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LDR stabilised oscillator
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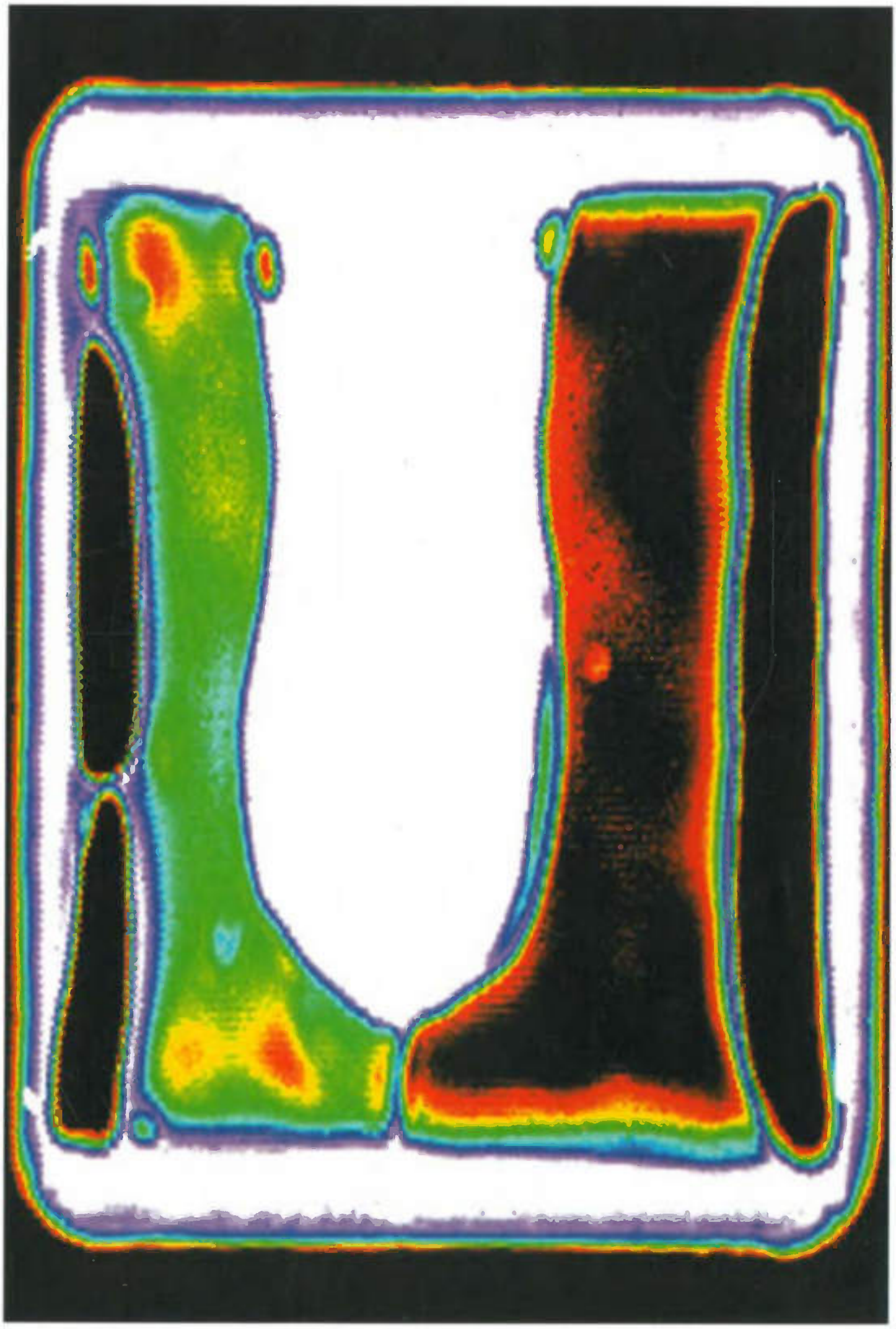

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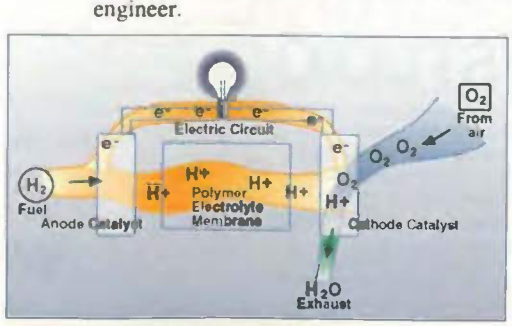
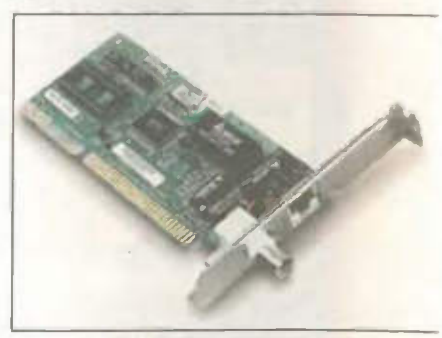



Acoustic imaging provides a unique insight into chip capacitor failure mechanisms – page 330.

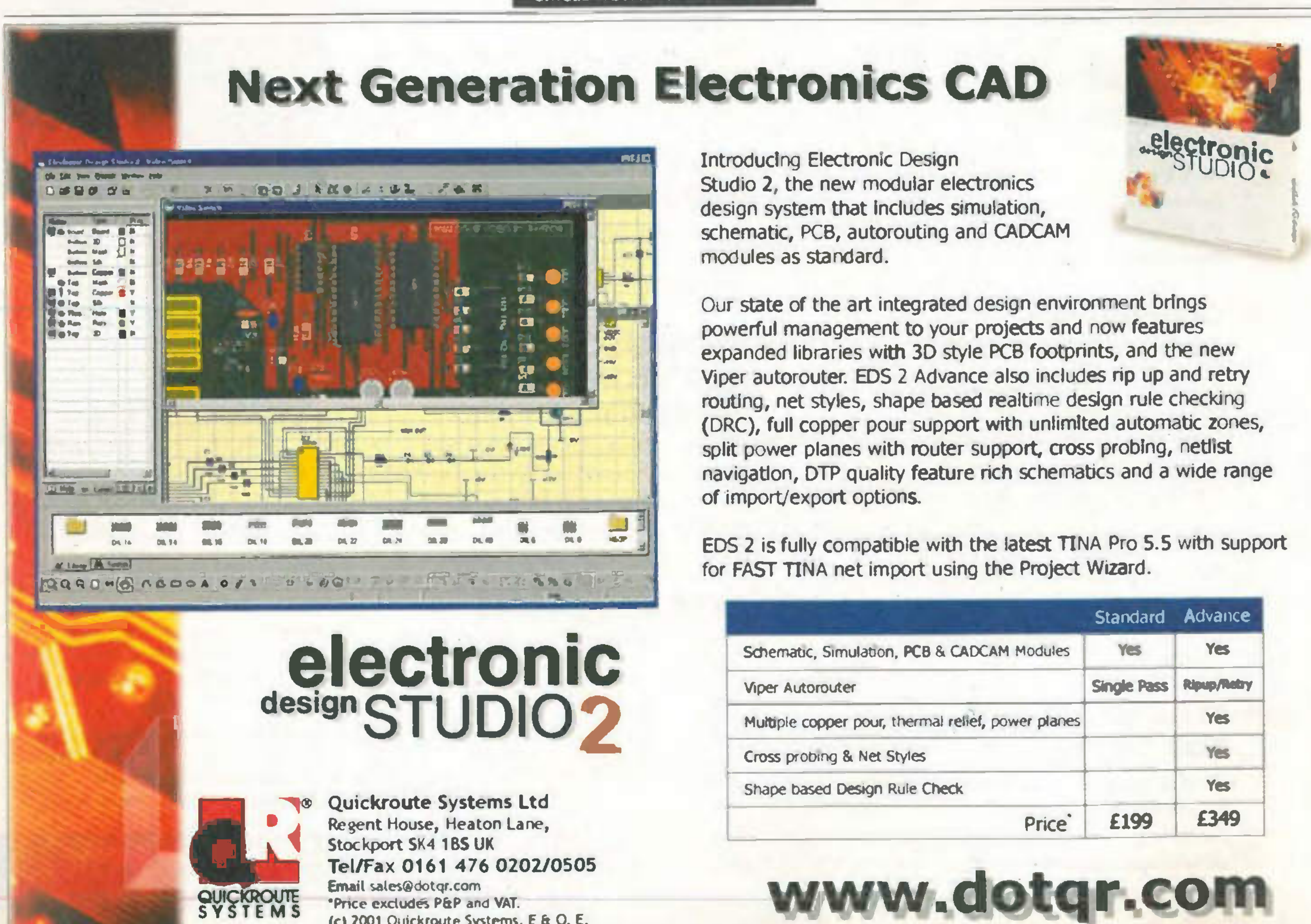

Reader offer – 10MHz single-trace oscilloscope. Turn to page 353 for details.


Ethernet – 10Mbit/s over a long length of coaxial cable and very cheap to implement. Wouldn't it be nice to use it for i/o? See page 336.

New generation power sources – a fuel cell can power a mobile phone for 20 days and it takes only seconds to recharge. See page 362.

June issue on sale 3 May

CIRCLE NO.104 ON REPLY CARD



CIRCLE NO.105 ON REPLY CARD

Killing fields – recognition at last

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The NRPB's recently published report on 'ELF Electromagnetic Fields and the Risk of Cancer' confirms a weak association between power line electromagnetic fields and childhood leukemia. This should be no surprise to readers of *Electronics World* who may recall a series of 'Killing Fields' features in the 1990s by independent researchers investigating the effects of power lines on those living and working nearby.

What is important is that over the intervening years the NRPB has slowly shifted from outright denial of any possible link to a grudging recognition that further research is needed to determine the exact mechanism linking power lines and cancer processes.

As one of those researchers and an *EW* feature writer, I'm pleased that the door to further research has creaked slightly ajar. Nevertheless, there's still a mountain to climb to make sure that future research is directed into those areas where it is likely to shed most light.

The main problem is one of definition. The eminent research group chaired by Sir Richard Doll was only briefed to investigate the effects of non-ionising ELF radiation emanating from electric power systems. This led to an obsessional concentration on the electromagnetic fields emanating from power lines.

There has been no interest in extending power line electrostatic and electromagnetic field research to interactions with other known harmful radiations, involving natural charged particles and background ionising cosmic radiation.

In some ways it's remarkable that the Committee found any link at all, bearing in mind that over a century of domestic and industrial electric power has more or less proved that power system magnetic fields *per se* are unlikely to be directly harmful.

The problem facing regulators like the NRPB is a reluctance to range across the EM spectrum to actively research interactions that may be harmful. This is partly due to NRPB resources being hijacked to allay public disquiet about siting mobile phone masts near schools, while ignoring broadcast transmitters generating far higher field strengths in the same bands and areas.

As I write, Vatican Radio faces shutdown by the Italian Government for massively exceeding HF field safety limits in urban areas near its short wave transmitters. If threatened by local TV transmitter shutdown and loss of soaps, public concern about transmitter safety is likely to wane in the UK!

The same goes for ionising radiation. Nuclear paranoia has ensured that radiation risk assessment

has failed to grasp the nettle that there may be no lower safe limit for human lionising radiation exposure, and that some public risk has to be accepted, as it is with road traffic accidents.

While the scientific jury is out, the precautionary principle has led to power companies in the USA buying up properties close to power lines deemed unsaleable, and planning codes and guidelines advising against domestic housing close to overhead lines.

In the meantime, the likelihood of a link between electrodynamic fields and human disease through background ionising radiation interactions is strengthened by the numbers of papers reporting solar cycle disease curves for cancers at high magnetic latitudes and high altitude urban locations where natural background radiation flux is intensified by location.

The NRPB must get away from its comfortable preoccupation with ELF non-ionising fields, and actively investigate ionising radiation interactions with all electrodynamic fields. ■

Anthony Hopwood

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UPDATE

Poll reveals serious concern over electronics skills shortages

A survey of electronics executives by City consultancy KPMG shows there is serious concern over skills shortages in the industry in the UK.

In a survey of executives from firms such as ARM, BT Cellnet, IBM and Motorola, 98 per cent of respondents in the survey said their major concern was over skills shortages.

"Much more active investment is needed in centres of learning," said KPMG's head of electronics, Crispin O'Brien. "If you compare what we have with partnerships in Cambridge, for example, we're a long way behind other countries."

According to O'Brien, a recent IDC report says that the shortage of skilled labour in Europe could reach 3.8m by 2003. "You could probably say that just under one million of those could be in the UK," he said.

However, he stressed that KMPG's report did not try to blame any one party for the situation and insisted that the industry must also do more.

"The Government is listening, we just have to wait and see how effective their measures will be," said O'Brien, commenting on the recent publication of the enterprise, skills and innovation white paper.

The report by KPMG, announced mid February, also highlights the lack of R&D funding and the industry's relationship with Government and education as key areas that need to be addressed.

Countries where R&D funding is high have a healthier industry and economy, said O'Brien. Competition in Europe for inward investment is much higher now, he said, and only five per cent of the UK electronics industry is actually UK owned, so the manufacturing base is not tied to Britain.

"Tax incentives are needed to keep them here. But although these incentives certainly help, the main reason that people invest in a country is the skills base," said O'Brien. "And right now, the biggest constraint is good quality people and access to a research base."

IT in school not hitting right spot

The effectiveness of tackling the shortage of science and engineering graduates by boosting investment on PCs and IT in schools has been questioned by a director of one of the UK's science and technology regional organisations (SATRO).

According to John Hindhaugh, director of Staffordshire SATRO, most of the Government's proposed £400m investment in new technology for schools will go on supporting IT in English, business studies, leisure & tourism, geography and every other subject area.

"This of course is no bad thing but these areas of the curriculum have little to do with electronic design. Design & technology in schools is not often seen as a priority for IT support," said Hindhaugh.

Firms team up to make superchip

IBM, Sony and Toshiba are to develop jointly a "super-computer on a chip". With a 300-person design centre in Texas, the three firms will invest $400m on the project over the next five years.

Called 'Cell', the sub-0.1μm chip will combine technologies such as copper interconnect, silicon-on-insulator transistors and low-k dielectric material.

Cell will be more powerful than IBM's Deep Blue supercomputer, the firms claim. Providing teraflops of processing power, it will be aimed at broadband consumer products.

Cambridge firm wins multilayer optical disk link up

Constellation-3D, the firm developing high capacity optical disks, has partnered with Plasmon to co-develop manufacturing processes.

Cambridge-based Plasmon will use its experience in recordable optical media to set up a prototype production line for fluorescent multilayer disks (FMDs), most probably in the UK.

"Our collaboration will focus on industrialisation of the production processes, to provide future manufacturers of FMD disks with efficient, low cost and durable mass production techniques," said Nigel Street, CEO of Plasmon.

FMDs use fluorescence, rather than reflection, to sense data. Dye placed in the pits of the disk fluoresces when a laser is focused on it.

Because the CD-sized FMD is essentially transparent, multiple layers can be formed. A 20 layer disk is capable of storing up to 100Gbyte of data, the firm claimed.

"C-3D has demonstrated multilayer read-out using their unique FMD technology at a level that is significantly greater than the two layers achievable with current reflective recording layers," added Street.

In January C-3D signed a deal with Lite-On to manufacture drives for the disks. Last November it signed a similar deal with optical disc equipment supplier Steag Hamatech.

Richard Ball

Amstrad profits plummet due to e-m@iler losses

Amstrad's telephone with e-mail capability – the e-m@iler – is continuing to lose money for the company, which saw interim pre-tax profits fall by over 80 per cent to £1.5m.

The consumer electronics manufacturer's e-m@iler business is operated through a joint venture with Dixons known as Amserve. As the majority shareholder, Amstrad incurred a pre-tax loss of £3.9m in its Amserve business.

Around 77 000 e-m@ilers have been installed since the launch last March. These are being sold at a loss in order to quickly build up a user base. It is hoped that they will then generate revenues through advertising and call charges.

"With over nine months experience, e-mail usage is currently generating an income for Amserve which equates to £20 per phone per year or £1.5m per annum on the current installed base of 77 000 units," said Amstrad chairman Sir Alan Sugar.

Sugar said that first advertising revenues were expected to start later this year when the installed base tops 120 000 units.

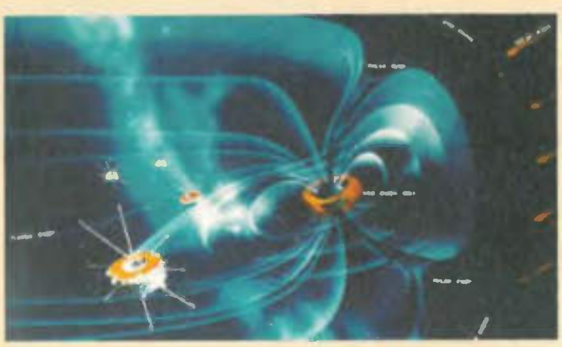
"We are looking for growth of the installed base and as more e-m@ilers are sold losses from the Amserve business will continue but the future profit potential of the Amserve business will increase," said Sugar.

Amstrad, which is one of five suppliers to satellite broadcaster BSkyB, also saw weakness in the digital TV set-top market.

Last week Amstrad also announced plans to license its first GSM mobile phone product to Chinese manufacturer Haier CCT.

Turnover for the six months was 27 per cent down from £60.8m to £44.1m.

Richard Wilson



Satellite mission investigates solar storm effects

The first results have been published from the four satellite Cluster mission which is measuring the Earth's magnetosphere. The bow shockwave, where the solar wind interacts with the magnetosphere, has been measured in detail for the first time. Findings from the mission may enable designers to increase the ruggedness of communication satellites which have been destroyed by solar storms in the past.

Patent bounty hunters pay out $40 000

BountyQuest has paid out $10 000 each to four people who may have found 'prior art' to break patents.

The company was set up last year to make money by putting bounties on the patents that other companies do not want to exist.

"Patents are a double-edged sword. While they encourage creativity and the introduction of new products that improve lives, they can also stifle competition – particularly when they don't represent genuine innovation," said Charles Cella, founder and CEO of BountyQuest when it was set up.

Patents are awarded only if there is no evidence that an idea has been thought of before. A search for evidence, or prior art as it is called, is made before granting the patent, but this search may not be exhaustive. Finding prior art can cause a patent to be withdrawn.

"BountyQuest taps into the world's knowledge market to uncover this hard-to-find information, which can be used not only to weed out bad patents, but also to validate good ones," Cella said.

BountyQuest rewards start at $10 000 and could go higher than $1m, depending on the value of the information to the client searching for it, said the company.

Prior art, claims BountyQuest, has been found that challenges the following patents: a method for on-line music sampling, held by Intouch Group; a method controlling access to an event venue through alterable tickets, held by Walker Digital; a technology for database copying, held by Oracle; and a technology for single-chip network routers, held by Cisco Systems.

Steve Bush

New CO sensor stands to benefit from tighter gas laws

Fuel-cell sensor technology developed by Scipher spin-off firm Monox stands to benefit from possible changes to EPA (Environmental Protection Agency) regulations in the US.

The Swindon-based firm, a spinout from the Scipher intellectual property group, has developed a hermetic plastic carbon monoxide sensor – the subject of 27 patents.

It uses conductive plastic to transfer the output signal to conventional solder pins while an internal platinum/ruthenium electrode system deposited directly onto plastic minimises precious metal use. Test gas passes into a sulphuric acid electrolyte via a semi-permeable membrane/wick system.

The company has already received a $1m order for the new sensor, with more promised.

A ruling in the US, although currently suspended, requires that all public buildings must have carbon monoxide (CO) detection alongside smoke and other fire detection systems.

An attempt was made to enforce the regulation several years ago but, following a massive spate of false alarms from the sensor technology then available, the requirement for CO detection was put on ice.

However, recent technology developments producing better sensors has caused legislators in Canada and the European Union to set much tighter limits on CO detection – and the US is under pressure to follow suit.

New Canadian and European legislation requires reliable detection at gas concentrations down to 10ppm, a sensitivity which, until recently, could only be achieved with bulk semiconductor heated wire transducers.

Frank Ogden

New technology will halve mobile antenna numbers

Quintel S4, the company that emerged from a deal between DERA, the research arm of the Ministry of Defence, and UK landlord, Rotch Group, was launched this week.

The company is combining technology from DERA with properties owned by Rotch to halve the number of mobile phone antennas across the UK and Europe.

Radio masts are often shared but several antennas are attached to them. DERA said its technology let each antenna receive up to five radio signals at once.

This means the services of all five 3G licence holders could be combined on one roof-top or mast antenna.

Quintel reckons that each operator will need up to 20000 sites to complete the roll out of third generation mobile services.

"Personal communications are transforming all our lives and the pace is hotting up," said Andrew Middleton, director of knowledge, information systems at DERA. "Not all change is good and it is important to offer socially responsible choices."

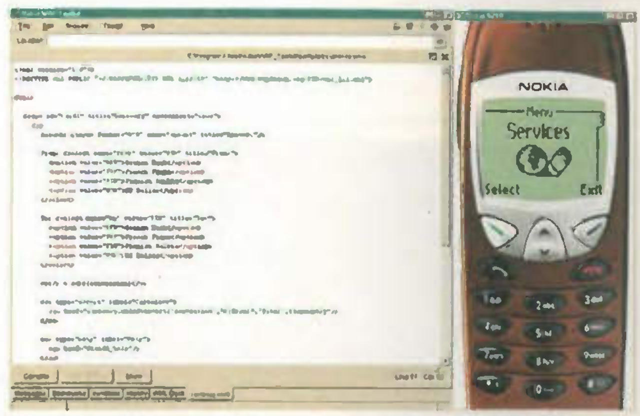
Rotch's part in the deal means making its £3bn portfolio of around 130000 possible sites available to Quintel.

Interactive audio plan

Broadcaster Capital Radio has teamed up with US digital radio technology firm, Command Audio to launch on-demand interactive audio through the UK's digital audio broadcasting (DAB) network.

A joint venture company also including UBC Media, Command Audio-UK (CA-UK) will produce on-demand interactive programmes and license other programmers and service providers.

According to the firms, when deployed in the UK this will allow listeners to choose from a range of programmes and listen to them whenever and wherever they want.



Software boost for WAP developers. Nokia's WAP Toolkit 2.1 is a free software tool that provides a PC-based environment in which developers can write, test and de-bug WAP applications. For this version, the company has added simulators for its 6200 and 7100 series phones. It also includes a June 2000 WAP Forum specification reference implementation simulator, which supports multipart push among other new features. The simulator enables the prototyping of next-generation WAP services that will be supported in hand-sets coming to the market later this year and next.

Orange unveils the house of the future. A detached house in Hertfordshire is being used as a research centre to test, monitor and evaluate advanced services and products for the home. Dubbed 'Orange at home' the project is being led by mobile operator Orange. The house was adapted at a cost of £2m to include a range of services that can be controlled using 'wire-free' technology such as lighting, heating, security, curtains and baths.

Metallic superconductor works at 39K

Japanese researchers have found a simple metallic compound that superconducts at twice the temperature of previous materials.

Magnesium diboride (MgB_2) superconducts at 39K, claims Tokyo's Aoyama Gakuin University, twice that of the previous best metallic material.

"It's certainly a new type of semiconductor," said Dr Mark Blamire, a materials scientist researching superconductivity at Cambridge University. "But it doesn't really compete with high temperature superconductors."

Blamire's group at Cambridge has already repeated the Tokyo experiments, creating 99.99 per cent pure MgB_2, with a T_c of 39.5K.

Ceramic and other intermetallic compounds remain much better superconductors, working at over 100K, but they are potentially harder to manufacture than metallic varieties.

The Tokyo work may open up new avenues of research, using less exotic and expensive elements than niobium, the current favourite.

At Cambridge and other research centres, scientists are at the stage of making bulk materials by sintering powders, said Blamire.

Work is under way to make useful electronic components which would involve laying down thin films on substrates.

LEDtronics has unveiled a set of incandescent replacement lamps based on clusters of high intensity LEDs. The DecorLED range uses a standard Edison-screw base and outputs in six colours from the 18 LEDs. Lifetime is claimed to be 11 years. Light output ranges from 3000mcd for a blue bulb, to 10 000mcd for green. Power consumption is just 1.0 to 1.7W, for lamps equivalent to a 15W incandescent bulb, the company said. Depending on the colour, the LEDs are made from either InGaAlP or SiC/GaN technology.

All new European Ford cars to have electronic telematics within 5 years

Ford aims to put electronic telematic systems in all its European cars within five years.

The car maker has stepped up its plans for in-car electronic systems through a partnership with mobile communications operator Vodafone with the intention of bringing in-car security and information services to its range of European vehicles by 2006.

The first production Ford Focus cars with telematics will appear in Germany next week. A UK launch using Vodafone's mobile network will follow shortly after, said a company spokesman.

"We anticipate that within five years nearly all new Ford vehicles will be fitted with some type of telematics system," said David Thursfield, president and CEO of Ford Europe.

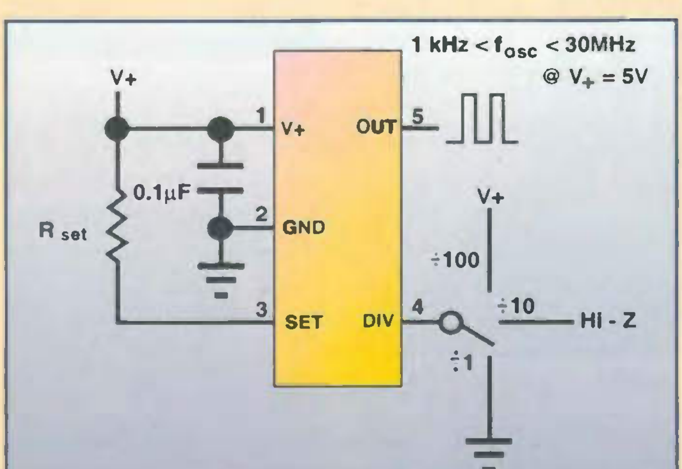
The in-car communications links supporting GPS-based location, security and information services will be provided by Vodafone's UK mobile network and its D2 subsidiary in Germany.

Services are expected to include providing emergency and roadside assistance, traffic information and dynamic re-routeing as well as an operator and voice controlled service.

For example, the driver will be connected with the emergency services, who will also be automatically alerted if the airbag is deployed. Also, the vehicle's position will be calculated using the GPS location system.

"Telematics is an integral part of our strategy," commented Vodafone's Thomas Geitner.

Typical additional cost to the first Ford Focus' being fitted in Germany will be □845. ■



1kHz to 30MHz oscillator IC

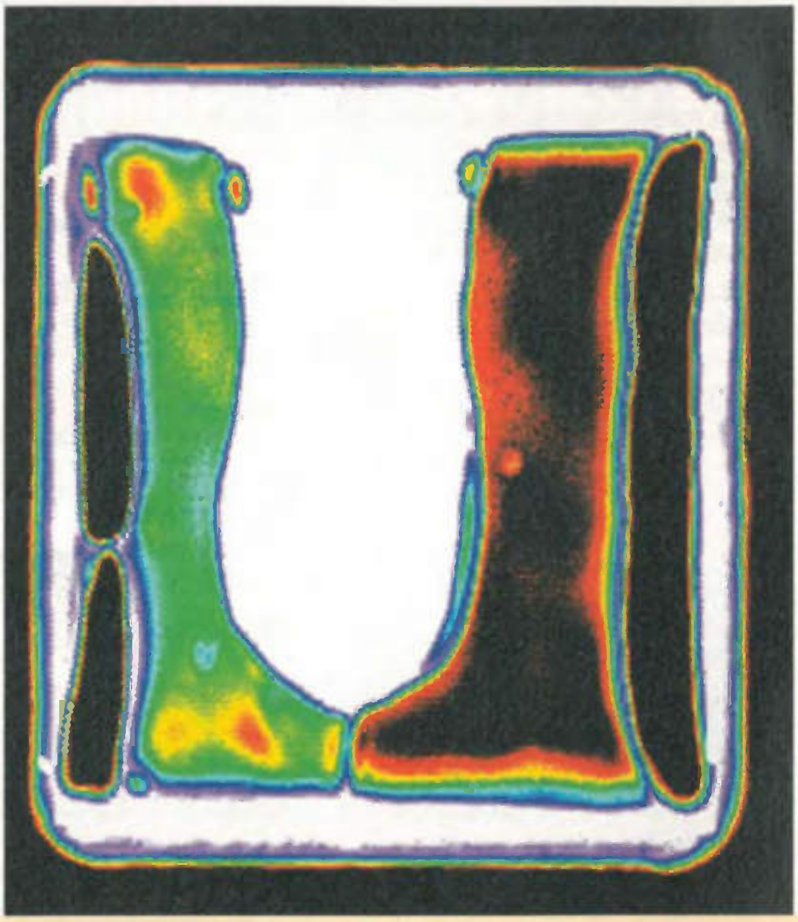
Linear Technology has produced the LTC1799, a handy 1kHz to 30MHz oscillator in an five-pin SOT-23 package.

Frequency is set between 100kHz and 30MHz with a single resistor (*f* has a linear relationship to *R*), and an output divide ratio of 1, 10 or 100 is selected with a single external pin.

Claimed frequency error is two per cent or under between 5kHz and 20MHz (0°C to 70°C) with ±40ppm/°C temperature and 0.05%/V supply stabilities.

The chip operates from 2.7 to 5.5V, although it will not reach 30MHz on lower voltages.

Typical supply current is 1mA and output impedance is 100Ω. Linear sees the chip driving charge pumps, clocking switched capacitor filters and replacing crystal and ceramic oscillators.



Ralph Carbone and Tom Adams provide a unique insight into the failure modes of ceramic chip capacitors.

Chip cap flaws investigated

Above Fig. 1. Nondestructive acoustic image looking down into a ceramic chip capacitor shows overlapping delaminations (green, red, black) between layers. Acoustic image courtesy Sonoscan.

Ralph A. Carbone is a Reliability Physicist in the Failure Analysis of Components (FAC) Laboratory of Hewlett-Packard Co., Roseville CA USA. Tom Adams is a Consultant with Sonoscan Inc., Elk Grove Village IL USA.

If a ceramic chip capacitor fails, don't automatically blame the assembly process. The mechanism of failure may have been built in at the factory.

Ceramic chip capacitors are among the least expensive of electronic components, and among the simplest in design. A ceramic chip capacitor consists of alternating layers of metal plates, or electrodes, and ceramic insulating layers.

At each end of the capacitor, one set of plates – positive or negative – joins together in a termination. Properly built and installed, a ceramic chip capacitor will store and release a charge thousands or millions of times per second without incident.

The primary function of a capacitor is to block DC voltages, while passing AC signals. As such they are often used in a variety of circuit designs.

By volume, they are most often used as 'bypass' components on voltage supply or bus line circuits, where they filter out unwanted high-frequency noise. In these applications, random circuit "glitches" are shorted to ground, thus preventing inadvertent errors from being generated.

However, the most common failure mode for a ceramic capacitor is the development of a resistive short. This causes DC signals to also be shunted to ground – i.e., a short circuit condition – resulting in the failure of the product.

Most ceramic chip capacitors sell for relatively low prices. If they were made and tested to the exacting standards of, say, a high-speed microprocessor, they would be more reliable, but they would also be exorbitantly expensive. Still, a failed ceramic chip capacitor can be an annoyance at the very least.

For example, it is typical for automotive air bags to contain a test circuit. If a capacitor in the test circuit becomes defective, a leakage current may flow around it. What should be a closed circuit is now open, and the driver will be looking at an erroneous 'Air Bag Failure' message.

On a given printed circuit board, it's usually not difficult to tell that a ceramic chip capacitor has failed – there may be a spike in the power supply for example. It may be more difficult to tell by electrical testing which of many capacitors has failed.

Without resorting to relatively heroic measures, it is nearly impossible to tell why the capacitor failed. Examining a capacitor visually doesn't give you much information unless the capacitor has sustained gross damage that is visible on the exterior.

Often – but not always – the failure is the result of an internal manufacturing defect that eventually reached a critical state. The most common internal defects are voids in the dielectric layers.

A void is a bubble of air – or possibly another gas – that became

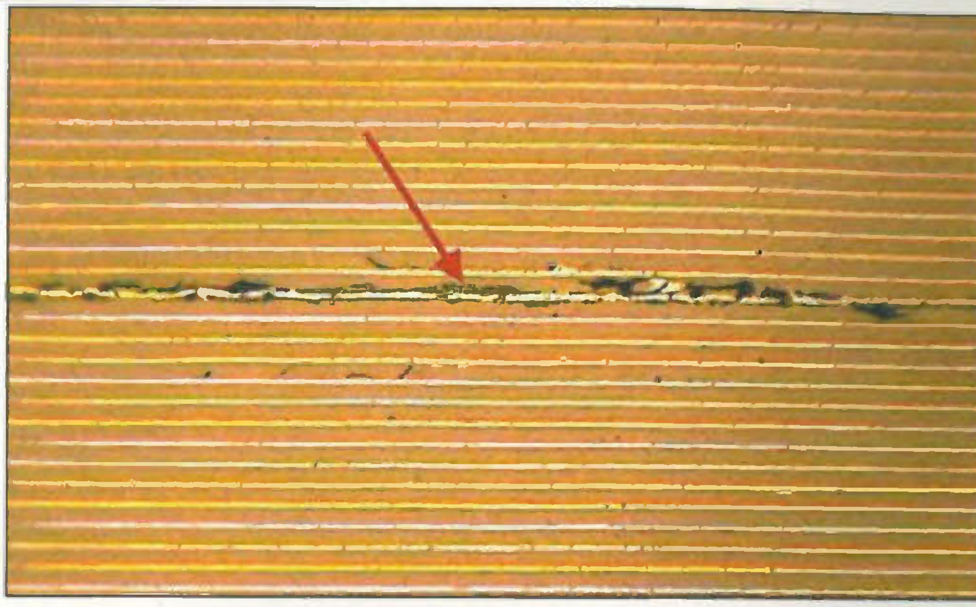


Fig. 2. Optical view of sectioned capacitor shows a delamination that, in this case, ran nearly the entire length of the capacitor. Photo courtesy Hewlett-Packard.

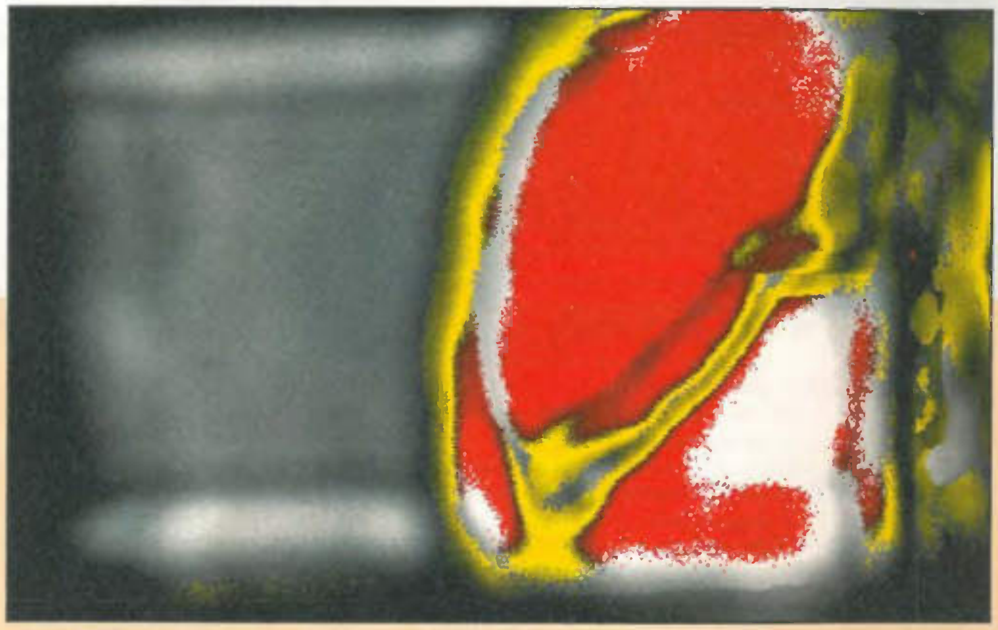


Fig. 3. Acoustic image showing damage – one or more delaminations, and probably cracks – in a ceramic chip capacitor. Acoustic image courtesy Hewlett-Packard.

trapped in the fluid ceramic before the capacitor was fired. If you sliced a capacitor open at just the right point, the void would look like a tiny flattened bubble. It might lie entirely within one layer of ceramic, or it might be in contact with one or both of the adjacent plates.

Sawing open a capacitor to examine a void is something not often done, because of the labour and time involved. In most applications, the condition of a single ceramic chip capacitor isn't truly critical. But in some systems – those that go into earth-orbiting satellites or marine buoys, for example – every capacitor has to be flawless. For these applications, capacitors are often inspected by acoustic micro imaging, which sees internal defects nondestructively. Voids and the other frequent defects, cracks and delaminations, are usually too small to be imaged by x-ray.

Detecting flaws via acoustic imaging

Acoustic micro imaging uses an ultrasound-pulsing transducer that scans over the capacitor. Several thousand times a second, the transducer switches between pulsing ultrasound and receiving the return echoes from the interior of the capacitor.

The return echoes are used to make data points. The whole collection of data points from a capacitor shows its internal structure, including defects.

Ultrasound is reflected only by interfaces between different materials. The stack of electrodes and dielectrics in a capacitor presents a great many material interfaces, but these are basically low-contrast interfaces, at least when compared to defects.

The three common defects – voids, cracks, and delaminations – amount to an interface between a solid material and the air or other gas inside the defect. Technically, what occurs is a difference in acoustic impedance, which is the density of a material multiplied by the speed of ultrasound through that material.

Since the density of a gas is extremely low compared to the density of a solid, the difference in acoustic impedance between either a metal or a ceramic and air is huge, and results in a very high-contrast data point.

In the completed acoustic image, defects are very easy to spot. The ordinary acoustic view, looking straight down into the acoustically transparent capacitor, shows the x-y outline of defects, but there are other kinds of acoustic views, including a nondestructive cross-section that shows feature depth.

Cracks in ceramic chip capacitors usually extend more or less vertically through several layers of ceramic and metal. Since they provide a direct pathway between plates, cracks create dead shorts. Voids can also cause shorts, by a slightly more indirect route.

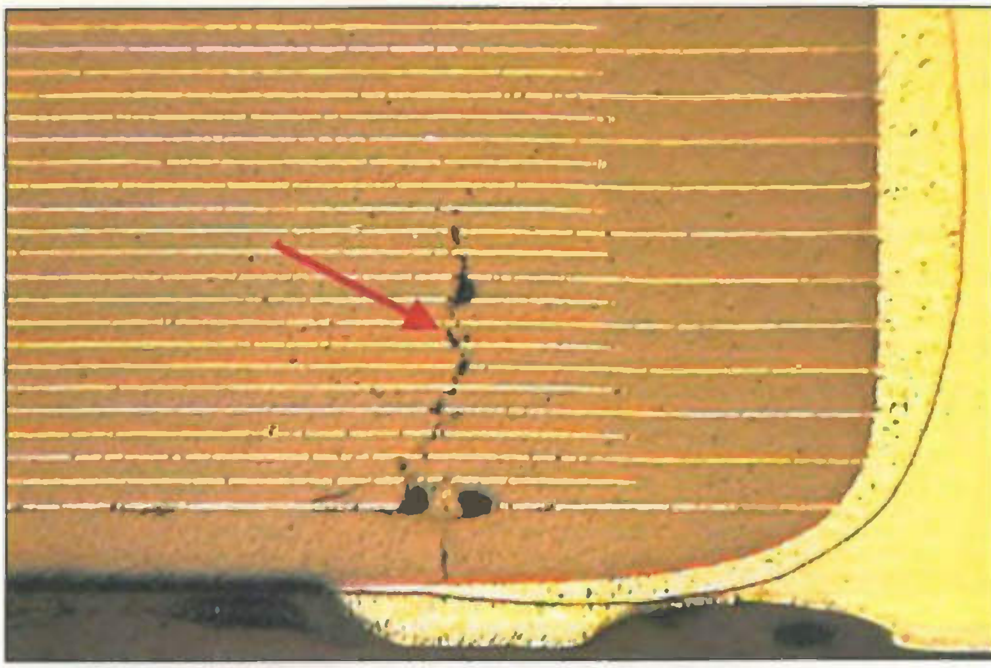


Fig. 4. Optical view of a nearly vertical firing crack first detected acoustically. The dimensional accuracy of the acoustic image simplifies and speeds up accurate physical sectioning. Photo courtesy Hewlett-Packard.

If a void lies entirely within a ceramic layer, it still encourages metal migration between the two adjacent plates. Eventually enough metal coats the inside of the void so that a short occurs between the two plates.

Delaminations are horizontal separations between layers. Capacitors having one delamination are likely to have several more delaminations at various layers, since delaminations are the result of a lack of bonding between layers.

Companies involved in high-reliability applications send around a million ceramic chip capacitors a year to the applications laboratory at Sonoscan [www.sonoscan.com] for acoustic inspection. The lab's acoustic imaging screens the capacitors into good and bad categories; for expensive high-reliability uses, this is far cheaper than having a system become impaired or fail outright in an inconvenient or impossible location.

The lab sometimes saws capacitors open too, chiefly so that customers can see defects optically. Sawing in exactly the right place is a simple business because the acoustic image has already shown exactly where the defects are.

Because acoustic micro imaging primarily operates in the reflection mode – pulse the ultrasound, receive the return echoes – ceramic chip capacitors can be imaged acoustically equally well when they are still mounted on a board. This became important recently at Hewlett-Packard, where a circuit board used in a medical product began to experience field failures.

The problem was identified electrically as a single ceramic chip capacitor on the board. The lab could have removed the capacitor from the board for acoustic imaging, but this would have created the possibility that the removal process had caused whatever defect was present – at least in the eyes of the capacitor manufacturer. Instead, capacitors on failed assemblies were imaged right on the boards.

The results show two types of defect – large delaminations between layers, and cracks resulting from the firing process. No voids were found, suggesting that manufacturing flaws were related to firing, and did not involve the fluid ceramic material. The board assembler was then able to set up a screening process for incoming capacitors, and the capacitor manufacturer was able to adjust his processes to make delaminations and cracks less frequent. ■

Contact information

Sonoscan Inc., 2149 East Pratt Blvd, Elk Grove Village IL, USA 60007. Phone: 847 437-6400, fax: 847 437-1550, e-mail: info@sonoscan.com, website: www.sonoscan.com

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Range	Resolution	Accuracy
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20.00V	10mV	±0.5% of rdg, ±2dig.
600V	1V	±1% of rdg, ±2dig.
AC volts		
200.0V	100mV	±1.2% of rdg, ±10dig.
600V	1V	±1.2% of rdg, ±10dig.
DC current		
200.0μA	0.1μA	±1% of rdg, ±2dig.
200.0mA	100μA	±1.2% of rdg, ±2dig.
10A	10mA	±2% of rdg, ±5dig.
Resistance		
200.0Ω	0.1Ω	±0.8% of rdg, ±4dig.
2.000kΩ	1Ω	
200.0kΩ	100Ω	±0.8% of rdg, ±2dig.
2.000MΩ	1kΩ	±1% of rdg, ±2dig.

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Design competition

Devise a useful and/or ingenious application for the ZXF36L01 versatile high-Q bandpass filter with integral mixer and you could win a £500 voucher to spend with Farnell. There's two runner up prizes of £100 vouchers too.

Launched this year, the ZXF36L01 is a versatile high-Q bandpass filter requiring a minimum of external components. In addition to the variable-Q analogue filter there is also a mixer block, making the device suitable for a wide range of applications.

All you have to do to enter the competition is send a design idea incorporating the ZXF36L01 to the address below. Entries will be judged on ingenuity, originality and usefulness. All entries are subject to the rules set out below.

A designer's kit is available from Farnell and you can find full data on the device on Zetex's web site http://www.zetex.com/pdf/ics/zxf36101.pdf.

It is not necessary for you to prove your design, and buying the kit is not a condition of entry into the competition. The design you submit has to work in practice but you will not be penalised for not having built a prototype.

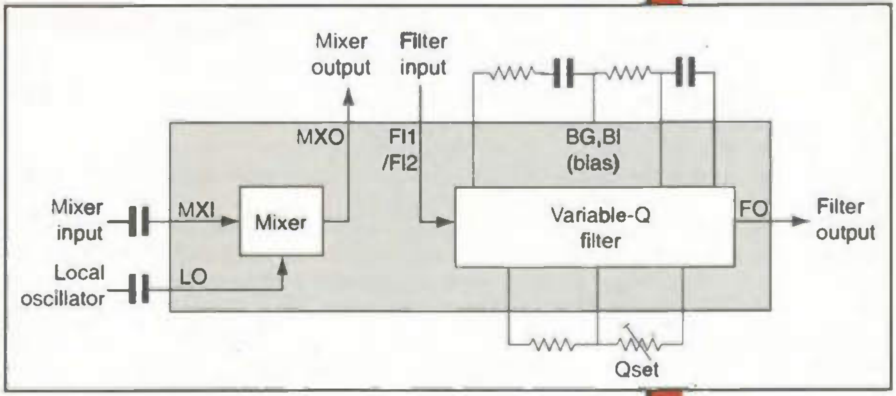
If you do submit a design that meets the competition criteria and you *have* bought the kit, then you will receive a Farnell voucher for £15, courtesy of Zetex.

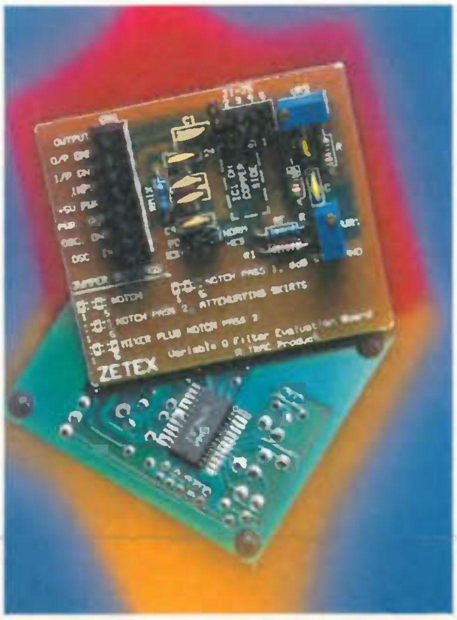
Send your entry to Filter Design, Electronics World, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. Note that it is not necessary to send your prototype! Simply send the circuit diagram and a clear, concise description of the circuit. It will help if you describe why you think that your circuit should be among the winners. You can also e-mail your entry to jackie.lowe@rbi.co.uk, but unless the e-mail has a subject heading that reads 'Filter Design' it will not be eligible. Please attach diagrams and text separately and include a daytime phone number with your entry if possible.

The closing date for the competition is 30 April.

Win a £500 voucher redeemable at Farnell.

For more information...
Visit http://www.farnell.co for details of the ZXF36L01 development kit or http://www.zetex.com/pdf/ics/zxf36101.pdf for more data on the filter chip.





You don't need to buy this this new development board for the ZXF36L01 in order to enter the competition, but if you do, and your entry meets the competition requirements, you will receive a Farnell voucher for £15 to help cover its cost.

This *Electronics World* competition is sponsored by UK semiconductor manufacturer Zetex and distributor Farnell Electronics Components.

Rules

- Electronics World reserves the right to publish submitted entries. All designs published will be attributed to their designers. A minimum payment of £50 will be made for each design published.
- Submission of an entry does not remove your right to exploit your design, but it does give Zetex the right to use the entry as an application note, or as the basis thereof, effectively making the design public domain.
- Winners will be chosen jointly by technical experts from Zetex, Farnell and the editor of Electronics World. The judges' choice will be final and no correspondence will be entered into regarding the choice of winner.
- No employee of Reed Business Information, Zetex and Farnell, or any of their associated companies, may enter this competition, nor may members of their families.
- No entry will win more than one prize, but multiple entries may be submitted.
- Prizes are as stated here and not negotiable.
- Entries arriving after the closing date will be void.
- No purchase in necessary to enter this competition.
- Winners will be notified by post, and the results may be publicised.
- For a list of winning entries, send an SAE to the editorial offices.
- Submitting an entry for the competition implies acceptance of these rules.

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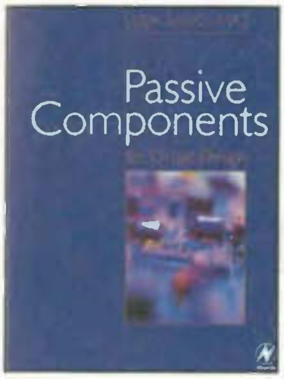

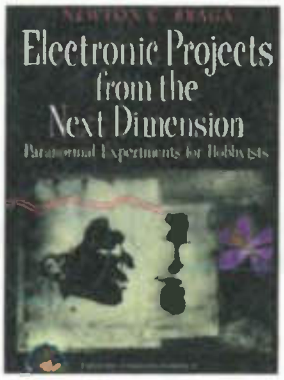

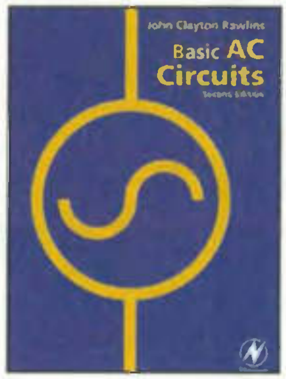

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Although paranormal studies are considered esoteric, Electronic Projects from the Next Dimension teaches the technical skills needed to make devices that can be used in many different kinds of experiments. Each section indicates how the circuit can be used in paranormal experiments with suggestions about procedures and how to analyze the results.

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PC interfacing via Ethernet

Connecting external devices to your PC via a local-area network card is not as difficult as it may seem. Eddy Insam explains how it all works and what you need to know. In a second article, Eddy will describe a development device that can get you going in no time at all.

Interactive publishing!
Interfacing via Ethernet is a complex topic involving new concepts for those of you used to RS232 and the like. If you have any queries regarding interfacing with Ethernet, e-mail martin.eccles@rbi.co.uk using the subject heading 'Ethernet interfacing'.

Any queries that are of general interest will be published in next month's article, together with their replies. We'll do our best to answer all your questions, but as the time available to prepare answers is finite, we cannot guarantee you a reply. Ed.

You are browsing the Internet looking at you car's own web page. The screen is full of messages and indicators telling you all about your car, but an orange flag tells you there is something that requires your attention.

You look at the various gauges: clutch, brake fluid, they seem OK. Oil looks a bit low though, so you place a tick under one of the oil brands in the 'garage reminder' memo pad.

You wonder how people did this in the past; did people actually open the bonnets and look inside their own cars? Then the door bell rings, the washing machine repairman is at your doorstep... "Your dishwasher just e-mailed us to say its drive belt is just about to go."

Whether you think the concept of networking your possessions is a good thing or not, it may be of some use knowing how it all works. In any case, this article is for you because it will at least put you on the first step of the "I am not afraid of the technology," ladder.

On the other hand, you may have already thought of network-enabling your own product or application, but been put off by the apparent complexities involved. This article will give you an insight into the expertise and effort involved. What's more, a readily available preprogrammed chip to be described in the next article will give you a head start on the prototyping stage.

Why use Ethernet?

As a consultant, I am sometimes asked about the Internet and its potential extended uses. Boring as the subject may be, the conversation sometimes ends in opinionated discussions about the need for Internet fridges and microwaves that e-mail you when the noodles are ready.

Nevertheless, there are some interesting possibilities for considering the use of a local-area network as a serious interface between a personal computer and external input/output devices. For one, it means the two can be as remote from each other as need be – anywhere in the world in theory.

You can also share a device among several users, say a rooftop web camera or weather monitoring station accessed by all users in a building or school – or even from home.

There are benefits at the practical level too. Remote data logging and controlling equipment becomes much easier when it can all be interfaced using standard and well-tested networking components, cabling and connectors.

New network models such as 'Real Time Publish Subscribe', or RTPS for short, are also making Ethernet more suitable for real time systems, data logging and control. Interesting possibilities arise too when interfacing to other proprietary networks such as Home Automation, X10, CEBus or LON.

But then, it can all sound very complicated: the protocols, the stacks, and so little information published. But is it? The answer is not really, and it is certainly not out of reach.

Embedding is the word

Internet-enabled hardware products are slowly becoming commonplace. From vending machines dialling up to report their stock, to pinball machines publishing their high scores on the Internet for all to see.

Internet appliances – the term used for browsers that do not use a computer – are predicted to overtake PCs for Internet use within the next four years. A new addressing scheme for the Internet (version 6) allows for a staggering 2^{96} times the number of addresses currently available. The address field used is 128 bits. Each nut and bolt in your washing machine will be able to have its own unique Internet address.

Many modern products are driven by internal microprocessors. These small devices are quite powerful, but one generally omitted fact is that in order to implement the functionality required for Internet and network access, a lot of program code space is required.

Gone are the days of simple ASCII dial-up interfaces, simple ZMODEM or Kermit protocols. Nowadays your processor has to deal with PPP, ARP, IP, ICMP, TCP and a host of others. More on this later.

Of PCs and interfaces

PCs are well known for their lack of suitable interfaces into the real world. They were not originally designed with many facilities for driving external equipment, or to act as data gathering stations.

Many alternatives using the parallel and serial port have been on offer, but this approach is becoming less practical nowadays – especially with NT and Windows 2000 where special low-level software system drivers are required.

Worse still, parallel and serial ports are now called 'legacy' devices, which is computer jargon for obsolete. The newest machines from the shops just do not have these ports any more. These are all being replaced by USB.

Eventually, USB devices may be accepted as the standard method for general-purpose direct, local interfacing to a PC.

The advantage of using a network, as opposed to a direct connection, is distance. Most PCs will have a local network connection. Low cost Ethernet cards are readily available and easy to install – even in older and non-PC machines.

From this point of view, using Ethernet for I/O external access is an attractive, cheap alternative. Furthermore, different brand, newer and older machines with different operating systems can access the devices. Macs, Linux, Unix and portable hand-held devices can all be used, Figs. 1&2.

Software at the PC end

If you develop a piece of network hardware, you will need to think about how to drive it from the PC.

You may not need to write any software at the PC end at all. Your device could for example emulate a web page, and be accessed as if it

Fig. 1. A cheap PC network card plus micro controller forms the basis for a simple unit that allows a PC access to external I/O devices via a local area network.

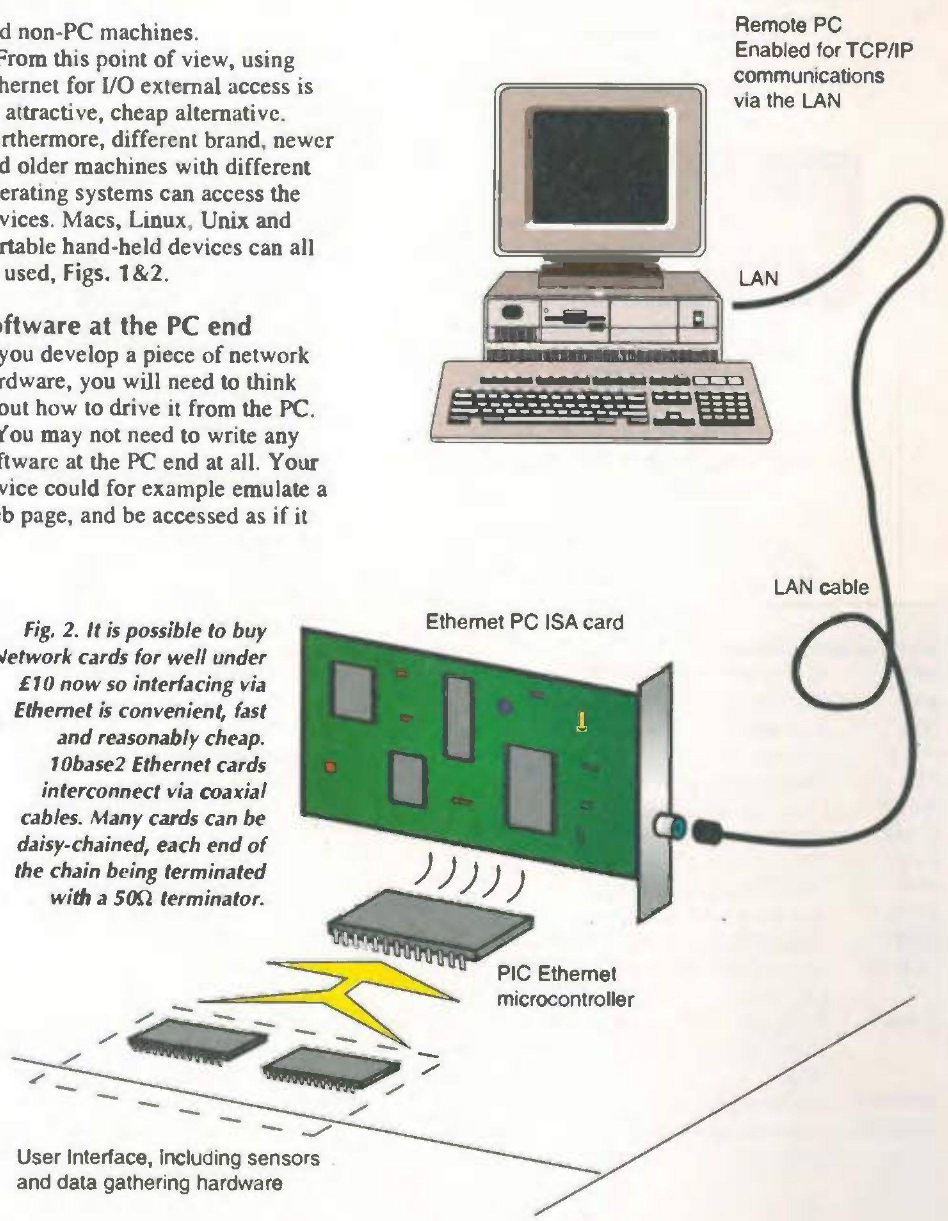

Fig. 2. It is possible to buy Network cards for well under £10 now so interfacing via Ethernet is convenient, fast and reasonably cheap. 10base2 Ethernet cards interconnect via coaxial cables. Many cards can be daisy-chained, each end of the chain being terminated with a 50Ω terminator.

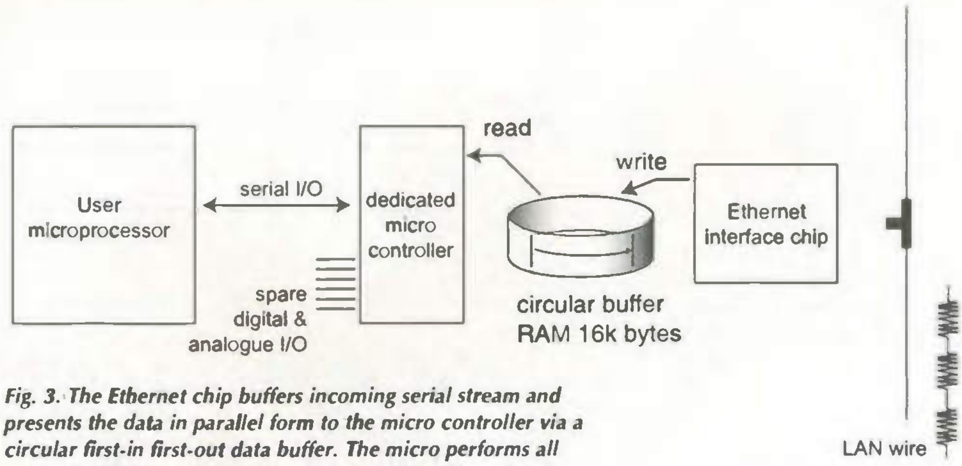

Fig. 3. The Ethernet chip buffers incoming serial stream and presents the data in parallel form to the micro controller via a circular first-in first-out data buffer. The micro performs all necessary high level addressing and decoding. Clean data is then transferred to the user application, which can be embedded in another microprocessor.

were a normal Internet page.

If you need more dedicated control, standard API libraries are available for network communications. The one in Windows is called Winsock, which is a family of API calls contained in a DLL file.

There is also higher level support in the form of ready made OCX components, add-ons for Visual Basic and C. **List 1** shows a simple 'C' demonstration program showing how Winsock calls can be used to send and receive data from a remote on the network.

How do they do that?

Figure 3 shows a block diagram of the business end of a simple Ethernet embedded device. It consists of a small dedicated microprocessor connected to a custom Ethernet interface chip, which is in turn connected to the local area network via suitable electrical isolation transformers.

The Ethernet interface chip acts like a sophisticated serial-to-parallel converter. Its job is to read serial packets of data from the wire, check their header bytes with an internal address, perform checksum calculations, and push the block into a user accessible first-in, first-out data buffer. This 'FIFO' queues the data blocks for processing by the application.

The job of the microprocessor is to retrieve the blocks, and according to the information within, perform a few more data calculations and checksums, then pass the 'clean' data on to another device or system. The micro must be quick enough to retrieve frames from the FIFO buffer before it overruns. If it isn't, packets may be lost.

During transmission, the opposite takes effect. The microprocessor places data blocks in a buffer, the Ethernet chip then adds any required headers and checksums, perform the parallel-to-serial conversion and then push the serial stream into the wire. At the same time, it checks for possible collisions. More or less, that is all there is to it. The rest is all done in the software.

What does the micro do?

The microprocessor's job looks simple. Take data from a buffer, do some conversions and then do whatever with it. Easy? Well, not quite.

A fair bit of housekeeping needs to be done along the way. Functionality needs to be included to communicate packets in the background with other users to let them know who and where we are for example. There are various established 'protocols' that describe exactly when and how this should be done.

Protocols, as camels designed by committees, are by definition complex. The following values give a rough idea of the amount of program code required to implement an average Ethernet enabled application. Values are for a PIC 16F877 using assembler: ARP, 1.5Kb, IP and ICMP, another 1.5Kb, TCP another 2.5Kb, PPP (for modem access) 3.5Kb.

So if you want to Ethernet enable your project, you may need to dedicate quite a bit of program space to handling the protocols.

But do you need to use these complex established protocols? Isn't it possible to just talk directly to other workstations using your own simple private encoding system?

The answer is yes. Each Ethernet packet carries a frame identifier that describes the protocol format used by its payload. Pick a number of your choosing and send any data format you like.

The rest of the network will just ignore your privately encoded packets – but first check with *www.isi.edu/in-notes/iana/assignments/ethernet-numbers/* to ensure the number you have chosen has not been already allocated!

Of course, you will need to program your PC to talk directly to the Ethernet card, and your packets will not be able to get past a router onto another network or the Internet. There may be real advantages in using alternative network models, for example to maintain speed and response times. There isn't that much software available at present out there. Expect little support from software vendors.

For real flexibility, you will need to use Internet protocols, and until dedicated TCP/IP interfaces are built in to the micros in hardware, you will need to live with the complexities of handling the protocol in software.

There's already a number of products in the market offering different levels of functionality. The best way to find out about these is to look at the web sites mentioned in the separate panel. What follows is just a simple summary.

The most common offerings come in the form of complete PCB cards with built-in micro, RAM, PROM and usually a built-in Ethernet interface driver chip. Units range in size from the smaller 8051 core-based, to larger, 386 embedded Linux-based cards.

Networking glossary

API	Application program interface
ARP	Addressing resolution protocol
DLL	Dynamic link library
FIFO	First in, first out
FTP	File-transfer protocol
HTTP	Hypertext transfer protocol
ICMP	Internet control message protocol
MAC	Media access control
PPP	Point-to-point protocol
RTPS	Real-time publish subscribe
SMTP	Simple mail transfer protocol
TCP/IP	Transmission-control protocol/Internet protocol
Telnet	Protocol within TCP that allows a remote terminal on the network to appear as a local one.
10baseT	Twisted-pair 10Mbit/s Ethernet
10base2	Coaxial-connected 10Mbit/s Ethernet
UDP	User datagram protocol
USB	Universal serial bus

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Kalmus A50822-30R 0.8-2.2GHz 30 Watt Amplifier	6950

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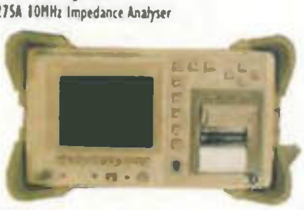

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Microtest MT340 Cat 5 Tester	950
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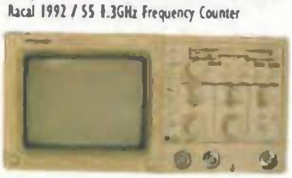

FUNCTION GENERATORS

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Tek 2465B 400MHz 4 Channel Analogue Scope	2500
Tek AM503/A6302/TM501 Current Probe System	1850
Tek TAS465 2 Channel 100MHz Analogue Scope	695
Tek TDS350 200MHz 2 Channel Digitising Scope	1850
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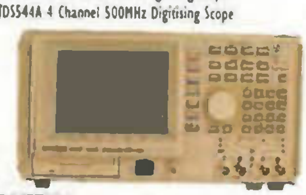
Tek TDS544A 4 Channel 500MHz Digitising Scope	5750



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Gigatronics 8542C Dual Channel RF Power Meter	2500
HP 436A/022 RF Power Meter With GPIB	750
HP 438A/002 Dual Channel RF Power Meter	1950
Various HP 848x Power Sensors (From)	300
HP EPM441A/003 (E4418A) RF Power Meter	2150
HP E4419A Dual Channel Power Meter	2850
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Marconi 6960 / GPIB RF Power Meter	695
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Rohde & Schwarz NRVD Dual Channel RF Power Meter	2500

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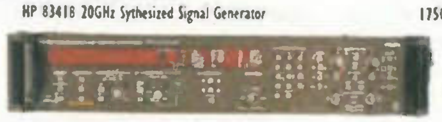

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CIRCLE NO. 112 ON REPLY CARD

Network functionality is usually supplied in the form of a 'C' software library or module that the user compiles or links with their existing code. This is sometimes a cut down, but workable, version of the standard sockets library.

If you do not want to use a ready-made card, there is nothing much available at the single chip level. Notable exceptions are the iChip systems from ConnectOne and Seiko. Originally offered as a set of software/firmware licences implemented in ASIC form, this is now available in single-chip form (the Seiko part number is 7600). A US company, Ipsil, has just announced another single chip device. More devices are expected to appear in the future.

I have found some of the claims made for these products are in the 'flexible with the truth' class. This is reflected in the unnecessarily long times taken to get the software to work properly and reliably. These difficulties are possibly due to the newness of the technology, but it is a hard way for you to learn.

Roll your own or boil in the bag?

If you want to network your application, depending on how complex it is, you will need to decide whether to go for the ready-made route, i.e. buy cards, modules or components in, or roll your own.

If you are starting from scratch, the initial learning curve is pretty steep. Using a ready-made solution may be your only option. It is pointless to re-invent the wheel.

If you are considering quantities or reliability, a deeper knowledge of the product and its performance may be important. In practice, this means that you could spend as much time trying to get an external offering to work properly and reliably – especially one that doesn't perform as well as advertised – as you would developing your own from scratch.

Again, depending on your requirements, you will need to evaluate how many functions are necessary for your application. It is pointless to include the full TCP stack into a product that would be happy to communicate using simple UDP packets. This is a waste of code space, components and resources. Is speed of access important? Is your field of work in real-time systems? If so, you should consider alternative network models.

As I mentioned earlier, the ready-made controller described in the next article may help you a little bit with this decision process. It will allow you to evaluate and try possibilities and use it in prototypes.

Because the controller provides access to the data stream at various levels, it can also be used as a teaching tool, and as a component in a more advanced network tester or server. It was originally designed as a tool for evaluating network stress.

I have used two processors for the controller. One handles the protocol interactions and another, supplied and written by the user, handles the application.

Data transfer between the two processors is via simple serial commands. The boring overheads such as checksums and framing are completely handled by the main controller.

Still confused?

If you have managed to get this far, and still you think you have not understood networks, don't despair. The next few sections will unravel some of the theory, and explain what you need to know.

No article on Internet basics can do without a guided tour of the technology, from the bit-shifting protocols to the higher level scripts. I am not going to cover this in any detail, as there is plenty of information around in books and magazines. What I have done is a quick tour of the basic concepts involved, with special relevance to a microcontroller-based implementation.

References mentioned later in this article contain all the extra detail you may ever need. The main sources for detailed specifications are 'RFCs' or 'requests for comments'. The text contains the reference number that relates to the topic. You can find RFCs on the Internet by searching under 'RFC'.

Ethernet

You may already have a network connector on the back of your computer. Look for a BNC socket with a coaxial cable (remember RG-58U?), or a flat cable ending in something looking like a plastic telephone connector.

In most offices, these wires just disappear down the back of the desk only to reappear at some obscure room at the end of the corridor.

Ethernet is one of the main survivors among a number of similar technologies developed in the 1970s and 80s, possibly because of its 'low tech' simple and reliable approach. The coaxial cable 'thin-wire' version – also known as 10Base2 – is widely used in low-end applications.

Thin-wire Ethernet is simplicity itself; all workstations are connected together in daisy-chain fashion with a 50Ω terminator at each end of the chain. Data packets are just bursts of current fed into the impedance of the wire, and are read as voltages by the receivers.

Transmitters fire bursts more or less without the knowledge of any other transmitters. Collisions – i.e. when two generators feed the wire at the same time – are detected by an abnormal rise in the voltage on the wire as two or more currents superimpose. Each transmitter then waits for a certain random time before attempting to transmit again.

The flat, or twisted, cable variation – known as 10BaseT – uses separate wires for transmit and receive; this gives better error immunity and simpler driver circuitry at each end. However, workstations cannot just be

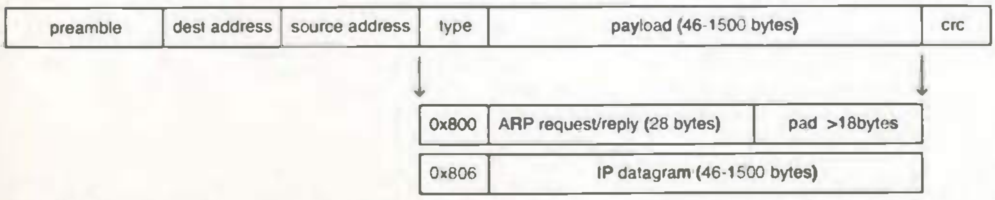

Fig. 4. Ethernet frames comprise a 6-byte destination and source addresses, plus a field word indicating the type of payload carried. The two most common payloads relevant to the TCP/IP world are shown in the figure. The preamble is a string of 62 bits used to synchronise the internal clock generator. A 4-byte CRC word terminates the packet. The Ethernet interface chip strips the headers, performs address comparison and checks for CRC validity before placing the data block in the RAM buffer.

connected to each other. Rather, they need to be connected to a central 'hub', which acts more or less like a repeater or distributor. Other methods are available, working on similar electrical principles.

In terms of speed, two main flavours are available, 10MHz and 100MHz. In many small office and home environments, 10MHz is the most popular. It is easy to install, and the cables are easily cut and crimped. I will only be considering the 10MHz version from now on.

How fast will it go?

A speed of 10MHz sounds appealing when considering using a LAN for interfacing to external I/O devices. Reality is different though; you have to consider the inefficiencies of any start-stop burst protocol, plus gridlock effect caused by collisions and other users sharing the network.

There are many good and bad statistics around showing relationships between usage and throughput. Just as on today's motorways, you can experience hold-ups at the most obscure times and for no apparent reason. Anybody designing equipment using a network for data transfer must be well aware of this.

As a conservative estimate, just one PC with one interface and no other users should be able to exchange data at between 70% and 90% of the full advertised speed.

Throughput decays drastically when more users are on the network at the same time. The 'sensormag' article in the reference includes some charts and calculations plus a pointer to an Excel program for estimating these delays.

In terms of hardware support, there are dedicated Ethernet interface chips available from various manufacturers. Most are compatible with a standard generic architecture, known as NE2000. They have a standard 8 or 16-bit data bus interface, compatible with most CPU addressing schemes.

Access to the chip is done via a number of internally paged registers, usually arranged as sixteen I/O or memory locations. Most chips can be directly connected to a CPU memory bus, or even directly to a PC-bus edge connector. The blocks of data being transferred are stored in FIFO memory, as a buffer

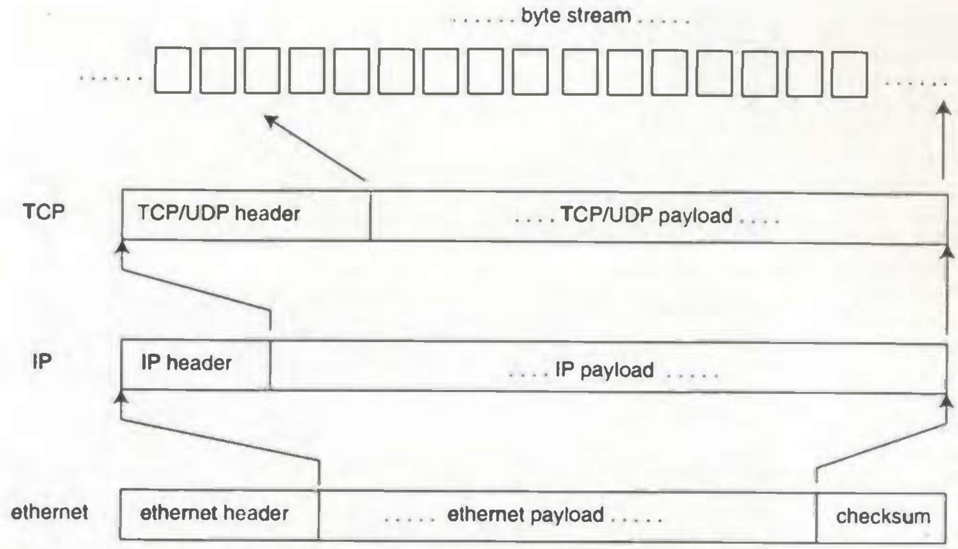

Fig. 5. Russian dolls: each protocol packet contains inside another packet of a higher level protocol. Each layer contributes something to the end result: addressing, routeing fragmentation, transport, error control and error correction. The end result, in the case of TCP, is a continuous, reliable data byte stream.

area for the different speeds between the LAN and the rest of the system.

Using the chip involves first initialising a number of registers to set the various operating modes to determine, for example, whether transfers are 8 or 16-bit. Then, using a loop or interrupt routine, the chip waits for a data register ready flag, denoting that so many bytes of received data are present on the FIFO buffer.

On transmission the system places its data in another part of the RAM buffer, and sets a flag, which is usually reset at the end of transmission.

More detailed information on the workings of Ethernet interface chips can be found in manufacturers' data sheets. Unfortunately, there doesn't seem to be much information available on the Internet apart from some National Semiconductor data sheets, as mentioned in the panel.

Protocols, addressing and payloads

Ethernet data packets – better known as frames – cannot be of just any size. If you were to do some simple calculations involving the maximum distance between workstations, the speed of light in coaxial cable and various other timing considerations about collision detection, you would work out that frames cannot contain fewer than 46, or more than 1500 payload bytes each, Fig. 4.

Every Ethernet frame has a header consisting of a 6-byte source address, a 6-byte destination address, and a 2-byte protocol identifier. This is then followed by the payload, which as mentioned before, can only have between 46 and 1500 bytes.

On receipt of a frame without errors, this payload is 'peeled off' and passed on to the rest of the system. The protocol identifier field specifies which type of protocol the payload is carrying. For example, 0x806 denotes an Internet protocol, or 'IP' message.

The payload will have its own header and payload part, which are dealt with by the next layer in the chain. This is the concept of protocol 'layers', Fig. 5.

It is important to know that Ethernet data bursts or frames are completely independent of each other. Frames are fired like bullets out of a gun, and, apart from a collision detection mechanism during transmission, what happens to them afterwards is of no further concern to the transmitter. In other words, the Ethernet network layer does not provide for any global form of flow control or error protection.

At the other end, received frames are checked for consistency by calculating their CRC. Frames arriving with errors are simply dropped or ignored. It is up to the higher layers to provide for any form of flow control and error

Fig. 6. Commands are available from the DOS prompt that allow you to check your network interfaces. A PC workstation maintains a local cache of other workstation addresses, which is dynamically updated every two minutes or so. Network stations regularly transmit ARP packets to each other to maintain their caches up to date. The DOS command arp is used to display and/or update your local cache.

```
C:>arp -a

Interface: 192.168.0.1 on Interface 0x2
    Internet Address      Physical Address      Type
    192.168.0.2           00-c0-df-e8-83-5c     dynamic
    192.168.0.15          45-54-48-50-49-43     dynamic

C:>
```

```
C:>ping 192.168.0.15

Pinging 192.168.0.15 with 32 bytes of data:

Reply from 192.168.0.15: bytes=32 time<10ms TTL=128
Reply from 192.168.0.15: bytes=32 time<10ms TTL=128
Reply from 192.168.0.15: bytes=32 time<10ms TTL=128
Reply from 192.168.0.15: bytes=32 time<10ms TTL=128

Ping statistics for 192.168.0.15:
    Packets: sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum =0ms, Maximum = 0ms, Average = 0ms

C:>
```

Fig. 7. Ping sends a probe packet to a remote IP destination, which just echoes the packet back. The sender can use the information collected on the way to deduce aspects of the path, delays, users, route taken, etc. The name ping is derived from submarine echo sounders. Ping is a very useful facility for advanced network support. The controller described in this article can be used to generate custom ping type packets.

protection.

It is also relevant to note that the source and destination addresses are 'hardware' addresses. Known as media access control, or 'MAC', numbers, they refer to 6-byte patterns uniquely associated with each Ethernet card and usually assigned at manufacture.

In practice, the address is stored in a separate serial EEPROM on the PC card. Blocks of addresses are assigned by the IEEE to each manufacturer, so when you buy your PC card, it will have its own unique number stored in it.

You can change this number if you want to. Apart from some simple restrictions, such as that the first byte in the sequence must have a '1' and a '0' as its least-significant bits, any number can be used as long as there are no clashes with other cards in your network.

It is not practicable to rely on fixed hardware addresses when managing a real computer network. Therefore, a more flexible form of addressing is used. This addressing scheme consists of four byte sequences, known as 'IP' addresses. They are displayed for human consumption as four decimal numbers, e.g. '192.168.0.1'.

In a computer network, each workstation is allocated its own IP address, maybe once only by the network manager, or dynamically at various times by a program in the network server. Each workstation with an Ethernet card will also have its own hardware MAC address.

The four-byte IP address means nothing to the Ethernet card. Ethernet frames contain only MAC addresses as destinations. Sending a packet of data to a remote location requires knowing its MAC address.

If you connect a black box into a network containing a controller and data logger for example, you must allocate it an IP address, and notify everybody else of it. But how does the rest of the network know what our hardware MAC address is, and how to access the controller? You need to know about ARP to answer this one. For more on Ethernet and IP, see RFC894.

ARP

As I mentioned earlier, the payload in an Ethernet frame can carry formats other than IP. One such format is ARP, which is a simple query-response packet protocol used to match workstations hardware addresses and IP addresses. ARP stands for address-resolution protocol.

In a typical network, computers spend a small part of their time sniffing each other, that is, sending short probe packets too see who else is around. This is usually done on a regular, or on a 'need to know' basis. The ARP protocol is used for just that. It makes use of a special MAC 'broadcast' destination address (0xFFFFFF).

All Ethernet stations on the network accept broadcast messages. The broadcast message basically says, "Hey out there, anybody with IP address 190.168.0.15?" The one and only station having this IP address allocated will then reply with a packet stating its hardware MAC address.

In a Windows network each workstation builds up and maintains a local table of IP versus MAC address pairs. Before sending a message to another station, the table is consulted. If there is no entry, an ARP query message is sent out. The table is dynamically maintained, flushed and refreshed every few minutes.

Windows provides a number of tools and facilities, mainly supplied as DOS console programs, which you can use to see this in action. Open an MS-DOS command box in your computer and enter "c:>ARP(if the program is not available in your machine, try installing these components from the New programs/communications tools Wizard). The program arp will display the current IP/MAC address pairs for all the local machines in your network. You may see nothing, especially if there was no recent network activity. Remember that the tables are dynamic and flushed every few minutes.

Next, enter "C:>ping 192.168.0.15" – or the address of any other station on your network – and wait to see any replies, then try "C:>arp -a" again. Assuming that your prototype controller is connected to the network, the screen will show '192.168.0.15 4E-54-54-50-49-43,' Figs 6, 7.

Any embedded Ethernet controller must include some form of ARP reply processing in order to respond to 'who are you?'-type requests made by other stations on the network. The controller also needs "multiSIM could very well herald the next step forward in PCB design methodology, because it can co-simulate both HDL and SPICE components... at a very affordable price"

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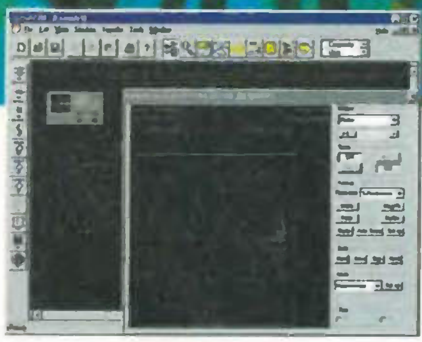

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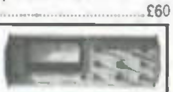

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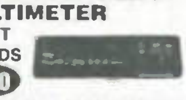

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to include methods for querying other workstations in the network for their MAC addresses using ARP requests. This is one of a number of necessary overheads that push up the amount of code required in the controller, but they are essential for the proper operation in a shared network.

More on ARP can be found in RFC 826. The next topic of interest is IP, the 'other' relevant format carried by Ethernet frames, Fig. 4.

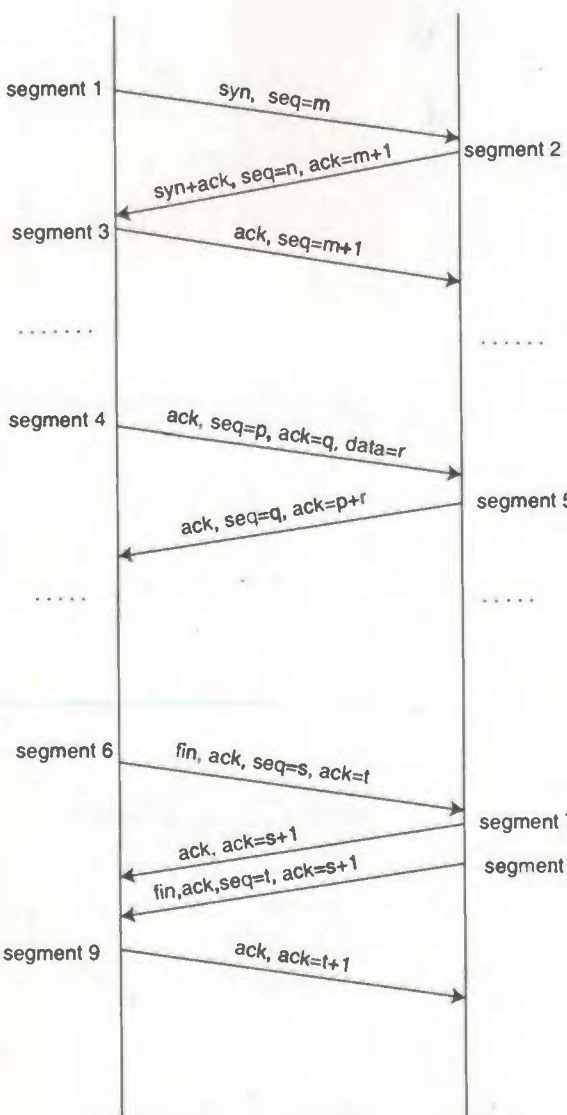

Fig. 8. Simplified diagram of a TCP conversation. Three stages are essential: setting up the channel, the actual data transfer process, and closing down the conversation. State transition tables are generally used in the software to implement the overall process. One set of tables and data memory buffers will be required for every open channel. This is not practical for small microcontroller memory limited applications.

Internet Protocol

Internet protocol, IP for short, forms the backbone of all TCP and UDP messaging. Like the rest, each IP packet – better known as datagrams – has itself a header and a payload component. RFC 791 is the basic document describing IP.

Within the IP header, the most important items of information are the source and destination IP addresses. For local communications between two stations in a local loop, the IP address in the IP header and the MAC address in the Ethernet frame header just preceding it will correspond to the same workstation computer. This may sound like unnecessary repetition, but this pairing is required for routers, where the fields may be different.

There are other various fields including a checksum, a fragmentation pointer, a protocol code for the payload, and the payload itself.

Like Ethernet frames, IP datagrams are independent of each other and contain no in-built error protection or recovery. So why is IP necessary? Well, IP is the common layer above all hardware-dependent transport mechanisms. Irrespective of how the devices are electrically connected together – be it via fibre, radio or phone lines – all data blocks end up as compatible IP datagrams.

The job of IP is to get the data block to its destination. Its main contributions are addressing, routing and fragmentation. Remember how Ethernet frames had a limited byte size range? Similar limitations also apply to other transport mechanisms: optical fibre, satellite links, etc. Internet protocol allows datagrams to be chopped (fragmented) into shorter sections of the right size for transmission and *vice versa*: short sections packed into single, longer datagrams.

The method employed for fragmentation is relevant for embedded systems. Fragmented datagrams include a 'pointer' indexing the position of the first byte of their data payload in an imaginary 64kb data buffer. Therefore, each IP datagram contains exact information about the position and size of their payload within this imaginary buffer. This allows for fragmented datagrams to be received out of sequence. A receiver accumulates datagrams until they all neatly fit into a contiguous block.

It follows that fragmented IP datagrams are not really independent of each other. This will introduce a time element in any system. A receiver for example, has to consider when to give up waiting for missing out of order packets, and dump any previously stored.

Fragmented datagrams cause problems with small embedded systems. In theory, a receiver needs to allocate a 64kb buffer for every first out of sequence datagram received. This means one buffer for every different open socket (or channel) being serviced. This is impractical for small RAM limited systems.

One practical solution is to disallow or ignore fragmented IP datagrams. This may not be much of a problem if the transactions involved are small, e.g. for a small data logger. However, there may be problems for systems dealing with long streams of block-encoded data such as voice or video. Fragmentation is not much of a problem with TCP (see later on) as TCP can be engineered to use small segments to start with.

In a typical situation, an embedded system may need to deal with many sources or originators. Datagrams may be arriving from more than one source at the same time. The microcontroller will need to keep track of all, keeping state variables for each contact, to ensure the right replies are sent back to the right originators. In a PC this is easily handled using concurrent threads. But small microcontrollers do not have such niceties.

Three types of IP payloads are of interest here: ICMP, UDP and TCP.

ICMP

ICMP stands for 'Internet control-message protocol'. This is not a protocol used to transfer messages, but rather to provide a kind of internal maintenance messaging service.

One of the most common uses for ICMP is a service known as 'pinging'. This is a method where a workstation can query another by transmitting a special short 'ping' message and wait for an echo response, Fig. 7.

Any embedded implementation

should incorporate facilities for echoing any 'ping' commands received. There's more on this later.

Replies in ICMP are also commonly sent in response to failed UDP datagrams. An embedded application should also incorporate simple facilities for dealing with ICMP 'unobtainable' messages.

ICMP is documented in RFC 792, 950, 1812, 1122, 1191 and 1256.

Datagrams and UDP

User-datagram protocol, or UDP for short, is a simple transport-layer protocol. It is a connectionless, unreliable protocol with no error or flow control mechanisms.

In effect, UDP is nothing more sophisticated than an IP datagram with an extra addressing field: a port number. A port number is an interesting concept. If a workstation has an IP number allocated to it, how can different processes or programs in the workstation communicate at the same time? The answer is using ports.

Workstation "192.168.0.31" can use port 21 to talk to another workstation, use port 80 for web access and use port 27 for file transfers. Think of telephone extensions working off a main private exchange number.

Document RFC 768 fully describes UDP. Sending a UDP message is somewhat like sending a postcard to a friend, a simple 'shoot and forget'-type protocol. It can be very reliable in networks that are reliable to start with such as LANs.

This method is normally used for simple file transfers and remote booting of PCs. It is also used anywhere where a failure to receive is not a disastrous issue, or one that can be simply compensated by a repeat transmission later on.

Because of this simplicity, UDP is a simple protocol to implement in an embedded application. Simple error recovery can be implemented at the user level. This can take the form of mindless repetition to a simple 'ACK'-based datagram response. Writing the software at the PC end is also easy, as the program in List 1 shows.

The controller described here uses UDP to demonstrate simple read and write to a parallel and the analogue port. It also uses UDP for simple data connection to and from the user serial port. UDP is an effective protocol for developing special user applications.

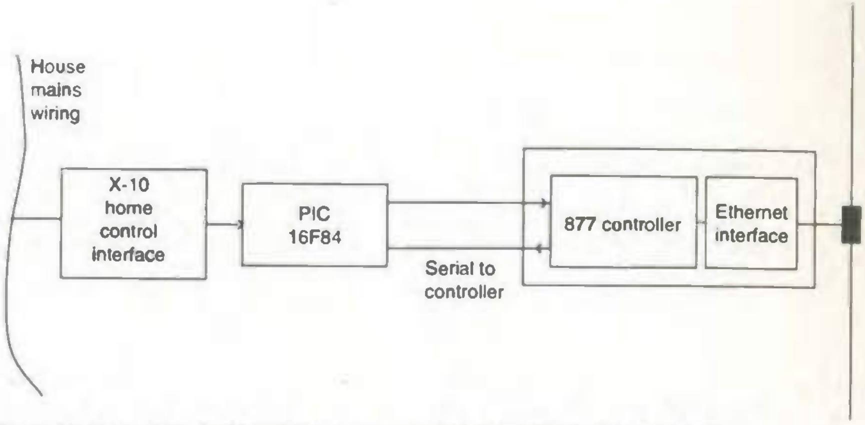

Fig. 9. X10 Home Control Interface: a separate PIC forms the basis of a simple interface between X10 home automation and the local area network. No interface standards exist at present for this kind of interactivity.

Transmission control protocol, TCP

Transmission control protocol, or TCP, is very different from UDP or to any of the protocols described previously. It is a point-to-point oriented, reliable, byte-stream service.

All error protection and flow control is carried out in TCP. The main document for this protocol is RFC 793. You will find additional information in RFC 896, 1122, 1323 and 2018.

Traditionally, error and flow control in telecommunications were handled at the lower layers. It was recently discovered that low-layer error handling is not as effective as higher layer handling. This is one of the reasons why the layers below TCP do no need to provide any form of error or flow management.

In UDP, stations just shoot packets at each other. TCP requires the two stations to establish a 'connection' first. Once the connection is established, data can flow from one station to the other.

Opening a connection is done by sending specially flagged segments – in TCP, a packet or unit of information is called a segment – that are used to synchronise counters and timers at either end, Fig. 8.

Transmission control protocol requires all data to be acknowledged. Rather than acknowledging each segment individually, TCP uses a pointer scheme where the receiver acknowledges the position of the index or pointer of the last reliable block of data received. Each segment thus carries a block of data plus an index pointer into an imaginary array of bytes, that is, where the data block belongs in the array.

This scheme is very convenient as it allows segments to arrive out of order. There is no need to acknowledge every segment received, a single ack can be sent for more than one transmission segment received.

Both transmitter and receiver also operate a 'data window' scheme telling a transmitter how many more bytes the receiver is willing to accept. This provides a form of data flow control.

By constant adjustment of the windows and delays, TCP can be honed to provide an efficient flow mechanism tuned to a particular channel's characteristics. In such a channel, the transmission line is nearly constantly active all the time, with very few ACKs sent back.

You could see efficient and inefficient TCP in action by observing the TX and RX lights on a modem. Inefficient TCP is when both TX and RX flash or flicker in opposition, with periods of no activity in between. Efficient TCP is when the RX light is nearly constantly on, denoting a nearly constant flow, with the occasional flicker of the TX 'ACK' light.

Implementing TCP requires the use of a state transition table, linking 'actions' with 'states' and 'events', plus a data control block to store all variables for each particular connection – also known as a socket.

In normal practice a server, or listener, opens a new thread for every open connection request received from a client. This thread is maintained until the connection is closed. The state table is described in detail in RFC 793.

Implementing the full set of TCP requirements in an embedded system is not trivial. Including each and every combination of events, states and actions will readily inflate a micro's valuable program and data memory space. In addition, threads are not easily implemented in the smaller devices.

Fortunately, some simplifications can be made if the connection has been coherent for a long time, and it is resilient to repeated and/or missing data. Depending on the use it is put to, it is possible to implement a perfectly workable 'lite' version of TCP in an embedded processor.

Telnet, HTTP, FTP SMTP...

Telnet, HTTP, FTP and SMPT are higher level application protocols. They were designed for specific end-to-end purposes – FTP for file transfer, SMTP for mail, HTTP for web access.

These protocols have one thing in common. They work by sending and receiving streams of bytes, usually ASCII characters, down an already opened TCP connection.

In terms of implementation, these are relatively simple. One just needs to generate the right sequence of characters. As long as there is an existing TCP open channel to convey the characters, you could even use a BASIC-like program.

Implementing a simple web server involves nothing more than writing a program that receives an ASCII serial stream, senses for special character sequences, and sends back another sequence of characters.

RTPS – real-time networking

A number of alternative network models exists. Most are designed for particular applications such as stream voice, video, and real time control.

An abbreviation for 'real-time publish subscribe', RTPS is a good example of a recent innovation in networking models. Nodes 'publish' data onto a network or 'subscribe' to any data they need from the network. Subscriptions eliminate the need for request traffic.

The model is aimed at real-time control systems using the Ethernet, where speed of response and reaction has to be tightly controlled. A number of companies, among them General Motors, have evaluated the use of Ethernet in such schemes, and have found it a very reliable real-time transport medium.

RTPS technology is very recent, and typical of a number of similar developments to move away from the limitations of TCP. Companies such as RTI (www.rti.com) are offering components and toolkits under a $10k licence.

For some small real-time applications, a subset of the technology is all that may be necessary. I have been looking at some implementation possibilities, and can see that this is an area that will see a lot more development in the future.

On telephones and modems...

I have limited the description to operation over a local area network. This may or may not be connected to the Internet via a router or server.

Most of you will be using a dial-up Internet service provider. The link between you and the ISP is via a modem. Generally, the protocol used on this link is called PPP (or the older variant SLIP).

The main purpose of PPP is to encapsulate IP datagrams into a form more suitable for modem communications; this is done by using special escape sequences to avoid transmitting characters such as ETX, which can produce odd effects on some modem links.

Extra PPP messaging sequences are used at the beginning of the transaction to negotiate details on the transmission methods used, types of compression, to exchange passwords and to allocate a dynamic IP address. Point-to-point protocol is not implemented in the present version of the controller. Even a simple version of PPP would take at least 2k of program space.

Implementing PPP is not trivial. 'Lite' versions of the protocol may not be very reliable, and can be very ISP dependent. PPP is a negotiated protocol; a negotiation can sporadically fail, say by a client requesting facilities that a server may refuse to provide at that time.

And home networks

The idea of intelligent buildings and home automation has been with us for a long time. Many proprietary standards and protocols for interfacing and control now exist; many are under development. These systems have found a slow uptake and difficult marketing, maybe because of the high cost of the interfaces and sensors.

The introduction of low-cost IP technology may influence future decisions on this subject. **Figure 9** shows a way a PC LAN could be linked to an X10 home-automation network. There are not many common or emerging protocols for such interfaces at present. ■

In the next article, Eddy discusses ways of implementing a simple controller based on a PIC 16F877 and a standard LAN PC card. This controller can be used for demonstrations or as the basis for an embedded prototype interface project.

Useful web sites

National Semiconductors Ethernet Chip data sheet
www.national.com/ds/DP/dp83905.pdf
General X-10 Home Control Information:
www.x10.com
More information on embedded Ethernet controllers:
www.embedded.com, www.chipcenter.com, www.connectone.com, www.ipsil.com
RFC papers are available from various websites in different formats. Try one of the search engines such as *www.google.com* and enter the search word "RFC".
Useful article on Ethernet throughput and RTPS
www.sensormag.com/articles/1100/22/main.shtml

Further reading

TCP/IP Illustrated, Vol. 1, W.Richard Stevens, Addison Wesley, 2000. A very comprehensive guide for all aspects of TCP/IP. This is one of the best known books in the subject.
Windows 2000 TCP/IP Protocols and Services, Technical Reference, T. Lee and J. Davies, Microsoft Press, 2000. This book contains a CD with all published RFCs to date.
Network Programming for Windows, A. Jones and J. Ohlund, Microsoft Press, 1999. A must for anybody involved in network and Winsock programming. Many examples are included.
Interfacing Tini, Les Hughes, *Electronics World*, July 2000. A description of the Dallas Java-based web controller.

The author

Dr Eddy Insam is a consultant in innovative applications of telecommunications and specialises in graphics and signal processing. He can be reached on *edinsam@eix.co.uk*.
If you are considering a serous application for this device, Eddy will endeavour to answer your queries via e-mail.

List 1. Simple C code for the PC showing how to use the Winsock API to communicate with an external I/O device. Refer to the literature for more examples. This demonstration program shows how Winsock can be used for communicating between a PC and an embedded ethernet device. This is a Windows console application. To run, open a MSDOS box, and enter the name of the program followed by optional arguments.
Programming notes: If using Microsoft Visual C, open as a Windows console application, and copy this file to the directory.
Program must be linked with the Winsock 2 library "WS2_32.lib".
The Winsock DLL file "WS2_32.DLL" must be present in your system, usually already present in W95(SP2), W98, NT and W2K.
In order to reduce listing clutter and improve readability the code is kept as simple as possible with many parameters hard-coded in. For the same reason, error handling is implemented with simple "goto" type statements.
A useful reference (with samples) for winsock programming is A. Jones & J. Ohlund, 1999. "Network Programming for Windows", Microsoft Press.

```
//*****************************************************
//      Copyright (c) 2001, EIX ltd
//*****************************************************
//Command Line options:
//c:> exename [ipaddress]
//where ipaddress is destination address, e.g. 192.168.0.15
//*****************************************************
#include <winsock2.h>
#include "stdio.h"
#include "stdlib.h"
//**  main entry point to the program
int  main(int argc, char* argv[])
{
//** First, initialise any global variables to their default
      char zIPadd[32];
      strcpy(zIPadd,"192.168.0.15");        // default
destination IP address
//** Next, deal with any user input provided in Command Line
      for (int i=1; i<argc; i++)
      {   if (argv[i][0]>='0') strcpy(zIPadd,&argv[i][0]);
      }
//** Initialise Winsock 2...
//Loads or increments DLL usage count.
//Must call WSCleanup() on exit!
      WSADATA wsadata;
      if (WSAStartup(0x202, &wsadata) != 0)
      { printf ("Winsock 2 cannot be loaded, error %d",
GetLastError());
        return -1;
      }
//** Create our socket...
// Socket is initialised for UDP datagram transactions
      SOCKET hSocket=socket(AF_INET, SOCK_DGRAM, 0);
      if (hSocket == INVALID_SOCKET)
      { printf ("Socket creation failed, error %d",
GetLastError());
        goto Exit;   //simple abort avoids listing clutter
      }
//** Define destination as a socket structure...
//Note the use of the standard Winsock functions htons and
inet_addr
// htons() reverses byte endian order, needed for IP packets
// inet_addr() converts IP strings such as "190.0.0.1" into
IP DWORD
      SOCKADDR_IN           Sdest;
      Sdest.sin_family=     AF_INET;
      Sdest.sin_port=       htons(0x5001);      //hard-coded
dest port
      Sdest.sin_addr.s_addr= inet_addr(zIPadd); //dest IP
address
//** Now transmit the data...
//Winsock will send the UDP datagram to the socket specified
//in Sdest. The function also generates a local receive"
//port number for replies.
      {
//Create some useful data to transmit. We shall be
//hardcoding the message for this demonstration.
        char pTx[8];
        pTx[0]=0x01; pTx[1]=rand();    //set the LEDs to some
random pattern
        pTx[2]=0x03; pTx[3]=0;         //read data port in A
        int  nTx=4;                    // tot of 4 bytes in tx
packet

        // The actual TX call
        SOCKET stx=sendto(hSocket, pTx, nTx, 0,
(SOCKADDR*)&Sdest, sizeof(Sdest));
        if (stx== SOCKET_ERROR)
        { printf("Sendto() failed, error %d",GetLastError());
          goto Exit;
        }
      }
//Having sent the data packet, we now need to wait for a
//response. Before calling the receive function, we
//could install a receiver timeout, this can be useful for
//avoiding call from blocking forever if no data received
      { int to=3000;   // hardcode a 3 second timeout
        int
nr=setsockopt(hSocket,SOL_SOCKET,SO_RCVTIMEO,(char*)&to,size
of(to));
        if (nr == SOCKET_ERROR)
        { printf("setsockopt(SO_RCVTIMEO) failed, error: %d",
GetLastError());
          goto Exit;
        }
      }
//** Waste one second...
//No need to include this in your program. This is only
//here to let the reply packet enough time to arrive before
//next function is called.
      Sleep(1000);

//** Check nr of bytes in rx buffer...
      // Again, no need to include this function in your
program.
      // This is only here to show a possible way of sensing
if there are
      // any bytes left in the receive buffer before calling
recvfrom().
      { DWORD nb;
        int e=ioctlsocket(hSocket,FIONREAD,&nb);
        if(e==SOCKET_ERROR) { printf("Ioctl
error:%d",GetLastError());
                             goto Exit;
                           }
        printf("Rx buffer has %d characters\r\n",nb);
      }
//** Call the receive function...
//This function may block until whole datagram is received
//(or until a defined timeout occurrs, if set as above).
      { SOCKADDR Sremot;
        Sremot.sa_family= AF_INET;
        int nremot=sizeof(SOCKADDR);
        char pRx[256]; int nRx=256;    // rx data goes here
        SOCKET srx=recvfrom
(hSocket,pRx,nRx,0,(SOCKADDR*)&Sremot,&nremot);
        if (srx== SOCKET_ERROR)
        { // handle the specific "error" case of a timeout
          int ee=GetLastError();
          if(ee==10060) printf("Receiver timed out, no data
received");
          else           printf("recvfrom() failed, error
%d",ee);
          goto Exit;
        }
// If we get this far, data was received OK, so do something
with it!
        printf("Received OK, first 4 bytes of data: ");
        for (int i=0; i<4; i++) printf("%02X ",(BYTE)pRx[i]);
        printf("\r\n");
      }
//** Lastly, close socket, unload Winsock, and exit...
Exit:
     closesocket(hSocket);
     WSACleanup();
     return 0;
}
```

Personal voice communications without a licence over a two mile radius for £75, exclusive.

Reader offer

A *pair* of two-way PMR radios for just £75*

RS 446 personal mobile radio...

To celebrate its launch, new test and instrumentation company Tecstar is offering *Electronics World* readers *two* RS446 personal mobile radios for just £75 excluding VAT and carriage.

Capable of transmitting and receiving voice over a distance of up to two miles, depending on terrain, the PMR 446 needs no licence. It offers eight channels, scanning – and with CTCSS up to 304 channel combinations.

A backlit liquid-crystal display shows volume level, channel number, sub-channel number, battery level and transmit/receive or channel busy. A unique call feature enables the user to alert the person they wish to contact.

Transmission distance is up to 2 miles. The radio has an accessory socket for an external headphone, earpiece or vox-microphone/headphone combination. A keypad lock and battery save feature are also standard.

The unit measures only 120 by 50 by 20mm and weighs less than 150 grams – including batteries. It is supplied complete with instructions and belt/mounting clip.

Compact, lightweight and low cost, the RS446 wireless personal-communications hand set has a wide range of applications. These include fetes, events and rallies. Builders on building sites could benefit from these radios, as could exhibitors at exhibitions and staff at warehouses, winter activities, sports events, maintenance departments, schools and care homes. Of course you can also use the RS446 just to keep contact with someone locally. The uses are almost limitless.

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RS446 key features...

- Up to 2 mile coverage radius
- Scans main and subchannels
- Eight channels, each with 38 sub channels
- Backlit display for night time use
- Unique call function
- Headphone and mic sockets allow discrete use
- Battery status indicator
- Auto battery save feature
- Keypad lock-out

What is CTCSS

CTCSS – or 'continuous-tone controlled squelch system' – allows sub channels of the main channels to be used. There are 38 sub channels to each main channel. Using subchannels decreases the likelihood that someone else will be using the same frequency.

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Quenching

The quest for performance in today's mobile world means that high power consumption is the curse of chip designers, but plenty of solutions exist. Richard Ball explains the traditional approach and looks at the latest attempts to keep pace with clock speeds

If today's trends continue, by 2015 we'll all be carrying small nuclear power sources to keep our laptops going. Why? Because microprocessors will be consuming more juice than a V8 dragster and spewing out more heat than a rocket nozzle. So claims Pat Gelsinger, CTO of Intel's architecture group.

Mind you, such comments are a bit rich coming from the company that's done more than most in the race to push up clock speeds.

So why are we heading towards nuclear-powered laptops, and what are chip designers doing about it?

The quest for performance has often been at the expense of power consumption – witness Compaq's latest Alpha processor which runs at 1200MHz (1.2GHz), producing 125W. Mind you, it does have 130 million transistors.

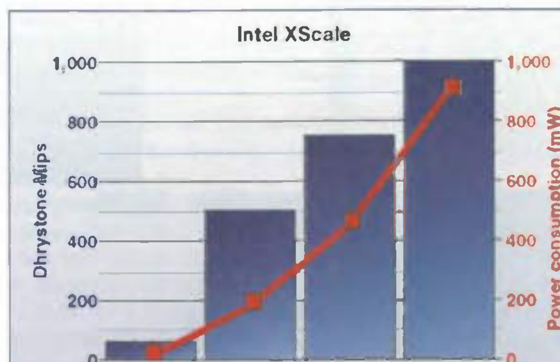
One of the traditional routes to higher performance is increasing the number of pipeline stages in the processor. As each stage has less to do, the clock speed can increase.

Increasing the pipeline depth might increase the clock speed, but it's a dubious method of improving overall performance and is definitely bad for power consumption. Pentium 4 and its 20-stage pipeline, for example, processes fewer instructions per clock than Pentium III on conditional code, and hence its power/performance ratio is worse.

An IBM paper at this year's ISSCC conference nicely sums up pipelining: "A deeper pipeline could have yielded even higher frequencies, but at the expense of reduced instructions per clock (IPC). Processor performance is not proportional to frequency but rather the product of frequency and IPC."

Another well trodden route to performance is parallelism in the processor – placing two, four or more arithmetic units in parallel to do more work in a single clock cycle.

The problem with these superscalar designs is that if the program code can't be written or reordered to take full account of the processing resources, then performance is wasted. And this happens a lot in systems with parallel



Frequency (MHz)	50	400	600	800
Dhrystone Mips	62	500	750	1,000
Power (mW)	10	180	450	900
Core Voltage	0.75V	1.00V	1.30V	1.65V

Intel's XScale processor can dynamically adjust voltage, frequency and hence power.

Power consumption runs wild

According to Patrick Gelsinger, chief technology officer of the Intel architecture group, increasing the absolute performance from the x86 processor series has resulted in less and less performance per gate per megahertz.

The law of diminishing returns has taken over and increasing power consumption is the result. Despite reduced supply rails, according to Gelsinger, if current Intel trends continue chip power density will reach that of a nuclear reactor in 2007 and dissipation will be the same as the surface of the sun, 10 000W/cm^2, in 2015.

His solution is less brute force – so smarter branch prediction and pipelines – and processors designed for specific tasks.

Perhaps Intel is waking up and breaking out of the Windows-PC mould.

processor thirst

architectures. The end result is more heat for less useful work.

Plenty of solutions exist to the problem of high power consumption in processors and hence, to a certain extent, any system-on-chip. However, different solutions fit different markets and applications.

Dynamic clock and voltage management

Power consumption in a circuit is proportional to frequency, but it is also proportional to the square of the voltage. Therefore, the easiest way to cut power is to reduce the voltage.

This does mean a reduction in frequency, but if the loss in performance can be absorbed, then the reduction in current and power is well worth the effort.

Intel has certainly taken this approach with XScale, its second generation successor to StrongARM. At one end the chip can run from 1.65V, hitting 800MHz and consuming 900mW. Throttling back the voltage to 1.0V, however, sees the clock halved to 400MHz while power plummets to 180mW. At the extreme end power reaches just 10mW at 0.75V and 50MHz.

Intel has still gone down the "let's get maximum performance" route, but in this case that performance might not always be used. Sometimes it's sacrificed for much lower power.

A similar scheme is being applied by Transmeta to its Crusoe processors. Its LongRun technology uses subroutines in the software to determine the processor's loading and adjust the voltage and frequency settings. However, LongRun is not accessible to the programmer - XScale's power tricks are, and XScale has a wider voltage scaling range.

Obviously this technique applies well to the handheld consumer device market.

Semiconductor process

Improving the semiconductor process is the simplest trick in the book for reducing power consumption. As the geometry size reduces, voltage is forced down – most of the time – and so power drops quickly.

Today the work-horse process is 0.18μm, but in R&D labs, firms are building circuits on 0.13μm or smaller. At this level some significant problems are beginning to surface.

As gate lengths decrease, then the gate oxide thickness must also reduce, and this defines the maximum voltage of the transistors. But for high performance devices, a thin gate oxide will result in high leakage current. For low power, a thicker gate oxide will impact performance.

Therefore many firms, such as Toshiba, IBM and Motorola, are using different flavours of transistors in a single device.

Motorola's 0.13μm (130nm) process detailed at last year's IEDM conference has gate lengths from 80 to 110nm, and gate oxide thicknesses of 1.8nm, 2.5nm for low power, 5nm for 2.5V I/O and 7nm for 3.3V I/O.

Another way to reduce leakage current and parasitics in to use silicon-on-insulator. Driven by IBM, this technology may well be used by AMD in its mobile PC processors.

Simultaneous multi-threading

SMT is not a new idea – it was first used by Cray in one of its chips over 30 years ago. However, the idea is only just appearing in mainstream devices, and it promises much, especially in the server or telecoms markets.

In a superscalar processor – even with the greatest compiler in the world – a single thread is hard pushed to keep all the execution units active. In deeply pipelined devices, a cache miss or mis-predicted branch causes

Power restrictions in 'system-on-a-chip' devices

Hitachi has taken a fresh look at power restrictions in system-on-chip-based appliances and come up with a hardware-based on-chip power management system called ChipOS, *writes Steve Bush.*

Processors tend to draw power in bursts. Inconveniently, power supplies have to be sized to match the power peaks, or include chunky capacitors to meet peak demands.

This problem is particularly bad in battery-powered devices where a high peak draw can bring a pair of AA cells to their knees and cause a system reset.

ChipOS tackles this by allowing the system designer to specify a maximum power draw from a system-on-chip.

The same chip, running the same software, can be allowed to run free in a mains-powered application, and peak-limited when battery powered.

And this peak limit is accurate, rather than just the average reduction which comes from processor clock speed switching.

Hitachi claims that a die with ChipOS could be used in a low cost 1W system or a 10W high-performance system.

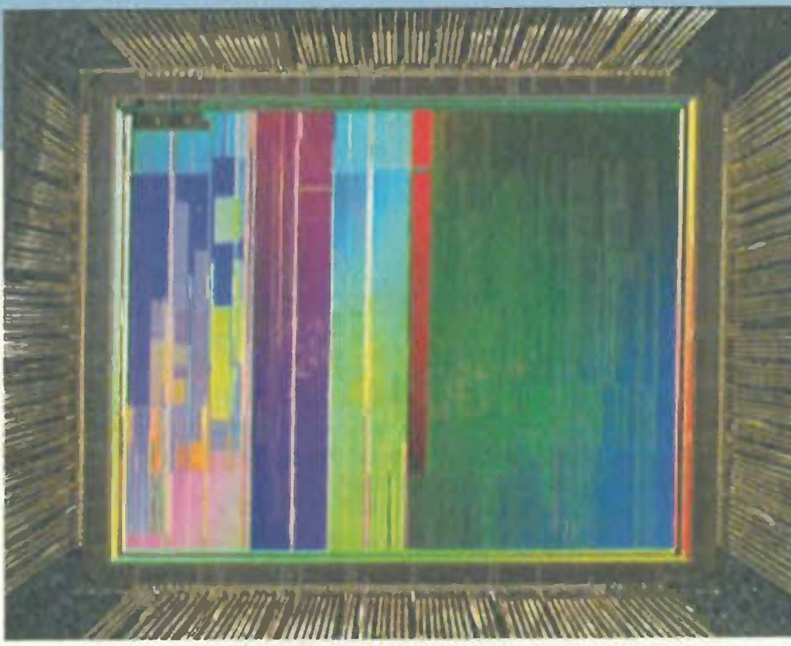
When multi-tasking, one task can be given priority and allowed to have all the processor's capacity up to the imposed power limit during an activity burst. The other tasks will be slowed or stalled until power becomes available again.

Power limiting clamps the overall performance of the system, but Hitachi's figures (for an undisclosed single-processor application) show a 48 per cent reduction in peak power only results in 10 per cent slower system speed.

With four processors under the same ChipOS controller, an 81 per cent reduction in peak power was available with 10 per cent slowing.

The penalty with ChipOS is additional hardware. Logic blocks have their clocks gated and their power rails switched.

Associated with each block is a block-specific power driver, which controls clock gating, and rail switching. Running above this is a power scheduler that uses knowledge of block power requirements to allocate blocks to tasks.



Alchemy is a name to be reckoned with in the chip design world, having its ancestry in the original StrongARM team. Its first chip, the Au1000 (above), is back from the fab and undergoing testing. Like Xscale, clock frequency and hence power can be dynamically scaled. Initial figures indicate that running at 1.25V and 200MHz, the chip dissipates 200mW, while at 1.5V and 400MHz power is up to 500mW.

large chunks of data to be flushed – wasting a considerable amount of power.

Multi-threaded processors can fill slots in the instruction issue with waiting threads. So the whole thing runs faster, or to look at it another way, the same amount of work is done with less wasted power.

However, SMT doesn't come for free – it adds around ten per cent extra hardware.

SMT may be about to become mainstream, especially if, as is rumoured, Intel puts it in Foster, the next spin of Pentium 4. It's already in the latest Alpha, described earlier.

Clock distribution

Better clock distribution design is also an avenue to reducing power dissipation, as a processor's clock tree can have a massive overall impact.

For example, another IBM paper from ISSCC describes its POWER4 chip. This dual microprocessor device contains a staggering 170 million transistors. At 1.1GHz it consumes around 115W.

"Approximately 70 per cent of the power is burned in the clock distribution and latches," the firm says. ■

Electromagnetic gun fires a pellet 20km in a second

Sandia Labs' Z machine electromagnetic pellet accelerator has boosted a projectile to 20km/s – i.e. 45 000mile/h. Inside Z machine, 20 million amps produces a magnetic field that expands in around 200ns and generates "several million atmospheres pressure" on the pellet, according to Sandia. When fired up to 13km/s, the aluminium pellets are neither distorted or melted, but with the wick turned up to achieve 20km/s the aluminium reaches 2500K and liquifies. Research over the last year has been to keep this temperature down as the pellet can no longer be accelerated once it vapourises. The picture shows researcher Mark Knudson holding two pellets in his right hand and the chambers of Z machine on his left.

Reader offer

10MHz single-trace oscilloscope for under £200

The Tecstar CS1010 oscilloscope is easy to operate and highly reliable. It is an ideal instrument for research, production, education and development work. This is a compact and portable oscilloscope with a frequency bandwidth of 10MHz and sensitivity of 5mV/div to 5V/div. It is equipped as standard with a switchable ×10:1 probe, extending the sensitivity up to 50V/div. The horizontal timebase is 0.1s/div to 0.1μs/div.

- **Simple operation**
- **Portable, small and lightweight**
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Features

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- Variable-Y attenuation
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- Variable trigger level
- +ve or –ve Ext trigger modes
- Internal, External or Line trigger
- Complete with ×1/×10 probes
- Low cost

Vertical system	
Sensitivity	5mV/div-5V/div±3%
Trimming ratio	2.5:1
Rise time	35ns
Bandwidth (–3B)	DC:0-10MHz AC:10Hz
Trigger system	
Int trigger sensitivity	1 div
Ext trigger sensitivity	0.3V
Ext. trig. input impedance	1MΩ, 30pF
Ext. trig. max. input	400V pk
Trigger sources	Int, Line, Ext
Trigger mode	Norm, AUTO, TV
Horizontal system	
Sweep time	0.1s/div-0.1ms/div, ±3%
Trimming ratio	≥2.5:1
X-Y mode	
Sensitivity	0.2V/div-0.5V/div
Bandwidth (–3dB)	DC: 0-1MHz AC:10Hz-1MHz
Calibration signal	
Waveform	Symmetric square wave
Amplitude	0.5V±2%
Frequency	1kHz±2%
CRT	
Display area	8 x 10div (1div=6mm)
Accelerating voltage	1200V
Display colour	Green
Power source	
Voltage range	220V ±10%
Frequency	50Hz ±2Hz
Power consumption	25W
Physical features	
Weight	3kg
Dimensions (H x W x D)	190 x 130 x 270mm
Working environment	
Working temperature	5°C to 40°C
Storage environment	–30°C to 60°C, 10-80%RH
Working altitude	2000m

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SPEAKERS' CORNER

Voltage or current drive?

Moving-coil loudspeakers are invariably driven by a voltage amplifier. Here, John Watkinson explores the alternative – current drive.

Traditionally, the moving coil loudspeaker drive unit has been connected to a voltage amplifier. **Figure 1a)** shows that an ideal voltage amplifier has zero output impedance such that the voltage at the output terminals is independent of the load impedance.

In reputable amplifiers this requirement is typically met with negative feedback, which simply compares the output voltage waveform with the input signal waveform.

Figure 1a) also shows that an ideal drive unit would have zero resistance and zero inductance. The only factor controlling the coil current is the back EMF. Any difference between the amplifier output voltage and the back EMF would result in an infinite current, so the coil velocity would have to be proportional to the amplifier voltage.

This is a desirable condition, in which the cone velocity follows the audio waveform.

If only...

In the real world though, this doesn't happen. Figure 1b) shows that the tight connection between input waveform and cone velocity is lost because the drive unit has finite resistance as well as inductance.

The result is that the cone velocity no longer follows the input waveform. In any other control discipline, this would be regarded as a major shortcoming and something would be done about it. Imagine an aircraft in which the control surfaces didn't follow the stick, but were blown about by the slipstream.

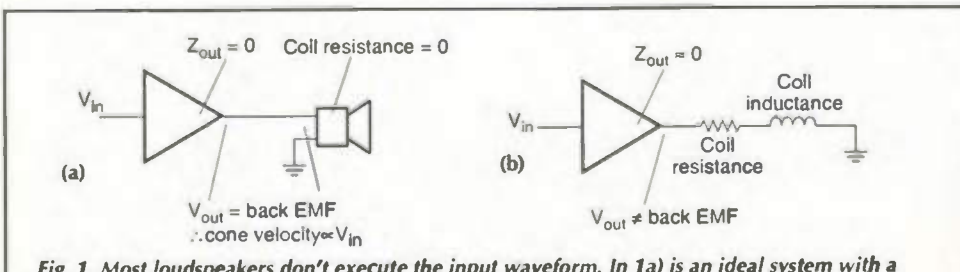

Fig. 1. Most loudspeakers don't execute the input waveform. In 1a) is an ideal system with a zero output impedance amplifier and zero coil resistance speaker. Fig. 1b) depicts a real system. Even though Z_{OUT} is close to zero in a real amplifier, coil resistance and inductance mean that back EMF is not equal to V_{OUT}. Cone is not under control of input waveform.

Generally the audio industry does nothing about this problem, even though the cone velocity becomes anti-phase to the input below resonance, making the output waveform a travesty of the input. Instead, new clothes continue to be made for the Emperor long after his death.

With voltage drive, a number of other factors can affect the cone velocity and potentially cause distortion. These include suspension non-linearity and coil inductance.

If the coil inductance were constant, the result would just be an HF roll-off. Unfortunately, coil inductance changes with the cone position as different amounts of the pole structure are within the coil. The impedance of the drive unit is also a function of coil temperature, which itself is a function of the power dissipated.

Figure 2a) shows an ideal current source driving a loudspeaker. An ideal current source has an infinite output impedance. The output current is proportional to the input voltage and is independent of load impedance.

Implementing current drive

Effectively, the power amplifier has become a transconductance amplifier. **Figure 2b)** shows that current drive can be achieved by providing a sense resistor in the coil current path. Amplifier negative feedback is then used to compare the voltage across the sense resistor with the input. When the two are identical the current in the coil must be proportional to the input voltage.

The current drive amplifier can be implemented with almost any amplification technology used for voltage drive – including switched-mode, error-correcting, Class-A or vacuum-tubes.

The operating principle is now different from that of voltage drive. The force produced by the coil is proportional to the current, so the coil operates in constant-force mode. As the cone mass is also constant, the drive unit operates in mass-control mode. In this mode the amplitude falls at 6dB/octave as required for constant velocity and flat frequency response.

A desirable result of current drive is that the effects of coil inductance and inductance modulation are eliminated, along with changes in sensitivity due to coil heating. This will reduce HF distortion and extend the frequency response while eliminating thermal compression effects. Both of these benefits are well worth having.

Infinite output impedance

However, the down side of current drive is that the infinite output impedance of the amplifier means that there is no electrical damping of the drive unit's fundamental resonance at all. The only damping is due to the drive unit's own structure, with a tiny amount due to sound radiation.

The strong resonance is audible and the drive unit can easily over-travel. Consequently the designer is forced into making some active compensation for the driver fundamental resonance in the shape of an analogue computer/op-amp circuit or DSP. In fact this is no great drawback, because this has to be done with voltage drive if any degree of precision is required. The difference is that with voltage drive it is possible to dispense with resonance compensation if a lower quality is acceptable.

At low frequencies the drive unit becomes compliance controlled. Non-linearities in the suspension, and modulation of the *Bl* product with coil position, will cause distortion whether voltage or current drive is used. In fact given good engineering and a correctly designed resonance-compensation mechanism, voltage and current drive would give exactly the same effect at low frequencies; the sound quality would be limited by the drive unit.

Inductance modulation is negligible at LF. The distortion there is dominated by magnet and suspension design, which amplifier topologies can't affect.

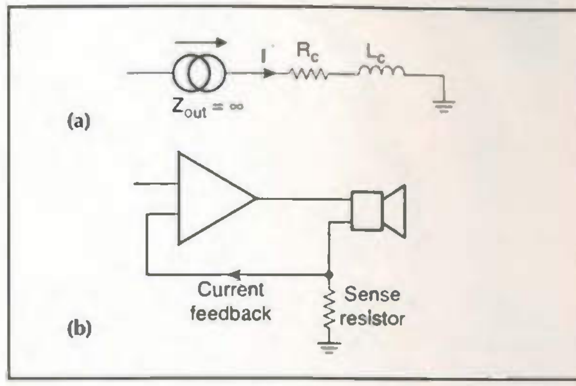

Fig. 2. Current drive principles. In a), with infinite output impedance, current is independent of coil resistance and inductance (and back EMF). Figure 2b) shows how current drive can be achieved using a load-current sense resistor.

The main advantage of current drive would appear to be in tweeters, where the elimination of the effects of coil inductance can give a useful improvement in frequency response and linearity. Tweeters tend to be used well above their fundamental resonance, so the lack of damping there may not be an issue.

At low frequencies, the use of current drive is less compelling because the problem comes down to one of precision drive unit design. If the suspension is non-linear, or if the *Bl* product changes as the coil moves because of an asymmetrical flux pattern, the choice of drive topology is irrelevant.

As has been stated countless times, to make a fine loudspeaker it is necessary to have fine drive units. ■

Power supply problems and solutions are the subjects of this second article describing Norman Thagard's high-performance, pick-up preamp, which exhibits 0.006% THD up to several kilohertz.

Phono preamp for the CD era

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In the second part of this preamp project, you'll discover that paying close attention to good power-supply design and construction techniques offers its own rewards.

I have favoured on-board regulation since my digital design days. However, my amplifier designs have had discrete regulators located on their own separate circuit boards. This was partly because I used voltage-doubling techniques that added enough bulk to the doubler/regulator that it was not practicable to place this circuitry on the preamplifier's PC board.

Here, I returned to my roots with small IC regulators located on the preamp circuit board.

Choosing a transformer

The current requirement for each preamp channel is only 20mA per rail, with another few milliamps required for the monolithic voltage regulator. Almost any transformer with sufficient secondary voltage should work.

I had a 48V, centre-tapped 150mA transformer in my parts bin. I also obtained a small 44V centre-tapped toroidal transformer at 73mA in case I decided to mount the power supply in the same enclosure as the preamp.

In the end, I decided to take the conservative step of placing the power supply, **Fig. 1**, in its own enclosure with the unregulated DC output supplied to the preamp through a connecting cable. So, I used the old parts-bin transformer.

If you want two true monaural channels, I would recommend using two of the aforementioned toroids and duplicating everything. I opted for the dual mono configuration, where the transformer secondary is the last common component with everything downstream electrically and electronically separate.

A given power transformer can radiate at a level sufficient to induce hum in the preamp.[1] In theory, a toroidal transformer would restrict its field to the torus. Even so, it is probably better to locate the AC power portions of the system away from the signal portions. If that is undesirable or impractical, I recommend a small toroidal power transformer located as far from the preamp boards as possible.

This is more than a theoretical consideration, since the hum induced in this preamp when it was located immediately above the power amplifier's power transformer was intolerably loud. This occurred even though the prototype phono preamplifier is in a steel enclosure, and the power amplifier used two toroidal power transformers.

Electrostatic shielding with aluminium will clearly not prevent such hum induction. Simply locating the preamp away from intense alternating magnetic fields is the most cost-effective solution. Moving the preamp just 6 inches away from the amplifier reduced the hum below the audible level.

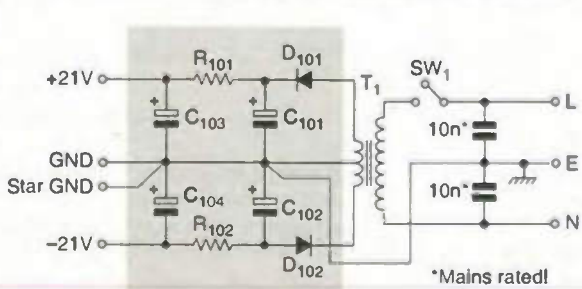

Fig. 1. Power-supply schematic. The circuit in the tinted area needs to be replicated for each channel. Switching, fusing, the transformer primary and the capacitor ratings will need to be chosen according to your country's mains supply and mains regulations.

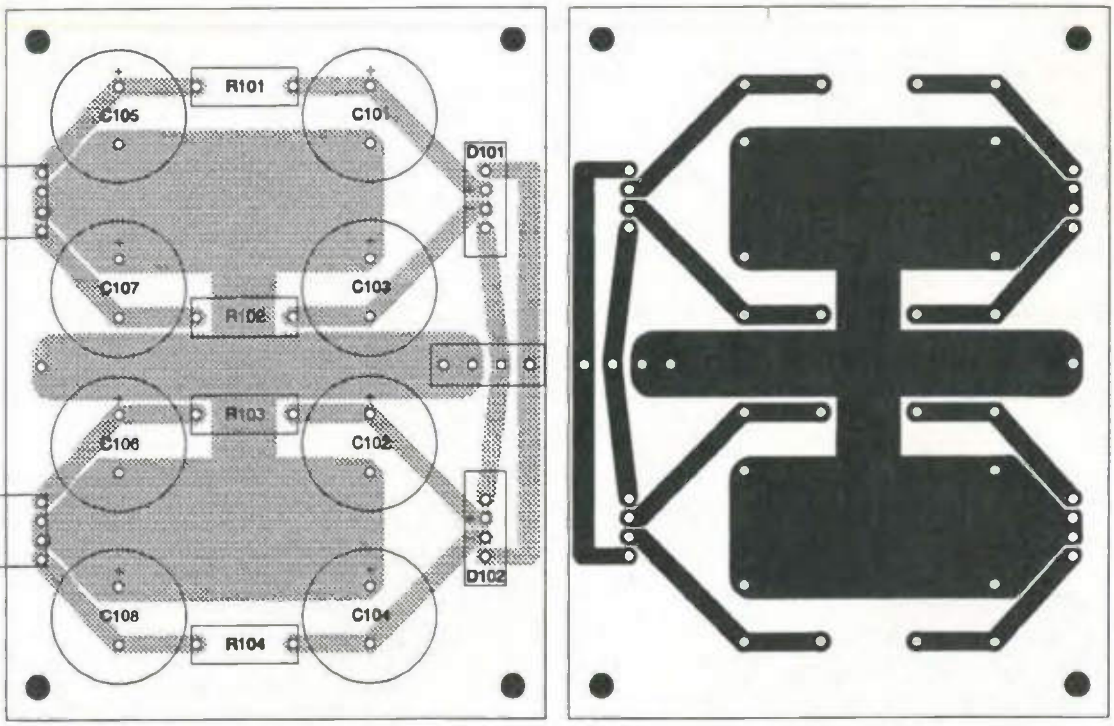

Fig. 2. Power-supply board parts placement (left) and PCB pattern (right).

Filter design

With such a small current requirement, it makes sense to try for additional ripple reduction by using two stages of filtering. This takes advantage of very large, but still very compact, electrolytic capacitors, where the usual capacitor-input power-supply filter is followed by an *RC* low-pass filter.

My criterion for the capacitor values was the size of those most readily available to me – four at 2200μF, 50V and four at 4700μF, 35V. The smaller capacitors are positioned as conventional capacitor-input filters, with one each in the positive and negative power supplies for each channel.

Four 220Ω resistors connect the four 2200μF capacitors to the four 4700μF capacitors. In this way, each positive and negative power supply of each channel follows the raw DC output across the 2200μF capacitors with an *RC* filter of 1.034s time constant. This corresponds to a filter cut-off frequency of $(2\pi RC)^{-1}$=0.154MHz. Capacitors of 470μF would be perfectly acceptable.

The total amount of ripple attenuation provided by the filter circuitry depends on whether you use half- or full-wave rectification. I know that this is almost always full-wave in high-end equipment. However, the amount of ripple attenuation is so high that either type is acceptable in this application. It may be that the 60Hz hum from residual ripple in a half-wave supply is less objectionable than any 120Hz hum from full-wave rectification.[2]

The idea is, of course, that no audible hum be present no matter which rectification scheme you use. There is no audible hum produced by residual ripple in this preamp with the power supply described here – a supply that uses half-wave rectifiers.

Since ripple is attenuated by a factor of ten (20dB) for each decade that the ripple frequency lies above the filter cut-off frequency, the second stage of filtering here provides, 20dB/decade×2.6 decades=52dB of additional reduction where,

$$\frac{60Hz}{0.154Hz} = 390$$

number of decades is x, where 10^x=390;

$$\log 10^x = x = \log 390 = 2.6$$

For this application, I chose 220Ω for the filter resistors. I assumed that the unregulated, but heavily filtered, output voltage delivered to the preamplifier circuit board would be no less than about 18V under worst-case conditions.

The above relationships show that if you select the full-wave rectifier, you will obtain 6dB more ripple attenuation from the *RC* filter.

Ripple blips

At 2mV/division, the ripple on an oscilloscope is barely visible, appearing almost as a pulse train of small 'blips.' The blips are probably due to the heavy current flow during the short period during which charging current flows through the rectifier diodes to the 2200μF capacitors of the capacitor-input filter.

A small resistor between the diodes and the capacitors would reduce the amplitude of the blips, but there is already heavy overkill here.

As a matter of interest, if ripple were to be reduced to 10mV with a capacitor input filter alone, the charging current through the rectifier diode would be about 5A – even though load current is a mere 25mA. Charge is the product of current and time. The charge removed from the filter capacitor during the 16.7ms cycle time T (T=8.3ms in a full-wave rectified supply) must be restored to the capacitor during the short (in a well-designed supply) recharge period, Δt.

If recharge (diode) current is considered constant (it is not, but the approximate answer so obtained is sufficient), then,

$$I_{LOAD} \times T = I_{RECHARGE} \times \Delta t$$

Solving this expression for charging current yields,

$$I_{RECHARGE} = \frac{T}{\Delta t} \times I_{LOAD}$$

This formula already suggests that charging current will be much greater than load current[3] because the small charging interval Δt is so short in comparison to the relatively long cycle period T.

Although diode conduction actually continues past the peak capacitor voltage V_{peak}, if you assume that conduction begins at time Δt before it ceases at V_{peak}, then voltage magnitude at the onset of conduction is $V_{peak}\cos\omega\Delta t$.

The quantity $\omega\Delta t$ is the diode conduction angle, and for a half-wave rectifier the ripple frequency is ω=377s^{-1}. The peak-to-peak ripple voltage is therefore,

$$V_{ripple}=V_{peak}-V_{peak}\cos\omega\Delta t.$$

Remember that $\omega\Delta t$ is intentionally made small to reduce ripple so that the trigonometric approximation,

$$\cos\omega\Delta t \cong 1-\frac{1}{2}(\omega\Delta t)^2$$

is valid. If the output voltage of the supply is to be about 21V, then you can solve for,

$$\Delta t \cong \frac{\left[2V_{ripple}/V_{peak}\right]^{1/2}}{\omega}$$

$$=\frac{\left[2(0.01)/21\right]^{1/2}}{377} \cong 82\mu s$$

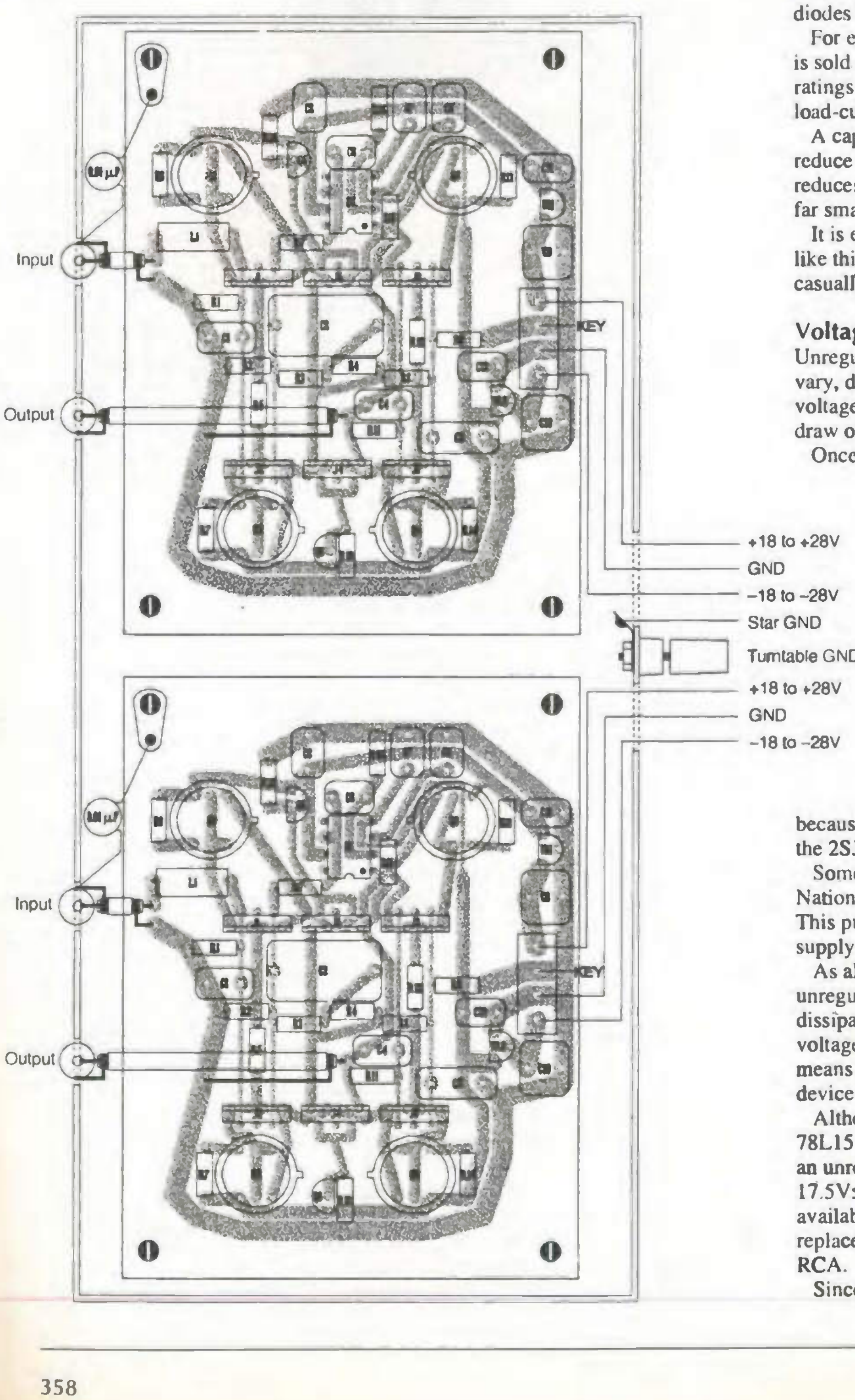

Fig. 3. Preamp-enclosure construction pictorial.

From this, it follows immediately that,

$$I_{RECHARGE} \cong \frac{0.0167}{0.000082}\times 0.025A = 5.09A$$

A pretty impressive number.

Current I_{LOAD} is constant at about 25mA and the capacitor discharges for almost the entire 16.7ms period T. The formula for the discharge of a capacitor at a constant current leads to $V_{ripple}{\approx}I_{LOAD}T/C$. For the 2200µF filter capacitors then,

$$V_{ripple} \cong \frac{0.025\times 0.0167}{0.0022} \cong 0.189V$$

Surge current through the diode in the preamp power supply is of the order of 1.2A. This is still a pretty startling number, but the surge ratings on even small rectifier diodes are well in excess of this.

For example, a 1N4002 diode has a 30A surge rating, but is sold as a 1A rectifier. It should be clear why surge ratings need to be so much higher than the average DC load-current rating.

A capacitor of almost 42000µF would be required to reduce the ripple to 10mV. Using the additional *RC* filter reduces the almost 200mV ripple to less than 0.5mV with far smaller capacitors.

It is enlightening – even eye opening – to look at things like this. Many designers treat power supply design very casually. I used to, too, until it bit me.

Voltage regulators

Unregulated output voltage from the rectifier/filter will vary, depending on the power transformer secondary voltage under load. Measured voltage was 24V at a current draw of 25mA with the transformer that I used.

Once you've selected the actual transformer, you could simply increase the resistor value in the *RC* filter. Better still, you could add yet another stage of *RC* filter so that approximately 15V would be presented to the preamplifier under load. In either case, it would require no voltage regulator.

While you are certainly free to use other schemes, the one chosen here was to use 78L15 and 79L15 IC voltage regulators on the preamplifier circuit boards to supply the needed ±15V power rails. The regulators are part of the main preamplifier circuit shown in last month's issue. Voltages from the regulators were limited to a 15V magnitude because of the 30V drain-to-source voltage limitation of the 2SJ109 JFETs.

Some features of on-card regulation are discussed in National Semiconductor's Voltage Regulator Handbook.[4] This publication is a good general reference for power-supply design.

As always, there are constraints you must consider. If the unregulated voltage is too high, the voltage and/or power-dissipation limits of the regulators will be exceeded. If this voltage is too low, then the regulator will 'drop out.' This means that it will cease to regulate because some active device within it is no longer in its active operating region.

Although these limitations are slightly different for the 78L15 and 79L15 regulators, the worst-case limits require an unregulated voltage magnitude in the range $17.5V \leq V_{in\text{-}unreg} \leq 28V$. These regulators are widely available from several manufacturers, including the replacement series manufacturers such as ECG, NTE, and RCA.

Since parts numbers will vary, be careful to select

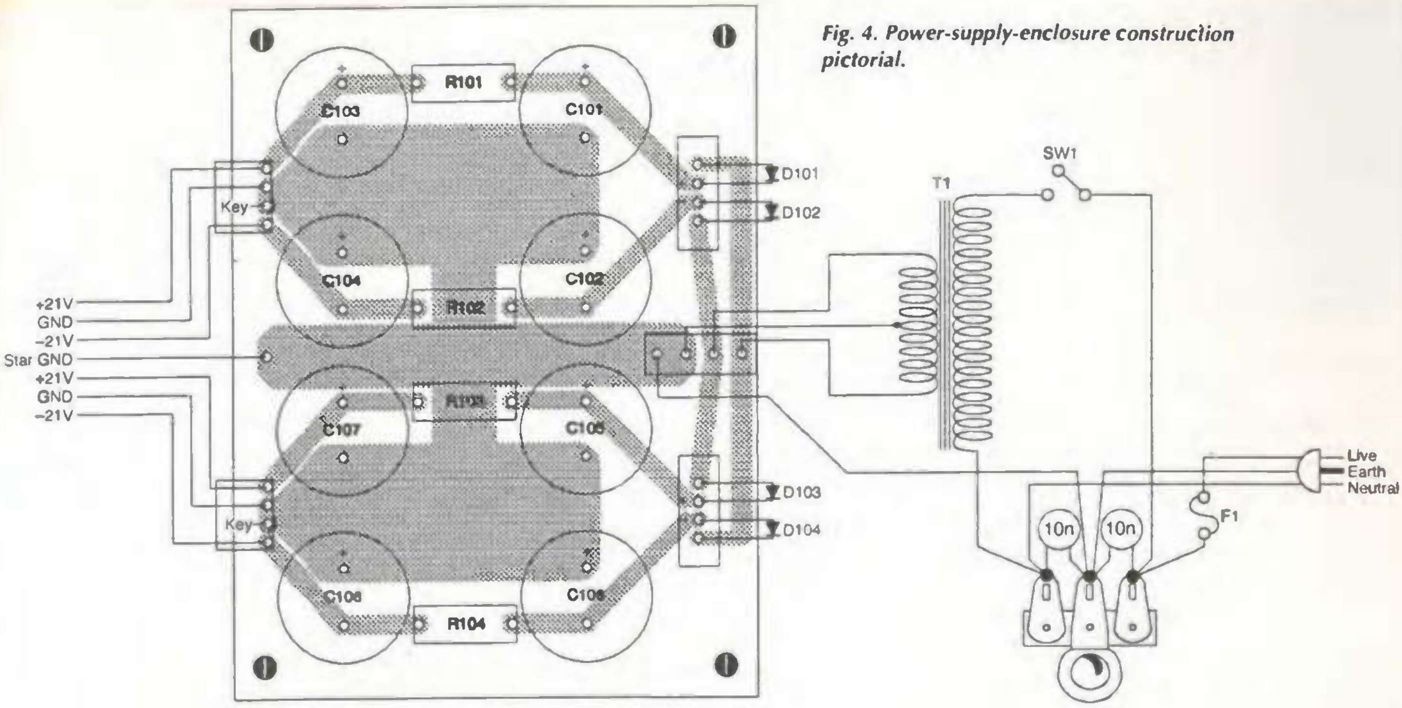

Fig. 4. Power-supply-enclosure construction pictorial.

regulators whose output-voltage tolerances are guaranteed to be within ±5%. There are even tighter-tolerance devices available if you wish to go to the trouble and expense of finding them, but it really isn't necessary to do so.

In the interests of stability, each regulator will require the input capacitor shown, unless you place the regulator immediately at the output of the unregulated supply.

With the recommended value for the 79L15's input capacitor, there was an intermittent, low-amplitude, high-frequency oscillation. This I tamed by increasing the capacitor value to 1μF. For consistency, I also used 1μF input capacitors for the 78L15 regulators.

A case could be made for deriving first-stage supplies from the output of the 78L15/79L15 regulators by using yet another *RC* filter, or perhaps a zener. This would mean that the first stage would operate at some lower voltage. This should be no problem, however, given that the output swing demanded from the first stage is significantly less than that required from the second.

Putting it together

Layout and construction details are reasonably well described in Figs 2-4. Nonetheless, I should elaborate on a few of the details.

As a designer, I always think about the possibility of modification or repair of the device, especially for the prototype version. For that reason, I liberally employ quick-disconnects (QDs) as well as transistor and IC sockets. The JFETs are not socketed here though because of their unusual pin-out.

The power cable between power supply and preamplifier enclosure has QDs at both ends. If you use QDs on this cable, be sure that it has male connectors at the power-supply end and female connectors at the preamp end. In this way, even if you use Molex header-type connectors, the 'hot' connector pins are not exposed.

I have serious reservations about claims of sonic effects of QD metals. Even so, I favour gold connectors because of past experience with other types' reliability problems due to corrosion.

I mounted chassis-mount RCA jacks to the edge of the PC board, and used uninsulated wire to both strap and ground the sleeve (outer portion) of each jack to the board.

Parts for the power supply

Resistors

$R_{101,102}$ 220Ω, 2W, 2% metal

Capacitors

$C_{101,102}$ 2 200μF, 50V aluminum electrolytic
$C_{103,104}$ 4 700μF, 35V aluminum electrolytic

Transformer

T_1 48V ct at 150mA (see text)

The mating portion of the jacks extend out beyond the board's edge. This arrangement allows unimpeded connection to the jack of the RCA plug from the tonearm.

I soldered a 0.01μF ceramic-disc capacitor to the ground trace immediately adjacent to the ground trace connection of the input jack, and soldered the other end of the capacitor to a solder lug. In turn, I grounded this lug to the chassis via the screw attaching the PC board to the nearby metal stand-off.

A stand-off under each corner of the board provides its secure mounting to the chassis while ensuring that the bottom of the board does not contact the chassis. All four stand-offs should obviously be of the same height. You can make them either of metal or insulating material, except that, as described earlier, the one to which the solder lug is attached must be made of conducting material.

I made the connection between the inner-conductor (centre) connector lug of the input jack and the board trace to inductor L_1 with a very short piece of uninsulated wire, since the jack was mounted immediately adjacent to L_1. Similarly, I strapped and grounded the output RCA jack at the board's edge, but made the connection between its inner-conductor connector lug and the appropriate board trace with small-gauge shielded cable because of the distance involved. The shield of this cable is only grounded at the phono-jack end.

With this mounting arrangement of the jacks, it was necessary to drill holes only in the front panel of the preamp enclosure, allowing the RCA jacks to protrude almost completely outside the enclosure. To do this, the front edge of the PC board must contact the inner side of the front panel of the enclosure.

The front-panel holes for the jacks must be sufficiently large that neither the jack nor the shield connector portion of any connected RCA plug contacts the front panel. Also be sure that no other PC board component or trace contacts the front panel.

You could achieve the same effect more easily by using PC-mount RCA jacks. If you use such jacks, you must modify the board's trace pattern accordingly.

Avoiding grounding problems

Some attention to the grounding scheme is required. For one thing, there are differences among various turntables, tonearms, and even cartridges in the way grounding is handled. For that reason, the actual interconnections may be different, depending upon the builder's specific system and its components. It will probably be true that most builders will be very familiar with the schemes that work best in their systems.

I emphasise again that the RCA input and output connectors are insulated from the enclosure. It is important that the input connectors be grounded to chassis only through the 10nF capacitors as shown.

While I understand that isolating the input connector ground from the chassis avoids a ground loop, I have never seen a reason given for the capacitors. I assume they are for RF bypass, given the small capacitance value.

These capacitors may be disc-ceramic types. Voltage rating is probably not critical, but since 10n, 1kV disc-ceramic capacitors are used as AC-line filters for the power supply, it is convenient to make all of these capacitors the same and perhaps save on quantity purchases.

A ground loop can occur anyway if the cartridge or tonearm cable connects both channel grounds at the turntable end. If a continuity check indicates this situation, then break the potential loop by opening the shield connection at the turntable end for one channel only.[6] If that is not possible, you can try omitting one shield connection to the PC board at the preamplifier end for one channel only.

I am not sure whether this, of itself, will give satisfactory results, because signal ground for that channel then comes circuitously from the other channel to the power supply and back to the first channel. I have seen amplifiers oscillate with such circuitous ground paths.

As an alternative, after breaking one shield connection for the PC-board RCA input jack, connect the ground trace of both channels' PC boards together and break the ground return to the power supply for one channel only.

Some turntable/tonearm combinations offer an optional ground lead for connection to the preamplifier chassis. Accommodation of this option is the reason for the binding post labelled 'Turntable GND' on Fig. 3. The decision whether or not to connect this optional ground lead is based empirically on the situation that results in the least hum.

For my system, the SME3009 tonearm cable provides this optional ground lead, which, at the tonearm end, is connected to the turntable platform of a Thorens TD125. Connection of the optional ground to the preamplifier binding post is the preferred configuration in my case, since this reduces hum below the audible level.

At the power supply, only one chassis interconnection point should exist. This is nicely illustrated in Fig. 4, which also indicates what is meant by such terms as 'Star GND.'

Setup and adjustment

No adjustments are required. It is a good idea, as mentioned in the text, to verify the differential amplifier currents by measuring the voltage across current source resistors R_5 and R_{12}. Unless you used severely mismatched BJTs in the current mirrors, cascode current should be OK.

I always check the power-supply voltages before I connect the rails to the circuit. I also use current-limited bench power supplies for breadboard work, and a Variac® for initial power up and check-out of the prototype version of a new design or after repairs.

The presence of the 220Ω resistors in the power supply affords short-term protection against short circuits downstream, but in the long term, their resulting power dissipation would exceed their rating. The IC voltage regulators are internally protected against short circuits.

In summary

I think that this pretty well covers the whys and wherefores of this design. It is a satisfying approach from the standpoint of precision in a relatively simple discrete design. The THD was only about 0.006% up to several kilohertz, rising to 0.026% at 20kHz with a 0.5V RMS output.

Obviously, it is possible to achieve significantly lower levels of THD with higher open-loop gain and therefore more feedback. It is difficult to do so, however, with the precise active-passive equalisation scheme realised through just two one-stage op-amps, as I did here. The proponents of 'less is better' – and especially those sceptical of the benefits of negative feedback – will appreciate this trade-off.

As for listening attributes, the sound is open and dynamic. You hear no stridency, even on massed strings. The bass is awesome, and I have no explanation for this. I do not know about the Adcom or Marantz preamps, but otherwise it is true that there are no coupling capacitors in the signal path – even at the input of the power amplifier currently in my system. This was possible because the servo limited DC offset at around 600μV. Still, there should be no perceptible difference in bass, even with coupling capacitors, as long as the low-frequency cut-off is well below the lower limit of hearing.

It is simply amazing how many good recordings there were in the days of vinyl. The ambience in the few Mercury Living Presence records that I have is remarkable. I am sceptical of many 'golden ear' claims of magical qualities of amplifiers and preamplifiers and I attribute none to this design. I simply assert that this phono preamp is good enough to accurately reproduce the information that is in the recording medium.

I believe you will thoroughly enjoy its use, provided that other components in the stereo system are equally good. I continue to be impressed with the sound even after several weeks. The more usual case is to be very impressed initially, with the enthusiasm fading after the first few listenings.

I am listening at higher volume levels than before. This may be a sign of lower apparent distortion, since there is a tendency to adjust volume to a level just below that at which distortion begins to be objectionable. ■

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3. Mark N. Horenstein, 'Microelectronic Circuits and Devices', Second Edition, Prentice Hall, 1996, (Problem 4.79, p. 225).
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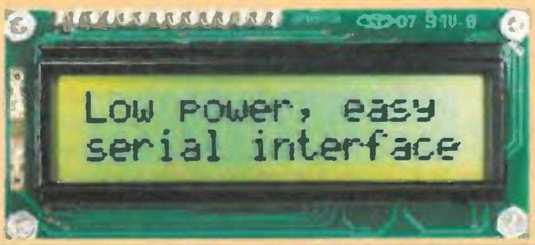

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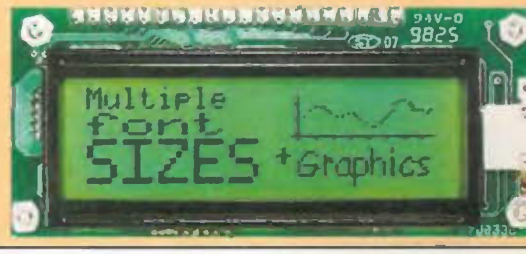

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ECC82	5.00	PL504	3.00	6BW6	4.00	12DW7	15.00
ECC83	3.00	PL508	3.00	6BW7	3.00	12E1	10.00
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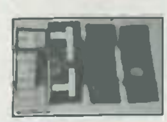

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Power for the

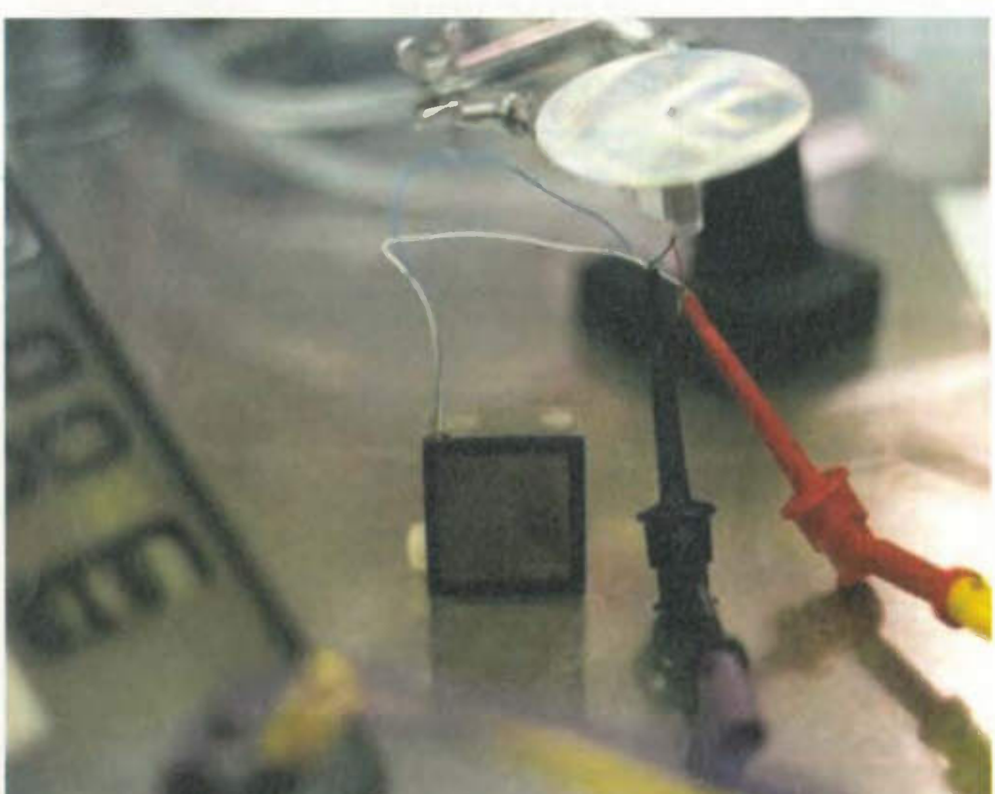
Sources of energy can have massive implications for all sectors of life, from the environment to lifestyles, but one alternative energy source is making waves. Chris Evans-Pughe looks at fuel cells

Delve into the subject of renewable energy sources and you may end up in a series of windmill-strewn, solar-panelled alternative websites populated by noble eco-types who apparently have the patience to wait half a day to cook dinner in a box of hay. Someone should tell them about pizza delivery... I'm kidding.

Alternative energy ideas are great, but not suitable for most everyday mass-market needs. But surf a little further and you'll find fuel cells – probably the most commercially promising renewable energy technology, and one of growing interest to the electronics industry.

At the heavy-duty end of the energy market, governments, utility companies and car firms are embracing fuel cell technology. Their zeal is mainly due to pressure to cut emissions prompted by concerns about climate change.

This image shows Energy Related Devices' methanol powered fuel cell.



The US Department of Energy projects that if 10 per cent of cars in the US were powered by fuel cells, regulated air pollutants would be cut by one million tons per year and carbon dioxide by 60 million tons.

The companies developing fuel cells for portable electronics applications have different motivations. They're interested in the technical advantages of a significantly longer operating time than today's batteries, cheap fuel and a re-fuel time of seconds. According to Motorola Energy Systems, fuel cells would be able to power a mobile phone for over 30 days and keep a laptop running for 20 hours. Consequently, fuel cells may be ideal for handling the increased power needs of multifunction mobile applications such as 3G that will support video and Internet surfing.

A fuel cell is a cross between an engine and a battery. Like an engine, a fuel cell will run as long as fuel (hydrogen) is supplied. Like a battery, it produces electricity by electrochemical reactions.

A fuel cell comprises two electrodes and an electrolyte. Hydrogen is fed into the anode and oxygen – or air – enters through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be used before they return to the cathode, to be reunited with the hydrogen and oxygen to form water.

The first fuel cell was built in

new generation

1839 by a Welsh judge called Sir William Grove, but the technology wasn't really used until the sixties, when the US space program chose fuel cells for the Gemini and Apollo spacecraft.

Nowadays there are many varieties of fuel cell around. At the high end are industrial systems using phosphoric acid and molten carbonate. At the very alternative end are entertaining concepts such as University of South Florida's microbial fuel cell. This can be powered by food, preferably meat because of its higher energy density. Within the fuel cell are bacteria that speed the breakdown of its food-fuel, releasing electrons that charge a battery.

The systems of most interest for electronics are proton exchange membrane (PEM) – the technology being used by firms such as Ballard for cars – and direct methanol fuel cells (DMFC). Both systems can operate at relatively low temperatures – from 40 to 80°C – have high power densities and can vary their output quickly to meet shifts in power demand.

PEM systems include a fuel reformer so they can use the hydrogen from any hydrocarbon fuel. DFMCs are less efficient but have the advantage that the anode catalyst draws the hydrogen directly from methanol, eliminating the need for a reformer.

Development work going on in Los Alamos, New Mexico looks to be the most significant for portable applications. Companies including Motorola Labs and recently Mechanical Technology are working with Los Alamos National Laboratory to develop miniature DMFC devices to replace batteries in laptop computers and mobile phones.

Motorola's fuel cells are two to four years away from a market launch, but the company says its liquid methanol-powered cell will be able to last up to ten times longer than existing rechargeable batteries. Fuel cell powered cell phones could be fuelled by a small methanol reservoir about the size of an ink-pen cartridge.

Energy Related Devices – ERD for short – is another Los Alamos-based firm working on miniature DMFCs for cell phone power supplies. ERD's micro fuel cell is made with multiple layers of thin films. The alcohol side of the film contains a catalyst that breaks the alcohol down into hydrogen ions and carbon dioxide.

The firm says its fuel cells can be made inexpensively using a printing process similar to the manufacture of ICs. It hopes to have production prototypes this year.

ERD is funded by New York-based Manhattan Scientifics that also owns NovArs – a German company in Passau developing PEM fuel cells to provide small external power supplies for products such as DVD players and laptop computers.

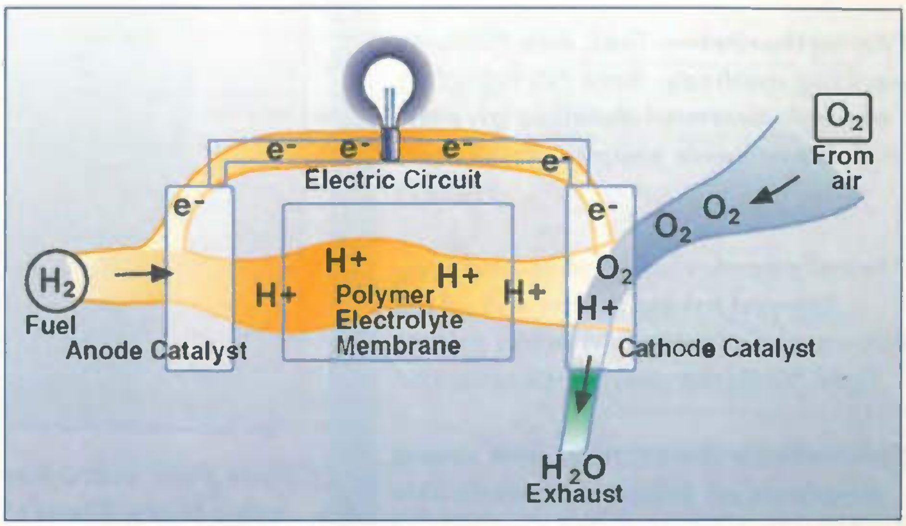
NovArs is also looking at domestic appliance applications and recently announced a joint agreement with Electrolux to develop an evaluation prototype of a fuel cell powered domestic vacuum cleaner.

The NovArs approach to fuel cell design uses composite materials and sealing technology to minimise size and weight. According to founder Dr Arthur Koschany, PEM systems have an energy density of nearly 100 times that of DMFCs making them less bulky for higher power applications.

Koschany sees two main challenges to commercialising the technology for electronics. The first is price. The second is more technical. "The price can be low only if we can make them in high enough quantities and this will involve considerable investment," he says.

"Technically, we need a source of hydrogen because compressed gases are not appropriate for using with electronics. We are developing hydrogen generating chemical hydrides for this purpose and these then need to be integrated into the fuel cell."

NovArs plans to have a pilot production line running in 2002 to produce quantities in the order of thousands. Full commercialisation is three to four years away reckons Koschany. ■



A PEM cell uses a catalyst to split hydrogen into H^+ ions and electrons. They recombine with oxygen to form water. Diagram courtesy of Breakthrough Technologies Institute/Fuel Cells 2000.

BOOK TO BUY

The definitive biography of the century's godfather of invention–from the pre-eminent Edison scholar "Israel's meticulous research and refusal to shy away from the dodgier aspects of Edison's personality offers a fresh glimpse into the life of the inventor."– New Scientist

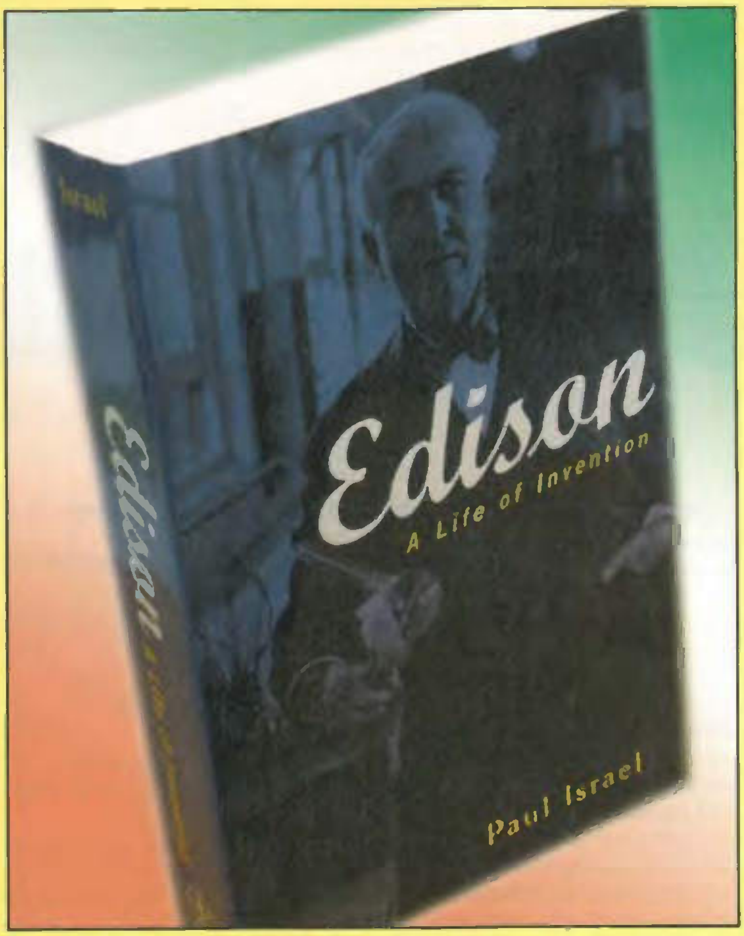
"Remarkable."– Nature

"An authoritative look into Edison's working methods, here leavened by enough personal detail to give the achievements shape."–Publishers Weekly

"Israel's book should go a long way toward taking Edison out of the shadows and placing him in the proper light."–Atlanta Journal-Constitution

"Exhaustively researched, with strong emphasis on Edison's methods and achievements."–Kirkus Reviews

The conventional story of Thomas Edison reads more like myth than history: With only three months of formal education, a hardworking young man overcomes the odds and becomes one of the greatest inventors in history. But the portrait that emerges from Edison: A Life of Invention reveals a man of genius and astonishing foresight whose career was actually a product of his fast-changing era. In this peerless biography, Paul Israel exposes for the first time the man behind the inventions, expertly situating his subject within a thoroughly realized portrait of a burgeoning country on the brink of massive change. Informed by Israel's unprecedented access to workshop diaries, notebooks, letters, and more than five million pages of archives, this definitive biography brings fresh insights to a singularly influential and triumphant career in science.



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Track

1 Washington Post March, Band, 1909
2 Good Old Summertime, The American Quartet 1904
3 Marriage Bells, Bells & xylophone duet, Burckhardt & Daab with orchestra, 1913
4. The Volunteer Organist, Peter Dawson, 1913
5. Dialogue For Three, Flute, Oboe and Clarinet, 1913
6. The Toymaker's Dream, Foxtrot, vocal, B.A. Rolfe and his orchestra, 1929
7 As I Sat Upon My Dear Old Mother's Knee, Will Oakland, 1913
8 Light As A Feather, Bells solo, Charles Daab with orchestra, 1912
9 On Her Pic-Pic-Piccolo, Billy Williams, 1913
10 Polka Des English's, Artist unknown, 1900
11 Somebody's Coming To My House, Walter Van Brunt, 1913
12 Bonny Scotland Medley, Xylophone solo, Charles Daab with orchestra, 1914
13 Doin' the Raccoon, Billy Murray, 1929
14 Luce Mia! Francesco Daddi, 1913
15 The Olio Minstrel, 2nd part, 1913
16 Peg O' My Heart, Walter Van Brunt, 1913
17 Auf Dem Mississippi, Johann Strauss orchestra, 1913
18 I'm Looking For A Sweetheart And I Think You'll Do, Ada Jones & Billy Murray, 1913
19 Intermezzo, Violin solo, Stroud Haxton, 1910
20 A Juanita, Abrego and Picazo, 1913
21 All Alone, Ada Jones, 1911

Total playing time 72.09

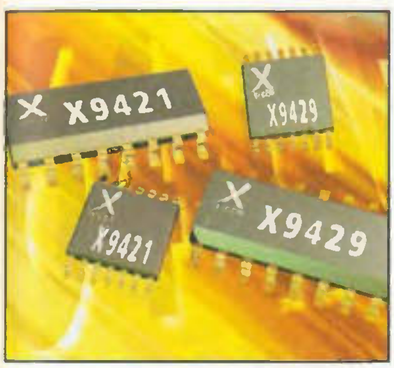
21 tracks – 72 minutes of music.
Published by *Electronics World*. All recordings reproduced by Joe Pengelly.

NEW PRODUCTS

Please quote *Electronics World* when seeking further information

64-tap pots with four 6-bit E^2PROM registers

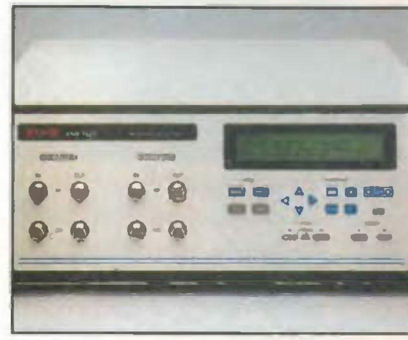
Xicor has introduced the X9421 and X9429 64-tap, single supply, non-volatile digital potentiometer ICs. The devices are for applications in which a variable resistance value must be maintained during the system manufacturing process. They have four 6-bit EEPROM registers per potentiometer for storage of tap settings and system parameters. This lets the system designer automatically save resistance values during power down and preset values to suit system demands. The X9421 communicates via a serial port supporting the SPI interface, while the X9429 uses a two-wire interface. Both operate from a 2.7V single supply voltage and each has four non-volatile registers that can be individually programmed. Applications include fibre optic modules, RF amplifier biasing, LCD brightness control, power supply calibration, battery operated applications and vending machines. They can recover their last position after a power down cycle and suit manufacturing applications that use preset analogue system values. Standby current is 200nA typical and 5μA maximum.



Xicor
Tel: 01993 700544
www.xicor.com

RF channel emulator with modelling feature

Telecom Analysis Systems has added a dynamic channel modelling feature to its 4500 Flex5 RF channel emulator. Available from Sematron, the 3G power-delay-profile emulation mode can be programmed to provide time-varying RF channel profiles that let it meet and exceed CDMA2000 and W-CDMA test specifications. It implements a dynamic, mobile propagation environment for time-sensitive algorithms such as rake finger management and wide band channel estimation. It also implements moving-propagation and birth-death channel models in accordance with 3G specifications. These two classes of channel models emulate the temporal variations in the propagation channel by changing delay spread characteristics versus time. A diversity technique lets the receiver pick up multiple signal paths over time and select the strongest rather than the average, which may be several decibels less than the strongest. This is for testing smart antennas that are proposed for 3G networks where up to four TAS4500 units can be combined. It also provides the ability to go beyond two-path dynamic models by letting all its paths be independently varied over time.

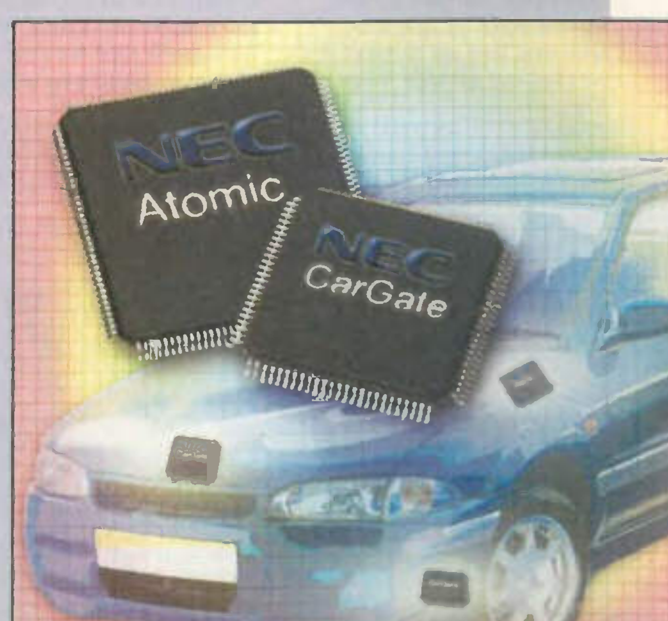


Sematron
Tel: 01256 81222
www.sematron.com

32-bit micros based on v850E Risc architecture

NEC has introduced 32-bit microcontrollers based on V850E Risc architecture with programmable CAN gateway engines. The Atomic and Cargate devices have a hardware-based CAN that lets them serve as gateways for communication between networks within the vehicle. This function lets them manage multiple tasks simultaneously from up to five automotive networks, such as the power train, navigation system or comfort control system. By implementing the CAN bridge in hardware, the microcontroller relieves the CPU of routine tasks, such as data transfer from one message buffer to another. Time triggered functionality lets signals be delivered based on time slots rather than arbitrary external events. Time out monitoring lets the microcontrollers anticipate the receipt of critical messages in a defined time frame. For example, an air bag system can be programmed to communicate with the microcontroller regularly, and then the microcontroller will investigate if no message is received. The Atomic controller supports three CAN interfaces and includes 256kbit on chip ROM and peripherals such as LCD controller, 12 channel A/D converter and various 16 and 32-bit timers. The Cargate has 128kbit ROM and supports five CAN interfaces. Flash memory versions of both are also available to support secure self-programming of the memory.

NEC Electronics
Tel: 01908 691133
www.nec.com



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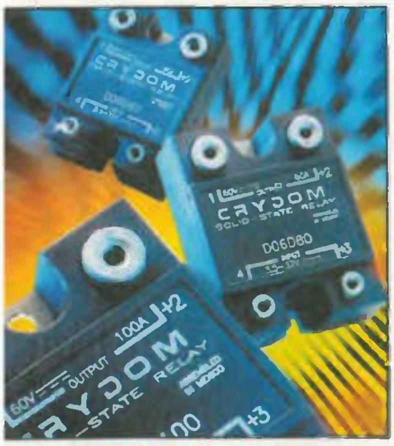


Solid-state relays for DC switching

Crydom has introduced its D06D chassis-mounting solid-state relays for DC switching applications. Rated at up to 100A DC at up to 60V DC, the devices are for DC motor control, solenoid switching, DC lamp switching and battery isolation. They can be operated by an input of 3.2 to 32V DC, typically drawing 10mA. Mosfet output technology provides on-state resistance of 10mΩ or less at full rated current, and simplifies parallelling of devices. Dielectric strength at 60Hz is 2.5kV rms and minimum insulation resistance at 500V DC is 1000MΩ. Maximum input-output capacitance is 50pF. They can operate in harsh environments regardless of orientation and there are no moving parts. UL and CSA approved, they are supplied in a panel-mount package weighing 87g.

Crydom
Tel: 01202 857300
www.crydom.com

Digital baseband for Eureka DAB radios

Texas Instruments has unveiled a reference design and single-chip digital baseband for Eureka DAB radios to help make products such as integrated digital radios and Internet audio players for automotive, portable and home applications. The TMS320DRE200 digital baseband includes programmable DSP technology and Radioscape software. The reference design contains components necessary to design a receiver including the DRE200 baseband, analogue parts and RF circuitry. The baseband consumes less than 200mW. The software lets users add applications on top of the baseband, such as integrating MP3 decoding with digital radio on one chip.

Texas Instruments
Tel: 01604 663000
www.ti.com

Power relay module is customisable

A power relay module that can be customised for automotive requirements has been introduced by Tyco Electronics. Applications include power windows, fuel pumps, power sunroofs, wiper control, vehicle lighting and cooling fans. With a footprint of 26.2 by 26.2mm and a height of 25.2mm, the F4/7 can be supplied with plug-in terminals positioned to ISO7558 or terminals preprepared for soldering to an integrated PCB. Terminals one, two, six, seven, eight and nine are optional, while terminals three, four and five are fixed. Pin assignment is according to ISO7880. Limiting continuous current is up to 70A at 23°C or 50A at 85°C. Nominal voltages are 12 and 24V; a 24V version with a contact gap more than 0.8mm can be supplied. Nominal unsuppressed power consumption is 1.6W at the nominal voltage, typical operating time 7ms and release time 2ms.

Tyco Electronics
Tel: 08706 080 208
www.tycoelectronics.com

Inlet filters rated at 16 and 20A

Schaffner EMC has introduced EN9222 IEC inlet filters rated at 16 and 20A for applications from industrial machinery to vending machines. They use the IEC320C20 connector and are safety rated for IEC950 applications. Other approvals include VDE, UL, CSA and Semko. The 20A version has dual 0.4mH inductors, with twin Y capacitors on the load side and one X capacitor on the line side.

Schaffner
Tel: 0118 977 0070
www.schaffner.com

Electrolytics come in laminated cases

The RU electrolytic capacitors from Nichicon come in laminated cases and have operating temperatures of –40 to +85°C at 6.3 to 400V and –25 to +85°C at 450V. Working voltage is 6.3 to 450V, capacitance 6.8 to 6800μF, tolerance 20 per cent and allowable ripple 190 to 930mA depending on capacitance and working voltage. The radial lead capacitors measure 12.5 or 25mm diameter by 12.5mm high and are available with trimmed or formed leads.

Nichicon
Tel: 01276 685531
www.nichicon-us.com

USB connectors take an eighth of the space

The Mini-BTM USB connectors from Molex take up about an eighth the space of standard USB-B connectors. They are for portable applications such as digital cameras, cell phones and PDAs and comply with USB 2.0, which enables speeds up to 480Mbit/s. The design includes five circuits, with one reserved for future use. Features of the 0.8mm pitch unit include metal shielding and grounding fingers for EMI protection and a lock for secure mating. The

connector is rated at 30V and 1.0A. There are through-hole and surface-mount versions, both with an above-board height of 3.95mm. The SMT version includes four solder tabs for PCB retention, and is available with cover tape for pick-and-place equipment. The cable plug has a standard length of 1.0m in Mini-B-to-USB-A construction, with other lengths available. The plug side can be ordered as a tested cable assembly or plug component kit.

Molex
Tel: 01252 720751
www.molex.com

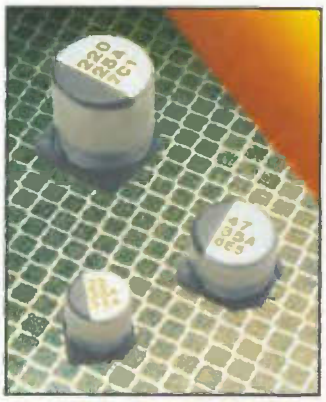
Two feed signal splitter

The Faraday passive splitter provides two SDI or AES feeds from one source. For short runs of cable, it can replace digital distribution amplifiers. From a good SDI signal source it will support up to about 40m of Belden 8281 cable. Typical uses are in small studios, edit suites and multiple displays in offices. The device is fitted with BNC connectors and does not require a power supply. It may be hung on the cable or, where multiple units are required, fitted into a 1U high 19in rack, which can be supplied.

Faraday Technology
Tel: 01782 661501
www.faradaytech.co.uk

SM capacitors extend to 100V DC rating

The VS surface mount aluminium electrolytic capacitors from Panasonic have capacitance values from 0.1 to 1500μF. Rated working voltage options are 4, 6.3, 10, 16, 25, 35, 50, 63 and 100V DC. Case diameters are 10mm for the highest capacitance parts, falling to 3mm for devices with lower values. All capacitors with case diameters of 6.3mm or lower have heights of 5.4mm, while the maximum board mounting height is 10.2mm. For operation



between –40 and +85°C, they have maximum DC leakage currents between 3 and 6μA and ripple currents at 120Hz and 85°C are 1mA rms for 0.1μF devices and 700mA rms for the 1500μF parts.

Panasonic Industrial
Tel: 01344 853667
www.piel.co.uk

Rectifier is efficient to 86 per cent

International Rectifier has introduced topology-specific Hexfet power Mosfets for isolated and buck DC-to-DC converters. As DC-to-DC converter output voltages approach 1V, the Mosfets increase efficiency by up to one per cent. The 100V IRF7473 in an SO-8 package is for the primary stage of two-stage isolated converters with 48V input, 1.6V output at 60A. Peak efficiency ratings up to 90 per cent can be achieved when it is matched with the IRF7822 synchronous rectification Mosfet. The IRF7473 can also be used in a full bridge configuration. The 40V Mosfets in SO-8 packages work with a 28V bus in notebook computers. There is a choice between two control parts, the IRF7468 and IRF7469, and two synchronous Mosfets, the IRF7470 and IRF7471. Synchronous buck topologies using the IRW7468 and IRF7470 reach an efficiency of 82 per cent in 28V input, 1.3V output converters running at 300kHz. Four additional Mosfets (IRF7453, IRF7450, IRF7451 and IRF5801) have reduced on-resistance and gate charge and are for 48V input, active and passive reset, primary-side isolated DC/DC converters below 30W.

International Rectifier
Tel: 0208 645 8003

SBC for Pentium III or Celeron applications

The Robo 678 single board computer from Portwell provides Intel Celeron or Pentium III processing power up to 600 or 850MHz respectively. It supports up to 512Mbyte of SDram and is based on the Intel 815E chipset. Onboard features include dual 10/100baseT Ethernet, FSB up to 133MHz and an integrated 3D graphic controller with DVMT and 4Mbyte display cache. It is PICMG compliant and has two UDMA dma 33, 66 or 100 IDE ports, one disk-on-chip socket that supports up to 288Mbyte of flash memory and a PCI connector for expansion. An optional Ultra-160 SCSI daughter board is available. Built in system monitoring and a watchdog timer are included.

Portwell
Tel: 01202 813816
www.portwell.co.uk

Micro reset circuit is radiation-hardened

Intersil has introduced a radiation-hardened power-up microprocessor reset circuit. The Star Power IS705RH can monitor power supply voltage levels and interface with satellite control units to ensure proper device operation during power-up. It sends a reset pulse to the microprocessor when the supply reaches a nominal operating voltage of 4.65V. This prevents code execution errors that occur when signals are present on microprocessor inputs during power-up. Features include a watchdog circuit that verifies proper reset has occurred and power-fail circuit for monitoring other supply voltages. Single event latch-up immunity is to 83MeV/(mg/cm^2) and single event upset capability is 38MeV/(mg/cm^2). It is available in an eight-lead flatpack package, either as QML class V or Q.

Intersil
Tel: 01344 350250
www.intersil.com

Simulator software for high-speed networking

Ansoft has announced version 8.0 of its HFSS structure simulator software. It is a full-wave finite element electromagnetic simulator that lets engineers design three-dimensional structures such as connectors, IC packages and antennas in cellular telephones, broadband communications systems and microwave circuits. Models can be generated for physical layer transient simulations of Gigabit Ethernet IC packages, boards and connectors, optoelectronic

Please quote *Electronics World* when seeking further information

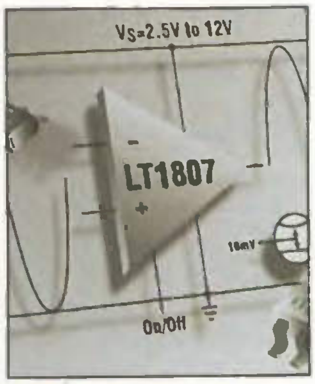
devices for broadband fibre modulators, receivers and routers, and electronic devices for signal conversion in hybrid fibre-coaxial systems. With the full-wave Spice add-on module, users can generate frequency-dependent Spice models automatically from full-wave electromagnetic field simulation.
Ansoft
Tel: 0208 891 6106
www.ansoft.com

Wafer-scale package saves on space

The USP-6 plastic moulded package from Torex is about two-thirds the size of an SOT-25 package. Doing away with the conventional lead frame, it measures 1.8 by 2.0 by 0.65mm and has a 0.5mm pin pitch.
Torex Semiconductor
Tel: 01509 211992
www.torex.co.jp

VDSL filters in a single package

APC's APC77110 and APC77112 are integrated hybrid filters for use with VDSL and 10baseS applications. Compatible with the Infineon PEB22810, 22811 and 22812 chipset, the components combine common mode choke, hybrid and transmit and receive filters. Samples are available to let users evaluate central office and user modem designs and for field trials. A Pots ISDN low pass filter (APC77101) is available to support designs using either product. In system tests over category five cable, the components connected at a symmetric data rate of 12Mbit/s to a distance of 1.2km, supporting telephony applications.
APC
Tel: 01634 290588
www.apc-pic.co.uk



Op-amp operates on supplies down to 2.5V

Linear Technology has introduced the LT1807 dual 3.5nV/√Hz, rail-to-rail single supply amplifier. Gain bandwidth product is 325MHz and THD –80dBc at 5MHz. Input common mode range includes both rails. The output stage swings within 12mV of each rail for supplies down to 2.5V. Maximum offset voltage is less than 0.5mV, CMRR is 106dB and signal voltage gain 300V/mV. Applications include broadband digital communications, data acquisition and video. Slew rate is 140V/μs, supply range 2.5 to 12.6V and output current 85mA. For operation over the industrial and commercial temperature ranges, it is available in eight-pin SOIC and MSOP packages.
Linear Technology
Tel: 01276 677676
www.ansoft.com

CCD products have 325MHz bandwidth

Marconi is launching products based on its L3Vision CCD technology, including scientific sensors, modules, digital and analogue cameras and camera subassemblies. Applications include night surveillance, industrial monitoring, dynamic bio-sciences, machine vision and astronomy. The sensors use an output amplifier circuit to improve vision at low light levels. Scientific and TV rate sensor formats, including 512 and 1024 pixels, are being developed. Drive circuitry comes in two compatible formats. The HV clock module provides all the inputs required for driving the sensors. A camera control module consists of a buffer and bias board with a video logic board and interfaces directly with the HV clock module allowing complete control of the CCD sensor. The camera subassembly is a circuit assembly where there is no case or lens mount. The incident light is converted directly into signal electrons and read out through a port at normal video frame rates allowing customer control of functional modes.
Marconi
Tel: 01245 493493
www.marconitech.com

Multiplexer IC with three DS3 framers

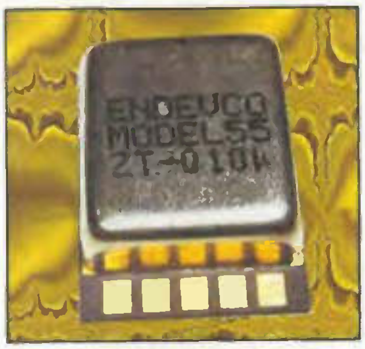
Vitesse Semiconductor has introduced the Timestream VSC9675 IC with three integrated DS3 framers, M13 multiplexers and 84 T1 and J1 framers. Applications in the access and switching infrastructure include access concentrators, routers, and switches. It supports a combination of channelised and unchannelised DS3 signals. Supported channelised formats include M23 and C-bit mode and supported T1 and J1 formats include SF and ESF. Features include performance monitoring and diagnostics such as network and local loopback. It is packaged in a 304-pin HBGA with power dissipations of 1.0, 1.5 or 2.0W.
Vitesse
Tel: 001 805 388 3700
www.vitesse.com

Accelerometer cuts monitoring costs

Endevco has introduced the Piezopak 56 accelerometer for commercial and industrial OEM engineering. The device is

PC/104 board with Elan-400 CPU

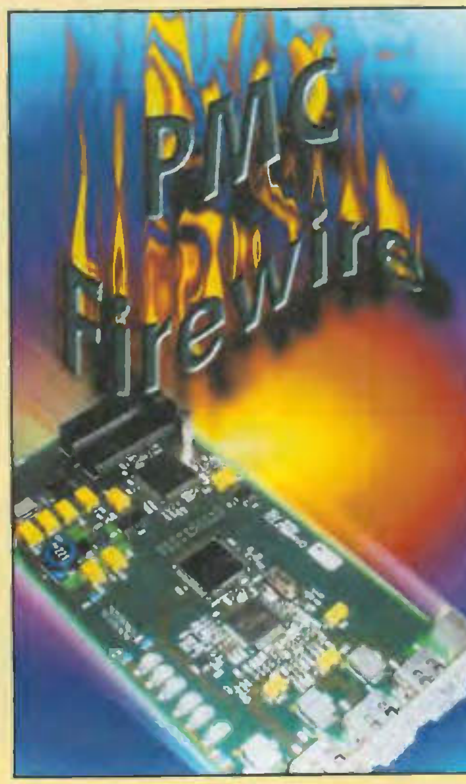
The PC/104 Microspace MSM4865V module from Digital-Logic is an embedded board based on an AMD 66MHz Elan-400 486SX CPU. Standard interfaces include a PS/2 keyboard, mouse, printer, floppy disk drive, EIDE hard disc and four com ports. A clock-controlled 5 to 3.3V DC-to-DC converter has more than 90% efficiency. Power saving functions make it possible to control power consumption in the 50 to 710mA range. It operates within a temperature range of –25 to +70°C and does not require active cooling. A version for –40 to +85°C is also available. Dram can be extended from 4 to 32Mbyte. Two flash technologies are available – program memory with capacities of 0.5 to 8Mbyte with a flash file system or an IDE hard disk-compatible flash drive that can be directly attached to the module. Features include an eight by 16 key matrix decoder, watchdog and E^{2}PROM for saving the setup settings. Graphics support is provided by a Chips & Technologies 65548 and 65550 SVGA controller with 1Mbyte of video memory.
Digital Logic
Tel: 00 41 32 681 5800
www.digitalogic.com



sealed against environmental contamination, shielded, ground isolated and configured with five solder pads for power and signal connection. It measures 20.3 by 15.2 by 5.3mm and can be packaged in custom housings. The model is powered by 2 to 10mA constant current, requiring a compliance voltage of +10 to +20V DC. Sensitivities of 10 and 100mV/g are available providing full-scale measurement ranges of 200 and 20g respectively. An optional temperature sensor with a linear output of 10mV/°C is available, requiring a separate supply from 4.5 to 10V DC.
Endevco
Tel: 01438 739020
www.endevco.com

Firewire controller with debug indicators

From BVM is the PMC-FW2 three-port PMC Firewire controller module. Using the Texas TSB12LV26 IEEE1394 OHCI compliant host controller and the TSB41AB3 three-port transceiver and arbiter, the module complies with IEEE1394a-2000. LED indicators for cable connected, transmit and receive, and throughput speed are on the back of the module. The module supplies cable power from an on-board converter powered from the host processor's +12V line, sufficient to power up the remote phy ICs on powered-off modules. It enables a hot swap plug-and-play capability for the attached peripherals, allowing, for instance, a faulty hard drive to be swapped out without powering down the host system. Each front panel mounted independent port supports transfer speeds of 100, 200 or 400Mbits/s, providing an interface from industrial workstations or servers to mass storage devices, video equipment, scanners and other equipment.
BVM
Tel: 01489 780144
www.bvmltd.co.uk

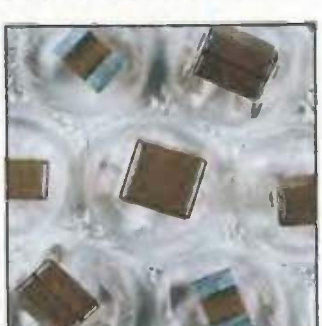


Packet processing engine for comms

Blue Wave Systems has extended its family of Comstruct communications processing building blocks with a packet processing hardware platform. The CPCI/C5441 provides OEMs with up to 672 channels, each of which can provide compressed voice or fax relay over IP or ATM, in a CompactPCI slot. It provides telecoms equipment makers with a platform for applications such as softswitches and IP-enabled services for wireline and 3G wireless networks. It uses the programmable TMS320VC5441 DSP from Texas Instruments and Telogy Software. The ATM interface makes the device a suitable building block for developing and deploying voice over ATM for DSL applications in the local loop. The device provides direct termination of multiple T1, E1, T3 and E3 and can use the H.110 interface for in-chassis call distribution and to support external line termination, such as OC/3. Features include HA drivers, an IPMI interface, SNMP management interface and hot swap capability. A redundant 100baseT Ethernet interface gives the board a multipath redundant architecture. It will initially run under the Solaris 2.8 64-bit operating system and Linux.
Blue Wave
Tel: 01509 654444
www.bluews.com

Ceramic capacitors have no polarity

Flint's Mega Cap ceramic capacitors in the TDK CGK series have no polarity, so can be mounted in either direction. There are two case sizes –



model 57D measures 5.5 by 5.5 by 7.0mm and model 45D 5.5 by 5.5 by 6.0mm. They can absorb stress from thermal and mechanical shocks even on metal substrates such as aluminium. Applications include smoothing circuits, temperature variable systems, maintenance free power supplies, vehicles and DC to DC converters. The Y5U and X7R models are constructed from slightly different materials to provide ratings of 16 to 100V and 16 to 630V respectively.
Flint
Tel: 01530 510333
www.flint.co.uk

High-speed matched impedance interfaces

Samtec can supply surface mount, micro pitch interfaces for matched impedance applications. Options include edge-mount designs and elevated designs with 16, 19 and 22mm board spacings. These interfaces in the QTE series terminate on 0.8mm pitch and have an integral ground plane. From 40 to 200 I/Os are available. They are tested for 50 and 70Ω systems for impedance, VSWR, attenuation, crosstalk, propagation delay and rise time at frequencies from 10MHz to 1GHz.
Samtec
Tel: 01236 739292
www.samtec.com

Enclosure houses Vme64x open system architecture

A VME64x compatible 19in subrack is being introduced by Schroff. The unit has built in EMC shielding and an integrated chassis monitoring module to control system parameters. Applications include industrial automation, measurement and control. Integrated modules provide power, thermal management and system monitoring. The 1kW DC power supply tray plugs directly into the backplane from the rear and can be installed and removed using IET handles. Two fan trays that are accessed from the front of the subrack each give 500m^3/hr airflow. Thermal management includes speed control and failure supervision. The 6U high boards fitted from the front of the enclosure plug into a 7U high backplane that uses SMT technology to provide 21 slots.

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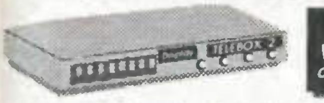

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TELEBOX ST for composite video input type monitors	£36.95
TELEBOX STL as ST but fitted with integral speaker	£39.50
TELEBOX MB Multiband VHF/UHF/Cable/Hyperband tuner	£69.95

For overseas PAL versions state 5.5 or 6 mHz sound specification.
*For cable / hyperband signal reception Telebox MB should be connected to a cable type service. Shipping on all Telebox's, code (B)

NEW State of the art PAL (UK spec) UHF TV tuner module with composite 1V pp video & NICAM hi fi stereo sound outputs. Micro electronics all on one small PCB only 73 x 160 x 52 mm enable full tuning control via a simple 3 wire link to an IBM pc type computer. Supplied complete with simple working program and documentation. Requires +12V & + 5V DC to operate.
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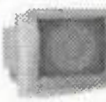

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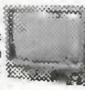
PHILIPS HCS35 (same style as CM8833) attractively styled 14" colour monitor with both RGB and standard composite 15.625 Khz video inputs via SCART socket and separate phono jacks. Integral audio power amp and speaker for all audio visual uses. Will connect direct to Amiga and Atari BBC computers. Ideal for all video monitoring / security applications with direct connection to most colour cameras. High quality with many features such as front concealed flap controls, VCR correction button etc. Good used condition - fully tested - guaranteed
Dimensions: W14" x H12¾" x 15½" D. **Only £99.00** (E)

PHILIPS HCS31 Ultra compact 9" colour video monitor with standard composite 15.625 Khz video input via SCART socket. Ideal for all monitoring / security applications. High quality, ex-equipment fully tested & guaranteed (possible minor screen burns). In attractive square black plastic case measuring W10" x H10" x 13½" D. 240 V AC mains powered. **Only £79.00** (D)

KME 10" 15M10009 high definition colour monitors with 0.28" dot pitch. Superb clarity and modern styling. Operates from any 15.625 khz sync RGB video source, with RGB analog and composite sync such as Atari, Commodore Amiga, Acorn Archimedes & BBC. Measures only 13½" x 12" x 11". Good used condition. **Only £125** (E)



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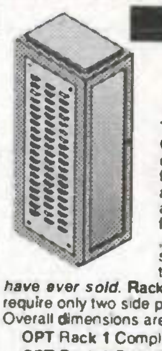

Superb quality 6 foot 40U
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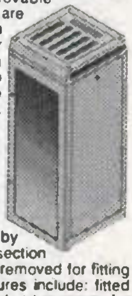
Top quality 19" rack cabinets made in UK by Optima Enclosures Ltd. Units feature designer, smoked acrylic lockable front door, full height lockable half louvered back door and louvered removable side panels. Fully adjustable internal fixing struts, ready punched for any configuration of equipment mounting plus ready mounted integral 12 way 13 amp socket switched mains distribution strip make these racks some of the *most versatile we have ever sold.* Racks may be stacked side by side and therefore require only two side panels to stand singly or in multiple bays.
Overall dimensions are: 77½" H x 32½" D x 22" W. **Order as:**

OPT Rack 1 Complete with removable side panels.	£345.00 (G)
OPT Rack 2 Rack, Less side panels	£245.00 (G)

Over 1000 racks, shelves, accessories 19" 22" & 24" wide 3 to 46 U high. Available from stock !!

32U - High Quality - All steel RakCab



Made by Eurocraft Enclosures Ltd to the highest possible spec, rack features all steel construction with removable side, front and back doors. Front and back doors are hinged for easy access and all are lockable with five secure 5 lever barrel locks. The front door is constructed of double walled steel with a 'designer style' smoked acrylic front panel to enable status indicators to be seen through the panel, yet remain unobtrusive. Internally the rack features fully slotted reinforced vertical fixing members to take the heaviest of 19" rack equipment. The two movable vertical fixing struts (extras available) are pre punched for standard 'cage nuts'. A mains distribution panel internally mounted to the bottom rear, provides 8 x IEC 3 pin Euro sockets and 1 x 13 amp 3 pin switched utility socket. Overall ventilation is provided by fully louvered back door and double skinned top section with top and side louvres. The top panel may be removed for fitting of integral fans to the sub plate etc. Other features include: fitted castors and floor levelers, prepunched utility panel at lower rear for cable / connector access etc. Supplied in excellent, slightly used condition with keys. Colour Royal blue. External dimensions mm=1625H x 635D x 603 W. (64" H x 25" D x 23¾" W)

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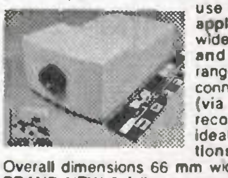

Overall dimensions 66 mm wide x 117 deep x 43 high. Supplied BRAND NEW & fully guaranteed with user data, 100's of applications including Security, Home Video, Web TV, Web Cams etc. etc.

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CIRCLE NO. 122 ON REPLY CARD

I/O transition 80mm PCBs can be fitted from the rear of the enclosure. The integration of boards corresponds to IEEE1101.10 and IEEE1101.11. Front panel mounted LEDs indicate status. The subrack has a height of 10U and a depth of 460mm. Extensions include adding a 1U disk drive tray for HD, FD and CD-ROM. This is fitted to the base of the system by removing the bottom cover.
Schroff
Tel: 01442 240471
www.schroff.co.uk

0.16µm NAND flash offers up to 1Gbit in TSOP package

As well as being available as discrete components, Toshiba's single-chip 512Mbit and 1Gbit NAND flash memory ICs can provide the storage for 64 and 128Mbyte Smartmedia cards. Based on a 0.16µm process, the 512Mbit chip was developed with Sandisk. The 1Gbit device has two 512Mbit ICs stacked on top of each other. Both can be supplied in 48-pin TSOPs. Smartmedia card applications include PDAs, portable audio players and digital cameras.

They operate from a 3.3V (±0.3V) supply and have a programming time of 200µs per page. Access times are 50ns serial and erasing time is 2ms per block. The packages measure 12.0 by 20.0 by 1.2mm.
Toshiba Electronics
Tel: 00 49 211 52960
www.toshiba-europe.com

Power amplifier handles 300A inrush

The Harmonics 1000 power amplifier from EMC Partner complies with EN61000-3-2, amendment 14 and EN61000-3-3. It can handle inrush currents above 300A and comes with Windows Harcs software. Simultaneous and real time input and output voltage

NEW PRODUCTS

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and current analysis can be measured visually via an external PC letting diagnostics be interpreted in relation to the operating conditions. The integrated amplifier can handle 16A per phase 230 or 115V 50 to 60Hz. It measures 48 by 10cm and weighs 24kg.
EMC Partner
Tel: 01494 444255
www.emcpartner.co.uk

Protocol analyser for Tetra radio tests

IFR Systems has added the Tetralog protocol analyser to its 2968 Tetra radio test set. The PC-based application enables capture and detailed analysis of mobile protocol transactions. As well as Tetra radios, it can also be used as a verification and evaluation tool for Tetra mobile developers who are not developing software in-house, but purchase protocol stacks from third parties. The application acquires data, analysing and displaying it graphically in the form of message sequence charts. The acquired messages are decoded to produce text files of the information elements contained in the messages for display, storage or printing. It can help evaluate and verify operation of a given radio type to be used on a system. Data capture is performed by connecting the mobile to the test set via its RF connection.
IFR Systems
Tel: 01438 772087
www.ifrsys.com

Serial cards download software to mobiles

QM Systems has announced multi-port PCI and PXI serial cards for downloading software to mobile phones. Using the card, a PC can program and control over 16 phones at once at up to 12.5Mbaud per phone. Programmable output levels and optional TTL or open drain outputs provide the flexibility to control and program different phone types. Available in four, eight, 12 and 16 port versions, each port provides output levels programmable between 0.5 and 10V. The unit incorporates RS232, RS485 and RS422 and the option of adding digital I/O for interfacing to input signal lines and output indicators and actuators.
QM Systems
Tel: 01252 336612
www.qmsystems.com

Smartcard reader software goes public

Applied Card Technologies has developed software for an intelligent dual-sided smartcard reader with Taiko Electronics and Oki. The technology will work with most public access devices such as vending machines, printers, PCs, photocopiers and set-top boxes. It will let large organisations, libraries and universities offer a cashless service. The reader is also suitable for secure entry systems and employee verification across multiple locations. The software lets the chipset interact with mainstream smartcards. The reader hardware includes a dual-sided smartcard connector, which lets a card be read either way up. A separate satellite reader connects to the main PCB containing the ACT coded Oki chip and extra peripheral ports, so operators can replace just the satellite reader unit in the event of vandalism or breakage. ■
Applied Card Technologies
Tel: 01249 751037
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Current-conveyors III

In this third and final article on low-voltage current conveyors and their applications, Giuseppe Ferri *et al* describe how easy it is to implement capacitance multipliers using conveyors, and how such multipliers can benefit filter designs.

In the following, we describe how capacitance can be multiplied using current conveyors.[1-7] **Figure 1** outlines such a multiplier. It comprises a current conveyor followed by a current amplifier A_I.

Ideal input equivalent capacitance is,

$$C_{EQ} = A_I C_S \tag{1}$$

This shows that an equivalent capacitance is obtained that is A_I times greater than C_s. Deviations from this ideal behaviour are mainly due to:

- Voltage and current-transfer inaccuracies in the conveyor and the conveyor's finite output resistance at terminal X.
- Bandwidth limitation of the current amplifier and its finite output resistance.

Equivalent input impedance is,

$$Z_{EQ} = \frac{V_{in}}{I_{in}} = \left[\frac{1}{\alpha\beta A_I}\left(r_X \frac{1}{sC_S}\right)\right] // r_o \tag{2}$$

Here, r_X is resistance at X and r_o is resistance at the amplifier output. Voltage and current transfer errors of the CCII– are,

$$\frac{V_X}{V_Y} = \alpha$$

and,

$$\frac{I_Z}{I_X} = \beta$$

respectively. **Figure 2** is the equivalent circuit.

Equation 2 shows that the impedance Z_{EQ} is the parallel of two terms. The first term is due to capacitance C_s. This is multiplied by a factor equal to $\alpha\beta A_I$ and a series resistance equal to,

$$\frac{1}{\alpha\beta A_I}$$

times the output resistance at X terminal. Therefore, this contribution decreases for high values of the current gain A_I.

The second term is due to the output resistance of the current amplifier. This contribution can be dominant at low frequencies.

It turns out that, in order to have an ideal capacitance, as multiplied by A_I, r_X must be low and r_o high. This last condition is more important because r_X is divided by the gain A_I.[8-10]

Now we will describe some configurations implementing both the CCII and the current amplifier.

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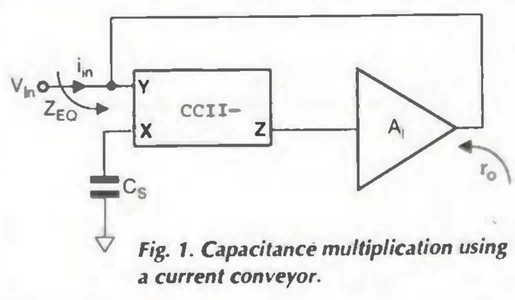
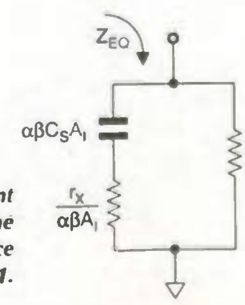


Fig. 1. Capacitance multiplication using a current conveyor.

Fig. 2. Equivalent circuit of the capacitance multiplier in Fig. 1.



Conveyor and current-amp solution

Figure 3 shows a capacitance multiplier made up using a a second-generation 'inverting' current conveyor, commonly called a CCII–, and a current-based operational amplifier, or COA. **Figure 4** is a simplified schematic of the COA used in simulations, while **Table 1** outlines its performance.

Capacitance C_s is the grounded capacitance that has to be multiplied. Resistances R_1 and R_2 accurately set the closed-loop current gain of the amplifier as given by,

$$A_I = \frac{I_Z}{I_o^+} = 1 + \frac{R_2}{R_1} \quad (3)$$

With this solution, high capacitance gain factors can be readily achieved by simply setting the resistance ratio R_2:R_1.

In addition, the gain factor can be further increased by exploiting the current-gain capabilities of the CCII. For example, if you choose a COA current gain, A_I, of 10^2 and set the current gain of the CCII, β, to 10, an overall multiplication factor of 10^3 is achieved with a limited increase in power dissipation.

Usually, the current gain of a CCII is determined either by controlling the aspect ratio of the output current mirror, or by using techniques that allow electronic control of the current gain. With these solutions, the quiescent current is proportional to the multiplication factor. This means that there's a trade-off between power dissipation and gain.

Standby current at the conveyor's Z terminal limits the amount of capacitance gain that can be obtained. This current, associated with R_2, produces an offset voltage that can saturate the op-amp's output. For this reason, the CCII needs an accurate offset control.[11-18]

C multiplier using two conveyors

In order to obtain high and controlled capacitance gain factors, the second topology shown in **Fig. 5** has been developed. It is made up of two CCIIs and two resistors. These resistors determine the multiplication factor.

For ideal CCIIs, the following expression gives the input equivalent capacitance:

$$C_{EQ} = \frac{R_2}{R_1} C_S \quad (4)$$

This equation shows that an equivalent capacitance $R_2 \div R_1$ times greater than C_S can be obtained.

For real CCIIs, the following expression for the input equivalent voltage can be deduced:

$$Z_{EQ} = \frac{V_Y}{I_Y} = \left[\frac{1}{\gamma} \frac{R_1 + r_{X1}}{R_2 // r_{Z1}} \left(r_{X2} + \frac{1}{sC_s} \right) \right] // r_{Z2} \quad (5)$$

Here, γ is $\alpha_1\beta_1\alpha_2\beta_2$ and α_i and β_i are the voltage and current gains for the *i*th CCII, respectively. All gains are nominally equally to 1.

This solution allows high gain factors. However, some limits on the values of R_1 and R_2 have to be considered.

The lower limit of R_1 is related to the output resistance at X_1 terminal, while the upper limit for R_2 is related to the output resistance at Z_1 terminal.

Multiplier using a single conveyor

This final multiplier is simple because it does not make use of a current amplifier. It uses only a current conveyor with a β current gain of greater than 1, as in **Fig. 6**.

In this case, taking into account the finite output resistance at *X* and *Z* terminals, r_X and r_Z, and the voltage transfer gain, $V_X/V_Y=\alpha$, you can evaluate the equivalent input impedance as follows:

$$Z_{EQ} = \frac{V_Y}{I_{IN}} = \left(\frac{r_X}{\alpha\beta} + \frac{1}{s\alpha\beta C_S} \right) // rZ \quad (7)$$

where the parasitic capacitances at terminals *Y* and *Z* of the CCII have been neglected.

Equation 7 shows that impedance Z_{EQ} is the parallel of two terms. The first term is due to the capacitance C_s, which is multiplied by a factor equal to $\alpha\beta$, with a series

Table 1. Main features of the current op-amp, or COA, of Fig. 3.

Parameter	Value
Loop gain	62dB
GBW	100MHz
PM	64°

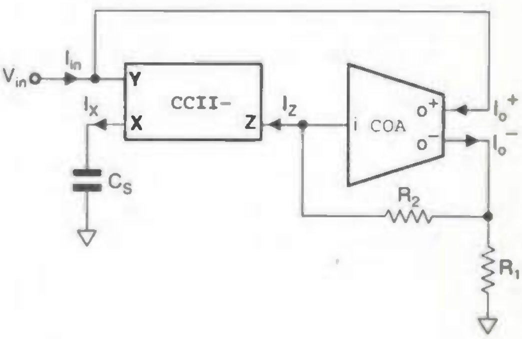


Fig. 3. Capacitance multiplier using a current conveyor followed by a current-based op-amp.

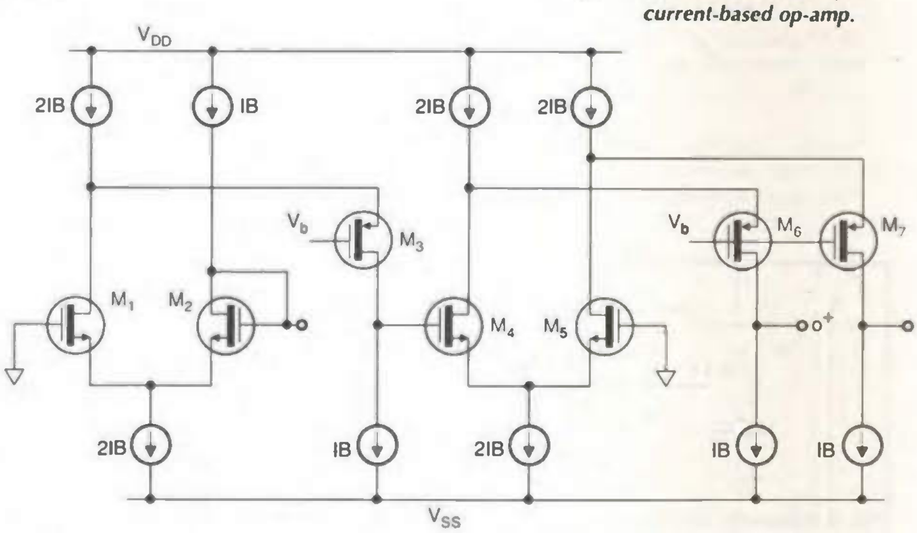


Fig. 4. Simplified schematic of the low-voltage COA used to simulate the performance of the circuit in Fig. 3.

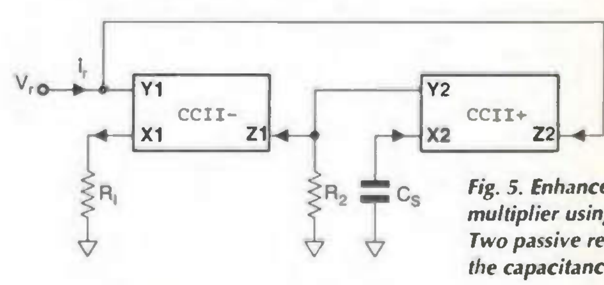


Fig. 5. Enhanced capacitance multiplier using two conveyors. Two passive resistances determine the capacitance gain.

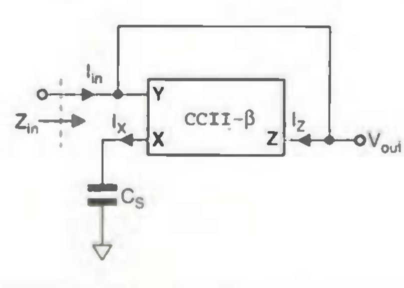


Fig. 6. The third multiplier topology uses a single current conveyor.

resistance equal to $1/\alpha\beta$ times the output resistance at X terminal. This term is predominant at high frequencies and decreases for high values of the current gain β.

The second term is due to the resistance at the Z terminal. This term is important at low frequencies. Its contribution can be made negligible by choosing CCII implementations with high values of r_Z.

Non ideal situations due to X and Z node resistances limit the circuit's capacitance multiplication range, as shown in **Fig. 7**.

Using CCIIs for low cut-off filters

Here we present a low-pass filter design based on a capacitance multiplier using current conveyors. This is a first-order low-pass filter with a low cut-off frequency, of below 10Hz, **Fig. 8**.[19-22]

This filter uses a CCII– with current gain,

$$\frac{i_z}{i_x} = \beta > 1$$

In Fig. 8, C_s is the capacitance to be multiplied. Resistance R was set to 160kΩ in order to achieve a cut-off frequency of 1Hz. **Figure 9** shows the magnitude response of the filter. The cut-off frequency is 0.96Hz, which is in good agreement with what you would expect.

The DC gain of the active filter is −1.1dB instead of 0dB. This is due to the partition effect caused by the finite value of r_Z.

In summary

Current conveyors are versatile building blocks suitable for many applications.

Many complex analogue functions are easily implemented using current-conveyors. The current conveyor can give better performance than traditional operational amplifiers. This is particularly so in terms of speed and bandwidth, due to the local feedback of the follower-based structure of the device.

Commercial current conveyors are easily realised in CMOS technology, and at low cost. In the first two articles of this review, we proposed some novel low supply voltage current conveyors for use in portable instrumentation application. In this final article, we have also shown how capacitance multipliers are easy to implement using current conveyors. Such multipliers make it possible to produce fully integrated filters that can work at very low frequencies. ■

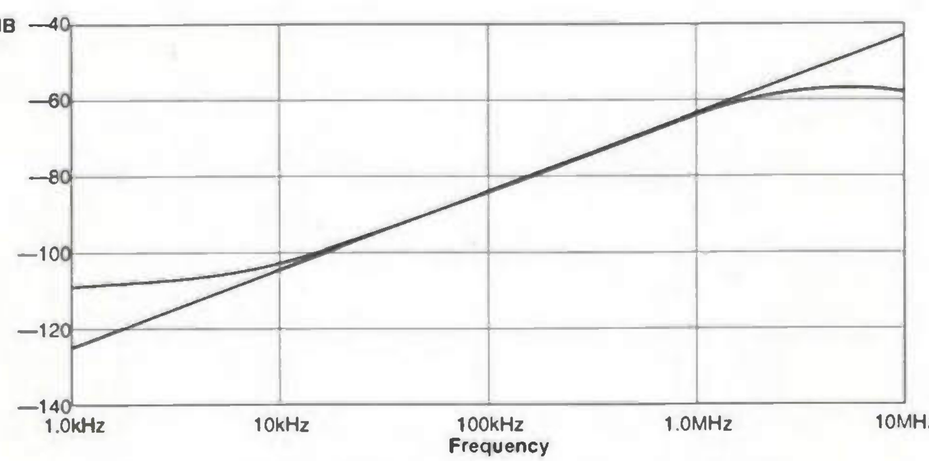


Fig. 7. Input admittance of the circuit of Fig. 6 for C_s=1pF and a capacitive gain of 10^2.

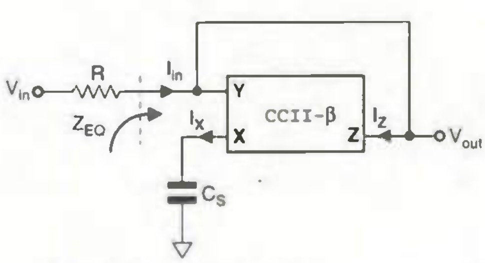


Fig. 8. Schematic of a low cut-off frequency low-pass filter implemented using current-conveyor technology.

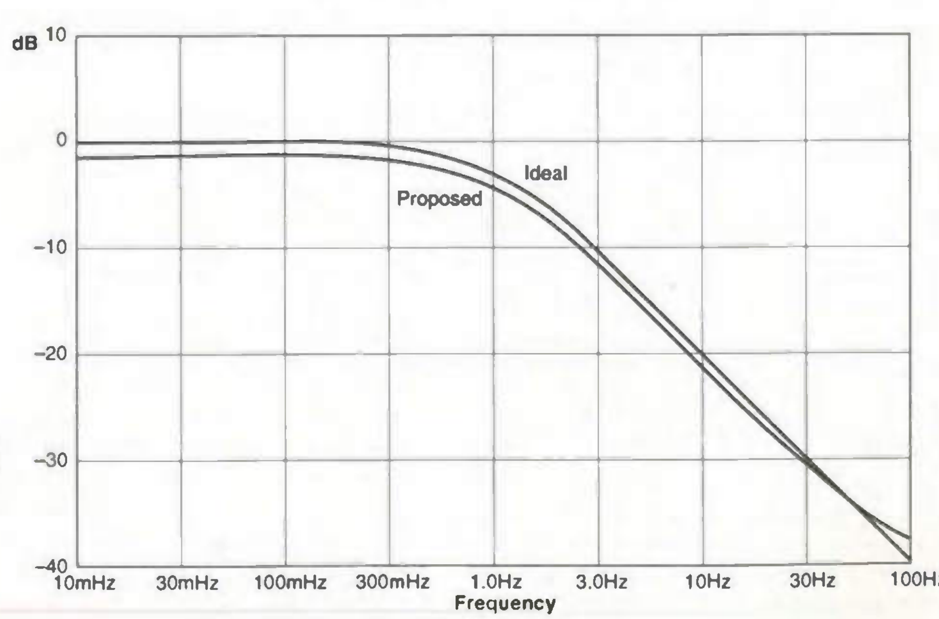


Fig. 9. Magnitude responses for an ideal RC filter and the one proposed in Fig. 8.

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CIRCUIT IDEAS

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The best circuit ideas are ones that save time or money, or stimulate the thought process. This includes the odd solution looking for a problem – provided it has a degree of ingenuity.

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Don't forget to say why you think your idea is worthy.

Clear hand-written notes on paper are a minimum requirement: disks with separate drawing and text files in a popular form are best – but please label the disk clearly.

Send your ideas to: Jackie Lowe, Room L514, Quadrant House, The Quadrant, Sutton, Surrey, SM2 5AS

Battery pack short-circuit protector

This circuit provides short circuit protection to a removable battery pack of up to 11V. It could be fitted in the battery pack as stand-alone protection. Or it could be included as part of the electronics if gas gauging or SMbus charging control circuit is embedded.

The circuit can be used with a working battery terminal voltage range between 2.5V and 11V. It is suitable for NiCd or NiMh batteries from 3 cells (where the lowest working limit of 0.9V per cell gives 2.7V) to 6 or 7 cells, depending on the worst case fast charge terminal voltage. It is also suitable for one or two Lithium Ion cells.

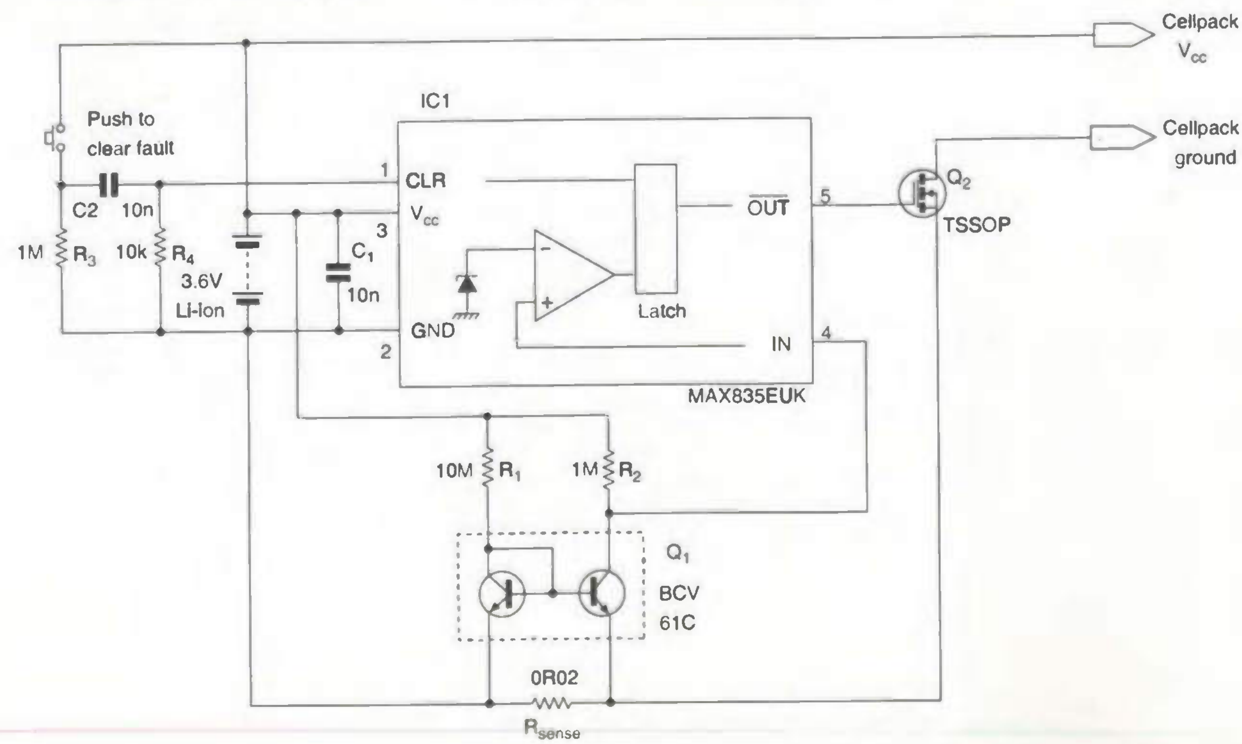
As drawn, the circuit trips at 2.7A current, but this limit can be easily changed by adjusting the value of R_{sense}. Quiescent current consumption on a 3.6V battery is 5pA maximum for the MAX835EUK, plus 0.4μA to 2.8μA – roughly proportional to current load – for current sensor Q_1.

The core element is the tiny 5-pin SOT-23 MAX835EUK latching voltage monitor. It has a rail-to-rail output at pin 5, which is normally high, turning on the N-channel MOSFET Q_2 and so allowing load current to pass from the battery to the external load.

Transistor Q_2 is a Temic TSSOP packaged transistor, chosen because it has a maximum $r_{ds(on)}$ of 40mΩ with a V_{gs} of 2.7V. When the input signal to pin 4 drops below the internal reference voltage of 1.2V, an internal latch is set which takes the output low. This turns off Q_2, thereby disconnecting the battery from its load. The latch can only be cleared by a pulse taking the CLR input (pin 1) above 2V for at least 1μs.

The reset pulse is provided by a push switch – typically, membrane type – which is AC coupled into the CLR input. The AC coupling prevents the user from disabling the protection by keeping the switch permanently pressed!

The value of R_4 (10kΩ) is deliberately quite low to give high noise immunity to the switch input. Resistor R_3 (1MΩ) can be high resistance because its purpose is just to discharge C_2 after the switch is released, and noise pickup at this point



cannot reset the latch.

The intrinsic body diode of Q_2 (cathode to drain, anode to source) is used to advantage. If the battery is totally flat, then Q_2 cannot be turned on. However the pack can still be charged because the body diode allows reverse (charging) current to flow.

When the pack is charged sufficiently, the protection latch can be cleared and the battery pack used in the normal way.

Dual transistor Q_1, a Siemens BCV61, amplifies the very small current sense voltage of 60mV up to IC's trip threshold of 1.2V. A transistor pair was selected because it is low cost and small, in a SOT-143 package. The transistors are monolithic, so thermal coupling and V_{be} matching is intrinsically good.

To understand the current sense amplifier's operation, first consider the case where no current is flowing through R_{sense}. The V_{be} voltages of the two transistors are the same in this condition. Now Q_{1B} (diode connected) has 10MΩ R_1 in its collector, whereas Q_{1A} has a 1MΩ R_2 load.

Transistor Q_{1B}'s emitter current is lower than that of Q_{1A} by virtue of this collector load disparity, and so its working V_{be} is lower than the working V_{be} of Q_{1A}. Hence Q_{1B} is essentially turned off when no battery load current is flowing.

Now consider an increasing load current through R_{sense}. This resistor will incur an increasing voltage drop, which has the effect of taking Q_{1A}'s emitter negative with respect to Q_{1B}'s emitter. This in turn increases the V_{be} of Q_{1A}, and at some point of increasing load current through R_{sense}, Q_{1A}'s V_{be} will be large enough for the collector voltages of Q_{1A} and Q_{2A} to equate.

Voltage across R_{sense} at which this occurs is $0.026\times\log(R_2\div R_1)$=60mV at room temperature. The IC will actually switch when the collector of Q_{1A} drops to 1.2V, so there is a small inaccuracy in the switch point calculation – the circuit will actually switch at a slightly lower current than calculated.

The higher the supply voltage, the smaller the error is because the difference between a V_{be} and 1.2V as a fraction of the supply voltage reduces. The table shows the latching currents for several supply voltages:

Supply voltage	Switching current
5.0V	2.88A
3.6V	2.75A
3.3V	2.69A
2.7V	2.56A

Also, the switch point varies with temperature because absolute temperature, *T*, is in the equation. This isn't as bad as it first appears. The working temperature range of a pack may be from as low as –20°C up to +40°C, which is a variation of ±30K around a mean of +10°C or 283K. So the variation in trip point is about ±10% with temperature.

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A microcontroller-based signal generator wit

The circuit of Fig. 1 uses a Microchip 8-pin PIC12C671 as a voltage-controlled audio-frequency oscillator. Since the 12C671 has an internal 4MHz oscillator, 4-channel 8-bit a-to-d converters and a built-in power-reset circuitry, no extra cqmponents are required to form the signal generator.

The PIC12C671 reads two analogue inputs through AN0 and AN1. The conversion reference voltage is the controller's power supply V_{dd}. Voltage V_f controls the output frequency while V_d determines the duty cycle of the output signal. Frequency and duty

```
LIST   P-12C671

TMRO           equ    0X01
STATUS equ     0x03
GPIO           equ    0X05
INTCON         equ    0x0b
PIR1           equ    0x0c
ADRES  equ     0xle
ADCONO equ     0xlf
ADCONI equ     0x9f
OPT    equ     0X81
port-dir       equ    0x85
period equ     0x21
cnt-I  equ     0x22
cnt - 2        equ    0x23
temp   equ     -0x24

w      equ     0
F      equ     1
c      equ     0
z      equ     2

       org     0xo
       goto .  main
       org     0x4
       decfsz cnt_1, F
       goto   send-out

get_range
       movlw   0x20
       movwf   cnt_1
       movf    GPIO,  W
       movwf   temp
       rrf     temp,  F
       rrf     temp,  F
       rrf     temp,  F
       movf    temp,  W       ;
       andlw   0x07           ;
       addlw                  ;
get-duty-cycle                         ;
```

```
          movlw  0x49          ;A/D input from AN1
                 movwf  0x80          ;
                 option ADCONO        ;
                 call   delay         ;data
acquisition
                 bsf    ADCONO, 2     ;start A/D
conversion
          loop_1 btfsc  ADCONO,2      ;
          =goto  loop_1       ;
          movf   ADRES, 0     ;
          movwf  period       ;
          rrf    period, F    ;
          rrf    period, F    ;
          rrf    period, F    ;
          movlw  0xlf         ;
          andwf  period, F    ;
          incfsz period, F    ;
          bcf    GPIO, 2              ;output low
get_frequency                 ;
          movlw  0x41         ;A/D input from ANO
                 movwf  ADCONO ;
                 call   delay  ;data acquisition
          bsf    ADCONO,        2     ;start A/D
conversion
loop_2 btfsc     ADCONO,        2     ;
          goto   loop_2       ;
          movf   ADRES, 0     ;
          movwf  cnt_2        ;
          bcf    STATUS,        C     ;
          rrf    cnt _2,        F     ;
          movlw  0x7c         ;
          addwf  cnt _2,        F     ;
          movf   cnt _2,        W     ;
          movwf  TMR0         ;
          Bcf    INTCON, 2    ;clear TMR0
interrupt flag
          retfie              ;
                              ;
send_out                              ;
          movf   cnt _2, W    ;
```

£75 winner

voltage-controlled frequency and duty cycle

cycle are independent: changing the frequency will not affect the duty cycle and *vice versa*.

Output frequency can be further controlled by 3-bit input A-C. These 3 bits set a pre-scaler between the controller's clock and timer 0. When A=B=C='0', the measured frequency is from 114Hz to 1.41kHz. When A=B=C='1', output frequency range is between 0.9Hz and 11Hz. See Tables 1 and 2 below.

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E72

```
        movwf  TMR0§          ;
        movf   cnt_1, W              ;
        subwf  period, W      ;
        btfsc  STATUS, C      ;
        bsf    GPIO, 2               ;output high
        bcf    INTCON, 2      ;clear TMR0 interrupt
flag
        retfie                ;
        delay                 ;
               movlw  0x03    ;
               movwf  temp    ;
        dly_1p decfsz temp, 1        ;
               goto   dly_1p  ;
               return         ;
                              ;
        main                  ;
               clrf   GPIO    ;
               movlw  0X01    ;
               movwf  cnt_1
               clrf   cnt_2   ;
               decf   cnt_2, F       ;
               movlw  0X80    ;
               movwf  period  ;
               bsf    STATUS,5       ;bank I
               movlw  0x80    ;
               option         ;
               movlw  0x1b    ;
               movwf  port_dir       ;
               movlw  0x04    ;
               movwf  ADCON1  ;
               bcf    STATUS, 5;bank 0
               movlw  0xa0    ;
               movwf  INTCON  ;
        loop                  ;endless loop
               goto   loop    ;
                              ;
               end
```

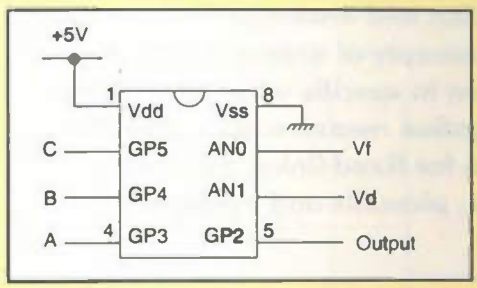


Fig. 1.

Table 1 (A=B=C=0)

Vf	Vd 0V	1V	2V	3V	4V	5V
	114Hz	114Hz	114Hz	114Hz	114Hz	114Hz
0V	3.7%	22%	41%	62%	92%	96%
	139Hz	139Hz	139Hz	139Hz	139Hz	139Hz
1V	3.8%	22%	45%	63%	81%	96%
	179Hz	179Hz	179Hz	179Hz	179Hz	179Hz
2V	4%	23%	41%	62%	79%	96%
	257Hz	257Hz	257Hz	256Hz	2S6Hz	256Hz
3V	4%	23%	41%	62%	80%	96%
	413Hz	413Hz	413Hz	413Hz	412Hz	412Hz
4V	5.1%	23%	44%	63%	81%	95%
	1.41kHz	1.41kHz	1.41kHz	1.41kHZ	1.41kHZ	1.41kHZ
5V	10%	26%	42%	61%	77%	90%

Table 2

C	B	A	Output frequency
0	0	0	f/1
0	0	1	f/2
0	1	0	f/4
0	1	1	f/8
1	0	0	f/16
1	0	1	f/32
1	1	0	f/64
1	1	1	f/128

12V battery voltage level detector

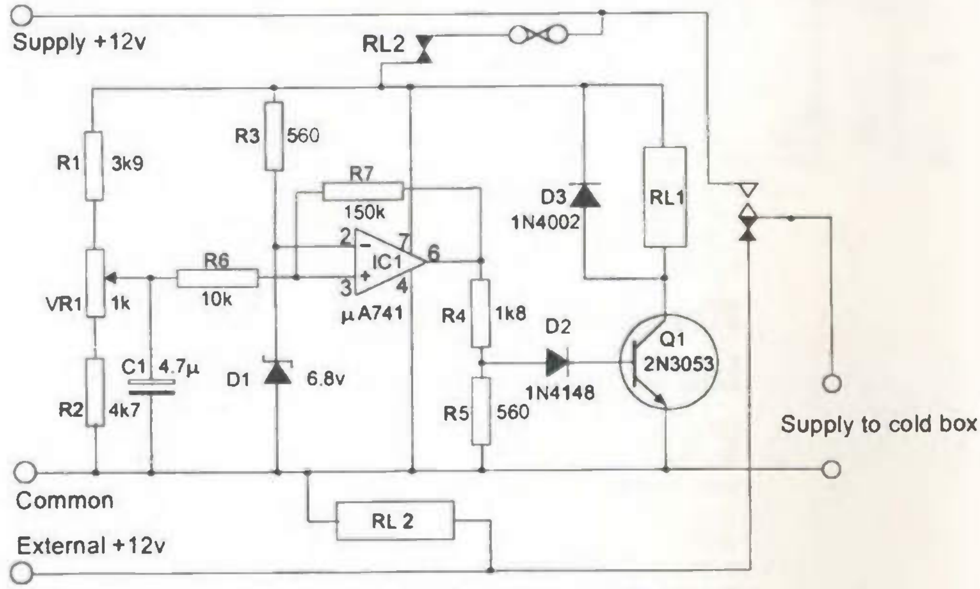
This circuit was designed for a Peltier-effect cold box on a sailing boat but could have other applications, for example, in a caravan. Load current of the cold box is about 4A and this is a large burden when sailing, but it can easily be met from the engine's alternator when under power.

The circuit detects the rise in the 12V supply when the battery is being charged. When this is about 14.2V (set by VR_1) RL_1 closes and connects the load. When the supply falls (to about 12.7V) on stopping the engine, RL_1 opens and the load is removed. The threshold between the two voltages prevents 'hunting' and can be changed by adjusting R_7 (see graph).

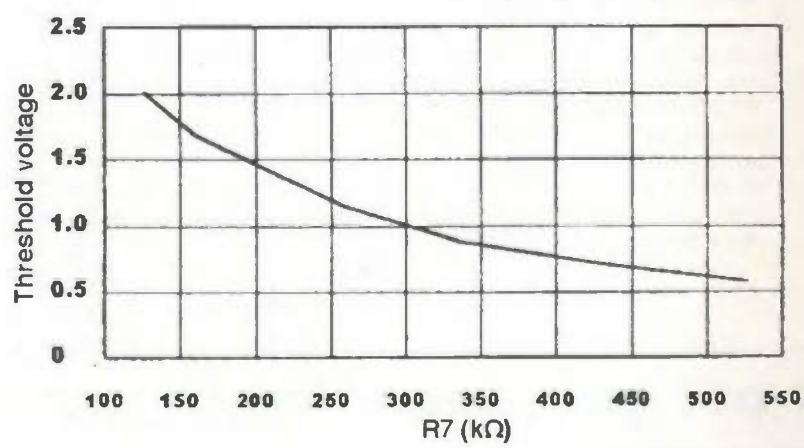
The normally closed contact on RL_1 connects an external 12V supply. This is for use in harbour when a mains connection is available. The external 12V supply also opens RL_2 and inhibits the detector. As the mains supply also feeds a separate battery charger, without RL_2 the detector will operate whenever the battery charger brings the battery voltage up to the threshold level and thus switch away from the external supply. The need for this relay was discovered in practice!

The detector should be installed as near to the battery as possible, to avoid the voltage drop in the cables to the cold box causing malfunction.

Tony Meacock
Norwich
Norfolk



RL1 12v spdt 10 amp. RL2 12v spdt.



LDR-stabilised Wien-bridge oscillator

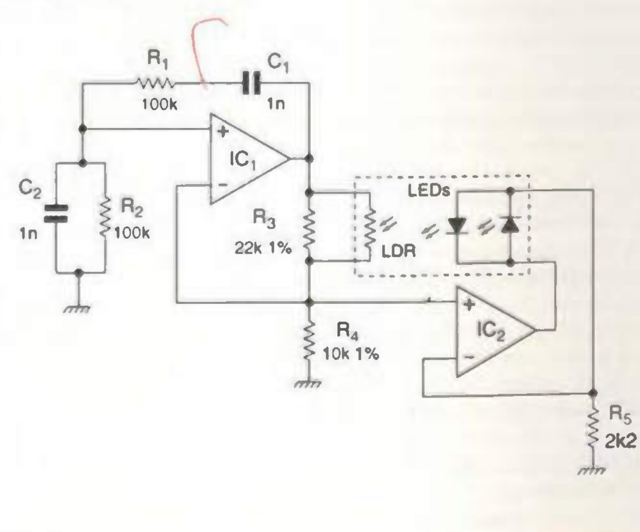
This sine wave oscillator uses feedback via an LDR to stabilise the output amplitude. The circuit arrangement of IC_1 should be familiar: if $R_1=R_2=R$ and $C_1=C_2=C$ then $f=1\div(2\times\pi\times R\times C)$. With values shown, the frequency will be 1.59kHz.

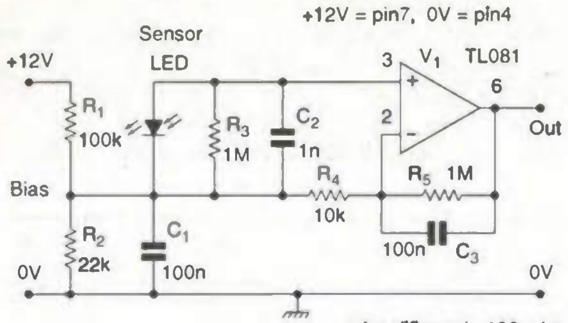
Op-amp IC_2 provides current to the LEDs according to output amplitude thus modifying the resistance of the LDR. Resistor R_3 should be just greater than twice the value of R_4. Adjust amplitude by modifying the value of R_5. The circuit will work from 0Hz to 10kHz with 358 op-amps and values shown. Using rail-to-rail output amps and low voltage red LEDS, the circuit will work from a 5V supply.

The LEDs and LDR should be put in a light proof box such as a black pill bottle cap. No claims are made for a perfect sine wave but it is adequate for exciting a transducer etc.

Some LDRs have a very slow response, which helps with distortion, especially at low frequencies.

Andy Little
Penzance
Cornwall





Amplifier gain 100, plus low-pass filter

Use LED as photo-diode

Light emitting diodes are cheap and readily available. They can also act as photo-diodes, an example being in the circuit shown.

Some sixty LEDs, of various colours, were tested in the photo-voltaic mode, and all acted as photo-diodes. Testing was done using a 2.4V 0.5A lamp over-run on 3V. Yellow/orange LEDs worked best, producing about 50mV into 1MΩ. It is reasonable to suppose that LEDs would also operate on the current-mode, which provides a wide dynamic range with response linearly related to intensity of illumination.

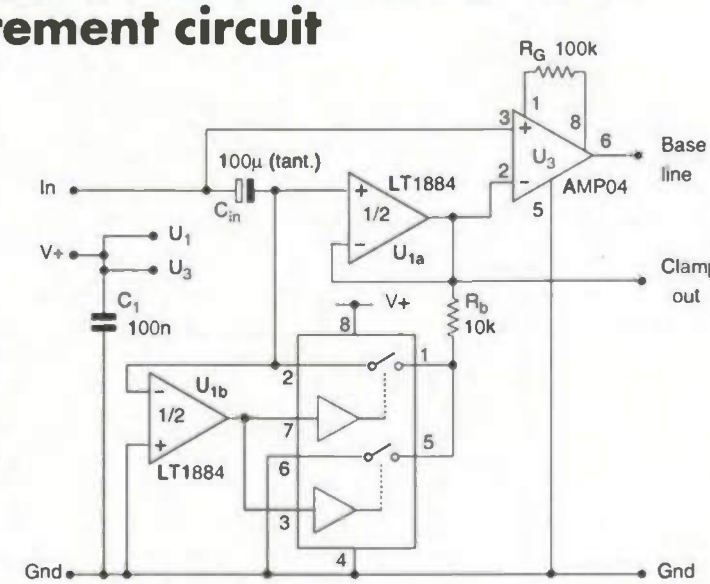
Colin Pye
Coventry
E67

Precise single-supply baseline clamp and baseline measurement circuit

The circuit shown, right, accurately clamps the baseline incoming waveform to within a couple of millivolts of zero volts. Subtraction of the clamped signal from the original measures the low point of the incoming waveform. Using two series analogue switches reduces baseline ripple to almost zero.

Bootstrapping the switches with the output signal reduces the switches' off-state leakage and keeps the DC component stored on C_{in} from drooping between cycles. Capacitor C_{in} was chosen to allow processing of signals from 1kHz down to 0.1Hz. For higher minimum frequencies, a lower capacitance value can be chosen.

Alex Birkett
London
E68



Linear pot gives logarithmic gain control

The volume control of an amplifier is generally logarithmic and sets the output to about 12% in the its position. Apart from expensive models though, the tracking of these potentiometers is far from ideal.

There are good linear potentiometers with 1% or better accuracy, but in general they are not suitable as volume controls. However the circuit of **Fig. 1** will give you a calibrated output signal with a gain depending on the value of the resistors used.

The input has a voltage divider R_1 and R_2; if R_1=R_2 the 0dB signal of a CD player will give 1V ac to the + input of Q_{1a}. With 10kΩ potentiometer R_4 at mid position and resistors R_3 and R_5 of 1.1kΩ, the gain of Q_{1a} is (5+1.1)÷1.1. But there is an equal signal attenuation to buffer Q_{1b}, hence the output signal will be 1V ac or 0dBV also.

With R_4 fully clockwise the gain of Q_{1a} is (10+1.1)÷1.1=×10 or +20dB. This is connected directly to Q_{1b}; hence the output signal is +20dB also.

However with R_4 fully counter clockwise, gain of Q_{1a} is ×1 but attenuation to Q_{1b} is now 1.1÷(10+1.1) or –20dB. The potentiometer scale will be almost linear in decibels, covering –20 through 0 to +20dB. This is accurate enough for audio applications.

Increasing $R_{3\text{-}5}$ to 4.7kΩ will give a range of –10 to 0 to +10dB. In fact you can set the zero dB point anywhere, e.g. at 3 o'clock to give a range of –15 to 0 to +5dB.

Instead of this op-amp, a current conveyor like the OPA660 will do an even better job. Here, V_{out}=V_{in}×R_2/P_1, so (R_3+R_4)÷R_5 for clockwise and R_3÷(R_4+R_5) for counter clockwise, hence the circuit of **Fig. 2** performs as Fig. 1.

J van Doorn
Amersfoort
The Netherlands
E66

Fig. 1.

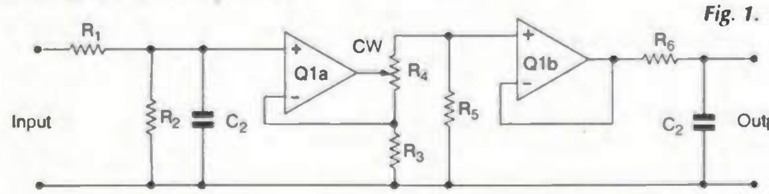
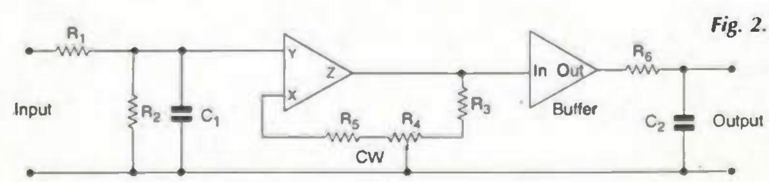


Fig. 2.



£75 winner

Letters to the editor

Letters to "Electronics World" Quadrant House, The Quadrant, Sutton, Surrey, SM2 5AS e-mail jackie.lowe@rbi.co.uk using subject heading 'Letters'.

High-voltage power amp

I am writing in response to a letter from Ged Landon in the march issue on high-voltage amplifiers for electrostatic loudspeakers.

Back in 1985, I designed and built a push-pull transistor amplifier with a 5kV HT supply as my master thesis while I was at Chalmers University of Technology in Gothenburg. I did not use CRT deflection transistors, as a typical beta specification of the devices available at the time was >2!

I used video transistors instead, with a voltage rating of 350V and a beta of greater than 40. Some 18 Darlington connected pairs were used for each leg.

Arni Ingvarsson
Linkoping
Sweden

On skill and training

I was very interested to read Malcolm Lisle's letter in the March issue – 'An Unskilled Generation' – on the lack of training in the electronics industry.

I'm under the impression that all the graduates get jobs in the software sector or in electronics design.

I work in the field of automated functional test of populated circuit cards and I'm keen to employ some intelligent, motivated trainees – not necessarily graduates.

How do I find them?

I've tried Job Agencies, Job Centres and the local Tec with no results.

It occurs to me that some of readers of *Electronics World* probably fit the bill, having a good knowledge of electronic circuitry, experience of software writing – possibly as a hobby – and who are addicted to electronics.

Alistair Gee
Worthing

More choice on FM

As the audio broadcast FM band is so much bigger than the AM MW and LW bands, it seems a pity that it is has so few stations – especially as Radio 1 decided to have a narrower appeal.

Digital radio doesn't seem much use. Presumably this is because it takes a lot of processor power to decode and hence digital personal radios will not sip batteries like conventional AM/FM personal radios.

I read that 30kHz AM was considered for the FM band before 200kHz wideband FM was chosen: I wondered if narrow-band FM could be used to squeeze in extra channels – and could it be backwards compatible? Could narrowband FM be combined with a digital helper signal? Even if in mono, extra stations would be good.

Alan Bradley
Via e-mail

EMC and the individual

In the April 2001 issue, Leslie Green commented on EMC standards and spread spectrum. While I agree with most of his comments, his statement that an individual can make a PC without CE certification is incorrect.

All electronic equipment built and put 'into use' must comply with the EMC directive, The maker is responsible, and there's no distinction between individuals or companies.

In theory, all equipment should be tested or have a Technical Construction File – even one offs that are used in house and not sold.

With Trading Standards enforcing the regulations, it is difficult to see how anyone could be caught unless they actually caused interference and a complaint resulted. The only exception to this rule is that radio amateurs – one presumes licenced ones – may construct equipment as long as it is not sold commercially.

Every time I have taken a system for EMC testing that included a ready built CE-approved PC, the PC has required work before it would pass on its own.

Lower cost monitors also tend to fail emissions tests. Enquires or complaints to the PC suppliers just get responses such as "well all the parts are CE marked" and a copy of a certificate (2 years old) for the monitor from an untracable Korean test house.

Robert Atkinson, G8RPI
Via e-mail

Mr Green is somewhat wide of the mark with his response to Mr Melia's undue anxiety over a 'dithered' switch-mode power supply.

As far as Britain is concerned, no proposals have been made to change the CISPR receiver and the emission requirements, in order to bear down on dithered devices. The reason that is that the subject has been investigated by the Radiocommunications Agency.

A voluminous report concludes that there is no need for a change. This is because the results of the existing tests are a fair measure of the threat posed by such devices to the reception of radio signals.

Mr Green is quite right in saying that a modification to the CISPR receiver specification might well be costly for every owner. The FCC may have decided on that ground, but in Britain, the subject has been investigated in some depth.

John Woodgate
Via e-mail

Valve substitute

I read with interest Dave Allen's article on his MOSFET replacement for a 6V6.

His idea was certainly ingenious, but I disagree that spare valves are difficult to get hold of, or very expensive. For example, Langrex Supplies Ltd, which advertise in this magazine, seems able to supply just about anything at very reasonable prices. Maplin has a much more limited range, but this includes the 6V6

More generally, there are some good web sites to interest the vintage wireless enthusiast. For instance, try http://www.vintage-radio.com.

Incidentally, I seem to remember that solid-state valve replacements were made commercially in the early seventies. Does anyone know anything about them?

Ranulph Poole
Via e-mail

A true dome tweeter

John Watknison's interesting treatise on dome tweeters was flawed on one minor point. A pulsating hemispheric tweeter has been developed and has been available commercially for several years. I refer to the fascinating Audax HD-3P – a novel and unique application of piezo polymers.

Trevor Wilson
Via e-mail

Phono preamp

Norman Thagard is not the first person to use a two-stage preamplifier design in order to avoid calculating the full RIAA network. This seems an extraordinarily negative approach to circuit design.

He does not draw attention to the massive loss of headroom caused by his amplify-then-attenuate structure. This loss starts at 1dB at 1kHz, and rises to 20dB at 20kHz.

The unwanted zero produced by the single-amp version, because the gain cannot drop below unity, is easily cancelled out by placing a passive HF pole after the amplifier, as I have pointed out many times.

It did indeed come as a surprise to learn that most of the noise comes from the resistive part of the cartridge impedance – because it is not true. RIAA inputs can be made with JFET op-amps, bipolar op-amps, discrete FETs or discrete bipolars, but in every case the major noise contribution is either the amplifier or the 47kΩ input resistor.

Mr Thagard overlooks that the modest resistive component of a typical moving-magnet cartridge is completely dominated by its huge inductance. To this he adds a 10mH choke in series with the input; this seems like a very high value for EMC purposes.

For a Shure M75ED II, the relevant values are

610Ω and 0.47H. Over most of the audio spectrum, the total cartridge impedance is much higher than the resistive part. So the noise generated by the 47kΩ input resistor is not shunted away, but goes into the amplifier input.

For the best noise performance it is necessary to design for a much higher impedance than the cartridge resistance; 10kΩ to 20kΩ is about right.

It is a great pity that no information was given on noise and distortion performance.

Douglas Self
Huntingdon
Cambs

Dr Thagard replies...

I made no claim for originality of the two-stage concept. To the contrary, I wrote that I used a National Semiconductor abstract as the basis of the design. The only new feature was the single-stage op amp, but this was also based on a text book example.

The 10mH choke was per 'The Art of Electronics' recommendation. I went so far as to explain the effect of adding the choke. Reduce the choke to 2.5 or 5mH or eliminate it entirely, if it offends your sensibilities. I prefer to keep it because the reception of radio stations through a phono preamp is less desirable than the negligible alteration in frequency response.

Anyhow, the original articles for all three of these references were appropriately cited in the footnotes.

I ran the article circuit on PSpice along with circuits such as the inverter that places the 47kΩ resistor in series with the input rather than in shunt. I did not overlook the "huge inductance" (of the cartridge). I went so far as to model balanced phono preamps, but could never get rid of the input resistor noise, as the 23.5kΩ (1/2 47kΩ) gate resistors are in series with the inputs.

The Shure V15xMR 1kΩ dc resistance and 425mH inductance were modelled as well. I also had and used the PSpice models for the input JFETs, types 2SK389 and 2SJ109. The only devices in the model that differed from the prototype devices were the current mirror BJTs. Even there, I edited their instance models to more closely conform to the dual ITS transistors of the prototype.

Unless PSpice is wrong, the cartridge resistance is the greatest source of noise throughout the audio band. The preamp, as I stated in the article, contributed little additional noise. I wrote the disclaimer in the article that, "If the model is correct, the preamp, itself, adds little to the total noise output." Obviously, I acknowledged the basis of my claim for good noise performance.

I don't believe that I am even the first author to cite the cartridge dc resistance as the biggest source of noise, but admittedly, I cannot recall the citation.

For an inverting input stage, most of the noise comes from the 47kΩ resistor. I don't pretend to understand everything about PSpice, but in general it gives similar results to the breadboard circuits based on the computer-modelled circuits.

In any event, since no noise is audible from the actual preamp operating in my system (Martin-Logan ReQuest loudspeakers), I can't imagine why this is worth much discussion on any but the theoretical plane. Too many designers spend too much time and money chasing the ultimate when much less would give the same subjective, if not objective performance in audio. In commercial work, over design is almost as heinous as under design.

If this argument is insufficient, I quote from AN-346: "In contrast (to the inverting op amp-my words), the 47kΩ damping resistor in figure 2(a) is in parallel with the source, and is a significant noise contributor only when the source impedance is high. This will occur near resonance, when the source is a moving magnet cartridge."

Resonance, according to the author, will occur between 15 kHz and 20 kHz. I was, therefore, not unaware of the point that Mr Self makes. However, I do dispute the significance since the application-note author goes on to say that the shunt location of the 47kΩ resistor has a 13-18 dB noise advantage over the series placement. Now I have to choose whether to believe Mr Self or Kerry Lacanette, the author of the application note. PSpice favours the application note author.

I don't have an ac voltmeter sufficiently sensitive for noise measurements. Noise measurement results were published for the application note circuit, which used LM833 op-amps in lieu of my "single-stage" op amps. Unweighted signal/noise referred to a 1 kHz, 5mV input was 82dB while 'A'-weighted S/N was 87 dB. These are certainly respectable.

If there is a headroom problem with the preamp, it is not obvious. It tests ok, and sounds fine using some pretty high-output cartridges in the face of any likely output from any cartridge.

I personally use a Shure V15xMR, whose data sheet is where I got the inductance and resistance figures that I used. But I have tried the preamp with a Stanton 681EEE, which audibly has much higher sensitivity.

Again, to address this issue by reference to the application note: "It should be noted that most real cartridges are very limited in their ability to track such large ("superdisc" record-my words) velocities, and will not generate preamplifier output levels above 1V rms even under high groove velocity conditions."

Again, I see little justification to design to a non problem. In fact, this is one of the most oft-repeated concerns about phono preamp design and yet seems to have almost no practical significance.

Folks, the cartridge will very likely distort due to inability to track before its output will exceed the preamp's output limitation! The very same loud passages that were distorted when played through my Dynaco and Krell preamps still distort through my circuit. The ones that don't distort through the Dynaco and Krell don't distort through mine, either.

I recently read an article involving a former designer of phono preamps. He stated that, in testing various design variations for listener impression, accuracy of RIAA tracking correlated most closely with a favourable rating. If that is true, then using a design such as mine with accuracy of ±0.1dB would seem to be one of the best approaches, notwithstanding the concerns cited by Mr Self.

I don't try to reinvent the wheel. Mr Self needs to take up his quarrel with the authors whose articles I used in reference and as my design basis. If my article or circuit is in error, it is because I merely followed the wrongful ways of some pretty astute designers.

I had a friend with a pretty good set of ears give the preamp a "thumbs up," too and I have a lot more confidence in him than any theoretical considerations that would seem to have little practical applicability in the present case. ■

Obituary – Karl-Heinz Lipschutz

We have learned of the death of Heinz Lipschutz at the age of 80, after many months of poor health. He left no family.

Heinz was known in several fields of interest: aviation, electronics (radio and audio), combustion engine design and building and, perhaps most of all, he was well known for the 44 years he spent in trying to persuade the MoD to show some interest in his design for a submersible craft, the U-plane. Other navies have now taken it up.

In electronics, he first came up against officialdom in 1939, when he presented to the Air Ministry the design of a navigation aid for bombers (*EWW*, May, 1992). It used radio direction finding in a novel arrangement and was capable of extension to provide an inertial navigation system. Again, the development was turned down, even though it had been built and successfully tested.

He was born in 1920 in Germany to a Jewish family and fortunately went with his family to Palestine, having matriculated in 1936. He worked at several stop-gap jobs until 1939, when he was taken on by the British-controlled Dept of Civil Aviation at Lydda (Lod) Airport, in meteorological work and air traffic control, later working with the RAF.

He became involved with designing and constructing broadcasting equipment for the British Mediterranean Broadcasting Station and, in 1948, was co-founder of Kol Israel, the Voice of Israel broadcasting station.

Aviation interests took him to El Al, where he was a Flight Radio Officer, and later to Cambrian Airways in Cardiff as a Captain (he had taken out a private pilot's licence in 1939 and had built several light aircraft).

He will be missed by many friends at Cambrian and in other fields, not least this one.

Philip Darrington

NEW THOUGHTS ON EMC

Ian Darney presents a new approach to EMC with a view to demystifying the subject.

During the last half-century, the subject of electromagnetic compatibility, or EMC for short, has become increasingly complex and confusing. It now presents an onerous burden to the system designer.

EMC is just another functional requirement on a system, and can be treated as such. All that is needed is an understanding of the coupling mechanisms. Given such an understanding, a few simple guidelines can be formulated.

Many books and learned articles have been published. None of them adopts the approach outlined here.

Circuit modelling

It is not unreasonable to suggest that any EMC problem can be analysed in terms of circuit modelling.

A wealth of analytical tools is available to anybody who has completed a course in basic circuit design. Just as circuit diagrams can be used to describe how the signals in a system are processed, so they can be used to define the interference coupling mechanisms. A circuit diagram gives the whole picture.

There is no point in trying to understand how a multivibrator works by focussing attention on the properties of resistors, or capacitors, or transistors. Analysing the electric and magnetic fields at different locations is just as futile, when assessing the EMC of a system.

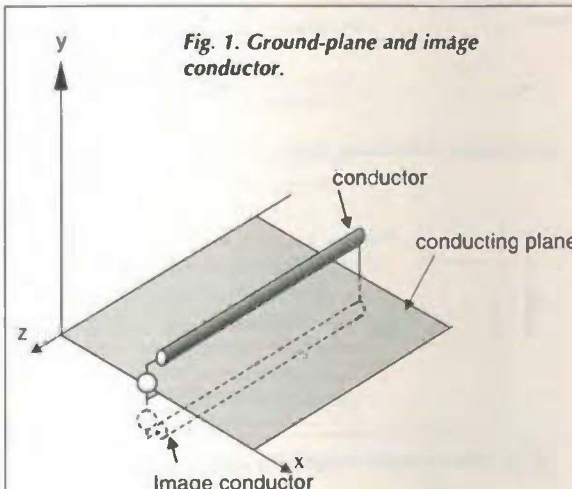
The ground plane

A widespread belief exists in the engineering profession that the construction of an equipotential ground plane is an essential feature of any good EMC design. This is less likely to be successful than the search for the Holy Grail, because there is no such thing as the equipotential ground plane.

Figure 1 illustrates the concept of the conducting plane and the image conductor. The plane lies on the x-z axis and the conductor is routed above it, parallel to the z-axis. When an alternating voltage source is connected at one end, and a short circuit placed at the other, a current flows.

It is true that, along any line on the surface parallel to the x-axis, the voltages are all the same. But it is not true that the entire plane is an equipotential surface. Along any line parallel to the z-axis, the voltage varies continuously.

Fig. 1. Ground-plane and image conductor.



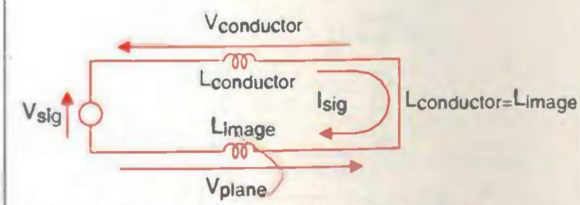


Fig. 2. Circuit model of wire and conducting plane.

As far as the electromagnetic field is concerned, replacing the conducting plane with the image conductor makes absolutely no difference. **Figure 2** is a circuit model of the upper conductor and its image. Since the image has identical physical properties, it must also have identical electrical properties. The ground plane can be represented by an inductance, and the value of that inductance is the same as the signal conductor.

Since the return current is the same magnitude as the signal current, it follows that the voltage drop along the ground plane is also equal to that in the signal conductor. Most definitely, the voltage is not zero.

However, this does not mean that the ground plane has no practical value. When implemented as one layer of a multi-layer printed circuit board, it acts as a dedicated return conductor for every signal track on the adjacent surface.

The return current is concentrated in that region of the plane immediately adjacent to the relevant signal track. Crosstalk between signals is minimised.

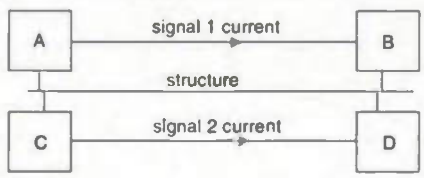


Fig. 3. Two separate wires along the structure.

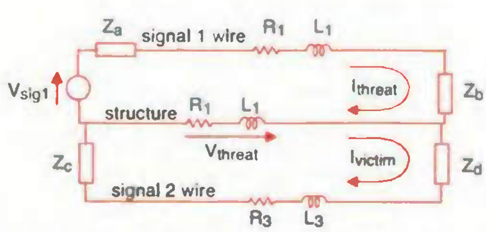


Fig. 4, Circuit model of coupling between two loops.

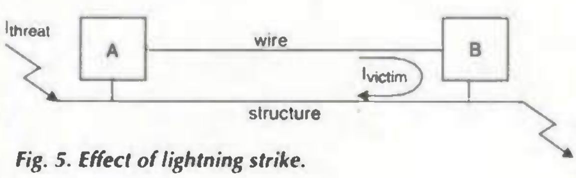


Fig. 5. Effect of lightning strike.

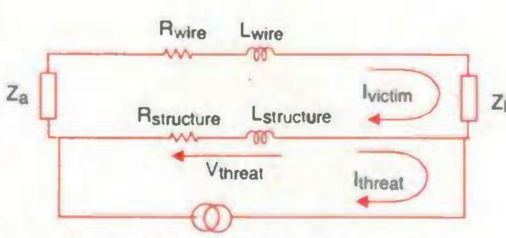


Fig. 6. Circuit model of lightning strike conditions.

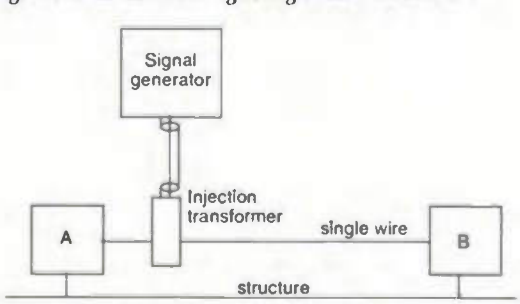


Fig. 7. Set-up for conducted susceptibility test.

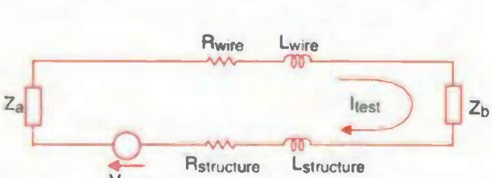


Fig. 8. Circuit model of conducted susceptibility test.

Intra-system design

Figure 3 illustrates an intra-system problem. During normal operation, signal 1 is carried from A to B, and signal 2 is carried from C to D. Both use the structure as the return conductor.

Coupling between the two signals can be analysed using the model of **Fig. 4**, where it is assumed that signal 1 is the threat, and signal 2 is the victim. If it is initially assumed that signal 2 is zero, then any voltages in the victim loop must be due to interference.

Component values for the circuit model can be derived from the physical construction of the assembly, or from electrical measurements made with general-purpose test equipment.[1]

When values have been assigned to all components of the model, then circuit analysis can be used to determine the level of interference in the victim loop. Spicycle[2] makes this task easy.

The results can be compared with the characteristics of signal 2, an assessment made of system performance, and an informed decision made on the design of the interface circuitry for C and D.

There are other options. Interface A or interface B could be redesigned to minimise the interference created by the threat current, or the layout of the cables could be altered.

Circuit loops

Circuit diagrams normally show a section of a system, with the various inputs and outputs displayed as open-circuit terminals. The interconnections between circuit sections are seldom depicted either. Few people are interested in drawings of parallel lines.

When electromagnetic coupling is being analysed, the focus of attention is reversed. The function of circuit sections is largely irrelevant.

The purpose of Fig. 4 is to analyse the effects of the magnetic field surrounding the three conductors. Values must be calculated for the loop currents I_{threat} and I_{victim} before spurious voltages at the interfaces can be determined. Such a calculation is only possible if all components of Fig. 4 are defined. If any detail is omitted, analysis is impossible.

So, every loop of the circuit under review must be completely defined.

Inter-system problems

Where the source of interference is outside the control of the designer, it is still possible to predict the response of the circuit-under-review.

Figure 5 illustrates a problem. Equipment units A and B are mounted on a framework which is subject to lightning strikes. A single wire is used to carry a signal from A to B, with the structure used as the return path. What level of protection is needed at the interface circuitry to ensure that the system survives a strike?

Figure 6 shows the circuit model. Component values are determined as before.[1]

A waveform is assumed for the lightning pulse, and a current generator is created to simulate that current. Carrying out a circuit analysis of the model enables currents and voltages at Z_a and Z_b to be predicted.

Predicting EMC test results

Figure 7 illustrates the set-up for a typical conducted susceptibility test. A toroidal injection transformer is used to induce a predefined voltage into the loop formed by cable and structure. The circuit model is shown in **Fig. 8**. Here, V_{test} simulates the voltage applied by the test equipment.

Again, frequency response analysis, or transient analysis, can be used to predict how the system will respond to an externally induced signal.

If the prediction is favourable, the system can confidently be submitted for formal EMC testing. If unfavourable, modifications can be carried out, and the cost of failure will be avoided.

Correlating results

A linear network that contains one or more voltage or current sources can be replaced by a single voltage source and a series impedance. (Thevenin's theorem). Hence, the set-up of Fig. 7 can be correlated with conditions during a lightning strike (Fig. 5) or with interference from another circuit in the equipment under review (Fig. 3).

In fact, any number of interference sources can be treated as a single voltage source in series with the structure.

The structure as a shield

The first line of defence of any system from external electromagnetic fields is the outer conducting shield. This could be the metal of an equipment box, an aircraft fuselage, or the framework of a building.

External electromagnetic energy is converted into transient currents in the shield, rather than in the functional circuitry. Transient voltages will be developed along the paths that the current takes, due to the shield inductance.

From the point of view of circuitry inside the shield, the source of interference is a voltage generator in series with the inductance and resistance of the shield.

In this context, the terms 'shield', 'ground', 'earth', 'structure', and 'framework' are synonymous

Return conductors

Up to this point, it has been assumed that all signals use the structure as the return path. It has been shown that any such configuration is subjected to the full threat voltage. (V_{threat})

If this 'single-wire' configuration is adopted, then every interface must be designed to withstand that level of threat.

A significant degree of protection can be provided, by routing a return conductor alongside every signal conductor, as illustrated in **Fig. 9**.

The circuit model for this configuration is shown in **Fig. 10**, where it is assumed that the return conductor is grounded at both ends.

The inductors L_{gnd} and L_{ret} act as a potential divider to reduce the voltage induced in the inner loop. As a result, the differential current, I_{diff}, is significantly less than the common-mode current I_{cm}. The effect of interference on the system is reduced.

If the wires are close together, L_{sig} and L_{ret} are less that L_{gnd}, improving common-mode rejection.

If in Fig. 10, the voltage source were in series with Z_a, and V_{threat} was zero, then I_{cm} would be less than I_{diff}. Emissions from power supply wiring would be reduced.

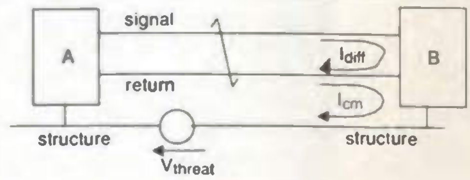


Fig. 9. Adding a return conductor.

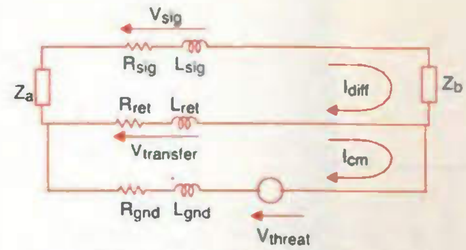


Fig. 10. Circuit model of three-conductor configuration.

Ground loops

It does not take long to deduce that the inclusion of return conductors will create innumerable ground loops in a normal system. This is no bad thing. Fear of ground loops is akin to being scared by bogeymen.

Every ground loop provides a measure of common-mode rejection.

Current balance

If the two conductors of Fig. 10 were identical, then the resistance and inductance values would also be equal. If the common-mode current were to be shared equally, then V_{sig} would be equal to $V_{transfer}$. There would be no interference. **Figure 11** illustrates this concept.

In **Fig. 12**, this circuit is viewed from the point of view of its normal function. Current in the signal conductor is balanced precisely by current in the return conductor, and the common-mode current becomes zero. There is minimal emission.

So, if the circuit design ensures that there is current balance in the signal and return conductors, then maximum common-mode rejection and minimum emission can be achieved.

Screened cable

Another way to improve common-mode rejection is to use a screened cable, as illustrated in **Fig. 13**.

The circuit model for this configuration is shown in **Fig. 14**. Here, the transfer impedance between the common-mode loop and the differential loop is just the resistance of the screen. At low frequencies, common-mode rejection is minimal,

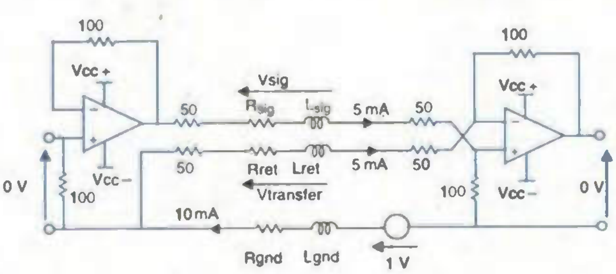


Fig. 11. Balancing the common-mode current.

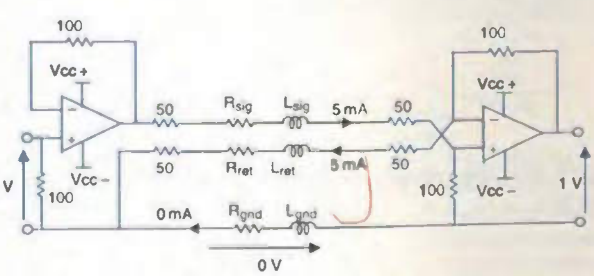


Fig. 12. Balancing the differential current.

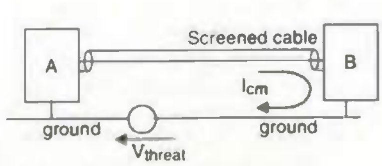


Fig. 13. Circuit configuration – screened cable.

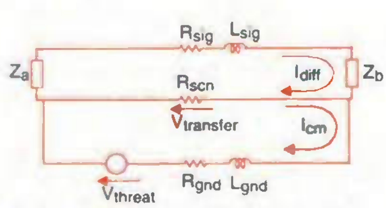


Fig. 14. Circuit model, screened cable, grounded at both ends.

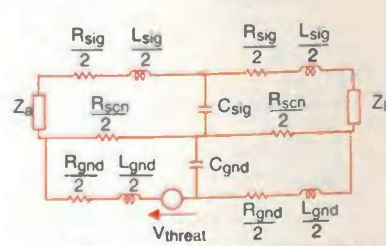


Fig. 15. Circuit model of screened cable – including capacitors.

but as the frequency increases, the impedance of L_{gnd} increases, I_{cm} decreases, the voltage across R_{scn} decreases, I_{diff} decreases, and so does the level of interference at the interface circuitry.

Capacitive effect

Taking capacitance into account, the circuit model changes to that shown on Fig. 15. Carrying out an analysis of the frequency response reveals that the common-mode current will drop to a minimum, then rise again to a peak. At this peak, common mode rejection is minimal.

Even so, performance of a screened cable is better than the single wire or wire-pair configurations.

Floating configuration.

By removing the link between unit B and structure, that interface can be made to float, giving rise to the configuration of Fig. 16. The circuit model now becomes as shown in Fig. 17. It is obvious that for the floating configuration, common-mode rejection is excellent at low frequencies. There is virtually no common-mode current.

However, as the frequency increases, the impedance of C_{gnd} decreases, I_{cm} rises and so does $V_{transfer}$. Interference level rises at 20dB per decade. Then the situation worsens. Inductance L_{gnd} comes into play, and the slope of the curve increases, and continues to increase until the response reaches a resonant peak. It would be unwise to expect much more than 10dB of common mode rejection at that frequency.[3]

Transmission-line considerations

When the loop formed by cable screen and structure is treated as a transmission line, a better explanation for the performance of the floating and grounded configurations emerges

When the floating configuration is used, and the frequency of the interference reaches that corresponding to the quarter-wavelength of the line, voltage reflection occurs at the open-circuit termination, with current reflection at the short-circuited termination. The amplitude of the current at the grounded termination builds up to a peak and a high level of interference is observed in the differential loop.[3]

When both ends are grounded, and the frequency of the interference corresponds to the half wavelength of the line, current reflections occur at both ends of the line. Again, the level of interference in the inner loop reaches a peak value.[3]

The inevitable conclusion is that neither the grounded configuration nor the floating configuration can give a consistently good performance across the entire spectrum. Even, so, they offer a vastly improved performance on the 'single-wire' configuration.

If the length of the line is defined, the frequency of resonance can be predicted.

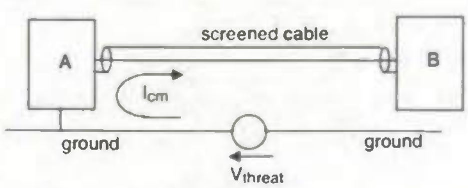


Fig. 16. Screened cable – floating.

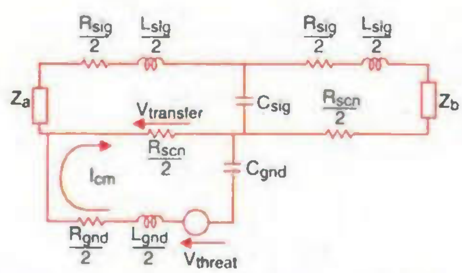


Fig. 17. Circuit model of screened cable – floating.

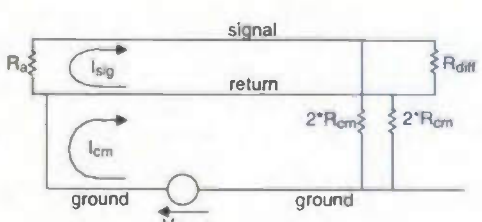


Fig. 18. Damping voltage reflections at a floating interface.

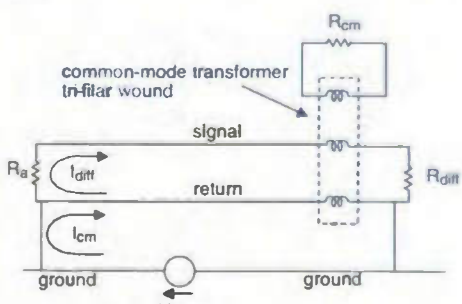


Fig. 19. Damping current reflections at a grounded interface.

Damping resistors

As well as providing an explanation to the problem of resonance, transmission line theory offers a solution. Terminate each line with a damping resistor, ideally, with the characteristic impedance.

Fig. 18 shows how voltage reflections can be avoided at a floating termination, by adding damping resistors. Since there are two loops involved, there are two transmission lines to be terminated. Values for R_{cm} and R_{diff} can range from less than 50Ω to 377Ω, depending on the configuration.

Fig. 19 shows one way of terminating a wire-pair when the return conductor is grounded at both ends. A common-mode transformer is used to insert a resistance in series with the cable. As far as differential signals are concerned, the transformer is transparent; any voltage across the signal winding is matched precisely by a voltage across the return winding.

The performance of this configuration is better than that of the common-mode choke, which looks like an open-circuit at high frequencies. As with the floating configuration, an open-circuit causes resonant peaks.

A common-mode resistance can be inserted into a screened cable without compromising the integrity of the screen. Just wind a few turns of cable onto a ferrite core and add a resistive loop.

Conclusion

A method of analysing various types of interference problems has been introduced. I have demonstrated that circuit modelling can be used to provide a clear understanding of the coupling mechanisms. A number of simple guidelines have been formulated.

Designing circuits to minimise interference is not particularly difficult. ■

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The biosensor: electronics meets biology

Biological materials combined with traditional transducers allow substances to be analysed much more rapidly than is possible using conventional laboratory techniques. David Clark looks at a device set to flourish in the twenty-first century – the biosensor.

Advances in materials and techniques have made sensors smaller and more sensitive than ever. Despite that, sensors still rely on the same principles of physics and chemistry that were used to make the measurements of physical parameters in the early days.

Now though, there is a new class of device coming into wide-scale use. It is based on biology and biochemistry – fields of science until now largely unexploited in instrumentation and control.

These sensors will determine the concentration of many of the substances found in industry, the environment and living organisms – including humans – that previously were not measurable electronically. Furthermore they will do this with a selectivity and sensitivity normally unachievable with standard sensors. The device is the biosensor, which the dictionary describes as "a device that uses a living organism or biological molecules, especially enzymes or antibodies, to detect the presence of chemicals".

Early days

Perhaps the first sensor ever manufactured was Galileo's thermometer **Fig. 1**, made around 1592 AD. This was followed half a century later by Torricelli's barometer; both were instruments for measuring physical parameters of course.

It took until the nineteenth century however before the rise of the science of electrochemistry. The increase in knowledge in this field was primarily due to the work of Michael Faraday. It eventually led to the development of sensors capable of measuring the presence and concentrations of atoms and ions in solution.

Perhaps the best known of these is the pH electrode, used for measuring the concentrations of hydrogen ions in solution, a measure of the solution's acidity. An important class of this type of electrode is the ion-selective electrode, which can be made sensitive to a particular ion through the use of a membrane that is only permeable to ions of a certain size. These membranes are often made of glass, Fig. 2.

The new generation of sensors now coming into widespread use takes this development a stage further. These sensors combine 'traditional' physical or chemical principles with those of biochemistry and biology. Interestingly this has come about because of a better understanding of how biological materials work on a chemical and physical level. This has enabled biological molecules to be linked directly to electrochemical and physical sensing devices.

To date, the main use of these devices has been in the health-care area, where measurements of the levels of gases, ions and metabolic products in the blood are often the best indicators of a patient's state of health. Using these devices in conjunction with some electronic indication can give a much quicker and more cost-effective result than a laboratory analysis.

These instruments are also making their way into high-street stores. Perhaps the best examples are the blood glucose level indicators available from chemists' outlets to aid sufferers of diabetes in the control of their blood glucose levels.

However, these devices are now of growing significance in the relatively new biotechnology industries. There, they are used as monitoring and control sensors in the large-scale production of materials in fields as diverse as brewing and drug manufacturing.

They are also finding applications in industrial-process effluent control, in monitoring for gases in the mining industry and in pollution monitoring in the general environment. This article takes a look at how biological materials can be connected into the electronic world, the interface that makes all these applications possible.

The biosensor

A biosensor consists of three main components: a biologically active agent, a transducer for generating a non-biological output that can be connected to some form of instrumentation and a fixing material. This fixer keeps the agent

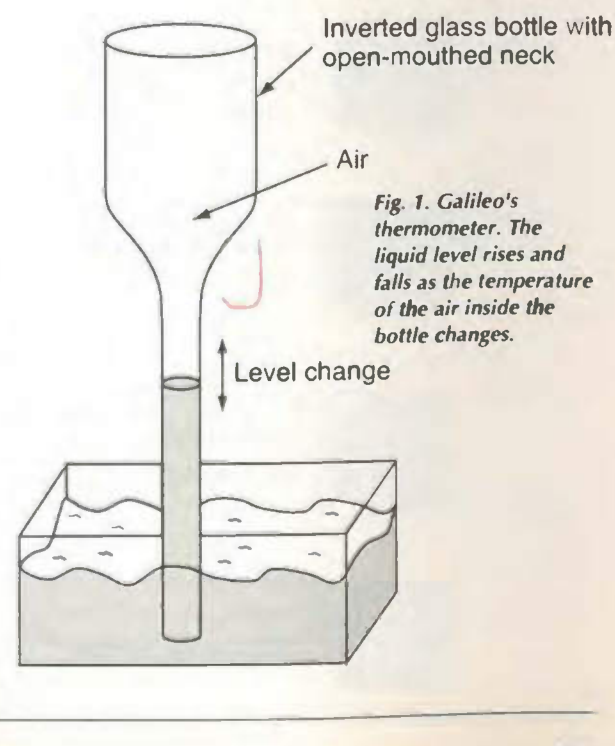

Fig. 1. Galileo's thermometer. The liquid level rises and falls as the temperature of the air inside the bottle changes.

in position, provides a medium for keeping the agent stable, allows the reactant access to the agent, and links the agent's output to the transducer, **Fig. 3**.

The next sections look in more detail at each of these three components.

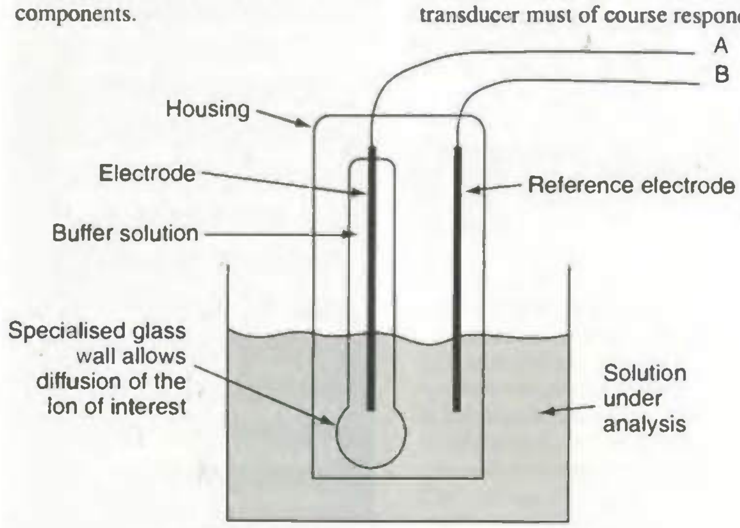

Fig. 2. Ion-selective electrode. A potential difference, related in value to the concentration in solution of the ion being analysed, develops between A and B.

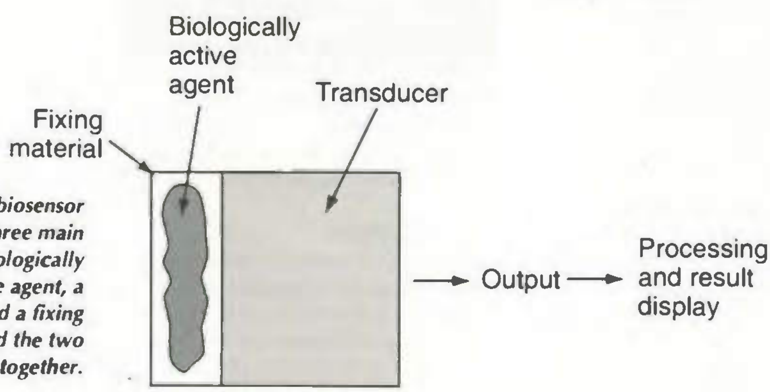

Fig. 3. Basic biosensor comprises three main parts – a biologically active agent, a transducer and a fixing material to hold the two together.

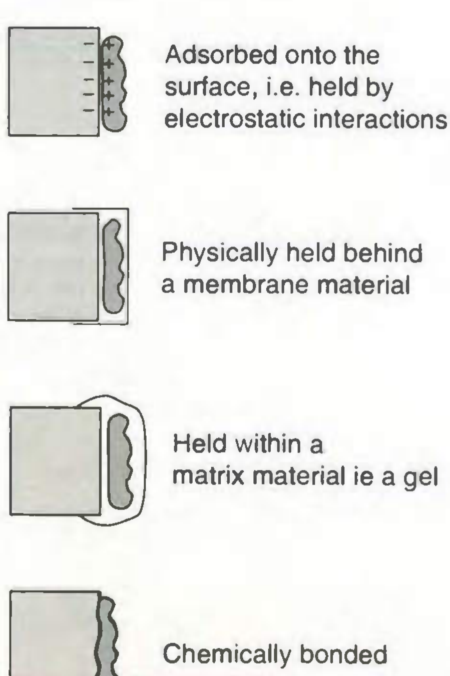

Fig. 4. Methods of fixing biological material.

The transducer. With perhaps one notable and fascinating exception – surface plasmon resonance, described later – the transducer part of a biosensor operates on the same principles as the traditional physical and electrochemical sensors. The transducer must of course respond to the output of the biological agent. Depending on the agent, this output can be electrical, physical or optical.

Electrical transducers can be amperometric, i.e. current measuring, potentiometric, i.e. voltage measuring, or even field-effect transistor (FET) linked. Here the gate of an FET is in intimate contact with the biological material. Changes in charge distribution within a biological material occur as a result of chemical reactions. These changes in charge directly control the FET. It is relatively easy to make the FET part of the signal-processing electronics associated with the sensor.

Outputs that can be categorised as physical include the microscopic changes of mass, conductivity, dielectric strength and temperature that can occur when reactions take place. These effects can be monitored directly or converted to electrical measurements using fairly straightforward techniques.

Optical outputs might involve monitoring via fibre optics. Changes in transparency, i.e. change in light transmission properties, can be monitored optically. Many organic compounds absorb very specific wavelengths of visible and ultra-violet light. Bioluminescence – the direct conversion of chemical energy to light energy by biochemical means – can also be monitored optically.

Output detection using surface plasmon resonance can also be considered an optical technique.

The fixer. One of the main problems in using biological material as part of a sensor is in fixing it in position as part of the sensor. As well as holding the material in position, the method chosen must also maintain it in an environment in which it remains active. Of course the fixing method must also ensure that the material is accessible to the substance which it is measuring.

There are four ways of achieving this. The material can be fixed by being: adsorbed onto a surface, held behind a membrane, held within a matrix or chemically bonded, **Fig. 4**.

The most dramatic advances that have come about in this sensor technology however have occurred due to the recent developments in knowledge of how biomaterials work at molecular level.

The biological agent. Currently there are four main classes of biomaterial used in biosensors. These are: enzymes, antibodies, receptor proteins, and whole cells and tissues. In the future, it is possible that even whole organisms could be used as biological detectors.

The most useful aspect of biological materials is that many only react with specific materials. Enzymes are perhaps the best-known example. They are the catalysts of the biological world; without them life as we know it would not exist.

Enzymes function by reducing the energy necessary for a reaction to begin, the activation energy, and achieve this at biological molecule level by having a structural shape that 'fits' – like a lock and key – with the molecules taking part in the reaction, **Fig. 5**.

As a consequence, enzyme action is very specific, each type catalysing only one reaction. As a result, it can be used to detect single substances in an environment where many may be present.

A good example of this class is the glucose oxidase enzyme, which can be used in biosensors for measuring glucose levels in blood. Here the shape of the glucose molecule is such that it fits into binding sites on the enzyme molecule.

The interaction affects the energy levels associated with the bonds between the atoms, and gluconic acid and hydrogen peroxide are produced as the glucose reacts with oxygen. This means that the concentration of glucose can be determined by measuring one of three changes – the reduction in oxygen concentration, the increase in acid concentration or the increase in hydrogen peroxide concentration.

There is a simple electrochemical transducer for detecting each of these three substances – the pH electrode for example will measure the acid concentration very simply.

Antibodies. The second class of biomaterial is the antibody, or immunoglobulin protein; this is also the second most frequently encountered biomaterial used in biosensors.

The antibody is a fundamental part of the body's immune system. There is a different type of antibody for every type of particle the body recognises as 'foreign', an example of which is an infective agent like a bacterium. These foreign particles are known as antigens. The antibody binds tightly to the antigen for which it is specific, just as an enzyme binds to a reacting molecule. **Figure 6** gives an indication of the action of antibodies.

In the immune system, this triggers a further process that attacks the foreign particle; in the biosensor however the property change that occurs as the antigen binds to the antibody is measured with an associated transducer.

The activity of antibody-based sensors means they are primarily useful in a medical context.

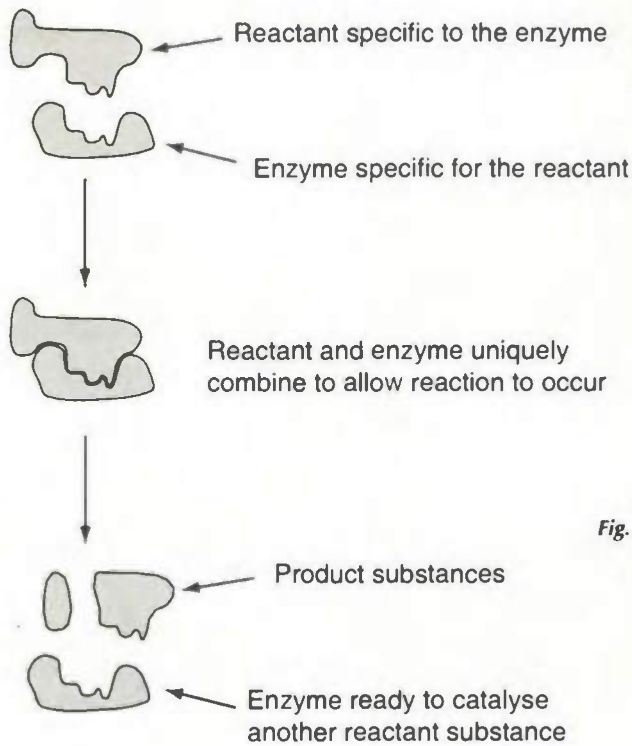

Fig. 5. Enzyme action.

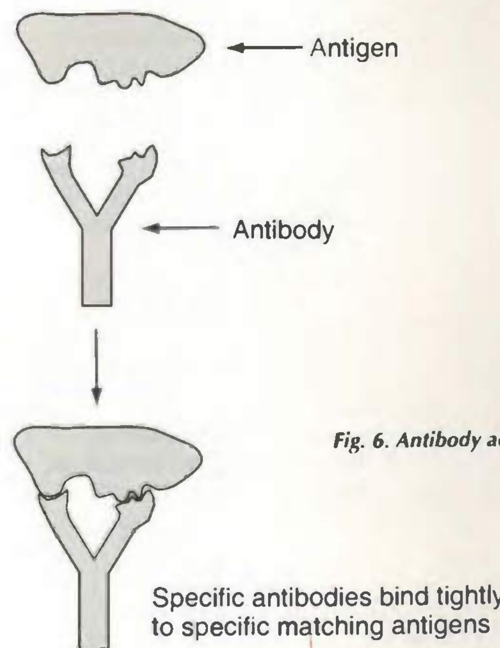

Fig. 6. Antibody action.

Receptor proteins. The receptor protein is a very flexible class of biomaterial for biosensor use. There are receptor proteins for many different types of biologically active materials including hormones and neurotransmitters, the chemicals that mediate the activity of the nervous system.

Drugs also usually act via receptor proteins. In biological cells the binding of the appropriate molecule to the receptor protein triggers the selective, active transport of another substance across the cell membrane, a normal, vital part of cell function. **Figure 7** shows how the receptor protein works.

For a biosensor this action means that a receptor protein can be chosen to give a detector that only responds to the hormone, drug, etc., of interest.

The use of whole cells and tissue in biosensors is more complex, primarily since living tissue needs a supply of nutrient and oxygen. Nevertheless the principle is the same; in the nose for example, particular tissues respond to the particular molecules that 'have' a particular smell. So a biosensor with some of this tissue as the detector could respond to the presence of those molecules.

Another, non-technical, complexity in this area is of course an ethical one concerning the source of this living material, whether animal or perhaps 'cloned'.

Surface-plasmon resonance

Changes that occur in biological molecules are subtle and often the reactions only involve one or two

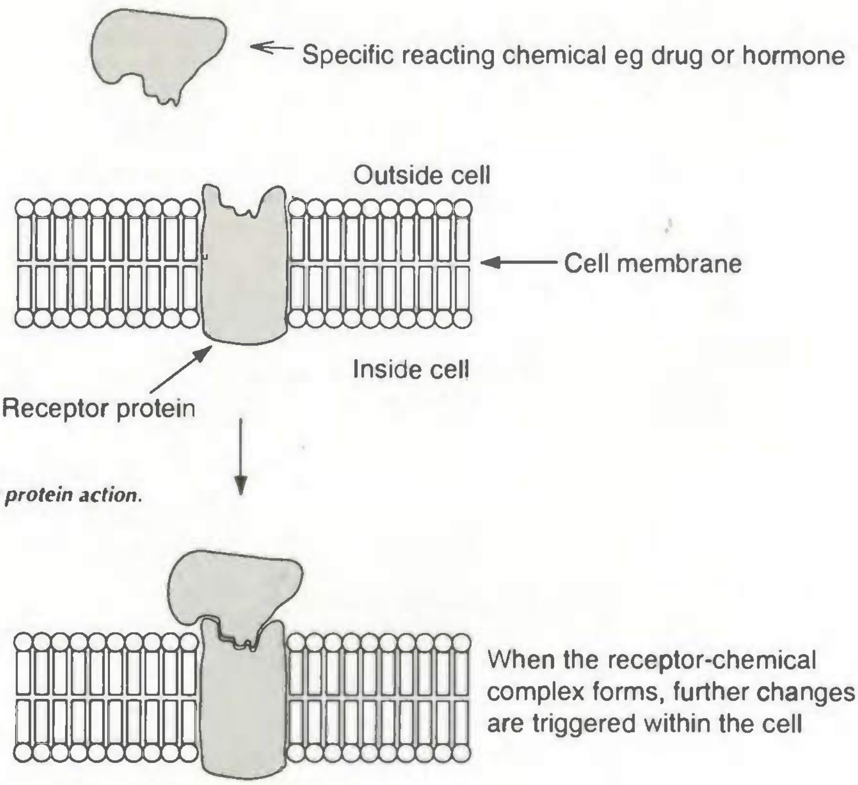

Fig. 7. Receptor protein action.

molecules. This gives biosensors their sensitivity advantage over conventional sensors as well as the advantage of their selectivity. It does however mean that the associated transducer also needs to be sensitive enough to convert the biological effect to one that can drive processing and display instruments.

Specialised techniques can be used to detect the small changes in voltage, current, temperature etc. that are used in conventional transducers. However an exciting new technique has been developed that enables the monitoring of the activity of biological molecules directly, one that operates at sub-atomic level. This technique is called surface plasmon resonance, **Fig. 8**.

The atomic and molecular structures, and hence properties of materials, are determined primarily by the electrostatic forces between the charges on the atoms and electrons that compose that material. Quantum theory explains that the distribution of these charges is not fixed, as in the classical description of electron orbitals. Rather, it is subject to random fluctuations, the electron orbitals for example being the 'places' where the electrons are most likely to be found at any instant.

A 'packet', or quantum, of energy associated with this charge fluctuation can be considered to act like an electron particle, and this type of 'quasi'-particle is known as a plasmon. Just as atomic particles fixed in a lattice can vibrate and have a resonant frequency associated with them due to the energy of the bonds holding them, plasmons too can vibrate and have a resonant frequency associated with them.

At the surface of a material, for example a thin film of gold, these plasmons can be excited by a source of energy, for example photons of light. These energy interactions affect the reflection of that light.

If a thin layer of biological material is attached to the gold surface, the energy interactions between the biological and gold materials will give a particular resonant frequency and angle of reflection for light directed at the surface. If the energy interactions are then modified, for example by the biological material binding to something else on its 'outer' surface, the resonant frequency and the angle of reflection will change.

So, by simply directing a beam of polarised light at the gold film-biological material interface and measuring the change in the angle of reflection, a highly sensitive method of detecting a substance that specifically binds to the biological material is obtained.

Prevention better than cure

Medical treatments are tending to become increasingly based on prevention through routine clinical testing, followed by early intervention when potential problems are recognised.

Similarly, better environmental protection is based on preventing contaminants reaching the environment in preference to cleaning pollution up after it has occurred. The need for increasingly specific and sensitive detectors for the relevant substances is therefore becoming greater.

Scientists are rapidly developing the ability to 'engineer' biological materials to specific requirements. Technological advances are enabling in many cases the agent and fixing medium to be screen-printed onto an electrode. This will allow the mass production of inexpensive biosensors, and it means that these devices are likely to be making greater and greater inroads into everyday life in the coming years, making a significant contribution to an increasingly healthy society and 'green' environment. ■

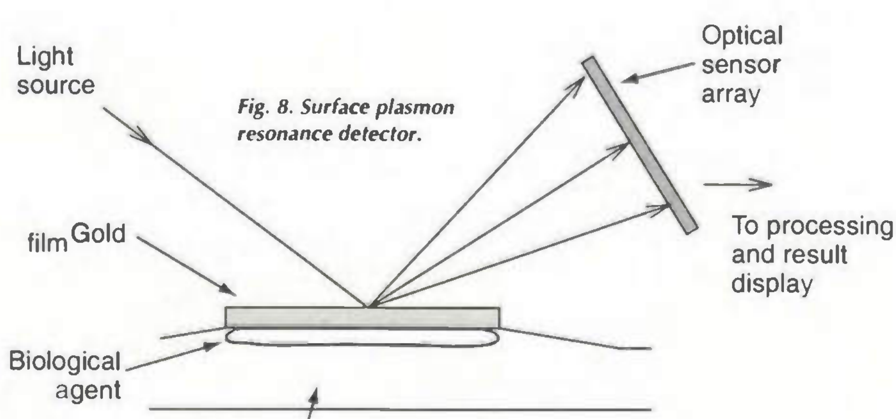

Fig. 8. Surface plasmon resonance detector.

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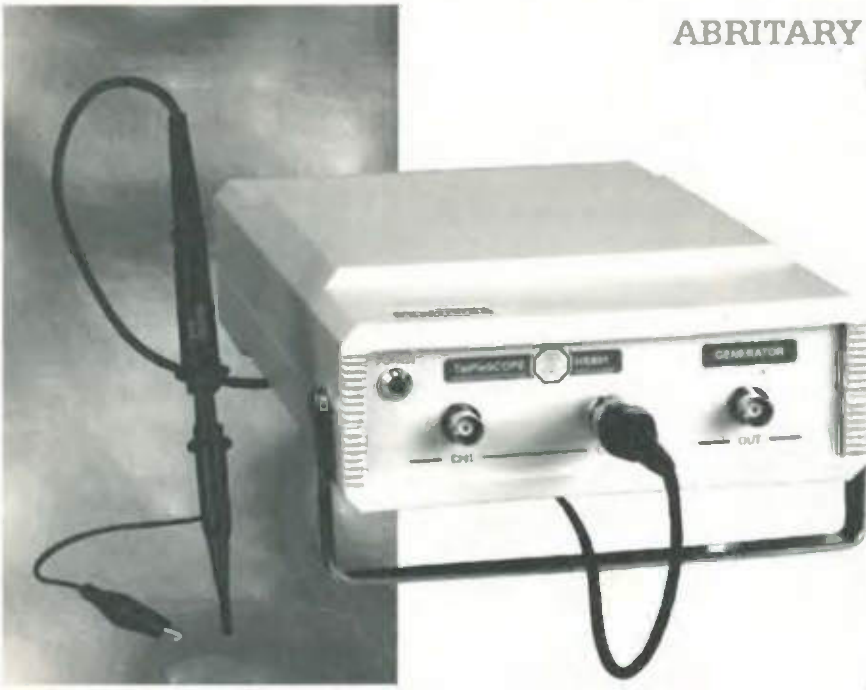

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- Measured signals and instrument settings can be saved on disk. This enables the creation of a library of measured signals. Text balloons can be added to a signal, for special comments. The (colour) print outs can be supplied with three common text lines (e.g. company info) en three lines with measurement specific information.

- The HS801 has an 8 bit resolution and a maximum sampling speed of 100 MHz. The input range is 0.1 volt full scale to 80 volt full scale. The record length is 32K/64K samples. The AWG has a 10 bit resolution and a sample speed of 25 MHz. The HS801 is connected to the parallel printer port of a computer.

- The minimum system requirement is a PC with a 486 processor and 8 Mbyte RAM available. The software runs in Windows 3.xx / 95 / 98 or Windows NT and DOS 3.3 or higher.

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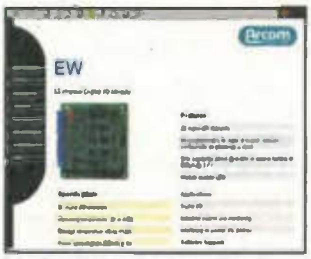

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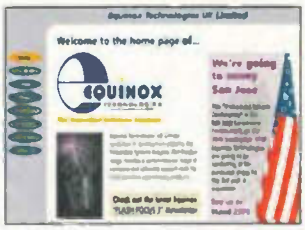

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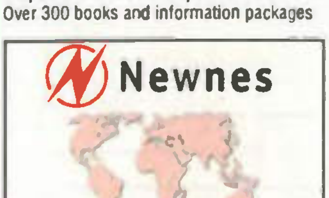

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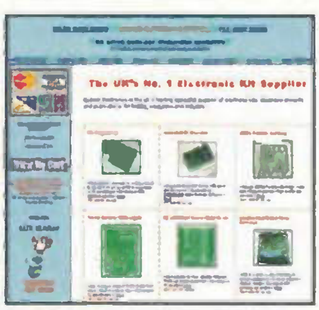

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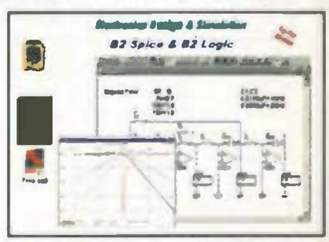

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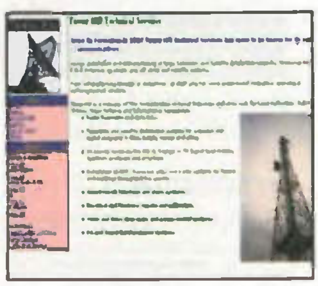

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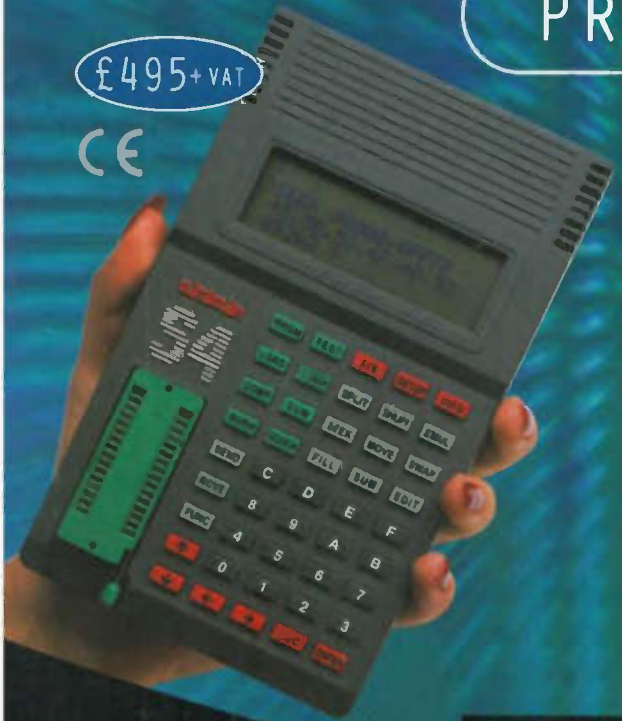

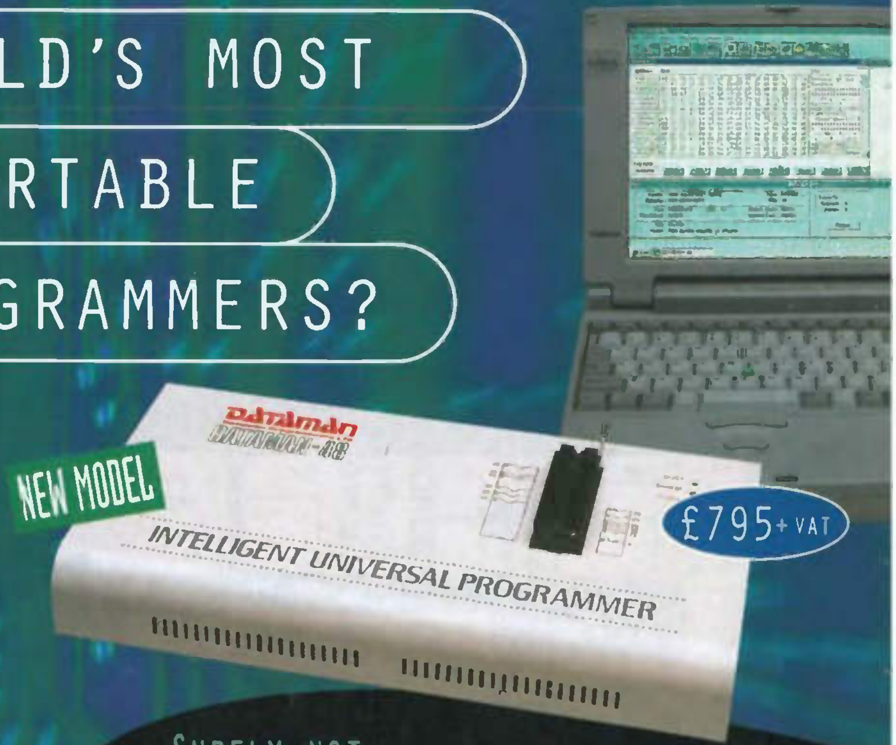

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