up to 3GHz. They are available in double-balanced mixer, distributor and directional coupler configurations in a range of turns ratios, being bifilar wound for good balance. These devices are pcb or surface mounted. Cirkit Distribution Ltd. Tel., 01992 444111; fax, 01992 464457.

CE-approved switches. EAO's *Series 61* push-button switches and indicators carry the CE mark for the European emc standard. The switches mount in a 16mm panel cut-out and are modular in form, having separate lens, actuator and contact block, so that the series provides many variations and options. Contacts are self-cleaning gold or silver, the gold type switching from 10mA at 5V to 250Vac at 6A. EAO-Highland Electronics Ltd. Tel., 01444 236000; fax, 01444 236641.

Connectors and cabling

Formula 1 connectors. *Micro AS Series II* miniature connectors from Deutsch are lower-cost developments of a type used in racing cars, in which the environment is, to say the least, hostile. Contacts are gold-plated and shells of aluminium alloy finished in conductive black zinc. Anti-vibration locking and seals that are proof against oils, water and many solvents are standard. Rear seals take wires from 0.6-1.37mm diameter. Deutsch Ltd. Tel., 01342 410033; fax, 01342 410005.

Emc-shielded connector. Framatome's *UTGS* connector has a twin-ferrule system to ensure 360° electrical continuity for grounding from the cable shield to the plug body. Plugs and receptacles are made of nickel-plated, glass-filled thermoplastic, the plug connectors having a metal PG tube and cable clamp. RM/RC machined contacts, SM/SC formed two-piece types and RMDX/RCDX coaxial contacts can be accommodated. The units are available in 4 to 48-way versions. Framatome Connectors UK Ltd. Tel., 01582 475757; fax, 01582 476203.

Pcb edge connector. Thermodata's new edge connector has spring-loaded clamp terminals for rapid wiring. *Edgeclamp* connectors come in 20, 56 and 72 ways on a 0.156in pitch and accept wires up to 0.19mm at 5A per way. Thermodat claim that wiring time is reduced by over 60% compared with soldering and still more than 50% compared with screw retainers. Alterations are, of course, much simpler. Thermodata Components. Tel., 01462 811757; fax, 01462 811536.

Long-lasting coax. connectors. 50/75Ω rf coaxial connectors for test jigs, capable of withstanding many thousands of mating cycles, have been added to the ODU *MAC* range of modular attachable contacts, which are aluminium frames taking plastic insulation. Bodies are inserted taking a variety of contacts. ODU UK Ltd. Tel., 01653 600489; fax, 01653 600493.

Displays

Low-profile graphics display. This new compact supertwist lcd module by Hitachi resolves 256 by 64 dots and has a single edge-lit cfl backlight, providing very good contrast, over 100cd/m^2 and a wide viewing angle. *LMG7380QHFC* has 8Kbyte of display ram and a *T6963C* graphics controller with character generation to show text and graphics simultaneously. Use of a fast-response crystal fluid makes it possible to show animation without ghosting or lag. Hitachi Europe Ltd. Tel., 01628 585163; fax, 01628 585160.

Filters

Active filters modules. These filters from Vicor complement its range of power supplies. The *VI-AM* input attenuator attenuates conducted emi and a passive/active circuit suppresses transient overvoltages. Common-mode and differential-mode chokes, in addition to the power supply decoupling, reduce noise to meet international standards. *VI-RAM* is a passive/active filter to reduce output noise and ripple to give ripple as low as 3mV pk-pk from low frequencies to tens of MHz. Vicor UK. Tel., 01276 678222; fax, 01276 681269.

Hardware

Heatsinks for power converters. Aavid produces a range of heatsinks for dc-to-dc converters, these devices being, apparently, particularly prone to heat stroke. The heatsinks are in extruded aluminium with a flat surface for least resistance; they come either unfinished or with anodised or chromate finish, All have six mounting slots, threaded or unthreaded to order. In sizes 4.6 by 2.4in and 2.4 by 2.28in, the units have various fin heights and orientations. A range of interface pads is also offered to further improve performance. Aavid Thermal Technologies Ltd. Tel., 01279 626161; fax, 01279 626208.

Industrial computer enclosures. Arcom offers two enclosures for STEbus industrial computer use, called ACE. They are described as 'boot-shaped', with the power supply in the heel, terminations and cable entry in the toe and up to six Eurocards about where the shin might go. These cases take up about half the volume of a 19in rack, many of which house mainly fresh air. The cases are die-cast and provide good noise protection and em compatibility, so that a computer built in this way can be CE self-certified. ACE-28 is for target systems, diskless pcs or remote i/o nodes, while ACE-42 is wider with 42E space and will take pcs with disk drives. Arcom Control Systems Ltd. Tel., 01223 411200; fax, 01223 410457.

Emc shielding strip. A low-compression emc shielding strip from TBA ECP takes account of small irregularities of mating surfaces, allowing equipment that does not fully compress the common type of strip to meet emi shielding standards, without increasing insertion forces. The strip is pressure sensitive and can be supplied cut to length. Finishes supplied include gold, silver, cadmium, tin/lead and nickel. TBA Industrial Products Ltd. Tel., 01706 47718; fax, 01706 46170.

Card brackets. Vero has a range of nine, nickel-plated steel brackets for use on PCI format expansion cards. They come blank, with 9-way and 25-way D cut-outs, the 9-way type having the cut-out at the top or the bottom and with or without pcb fittings. Vero Electronics Ltd. Tel., 01489 780078; fax, 01489 780978

Rfi/emc shielding. Hughes Wynne offers *Practi-Shield*, a range of materials and components for rfi and emc protection. On offer are aluminium and copper barrier shielding laminates with an insulating film on both surfaces; elastomeric gaskets from silicone rubber loaded with carbon, nickel and silver-plated glass, or from E-PTFE Gore-Shield; and Mumetal components for magnetic shielding. The company offers a computer-controlled laser profiling service. Hughes Wynne Ltd. Tel., 01932 569700; fax, 01932 569652.

Test and measurement

Isolation amplifier. On offer from Nicolet is the *BE1100* modular isolation amplifier which gives 1500Vrms isolation with filtered outputs on up to nine channels in a stand-alone instrument. Four types of amplifier module are available with inputs of 62mV to 1000V and can be mixed in any combination. Inputs are differential and floating, and outputs filtered and short-circuit protected. Nicolet Technologies Ltd. Tel., 01908 679903; fax, 01908 677331.

Digital video measurement. New facilities provided by Tektronix for its *2715* cable spectrum analyser turn the instrument into an rf test set for digital channels. The additions provide measurements of: digital average power across the channel bandwidth; desired:undesired signal power ratio (signal-to-noise and distortion power); channel triple beat and second-order distortion, the level of distortion to average power; and adjacent-channel leakage. There are facilities for unattended operation and

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collection of data. Tektronix UK Ltd. Tel., 01628 403300; fax, 01628 403301.

Dummy head measurement. *HEAD* by Head Acoustics is a sound measuring system using an anatomically and auditorily accurate model head (bald, actually) to provide reproducible recordings of sound signatures in noise diagnosis and analysis, product development and architectural acoustics, among other areas. There is a range of measuring and support equipment for the head, including storage, filtering and reproduction using the *HEADphone* playback system. Acsoft Ltd. Tel., 01296 662852; fax, 01296 661400.

Real-time/storage oscilloscope. Hitachi Denshi's *VC-6645* real-time and storage oscilloscope is characterised by a four-channel 100Msample/s rate, 100MHz bandwidth, 4Kword instrument with delaying sweep and a 100MHz frequency meter. An RS-232C interface, which is standard, conveys data to a pc using *HIMES* software. Four waveforms may be captured and memorised in a 72h-10day memory. Hitachi Denshi (UK) Ltd. Tel., 0181-202 4311; fax, 0181-202 2451.

Interfaces

Signal conditioners. *ADAM-3000* isolated signal-conditioning modules use optical techniques to provide 1000V dc isolation of input, output and power lines to protect against ground loops and interference. There are models for analogue input and output signal conditioning and for direct sensor conditioning in thermocouples, 4-20mA loops and voltage-output sensors, a 1kHz or 5Hz active low-pass filter giving extra noise rejection. Integrated Measurement Systems Ltd. Tel., 01703 771143; fax, 01703 704301.

Literature

Hitachi microcontrollers. Hitachi's *H8 Power in design* is an overview of the *H8* microcontroller family of 8/16-bit devices. It includes a summary of applications ideas and there is a section on support tools from Hitachi and other companies. Hitachi Europe Ltd. Tel., 01628 585163; fax, 01628 585160.

Production equipment

Desoldering iron. The Weller/Ungar *4024IL-A* desoldering instrument is variable in temperature from 260°C to 540°C and is electronically controlled for printed-board repairs and rework; it has a self-contained pump for desoldering and has a desoldering iron. Control is by zero-switching circuitry, the supply is isolated and the instrument is fully grounded. Cooper Tools. Tel., 0191-416 6062; fax, 0191-417 9421.

Power supplies

Fast chargers. Fast NiCd battery chargers, one for ac and the other for dc input, are announced by Relec. Both are of the switched-mode type and achieve up to 75% efficiency. The *9243* 10-18V dc model delivers a constant fast charge of 700mA to up to 16 cells, while the *8715* ac-powered unit delivers 520mA to 10 cells. The chargers contain circuitry to protect against overcharging; approaching full charge, the fast charge gives way to a trickle charge of 18mA, or 14mA in the ac type. Relec Electronics Ltd. Tel., 01962 863141; fax, 01962 855987.

5V regulator. Zetex's *ZSAT500* 5V positive regulator is particularly meant for satellite receiver low-noise blocks, offering ripple rejection of 65dB up to 22kHz and 40dB to 200kHz. Quiescent current is 350μA and maximum load current 200mA. Zetex plc. Tel., 0161-627 5105; fax, 0161-627 5467.

Small psu. Said to be the world's smallest 40W ac/dc supply, the *NLP40* by Computer Products measures 108-by-63.5 by 28.45mm, also meeting the relevant standards for conducted noise and emc and producing 36% more power per unit volume than any other known supply. Input is 86-264V ac and five single-output models give 5, 12, 15, 24 or 48V dc; two duals provide 5/12Vdc or ±12V dc; and two triples give 5/12V dc and 5/±15V dc, all regulated to within ±2%. Computer Products, Power Conversion Ltd. Tel., 01494 883113; fax, 01494 883419.

Surface-mount dc-to-dc converters. Small, self-contained dc-to-dc converters by TOKO may be paralleled together for higher currents. Both step-up and step-down models are available: 12V-to-5V at 600mA and 5V-to-12V at 115mA, with dual-rail types available. Efficiency is 87% and the units are fitted with a on-off control. Package is 14.5mm^2. Cirkit Distribution Ltd. Tel., 01992 444111; fax, 01992 464457.

High-voltage supply. Advance Hivolt announces the first of a series of high-voltage power supplies giving up to 40kV at 2.5mA, controllable in current or voltage mode by remote potentiometer or 10V analogue voltage. There is a 0-10V output for monitoring. Ripple is 20V maximum, 200ppm variation for ±10% input change and 500ppm output variation for a 0-100% load change. Other modules for outputs of 5-25kV are to be announced. Advance Hivolt. Tel., 01243 841888; fax, 01243 820555.

Radio communications products

Surface-mounted antenna. Meant for use in DECT portable telephones, Murata's *ANCLC* series of antennas uses a dielectric material and operates over a 60MHz bandwidth centred on 1890MHz. Input impedance is 50Ω and vswr in bandwidth a maximum of 2. Murata Electronics (UK) Ltd. Tel., 01252 811666; fax, 01252 811777.

73kHz amateur receiver. Cambridge Kits points out that it already has a kit suitable for the new 73kHz band – the 60kHz MSF receiver, which is easily modified. It has a built-in directional antenna, a 100Hz bandwidth if, 50dB agc and outputs for an S-meter and headphones or a speaker amplifier. Modification is only a matter of retuning and adding a variable capacitor. Using its internal antenna, the receiver will get HBG in Switzerland, MSF at Rugby and DCF77 in Germany. Cambridge Kits. Tel., 01223 860150.

GPS for telecomms. Motorola has a new GPS receiver for the telecommunications market, in which accurate timing is becoming of greater importance; for example, in simulcast operation. *VP Oncore* provides one pulse/s to a 43ns accuracy and also *T-RAIM*, which prevents faulty satellite data being used in the timing calculation. On Core can be embedded, being the size of a credit card, and an enhanced version is fitted with more memory, a battery, a low-noise amplifier and phase-carrier software. It also has an RS232/ttl interface. Motorola Automotive and Industrial Electronics Group. Tel., 01462 831111; fax, 01462 835602.

Protection devices

Programmable voltage clamp. From Unitrode, the *UC3908* clamp, which is designed to protect the load from power supply overvoltage, sustained or transient. It takes the form of a shunt regulator which, in the presence of overvoltage, keeps the output to a programmed maximum level. In the event of this circuit saturating, excess shunted current or activation of thermal shutdown, the device emits an scr gate signal to crowbar the output. When no untoward state exists, the circuit takes less than 100μA; when it springs into action, it will shunt up to 17A to maintain the output at the maximum programmed limit and sets the flag signal. Unitrode (UK) Ltd. Tel., 0181-318 1431; fax, 0181-318 2549.

Current/thermal fuses. Microtherm offers the *CT* range of fuses, which combine both overcurrent and high temperature protection in one surface-mounted package, handling up to 15A ac with special versions available. Microtherm Ltd. Tel., 01483 450100; fax, 01483 451816.

Fast suppressors. Surface-mounted transient voltage suppressors by Liteon dissipate 400W and exhibit a response time of 1ps. There are 35 types in the range of unidirectional and bidirectional devices, all in SMA style, handling forward currents up to 40A and having leakage current of less than 1μA at more than 10V. Standard breakdown voltage tolerance is 5%, but 10% types are available. Flint Distribution. Tel., 01530 510333; fax, 01530 510275.

Handheld 'scope/multimeter. New from Tektronix, the *THS700* Series of handheld instruments combining the functions of a digital multimeter and a digital oscilloscope with digital, real-time sampling. Maximum sampling rate is 500Msample/s in the *THS720*, presenting real-time displays on a 5ns/division, 100MHz timebase, dual digitisers giving full sampling on both channels simultaneously. The instrument's white, backlit lcd gives a brightness of 10foot-lamberts, much brighter than is often found. Thurlby Thandar Instruments Ltd. Tel., 01480 412451; fax, 01480 450409

Please quote *"Electronics World"* when seeking further information

Switches and relays

Quad pwm relay driver. *UC3702* from Unitrode drives up to four relays from a common bus and does not need secondary regulation of the relay bus voltage. It will drive 9V, 12V and 24V relays from a possibly poorly regulated, ripply, higher bus voltage such as 34V in a power-efficient pwm manner, the coil being used as the inductive element in a switched-mode supply. Unitrode (UK) Ltd. Tel., 0181-318 1431; fax, 0181-318 2549.

TO-5 relays. Magnetic-latching relays in Teledyne's *422 Series* are intended for applications in which reliability is vital and have been specified for satellite work. Single-pulse activation also means that no holding power is needed. Frequency handling extends well into the uhf region. Teledyne Electronic Technologies. Tel., 0181-571 9596; fax, 0181-571 9637.

Television components

Comprehensive tv signal processing. Toshiba announces the *TB1226N*, which performs video, chroma and synchronous processing for Pal, Secam and NTSC, cutting the number of external components by around half. The chip contains the I-H delay circuit and needs only one crystal for the colour carrier base frequency. Toshiba Electronics UK Ltd. Tel., 01276 694600; fax, 01276 694800.

Digital video encoder. *VP531* and *VP551* represent GEC Plessey's entry to the digital set-top box arena. The two cmos decoder chips are used with the company's bipolar rf tuner and a-to-d converters to give a low-cost core for digital decoders converting the decompressed Y, Cr and Cb MPEG outputs to NTSC or Pal. A unique feature is the provision of genlock, which allows the device to lock to the colour burst phase of an analogue signal and thereby enable digital overlay on an analogue signal in combined systems at lower than usual cost. GEC Plessey Semiconductors Ltd. Tel., 01793 518510; fax, 01793 518582.

1.3GHz counter. Thurlby Thandar has introduced the *PFM1300*, a handheld counter capable of measuring signals in the 5Hz-1300MHz range. Sensitivity is 15mV and a low-pass filter can be selected. Period measurement is provided up to 25MHz and, for very low frequencies, reciprocal counting to give readings on inputs down to 0.001Hz. Cost is £99. Thurlby Thandar Instruments Ltd. Tel., 01480 412451; fax, 01480 450409.

Transducers and sensors

Gas microvalve. EG&G IC Sensors offers the *Model 4425* silicon microvalve gas controller, a normally closed valve giving proportional control of gas flow in the 0-150cc/min range. A diaphragm forms a bi-metallic actuator and has implanted resistors; by varying the power in the resistors, the bi-metallic diaphragm distorts and moves away from its seat in a controlled manner to allow gas to flow. The device is in a pcb-mounted package and contains filtering to prevent particles in the gas affecting operation. Eurosensor. Tel., 0171-405 6060; fax, 0171-405 2040.

Signal-conditioned accelerometer. Made by EG&G IC Sensors, the *Model 3255* is believed to be the smallest signal-conditioned dc-response accelerometer available, mounting flat on a 7.5 by 13.5mm area for hand or reflow soldering. It consists of a silicon sensor and a dedicated asic in the same case, which is hermetically sealed by a gold-plated Kovar lid. The unit was designed for ±50g airbag activation, providing an output of ±40mV/g about a 2.5Vdc reference and there is a digital warning of malfunction, and a self-test facility. Eurosensor. Tel., 0171-405 6060; fax, 0171-405 2040.

Triaxial accelerometers. Isotron *2258AM2* series piezoelectric accelerometers by Endevco contain the relevant electronics and are designed to measure vibration in three orthogonal axes in small structures, having output sensitivities of 10mV/g or 100mV/g with a bandwidth of 1Hz-20kHz. Cost of operation is greatly reduced by the use of replaceable transducer elements in case of damage to one of the axes. Only one, four-conductor cable is needed. Endevco UK Ltd. Tel., 01763 261311; fax, 01763 261120.

COMPUTER

Data acquisition

PCMCIA data acquisition. Intelligent Instrumentation's i/o card system is a portable acquisition system to connect to a PCMCIA Type II slot. It consists of a card and a termination pad which provides all analogue and digital i/o on screw terminals. The card has eight differential analogue inputs with 12-bit resolution, 30kHz throughput and external triggering. Unipolar at 0-10V and bipolar on ±5V and ±10V are provided with selectable gain and input ranges. There are four digital input and output channels at ttl levels, a cold-junction compensation circuit for seven thermocouples and an adjustable voltage reference for sensors needing excitation. Intelligent Instrumentation. Tel., 01923 249596; fax, 01923 226720

Development and evaluation

PIC emulator. *ICEPIC* from Microchip is a low-cost development tool for the 8-bit *PIC16C5X* and *PIC16CXX* microcontrollers. The emulator operates under Windows 3.1 to give source-level debugging in assembly or C. Modular in design, the emulator has a motherboard with common logic and a device-specific daughter board. *ICEPIC* runs with *MPASM* and the company's *MP-C* compiler. Arizona Microchip Technology Ltd. Tel., 01628 851077; fax, 01628 850259.

Data logging

Handheld logger. Mitec's *AT40* handheld data logger has intelligent inputs to identify the type of sensor automatically and program the instrument accordingly. It has four or eight channels, a 512Kbyte memory and accepts signals of ac/dc voltage or current, resistance, temperature transducers, pulses and time/frequency; a non-contact magnetic probe can be supplied for electrical measurements. An internal processor analyses the data to allow the immediate plotting on a portable inkjet printer and display on the instrument's lcd. Interface to a pc can be direct or by way of a modem. Martron Instruments Ltd. Tel., 01494 459200; fax, 01494 535002

Programming hardware

Debugger for *68HCO5/8*. Cosmic Software offers the *ZAP* debugger for Motorola *68HCO5* and *69HCO8* microcontrollers. The debugger works with the Motorola modular evaluation system and with in-circuit emulators from Motorola and Pentica. Cosmic expects that designers will choose the *ZAP* in preference to the Motorola *MMEVS* debugger in view of its integration with Cosmic's C compiler. Four standard *ZAP* configurations form a simulator, monitor, background debugger and in-circuit emulator, so that the same debugger can be used at each stage of the design. Cosmic Software. Tel., 01734 880241; fax, 01734 880360.

Multimedia

CD-roms for notebooks. Using a PCMCIA slot in a notebook pc, you can now operate a CD-rom drive by means of a single cable. DIP Systems produces dual, quad and six-speed versions of the drive, all being compatible with MSCDEX, Windows and Windows 95 and the six-speed type giving a 900Kb/s transfer rate. The PCMCIA card is a Type 1 to fit any pc card slot and software provided makes for easy installation. The drives will also handle audio CDs and have line output and headphone jacks. DIP Systems. Tel., 01483 202070; fax, 01483 202023.

Software

Lookout for Windows. National's Lookout industrial automation software is now available in 32-bit Windows 95 and NT versions., giving users a 32-bit, object-oriented, event-driven system for building applications from a simple human interface to supervisory control and data acquisition (Scada) systems, working at a rate almost twice as fast as in a 16-bit version. National Instruments UK. Tel., 01635 572400; fax, 01635 523154.

Data visualisation. HiQ by National Instruments is an interactive package to allow the visualisation of maths and data. It runs as a native, 32-bit application in Windows 95 or NT, uses ole and ActiveX and the OpenGL 3-d graphics library to provide ActiveMaths and visualisation to ActiveX and Microsoft Office applications such as Word and Excel. National Instruments UK. Tel., 01635 572400; fax, 01635 523154. ■

Precision preamplifier '96

"Could this be the quietest audio preamplifier design in existence?" asks Douglas Self. Part II concentrates on circuit design, revealing a new concept in hi-fi tone control.

Morgan Jones raised the excellent point of crosstalk in the input-select switching in a recent article*. If the source impedance is significant then this may be a serious problem.

While I agree that Morgan's rotary switch with every other contact grounded may be slightly superior to conventional rotary switches, measuring a popular Lorlin switch type showed the improvement to be only 5dB. I am also unhappy with all those redundant 'mute' positions between input selections, so I instead chose interlocked push-switches rather than a rotary. A four-pole-changeover format can then be used to reduce crosstalk.

The problem with conventional input select systems like **Fig. 1a** is that the various input tracks necessarily come into close proximity, with significant crosstalk through capacitance C_{stray} to the common side of the switch, ie from A to B. Using two changeovers per input side – ie four for stereo – allows the intermediate connection B-C to be grounded by the NC contact of the first switch section. This keeps the 'hot' input A much further away from the common input line D, as shown in Fig. **1b**.

Crosstalk data in **Table 1** was gathered at 10kHz, with 10kΩ source impedances. The emphasis here is on minimising inter-source crosstalk, as interchannel (L–R) crosstalk is benign by comparison. Interchannel isolation is limited by the placement of left and right on the same switch, with the contact rows parallel, and limits L–R isolation to –66dB at 10kHz with 10kΩ source impedance.

With lower source impedances, both inter-source and interchannel crosstalk is proportionally reduced. In this case, a more probable 1kΩ source gives 115dB of intersource rejection at 10kHz for the four-pole-changeover method.

* Valve preamplifiers, Morgan Jones, March and April issues.

Line input criteria

Nowadays the input impedance of a preamp must be high to allow for interfacing to anachronistic valve equipment, whose output may be taken from a valve anode. Even light loading compromises distortion and available output swing. A minimum input impedance is

Table 1. Crosstalk exhibited by four switch arrangements using a 10kHz test signal.

Simple rotary:	71dB
Morgan-Jones rotary:	76dB
2 c/o switch	74dB
4 c/o switch	95dB

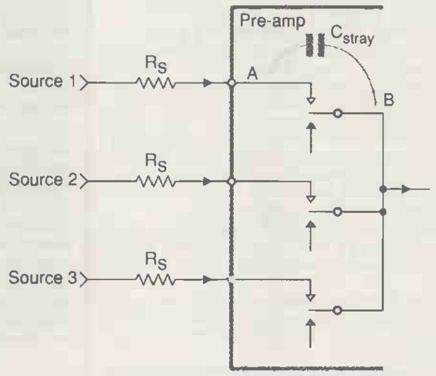

Fig. 1a). Input-select switching for audio preamplifiers – the conventional method, with poor rejection of unselected sources due to C_{stray}.

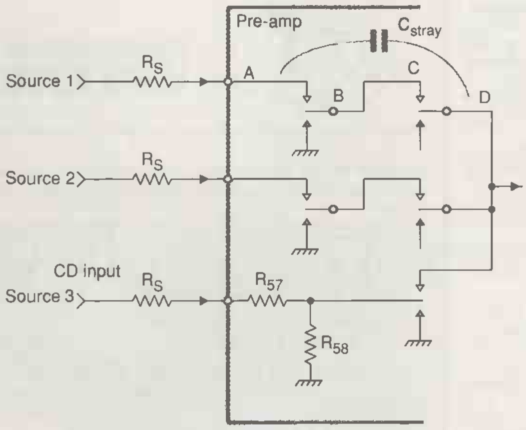

Fig. 1b). Improved input selection using four-pole switching to reduce capacitance between the different sources. The CD input attenuator can be grounded when not selected, so 2-pole switching is sufficient for high isolation of Source 3.

100kΩ, which many preamp designs fall well short of.

The CD input stands out from other line sources in that its nominal level is usually 1V rather than 150mV. This is perfectly reasonable, since digital sources have rigidly defined maximum output levels, and these might as well be high to reduce noise troubles. There is no danger of the analogue output section clipping. However, this means a direct line input cannot be used without the trouble of resetting volume and recording-level controls whenever the CD source is selected.

This problem is addressed here by adding a 16dB passive attenuator, as shown for Source 3 in Fig. 1b. The assumption is that a CD output has a low impedance, and that a 10kΩ input impedance will not embarrass it. As a result, resistance values can be kept low to minimise the noise degradation.

Output impedance of this attenuator is 1.4kΩ, which generates –120.9dBu of Johnson noise as opposed to –135.2dBu from a direct 50Ω source. This is still much less than the preamp internal noise and so the noise floor is not degraded. It is now possible to improve inter-source crosstalk simply by grounding the CD attenuator output when it is not in use, so only a two-pole switch is required for good isolation of this source.

The tape-monitor switch allows the replay signal from the tape deck to be compared with the source signal. With three-head machines, this provides a real-time quality check. But with the much more common two-head appliances, where the input signal is looped straight back to the amplifier in RECORD mode, it only provides confirmation that the signal has actually got there and back.

Line input buffering

This stage has to provide a high input impedance and variable gain for the balance control. My last preamp[1] had the balance control incorporated in the tone stage, but this does not appear to be practical with the more complex tone system here.

The vernier balance control alters the relative stage gain by +4.5, –1.1dB – a difference of 6dB – which is sufficient to swing the image wholly from one side to the other. Since the minimum gain of this non-inverting stage is unity, the nominal gain with balance control central is 1.1dB. Maximum gain of the active gain stage, or AGS, is reduced to allow for this. The active nature of this balance control means that the signal never receives unwanted attenuation that must be undone later with noisy amplification. The gain law is modified by R_{34} to give as little gain as possible in the centre. Maximum gain is set by R_{35}, Fig. 11.

A high input impedance is obtained simply by using a high-value biasing resistor R_{33}, accepting that the bias current through this will give some negative output offset; at –180mV this is not large enough to reduce headroom. Input impedance is therefore 470kΩ, high enough to prevent loading problems with any conceivable source equipment.

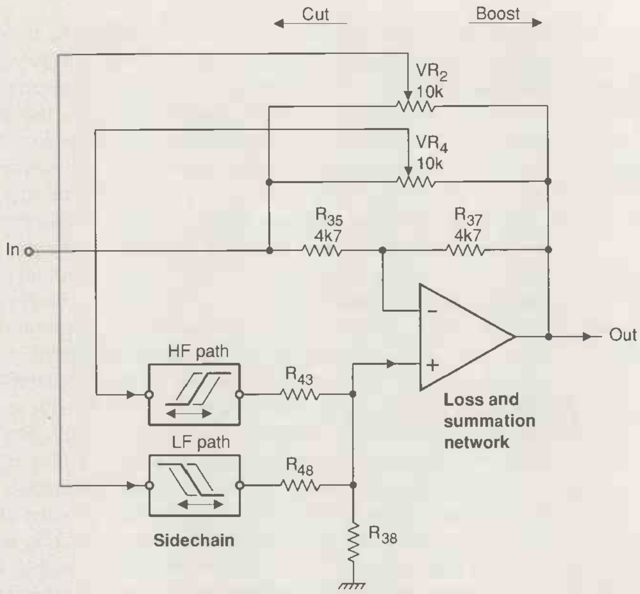

Fig. 2. The basic tone control circuit. The response only deviates from unity gain at frequencies passed by the hf or lf side-chain paths.

In discussing noise there are fundamental limits that lend perspective to the process. If the external source impedance is 50Ω, which is about as low as is plausible, the inherent thermal noise from it is –135.2dBu in 22kHz bandwidth. This is well below the measuring equipment, (AP System 1) which has an input noise floor I measured at –116.8dBu, 50Ω source again.

The noise output of the buffer/balance stage is of the same order and cannot be measured directly – a good way would be to use the flat moving-coil cartridge stage as a preamp for the testgear[2]. Calculated noise output is –116dBu with balance central.

Controlling tone

I plan to ignore convention once again. I think tone controls are absolutely necessary, and it is a startling situation when, as frequently happens, anxious inquirers to hi–fi advice columns are advised to change their loudspeakers to correct excess or lack of bass or treble. This is an extremely expensive way of avoiding tone controls.

This design is not a conventional Baxandall tone control. The break frequencies are variable over a ten to one range, because this makes the facility infinitely more useful for correcting speaker deficiencies. This enhancement flies in the face of Subjectivist thinking, but I can live with that. Variable boost/cut and frequency enables any error at top or bottom end to be corrected to at least a first approximation. It makes a major difference, as anyone who has used a mixing console with comprehensive EQ will tell you.

Middle controls are quite useless on a preamplifier. They are no good for acoustic correction: after all, even a third-octave graphic equaliser isn't that much use. Variable frequency mid controls are standard on mixing consoles because their function is voicing – ie giving a sound a particular character – rather than correcting response anomalies.

Certain features of the tone control may make it more acceptable to those with doubts about its sonic correctness. The tone control

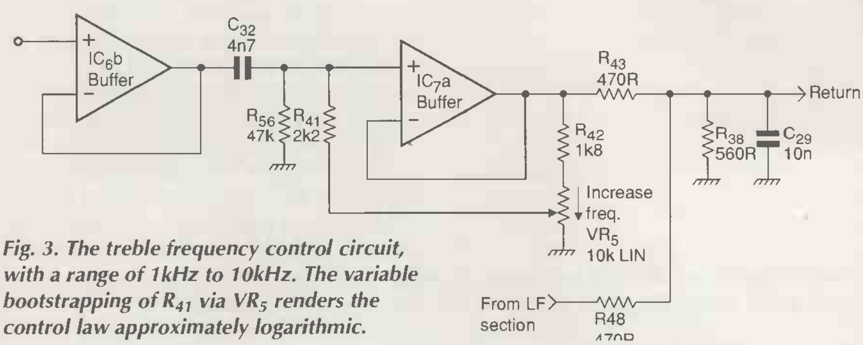

Fig. 3. The treble frequency control circuit, with a range of 1kHz to 10kHz. The variable bootstrapping of R_{41} via VR_5 renders the control law approximately logarithmic.

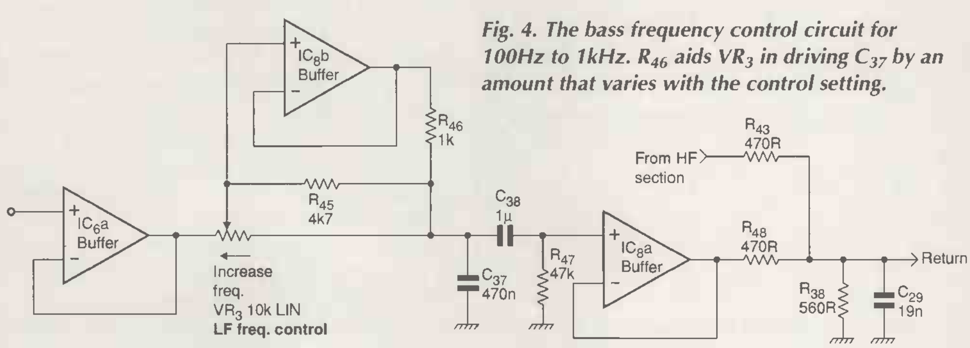

Fig. 4. The bass frequency control circuit for 100Hz to 1kHz. R_{46} aids VR_3 in driving C_{37} by an amount that varies with the control setting.

range is restricted to ±10dB, rather than the ±15dB which is standard in mixing consoles. The response is built entirely from simple 6db/octave circuitry, with inherently gentle slopes. The stage is naturally minimum-phase, and so the amplitude curves uniquely define the phase response. This will be shown later, where the maximum phase-shift does not exceed 40° at full boost.

This is a return-to-flat tone control. Its curves do not plateau or shelve at their boosted or cut level, but smoothly return to unity gain outside the audio band. Boosting 10kHz is one thing, but boosting 200kHz is quite another, and can lead to some interesting stability problems. The fixed return-to-flat time-constants mean that the boost/cut range is necessarily less at the frequency extremes, where the effect of return-to-flat begins to overlap the variable boost/cut frequencies.

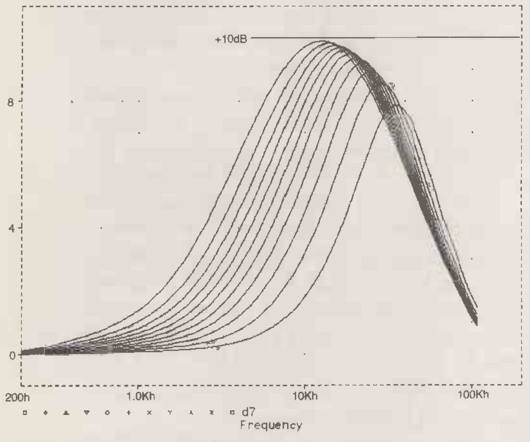

Fig. 5. Treble frequency control law for constant increments of rotation. The curves approximate to linear spacing on the log frequency axis. PSpice simulation.

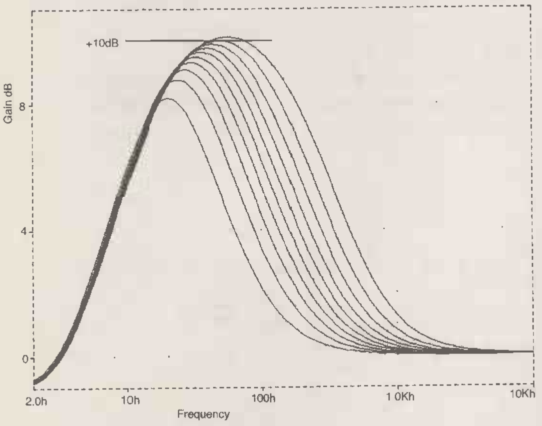

Fig. 6. Bass frequency control law with near-linear spacing on the log frequency axis.

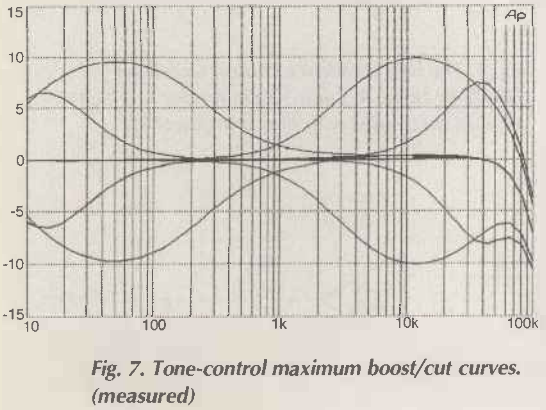

Fig. 7. Tone-control maximum boost/cut curves. (measured)

The basic principle is shown in **Fig. 2**. The stage gives a unity–gain inversion, except when the selective response of the side-chain paths allow signal through. In the treble and bass frequency ranges, where the side-chain does pass signal, boost/cut potentiometers $VR_{2,4}$ can give either gain or attenuation. When a wiper is central, there is a null at the middle of the boost/cut potentiometer, no signal through that side-chain, and gain is unity.

If the potentiometer is set so the side-chain is fed from the input then there is a partial cancellation of the forward signal; if the side-chain is fed from the output then there is a partial negative-feedback cancellation. To put it another way, positive feedback is introduced to counteract part of the negative feedback through R_{37}.

This apparently ramshackle process actually gives boost/cut curves of perfect symmetry. In fact this symmetry is pure cosmetics, because you can't use both sides of the curve at once, so it hardly matters if they are exact mirror-images.

Bass and treble

The tone control stage acts in separate bands for bass and treble, so there are two parallel selective paths in the side-chain. These are simple *RC* time-constants, the bass path being a variable-frequency first-order low-pass filter, and the associated bass control only acting on the frequencies this lets through.

Similarly, the treble path is a variable high-pass filter. The filtered signals are summed and returned to the main path via the non-inverting input, and some attenuation must be introduced to limit cut and boost.

Assuming a unity-gain side-chain, this loss is 9dB if cut and boost are to be limited to ±10dB. This is implemented by R_{43}, R_{48} and R_{38}, Figs 2, **3** and **4**. The side-chain is unity-gain, and so has no problems with clipping before the main path does. As a result, it is highly desirable to put the loss after the sidechain, where it attenuates side-chain noise.

The loss attenuator is made up of the lowest value resistors that can be driven without distortion. This minimises both the Johnson noise therein and noise generated by op-amp IC_{7b}.

The tone cancel switch disconnects the entire sidechain, ie five out of six op-amps, from any contribution to the main path, and usefully reduces the stage output noise by about 4dB, depending on the hf frequency setting. It leaves only IC_{7b} in circuit, which is required anyway to undo the gain-control phase-inversion.

Unlike configurations where the entire stage is by-passed, the signal does not briefly disappear as the switch moves between two contacts. This minimises transients due to suddenly chopping the waveform and makes valid tone in/out comparisons much easier.

Having all potentiometers identical is very convenient. I have used linear 10kΩ controls, so the tolerances inherent in a two-slope approximation to a logarithmic law can be eliminated. This only presents problems in the tone stage frequency controls, as linear potentiometers require thoughtful circuit design to give the logarithmic action that fits our perceptual processes.

Basics of the treble path are shown in Fig. 3. Components C_{32}, R_{41} are the high-pass time-constant, driven at low-impedance by unity-gain buffer IC_{6b}. This is needed to prevent the frequency from altering with the boost/cut setting. The effective value of R_{41} is altered over a 10:1 range by varying the amount of bootstrapping it receives from IC_{7a}, the potential divider effect and the rise in source resistance of VR_5 in the centre combining to give a reasonable approximation to a logarithmic frequency/rotation law, **Fig. 5**.

Resistor R_{42} is the frequency end-stop resistor. It limits the maximum effective value of R_{41}. Capacitor C_{29} is the treble return-to-flat capacitor. At frequencies above the audio band it shunts all the sidechain signal to ground, preventing the treble control from having any further effect.

The treble side-chain does degrade the noise performance of the tone control stage by 2–3dB when connected. This is because it must be able to make a contribution at the hf end of the audio band. As you would expect, the noise contribution is greatest when the hf frequency is set to minimum, and so a wider bandwidth from the side-chain contributes to the main path.

The simplified bass path is shown in Fig. 4. Op-amp IC_{6a} buffers VR_2 to prevent boost/frequency interaction. The low-pass time-constant capacitor is C_{37}, and the resistance is a combination of VR_3 and $R_{45,46}$.

Capacitors $C_{38,39}$ with R_{47} make up the return-to-flat time-constant for the bass path, which blocks very low frequencies, limiting the lower extent of bass control action. The bass frequency law is made approximately logarithmic by IC_{8b}; for minimum frequency VR_3 is set fully counter-clockwise, so the input of buffer IC_{8b} is the same as the C_{37} end of R_{46}, which is thus bootstrapped and has no effect.

Turnover

When VR_3 is fully clockwise, $R_{45,46}$ are effectively in parallel with VR_3 and the turnover frequency is at a maximum. Resistor R_{45} provides some extra law-bending, **Fig. 6**. Sadly, an extra op-amp is required. However, despite its three op-amps, the bass side-chain contributes very little extra noise to the tone stage. This is because most of its output is inherently rolled off by the low-pass action of C_{37} at high frequencies, almost eliminating its noise contribution.

Once the active elements have been chosen – here *5532*s – and the architecture made sensible in terms of avoiding attenuation-then-amplification, keeping noise-gain to a mini-

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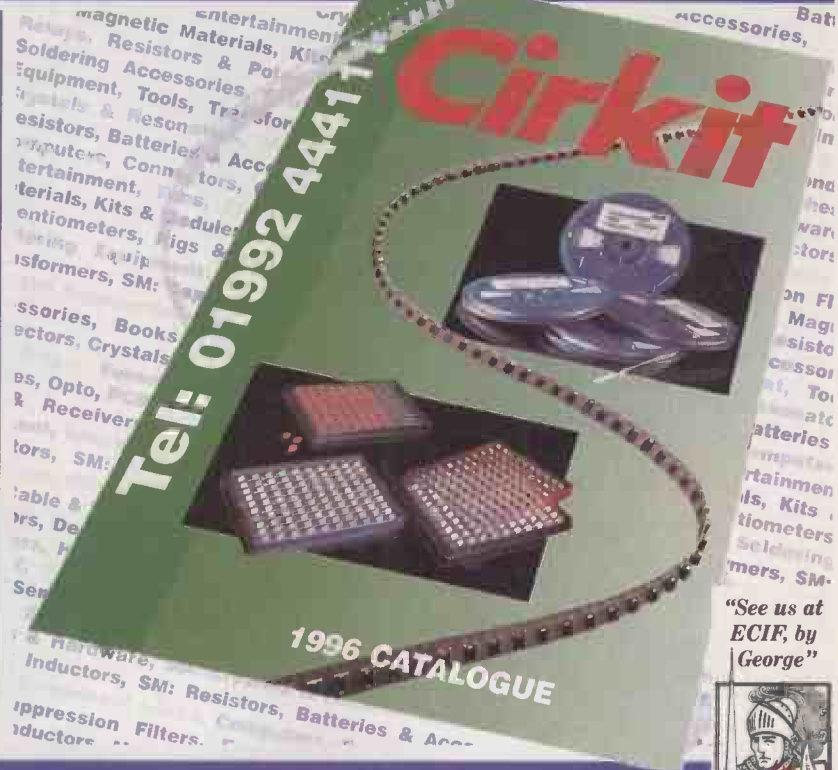

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HP 214A high power pulse generator 10 Hz-10 MHz OPT 001 .... £750
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GIGA GR1101A 12 GHz-18 GHz pulse generator (as new) £650
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MARCONI TF2016 10 KHz-120 MHz (£250) TF2016A £295
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mum, and so on, there remains one further means of improving noise performance. This is to reduce the impedance of the circuitry.

The resistances are lowered in value, with capacitances scaled up to suit, by a factor that is limited only by op-amp drive capability. This is another good reason to use the *5534/2*.

Two examples of this process as applied to the tone stage are given here. In each case the noise improvement is for the stage in isolation, set flat with high frequency set at minimum:

Firstly, in this sort of stage $R_{36,37}$ are conventionally 22kΩ. This was reduced to 4.7kΩ, and noise output dropped by 1.3dB. Secondly, the summation/loss network began with $R_{43,48}$ as 4.7kΩ, and R_{38} as 5.6kΩ. Reducing this by a factor of ten to 470Ω and 560Ω respectively reduced output noise by 0.6dB.

With balance control central and tone cancel pressed, noise output of the tone stage, plus the line/balance buffer before it is –107.2dBu. This is 22kHz bandwidth. With tone controls active but set flat, noise output at minimum high frequency is –104.7dBu, and at maximum is –106.7dBu.

The final tone stage may look rather a mess of pottage, and be afflicted with more buffers than Clapham Junction. This is unavoidable if control interaction is to be wholly eliminated. Sadly, the practical tone circuit is somewhat more complex than Figs 2, 3 and 4, reflecting one of the disadvantages of low-noise op-amps. This is that bipolar input stages mean that the bias currents are non-negligible. They must not be allowed to flow through potentiometers if crackling noises are to be avoided when they are moved.

These bias currents also tend to be reflected in significant output offset voltages, as the source resistances for the two op-amp inputs are not normally the same. All gain-variable circuit stages therefore have their gain reduced to unity at dc. This subject is detailed later.

Figure 7 shows the measured extremes of cut and boost at the frequency extremes. **Figure 8** gives the phase-shift at hf while **Fig. 9** shows phase-shift at low frequencies. In both cases it is very modest.

Active gain stage

The active gain stage, or AGS, used here as in[1], is due to Baxandall[3]. Maximum gain is set to +23dB by the ratio of $R_{52,53}$, to amplify a 150mV line input to 2V with a small safety margin.

An active volume-control stage gives the usual advantages of lower noise at gain settings below maximum, and for the Baxandall configuration, excellent channel balance that depends solely on the mechanical alignment of the dual linear potentiometer. All mismatches of its electrical characteristics are cancelled out, and there are no quasi-log dual slopes to induce anxiety.

Note that all the potentiometers are 10kΩ linear types and identical, apart from the question of centre-detents, which are desirable only on the balance, treble and bass boost/cut controls.

Compared with[1], noise has been reduced by an impedance reduction on the gain-definition network $R_{52,53}$. The limit on this is the ability of buffer IC_{5a} to drive R_{52}, which has a virtual earth at its other end. **Figure 10** shows the volume control law for different maximum gain settings; only the very top end of the curve alters significantly.

For the rear section of the preamp – ie that shown in **Fig. 11a** – the noise performance depends on control settings. The table below gives results for hf frequency at minimum, the worst case, **Table 2**.

The figures for maximum gain may look unimpressive, but remember this is with +23dB of gain; at normal volume settings the noise output is below –100dBu. I think this is reasonably quiet.

Output muting and relay control

The preamp includes relay muting on the main outputs. This is to prevent thuds and bangs from upstream parts of the audio system from reaching the power amplifiers and speakers at power-up and power down. Most op-amp circuitry, being dual-rail (ie outputs at 0V) does not inherently generate enormous thumps, but it cannot be guaranteed to be completely silent. It may produce a very audible turn-on thud, and often objectionable turn-off noise. I recall one design that emitted an unnerving screech of fading protest as the rails subsided...

Electronic muting is desirable, but introduces unacceptable compromises in performance. Relay muting, given careful relay selection and control, is virtually foolproof. The relay must be normally-open so the output is passively muted when no power is applied. The control system must:

- Delay relay pull-in at power-up, to mute turn-on transients. A delay of at least 1 second before the relay closes.
- Drop out the relays as fast as possible at power-down, to stop the dying moans of the preamp, etc, from being audible.

My preferred technique is a 2ms or thereabouts power-gone timer, held in reset by the ac on the mains transformer secondary, except for a brief period around the ac zero-crossing, too short to allow the timer to trigger. When the ac disappears, this near-continuous reset is removed, the timer fires, and relay power is removed within 2ms. This is over long before the reservoir capacitors in the system can discharge, so turn-off transients are authoritatively suppressed.

However, if the mains switch contacts generate an rf burst that is in turn reproduced as a click by the preamplifier, then even this method may not be fast enough to completely mute it.

Fig. **11b** shows the practical relay-control circuit. At turn-on, R_{211} slowly charges C_{224} until Tr_{205} and D_{207} are forward biased, ie when C_{224} voltage exceeds that set up by $R_{214,215}$. This is the turn-on delay. Transistor Tr_{206} is then turned on via R_{213}, energising the relays, and LD_{201} is brightly lit through D_{208} and R_{216}. This led is dimly lit via R_{217} as soon as power is applied, but only brightens when

Table 2. Characteristics of the tone-control stage.

	Tone cancel	Tone flat
AGS zero gain	–114.5dBu	–114.5dBu
AGS unity gain	–107.4dBu	–105.3dBu
AGS fully up	–90.2dBu	–86.4dBu

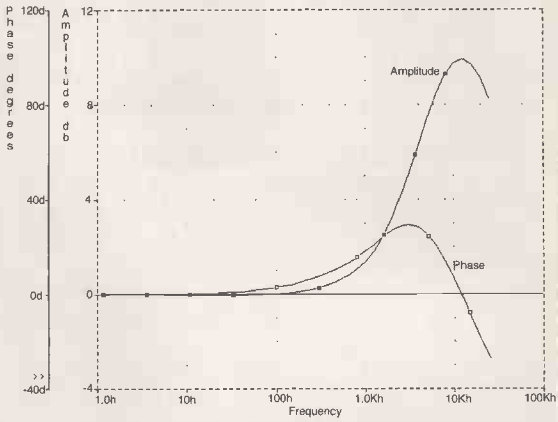


Fig. 8. Tone control phase curve for maximum treble boost. Maximum phase-shift is 29° at about 4kHz. PSpice simulation.

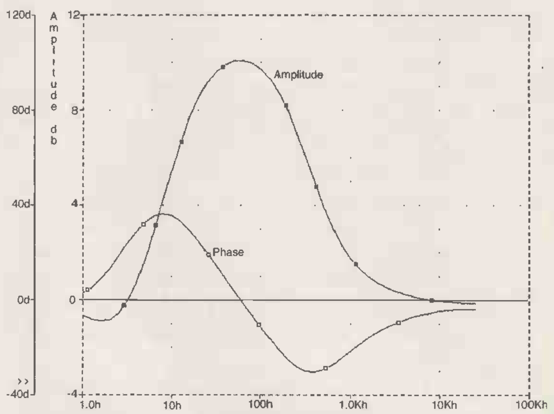


Fig. 9. Tone control phase curve for maximum bass boost. Maximum phase-shift is 31° at 40Hz.

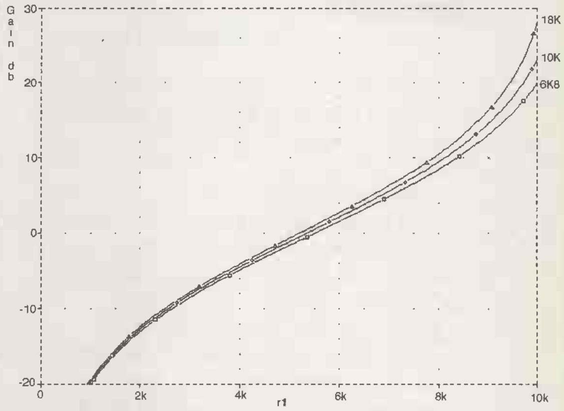


Fig. 10. Plot of the Active Gain Stage volume control law. Varying the maximum gain has little effect except at the top end; the middle curve is the one used in the preamp.

the initial mute period is over.

As long as mains power is applied, Tr_{203} is kept turned on through $D_{205,206}$ by the ac ahead of the bridge rectifier, except during the zero-crossing period every 10ms, when the voltage is too low for Tr_{203} base to conduct. When Tr_{203} switches off, C_{223} starts to charge through R_{208}, but is quickly discharged through R_{207} when the very brief zero-crossing period ends. If it does not end – in other words mains power has been switched off – C_{223} keeps charging until Tr_{204} turns on, discharging C_{224} rapidly via R_{210}, and removing power from the relays almost instantly.

DC blocking and additional details

The preamp circuitry has been described as each stage was dealt with, so this section is confined to dc blocking problems and other odd subjects.

The complete circuit of the line section of the preamp is Fig. 11a. Bias current is kept out of balance potentiometer VR_1 by C_{27}, and dc gain held to unity by C_{28}. Capacitors C_{31} and C_{35} keep bias currents out of $VR_{2,4}$, necessitating bias resistors R_{40},R_{44}.

The treble frequency law is corrected by bootstrapping through C_{33}, which keeps the bias current of IC_{7a} out of VR_5. Similarly, C_{34} prevents any offset on IC_{7a} output reaching VR_5. In the bass path C_{36} keeps IC_{8b} bias out of VR_3, while return-to-flat components $C_{38,39}$ and R_{47} provide inherent dc-blocking.

Final offsets at the side-chain output are blocked by C_{40}, while IC_{7b} bias is blocked by C_{30}. This is essential to prevent the tone-cancel switch clicking due to dc potentials. Bear in mind that this switch may still appear to click if it switches in or out a large amount of response-modification of a non-zero signal. This is because the abrupt gain-change generates a step in the waveform that is heard as a click. This is unavoidable with hard audio switching.

Capacitor C_{41} keeps IC_{7b} output offset from volume control VR_6, while C_{42} blocks IC_{5a} bias current from the pot wiper. Capacitor C_{44} gives final dc blocking to protect the following power amplifier.

Many components in this design are the same value; for example, wherever a sizable non-electrolytic is required, 470nF could usually be made to work. This philosophy has to be abandoned in areas where critical parameters are set, such as the RIAA network and tone control stage.

Supplying power

This is a conventional power supply using IC regulators. I strongly recommend that you use a toroidal mains transformer to minimise the ac magnetic field.

Supply rails have been increased from ±15V to ±18V to maximise headroom. Nonetheless, 15V regulators are specified as they are easy to obtain. Their output increased to 18V by means of $R_{201,203}$, Tr_{201} and $R_{202,204}$, Tr_{202}.

It is common to use a potential divider to 'stand-off' the regulator by a fixed proportion of the output voltage. In the improved version here, positive divider $R_{201,203}$ is buffered by emitter-follower Q_{201}. Thus $R_{201,203}$ can be higher in value – saving power – while Tr_{201} absorbs the ill-defined quiescent current from the regulator COM pin.

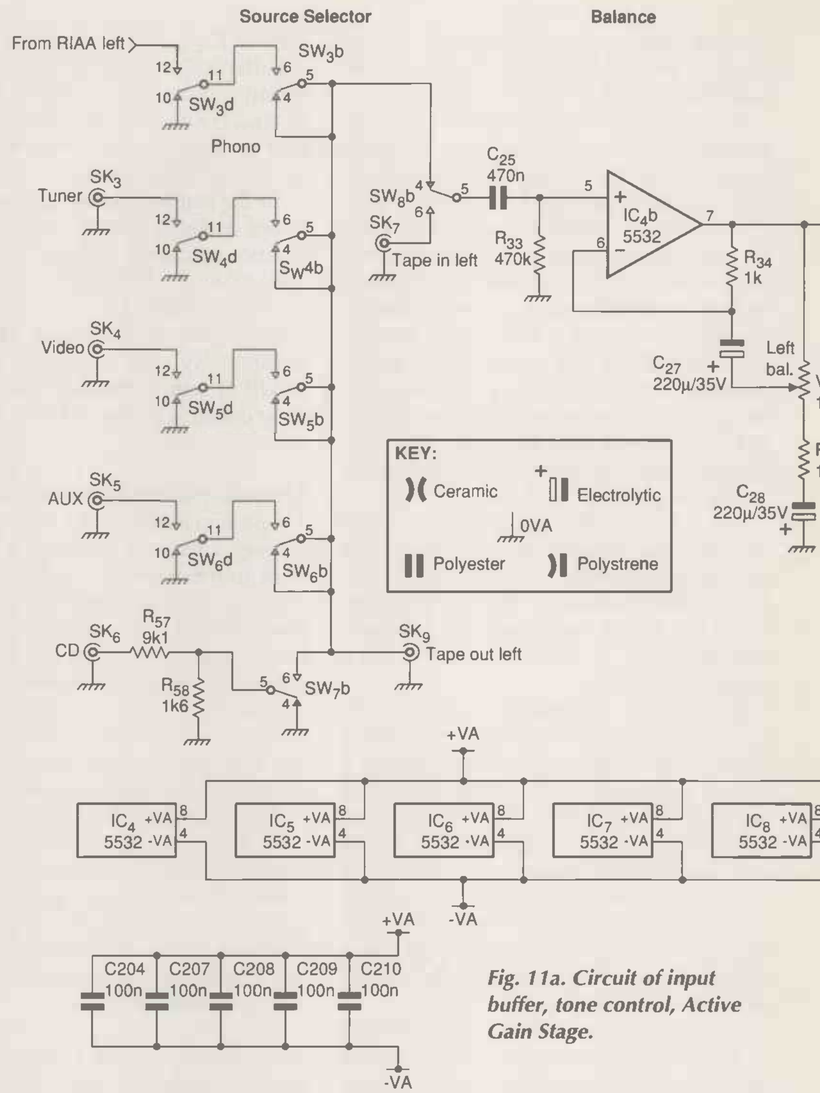


Fig. 11a. Circuit of input buffer, tone control, Active Gain Stage.

Choosing the right op-amps

Exotic and expensive op-amps will probably give a disappointing noise performance. The bipolar input of the *5534/32* is well matched to the medium-low impedances used in this preamplifier. For example, an *OP-27* might be expected to be quieter in the moving-magnet cartridge stage; but when measured, or calculated, it is 2dB noisier.

The performance

Figure 12 shows the thd of the flat moving-coil cartridge stage alone, at maximum gain. The rise at extreme lf is due to the integrator time-constant. **Figures 13 & 14** give the thd of the moving-magnet cartridge disc input and the entire rear section respectively. Levels involved are ten times those found in real use. Distortion is not a problem here.

Crosstalk performance attained depends very much on physical layout. Capacitive crosstalk can be minimised by spacing components well apart, or by simple screening. Resistive crosstalk depends on the thickness of the various ground paths.

It would be desirable to specify a grounding topology for optimal results, but this is not so easy. I found that the more tightly the various grounds are tied together with heavy conductors, the better the crosstalk performance. There seemed little scope for subtlety.

As with noise performance, the results depend somewhat on control settings, but under most conditions the prototype gave about –100dB flat across 20Hz–20kHz, with noise contributing to the reading. This was not hard to achieve.

The preamplifier in perspective

In determining what (if anything) has been achieved by this design, we must see if it is capable of any further improvement.

- The moving-magnet stage input noise performance is limited by the electrical characteristics of the cartridge and its loading needs.
- Making the RIAA any more accurate will be expensive.
- Increasing disc input headroom would require the use of higher supply rails, demanding discrete amplifier stages.

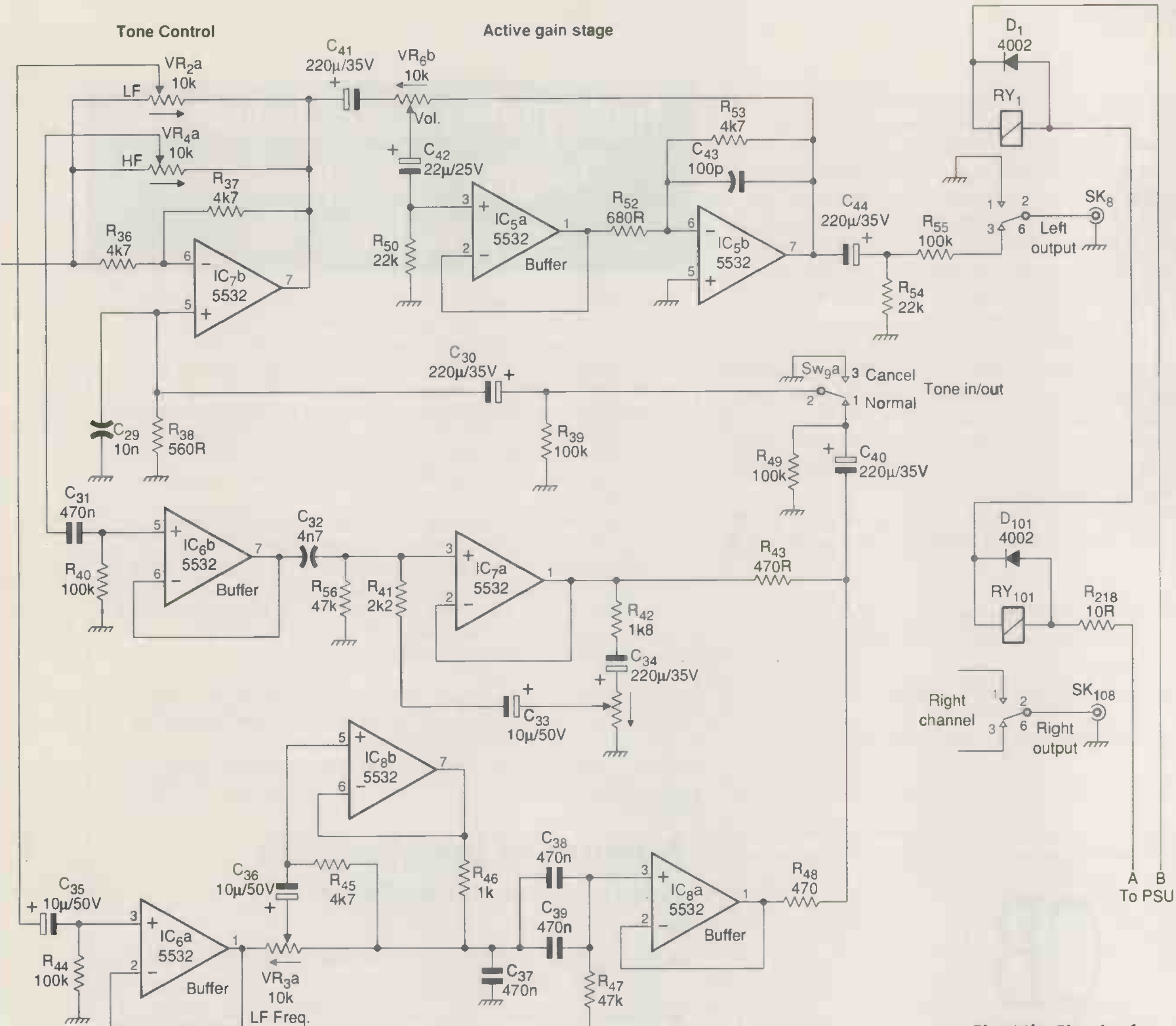
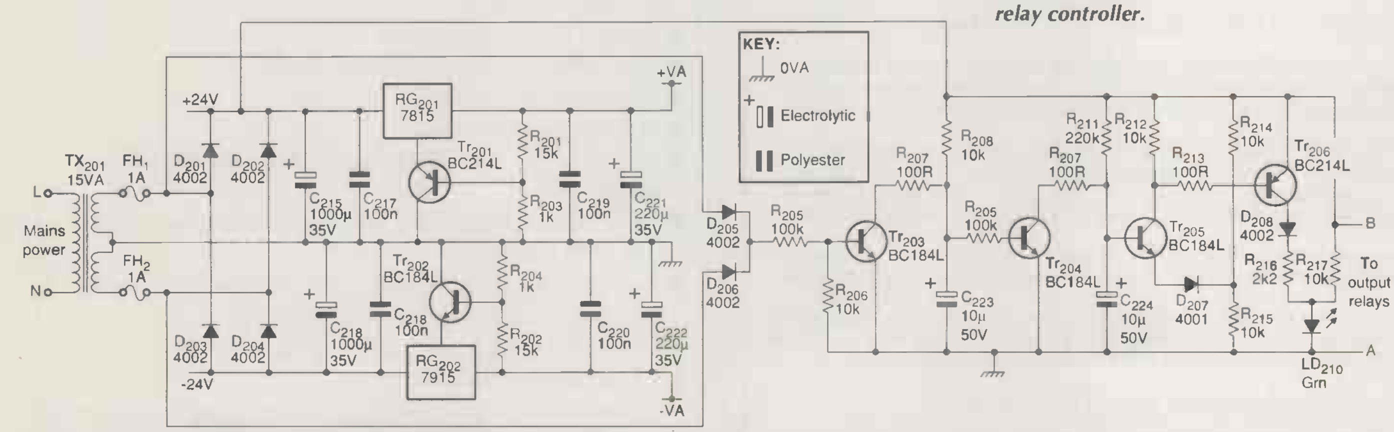


Fig. 11b. Circuit of power-supply and relay controller.



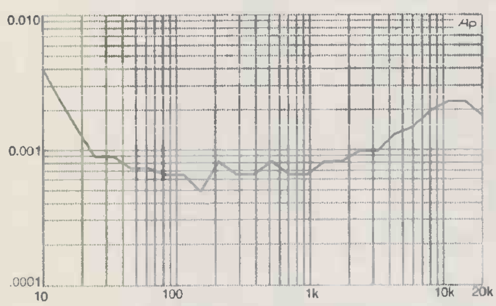


Fig. 12. THD of the moving coil stage alone, at $2.2V_{rms}$ output. Measurement bandwidth 30kHz.

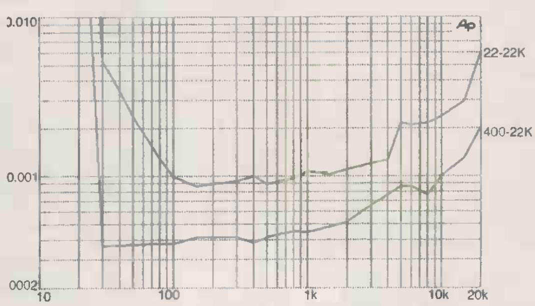


Fig. 13. THD of disc input stage in moving-magnet mode, at $8V_{rms}$ output. Bandwidth 22–22kHz upper trace and 400–22kHz lower trace, which gives a more valid result as magnetic hum is excluded. Distortion is very low, but rises at hf due to increasing loading.

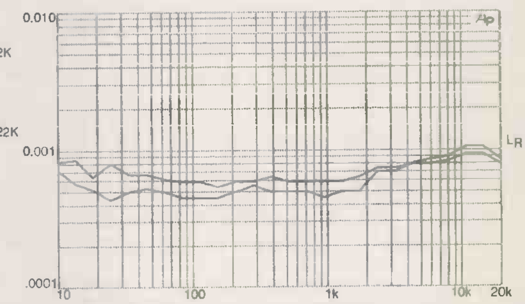


Fig. 14. THD of rest of preamplifier at $8V_{rms}$ in and out, ie volume control set for unity gain. Tone control set flat, bandwidth 80kHz. Distortion is below 0.001%.

Having gone to some effort to make the preamplifier as noise-free and transparent as possible, we should ask how it compares with other parts of the system. The standard Blameless Class B power amplifier[4] output noise is –93.5dBu, and the Trimodal[5] with the low-impedance feedback network reduces this to –95.4dBu. In both cases the source impedance is 50Ω.

Both amplifiers have a closed-loop gain of +27.2dB, and so the equivalent input noise (EIN) is –120.7dBu and –122.6dBu respectively. This can be compared with the source-resistance Johnson noise of 50Ω, which is –135.2dBu. The best power-amp noise figure is therefore 12.6dB, which is some way short of perfection.

In contrast, the noise output from the preamplifier is never less than –114.5dBu with the volume control at zero. Even in this rather useless condition, the preamplifier increases the total noise output, as it produces 8dB more than the Trimodal power amplifier input noise. At mid-volume (in-line mode) the preamplifier noise is –105.3dBu, which is 17dB worse than the power-amp; clearly as far as preamp design is concerned, history has not yet ended.

Even so, serious thought has been given to whether this may be the quietest preamp yet built. Comments and opinions on this are invited.■

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1. D. Self, 'A Precision Preamplifier', *Wireless World*, Oct 1983, p31.
2. D. Self, 'Ultra-Low-Noise Amplifiers and Granularity Distortion', *Journ AES*, Nov 1987 pp907-915.
3. P. Baxandall, 'Audio Gain Controls', *Wireless World*, Nov 1980, pp 79-81.
4. D. Self, 'Distortion in Power Amplifiers: Part 2', *Electronics World*, Sept 1993, p736.
5. D. Self, 'Trimodal Audio Power', *Electronics World*, June 1995, p462.

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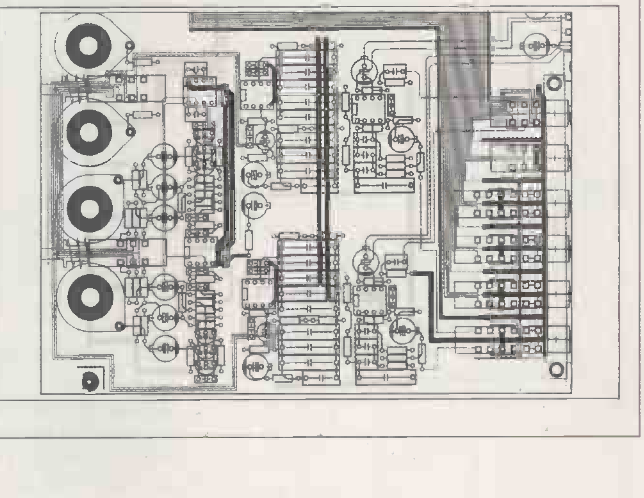

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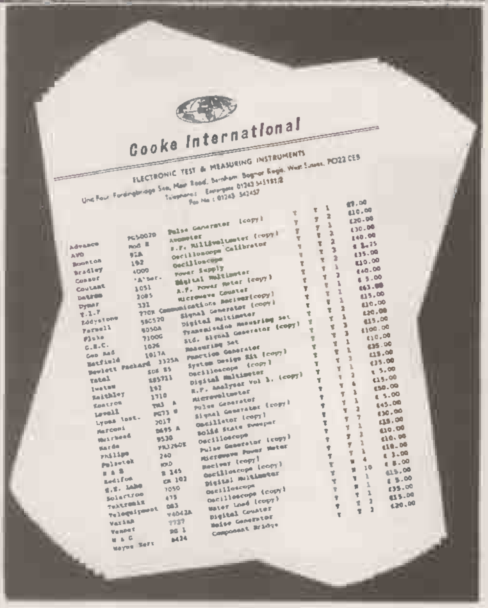

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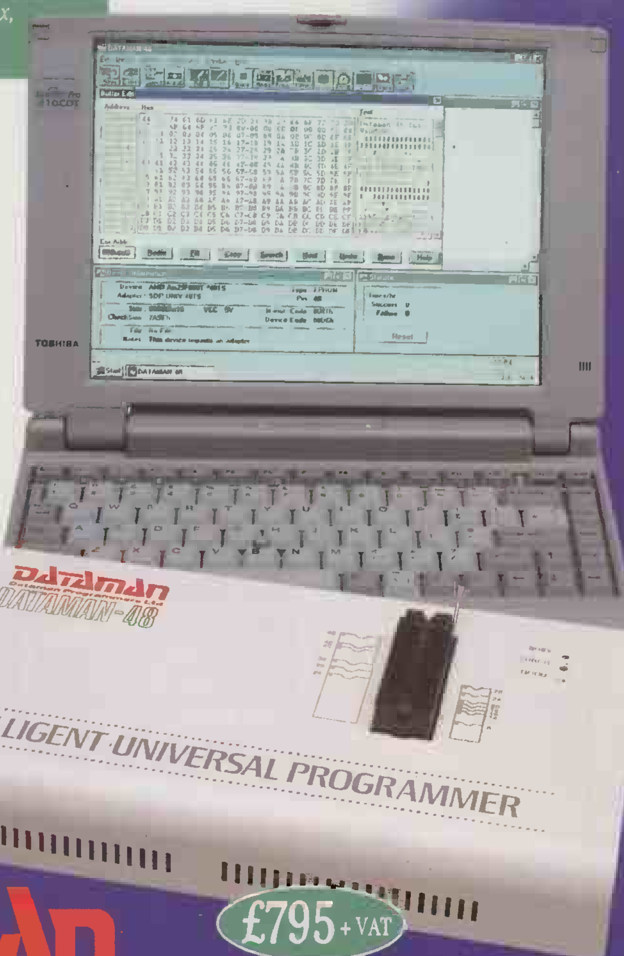

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