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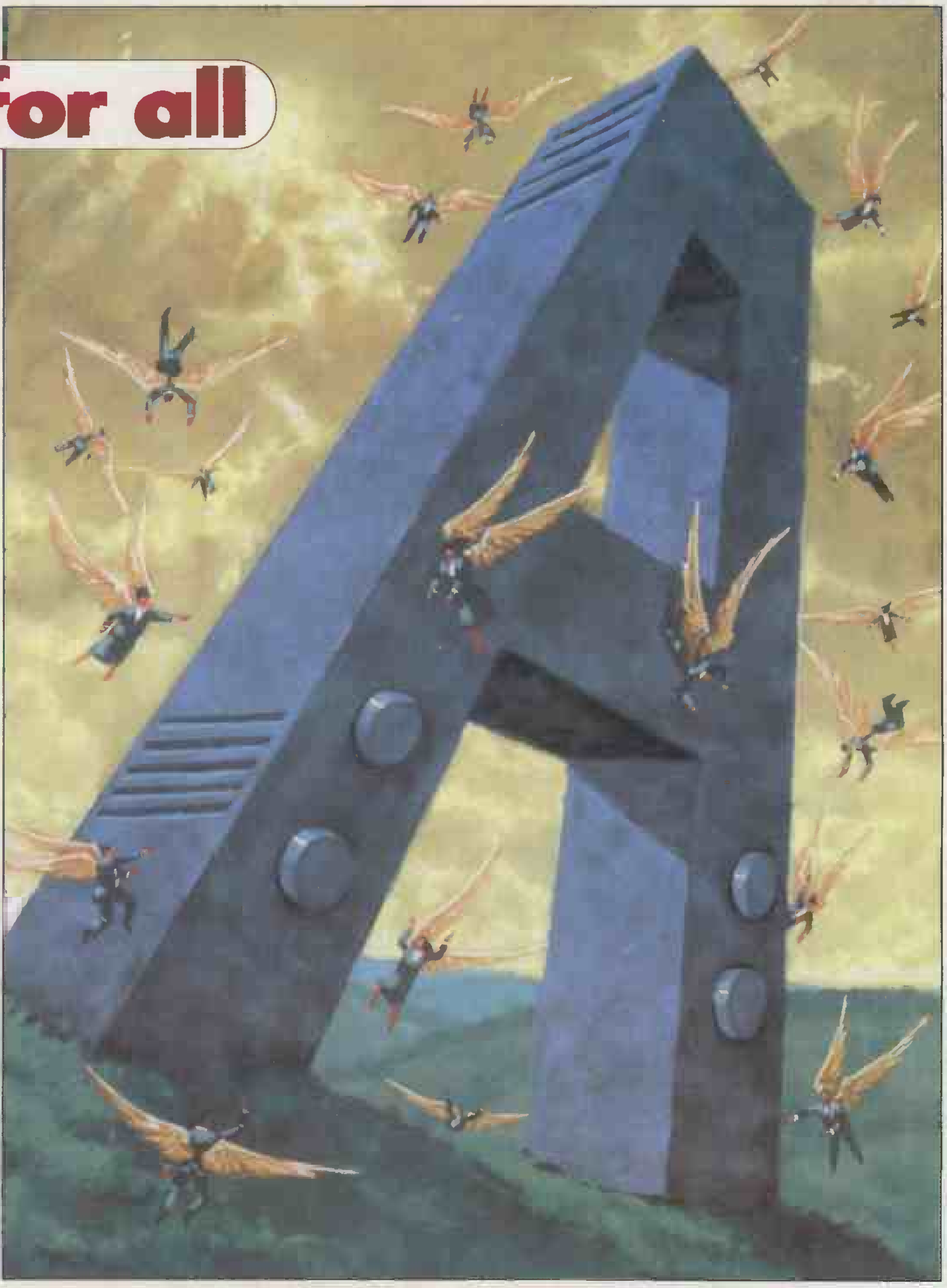

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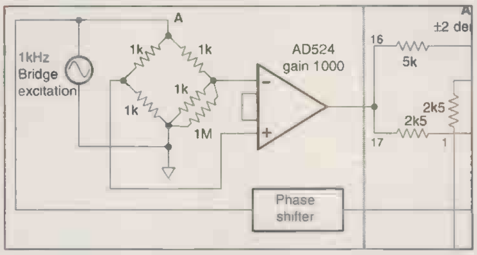
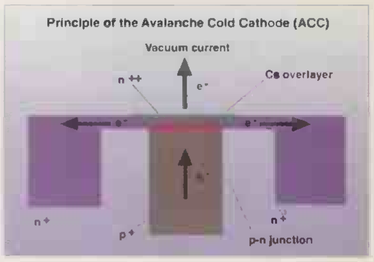


Interested in rms measurement? Cyril Bateman presents a variety of circuit options on page 215.

Cover artwork: Jamel Akib



Steve Bush reports on new CRT technology on page 181.

Our exclusive reader offer gives you over £80 discount on a 1GHz spectrum analyser. This superb instrument attains its low price by making use of the display facilities of your existing oscilloscope. Page 231 for more details.

Details of this month's cover CD rom are on page 232.

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We Brits will put up with anything

The cost of using the telephone and the Internet will plummet across Europe, but not in the UK.

In Britain we have grown accustomed to paying more than our European neighbours for most things. How many of us have marvelled at the lower cost of food and drink in French supermarkets? Even cars manufactured in this country will consistently cost us ten per cent more to buy than they would on the Continent.

Apples and Volvos are one thing, but when someone points out that as a nation we are paying more for our telephone calls than people in almost any other country in the world, then you know someone is taking the mickey.

Surely not, after all this is Britain – a country which has prided itself over the last dozen or so years on having one of the most open and highly competitive telecommunications markets in the world.

We are told that free-market competition will inevitably drive down prices by forcing companies to be more competitive. But it has not worked in the UK's deregulated telephone market, and what is more worrying for phone users is that the future telephone market in this country looks like it could become less, not more, open.

It seems that after a dozen years of free-market competition for both fixed-line telephones in the home and for mobile phones, the British telephone user has been ripped-off. That was the view of the man who up until 12 months ago was responsible for ensuring fairness reigned in the UK's telephone market.

Of course, BT and other telephone operators hotly dispute the merest suggestion that the cost of calls may be unjustifiably high. But in December some of those particular chickens came home to roost when the new industry regulator at the Government's Office of Telecommunications – Oftel for short – accused BT and mobile phone operators Vodafone and Cellnet of overcharging customers and ordered them to slash the price of calling mobile phones by 25 per cent.

Remember that the deregulated UK telephone market has more public telephone operators and more mobile phone companies than nearly any other country outside of North America.

Deregulation of telephone services has not worked as effectively as we might have expected. After more than a decade, too much competitive power still remains in the hands of too few companies. Market leading operators like BT, Vodafone and Cellnet literally call the shots and the regulator Oftel seems less than determined to act, despite last December's 25 per cent price cut.

If we thought that the last change of government would shake things up a bit and create a situation where the industry regulator has real teeth and the will to use them, then may be we will have to think again. It now seems that far from becoming more open the UK market is about to take a backward step, incredible as that may seem.

Oftel may have ordered BT to slash its call-charges, but it is not prepared to tackle the relatively high cost of telephone services by opening up the market to even greater competition, as is happening in the US and soon to start in mainland Europe.

It is the level of cut-throat competition allowed in the US, which has driven telephone charges down and Internet usage up. It seems that the European Union – traditionally bastion of monopolistic telephone operators – is changing the colour of its spots with drastic plans to open up the provision of telephone lines to greater competition.

The cost of using the telephone and the Internet will plummet across Europe, but not in the UK.

Oftel is dismissive about EU plans to compel market leading operators to rent lines to rival firms at cost prices. This is what already happens in the US and the benefits to the customer are obvious. But if Oftel gets its way then it will not happen here – potentially making a mockery of the UK's deregulated telephone market.

Oftel's argument is that the provision of telecommunications services is a high cost activity, requiring high levels of investment. If the market is divided up between too many smaller operators the ability to invest will be threatened.

This may be a valid objection if it were not for the fact that the competitive US market seems to break the rule. Not only does it have the lowest telephone charges in the world, but its operators are the most advanced at introducing broadband services like ADSL and cable modem technology.

Oftel seems to accept that the provision of telephone services will remain the preserve of a small number of operators then the pressure to drive down the cost of telephone connections will be considerably less than in most other countries of the world.

We must be grateful for Oftel's recent moves on the UK's high telephone charges, but it seems that the regulator's long term view of the telecoms market is more than a little short-sighted. ■

Richard Wilson, Editor *Electronics Weekly*

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CIRCLE NO.104 ON REPLY CARD

CRTs still shine brightest

The good old cathode ray tube seems still to have some tricks up its sleeve to beat off the advance of potential rivals.

CRTs continue to out-perform all contenders when it comes to brightness and colour. Now the latest technology from Philips Display Components is claimed to improve picture quality even further.

"It can produce a smaller spot at higher brightness," said Fritz Gehring, responsible for the Philips development. "This will give you a brighter, crisper picture."

What Gehring and his team have done is develop a semiconductor replacement for the hot cathode electron-emitter, which has featured in crts since they first appeared more than a century ago.

Philips is calling it ACC, for avalanche cold cathode.

A conventional crt cathode is a metal surface, coated and electrically heated to red hot to excite electrons within the material sufficiently to allow them to be pulled off by a local electric field.

These electrons are then focused, deflected and further accelerated, forming the electron beam that writes the picture on the phosphors at the front of the tube.

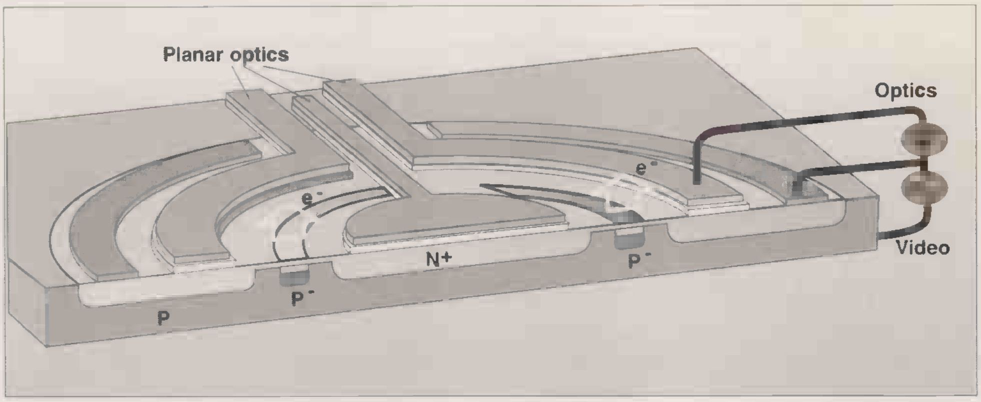
By modulating the local extraction field, the beam strength is altered to produce a grey scale in the image.

The ACC electron source works in a completely different way.

It consists of a buried diode junction, made just below the surface of a silicon chip, as in the junction diagram.

The p-type material is biased negative, reverse-biasing the junction, but the voltage applied is high enough, at 5V, to push electrons through the junction by Zener action.

These electrons, flowing from the p-type material, accelerate as they cross the barrier. Some have enough energy to escape from the material surface into the vacuum beyond.



Electrons are emitted from two buried cathodes, each 1μm wide and 25μm long. Potentials of –30V on the inner disk and +30V on the outer 100μm diameter ring produce a field that causes the electrons to leave as a single beam. One of these ring structures, on separate chips, would be required for each electron gun in a colour tube.

"The junction is less than 1μm below the surface and you get a lot of field strength," said Gehring. "With a single atom layer of caesium on the surface to lower the work function, we get between five and ten per cent of the electrons flowing through the junction emitted."

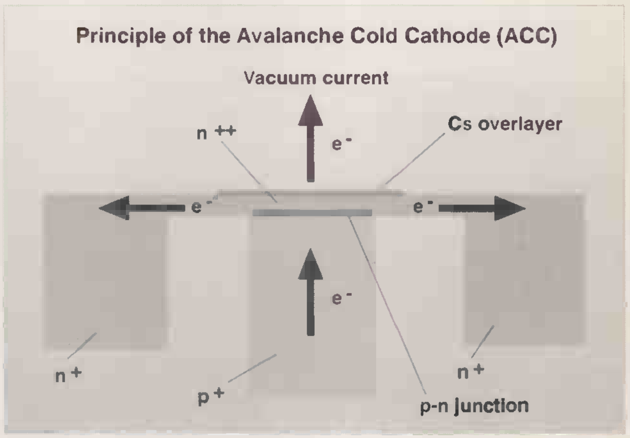
He added: "This gives us a lot of electrons per square mm, in comparison [with thermionic emission]."

Adjusting the junction current varies the number of electrons emitted.

The electrons are 'hot', flying out of the surface. Gehring said: "In comparison, the thermionic electrons in a crt are only evaporating out."

An electrostatic lens, made on the surface, forms the fleeing electrons into a beam where they can be deflected and further accelerated.

For a colour display, three ACCs are needed. "We can get six to ten thousand cathodes from a wafer," said Gehring, "The final system cost, in a monitor for instance, will be the same as the conventional approach, but the image will be better."



A buried zener diode junction has the potential to out-perform traditional thermionic electron sources in cathode ray tubes.

The future of the ACC is currently uncertain. "We are not sure if it will be introduced," said Gehring, explaining: "Lifetime and reliability need to be assessed."

Steve Bush, *Electronics Weekly*

Electronics job prospects on the up

The electronics industry is optimistic about employment prospects despite the overall job trend being at its lowest since 1994.

According to the latest Manpower Survey of Employment Prospects, the electronics industry is leading the manufacturing sector with 26 per cent of electronic employers forecasting increased job prospects for the first quarter of 1999. Against this, nine per cent anticipate a decrease which gives a balance of 17 per cent. While this is above the national average it still represents a downswing of 21 points on the same quarter in 1998.

The survey also shows evidence that the economy is faltering with the overall job trend being similar to that which proceeded the recession in the early 90s.

Over 2000 employers were questioned in December 1998 by Manpower about their intentions for staffing levels for the first quarter of 1999. For this period 16 per cent predicted an increase in job levels and 16 per cent forecast a decrease. The balance of 0 per cent is 10 points lower than the same period in 1998 and also the largest year on year downswing since 1991.

The most optimism came from the telecoms sector, which showed a balance of 19 per cent.

Sir Clive Thompson, president of the Confederation of British Industry, has warned of the likelihood of recession in the manufacturing industry this year.

A recent survey by the Chartered Institute of Purchasing and Supply indicated that the slowdown in manufacturing business may be easing although output and new order levels remain near their all-time lows.

C++ enhancements announced for hardware design

Belgium's inter-university microelectronics centre, has developed a version of C++ for designing hardware.

The C++ programming language is used to directly generate hardware description language (HDL) code ready for synthesis to logic gates.

"We didn't change anything in C," said Marc Engels, director of IMEC's telecom department, which developed the system. "We designed a set of C++ classes of basic objects." These enable a parallelism not normally found in C++.

"We have now done three chips with the system, and there are no hits on area and performance," Engels claimed.

These devices are a DECT equaliser, 10Mbit/s cable modem and part of an MPEG-4 compression chain. "This silicon is all processed and working," said Engels.

Such a development system offers two essential benefits, not available using a traditional design environment.

First, if hardware and software use the same programming language, then making trade-offs between the two is easier. "And we can co-simulate the whole thing in C which gives you an incredible speed," said Engels.

Second, the object oriented nature of C++ makes it good for design reuse.

Hyundai to buy LG Semicon chip fab

After fighting tooth and nail for months against merging with Hyundai, LG will sell Hyundai its semiconductor division.

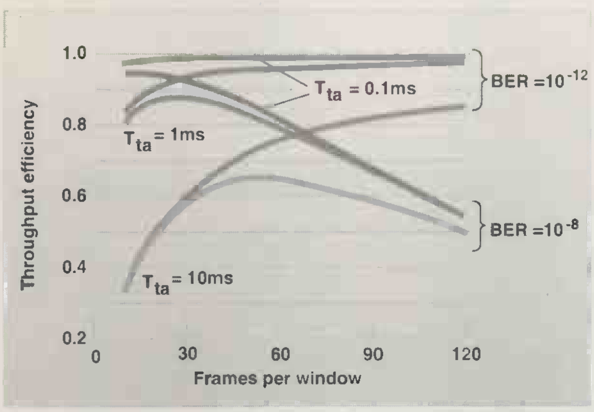
The deal followed a meeting between the Korean president and the president of LG. The company will now sell LG Semicon outright to Hyundai.

The question now is which of the two shelved UK fab sites – Hyundai's in Fife or LG's in Newport – will be used. "Our Korean people say that the smart money is that the LG fab is the one to be canned," said Richard Gordon of analysts Dataquest.

The Welsh Development Agency tried to dampen down such speculation but Cardiff West MP Rhodri Morgan said the company or the South Korean government should repay the £30m spent at Newport if the Fife site goes ahead instead.

At Newport, an LG executive told us: "We've had no instructions from HQ. We're still in talks with Hyundai to

Infra-red pc link: more speed, less haste



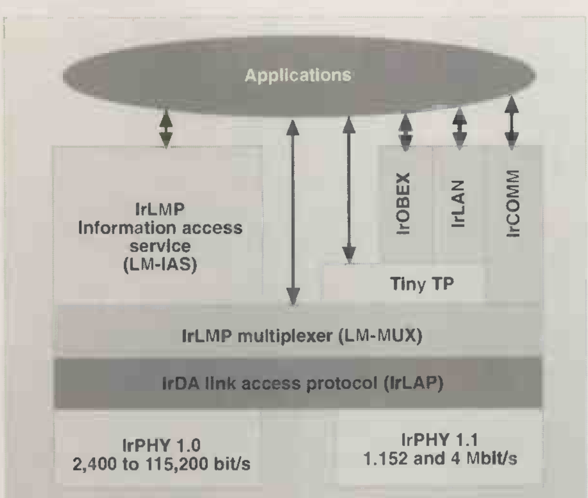
Throughput of the proposed 16Mbit/s IrDA standard plotted against number of frames sent in each transmission window. One hundred and twenty seven frames per window will be allowed, but 60 looks like a better bet, particularly under typical (BER 10-8) conditions. The long turn-around times (Tta), mandated by the current generation of low cost transducers, will also have to be reduced if the 16Mbit/s data rate is to be met.

Added flexibility in proposals for a new 16MHz IrDA infrared communications standard may reduce rather than increase data throughput. This is the finding of research at Bournemouth University.

IrDA ports, which were originally only to be seen on handheld computers and portable digital assistants, are increasingly appearing on desktop computers and peripherals like printers – so much so that Windows 98 includes an IrDA protocol stack as standard.

The initial specification drawn up by the Infrared Data Association, IrDA, called for a maximum data rate of 115.5kbit/s. This was subsequently raised to 4Mbit/s and now there are proposals to further raise this to 16Mbit/s.

For various good reasons, a IrDA transmitter can only send for up to 500ms before it must switch to receiving. In this time, called a window, it sends multiple frames of up to 16,384 bits.



It's in the protocol... IrDA is a flexible standard that is becoming widely adopted. Moving to 16Mbit/s requires changes to the link access protocol (IrLAP) to allow more than seven frames per window. Proposed is 127 but less may be best. The last change to the IrDA specification boosted operation from 115.2kbit/s to 4Mbit/s by adding a second physical layer (IrPHY)with pulse position modulation.

The 115.5kbit/s and 4Mbit/s standards allow a maximum of seven frames, but at 16Mbit/s these could be sent well within the 500ms. To make full use of the time, up to 127 frames have been allowed in the proposal.

What the Bournemouth research has shown is that, allowing for reception errors, using all 127 frames will slow data transmission in many situations. "A window size of around 60 frames looks like it will give better throughput," said Bournemouth researcher Peter Barker.

A second issue arises with the increase in data rate. To allow a terminal's receiver to come out of saturation (caused by its own transmitter) there is a period called the turn-around time allocated between finishing transmission and starting reception. The maximum available is 10ms; most terminals use 1ms.

Making full use of the turn-around time makes an extensive dent in the data transfer rate at 16Mbit/s. "IrDA is a low cost technique and so-called 'zero turn-around time' transducers are expensive. Some cheaper alternatives are needed to make full use of 16Mbit/s IrDA," said Barker.

Bournemouth's analytical technique is probabilistic, using random errors in the raw receive data stream and taking into account the duration of re-sends necessary to correct them and the likelihood of these needing further correction.

The research at Bournemouth is sponsored by BT Laboratories.

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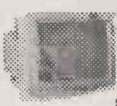

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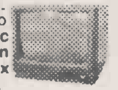

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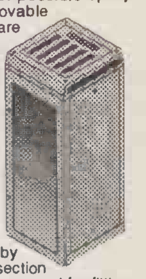

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CIRCLE NO. 106 ON REPLY CARD

The end of the pc as we know it?

The future of the pc could be set in 1999. Many believe it is a different future from the one expected between 1968 and 1998.

The expectation was, that sometime around 2000, pcs would have gigahertz processors accessing a gigabyte of wide-bandwidth DRAM.

Now the future could be pcs so cheap that they could be free to the user – and so easy to use they'll be usable by everyone.

Going, going... Has PC evolution ended with 450MHz processors and 128Mbytes of DRAM?

From racing up the hertz and bytes trail, Intel and Microsoft are said to be diverting their focus towards the never-have adopters, those technological laggards representing about 70 per cent of the western world who have never bought a pc.

At the same time, pc manufacturers are discussing with Internet service providers and telcos the possibility of subsidising pc sales in the same way as mobile phones are funded in a move towards the 'free pc'.

And pc retailers – which include supermarkets these days – are linking with pc assemblers to provide cheap machines and subsidise their selling price by doubling them as advertising channels.

The moves to commoditising the pc look irresistible, and the strongest influence towards commoditisation is the move to cheap processors.

New Celerons at 400MHz are being introduced at £100. At 333MHz they are under £50.

With AMD and Cyrix selling equivalent processors even cheaper, the most expensive component in a pc is now a commodity.

Many remember in the mid-eighties the shock at seeing Intel selling commercial processors for $1000 – a price which, up to then, had been reserved for military processors.

Intel was pricing for a monopoly market, not pricing to cost. It has taken some fifteen years for processors to get back to being priced on cost.

What does this mean for the future of the pc? Some might say it's the end of the over-complicated, ultra-fragile concoctions of Microsoft and Intel which continually crash, refuse to do what you want, and purvey incomprehensible error messages.

Does Bill Gates wake up laughing every night at the hair-tearing frustration his products cause to users every day?

Commoditisation might mean that pcs will be tailored to the needs of consumers – easy to use, performing simple functions like e-mail, word processing and web browsing efficiently and reliably, sending error messages in clear comprehensible English, and which don't crash.

Commoditisation might mean that these machines will get cheaper to produce by 30 per cent every year, like other electronics goods, and that manufacturers will pass on these cost reductions to consumers.

Commoditisation might mean the end of the creeping obsolescence of pcs as new, more powerful models running new software make last year's machine old hat.

Commoditisation could even mean the end of evolution of the PC at 450MHz processors, 128Mbyte of DRAM and 10Gbyte hard disk drives.

Will it? If pcs are just going to provide e-mail, word processing and web browsing, then they can be made on a single chip and sold as cheap consumer items called 'information appliances'. Or they can be incorporated into tvs, set-top boxes, or even telephones.

However, if pcs are to handle large amounts of graphics – as in games playing and in new features such as videophone, speech control and translation – then the pc's technological evolution is not yet ended.

Accepting voice instructions like 'find me the most economical flight to reach Rome by 2pm on Jan 22nd from Gatwick' and delivering the output in speech, or accepting dictation in one language and displaying it in another, are applications which will require huge amounts of processing power and memory.

If these sorts of uses are what people want – and many think they are – then the evolutionary future of the pc is assured. Having supercomputer-type power in the home will be justified.

But many people won't want these uses, requiring only e-mail, web browsing and word processing.

For these people, the over-elaborate Intel/Microsoft model can be junked and, if clever financing arrangements like those for mobile phones can be devised, simplified PC/IT technology will at last get into the majority of homes.

It has taken a long time. Back in the 70s the French government tried to kick-start the process with the 'Minitel' data terminal, and the UK tried to do the same with Teletext.

Like many government schemes of that era, people liked them, but no one could find a way to make money from them.

Then came the runaway success of the mobile phone and everyone was carrying around sophisticated technology. But would mobile phones have succeeded if they'd been sold at cost?

Now it's the turn of the set-top box which is following the subsidised route pioneered by the mobile phone. As well as extra entertainment, they provide telecoms and datacoms via the tv – e.g. e-mail, web-browsing and even word processing.

Next may come the subsidised – even free – pc. Will it be the vehicle which finally turns on the non-techie majority to IT? Or has the pc's future already been overtaken by events.

David Manners, *Electronics Weekly*

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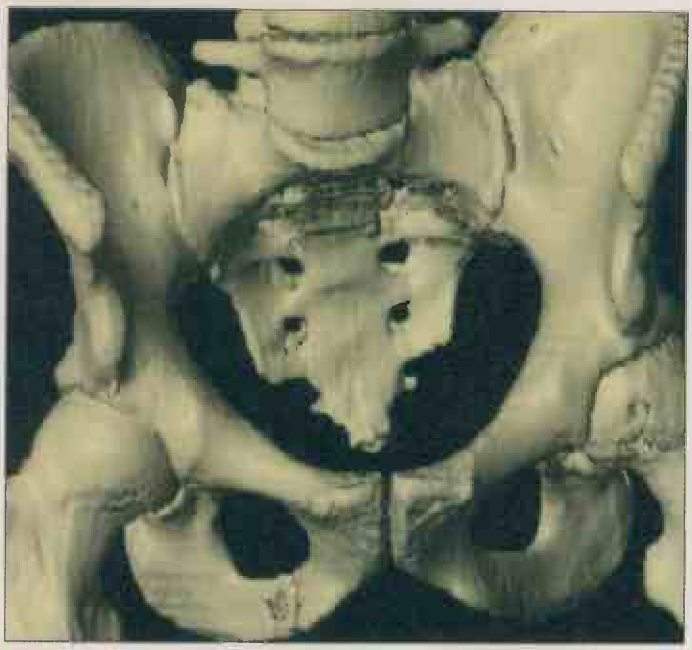
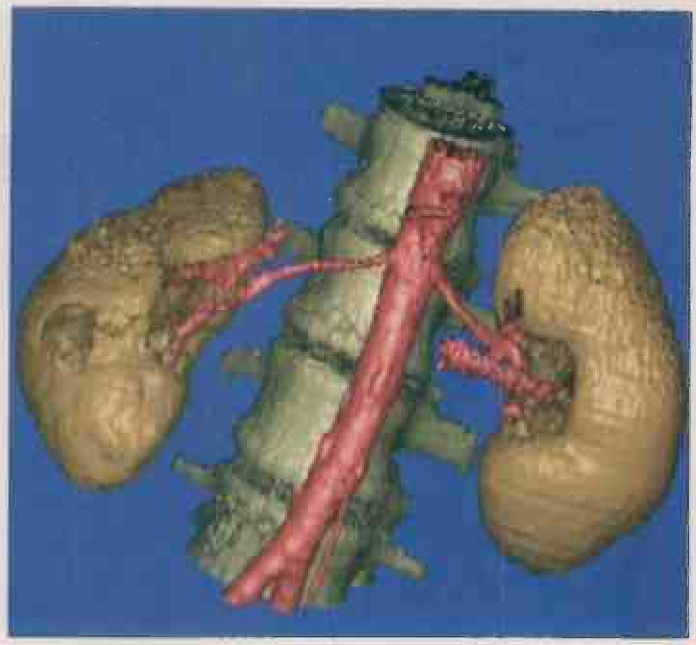




Off the bone... These are 3D images of the pelvis and kidneys using a series of axial computed tomography slices. Source: Philips

Imaging all the people

There are several different techniques currently doing the doctor's rounds in the medical diagnostic imaging market. Roy Rubenstein examines their progress.

It's a mixture of wonderment, excitement and – when all is well – immense relief. Such are the emotions an ultrasound scan evokes when parents gain the first glimpse of their child – even if the image is of questionable quality.

Ultrasound is just one of several approaches that comprise the diagnostic imaging market, valued worldwide at $14.6bn. The others are computed tomography (CT), magnetic resonance imaging (MRI) and X-ray. There's more on these in the panel on the right.

While their underlying technologies differ, all share several common elements: a source – an X-ray tube or an rf coil in a magnetic field, for instance; a detector that senses what happens to the source as it travels through the body; and circuitry to create a digitised image from the detected data.

Once digitised the information is treated like any other data: it can be stored, transmitted or processing prior to viewing.

"This is a fantastic time to work in the field," said Dr Kirby Vosburgh, director of the electronic systems laboratory at General Electric's research and development centre in Schenectady, New York. "Not only have there been significant advances in the physics and materials – much higher power X-rays, more sophisticated transducers and more successful magnetic configuration in MRI – but there have been massive increases in computational power, displays and in storage."

The result has been a transformation in medicine in the last 25 years. "Lots of diseases which were then undiagnosable now have highly successful treatments," said Vosburgh.

While the techniques have their own characteristics, there are no hard rules as to when each is used. "For different applications there is certainly some overlap," said Dr Guy Sohie, a US medical systems specialist. Ultrasound and MRI are used to look at soft tissue, whether it is to find internal injuries or to scan a brain, CT is used for both bones and soft tissue while X-ray uses include skeletal injuries and breast cancer.

Jan-Kees van Soest, chief technology officer at Philips Medical Systems, stresses that MRI is the most universal diagnostic tool, capable of imaging 'almost anything'. It is also a non-ionising technique – unlike CT and X-rays. The complementary nature of diagnostic techniques also means that they can be used in tandem. For head injuries CT can help view the skull while MRI scans brain tissue. "The two high-resolution images can then be blended; where they don't match, landmarks can be looked for and stretched [to fit the two]," said van Soest.

The various imaging techniques are now at a level that they are proving valuable aids during noninvasive and minimally-invasive surgery. "Their greater sophistication allows more subtle, specific surgical approaches," said Vosburgh.

He cites GE's latest 'double doughnut' vertical MRI system, which is used while removing brain tumours. "It allows surgeons to see below the knife; you can even watch the bones holding the scalpel."

Another development is pain management, selectively injecting highly localised anaesthetic. Other MRI uses include the implanting of radioactive seeds to treat prostate cancer. Here the key is to accurately distribute the seeds over a volume to best 'denature' the tissue. MRI is also being used to focus ultrasound, acting as a virtual scalpel, to burn tissue within the body. Temperatures of 100°C can be achieved within seconds.

For all designers of diagnostic equipment, one driving factor is cost reduction. "All health-care systems are under horrendous pressure to reduce costs," said Sohie – especially when an MRI machine can cost between $2m to $3m.

Increasing machine efficiency, enabling it to treat more patients, is one obvious requirement. "In radiology, the biggest delay is developing the X-ray film and once the film is viewed a further X-ray may be needed," said Sohie. This has resulted in the development of flat panel detectors.

According to van Soest, Thomson, Siemens and Philips are collaborating on developing flat detectors to better compete with Japan.

Another way to improve efficiency is to use advanced imaging software and pattern recognition techniques. "Mammography is a difficult field, detecting a cancer growth is not easy to see on an X-ray," said Sohie. "If you make the doctor more successful, you save a lot."

van Soest agrees: "The earlier you detect a lesion the better." However, he stresses that current techniques give resolutions no finer than 2 to 3mm. "That represents millions and millions of cancerous cells".

Vosburgh cites recent pattern recognition software that is proving a valuable tool for radiologists: "It helps identify areas of interest [on an X-ray film], acting like a 'spellchecker for radiologists'."

Another development helping to reduce cost is the increasing use of commodity technologies: communication and pc technologies through to database software. This not only addresses cost: it is also reducing the very long product cycles that characterise diagnostic machines.

So what significant developments are in the pipeline? Vosburgh believes that as imaging accuracy improves, automated surgery will become possible. But he believes this is still at least five years away. van Soest suggests that future advances in MRI will allow functional processes to be monitored. "This will allow chemical content to be viewed, potentially nipping disease in the bud." ■

Diagnostic imaging techniques

Ultrasound

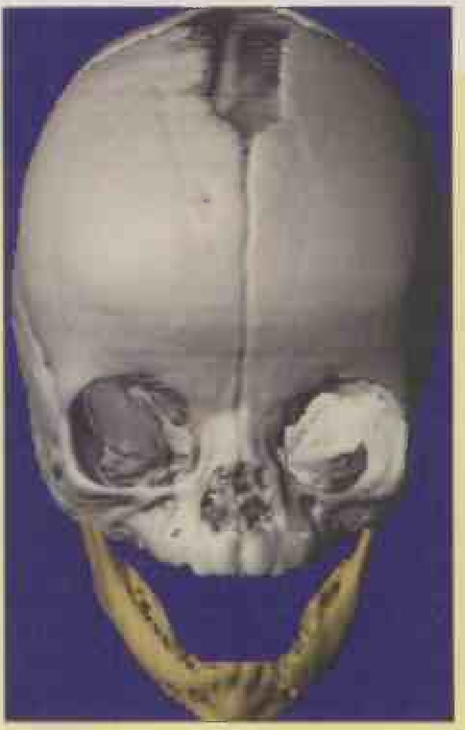
Ultrasound is ideal for viewing soft tissue. Current state-of-the-art machines are fully digital. This includes the beam-forming which transmits and receives the ultrasonic waves. Another development is colour Doppler flow imaging. By measuring frequency shifts in the ultrasound, movement can be detected and shown using a colour code. This is a particularly effective way of showing blood flow. 3D ultrasound images are another advancement.

Magnetic Resonance Imaging (MRI)

MRI uses electromagnetic resonance of atoms to image cross sections of the body. The various body locations are distinguished by subjecting them to various magnetic fields. This makes the atoms resonate at different frequencies, resulting in high-resolution images. As such, MRI, unlike X-rays, can detect both soft tissue and bone.

Computed tomography (CT)

CT typically involves a single X-ray detector and a single source which circle the body. X-ray provides a portrayal of the density of matter and is therefore ideal for viewing hard material such as bones. Advances in CT include the number of slices that can be processed in a single scan. Intensive computation is needed to calculate the intensity at each point of the 2D slice after it has been exposed from all the various directions. Hence the name.



X-Ray

X-ray involves projecting the human body onto a plate. Because X-ray machines are widely used and relatively cheap, much work is being undertaken to extend their capabilities. This includes volumetric X-ray, essentially an extension of CT using a two-dimensional detector. This allows for a full volumetric reconstruction of the image, as opposed to reconstruction of separate slices. Of particular importance is the arrival of direct X-Ray: flat panel detectors which produce a direct digital image which is more faithful to the anatomy.

Dynamic Imaging

Dynamic Imaging is not your average diagnostic imaging company.

Unlike the large multinationals that characterise the field, Dynamic Imaging, employing 75 people, is based in Livingston, Scotland and specialises in ultrasonic systems.

Its latest system is a mobile one that improves image quality by a factor of ten. This allows small blood vessels in fingers and legs to be viewed.

"It's particularly suited to spotting sports injuries and for looking at joints," said Allan Findlay, the company's engineering manager.

A second area the company is targeting is breast imaging and, in particular, guiding a needle when performing a biopsy.

To achieve the improved resolution, Dynamic Imaging has extended the operating frequency from the typical 3.5MHz to beyond 20MHz.

Class A to 300W

This range of hi-fi audio amplifiers includes what is probably the most powerful single-ended Class-A design ever. Produced by Colin Wonfor, these five amplifiers use readily available devices and are relatively easy to implement.

The first time I designed this amplifier was in the late seventies. At the time, the only Class-A designs were push-pull types or valve based. Some had very large inductors to provide the output bias. None was single ended and solid state throughout.

At the time, the problem was that the output devices did not have sufficient safe-operating-area parameters to insure long-term stability. In the late eighties, I redeveloped the design using much better devices. But the biggest single ended version was still only 25W. It had massive heat sinks and only three output devices.

Although not powerful enough to drive modern loud speakers, the design proved to be clean and simple design with excellent performance.

In the early nineties, I looked at the design yet again and set out to build the most powerful ever range of class-A amplifiers. That was some challenge.

I started with the 25W stereo version using much better components and five output devices. This was a massive improvement on the earlier designs. The heat sinks for each channel had 40mm fins and measured 300mm high by 300mm deep. Total power consumption was about 500W – all of which had to be dissipated as heat.

The next step was a 50W version, followed by 100W, 200W and 300W mono-blocks. The largest has a power consumption of about 1500W per channel.

Circuit detail

The input stage is a standard long-tail pair or differential input pair Tr_3 and Tr_4, with a constant current source Tr_6 and Tr_8 in the common emitters. Output from this stage drives the p-n-p transistor Tr_1 with its collector current controlled by Tr_9 and Tr_{11}. In turn, the output of Tr_1 drives the emitter-follower stage Tr_2. Again, Tr_{10} and Tr_{11} provide constant current. All this so far is in Class A.

For every five output fets, one emitter follower Tr_2 is needed to provide sufficient drive current to the gates of the fets in dynamic conditions. If this rule is not followed, frequency roll off becomes excessive.

Each output fet has a separate constant current source via a current limit resistor connected as a source follower. The simple current limit senses the voltage across the R_{10} resistors and shunts the drive to the fets Tr_2. This shuts down the output positive voltage swing, protecting the fets. To protect the speakers a series fuse is recommended.

Set all output current adjust potentiometers, R_{15}, so that the wiper voltage is the same as the emitter voltage on Tr_7, the Darlington constant current driver. Then adjust current limiting via each R_{15} according to the output device and power level required.

The dc offset can be fine-tuned to a few tens or less millivolts by adjusting R_{11}. Settings should be made after the amplifier has settled, and rechecked after about half an hour.

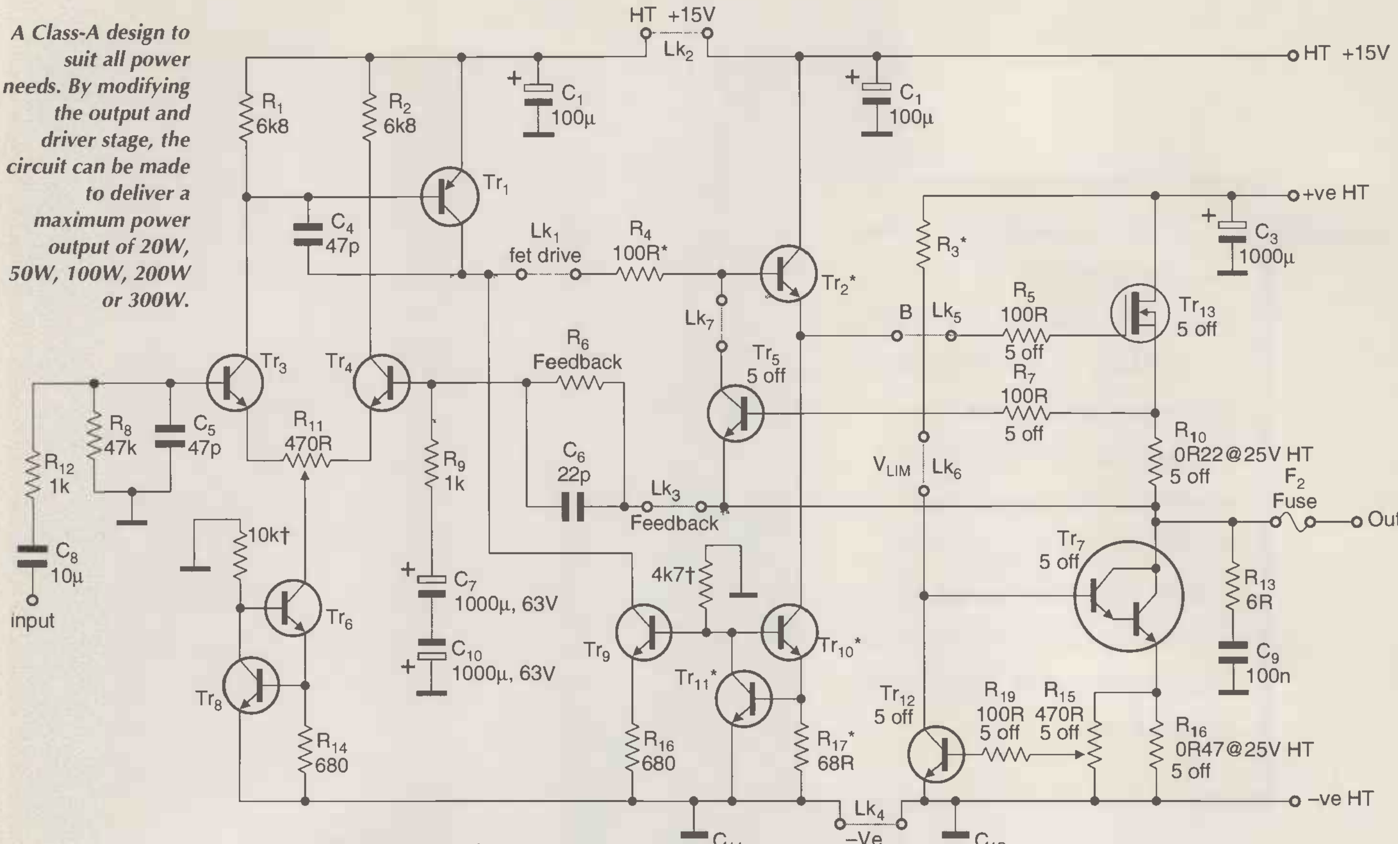
This circuit is designed for simplicity. It uses standard, readily available components or equivalents and is basically self-explanatory. I used natural

Features: all versions
Single-ended Class A throughout, short and open-circuit protection, 0.01% maximum distortion and 10Hz to 65kHz bandwidth.

Recommended components for the range of amplifiers.

	20W	50W	100W	200W	300W
Tr_1	BD140	BD140	BD956	2SA968	MJE350
Tr_9	BD139	BD139	BD955	2SC2238	MJE340
Tr_2	TIP29C	TIP29C	2SC2238C	2SC2238	TIP47
Tr_{10}	TIP29C	TIP29C	2SC2238C	2SC2238	TIP47
Tr_3	2SC2547	2SC2547	2SC3467D	2SC3467D	2SC3467D
Tr_4	2SC2547	2SC2547	2SC3467D	2SC3467D	2SC3467D
$Tr_{6,8,11}$	2SC2547	2SC2547	2SC3467D	2SC3467D	2SC3467D
$Tr_{12,5}$	ZTX450	ZTX450	ZTX450	ZTX450	ZTX450
R_6 feedback (Ω)	18k	28k	39k	47k	47k
Gain	18	28	39	47	47
R_{18} const I_{ref} (Ω)	0.42	0.83	0.94	1.02	1.24
R_{10} I_{limit} (Ω)	0.21	0.42	0.48	0.52	0.63
R_3 (Ω)	3k9	6k2	9kl	12k	15k
R_3 power (W)	0.103	0.145	0.223	0.300	0.375
Heat sink (°C/W)	0.248	0.109	0.062	0.040	0.033
Redpoint EF range	300*300*40	1300*700*40	300*1000*40	300*1500*40	300*1800*40

A Class-A design to suit all power needs. By modifying the output and driver stage, the circuit can be made to deliver a maximum power output of 20W, 50W, 100W, 200W or 300W.



* one for each five output devices
† values for 30V rails.

convection and very large heat sinks for cooling. Using a fan defeats the object of minimising amplifier noise contribution..

The power supply needs to be either regulated or have large reservoir capacitors, somewhere around 120000μF/5A for each main power rail. The +15V +HT supplies need about 10 000μF. This means about 250 000μF for the positive and negative HT rails of the 300W versions to achieve the best performance.

In summary

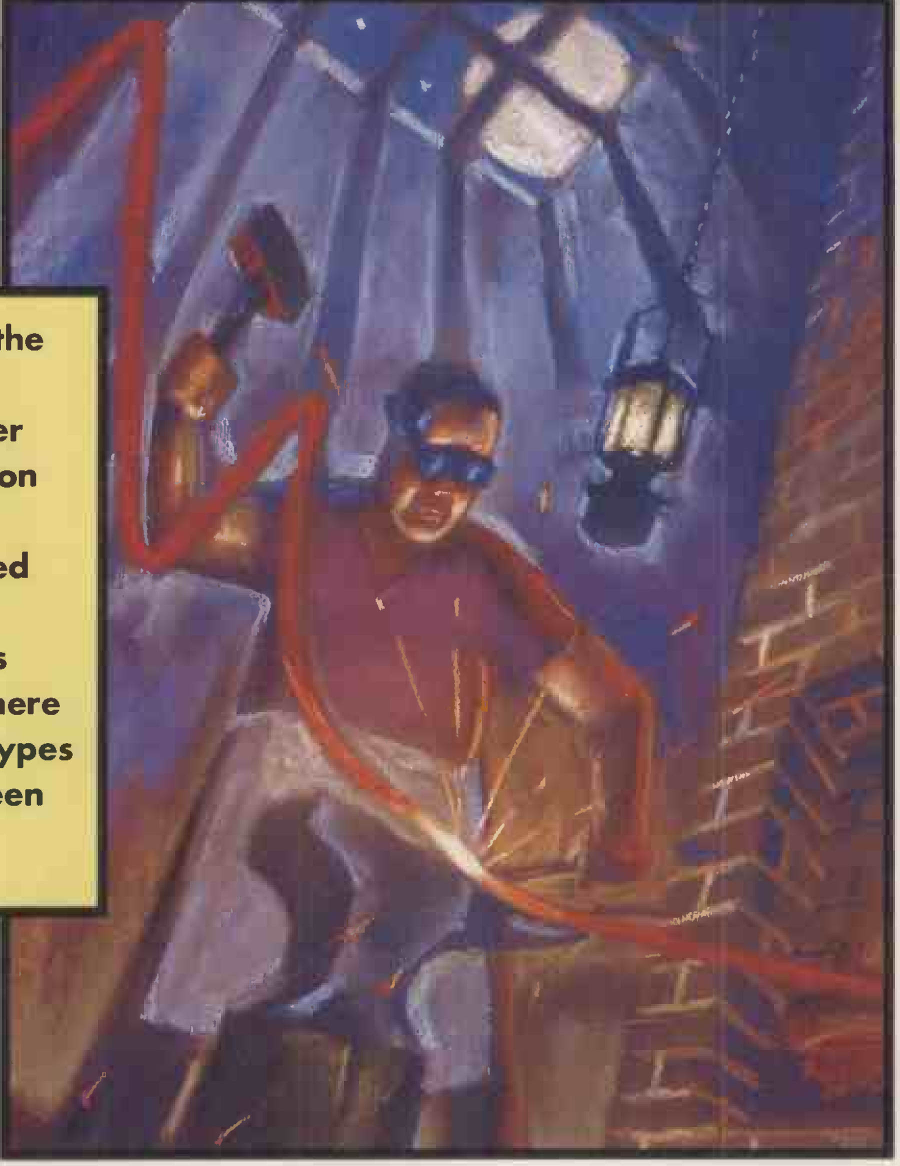
Be warned. These amplifiers get very hot, and can cost a fortune to repair if you are careless.

A drawback of this form of Class-A is poor ripple rejection, so you need a smoothed power supply and intolerance to non-standard loads. In addition, the lower power versions are not sufficiently powerful to drive speakers with a sensitivity of less than 88dB and the output is intolerant of non-standard loads.

But the sound reproduction quality is fantastic. ■

Requirements and components for the 20 to 300W range of Class-A amplifiers.

	20W/8Ω	20W/4Ω	50W/8Ω	50W/4Ω	100W/8Ω	100W/4Ω	200W/8Ω	200W/4Ω	300W/8Ω	300W/4Ω
Input power/channel	201.21		457.65		802.63		1237.01		1531.37	
RMS o/p (V)	12.60	8.90	20.00	14.10	28.30	20.00	40.00	28.30	48.98	34.64
RMS o/p (A)	1.58	2.23	2.50	3.53	3.53	5.00	5.00	7.07	6.12	8.66
Max o/p (W)	19.91	19.85	50.00	49.77	99.90	100.00	200.00	200.08	299.76	299.98
$I_{quiescent}$ (A)	5.00	5.00	7.60	7.60	8.89	8.89	10.28	10.28	10.18	10.18
P_w Darlingtons Tr_7 (W)	100.00	100.00	228.00	228.00	400.16	400.16	617.02	617.02	763.87	763.87
Darlingtons needed	5	5	15	15	20	20	25	25	30	30
Darlington P_{dis} each (W)	20.00	20.00	15.20	15.20	20.01	20.01	24.68	24.68	25.46	25.46
Recommended Tr_7	TIP141		TIP142		TIP142		TIP162		TIP162	
Tr_{13} power total (W)	100.00	100.00	228.00	228.00	400.16	400.16	617.02	617.02	763.87	763.87
Fets needed	5	5	15	15	20	20	25	25	30	30
Tr_{13} fet P_{dis} each	20.00	20.00	15.20	15.20	20.01	20.01	24.68	24.68	25.46	25.46
Recommended Tr_{13}	IRFP048		IRFP140		IRFP240		IRFP250		IRFP264	
+ve HT (V)	20	20	30	30	45	45	60	60	75	75
–ve HT (V)	20	20	30	30	45	45	60	60	75	75
HT +15V	35	35	45	45	60	60	75	75	90	90
$I_{quiescent}$ $Tr_{2,10}$ (mA)	10	10	10	10	10	10	10	10	10	10
P_w Tr_2 (W)	0.55	0.55	0.75	0.75	1.05	1.05	1.35	1.35	1.65	1.65
P_w Tr_{10} (W)	0.55	0.55	0.75	0.75	1.05	1.05	1.35	1.35	1.65	1.65
$I_{quiescent}$ $Tr_{1,9}$ (mA)	1	1	1	1	1	1	1	1	1	1
P_w Tr_1 (W)	0.055	0.055	0.075	0.075	0.105	0.105	0.135	0.135	0.165	0.165
P_W Tr_9 (W)	0.055	0.055	0.075	0.075	0.105	0.105	0.135	0.135	0.165	0.165
Optimum load (Ω)	2.52		3.40		4.5		5.5		6.8	
Optimum load power (W)	63.00		68.00		127.35		220.00		333.06	



Doug Self explores the inadequacies of the popular audio power amplifier classification system and puts forward an enhanced method to cover all existing designs. His work reveals that there are amplifier class types that have not yet been explored.

Class distinction

Power amplifiers are usually distinguished by their operating class – A, AB or B, and so on. Unfortunately this classification scheme only begins to address the problem, as amplifiers come in many more than three kinds. There is current-dumping, Class-G, error-correction, and so on. Amplifiers that work in quite different ways are all called 'B' or 'AB', and there is still confusion between B and AB in many quarters.

Traditionally, further letters such as G, H, and S have been used to describe more complex configurations. It occurred to me that rather than proliferating amplifier classes on through the alphabet, it might be better to classify amplifiers as combinations of the most basic classes of device operation.

It may be optimistic to think that this proposal will be adopted overnight, or indeed ever. Nevertheless, it should at least stimulate thought on the many different kinds of power amplifier and the relationships between them.

Class structure

At the most elementary level, there are five classes of device operation, as outlined in the panel. More sophisticated amplifier types such as Class-G, Class-S, etc., are combinations of these basic classes. Class-E remains an rf-only technology,[7] while Class-F does not apparently exist.

All the operating classes above work synchronously with the signal. The rare exceptions are amplifiers that have part of their operation driven by the signal envelope rather than the signal itself.

Krell[8] has produced Class-A amplifiers with a quiescent current that is rapidly increased by a sort of noise-gate side-chain, but slowly decays. An interesting study of a syllabic Class-G amplifier with envelope-controlled rail switching was presented in ref. 9.

Combinations of classes

The basic classes mentioned in the panel on the right have been combined in many ways to produce the amplifier innovations that have appeared since 1970. Since the standard output stage could hardly be simplified, all of these involve extra power devices that modify how the voltage or current is distributed.

Assuming the output stage is symmetrical about the central output rail, then above and below it there will be at least two output devices connected together, in either a series or parallel format. Since these two devices may operate in different classes, two letters are required for a description, with punctuation – a dot or plus sign – between them to indicate parallel or series connection.

Five basic classes

Class-A. The device conducts 100% of the cycle. This includes Class-A push-pull, where at full output, device current varies from twice the quiescent current to almost zero in a cycle, and Class-A constant-current mode, also known as single-ended Class-A. Any intermediate amount of current swing clearly also qualifies as Class-A, so unlike Class-B there exists an infinite range of variations on Class-A operation.

Class-AB. Conducts less than 100% but more than 50% of the cycle. This is essentially over-biased Class-B, giving Class-A operation up to a certain power level, but above that at least twice as much distortion as optimal Class-B. Once more there is a range of variations on Class-AB, depending on the amount of overbias chosen.

Class-B. The device conducts very nearly 50% of the cycle. The exactness of the 50% depends on the definition of 'conducts' because with Class-B optimally adjusted for minimum crossover distortion, there is always some conduction overlap at crossover, otherwise there would be no quiescent current. This will be 10mA or so for a complementary feedback pair stage, or about 100mA for an emitter follower version. With bipolar transistors, collector current tails off exponentially as V_{be} is reduced, and so the conduction period is rather arguable. So-called 'non-switching' Class-B amplifiers, which maintain a small current in the output devices when they would otherwise be off, such as the Blomley[1] and Tanaka approaches[2] are treated as essentially Class-B.

Class-C. The device conducts less than 50% of the cycle. It is frequently written – indeed I have written it myself – that Class-C is inapplicable to audio and never used therein. A little more thought showed me that this is untrue. The best-known example is Quad current-dumping, a scheme specifically intended to allow the high-power output stage – the 'current-dumpers' – to be run at zero quiescent.[3]

An emitter-follower output stage with no bias has a fixed dead-band of approximately ±1.2V, so clearly the exact conduction period varies with supply voltage; ±40V rails and a 1mA criterion for conduction give 48.5% of the cycle. This looks like a trivial deviation from 50%, but crossover distortion prevents direct audio use.

Class-D. The device conducts for any percentage of the cycle but is either fully on or off. Class-D usually refers to a pulse-width modulation scheme where the mark/space ratio of an ultrasonic squarewave is modulated by the audio signal.[4,5,6] However, in this case I am concerned only with the on-off nature of operation, which can be of use at audio frequencies, though not of course for directly driving the load. The conduction period during a cycle is not specified in this definition of Class-D.

Parallel or series connection

In parallel, i.e. shunt, connection, output currents are summed, the intention being either to increase power capability, which does not affect basic operation, or to improve linearity.

A subordinate aim is often the elimination of the Class-B bias adjustment. The basic idea is usually a small high-quality amplifier correcting the output of a larger and less linear amplifier. For a parallel connection the two class letters are separated by a dot, i.e. '•'.

In a series connection the voltage drop between supply rail and output is split up between two or more devices, or voltages are otherwise summed to produce the output signal. Since the collectors or drains of active devices are not very sensitive to voltage, such configurations are usually aimed at reducing overall power dissipation rather than enhancing linearity. Series connection is denoted by a plus sign between the two Class letters.

The order of the letters is significant. The first letter denotes the class of that section of the amplifier that actually controls the output

Table 1. Sub-class definitions.

Parallel		
A•B	Sandman Class-S scheme	Fig. 1
A•C	Quad current-dumping	
B•B	Self Load-Invariant amplifier	
B•C	Crown and Edwin types	Fig. 2
B•C	Class-G shunt. (Commutating) 2 rail voltages	Fig. 3
B•C•C	Class-G shunt. (Commutating) 3 rail voltages	Fig. 4
Series		
A+B	'Super Class-A'	Fig. 5
A+B	Stochino error correction	Fig. 6
A+D	A possible approach for cooler Class-A	
B+B	Totem-pole or cascade output. No extra rails	Fig. 7
B+C	Classical series Class-G, 2 rail voltages	Fig. 8
B+C+C	Classical series Class-G, 3 rail voltages	
B+D	Class-G with outer devices In D	Fig. 9
B+D	Class-H	Fig. 10

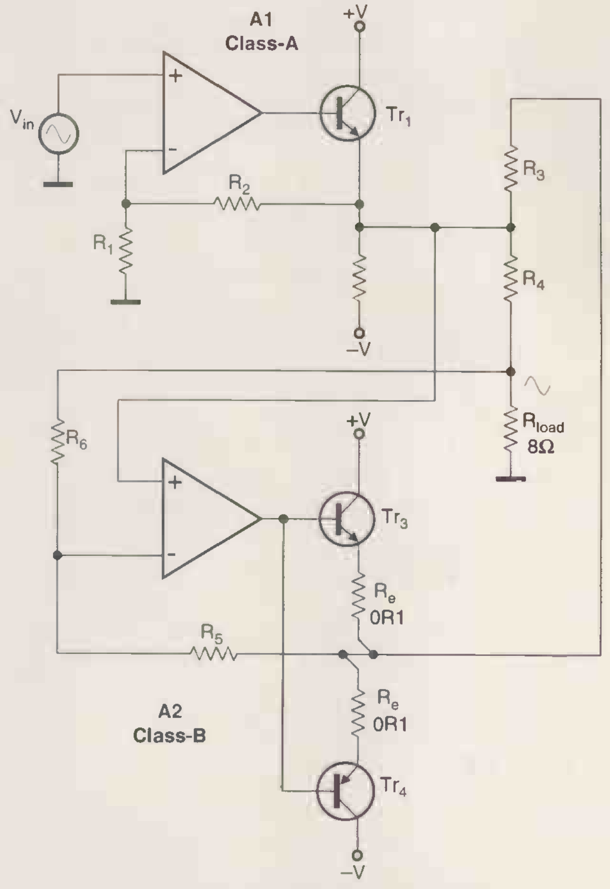


Fig. 1. Sandman 'Class-S' scheme. Resistors $R_{3,4,5,6}$ implement the feedback loop controlling amplifier A_2 so as to raise the load impedance seen by A_2.

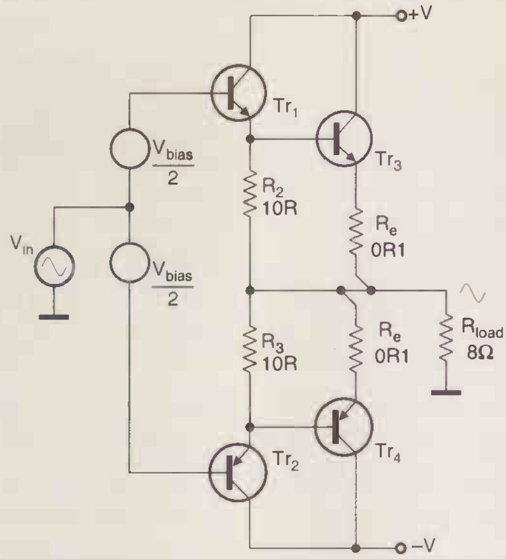


Fig. 2. Edwin type amplifier; standard Class-B except for the unusually low driver emitter resistors. Effectively B•C.

voltage. Such a section must exist – if only because the global negative feedback must be taken from one specific point – and the voltage at this point is the controlled quantity. The shunt configurations are dealt with first; see **Table 1**.

Class A•B. Class A•B describes an output stage in which the circuitry that actually controls the output is in Class-A, while a second Class-B stage is connected in parallel to provide the muscle.

The best-known example is probably the Sandman output configuration, in which the high-power amplifier A_2 is controlled by its own negative feedback loop so as to increase the effective load impedance until it is high enough for the Class-A stage to drive it with low distortion.[10]

In **Fig. 1**, A_1 is the Class-A controlling amplifier while A_2 is the Class-B heavyweight stage. As far as the load is concerned, these two stages are delivering current in parallel. The aim was improved linearity, with the elimination of the bias preset of the Class-B stage as a secondary goal.

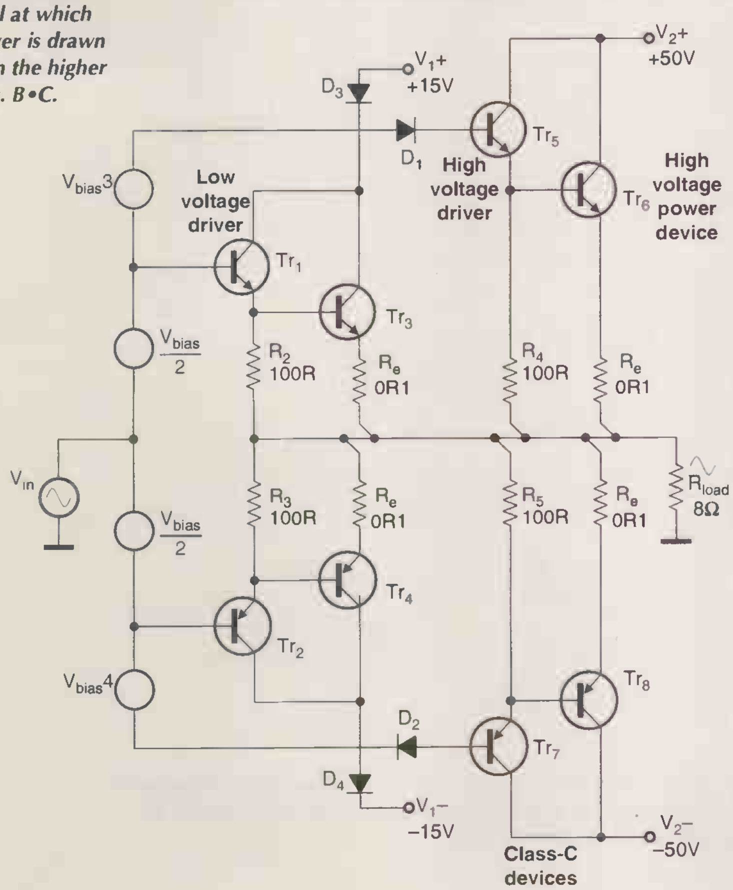


Fig. 3. A Class-G-shunt output stage, composed of two emitter-follower output stages with the usual drivers. Voltages $V_{bias3,4}$ set the output level at which power is drawn from the higher rails. B•C.

If A_2 is unbiased and therefore working in Class-C, A_1 has much greater errors to correct. This would put the amplifier into the next category, Class A•C.

Class A•C. The power stage A_2 is now working in Class-C, the usual motivation being the reduction of power dissipation because current is flowing for less of the cycle. The absence of any bias for a Class-B-type output stage puts it in into Class-C, as conduction is less than 50% – though probably not much less.

If the bias voltage is dispensed with then a number of problems with setting and maintaining accurate quiescent conditions are eliminated. A good example of such use of Class-C is the Quad current-dumping concept. Here, the use of feed-forward error-correction allows the substantial crossover distortion from a heavyweight Class-C – i.e. underbiased Class-B – stage to be effectively corrected by a much smaller Class-A amplifier.[3]

Class B•B. At first there seems little point in using one Class-B stage to help another, as they both have inherent crossover distortion. However, since reducing the current handled by an output stage reduces both crossover and large-signal distortion, the concept can be useful.

An example is my load-invariant amplifier, which can be considered as two Class-B output stages collapsed into one.[12]

Class B•C. Here, the controlling stage A_1 is Class-B, accepting that some crossover distortion in the output will be inevitable. This approach appears to have been introduced by Crown (Amcron) around 1970.[13]

Once more two stages are combined; the drivers – usually compound – are required to deliver significant power in Class-B, while the main power devices only turn on when the output is some way from the crossover point, and are in Class-C.

Similarly, the 'Edwin' type of amplifier, Fig. 2, was promoted by Elektor in 1975.[14] It was claimed to have the advantage of zero quiescent current in the main output devices-though why this might be an advantage was not stated; in simulation linearity appears worse than usual.

Another instance of B•C is Class-G-shunt.[11] **Figure 3** shows the principle; at low outputs only $Tr_{3,4}$ conduct, delivering power from the low-voltage rails. Above a threshold determined by V_{bias3} and V_{bias4}, D_1 or D_2 conducts and $Tr_{6,8}$ turn on, drawing from the high-voltage rails.

Diodes $D_{3,4}$ protect $Tr_{3,4}$ against reverse bias. The conduction periods of the Class-C devices are variable, but much less than 50%. Class-G-Shunt schemes usually have A1 running in Class-B to minimise dissipation, giving B•C; such arrangements are often called 'commutating amplifiers'.

Class B•C•C. Some of the more powerful Class-G-shunt public-address amplifiers have three sets of supply rails to further reduce the average voltage-drop between rail and output.

The extra complexity is significant, as there are now six supply rails and at least six power devices. It seems most unlikely that this further reduction in power consumption could ever be worthwhile for domestic hifi, but it is very useful in large PA amplifiers, such as those made by BSS. Three letters with intervening dots are required to denote this mode, **Fig. 4**.

Series connection category

In the second group of configurations, voltages are summed by series connection. The intention is usually the reduction of total power dissipation, rather than better linearity.

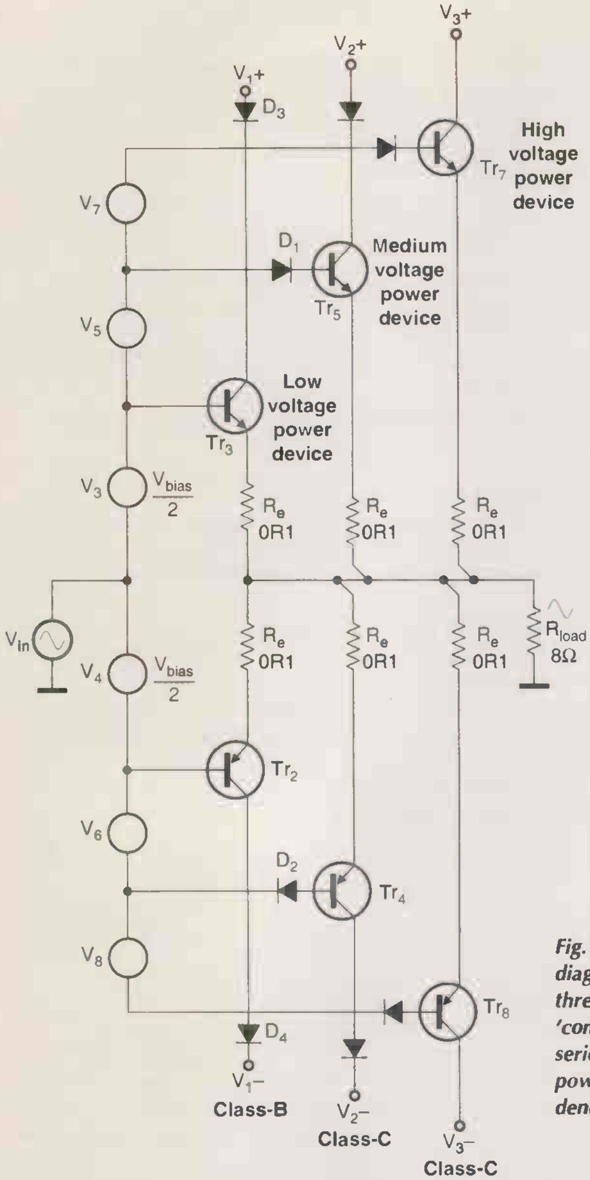


Fig. 4. Simplified diagram of a three-rail 'commutating' series-Class-G power amplifier, denoted as B•C•C.

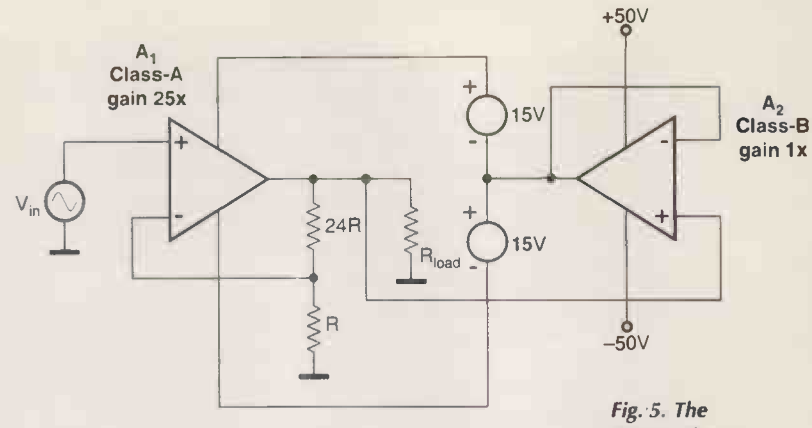


Fig. 5. The 'Super-Class-A' concept. Amplifier A_1 runs in Class-A, while high-power Class-B amp A_2 drives the two floating supplies up and down. Denoted as A+B.

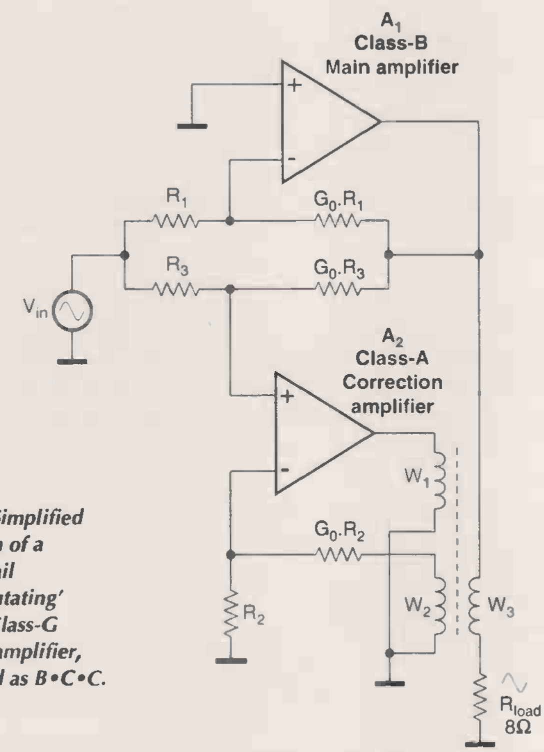


Fig. 6. The Stochino error-correcting system voltage-sums the outputs of the two amplifiers using transformer $W_{1,2,3}$. A+B.

Since the devices are not usually operating in the same class, two letters are again required for a description, and I have used a plus-sign between them to indicate the series connection.

Class A+B. **Figure 5** shows the so-called 'Super-Class-A' introduced by Technics in 1978.[15] The intention is to combine the linearity of Class-A with the efficiency of Class-B.

The Class-A controlling section A_1 is powered by two floating supplies of relatively low voltage, around ±15V, but handles the full load current. The floating supplies are driven up and down by a Class-B amplifier A_2. This amplifier must sustain much more dissipation as the same current is drawn from much higher rails, but it need not be very linear as in principle its distortion will have no effect on the output of A_1.

The circuit is complex and costs more than twice that of a conventional amplifier. In addition, the floating supplies are awkward. This seems to have limited its popularity.

Another A+B concept is the error-correction system of Stochino.[16] The voltage summation – the difficult bit – can be performed by a small transformer, as only the flux due to the correction signal exists in the core. This flux cancellation is enforced by the correcting amplifier feedback loop. Complexity and cost are at least twice that of a normal amplifier; **Fig. 6**.

Class A+D. The 'Super-Class-A' concept mentioned above can be extended to A+D by running the heavyweight amplifier in the usual high-frequency pwm Class-D configuration.[17] Alternatively, an A+D amplifier can be made by retaining the Class-A stage but powering it from rails that switch at audio frequency between two discrete voltages. Recall that this definition of Class-D does not mean high-frequency pwm.

Class B+B. Sometimes called a totem-pole stage to emphasise the vertical stacking of output devices, this arrangement shares the power dissipation between two devices. However, a parallel connection does the same thing more simply and with lower voltage losses.

Class B+B has been used to permit high power outputs from transistors with limited V_{ceo}, but this is rarely necessary with modern devices. The concept is usually regarded as obsolete, **Fig. 7**.

Class B+C. The basic series Class-G with two rail voltages – i.e. four supply rails, as both voltages are positive and negative – is shown in **Fig. 8**. This configuration was introduced by Hitachi in 1976 with the aim of reducing amplifier power dissipation.[18,19]

Musical signals spend most of their time at low levels, and have a high peak:mean ratio, so dissipation is greatly reduced by running from the lower $\pm V_1$ supply rails when possible.

When the instantaneous signal level exceeds $\pm V_1$, Tr_6 conducts and D_3 turns off, so the output current is now being drawn from the higher $\pm V_2$ rails, with the dissipation shared between Tr_3 and Tr_6. The inner stage $Tr_{3,4}$ normally operates in Class-B, though AB or A are equally possible if the output stage bias is increased.

In principle movements of the collector voltage on the inner device collectors should not affect the output voltage, but practical Class-G is often considered to have worse linearity than Class-B because of glitching due to diode commutation. However, glitches if present occur at moderate power, well away from the crossover region.

Class B+C+C An obvious extension of the Class-G principle is to increase the number of supply voltages, typically to three. Dissipation is reduced and efficiency increased, as the average voltage from which the output current is drawn is kept closer to the minimum.

The inner devices will operate in Class B/AB as before, the middle devices will be in Class-C, conducting for significantly less than 50% of the time. The outer devices are also in Class-C, conducting for even less of the time. Three letters with intervening plus signs are required to denote this.

To the best of my knowledge three-level Class-G amplifiers have only been made in shunt mode. This is probably because in series mode the cumulative voltage drops become too great. If it exists, such an amplifier would be described as operating in B+C+C.

Class B+D. Since the outer power devices in a Class-G-series amplifier are not directly connected to the load, they need not be driven with waveforms that mimic the output signal. In fact, they can be banged hard on and off so long as they are always on when the output voltage is about to hit the lower supply rail.

The outer devices may be simply driven by comparators, rather than via a nest of extra bias generators as in Fig. 8. Thus the inner devices are in B with the outer in D. Some of the more powerful amplifiers made by NAD – like the *Model 340* – use this approach, shown in **Fig. 9**.

The technique known as Class-H is similar but uses a charge-pump for short-term boosting of the supply voltage. In **Fig. 10**, at low outputs Tr_6 is on, keeping *C* charged from the rail via *D*.

During large output excursions, Tr_6 is off and Tr_5 turns on, boosting the supply to Tr_3. The only known implementation is by Philips[20,21] which is a single-rail car audio system that requires a bridged configuration and some clever floating-feedback to function.

Full circuitry has not been released, but it appears the charge-pump is an on/off subsystem, i.e. Class-D.

In summary

The test of any classification system is its gaps. When the periodic table of elements was evolved, the obvious gaps spurred the discovery of new elements; convincing proof the table was valid.

Table 1 is restricted to combinations that are, or were, in actual use, but a full matrix showing all the possibilities has several intriguing gaps; some, such as C•C and C+C are of no obvious use, but others like A+C are more promising – a form of Class-G with a push-pull Class-A inner stage. Glitches permitting, this might save a lot of heat.

The amplifier table really gets interesting when it becomes clear that there are gaps in the entries – things that could exist but are not currently known. ■

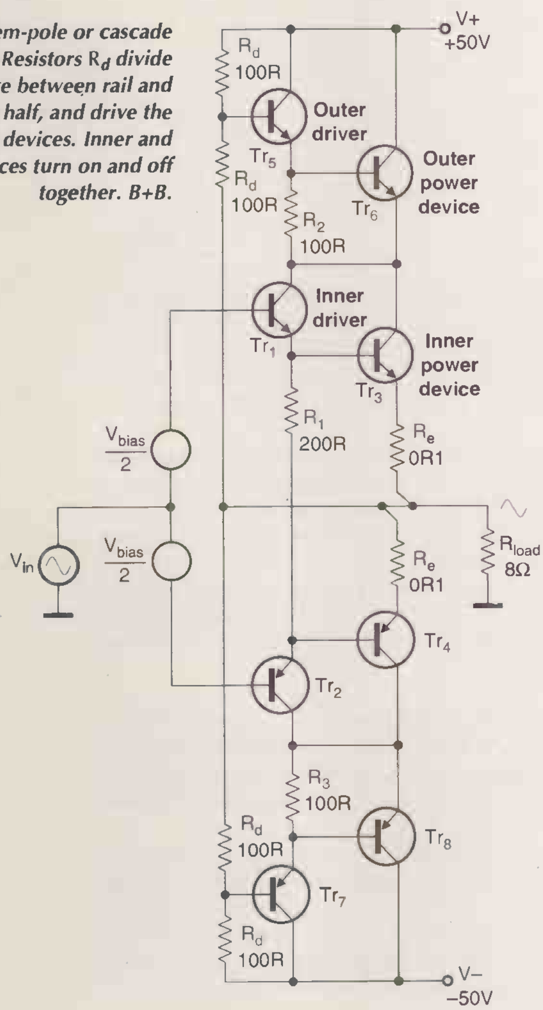


Fig. 7. A totem-pole or cascade series output. Resistors R_d divide the voltage between rail and output in half, and drive the outer power devices. Inner and outer devices turn on and off together. B+B.

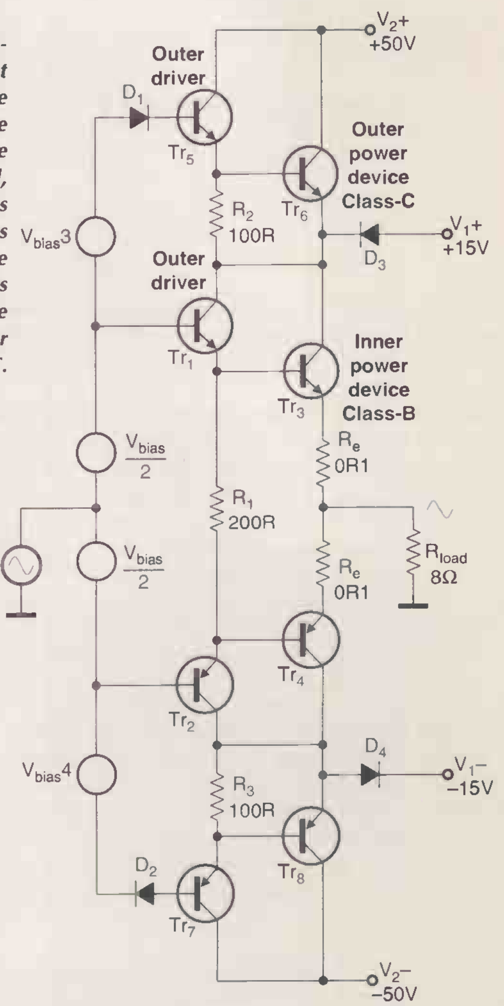


Fig. 8. Class-G-series output stage. When the output voltage exceeds the transition level, D_3 or D_4 turns off and power is drawn from the higher rails through the outer power devices. B+C.

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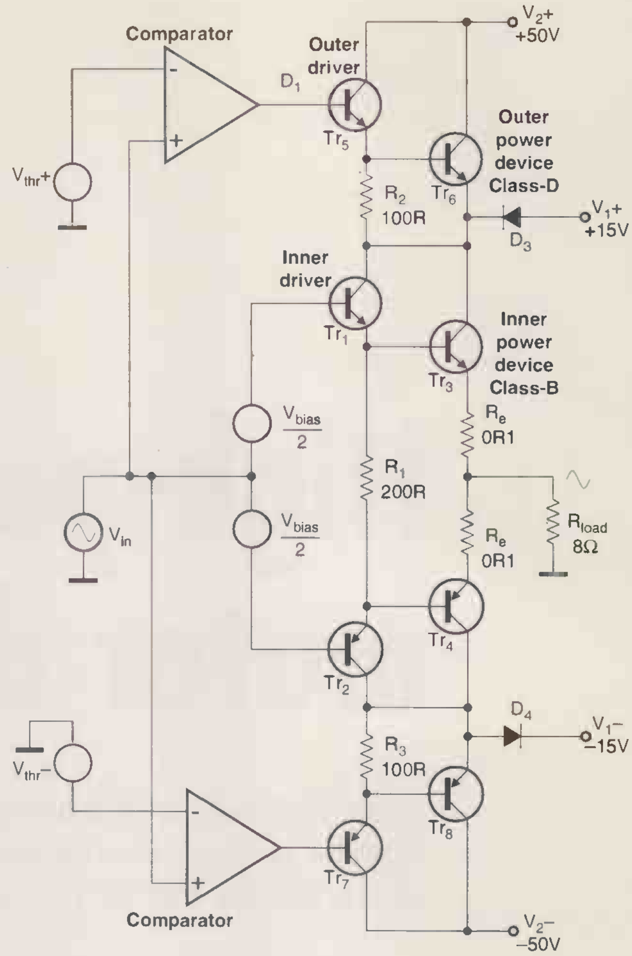


Fig. 9. Class-G output stage with outer devices in Class-D. Described as B+D.

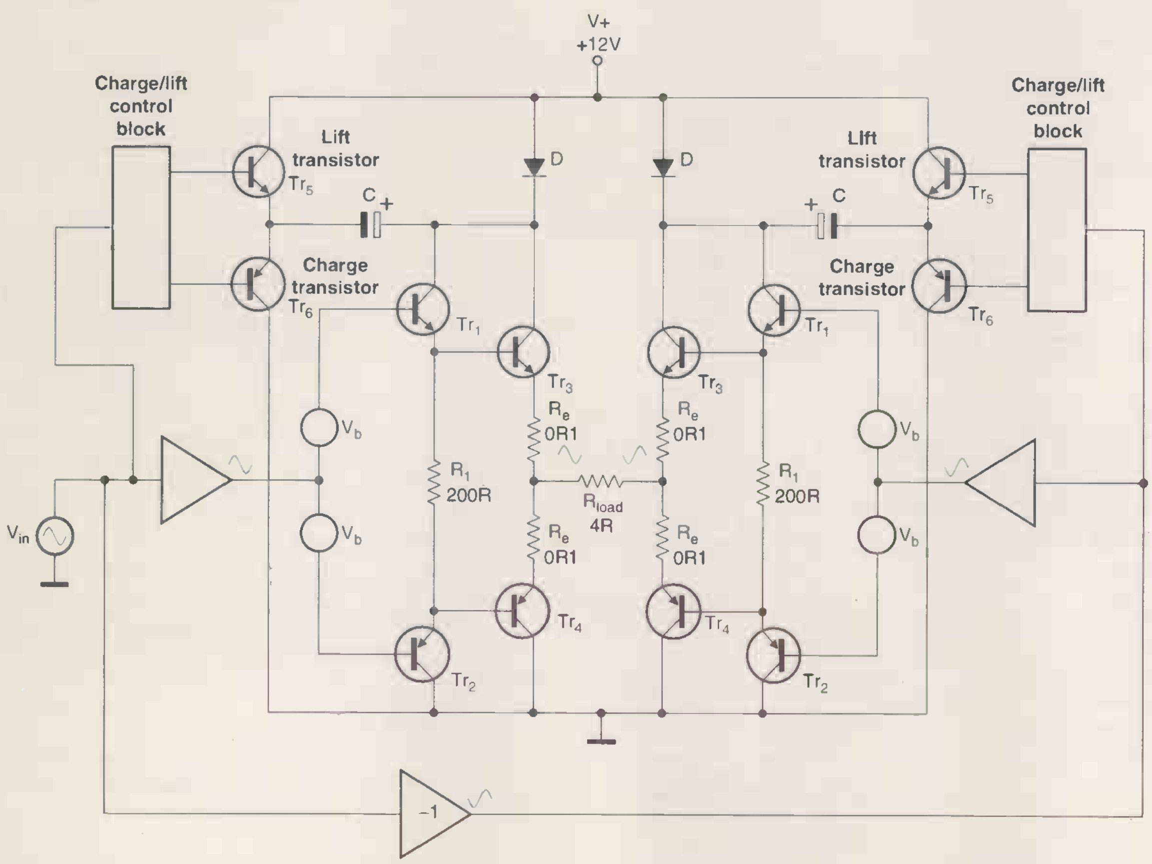


Fig. 10. The Class-H principle applied to a bridged output stage for automotive use. B+D.

High-performance motor drives

John Wettroth and Damian Anzaldo provide an overview of modern motion control technology and highlight two mixed-signal devices designed for use in the new generation of motor drives.

The authors are with Maxim Integrated Products in the US. John is a senior scientist and Damian is a field applications engineer.

Direct current drives are the oldest servo drive scheme and are still widely used. The DC drive shines in applications with large torque variations or in low power applications. It is also good for variable speed control because it can easily achieve good torque and speed response with high accuracy using simple control schemes.

Field orientation of the motor is achieved using a mechanical commutator with brushes. Simple commutation makes for a lower cost controller, but it also makes for an expensive and less reliable motor.

Control however, is very straightforward; varying current controls torque and speed is controlled by voltage, minus back emf. A typical block diagram of a simple DC drive for a portable medical device is shown in **Fig. 1**.

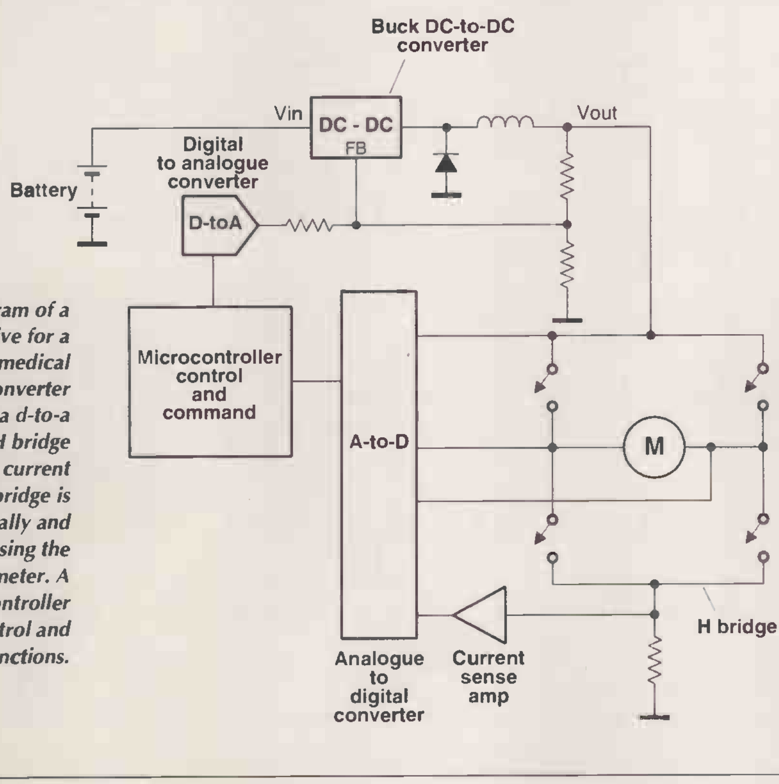


Fig. 1. Block diagram of a low power DC drive for a battery powered medical product. A buck converter controlled by a d-to-a converter drives an H bridge with low side current sensing. The H bridge is disabled periodically and back-EMF is sensed using the motor as a tachometer. A simple microcontroller provides the control and measurement functions.

The main drawback of this technique is the limited reliability of the brushed DC motor. As AC drive systems improve, they are eroding even the special areas where DC drives have prevailed.

Note that there is a class of motors called 'brushless DC motors' that can be confusing to sort out. These aren't actually DC motors, but an AC motor with an embedded electronic commutator making them look to the outside world like a DC motor.

Brushless DC motors are common in high run life, constant speed applications like small fans. They represent the simplest type of AC drive covered in the next section.

AC drives

The evolution of AC variable speed drives is mainly driven by the desire to emulate the performance of a DC drive

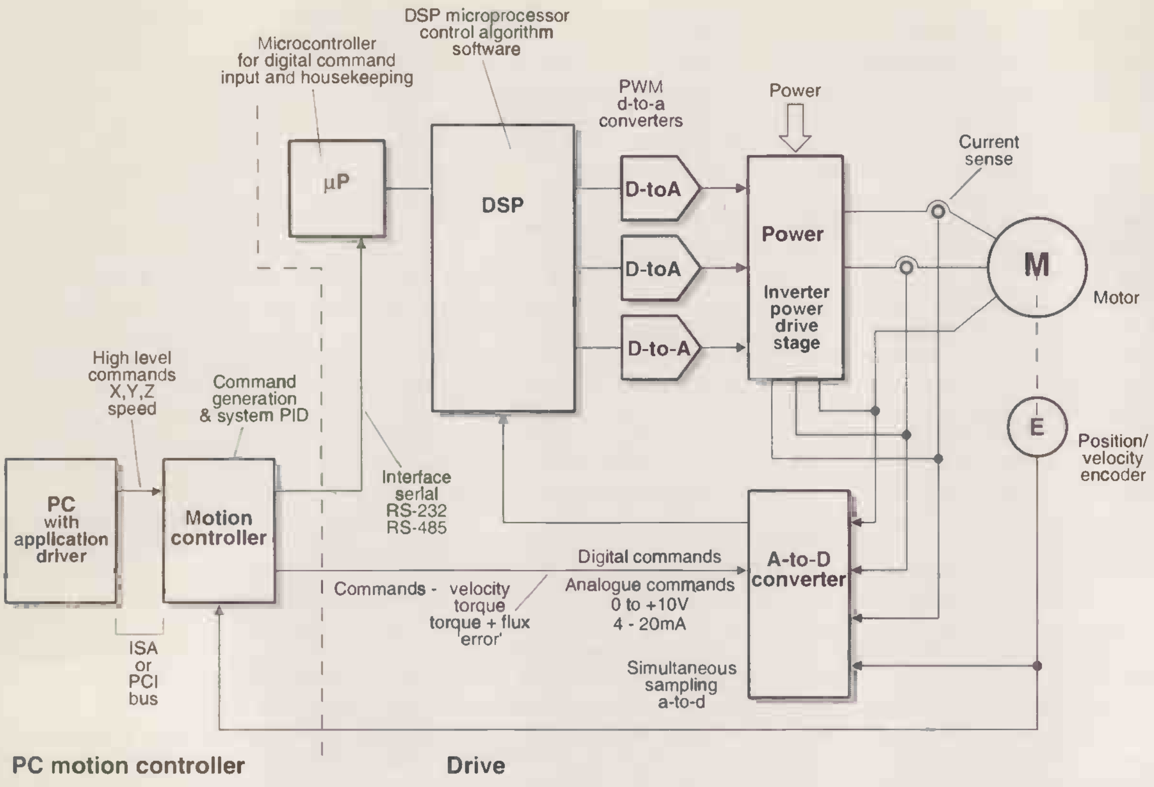


Fig. 2. Block diagram of the common elements of a complete AC drive motion control system. Details vary somewhat. Variable frequency inverters for example are typically operated open loop and don't include a dsp in the drive. Simple fixed speed drives will often include command generation with a front panel keypad/display. The command signals from the controller to the drive vary somewhat, too. The command may be velocity or torque and may be transmitted as an analogue voltage or using one of several common serial digital interfaces.

with its fast torque response and speed accuracy, while using low cost, reliable and most importantly brushless, AC motors. It is ironic that even today, the highest tech motors and controls still compare their performance to that of a DC drive.

Most motor control systems are physically built as two or more separate units. The first unit is called a motor or motion controller. This section generates the command signals and gets overall system feedback. It is usually implemented as a proportional-integral-derivative, or PID, controller that tracks position and velocity or velocity and acceleration.

The second unit is called the drive. This unit takes a velocity or torque command as input and operate the motor. The drive is often further divided into a control portion and a power portion with the power portion co-located with the motor.

What all the boxes do in a sophisticated motion control system can be confusing since both the motion controller and the drive contain a digital signal processor or some other form of processor. To make matters worse, there is also another computer that feeds commands to the motion controller.

To clarify the situation of what all these processors are doing; the digital signal processor in the drive is intimately involved with the details of commutating and controlling the current and voltage in the motor. The motion controller runs the real time servo-positioning portion of the customer's application code. It provides command signals to the drive usually in the form of analogue signals.

The motion controller is often located in a personal computer as an ISA or PCI plug-in card. The pc's processor runs the final customer application code and user interface. Its job might be for example to interpret G-codes for a computer numerical control program and feed X, Y and Z values to the motion control card over the bus. These values would ultimately control the axes of a CNC milling machine.

While the entire motor control market is buoyant, it is the drive portion where tremendous development is taking place in algorithms, semiconductors and signal processors. The drive is what really allows for the efficient variable speed or servo operation of a low-cost AC motor, **Fig.** 2.

AC inverter drive

Inverter drives are the simplest form of AC drives. All AC drives contain an inverter output stage as the final power output amplifier. The inverter operates by generating multi-phase AC signals for the motor under the control of a pulse-width modulator. The motor sees a low variable frequency drive that is generated by a high-frequency class-D style amplifier.

Typical pulse-width modulation, pwm, frequencies used are in the high audio range up to about 25kHz. These higher frequencies have advantages acoustically but cause problems with EMI and parasitic losses.

Supply for the DC inverter is rectified line power. The inverter switches this high voltage DC using high-voltage saturated switches such as insulated-gate bipolar transistors, i.e. IGBTs.

The speed of the motor is proportional to frequency. Voltage is also variable and a fixed voltage-to-frequency ratio is maintained as frequency is changed to maintain torque. Temperature corrections are also used to compensate for copper losses.

Inverter drives vary significantly in sophistication. When they are operated open loop, they are usually fine for simple industrial requirements but open-loop operation presents problems at low speeds and with loads of variable torque.

The trend is towards higher pwm frequencies and lower sine wave distortion to meet EMC standards such as IEEE 519 and European CE requirements. More advanced control techniques such as those that follow are more common today as the cost of these techniques fall and the shortcomings of a straight inverter drive are felt in other areas.

Flux-vector control

Simply adding a resolver and closing a velocity loop around an inverter drive will improve steady-state velocity accuracy but will do little to improve transient behaviour as load torque is varied.

Synchronously measuring stator currents, voltages and rotor position and then applying some significant calculations can independently control the torque and flux of an AC motor. This technique, called flux-vector control, is used to control the position and magnitude of the stator flux relative to the position and magnitude of the rotor flux.

Independent control of flux and torque is inherent in DC motors. Flux-vector control brings this independent control to AC motors. Low-cost real-time data acquisition required for this method is made possible by a new class of a-to-d converters like the *MAX125* described later.

The trigonometric transformations required are made possible by high-speed digital signal processors. A block diagram of a vector-controlled drive is shown in **Fig.** 3. A detailed description is beyond the scope of this article.

Flux-vector control offers very high levels of performance across a wide power range, comparable to that of DC drives. It has the disadvantage though of requiring a sensor for rotor position that is costly and can require additional maintenance.

A refinement to flux-vector control which maintains nearly all the benefits but eliminates the position feedback sensor is called 'sensorless flux-vector control.' This method measures stator currents and voltages and infers rotor position from a precise mathematical model of the motor.

Sensorless control involves still more precise data acquisition and dsp calculation. Several vendors claim further proprietary refinements of vector control scheme.

Mixed signal ICs for motor control

A block diagram of sensorless flux-vector control drive is shown in **Fig. 4**. This diagram highlights a simultaneous sampling a-to-d converter that is tailored to the motor control market.

The converter provides 14-bit conversion accuracy with fast aperture times that allow precise measurement of stator parameters in the latest motor controls.

Maxim's *MAX125* and *MAX126* are 14-bit, multi-channel data-acquisition systems designed for AC motor drive control, **Fig. 5**. These devices contain four simultaneous-sampling track/hold amplifiers. Having four such amplifiers allows four input channels to be sampled simultaneously, preserving relative phase information of the four input signals. This is not possible in a system using a single track/hold amplifier.

For applications demanding optimum motor speed control and good regulation at close to zero speed, additional velocity and position sensors can be digitised using spare channels. Being highly integrated, these devices improve system performance while lowering overall cost and reducing board space.

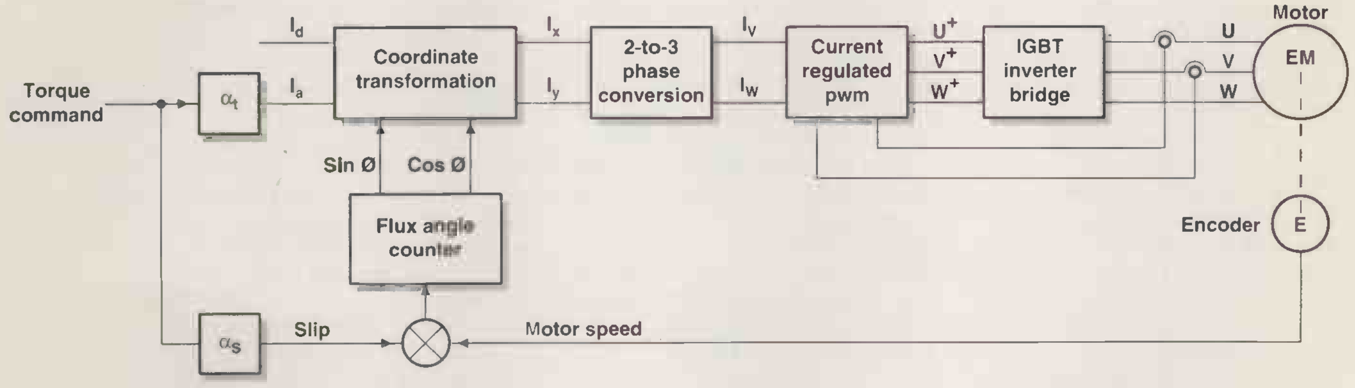
As motor control software becomes increasingly burdened with system tasks, improvements in a-to-d converter accuracy, sampling time and aperture delay can relieve the processor of software overhead. The *MAX125* and *MAX126* have DC accuracy specifications of 14-bit resolution combined with ±2 lsb inherent linearity error. Monotonicity is guaranteed.

This accuracy reduces processor maths in motor control applications involving precision vectors. Aperture delay of the devices is specified at 5ns with channel matching of 500ps, eliminating phase errors between sampled signals.

Conversion time for both ICs is 3µs with a track-and-hold amplifier acquisition time of 1µs, allowing fast throughput per channel at rates of 250ksample/s for one channel, 142ksample/s for two channels, 100ksample/s for three and 75ksample/s with four channels.

Combining high accuracy with improved track-and-hold amplifier performance, these controllers free the system designer from bandwidth limitations and computation errors that result from intensive software needed to support lower resolution a-to-d converters.

The input signal range of the *MAX125* is ±5V and the *MAX126* is ±2.5V. The inputs are fault protected to ±16.5V. Input fault protection



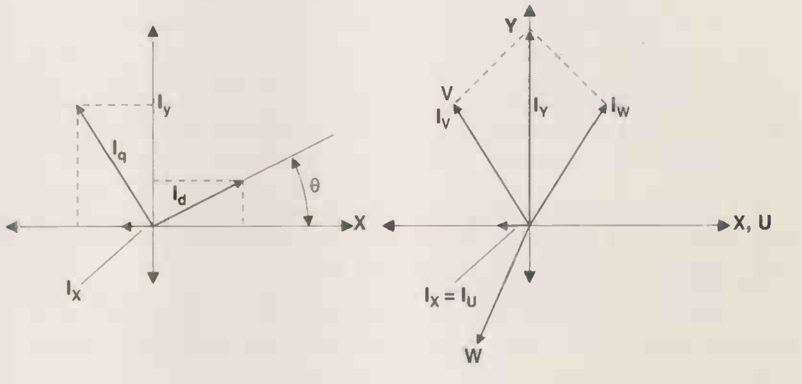


Fig. 3. Block diagram of the flux vector control drive. A dsp calculates coordinate transformations that change the d-q current and slip angle to x-y and u-v vectors. The pulse-width modulator provides the w vector and drives the inverter. A resolver provides feedback of the rotor position.

structures allow input voltages to ±16.5V without adversely affecting conversions on other channels.

Track and hold with 8MHz bandwidth

The track-and-hold input tracking circuitry has an 8MHz small-signal bandwidth. This makes it is possible, using undersampling techniques, to digitise high-speed transient events and measure periodic signals with bandwidths exceeding the a-to-d converter's sampling rate. For this application, anti-alias filtering is recommended to avoid high-frequency signals being aliased into the frequency band of interest.

The *ICs* have a buffered internal 2.5V reference with an initial accuracy of ±1% and temperature coefficient of 30ppm/°C. For applications requiring operation over a wider temperature range an external reference can be used.

The parallel digital interface of the devices has data-access and bus-release timing specifications that are compatible with most popular digital signal and 16/32-bit processors. As a result, direct digital interfacing is possible without resorting to wait states.

Both ICs have eight modes of operation plus power-down. These modes are programmed through the bi-directional parallel interface.

An internal microsequencer can be programmed to perform four simultaneous channel conversions of selected input banks per sample. Once programmed the converter continues operating in this mode until reprogrammed or power is removed. Digitised data are stored in memory to be read out via the parallel interface.

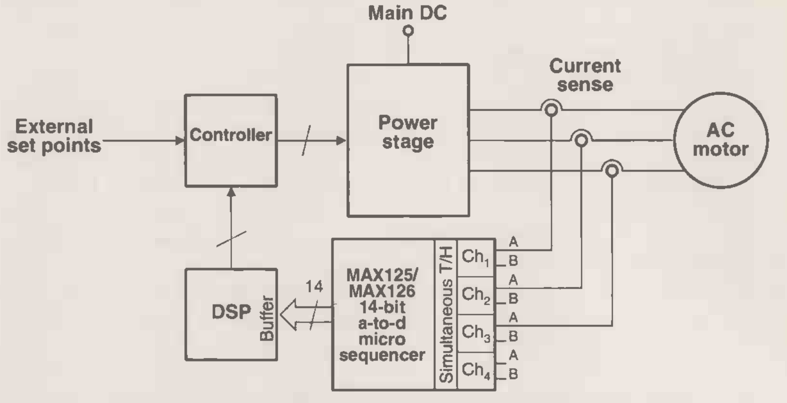


Fig. 4. Block diagram of the sensorless flux vector control drive highlighting a new 14-bit a-to-d converter from – the MAX125. It simultaneously samples four inputs to maintain phase information for motor control. It provides an additional bank of four inputs that make it ideal for other polyphase power applications such as synchronising two systems. It also off-loads the digital signal processing by including a microsequencer that automatically initiates and stores a-to-d converter readings internally.

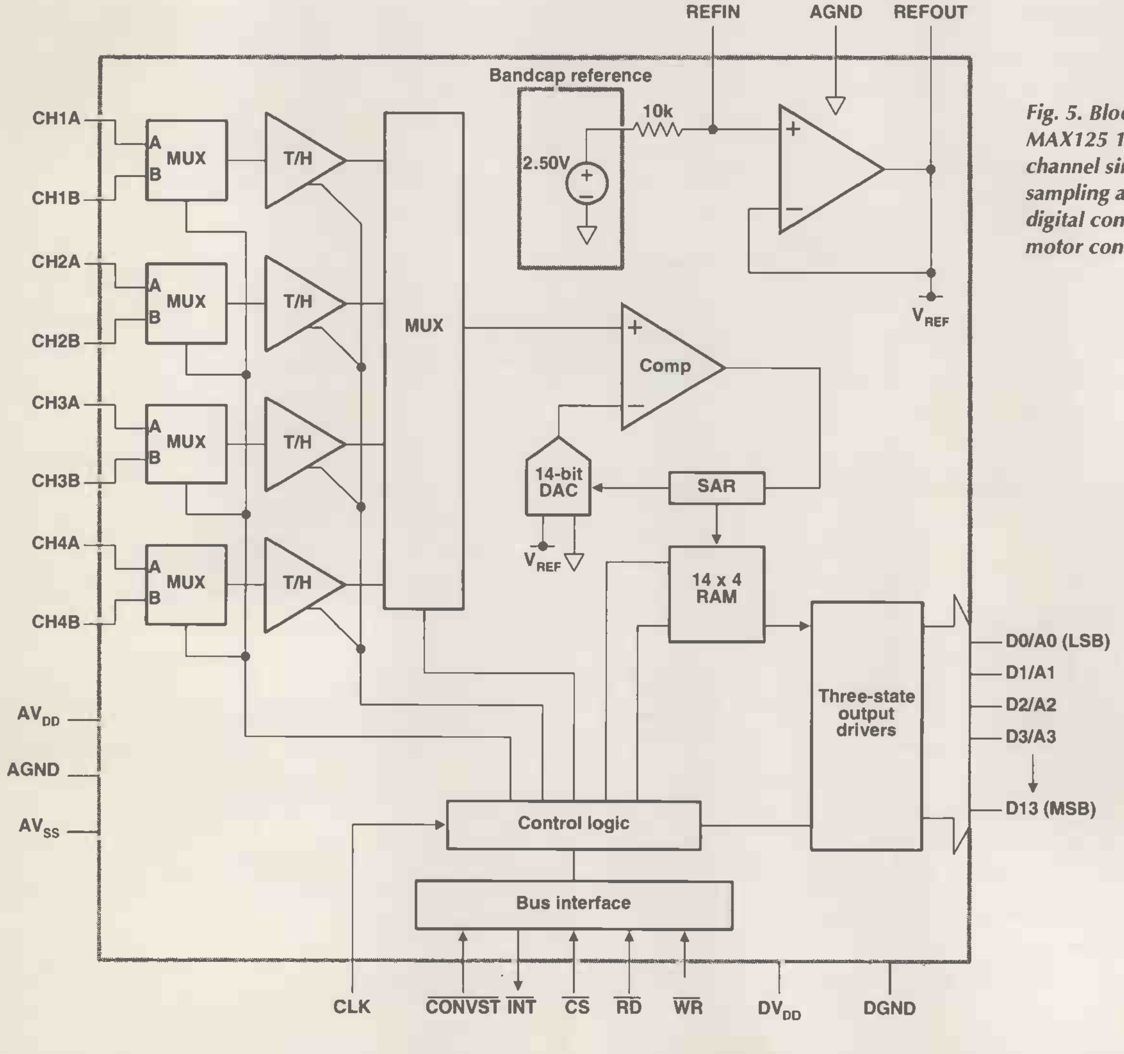


Fig. 5. Block of the MAX125 14-bit 2-by-4 channel simultaneous sampling analogue-to-digital converter for motor control.

Quad 12-bit d-to-a converter with serial i/o

The *MAX525* comprises four 12-bit, digital-to-analogue converts and four precision output amplifiers intended for motion control applications, **Fig. 6**.

This device has a double-buffered input organised as a 16-bit input register followed by a d-to-a converter register, allowing the input and d-to-a converter registers to be updated independently or simultaneously with a single software command. These features and a three-wire serial interface facilitate optically isolated industrial control designs.

Accuracy of the *MAX525* is 12-bit resolution with an inherent non-linearity error of ±1/2 lsb. Linearity matching is specified at ±1 lsb and gain-error matching at ±2 lsb, ensuring matched tracking amplitudes in three-phase sine wave generation applications.

Precision amplifiers internally buffer the *525*'s d-to-a converter outputs. The amplifiers slew at 0,6V/μs and settle to 1/2 least-significant bits in 12μs.

The output voltage swing extends from 0V to V_{DD} providing rail-to-rail outputs. Also, the inverting input of each output amplifier is accessible which provides greater flexibility in output gain setting and signal conditioning.

A typical application for this feature is a digitally programmable current source. Here, the amplifier output drives the base of an n-p-n transistor and the amplifier feedback pin monitors a sense resistor within the current loop. The output amplifier acts as an error amp comparing the d-to-a converter output to the current loop sense voltage.

The *525* has two reference inputs each input internally connected to a pair of d-to-a converters. The reference inputs accept DC and AC signals ranging from 0V to V_{DD}–1.4V.

Both reference inputs have a 10kΩ guaranteed impedance. When the two are driven from the same source the effective minimum impedance is 5kΩ. When driving the reference inputs simultaneously at 2.5V, a reference with load regulation of 6ppm/mA would typically deviate by 0.025 of a least-significant bit. A *MAX873* voltage reference could be used in this application.

The *525* has an internal power-on-reset which clears all registers and d-to-a converters to zero upon initial power up. In addition, hardware clear, designated CL, and power-down lock-out, PDL, functions are provided. The PDL function disables software shutdown and can also be used to asynchronously wake up the device.

The software shutdown feature reduces supply current to 10μA. In power-down mode, the device's serial interface remains active and data in the input registers is retained.

A unique feature of the *525* is its user-programmable output, designated UPO. This logic output can be used to control an external device via the *525*'s serial interface. A DC motor control application using UPO is a motor disable switch that operates a motor shutoff relay if the power mosfet fails. The shutoff relay disconnects power to the motor.

A high-side driver switch controlled via a microprocessor output port typically drives the relay. To free up processor port pins the high-side driver can be controlled by the UPO pin by way of a serial-interface program command.

The *525* operates from a single 5V supply with a current requirement of 0.98mA or less.

In summary

Motor control is a refined and rapidly growing field. Advanced control techniques demand high performance, specially tailored semiconductors. The *MAX125* and *MAX525* are examples of these advanced ICs, which will enable designers to develop the next generation of advanced motor controls. ■

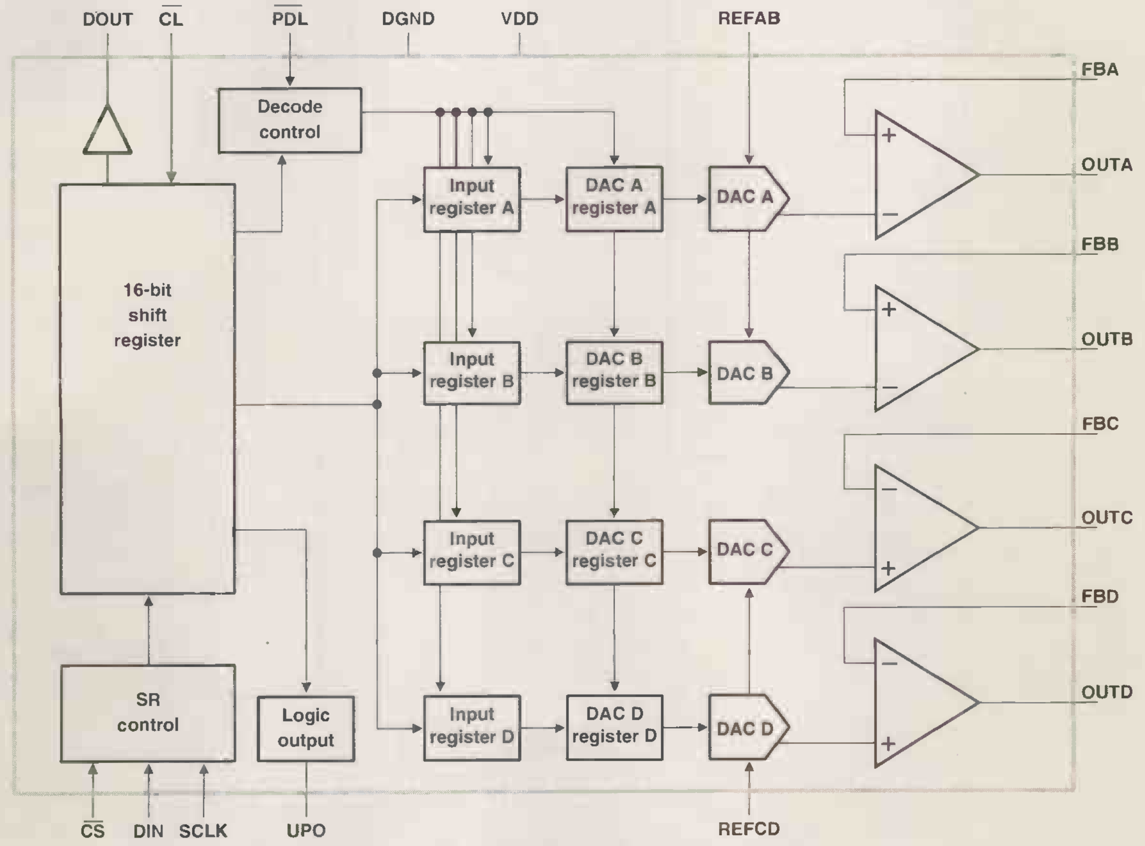
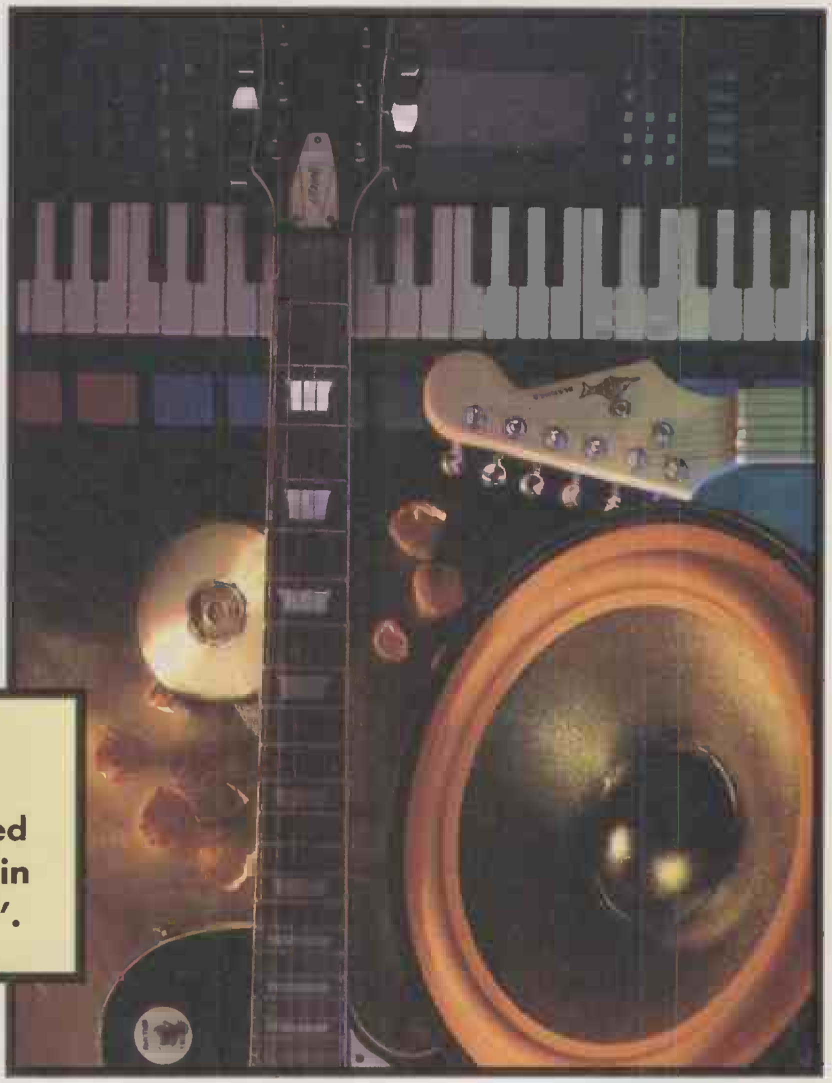


Fig. 6. Block of the MAX525 quad 12-bit, voltage-output d-to-a converter with serial interface.



Richard Brice looks at various ways in which intentional electronic signal distortion is used to enhance music – article three in the series 'Music and electronics'.

Electronic effects in music

The contribution of electronics to the recording and reproduction of music is not solely limited to its capacity to transmit the musical performance. Electronics engineers have contributed – and continue to contribute – the means by which modern music is created. This is an act which is a part of the common ongoing creative enterprise we call 'art'.

I don't think it's stretching the truth too much to say that a host of today's trade names will become the Stradivarius or Broadwood of tomorrow. Nowhere is this contribution clearer than in the design of electronic musical effects.

Echo and reverberation

A true echo is only heard when a reflected sound arrives a twentieth of a second or more after the direct sound first reaches our ears. Compare that with the sound that accompanies the voice of a priest or of a choir as their effusions stir the roar of reverberation in the atmosphere of a vast, medieval cathedral.

Reverberation is made up of echoes too, but by a mass of echoes following more swiftly than those of a discrete echo.

Clearly most recording studios are not large enough for an echo to be a natural consequence of their design. Neither are most cavernous enough to possess the acoustics of a cathedral. And a good thing too for it is far easier to add artificial reverberation and echo electronically than it is to eliminate the natural form.

Electronics thereby underpins the philosophy embraced by most modern recording studio designers – aim for a dry natural acoustic and augment this with artificial reverberation, as required.

Artificial echo was originally accomplished by means of a tape delay device as illustrated in **Fig. 1**, the signal being fed to the record head and the 'echo' signal picked off the replay head which was situated separately and 'downstream' of the record head. The distance between the two heads and the tape speed determined the delay.

On commercial units, the tape speed was usually made continuously variable so as to realise different delay times. This arrangement, obviously, only produced a single echo. In order to overcome this limitation, to this simple device a circuit was added which allowed a proportion of the output of the replay head to be fed back and re-recorded. By this means was an infinitely decaying echo effect performed.

By altering the degree of feedback – known in this context as re-circulation – differing reverberant 'trails' could be achieved. Just as the early microphones had, in their time, fathered the vocal style of crooning – because they per-

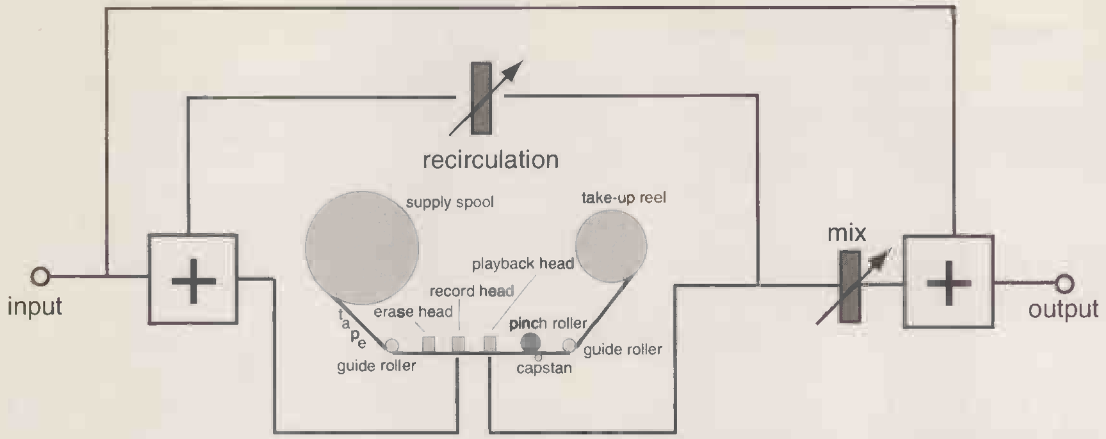


Fig. 1. Early machines produced an echo whose delay time was determined by tape speed and the gap between the record and replay heads. Next generation echo machines fed back some of the replay head output, allowing multiple echoes.

formed best when capturing slight sounds very close to the diaphragm – so the tape-based echo unit spawned an entire vocal technique too.

Modern digital delay devices have shunned tape techniques but accomplish the same effect by delaying suitable digitised audio signals written into, and read out of, a random-access memory store, **Fig. 2**. Alternatively hybrid digital/analogue techniques are utilised which exploit 'bucket-brigade' delay lines.

Both these techniques have all the obvious advantages of a purely electronic system over its electromechanical precursor. But there is one exception. Often, the rather poor quality of the tape transport system in the early devices introduced a degree of randomness – in the form of wow and flutter – into the replay system which help ameliorate a 'mechanical' quality which the resulting echo otherwise has.

Digital devices exhibit this quality quite distinctly – particularly at short delay times when the tail takes on a characteristic 'ring'. This unwanted outcome manifests itself more clearly still when the initial delay shortens. When a simple delay and re-circulation technique is employed to synthesise a reverberant acoustic, it can take on a very unnatural quality indeed.

Better results are obtained when a number of unequally spaced delay points, or taps, are used and these separate signals fed back in differing proportions, i.e. weightings, for recirculation.

Top quality delay and artificial reverberation units go so far as to introduce quasi random elements into the choice of delay taps and weightings so as to break up any patterns which may introduce an unnatural timbre to the artificial acoustic. Fortunately digital techniques have come so far that reasonable results are obtainable at very low cost. Artificial delay and reverberation are almost always incorporated in the audio system via the audio console effect send and return.[1]

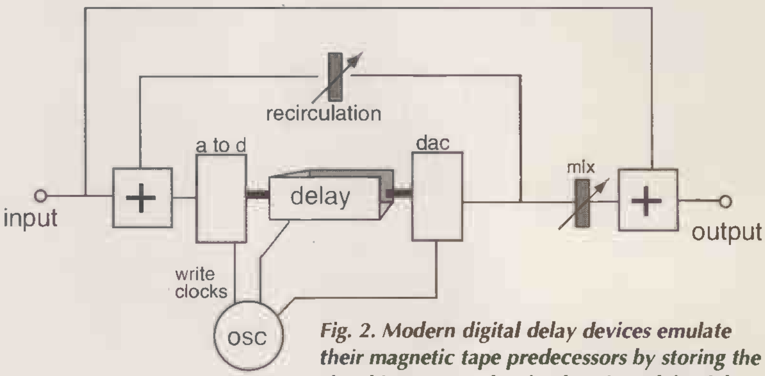


Fig. 2. Modern digital delay devices emulate their magnetic tape predecessors by storing the signal in memory for the duration of the delay time.

Table 1. Even harmonics tend to be musically related to the original input tone, whereas high-order, odd harmonics are musically unrelated to the original guitar signal.

Harmonic	Musical note	Comment
Fundamental	C	
2nd (1st overtone)	c	octave
3rd	g	twelfth (octave + fifth)
4th	c'	fifteenth (two octaves)
5th	e'	seventeenth (two octaves + major third)
6th	g'	nineteenth (two octaves + perfect fifth)
7th	b-flat' (nearest note)	dissonant; not in natural scale
8th	c"	three octaves
9th	d"	major 23rd (three octaves + second)
10th	e"	major 24th (three octaves + third)
11th	f" (nearest note)	dissonant; not in natural scale
12th	g"	major 26th (three octaves + fifth)
13th	a"	dissonant; not in natural scale
14th	b-flat"	dissonant; not in natural scale
15th	b"	major 28th
16th	c"'	four octaves
17th	C#"'	dissonant; not in natural scale
18th	d"'	major 30th
19th	d#"'	dissonant; not in natural scale
20th	e"'	major 31st

Guitar amplifiers – distortion and fuzz

Usually an effect to be guarded against in both design and operation of any audio circuit is the severe amplitude distortion known as clipping. But for guitarists, this effect is amongst their stock-in-trade. 'Grunge' has re-established this sound in recent years.

Known variously as fuzz, overdrive or plain distortion, the manner in which the circuit overloads becomes an integral part of the sound timbre. So much so, that for guitarists, a whole mythology surrounds this subject.

The first commercially available unit intended for the purpose of generating severe waveform distortion was the Gibson Maestro *Fuzztone* amplifier.† In developing the *Fuzztone*, Gibson crossed something of a Rubicon in audio electronics design. Before it, the role of the audio amplifier was not intended to be a feature of the sound; indeed many of the amplifiers were intended to be 'distortionless'. But guitarists pushed the equipment to its limits in search of expressive potential and thereby uncovered corners of the performance-envelope unforeseen by the equipment's designers.

Ironically, often it was precisely at these boundaries that the greatest potential for artistic utterance was found, thereby establishing the sonic signature of a particular perfor-

† It was this unit that was used on the Rolling Stones record *Satisfaction* in 1965.

mance limitation as a *de facto* standard for acolytes and imitators alike.

In turn, manufacturers have been forced to continue to build equipment which is deliberately designed to expose a design limitation or else find a way of simulating the effect with more modern equipment. Hence the inclusion of the apparently objective subject of amplifier design in this article on creative effects.

Relieved of a duty to be accurate, instrumental amplification is very difficult to analyse objectively. However a few observations may be made with some certainty: Firstly, most amplification is not usually designed with a deliberately modified frequency response. This is more usually a function of the designer's choice of loudspeaker and housing. Amplifiers – both low-level and power-level – are more usually engineered for their distortion characteristics.

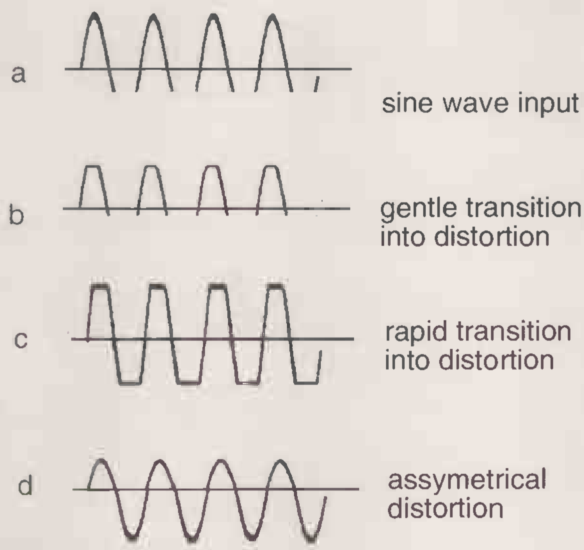


Fig. 3. From a) to d), original signal, sluggish transition into overload, fast transition into overload and finally, the result of an asymmetrically overloaded amp.

Difficult to see – easy to hear

Research has been done to connect various transfer curve characteristics with subjective perceptions. Once again the ear proves to be a remarkably discerning apparatus. So that, in spite of the fact that all distortion mechanisms perform roughly the same 'function', each commercially available amplifier has its own distinctive sound and loyal adherents – some units having acquired an almost cult status.

While many of these differences might be difficult, if not impossible, to analyse, a number of distinguishing characteristics are obvious enough. Firstly, the forward gain of the amplifier has an effect on the rate of discontinuity between the linear and non-linear portions of the transfer characteristic.

A unit with a low forward gain and a small degree – or no – negative feedback will show a sluggish transition into the overload region. Such a unit will produce a distortion on a sine wave input like that illustrated in **Fig. 3b**. On the other hand, unit with a high forward gain and a good deal of negative feedback, and thus a faster transition into the non-linear region, will produce an output waveform more like that shown in **Fig. 3c**.

Secondly, the character of the distorted sound depends to a large measure on the degree of asymmetry imparted to the output waveform by the overdriven amplifier stage. An asymmetrically distorted waveform – like the one in **Fig. 3d** – has a far higher proportion of even harmonics than the waveform shown in Fig.3c, which has a high proportion of odd harmonics.

Even harmonics tend to be musically related to the original input tone, whereas high-order, odd harmonics are musically unrelated to the original guitar signal, **Table 1**. This suggests that an amplifier producing a symmetrical overload characteristic will tend to sound 'harsher' than a unit yield-

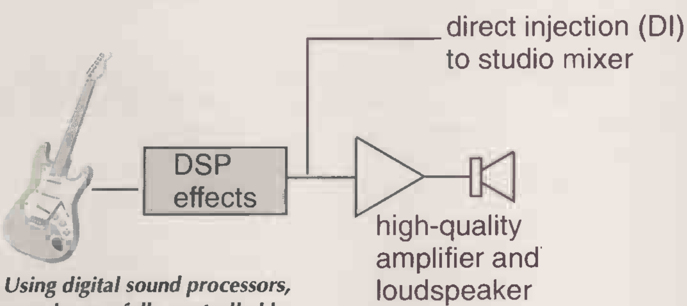


Fig. 4. Using digital sound processors, distortion can be carefully controlled by passing the linear pulse-code modulated signal through a look-up table stored in read-only memory with any desired transfer-function.

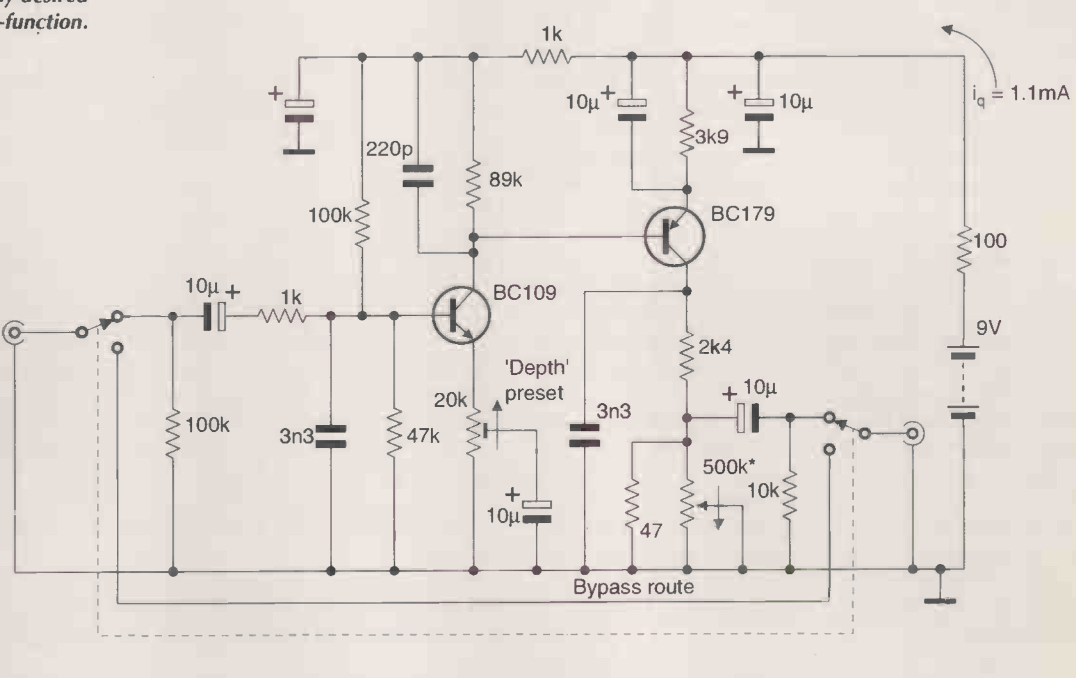


Fig. 5. There are complex digital circuits for producing distortion, but simple analogue alternatives like this one are often preferred.

ing asymmetrical distortion, and subjectively this is indeed the case.

Why valves?

Valve amplification is almost certainly preferred for its asymmetrical transfer characteristic and for its longer transition band from 'non-distorting' to 'distorting' regimes. This gives the instrumentalist a wider and more controllable tonal and expressive palette. This characteristic is enhanced by very limited amounts of negative feedback.

More elaborate semiconductor-amplifier counterparts, due to a high level of derived linearity and very high forward gain, tend to elicit a rasping, strident tone when in overload. Unfortunately, the designer has little or no option when faced with the design of a solid state amplifier.

Being of essentially Class-B design, these amplifiers cannot function without large amounts of negative-feedback therefore the designer of such an amplifier is forced to adopt up-stream electronics to try to emulate the gradual distortion characteristics of a valve amplifier.

With the advent of digital electronics, this philosophy has blossomed. Inside digital sound processors, distortion can be carefully controlled by passing the linear pulse-code modulated signal through a look-up table stored in read-only memory with any desired transfer-function – **Fig. 4**.

Nevertheless analogue alternatives are often preferred and may be extremely simple. A design which has been used for some years, and which has appeared on many professional recordings, is illustrated in **Fig. 5**. Effectively the transistor pair creates a high gain amplifier – enough to drive the output signal well beyond the supply rails.

The collector load on the second stage is split. This reduces the overall gain back to around unity and provides an adequately low output impedance. Control of the ac emitter load of the first transistor alters the gain of the amplifier and therefore the depth and character of the distorted output.

Wah-wah

Wah-wah is a dramatic effect derived from passing the signal from the electric guitar's pickup through a medium-Q band-pass filter, the frequency of which is adjustable usually by means of the position of a foot-pedal as illustrated in **Fig. 6**.

The player may the use a combination of standard guitar techniques together with associated pedal movements to produce a number of instrumental colours from an almost percussive strumming technique to a lead guitar style – usually in combination with fuzz effect – in which the guitar almost 'cries' in a human-like voice.

Pitch shifting

Pitch shifting is used for creating 'instant' harmony.

Simple pitch shifters create a constant musical interval above or below the input signal. You might think that such a limitation was pretty devastating. However, various automatic transpositions produce acceptable results. For instance, a harmony at a perfect fifth produces the scale in **Fig. 7**. This scale is usable except for the F-sharp.

Harmony at a perfect fourth is even better, **Fig. 8**. It has only one note that is not present in the key of C major, like the harmony at the perfect fifth. But the note is B flat which is a prominent 'blue' – i.e. blues scale – note in C major. For this reason, it is often acceptable in the context of rock music.

The instant transpositions of perfect fourth up – or its lower octave equivalent, perfect fifth down – are the most common transpositions employed in simple pitch shifters, with the exception of octave transpositions. Guitarists in particular most often employ a pitch shifter in one or other of these two roles.

Table 2. For pitch shifting, natural ratios of input versus output clock are preferred since they are related by simple numerical ratios.

Interval	Frequency ratio
Octave	2 : 1
Fifth	3 : 2
Fourth	4 : 3
Major third	5 : 4
Minor third	6 : 5
Major sixth	5 : 3
Minor sixth	8 : 5

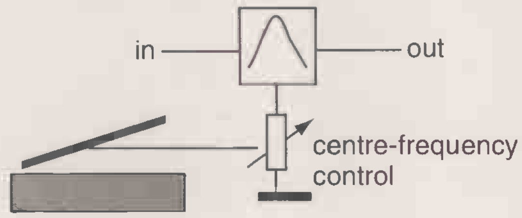


Fig. 6. Normally, a foot pedal is used to control the wah-wah effect's centre frequency.

Fig. 7. Scale representing harmony at a perfect fifth.

Fig. 8. Harmony at a perfect fourth is even better than that of the perfect fifth in Fig. 7.

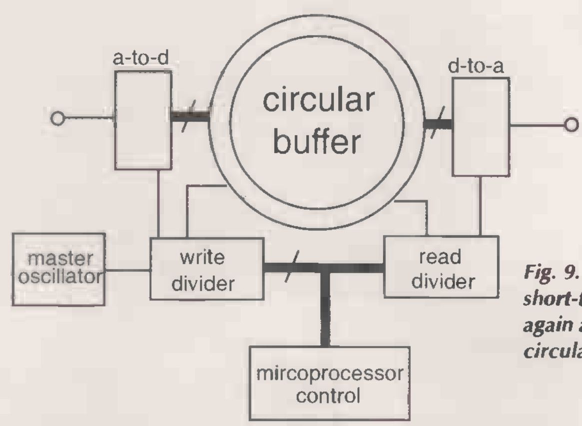


Fig. 9. In pitch shifting, the short-term store is re-used again and again, i.e. it is a circular buffer.

Intelligent pitch shifters can be programmed to produce a harmony related to a selectable musical key, so that a musical harmony can be created.

Technically, pitch shifting is achieved by converting the input signal to a pulse-code modulated digital signal, writing audio data into a short term store, and reading it back out at a different sample rate. Thereafter, the resulting pcm signal is converted back to an analogue signal. Because the short-term store is used over and over again it is referred to as a circular buffer, **Fig. 9**.

Pitch shifting by various musical intervals is achieved by adjusting the ratios of the input and output clocks.

Natural ratios are preferred for – as Pythagoras noticed two-and-a-half thousand years ago – these are related by

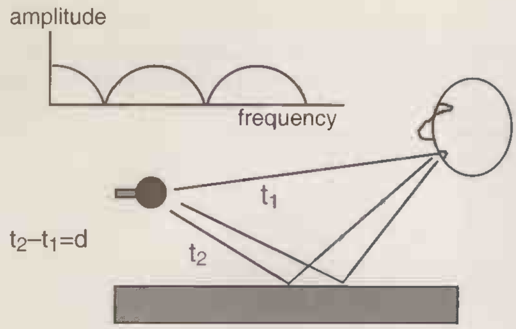


Fig. 10. A common problem encountered in microphone technique is the accidental establishment of multiple path lengths between sound-source and microphone element

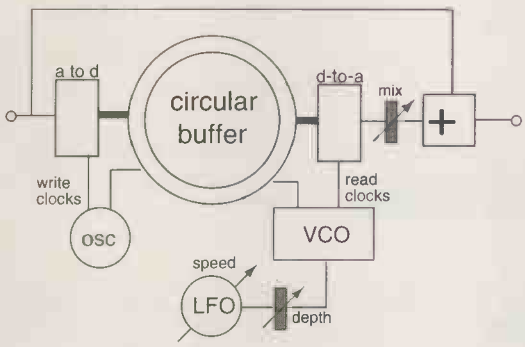


Fig. 11. Early flangers were based on magnetic tape, the flanging effect being produced by manually slowing one of two synchronous tape recorders. In this electronic version, a low-frequency oscillator simulates the hand.

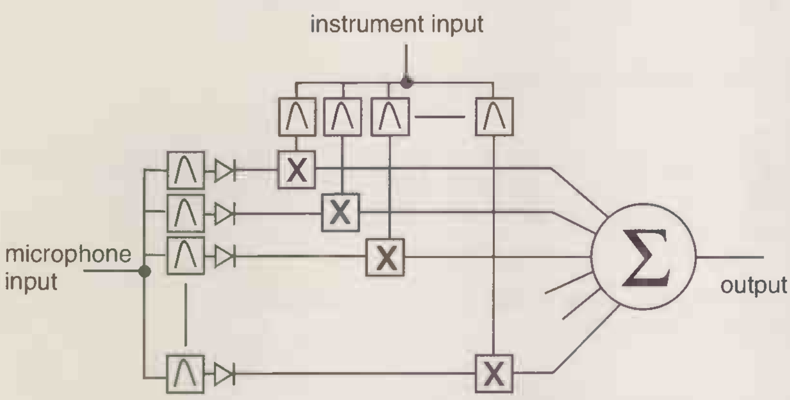


Fig. 12. The principal feature of the vocoder is its two inputs – one for an instrument and another for a microphone.

simple numerical ratios, **Table 2**. Note that most pitch shifters allow for a bypass route so that the original sound can be mixed with the harmony in a desired proportion before the signal leaves the unit.

Another application of the pitch shifting technique described in the last section is in creating audio effects which, to the uninitiated, sound nothing like pitch shifting as all. Instead effects such as chorus, flanging and so on, create a swirling, thickening texture to a sound.

Flanging, phasing and chorus

A common problem encountered in microphone technique is the accidental establishment of multiple path lengths between sound-source and microphone element, which creates a 'comb-filter' effect whereby successive bands of frequency are reinforced and cancelled, as illustrated in **Fig. 10**.

Although such an eventuality is extremely undesirable in the context of recording speech or sung sounds, the phenomenon produces an interesting acoustic effect – a kind of hollow ring.

Even more interesting is the effect as the microphone is moved in relation to sound source and reflecting body. This causes the frequency bands of reinforced and cancelled output to change. Imparting on the captured sound a strange, liquidity – a kind of 'swooshing, swirling' ring.

Of course, such an effect is not practically obtainable using moving microphones.* Instead it relies on utilising an electronic or electromechanical delay-medium to recreate an acoustic delay.

This effect has come to be known as flanging. It came about due to the slight lack of synchronisation between two 'locked' tape recorders; an effect which was exacerbated by rubbing a hand against the supply-reel flange of one of the tape recorders in order to slow it down in relation to the other.

A modern flanger dispenses with a tape mechanism to create the delay and, instead, a digital lag circuit is almost always employed. A low-frequency oscillator, or lfo, replaces the flange-rubbing hand.

The amplitude of the lfo signal controls the depth of the flange. This is equivalent to the amount of 'de-synchronisation', and it is controlled as shown in **Fig. 11**. The speed of the flange controls the frequency of the lfo and the degree of the effect is controlled in a mixing stage as shown.

Attempts at non tape-based analogue flange techniques involved the use of adjustable, cascaded all-pass filters providing the necessary delay elements. These circuits only produce a very small amount of delay per circuit. Even with a relatively large numbers of delays cascaded together, the delay was small in comparison to that required for a full flange effect. Because of this, these devices produced a particular, gentle effect, sonically apart and worthy of its own name – 'phasing'; a term based on the fact the circuits produce phase-shift, rather than full delay.

In a modern digital processor, the terms phasing and flanging really describe the same effect; the term phasing being used to describe very light degrees of flanging with delays up to about 1ms. Flanging uses delay variations in the region 1ms to 7ms.

Chorus is the next term in this continuum. In a chorus effect, the feedback fraction and the minimum delay-time are limited so as to ensure the depth of the comb-filter effect is much less pronounced than in the flanger or phaser. In a chorus effect the delay typically varies between 20 to 40ms.

Phasing and flanging and chorus find their metier in the hands of guitarists. Or should I say feet? Usually, this effect is incorporated in a pedal. This refinement facilitates switching the effect in and out without the guitarist having to take his or her hands off the instrument.

Vocoder

The vocoder is a device which allows the unique expression of the human voice to modulate an instrumental sound which may be monophonic or, more often, polyphonic. In order to understand the vocoder, it's worthwhile taking a few minutes to understand the production of vocal sounds.

The fundamental sound source involved in vocal production is a rather low frequency complex tone produced when air from the lung travels up the windpipe and excites the vocal folds in the larynx. The source of sound energy is known as the glottal source because the space between the vocal folds, and between which the air from the lungs is forced, is known as the glottis.

The vocal tract, comprising the pharynx (throat) the nose and nasal cavities and the mouth, subsequently modifies the spectrum of this glottal source. The vocal tract's shape can be varied extensively by moving the tongue, the lips and the jaw. In so doing, the spectrum of the glottal source is modified as it is filtered by the various resonances formed in the discrete parts of the vocal tract. Each of these resonances is known as a formant and each is numbered; the lowest frequency formant being termed the first formant, the next – the second and so on.

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* It is practical to generate such an effect by moving loudspeakers in relation to a fixed listening or microphone position. The *Leslie* loudspeaker works in just such a fashion.

The principal feature of the vocoder is its two inputs – one for an instrument and another for a microphone. The block diagram for a simple instrument is given in **Fig. 12**. Vocoder operation relies on the amplitude envelope of the vocal formants modulating the instrumental inputs via audio signal multipliers: these are voltage-controlled amplifiers in an analogue vocoder.

In circuitry terms this involves splitting the vocal signal and the instrumental signal into a number of frequency bands by means of band-pass filters. The greater the number of bands, the better the performance of the vocoder function. In a digital vocoder, the frequency spectrum can be split into a great many bands by means of a wave filter.

Following the band-dividing filters, the vocal signal path passes to a number of amplitude envelope-detector circuits, i.e. peak rectifiers in an analogue circuit). These envelope signals are then used as the variables applied to each of the multipliers following every band-dividing filter in the instrumental signal path. In this way, the frequency spectrum of the speech is 'imprinted' on the instrumental sound.

A physiological analogy

You can draw a physiological parallel by saying it is as if the lungs and vocal folds were replaced with the instrumental sound while the function of larynx, mouth and nasal cavities remain the same.

Not only is the Vocoder capable of some exotic 'colouristic' effects. An example of this is found in Laurie Anderson's *O Superman*. But the physiological analogy may also have suggested to you an application whereby the instrumental input can be a synthesised tone similar to that produced by the lungs and vocal folds.

If that synthesised tone – or tones – is under MIDI control, the vocoder can be used as an artificially enhanced voice - always in tune and able to sing in perfect harmony with itself. In this variation, the vocoder is worthy of the separate name – 'harmoniser'.

Note that the harmoniser is not a pitch shifter. If harmonisation was achieved as described above – and it can be for certain effects – the vocal formants would be transposed along with the pitch; producing an effect termed 'munchkinisation'.

Talk-box guitar effect

Lying somewhere between the wah-wah pedal and the vocoder is the talk-box guitar effect.

The talk box exploits the unique and expressive acoustic filter formed by the various resonances of the vocal tract and mouth to modify the sound of an electric guitar. This is done by driving a small loudspeaker with the amplified guitar signal, feeding it through a horn and into a plastic tube. The tube is then clipped or gaffer-taped up the microphone-stand into a position so that it can be fed into the mouth of the guitar player.

The resulting sound is recorded via the microphone feed. Talk boxes feature in the recordings of Aerosmith, Frampton and Joe Walsh among others. ■

Reference

1. Brice, R. (1988), Music Engineering, Newnes.

Mobile phones are marvellous – within their own mobile world. New developments will integrate them seamlessly into the mainstream network and add full multimedia capabilities. Andrew Emmerson reports.

Upwardly mobile

In Britain and many other countries, the modern mobile phone has reached a high standard. Prices are affordable, performance is generally excellent and radio coverage is remarkably good in most locations.

The sole aggravation is that mobile phones are poorly integrated into the main public telephone system; they have separate numbers, they behave differently and hinder 'reachability'.

It's precisely this shortcoming that the next generation of mobile communication systems addresses – with the added bonus that existing GSM hand portables will not be rendered obsolete overnight. The whole point of these so-called third-generation technologies is that they will enhance, not replace, existing systems.

The name given to this third generation mobile system is UMTS – the Universal Mobile Telecommunications System. It will build on the success of the capabilities of today's digital GSM, or Global System for Mobile Communication, networks to create a new, much broader and more feature-rich mobile radio system.

There's one key feature which underpins the whole concept of UMTS that's radically different from existing systems, as Nigel Lobley, team leader in the mobility engineering unit at BT's Martlesham Heath laboratories site near Ipswich, explains.

"Up to now mobile communication networks have always been conceptually separate from the existing wire-line telephone system. Your mobile phone has a different number from your fixed phones and people can easily have three different numeric identities depending on whether they happen

What UMTS is not

UMTS is not just another radio access system; it embraces fixed telecommunications as well and creates an opportunity for complete fixed-mobile convergence.

Nor should UMTS be seen as merely 'GSM-plus'; it is much more than a mere enhancement for GSM and offers major new functionality above and beyond second generation digital radio.

UMTS is not a replacement for GSM either; the two networks will co-exist, leaving GSM to remain in place for customers who are satisfied with its simpler capabilities.

to be at home, at work or on the move. UMTS is different; not only does it embrace speech, data and multimedia, it also actually integrates fixed and mobile communication in a seamless way to achieve something that is far more valuable to users," says Nigel.

This integration of connectivity is what differentiates UMTS. The system will also support interconnection with wireless LANs and other kinds of radio network.

The driver for UMTS is the growing market for mobile 'reachability' and the increasing requirement for multimedia-type data communication. UMTS will support user applications in both real-time and non real-time modes, using a single method of connection and integrated networks that support both wireless and wired access.

As Nigel elaborates, "UMTS takes the fixed phone into the mobile environment. You'll be able to personalise your service package to work in a uniform, seamless manner across networks and operators independently of the different radio access mechanisms actually used. We call this concept the 'virtual home environment'; it means you can use your phone, radio-enabled palmtop computer or whatever the same way wherever you happen to be.

"You won't worry about dialling codes that vary between networks and locations – such as for accessing your voice mailbox or for call return. All this will be handled for you by intelligence in the network and terminal. The fact that full rollout of UMTS won't happen overnight will not concern you either; UMTS phones will be dual-band and will revert to GSM networks where UMTS service is unavailable."

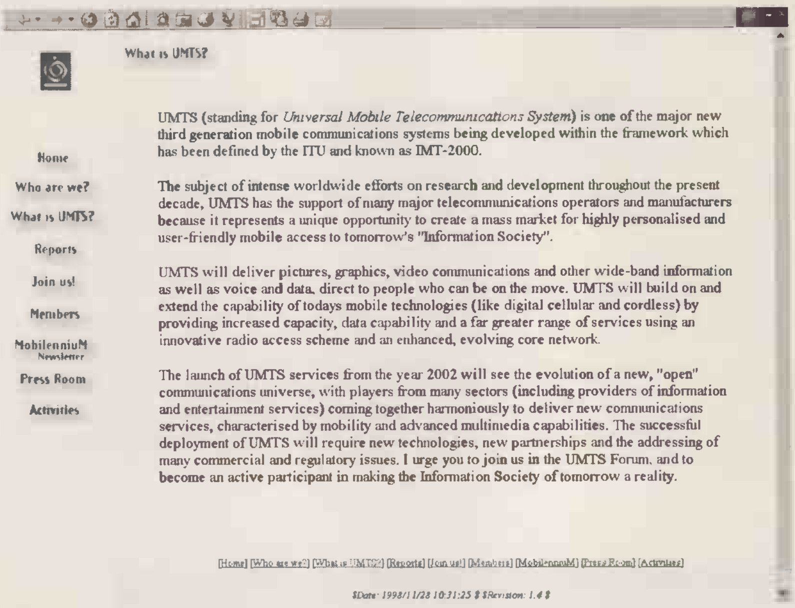
Countdown to airtime

Commercial availability of UMTS is not far off. Japan is committed to launching its third generation networks in just two years time, while most European countries – Britain included – are targeting the year 2002. By this time service providers will need to have planned and tackled all the requirements of switching and routeing, i.e. Internet Protocol and ATM. They will also need to have sorted out all aspects affecting network intelligence, processing, management and the operational support systems.

To describe this as a major challenge would be understatement. While a common vision of third generation mobile networks is shared by all operators and equipment manufacturers, there is less agreement on the precise wireless access technologies that will enable users to make their calls.

Squabbles over intellectual property rights make it look unlikely that a single unified air interface will be agreed, although total agreement looks probable over the network interface. The end result for users is that mobile telephones should work globally but some enhanced features will not work in all territories.

Finding radio frequencies for the new service is no trivial matter either. The WARC 92 allocated three frequency bands in the region 1.9-2.2GHz to accommodate future terrestrial and satellite mobile services. Of this allocation, the ITU has designated 155MHz for third generation mobile services, under its IMT-2000 initiative. This has already been declared woefully inadequate for supporting a technically adequate and commercially viable service in mature or mass-market conditions. It remains to be seen how this aspect is managed.



What is UMTS?

Home
Who are we?
What is UMTS?
Reports
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MobilenniuM Newsletter
Press Room
Activities

UMTS (standing for *Universal Mobile Telecommunications System*) is one of the major new third generation mobile communications systems being developed within the framework which has been defined by the ITU and known as IMT-2000.

The subject of intense worldwide efforts on research and development throughout the present decade, UMTS has the support of many major telecommunications operators and manufacturers because it represents a unique opportunity to create a mass market for highly personalised and user-friendly mobile access to tomorrow's "Information Society".

UMTS will deliver pictures, graphics, video communications and other wide-band information as well as voice and data, direct to people who can be on the move. UMTS will build on and extend the capability of todays mobile technologies (like digital cellular and cordless) by providing increased capacity, data capability and a far greater range of services using an innovative radio access scheme and an enhanced, evolving core network.

The launch of UMTS services from the year 2002 will see the evolution of a new, "open" communications universe, with players from many sectors (including providers of information and entertainment services) coming together harmoniously to deliver new communications services, characterised by mobility and advanced multimedia capabilities. The successful deployment of UMTS will require new technologies, new partnerships and the addressing of many commercial and regulatory issues. I urge you to join us in the UMTS Forum, and to become an active participant in making the Information Society of tomorrow a reality.

[Home] [Who are we?] [What is UMTS?] [Reports] [Join us!] [Members] [MobilenniuM] [Press Room] [Activities]

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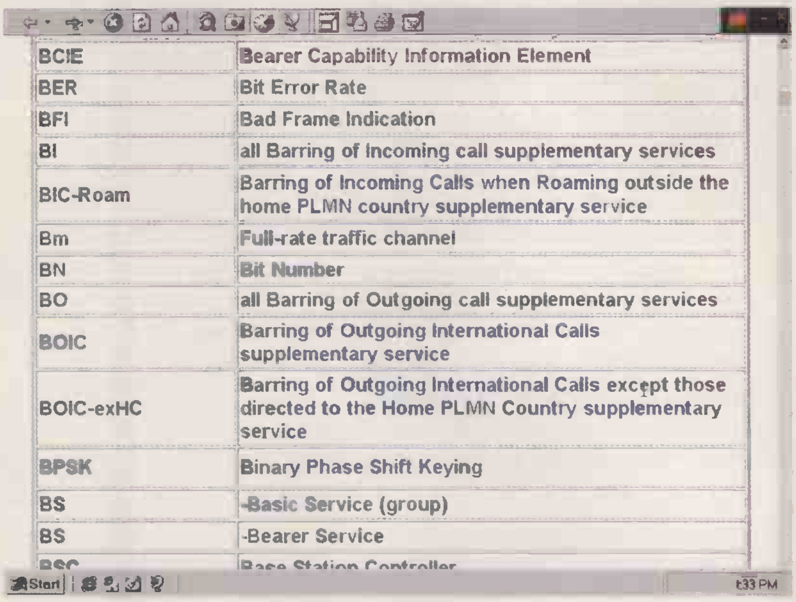
UMTS Forum's website is at http://www.umts-forum.org



BCIE	Bearer Capability Information Element
BER	Bit Error Rate
BFI	Bad Frame Indication
BI	all Barring of Incoming call supplementary services
BIC-Roam	Barring of Incoming Calls when Roaming outside the home PLMN country supplementary service
Bm	Full-rate traffic channel
BN	Bit Number
BO	all Barring of Outgoing call supplementary services
BOIC	Barring of Outgoing International Calls supplementary service
BOIC-exHC	Barring of Outgoing International Calls except those directed to the Home PLMN Country supplementary service
BPSK	Binary Phase Shift Keying
BS	Basic Service (group)
BS	-Bearer Service
BSC	Base Station Controller

Useful list of abbreviations, to be found at ETSI's website – http://www.etsi.fr.

Need more information?

The official IMT-2000 website for international mobile communications is at http://www.itu.int/imt
ETSI's website is at http://www.etsi.fr
UMTS Forum's website is at http://www.umts-forum.org
The GSM MoU site is at http://www.gsmworld.com

It would be easy to dismiss UMTS as just another cellular system to confuse customers, with a few extra bells and whistles. Nigel Lobley denies this emphatically, however and sums up, "The combination of a far more feature-rich multimedia mobile service plus the uniform method of use and service presentation is an extremely attractive and powerful proposition that 'power user' customers will readily perceive; it's also something that service providers can customise and differentiate in order to win market share. UMTS is the key technology that will enable phone companies to integrate their fixed and mobile networks and create something that meets customer needs far more closely than before. Soon the universal pocket communicator may no longer be just a dream."

Third time lucky?

UMTS is one of the so-called 'third-generation' mobile radio systems. Devout hopes were held out that the third generation might finally bring about a consensus for creating a single global technical standard for mobile radio to replace the mutually incompatible regional schemes in use at present.

Immense work is in hand to achieve this, although it appears that practical hurdles will mean that technical interoperability on in international scale will be less than 100 per cent. For many users this will not be a major problem.

Change for change's sake?

When many mobile phone users have yet to change up to GSM – the current 'second-generation' technology – you might ask why telecomms operators around the world are expending so much energy on devising next-generation systems. The answer lies in the user imperative – the expanding number of mobile radio customers, their continually maturing aspirations and the sheer range of new applications for mobile communication.

In fewer than fifteen years, the market for cellular radio has seen total shift from a high-cost, low-volume operation to mass-market affordability. All branches of business and commerce now find mobile communication essential, while a whole new generation of students, job entrants and other young people make a low-cost mobile phone their primary means of contact. Some of them don't even have a fixed-line phone.

Coupled with this transformation is the data wave. Voice and even simple data are old hat; users expect to be able to send and collect e-mail on the move, and to consult the Internet. Broadcasters and newspaper people may need to send photographs in high-resolution, while the emergency services are already sending moving pictures of incidents back to base. ■

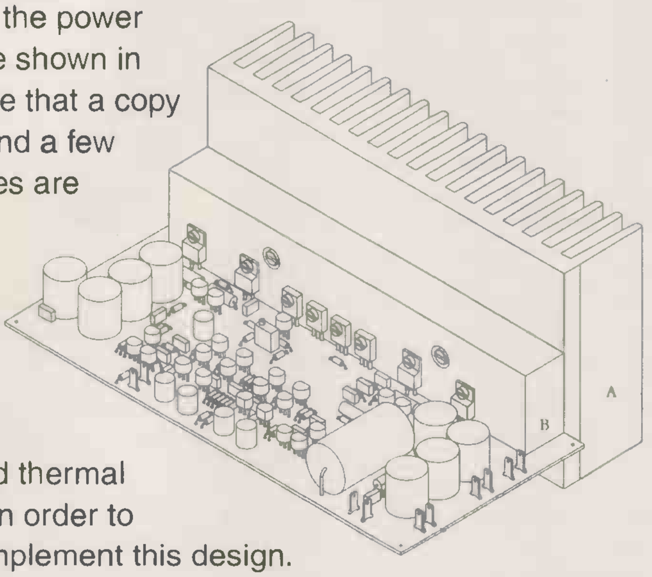
Power amplifier circuit boards

£42 per pair fully inclusive or £25 each

Professionally designed and manufactured printed circuit boards for Giovanni Stochino's no compromise 100W power amp are available to buy.

These high-quality fibre-glass reinforced circuit boards are designed for Giovanni Stochino's fast, low-distortion 100W power amplifier described in the August 1998 issue. Layout of the double-sided, silk screened and solder masked boards has been verified and approved by Giovanni.

This offer is for the pcbs only. The layout does not accommodate the power supply scheme shown in the article. Note that a copy of the article and a few designers' notes are included with each purchase, but you will need some knowledge of electronics and thermal management in order to successfully implement this design.



Giovanni's high-performance power amplifier mounted on its heat sink.

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Measured output offset voltage	+32mV

Distortion performance

V_{out}, pk-pk	1kHz	20kHz
5	0.0030%	0.0043%
10	0.0028%	0.0047%
20	0.0023%	0.0061%
40	0.0028%	0.0110%
80	0.0026%	0.0170%

Slew rate

Positive slew-rate	+320V/μs
Negative slew-rate	–300V/μs

SPEAKERS' CORNER

Motional feedback II. Last month's Speakers' Corner showed how feedback improves the performance of certain loudspeakers. Here, John Watkinson expands on the topic.

In a real low-frequency loudspeaker the main sources of distortion will be the drive unit itself and the non-linear air spring due to the enclosure. In principle, motional feedback can reduce the effect of both.

The performance of any feedback mechanism is limited by the accuracy of the feedback signal. If the feedback signal does not represent the cone motion accurately, then the cone motion cannot be controlled accurately.

Designers have found various ways of measuring the cone motion. It doesn't matter whether the displacement, velocity or acceleration is measured, as these parameters can be exchanged in signal processing circuitry by integration or differentiation.

One approach is to use an accelerometer. **Fig. 1** shows that this is simply a small inertial mass mounted via a force sensor on the cone. The force sensor is typically a piezo-electric crystal requiring a high input impedance amplifier.

An alternative is to measure the cone velocity using a separate moving coil as shown in **Fig. 2**. This is mechanically complicated and expensive, but, when well engineered, the coil voltage is directly proportional to the velocity.

Some low-frequency drive units designed for sub-woofers have dual coils so that a stereo amplifier can drive a single unit. The two channels are simply mechanically added in the coil former.

Amateur designs have appeared ingeniously using one of the dual coils as a velocity feedback coil. While this works, the efficiency is low because half of the magnetic energy in the gap is wasted. There is also a possibility of mutual inductance between the two coils that are effectively an accidental transformer.

Sensing drive current

Figure 3 shows another possibility, which uses a relatively conventional drive unit. Here, a sense resistor samples the current passing through the coil, and the voltage across the coil is measured. If the coil resistance is known, the voltage across the coil due to ohmic loss can be calculated from the current. Any remaining voltage across the coil must be due to back emf, which is proportional to the coil velocity.

A suitable signal processor can extract the back emf, which can then be used in a feedback loop. One difficulty with this method is that as the temperature of the coil changes, its resistance will change, causing an error in the emf calculation.

One solution is to connect a length of the same type of wire used in the coil in series with the main coil so that it experiences the same heating current. The voltage across this compensating coil can be sensed to allow for temperature changes. The compensating coil may conveniently be fitted at the end of the coil former but it is important that it is screened from the magnetic circuit.

The back emf extraction approach seems attractive, but it does rely heavily on the linearity of the main magnetic circuit and coil. The integral of the flux cutting the coil must be independent of coil position or the back emf measurement isn't accurate.

This technique can't be used to linearise a cheap drive unit because these invariably have position dependent flux problems. As a result it only works in drive units which are already quite linear.

Accelerometer benefits

The attraction of the accelerometer approach should now be clear. The addition of the accelerometer to the drive unit is fairly simple, and its operational accuracy is independent of the drive unit so that a less-than-perfect driver can be linearised.

The degree of linearisation achieved with motional feedback is a function of the open-loop gain available. The more gain that can be used, the smaller the residual error will be. The natural conclusion is that the ideal gain is infinite, like an operational amplifier.

Unfortunately this can't be

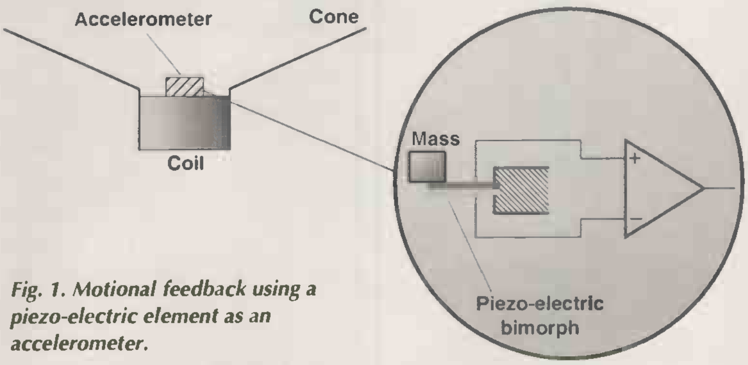


Fig. 1. Motional feedback using a piezo-electric element as an accelerometer.

achieved because real drive units have a sub-optimal phase response. Negative feedback will fail in the presence of phase shifts within the loop, because these can result in positive feedback if the loop gain is above unity when 180° of shift has occurred.

An earlier Speakers' Corner explained how a real woofer has a fundamental resonance. Below this frequency it is stiffness controlled, above it is mass controlled. There is a change in phase response of 180° as the resonant frequency is traversed. The rapidity of the phase change is a function of the *Q* factor of the resonance. This is affected by the design of the drive unit and by the nature of the enclosure and its filling.

Clearly if the feedback loop contains a speaker whose phase response can reverse, an equivalent but opposite phase compensation circuit must be included in the loop so that the feedback will remain negative at all frequencies.

Once the phase reversal of the drive unit is compensated, the feedback can be used to flatten the response of the driver well below its natural resonance.

The low-frequency response is now determined electronically. It cannot be set arbitrarily low, however, as the drive unit may not have enough displacement to reproduce very low frequencies. Thus a motional feedback speaker may have a small enclosure, but it will have to contain a drive unit that would be considered disproportionately large in a conventional speaker.

The end of the road

One of the problems with motional feedback is the overload condition.

If the cone meets resistance, feedback will cause the driver to receive an increasing signal to overcome the resistance. If this resistance is due to the driver reaching the end of its travel then the result could be damage.

The solution is that the input signal has to be limited in some way so that the feedback loop is never asked to follow an impossible signal. In this way high gain can be safely used at all times.

The amplitude limit will have to be frequency dependent as the displacement rises at 6dB per octave as frequency falls. ■

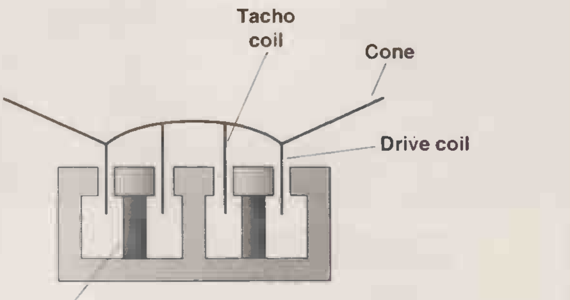


Fig. 2. Adding a coil to the speaker to provide the motional feedback signal is complicated and expensive, but if it is done well, the feedback coil's voltage is directly proportional to the coil's velocity.

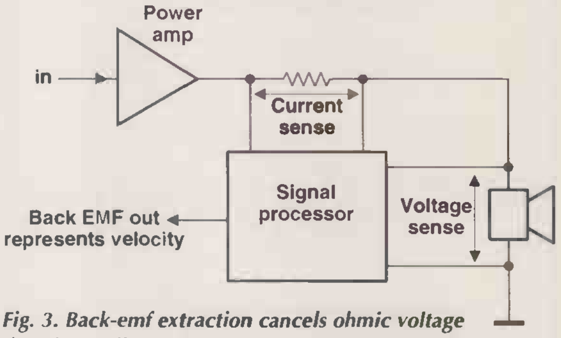
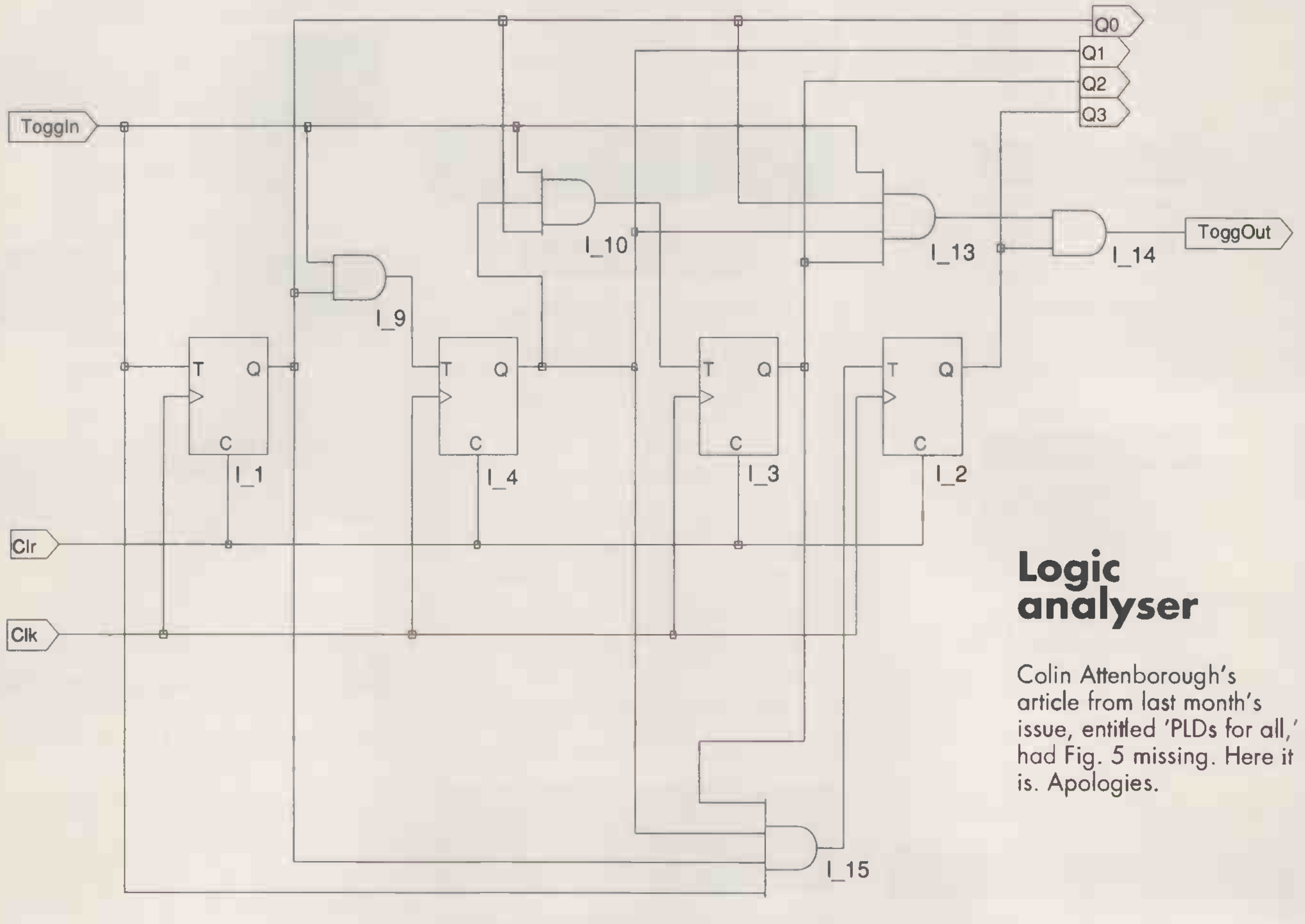


Fig. 3. Back-emf extraction cancels ohmic voltage drop in a coil.



Logic analyser

Colin Attenborough's article from last month's issue, entitled 'PLDs for all,' had Fig. 5 missing. Here it is. Apologies.

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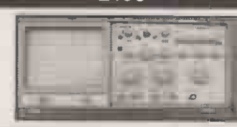

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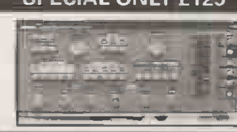

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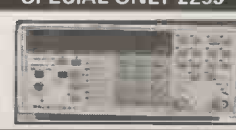

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Hands-on Internet

The focus of Cyril Bateman's web sleuthing this month is measuring rms – but first some tips on finding data...

So-called data-mining software packages are intended to help you search for technical data. These search engines tour the Internet looking only for Web page content that matches the chosen search criteria. As with a conventional search engine, such as AltaVista, you can then access the data miner's much smaller and targeted database.

PartMiner is a free software package that is downloadable from the partminer.com page.[3] It can be run as a background task while you work. This parts locator is primarily designed as an aid for component buyers, but it also has facilities useful to engineers. It works by visiting on-line component distributors, to check their inventory and price levels.

Partminer.com is linked to the The Electronic Design Technology and News network. The EDTN design resources section[4] comprises a reference library of 4000 application notes, an application note searcher, an EDA tools search facility and an IC selector.

My application note search on thermocouples initially found 22 hits. Curiously a later repeated search found only 12 hits.

Measuring alternating waveforms

Whether intended for performance verification or application, every electronic design shares a common need – the measurement of voltages. While direct voltage or current is easily measured, alternating waveforms are usually first converted to dc then measured via a dc instrument.

Alternating voltage meters and converters can measure a waveform's peak, average or rms values. Of these, a waveform's rms value – which is related to its capacity to heat up a load

Where to look

1) Microsoft Windows Family.	http://www.microsoft.com/windows/euro.asp
2) AllChars for Windows.	http://freeweb.digiweb.com/computers/AllChars
3) PartMiner.	http://www.partminer.com/partminer/information.html
4) Electronic Design Technology Network.	http://www.edtn.com/centers/descenter.html
5) National Semiconductor.	http://www.national.com
6) Analog Devices.	http://www.analog.com
7) Burr Brown Corporation.	http://www.burr-brown.com
8) Maxim Integrated products.	http://www.maxim-ic.com
9) Linear Technology Corporation.	http://www.linear-tech.com

– is the most useful.

Most average or peak responding meters are calibrated as rms equivalent, assuming a sinewave is being measured. If the required waveform is sinusoidal or has a recognisable and regular shape, mathematical conversion between these values is simple. When the waveform is irregular or contains unknown harmonics though, alternating waveform measurements can become a trap for the unwary.

While all digital multimeters can measure low-frequency ac, by 1kHz most have significant errors which can also be amplitude dependent. Some time ago, I built a true rms meter, accurate from dc to 2MHz, but I now need to be able to measure higher frequencies. While I could measure the peak amplitudes with an oscilloscope, the waveshape made converting these to rms much too difficult. So before committing to a new purchase, I decided to use Internet to explore other options.

Using the three search sites featured in my February 1998 Internet article, together with this month's partminer.com site, I found several useful tutorials, as well as application notes and data sheets.

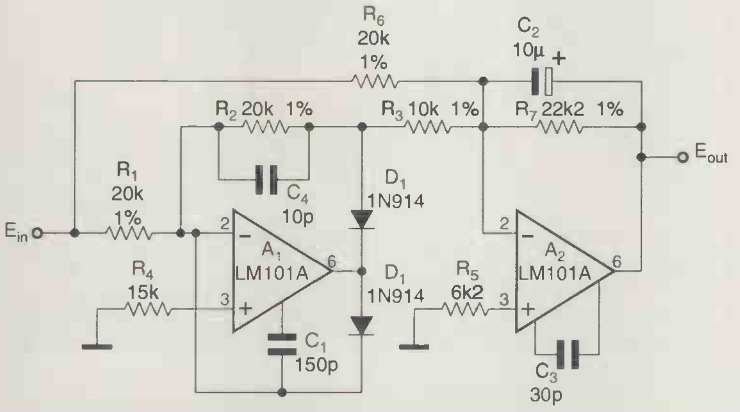


Fig. 1. One early precision ac-to-dc converter that works to at least 100kHz using relatively modest devices. With feedforward compensation, amplifier slew rate is improved to some 10V/µs.

Optimised measurements

Low-frequency voltages and currents can be rectified to dc for measurement using simple diode circuits. With diodes connected in the feedback loop of a high-gain amplifier, their threshold voltage is overcome, allowing millivolt level signals to be measured.

The 30-year-old National Semiconductor briefing note LB-8, discusses accurate methods to measure millivolt level sinewave signals up to 100 kHz, using relatively slow op-amps.[5] This note describes a precision, average-responding ac-to-dc converter. Built using *LM101A* op-amps with feedforward compensation and *1N914* diodes, it attained 1% accuracy at 100kHz, **Fig. 1**.

This circuit's high-frequency performance is determined in part by the switching speed of the diodes used and the op-amp's loss of gain in overcoming the diodes threshold voltage.

Synchronous detection systems which perform full wave rectification without using diodes offer improved accuracy at high frequencies and with millivolt signals. Two widely used examples – the Motorola *MC1330* and Mullard *TCA270* – working at 39.5 MHz, were responsible for greatly improving video detector performance in domestic solid state colour televisions in the early seventies.

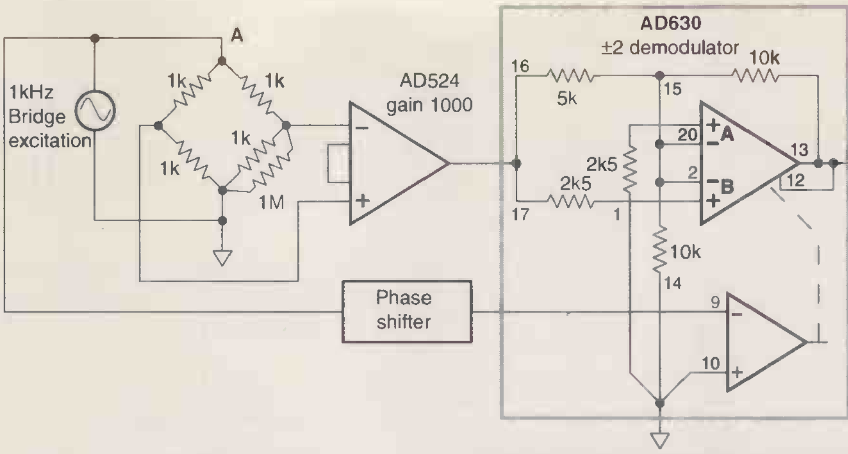
The *AD630* commutating modem

Want a Euro on your keyboard?

Now that Europe is using the new 'Euro' currency, you might wonder how your computer can print this new symbol. Windows 98 has built in support, with a limited range of fonts. Other members of the Windows family require operating system and font updates. Patches for Windows 95 and NT4 can be downloaded[1]

As yet, Windows 3.1 is not upgradable for the Euro sign, but there is some third party support listed in Microsoft's Euro page FAQ.[1] Alternatively, pending the promised support from Microsoft, you could download a freeware utility from the AllChars for Windows page.[2] Running in the background, AllChars can be quickly activated when needed to provide a great many special characters. It is compatible with most Windows software. AllChars is available for 32-bit and 16-bit operating systems.

Visit this Microsoft page to download the free updates your system needs to become 'Euro' capable.



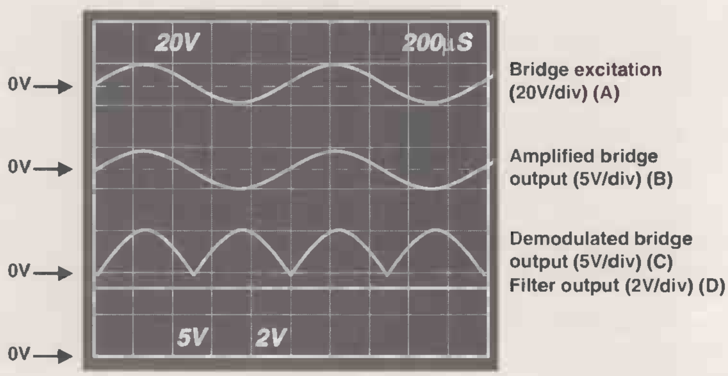


Fig. 2. The AD630 balanced modulator/demodulator integrated is easily configured to provide a no-diodes, full-wave synchronous rectifier. The phase shifting circuit compensates for signal delays in the AD524 pre-amp, ensuring precise waveform coincidence. This 'ideal' behaviour is clearly seen in the attached oscillogram.

IC from Analog Devices,[6] simplifies synchronous detection. I mentioned this chip in the October 1998 issue, where it was used to recover a wanted signal from overwhelming background noise.

The *AD630* is essentially two switch-selectable, identical op-amps. Output from the selected input amplifier is directed to the communal output buffer. The device can be used as a precision rectifier absolute value detector. With some –100dB of input channel crosstalk at 10kHz, this chip is optimised for wide-dynamic-range, low-frequency use. At higher frequencies I find it outperforms the traditional diode feedback op-amp arrangement, Fig. 2.

Burr-Brown offers a similar arrangement, but intended for high frequencies, which they call a SWOP-amp.[7] Their *OPA678* features a 200MHz bandwidth and 4ns input switching.

Root-mean-square

The above circuits all respond to the average level of the detected signal. They can be adjusted or calibrated to indicate the peak or rms equivalent values, of a rectified sinewave.

The ratio of volts peak to volts rms, called the 'crest factor' of the waveform, is important. A sinewave has a crest factor of 1.414. Given a 1V peak input signal, an average reading meter will be adjusted to read 0.707V rms. This meter will then over-read by 11% when measuring a 1V peak symmetrical square wave, i.e. a unity crest factor.

Since the rms value of a waveform is defined as its heating value in a load, calorimetric methods could be used. These would provide the most

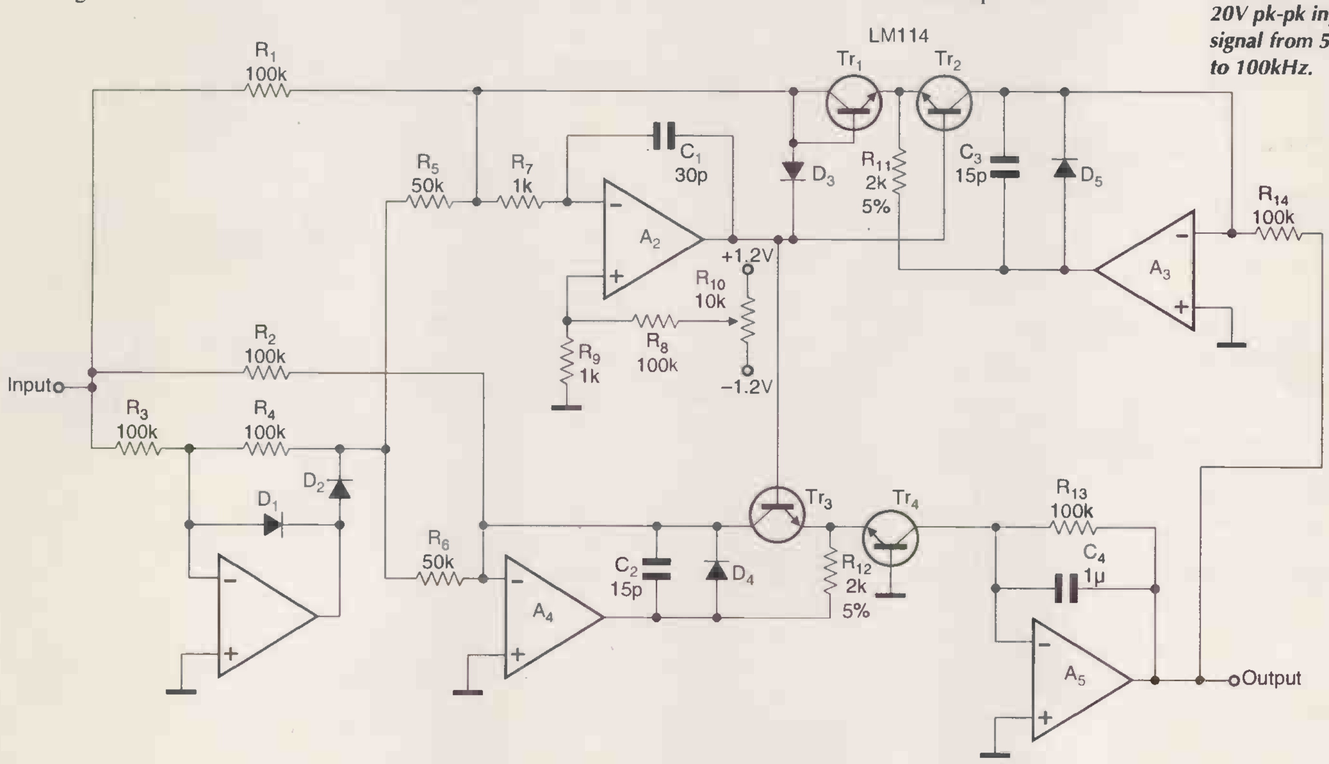


Fig. 3. Using only standard devices from the early seventies, this true rms detector was usable to 500kHz. Accuracy was typically 2% for a 20V pk-pk input signal from 50Hz to 100kHz.

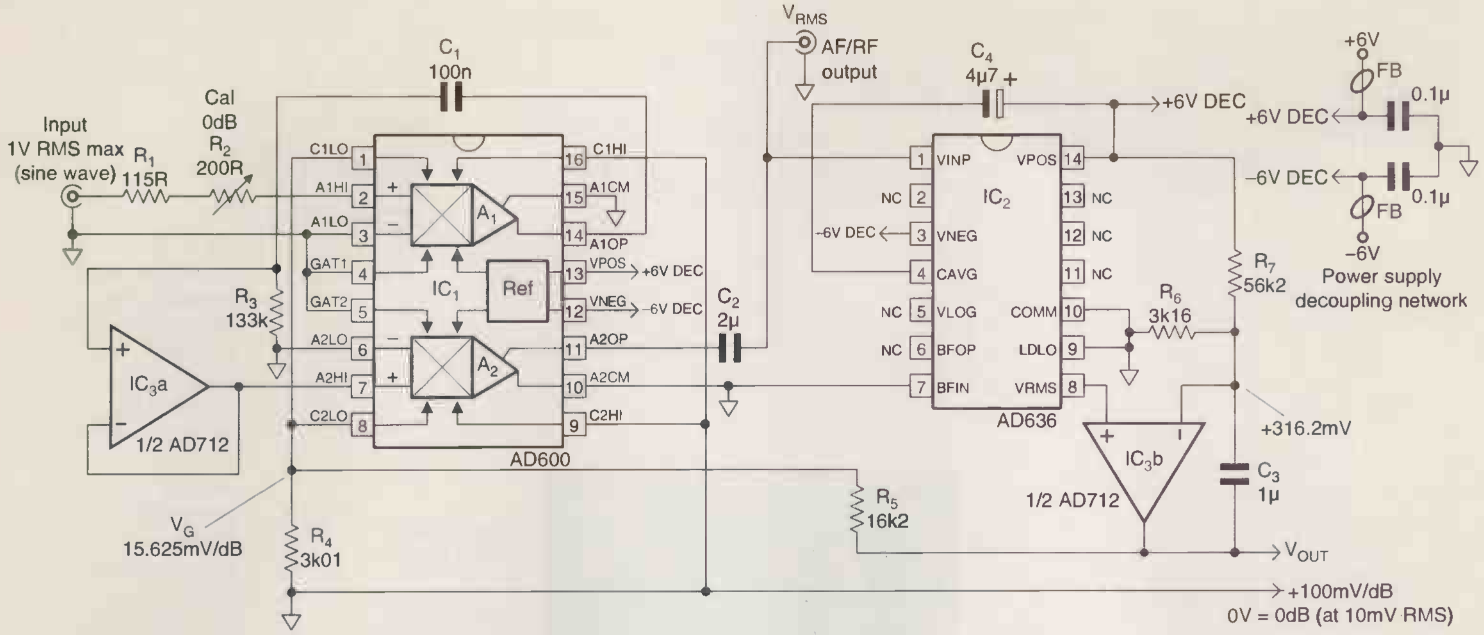


Fig. 4. While using two expensive components, this true rms detector provides an exceptional 80dB dynamic range and a constant bandwidth, which is limited to 2MHz by the AD636. The AD600 variable gain 'X' amplifier has a 35MHz bandwidth.

accurate measurements for laboratory use, but can be slow and cumbersome.

A quick responding and portable electronic version of the calorimetric method has been devised. It has two identical heating elements each coupled to a temperature sensor and mounted in an insulated, isothermal enclosure. The heating effect of the unknown waveform, applied to one heating element, is temperature matched by a known dc supply to the comparison element.

These techniques were used in 1965 to produce the Hewlett Packard *HP3400A* voltmeter, which provided accurate rms measurements from 1mV to 300V at frequencies to 10MHz.

To reduce costs, semiconductor makers explored simpler integrated circuit methods to solve the rms equation. One early method was to first square then integrate the voltage waveform, and finally to compute the square root of this running average. Known as an 'explicit' computation, this system works well with low crest factor waveforms. But it has problems coping with the dynamic range of the squared signal peak amplitudes, of high crest factor waveforms.

To eliminate this problem, the method of 'implicit' computing was devised, in which the near constant output value is used to divide the

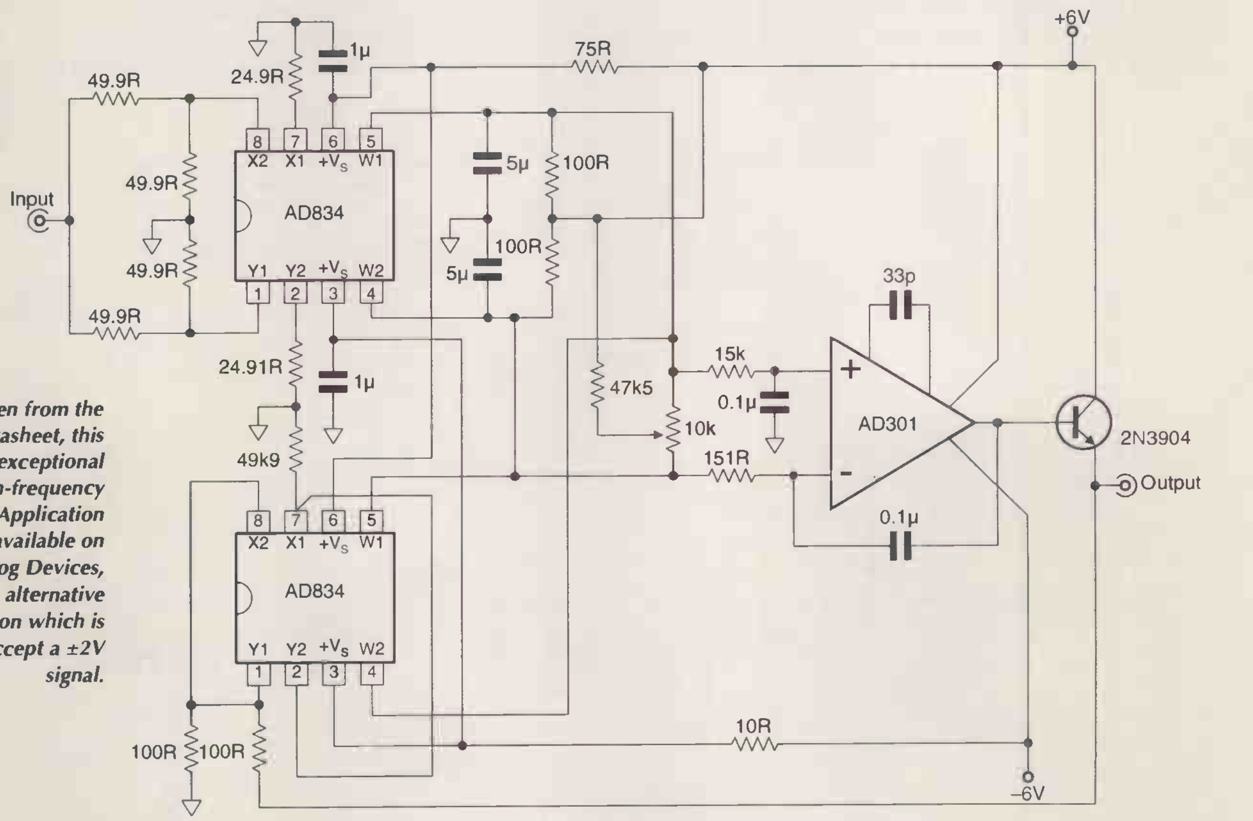


Fig. 5. Taken from the AD834 datasheet, this circuit offers exceptional high-frequency performance. Application note AN212, available on request to Analog Devices, provides an alternative configuration which is designed to accept a ±2V signal.

squared signal prior to its integration.

In 1973, National Semiconductor published a true rms detector application note using five op-amps and diodes with four transistors.[5] Called Linear Brief 25, this application note can downloaded from National's Web site, **Fig. 3**. A similar arrangement but integrated into one 16-pin dual-in-line package, was later marketed as the *LH0091* true rms to dc converter.

The 500-page 'non-linear circuits handbook', first published in 1974 by Analog Devices, still appears in the company's literature list. It explores all aspects of the various methods, used to measure or compute the rms of any waveform.

Today, most commercially available integrated circuit rms to dc converters are based on this implicit computation method, as typified by the *xx536A* and *xx636* converters available from both Analogue Devices[6] and Maxim.[8]

Depending on input signal magnitude, these parts can accurately convert waveforms having a crest factor of six at frequencies up to 1MHz. The informative 'RMS-to-DC Converters Ease Measurement Tasks' application note can be downloaded from the Analog Devices Web page.

If you need a wider dynamic signal range than offered by these packages, the *AD636* can be used together with the *AD600* low noise variable gain amplifier. This combination provides a constant 2MHz bandwidth with 80dB dynamic range and a 2MHz upper frequency limit. It produces a decibel-scaled output voltage.

I have used just this combination for one of my test meters. Due to the very wide gain bandwidths of this configuration though, much care is needed with your layout, **Fig. 4**.

Analog Devices' data sheet for the *AD834* describes how to use two of these extremely fast, four-quadrant multiplier chips, to produce a 1kHz to 500MHz rms-to-dc converter.[6] Designed to accept a +15dBm maximum input, the accuracy of the circuit at small signal levels is limited by the inevitable offset voltages. Correct physical construction and layout is critical to realising the potential of this very high speed circuit, **Fig. 5**.

Linear Technology has devised an integrated circuit solution for the calorimetric techniques.[9] The company's *LT1088* – a 14-pin DIL device first listed in their 1990 databook – is still available. It provides both 50 and 250Ω matched heater pairs together with matched diodes which are used to sense both heaters temperature.

This circuit, used with six op-amps, replicates the rms-to-dc functions used in the Hewlett Packard *HP3400A* meter. This sensitive, thermally based true rms-to-dc converter integrated circuit provides conversion from dc to 10MHz with less than 1% error and a voltage gain of 10, **Fig. 6**.

The *LT1088* converter is capable of exceptional performance. It has a 300MHz 3dB bandwidth and 2% accuracy at 100MHz. Its heater systems can handle extreme crest factors of 50:1, it has a 35V peak maximum heater input together with a 20:1 dynamic range.

Full details can be found in the company's application note 61. This publication highlights how easy it is to implement the design using modern components – relative to the problems that Hewlett Packard faced when implementing the same design in 1965.[9] ■

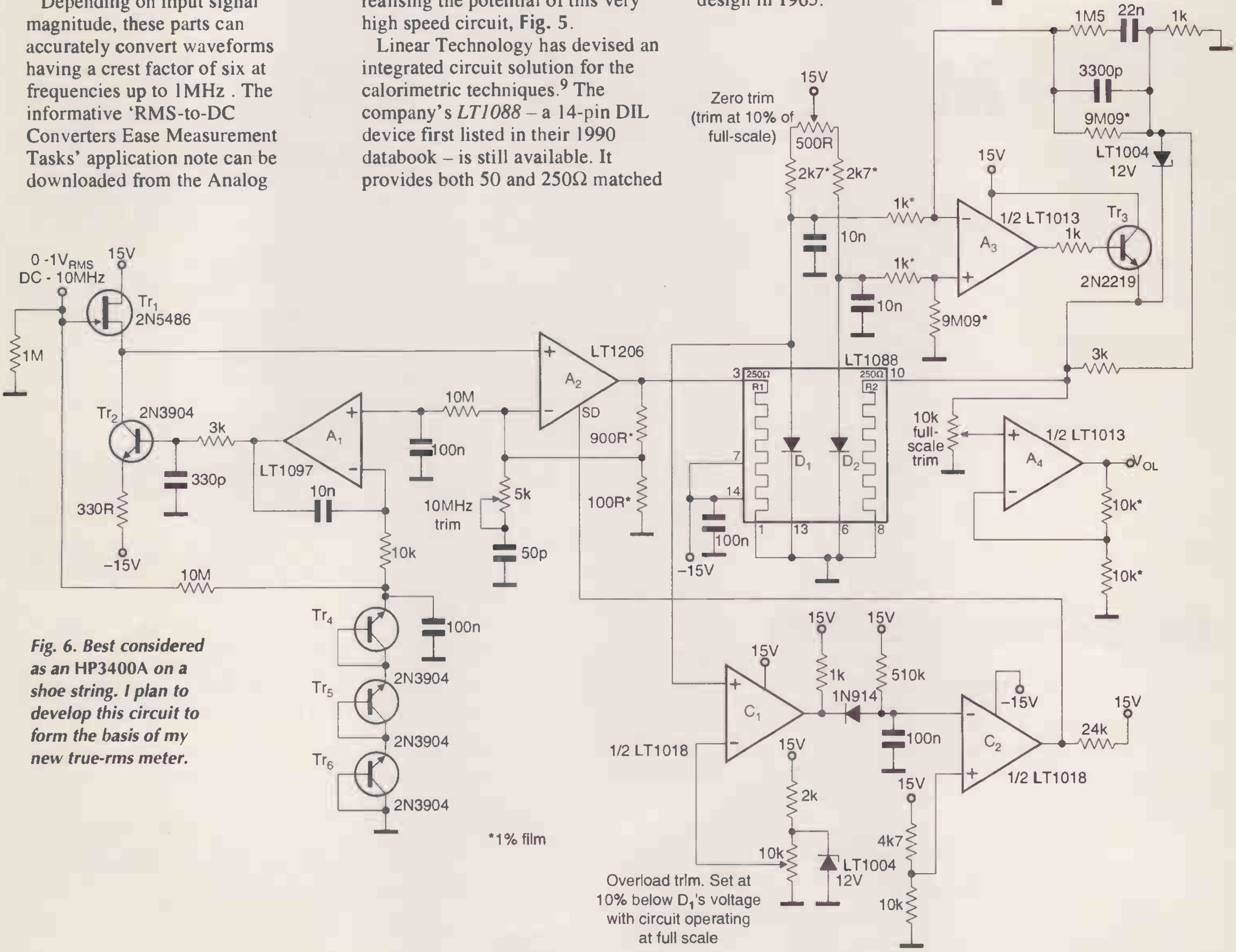
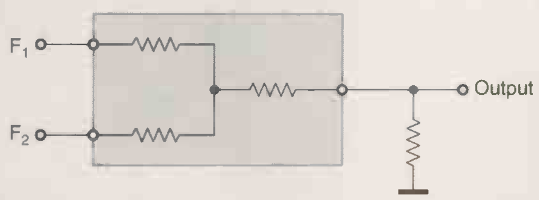


Fig. 6. Best considered as an HP3400A on a shoe string. I plan to develop this circuit to form the basis of my new true-rms meter.

RF receiver mixers

In the first of three articles explaining rf mixers, Joe Carr looks at their operation and demonstrates the basic single-ended diode-mixing configuration.

Mixer circuits are used extensively in radio frequency electronics. Applications include frequency translators – in radio receivers – demodulators, limiters, attenuators, phase detectors and frequency doublers.



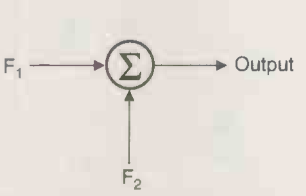


Fig. 1a) The basic linear mixer is actually a summer; b) is the linear mixer's symbol.

Detecting receiver radiation

There is a number of possibly apocryphal legends from World War II of receiver local-oscillator radiation back through the antenna circuit being responsible for an enemy detecting the location of the receiver, so this effect is rather important.

One such legend is from British airborne radar history. According to one source of doubtful authority, German submarines sailing on the surface learned to listen for Beaufighter centimetric radars using a receiver that was poorly suppressed.

The aircrews then learned that they could locate the submarine with just the radar's receiver tuned to listen for the submarine receiver's local oscillator. Anyone with first hand knowledge of this matter please let me know.

There is a number of different approaches to mixer design. Each of these approaches has advantages and disadvantages, and these factors are critical to the selection process.

Linear *versus* non-linear mixers

The word 'mixer' is used to denote both linear and non-linear circuits. And this situation is unfortunate because only the non-linear is appropriate for the rf mixer applications listed above.

So what's the difference? The basic linear mixer is actually a summer circuit, as shown in **Fig. 1a)**. Its schematic symbol is shown in Fig. **1b)**. Some sort of combiner is needed. In the case shown, the combiner is a resistor network. There is no interaction between the two input signals, F_1 and F_2. They will share the same pathway at the output, but otherwise do not affect each other. This is the action one expects of microphone and other audio mixers.

If you examine the output of the summer on a spectrum analyser, **Fig. 2**, you will see the spikes representing the two frequencies, and nothing else other than noise.

The non-linear mixer is shown in **Fig. 3a)**, and the circuit symbol in Fig. **3b)**.

While the linear mixer is a summer, the non-linear mixer is a multiplier. In this particular case, the non-linear element is a simple diode, such as a 1N4148 or similar devices.

Mixing action occurs when the non-linear device, such as diode D_1, exhibits impedance changes over cyclic excursions of the input signals. In order to achieve switching action one signal must be considerably higher than the other. It is commonly assumed that a 20dB or more difference is necessary.

Whenever a non-linear element is added to the signal path a number of new frequencies will be generated. If only one frequency is present, then we would still expect to see its harmonics. For example, F_1 and nF_1 where n is an integer. But when two or more frequencies are present, a number of other products are also present. The output frequency spectrum from a non-linear mixer is,

$$\pm F_o = mF_1 \pm nF_2 \qquad (1)$$

where F_O is the output frequency for a specific (m,n) pair, F_1 and F_2 are the applied frequencies and m and n are integers or zero, i.e. 0, 1, 2, 3...

There will be a unique set of frequencies generated for each (m,n) ordered pair. These new frequencies are called mixer products or intermodulation products. **Figure 4** shows how the output would look on a spectrum analyser. The original signals F_1 and F_2 are present, along with an array of mixer products arrayed at frequencies away from F_1 and F_2.

The implication of equation (1) is that there will be a large number of (m,n) frequency products in the output spectrum. Not all of them will be useful for any specific purpose, and may well cause adverse effects.

So why do we need mixers? There are other ways to generate various frequencies, so why a frequency translator such as a heterodyne mixer?

The principal answer is that the mixer will translate the frequency, and in the process transfer the modulation of the original signal. So, when an amplitude-modulated signal is received, and then translated to a different frequency in the receiver, the modulation characteristics of the AM signal convey to the new frequency essentially undistorted. Those of you who know that there is no such thing as a 'distortionless' circuit, please refrain from snickering. Perhaps the most common use for mixers, in this regard, is in radio receivers.

The receiver mixer

The vast majority of radio receivers made since the late twenties have been superheterodynes. The process of heterodyning is the translation of one frequency to another by the use of a mixer and local oscillator, or LO, **Fig. 5a)**.

The antenna picks up a radio signal of frequency F_{RF}, and mixes it with a local oscillator signal F_{LO}. This produces a number of new frequencies in the spectrum defined by equation (1), but those of principal interest are the cases where (m,n)=(1,1), i.e. the *sum* and *difference* frequencies $F_{RF}+F_{LO}$ and $F_{FR}-F_{LO}$.

An intermediate-frequency filter will select one of these second-order products, and the other is rejected. Why would receiver designers use this approach?

The principal reason is that it is very much easier to design the receiver using this approach. It is much easier to provide the gain and selectivity filtering needed to make the receiver work properly at a single frequency. This frequency, regardless of whether the sum or difference product is used, is called the intermediate frequency, or IF, or F_{IF}. The high gain stages, and the bandpass filtering, are all provided in the IF stages.

At one time, it was universally the practice to select the difference frequency, but today the sum frequency is often selected. It is quite common to find high-frequency shortwave receivers with a dual conversion scheme in which F_{RF} is first up-converted to the sum frequency, and then a new mixer down-converts it to a lower second intermediate frequency.

In the remainder of this article, F_1 and F_2 will be expressed much of the time as F_{RF} and F_{LO} in view of the receiver being the most common use for mixer devices.

The sum or difference second-order products are selected for the IF, but the other frequencies don't simply evaporate. They can cause serious problems. But more of that later.

Simple diode mixer

Figure **5b)** shows a block diagram circuit for a simple form of mixer. Although not terribly practical in most cases, the circuit has been popular in a number of receivers in the high uhf and microwave regions since World War II.

The two input signals are the rf and local oscillator. The oscillator signal is at a very much higher level than the rf signal. It is used to switch the diode in and out of conduction, providing the non-linearity that mixer action requires.

There are three filters shown in this circuit. The rf and local oscillator filters are used for limiting the frequencies that can be applied to the mixer. In the case of the rf port it is other radio signals on the band that are being suppressed.

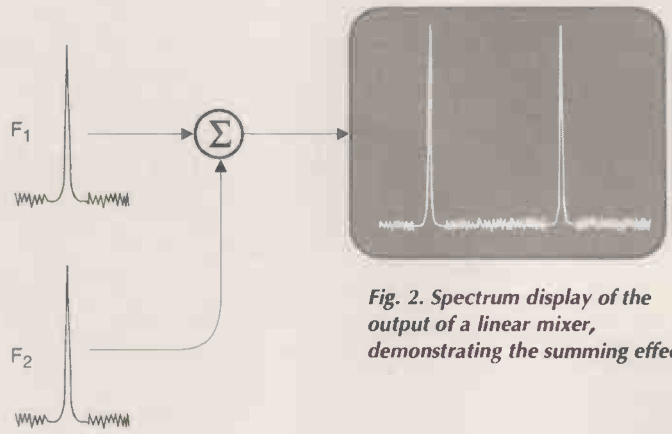
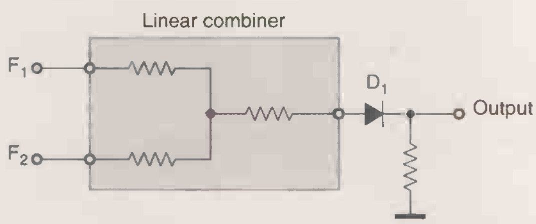


Fig. 2. Spectrum display of the output of a linear mixer, demonstrating the summing effect.



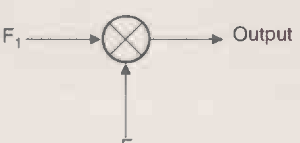


Fig. 3a) Unlike the linear mixer, which is essentially a summer, the non-linear mixer is a multiplier; b) is the non-linear mixer's symbol.

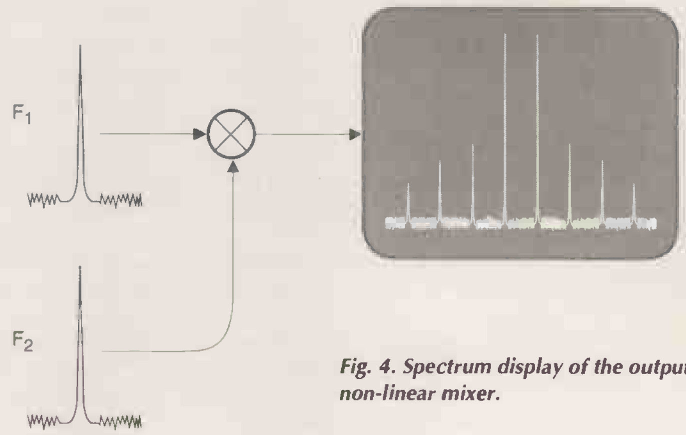


Fig. 4. Spectrum display of the output of a non-linear mixer.

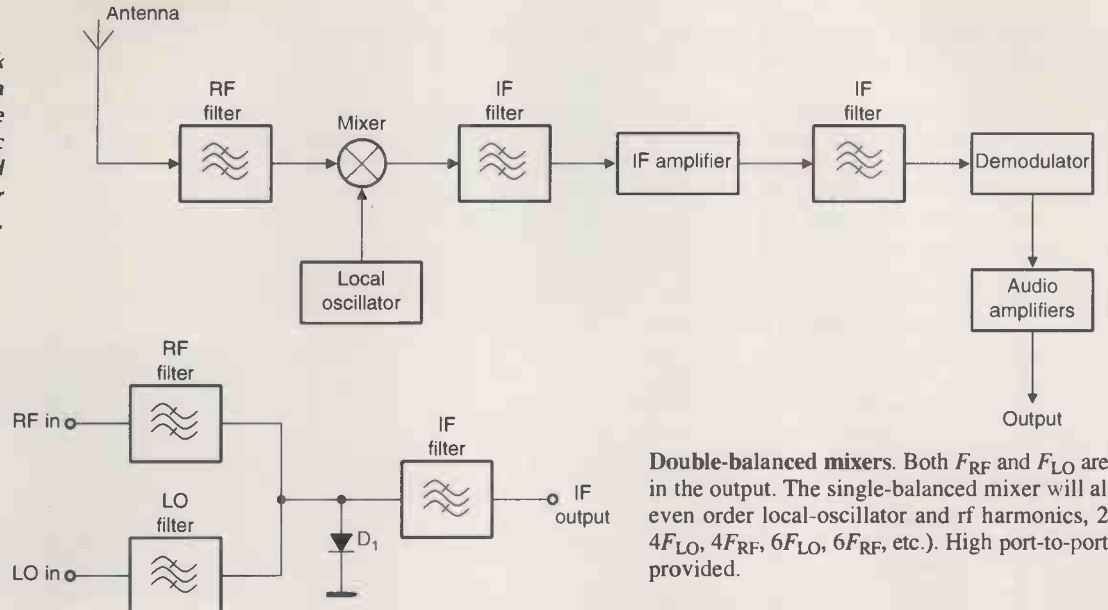


Fig. 5a) Block diagram of a superheterodyne receiver; b) basic single-ended unbalanced mixer circuit.

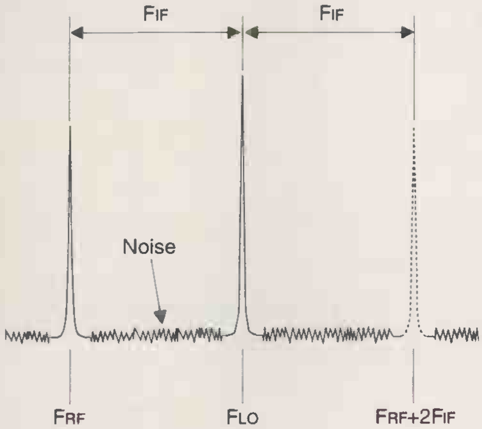


Fig. 6. Image frequency for high-side injection mixer. Image response is due to the fact that two frequencies satisfy the criteria for the intermediate frequency.

In the case of the local oscillator it is oscillator noise and harmonics that are suppressed.

The rf filter also serves to reduce any oscillator energy that may be transmitted back towards the rf input. Take a look at the panel entitled, 'Detecting receiver radiation' for more on this.

The question of 'balance'

One of the ways of classifying mixers is whether or not they are unbalanced, single balanced or double balanced. Although there are interesting aspects of each of these categories, the important aspect for the moment is how they affect the output spectrum.

Unbalanced mixers. Both F_{RF} and F_{LO} appear in the output spectrum, and there may be poor LO-RF and RF-LO port isolation. Their principal attraction is low cost.

Single-balanced mixers. Either F_{RF} or F_{LO} is suppressed in the output spectrum, but not both. In other words, if F_{RF} is suppressed, F_{LO} will be present, and *vice versa*.

The single balanced mixer will also suppress even order local-oscillator harmonics, $2F_{LO}$, $4F_{LO}$, $6F_{LO}$, etc. High LO-RF isolation is provided, but LO-IF isolation must be provided by external filtering.

Double-balanced mixers. Both F_{RF} and F_{LO} are suppressed in the output. The single-balanced mixer will also suppress even order local-oscillator and rf harmonics, $2F_{LO}$, $2F_{RF}$, $4F_{LO}$, $4F_{RF}$, $6F_{LO}$, $6F_{RF}$, etc.). High port-to-port isolation is provided.

Spurious responses

The IF section of a receiver will use one of the second-order products in order to convert F_{RF} to F_{IF}. Ideally, the receiver would only respond to the single radio frequency that meets the need. Unfortunately, reality sometimes rudely intervenes, and certain spurious responses might be noted.

A spurious response in a superheterodyne receiver is any response to any frequency other than the desired F_{RF}, and which is strong enough to be heard in the receiver input. Most of these 'spurs' are actually mixer responses, although overloading the rf amplifier can cause some responses as well.

The mixer responses may or may not be affected by premixer filtering of the rf signal. Candidate spur frequencies include any that satisfy the following equation,

$$F_{spur} = \frac{nF_{LO} \pm nF_{IF}}{m} \qquad (2)$$

Image

The image response of a mixer is due to the fact that two frequencies satisfy the criteria for F_{IF}.

Figure 6 shows how the image response works. The frequency that satisfies the image criteria depends on whether the local oscillator is high-side injected, in which case $F_{LO}>F_{FR}$, or low-side injected, when $F_{LO}<F_{RF}$.

In the high-side injection case (m,n)=(1,–1), shown in Fig. 6, the image appears at $F_{RF}+2F_{IF}$. If low-side injection, (m,n)=(–1,1), is used, then the image is at $F_{RF}-2F_{IF}$. The image always appears on the opposite side of the LO from the RF, so will be $F_{LO}+F_{IF}$ for high-side injection and $F_{LO}-F_{IF}$ for low-side injection.

Consider an actual example based on an AM broadcast-band receiver. The IF is 455kHz, and the receiver is tuned to F_{RF} of 1000kHz.

The usual procedure on AM broadcast-band receivers is high-side injection, so,

$$F_{LO}=F_{RF}+F_{IF}=1000\text{kHz}+455\text{kHz}=1455\text{kHz}.$$

The image frequency appears at,

$$F_{RF}+2F_{IF}=1000\text{kHz}+(2(455\text{kHz})=1910\text{kHz}.$$

Any signal on or near 1910kHz that makes it to the mixer rf input port will be converted to 455kHz along with the desired signals.

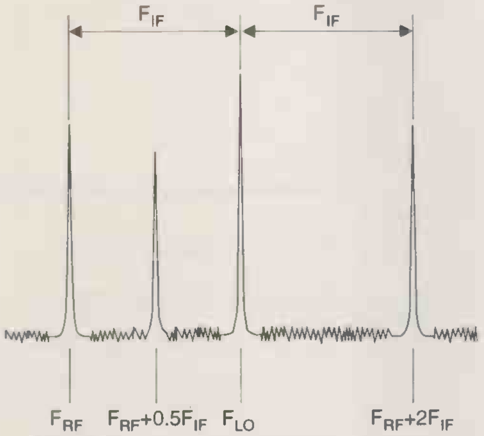


Fig. 7. Another set of images occurs when (m,n) is (2,-2) for the low side or (–2,2) for the high side – so-called half-IF response.

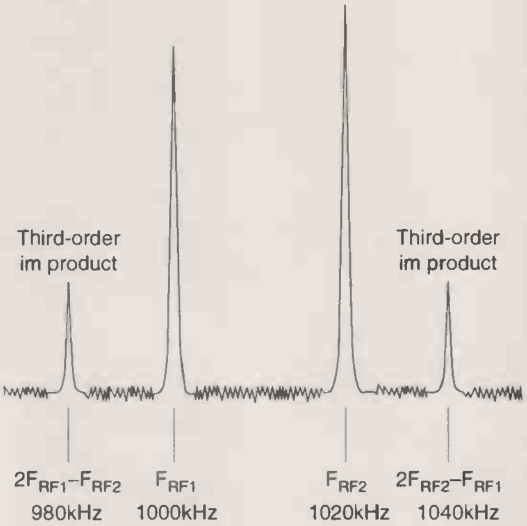


Fig. 8. Third-order products close to test signals.

The problem is complicated by the fact that it is not just actual signals present at the image frequency, but noise as well. The noise applied to the mixer input is essentially doubled if the receiver has any significant response at the image frequency.

Pre-mixer filtering is needed to reduce the noise. Receiver designers also specify high intermediate frequencies in order to move the image out of the passband of the rf pre-filter.

Half-IF. Another set of images occurs when (m,n) is (2,–2) for low-side or (–2,2) for high side. This image is called the *half-IF image*, and is illustrated in **Fig. 7**. An interesting aspect of the half-IF image is that it is created by internally generated harmonics of both F_{RF} and F_{LO}. For our AM broadcast-band receiver where F_{RF}=1000kHz, F_{LO}=1450kHz and F_{IF}=450kHz, then the half-IF frequency is 1000+(450/2)=1222.5kHz.

IF feedthrough. If a signal from outside passes through the mixer to the IF amplifier, and happens to be on a frequency equal to F_{IF}, then it will be accepted as a valid input signal by the IF amplifier. The mixer RF-IF port isolation is critical in this respect.

High-order spurs

Thus far we have considered only the case where a single radio frequency is applied to the mixer. But what happens when two radio frequencies – F_{RF1} and F_{RF2} – are applied simultaneously? This is the actual situation in most practical receivers. There is a large number of higher order responses – i.e. where m and n are both greater than 1, defined by $mF_{RF1} \pm nF_{RF2}$.

The worst case is usually the $2F_{RF1}-F_{RF2}$ and $2F_{RF2}-F_{RF1}$ third-order products because they fall close to F_{RF1} and F_{RF2} and may be within the device passband.

Although any of the spurs may prove difficult to handle in some extreme cases, the principal problems occur with the third-order difference products of two rf signals applied to the rf port of the mixer, $2F_{RF1}-F_{RF2}$ and $2F_{RF2}-F_{RF1}$.

Figure 8 illustrates this effect for our AM broadcast band-receiver. Suppose two signals appear at the mixer input: F_{RF1}=1000kHz and F_{RF2}=1020kHz. This combination is highly likely in the crowded AM broadcast band!

The third-order products of these two signals hitting the mixer are 980kHz and 1040kHz, and appear close to F_{RF1} and F_{RF2}. If the pre-mixer filter selectivity is not sufficiently narrow to suppress the unwanted radio frequency, then the receiver may respond to the third-order products as well as the desired signal.

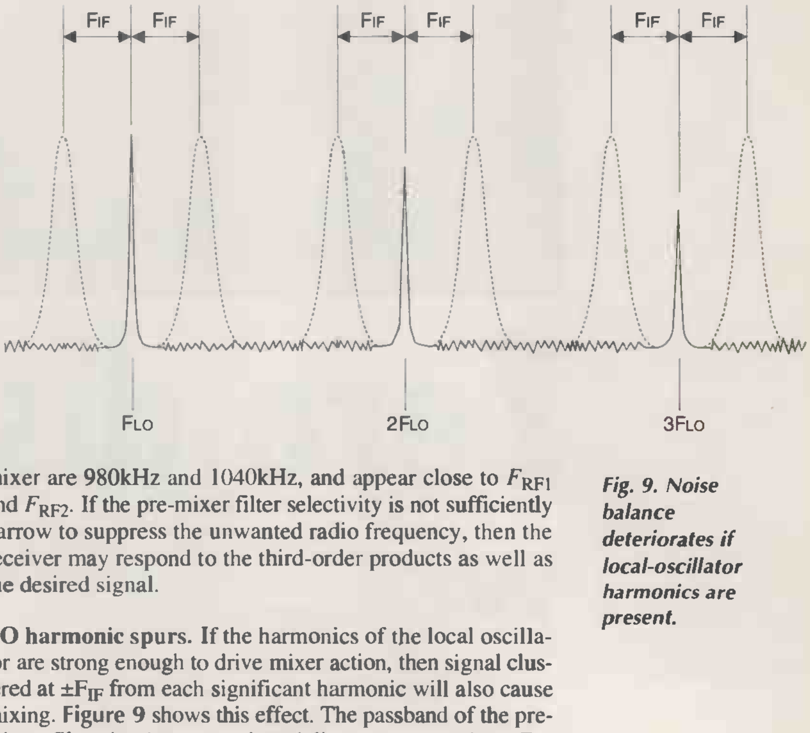


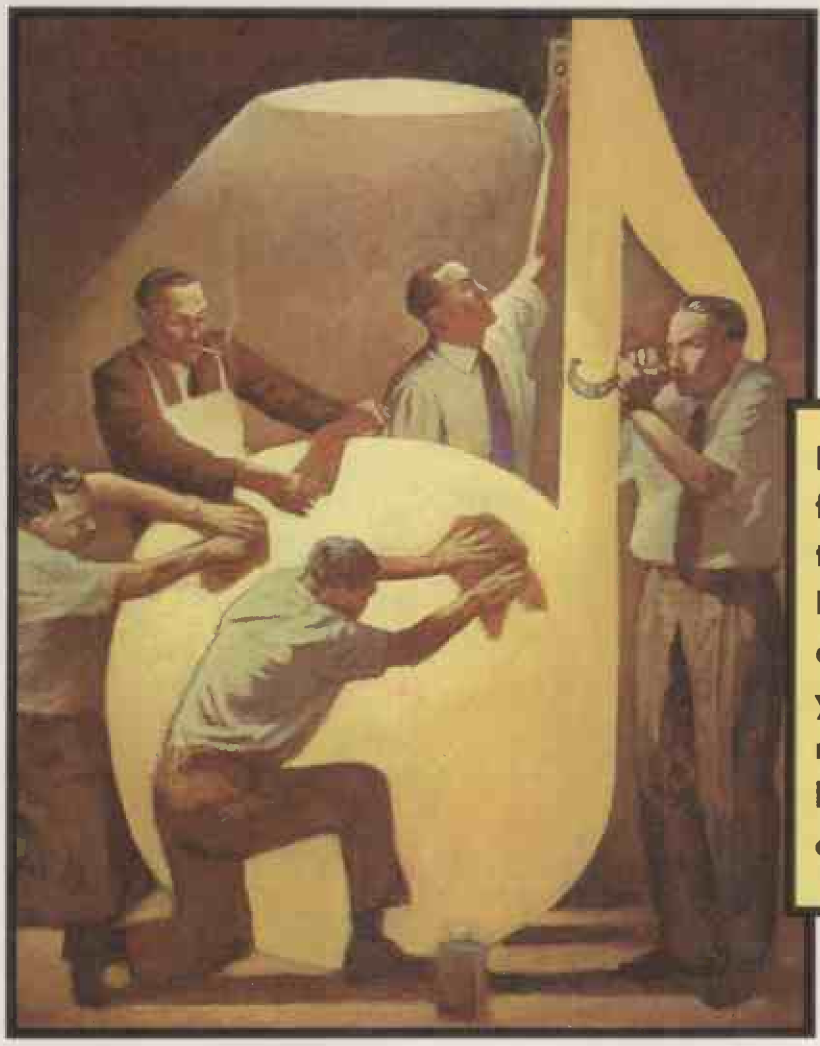
Fig. 9. Noise balance deteriorates if local-oscillator harmonics are present.

LO harmonic spurs. If the harmonics of the local oscillator are strong enough to drive mixer action, then signal clustered at $\pm F_{IF}$ from each significant harmonic will also cause mixing. **Figure 9** shows this effect. The passband of the pre-mixer filter is shown as dotted line curves at $F_{LO} \pm F_{IF}$, $2F_{LO} \pm F_{IF}$ and $3F_{LO} \pm F_{IF}$.

LO noise spurs. All oscillators have noise close to the LO frequency. The noise may be due to power supply noise modulating the LO, or it may be random phase noise about the LO. In either case, the noise close to the LO, and within the limits imposed by the IF filter, will be passed through the mixer to the IF amplifier. ■

What's next?

In part two of this three-part series on rf mixers, Joe looks at intermodulation distortion, third-order intercept point, mixer losses, noise figure and noise balance, and gets into actual circuits by considering the single-ended unbalanced active mixer circuit.



Perfect amplifier fidelity is thought to be unattainable. But Ian Hickman explains here that you could indeed make a distortion-less amplifier, if only...

Zero distortion?

Wisdom says beauty is in the eye of the beholder, and surely high-fidelity audio is in the ear of the hearer. If a system sounds good to you, then it is good – for you.

Strangely, the reverse also seems to hold true. If you are an ardent advocate of this or that particular amplifier architecture, then that sort of amplifier will sound best to you.

Distortion background

In the earliest days of wireless, distortion was not an issue; inadequate sensitivity and sound output were the main concern of designers. But in the later 1930s, once battery valves with their 2V filaments, and balanced iron-armature loudspeakers had been replaced by mains superhets with a few watts of output, distortion became an important consideration.

Output triodes, such as the 4V directly heated PX4 used in my father's pride and joy – a Cossor model *365* – were much favoured for their purity of tone. True, they were far from distortion free, but the distortion they introduced was mainly second harmonic.

This introduces not only second harmonics of all the tones present, but also sum and difference terms. However, the distortion was only severe on very loud passages, with the volume control turned well up, and the ear soon became used to it. At all other times, distortion was minimal, certainly much less noticeable than the muddy sound produced by the sound tracks of movies of the era.

Later, pentodes as output valves became popular with designers, perhaps because the extra gain they provided enabled adequate performance to be achieved with a line-up including one less valve. But pentodes were said to exhibit larger amounts of third-order distortion. This brings not only third harmonics, but third-order intermodulation products, producing, it was said, a shriller tone.

The designer's answer was the incorporation of a vicious tone control. This enabled the listener to chop off such treble response as had managed to survive the selectivity of the intermediate-frequency transformers – and most listeners did. A common view was that the 'mellow position' of the tone control was best for music, and the 'bright position' for speech, which was otherwise often so muffled as to be difficult to follow.

The current scene

Nowadays, power amplifiers are available that contribute only very small amounts of distortion – far less than anything that has been available in the past. Yet specialist designers are still seeking ever lower levels of distortion in the power amplifier – an obsession which may seem perverse, in view of the blithe way they ignore distortion in pick-ups and particularly loudspeakers.

Perhaps the reason is that a quoted power-amplifier distortion level of nought point umpteen noughts one is seen as a selling point, whereas loudspeaker manufacturers trumpet their wide frequency response but, wisely, do not quote distortion levels.

The fringe

In addition to the more orthodox school of power-amplifier designers, there is a fringe world of would-be audio gurus who strenuously maintain the superiority of this or that type of amplifier, usually with no recourse to quoted performance measurements. Thus there are those who swear by valve amplifiers in general.

Others are even more specific, expounding the virtues of triode valve single ended amplifiers in particular. After all, they only produce a little second harmonic, which isn't important, is it? And they don't produce any of those those terrible third-order products.

The more extreme exponent of this school even advocates the abandonment of negative feedback, though what reasoning there is behind this view is usually not stated. At least with no negative feedback, transient intermodulation distortion due to overload of intermediate stages when the output stage clips, cannot occur.

Benefits of negative feedback

As is well known, negative feedback reduces not only the gain, but also gain variation with frequency. It flattens the frequency response. It also reduces noise and hum, assuming of course that these have originated within the loop. But probably its most highly regarded effect is the reduction of distortion that it can offer.

The higher the 'gain within the loop', the greater is the reduction of distortion. The gain within the loop is given by the open-loop gain minus the gain reduction effected by the application of the negative feedback, or nfb.

A large degree of nfb, evidenced by a large gain reduction when the loop is closed, reduces the distortion substantially: $D_f=D_o/(1-\beta A_o)$. Thus if the open loop gain A_o is 1000 and the feedback fraction β is $-1/100$, the distortion with feedback D_f will be one eleventh of the open loop distortion D_o, while the gain has fallen from ×1000 to ×(1000/11).

It looks like a pure performance improvement, apart from the need to make up for the lost gain with a preamplifier. But as pointed out in that excellent text of reference 1, in certain circumstances nfb can make the distortion *worse*. By way of demonstration, the reference's author reproduced a graph from ref. 2, shown here as **Fig. 1**.

No such thing as a free lunch

The logic seems inescapable. If an open-loop amplifier displays only second harmonic distortion, then a modest amount of nfb will result in the introduction of third and higher harmonics not previously there. For with only a modest amount of nfb, the improvement is limited so there must still be some second harmonic $2f_0$ at the output.

A fraction of the $2f_0$ content will be fed back to the input and thus be applied, along with the original input f_0, to the non-linearity. This, being a second-order effect, will result in the production of sum and difference products between f_0 and $2f_0$. The result is a small sum term at $3f_0$, and by the same argument, some of this will be fed back and produce an even smaller component at $4f_0$, and so on.

The lesson seems clear; if you are considering negative feedback, use lots, or none at all. However, this seems to go against my own experience, and that of many a designer. It is common knowledge that even a modicum of nfb is highly beneficial in many instances. For instance it is commonly used to improve the fidelity of a tranny portable from shocking to poor.

What do you mean by distortion?

If an amplifier shows only even-order distortion, and a lot of it at that – say 10% – then it must be true that a little nfb will

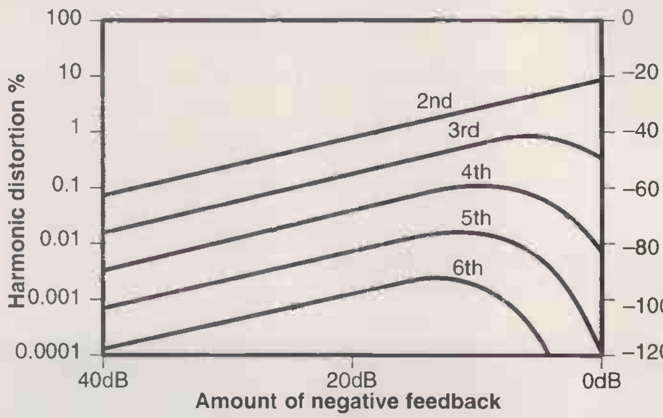


Fig. 1. Effect of different amounts of negative feedback on an amplifier with predominantly second harmonic distortion. (Reproduced by courtesy of Newnes)

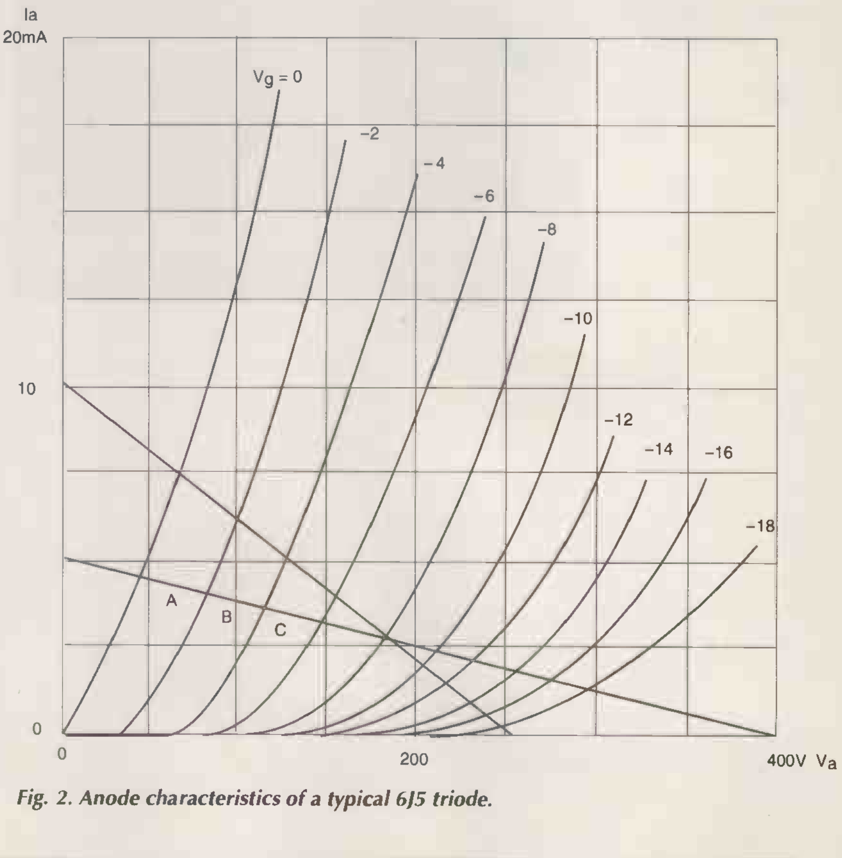


Fig. 2. Anode characteristics of a typical 6J5 triode.

introduce an appreciable amount of third harmonic, as per Fig. 1. And if you subscribe to the view that a given amount of third-order distortion sounds worse than the same percentage of second, which I would not dispute, then heavy nfb sounds a good idea, subject to the usual stability criteria.

But how many amplifiers really show nothing but second harmonic distortion? How about a big output triode like a *PX4* or even the much beefier *300B*? This latter device is frequently advertised in these pages at a mere £50 or so. Add a suitable output transformer, power supply and driver stages, and for only one or two hundred pounds you could build yourself a single ended class A leviathan – with or without nfb to taste.

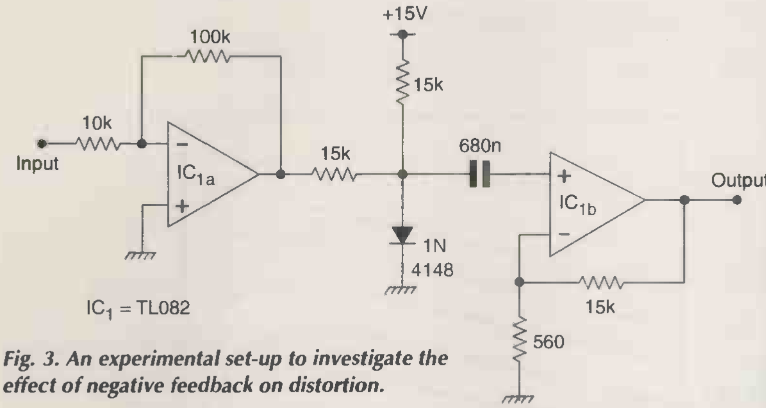
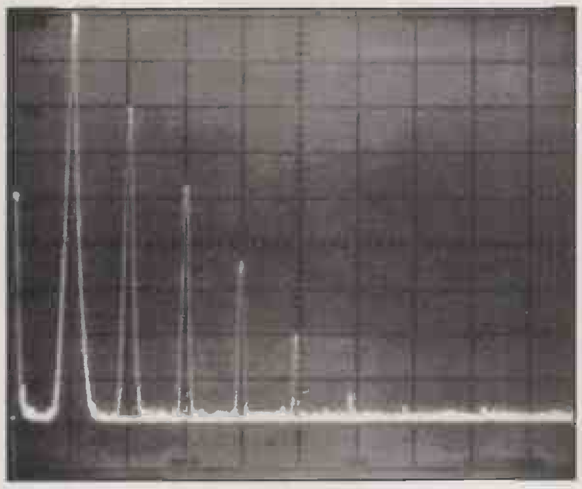


Fig. 3. An experimental set-up to investigate the effect of negative feedback on distortion.

Fig. 4. Showing the 1.12V pk/pk 1kHz input in Fig. 3, with the output superimposed on it. Span 0 to 10kHz, 10dB/div vertical, 30Hz resolution bandwidth, 2s/div sweep rate.



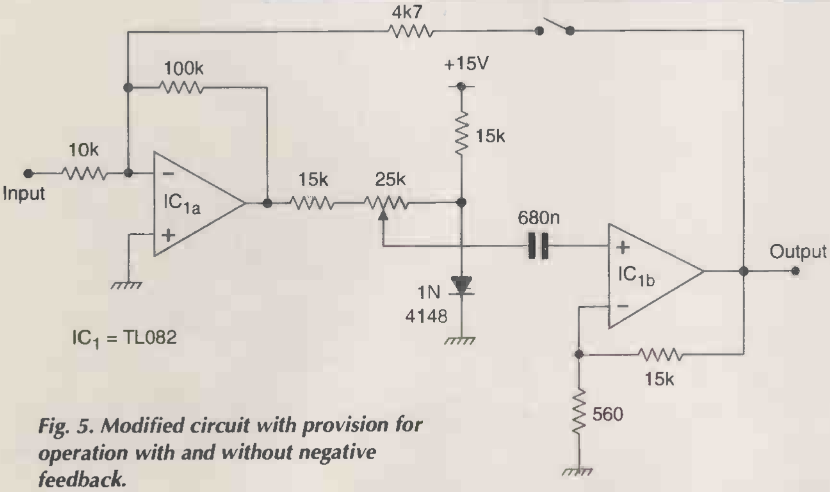


Fig. 5. Modified circuit with provision for operation with and without negative feedback.

In practice though, second-order distortion effects seldom appear on their own. I do not have characteristics of a large triode output valve to hand, but **Fig. 2** shows those of a small amplifier triode, the *6J5*, copied more or less exactly from reference 3. Two different values of load line are shown, the exact load chosen being, as usual, a compromise between power output and distortion.

Note the two volt increments of grid bias, and the load line distances *A*, *B*, *C*, etc., cut off between them. If $A=B=C$, etc., then the change in anode current for each 2V step is constant, and the stage is perfectly linear. This is clearly not the case.

Now suppose that $A–B=X$ and that $B–C$ also equals X, and so on. Then by the algebra of finite differences – closely related to differentials – the second differences of anode current are constant. As a result, only second-order distortion is present.

If however, X is not constant over the whole range of grid input voltages, then third-order and or higher order distortion will be present.

Suck it and see

Not having a large triode to hand, or even a *6J5*, I still wanted to look at the effect of a modest amount of nfb, like 10dB, on second harmonics. So I built up the circuit of **Fig. 3**, with a diode to provide a deliberate amount of second harmonic distortion built in.

Figure 4 shows the input and output, in stored traces. The input was a 1.12V peak to peak 1kHz sinewave from a very low distortion oscillator, ref. 4. Its trace is visible in Fig. 4 reaching to top of screen at one division in from the left, and remaining below the spectrum analyser's noise floor thereafter.

The gain of the *HP3580A* spectrum analyser was then adjusted so that the fundamental component of the circuit's output was superimposed on the stored input trace. You can see that, at –20dBc, the distortion is indeed principally second harmonic, as would be expected from a diode. But there are substantial harmonics up to the fifth, whilst the sixth and seventh are also visible above the analyser's noise floor, which is almost 90dB down.

Table 1 gives the levels of the harmonics, relative to the fundamental, as the amplitude of the fundamental is decreased in 10dB steps.

Thus, for example, for each 10dB reduction in the fun-

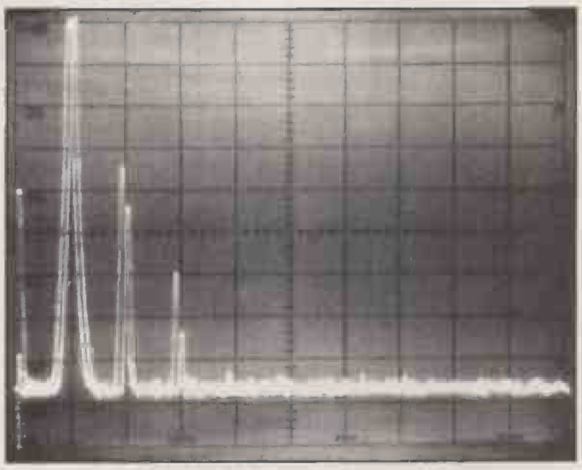


Fig. 6. Showing the performance of the circuit of Fig. 5, with and without 10dB of negative feedback. Span 0 to 10kHz, 10dB/div. vertical, 30Hz resolution bandwidth, 2s/div sweep rate.

damental, the level of the second harmonic falls by 10dB relative to the fundamental – a reduction of 20dB in absolute terms. Likewise, for a 10dB reduction in input level, the third harmonic falls by 30dB in absolute terms, as expected. For in general, for every 1dB reduction in input level, the level of the *n*th harmonic falls by *n*dB.

Now 10% second harmonic was a bit much for the experiment I had in mind. Even triode output valves without feedback generally have their power output rated at the 5% distortion level. So the circuit was modified as shown in **Fig. 5**.

With the negative feedback not connected, the 25kΩ potentiometer was adjusted so that the gain from A to B was unity, and the input amplitude set to 1.12V pk-pk as before. The output spectrum was measured and stored, appearing as the trace slightly offset to the left in **Fig. 6**.

Next, the 4.7kΩ feedback resistor was connected, reducing the gain by 10dB. The input was increased to restore the previous output level, the spectrum measured and recorded as the trace slightly offset to the right in Fig. 6.

Application of a modest 10dB of negative feedback can be seen to have reduced the level of the second harmonic by about the expected 10dB, but the reduction in third harmonic is nearer 15dB. This is presumably due to the third harmonic component, generated from the second harmonic by the mechanism discussed earlier, combining with the third harmonic component that was present originally.

However, besides demonstrating the reduction of distortion by negative feedback, the main conclusion I drew from the experiment and the triode characteristic mentioned earlier, is an important one. It is that in the real world, second harmonic distortion in a single-ended stage is always accompanied by third, albeit often at a lower level.

By contrast, although a well balanced push-pull stage may exhibit some odd-order distortion, it can achieve very low levels of second-harmonic distortion – even before the application of any nfb.

The ideal amplifier

There may be those who deny that second-harmonic distortion is always accompanied in practice by third, saying that I just haven't looked hard enough. But if it is indeed possible to make an audio amplifier with no third harmonic distortion, using a big thermionic triode or whatever, then a fortune awaits its inventor. And this is so, however bad the second-harmonic distortion may be, as I shall demonstrate.

Figure 7 shows the outputs of two amplifiers, the distortion in each consisting solely of 10% second harmonic, driven in antiphase. Also shown is the difference between them, which is the voltage which would be applied to a floating bridge-tied load loudspeaker, or BTL. This looks very like a sinewave and the reason is not far to seek.

The shortfall on the negative peak of one amplifier is compensated for by the peakier output of the other. You might imagine that this would reduce the 10% of second harmonic distortion in each amplifer to 1% or less of third across the loudspeaker. While this might sound like a good bargain, in practice things are even better.

The flattening and peaking of the fundamental is due to the second-harmonic component. And the positive and negative peaks of this are of course equal in amplitude. So the sharpening of one peak compensates *exactly* for the flattening of the other.

Consequently, the second harmonic distortion just does not appear across the loudspeaker, and the same applies to any other even-order harmonics. Notice however, that the while the amplitude across the load is ±2 arbitrary units, the swing at the output of each individual amplifier falls short of −1 unit but exceeds +1 unit.

Thus the presence of the second-order distortion eats away slightly at the maximum available power output, if clipping is to be avoided. If even a small degree of clipping be allowed, it will affect equally both positive and negative

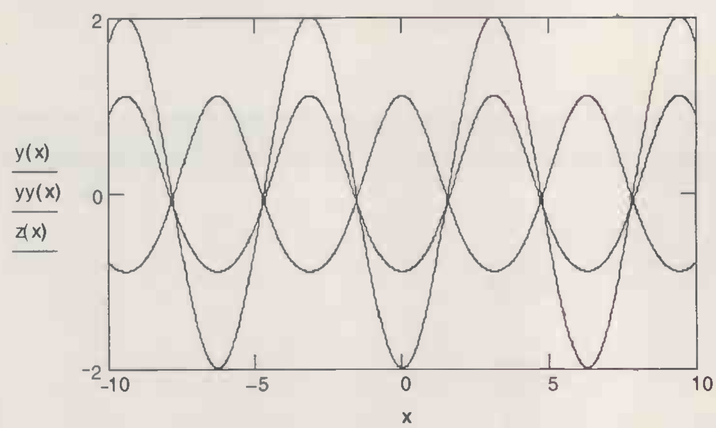
$$x := -10, -9.98 .. 10$$

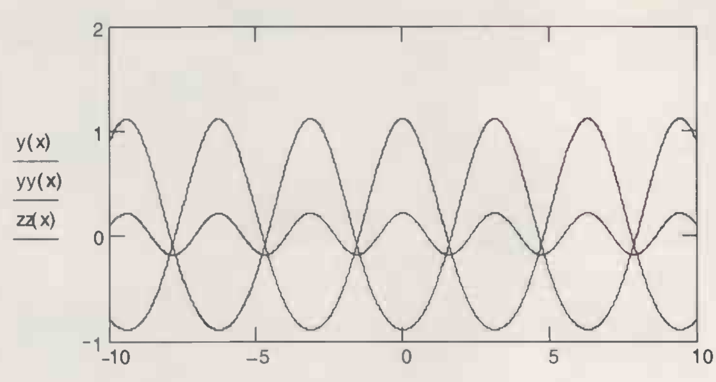
$$y(x) := \cos(x) + 0.1\cos(2x)$$

$$yy(x) := \cos(x+\pi) + 0.1\cos(2(x+\pi))$$

$$z(x) := yy(x) - y(x)$$

$$zz(x) := yy(x) + y(x)$$





Figs 7, 8. The upper waveforms are simulations of the outputs of two amplifiers, the distortion in each consisting solely of 10% second harmonic, driven in antiphase. Also shown is the difference between them, which is the voltage which would be applied to a BTL loudspeaker.
Fig. 8. Waveforms in the lower diagram are as Fig. 7, but show the sum of the two distorted outputs. This consists purely of the second harmonic component with respect to ground. But as it is a common-mode signal, it does not appear across the speaker terminals, assuming the speaker is floating.

Table 1. Levels of harmonics relative to the fundamental as its amplitude is decreased in 10dB steps.

Input level level (1kHz sinewave)	Harmonic output, decibels re input 2nd	3rd	4th	5th	6th
1.12V pk-pk=0dBref	−20	−38	−53	−70	−83
−10dB	−30	−59	−82	–	–
−20dB	−40	−79	–	–	–

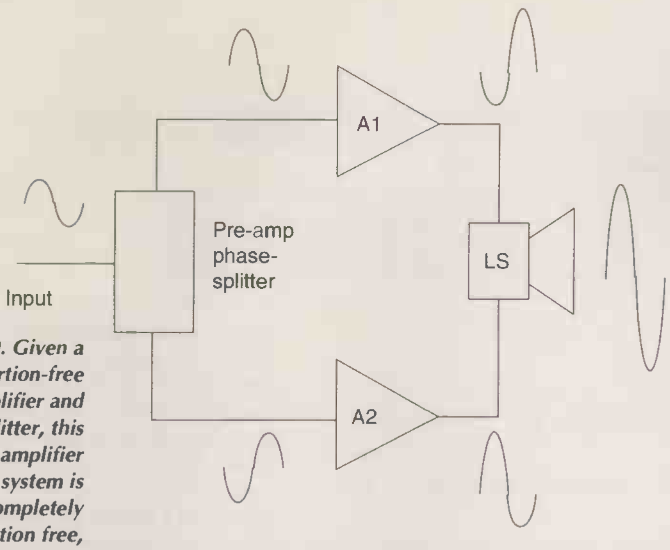


Fig. 9. Given a distortion-free preamplifier and phase-splitter, this power amplifier system is completely distortion free, provided solely that the output amplifiers show only even order distortion – 2nd, 4th, 6th etc. harmonics).

peaks fed to the loudspeaker, representing odd order distortion.

Figure 8 shows the two distorted outputs again, together, this time, with their sum. This appears as a common-mode component at the outputs, which will not affect the loudspeaker, assuming that it is operated as a floating BTL. The arrangement of a distortion free amplifier is shown in **Fig. 9**.

The arrangement only succeeds on the crucial assumption that the two amplifiers individually exhibit zero odd-order distortion. This is probably more likely to be achievable – if at all – if each amplifier is single ended. For a push-pull arrangement will usually convert even-order distortion in each half of the pair, into odd order distortion in their output.

Each amplifier in Fig. 9 could consist of a large triode, bipolar transistor of fet. For matching, the triode would require an output transformer. Having lower operating impedance levels, a bipolar transistor or fet stage could use choke coupling, or some other high impedance arrangement, such as a constant current source.

The possibilities are endless – provided only that you can design that elusive but essential odd-order-distortion-free amplifier. If you can, negative feedback is not needed, so there can be no nfb-induced transient intermodulation distortion in the event of overdrive. ■

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1. 'Valve and Transistor Audio Amplifiers,' J. Linsley Hood, Newnes 1997, ISBN 0 7506 3356 5.
2. Article by P. J. Baxandall, *Wireless World*, December 1978, pp. 53-56.
3. 'Radio Designer's Handbook,' F. Langford-Smith, Newnes 1997 (reprint), ISBN 0 7506 3635 1.
4. 'Low-Distortion Audio Oscillator,' Hickman's Analog and RF Circuits, Newnes 1998, ISBN 0 7506 3742 0.

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You can append your own notes to each of the sections of the index – click on the *Notes* button.

2

Spice CAD software

A working version of Spiceage from Those Engineers is included on the CD. This version is limited to 200 nodes and file saving is inhibited, but otherwise the program is fully working. Spiceage is in a folder, the name of which you will probably guess. The file to run for installing Spiceage is called Setupeval.exe. There's a readme.txt file if you need help with installing. Those Engineers can be reached on 0181 906 0155.

3

Spice models

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4

Data and applications information

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5

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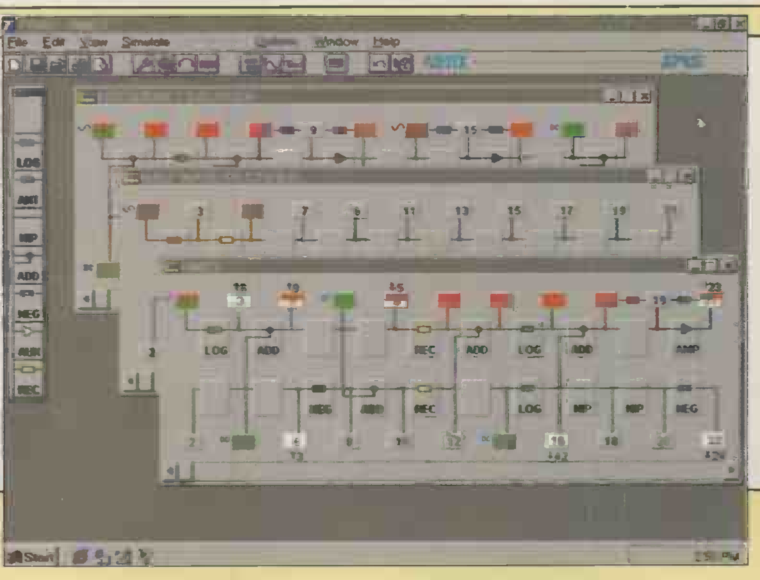

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ADC42 is a low-cost, high-resolution a-to-d converter sampling to 12 bits at 20ksample/s. This single-channel converter benefits from all the instrumentation features of the ADC200-50.

One telephone – two lines

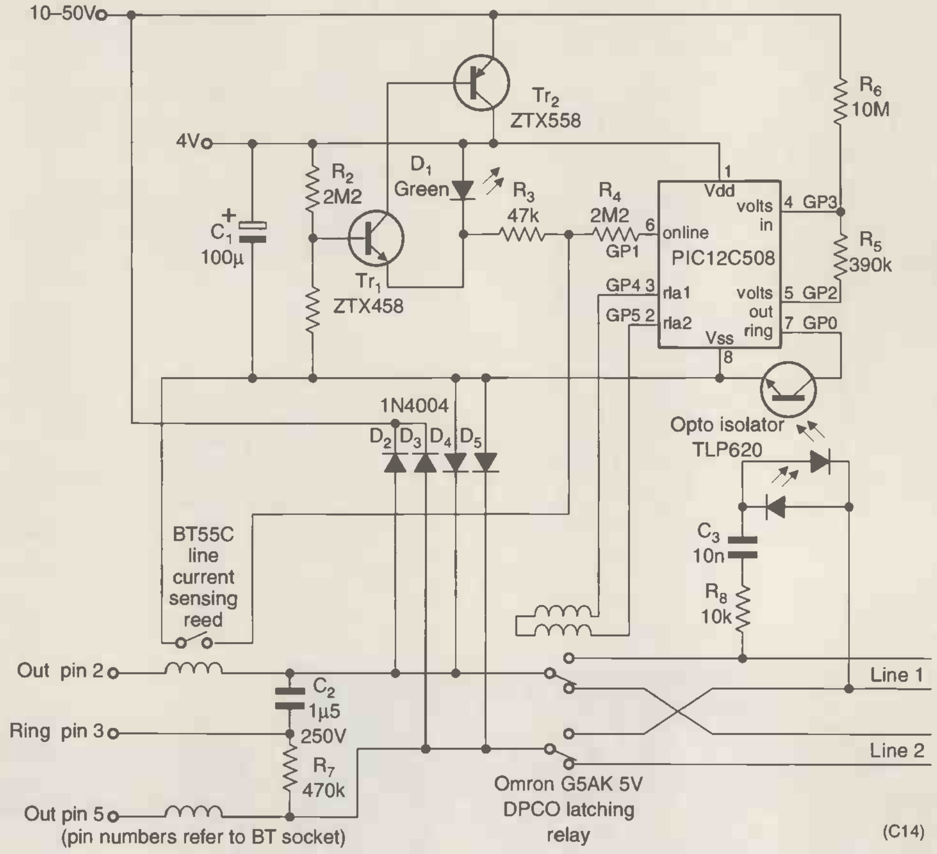
ADC42 Winner

If you have two telephone lines, this circuit allows the use of one 'phone, automatically switching lines when one is in use. Connection is normally to line 1 and the circuit switches incoming calls to line 2 if that rings. Putting the receiver down briefly changes lines.

The circuit is controlled by a *PIC12C508* and, since the logical process is wholly in the PIC, it is easily adaptable for individual needs. It is line powered and takes 5-10μA normally or 20-30μA when in use and, since this is much less than that taken by most telephones, several switches may be used.

The PIC is an eight-pin controller with an internal 4MHz oscillator; it runs here on interrupts generated by its watchdog timer at 144ms intervals. It executes a short burst of code and returns to "sleep"; this method of timing is not accurate but power is low.

Since power comes from the line, whose voltage may peak at 100V, most ic regulators were out and zeners or reference diodes need bias of several tens of microamps - far too much. The PIC needs 1mA for startup, but operates at 3-6V. Current is acceptable at 4V.



Automatic telephone line switch to allow the use of one handset on two lines, switching between the two.

A green led is used as voltage reference, working well at 1μA. The power supply does not work until V_{dd} is at least 0.7V and bias current flows through R_3, the 0.7V being provided by a slow charging current through R_6 through the PIC to the V_{dd} pin and the R_3 current by lifting the phone to connect R_3 to V_{ss}. GP1 on the PIC acts as an input to detect online/off-line and as a negative bias for the green led, this increasing when the attached 'phone is off the hook to ensure reliable reset for the PIC at startup. The PIC drives a latching double-pole changeover relay, an 8ms pulse at 3.5V minimum from the power supply.

Three inputs go to the PIC. Firstly, a ring on line 2 is detected by the ac optoisolator, which uses the PIC's internal pull-ups, a simple arrangement but so sensitive that software has to reject false signals. Secondly, the line-current sensing reed switch detects an off-hook 'phone. And thirdly, resistors $R_{5,6}$ detect line voltage of 10V off hook and 40-50V on hook.

If readers would like details of the short PIC program, e-mail *g.rutter@thefree.net* and quote 'Phone switch.'

GGR Rutter
London NW2
C14

Faster charging for xenon flash

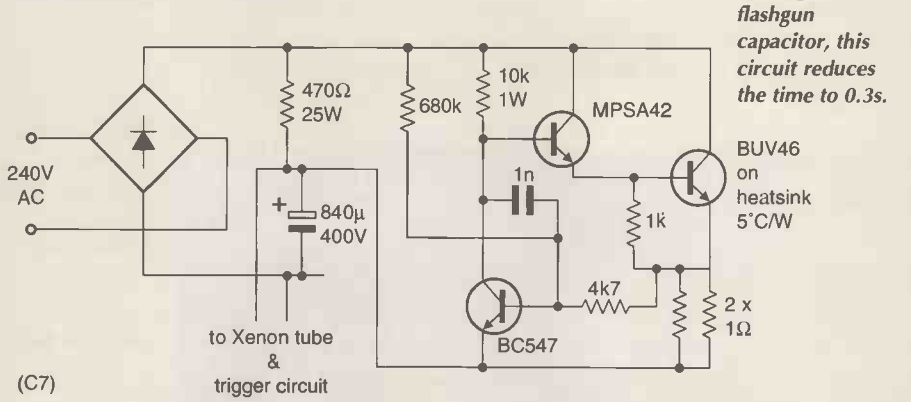
From about three seconds to recharge a flashgun capacitor, this circuit reduces the time to 0.3s.

This circuit reduces the time taken to recharge a xenon flash capacitor using a resistor by about ten times.

In the modified current source the 680kΩ resistor reduces current supplied while capacitor voltage is low since the 470Ω resistor is supplying plenty of current.

As capacitor voltage rises, current through the 470Ω falls and that through the *BUV46* rises to keep the transistor power dissipation in the safe area.

Neville Ward
Norwich
Norfolk



High-Q, programmable notch filter

A logarithmic amplifier such as the *TL441* may be used as a multiplier to give an output $V_o=X_1X_2$, as in **Fig. 1**. It may also be used to give the *n*th root or *n*th power of an input, depending on the resistance values. If $R_2=R_3=nR_1$, the output is, for $n=1$, a multiplier; for $n>1$ the *n*th power output and, for $n<1$, the *n*th root.

This arrangement is used in the circuit shown in **Fig. 2** to give a programmed notch at high Q. One multiplier provides a dc output and the other takes the dc as input and converts it back to the input frequency.

The low-pass filter and a 5MHz local oscillator then form a band-pass filter having an effective Q of 5000 and a 5MHz centre frequency, the low-pass section determining the bandwidth of $2f_c$.

Kamil Kraus
Rokycany
Czech Republic
C13

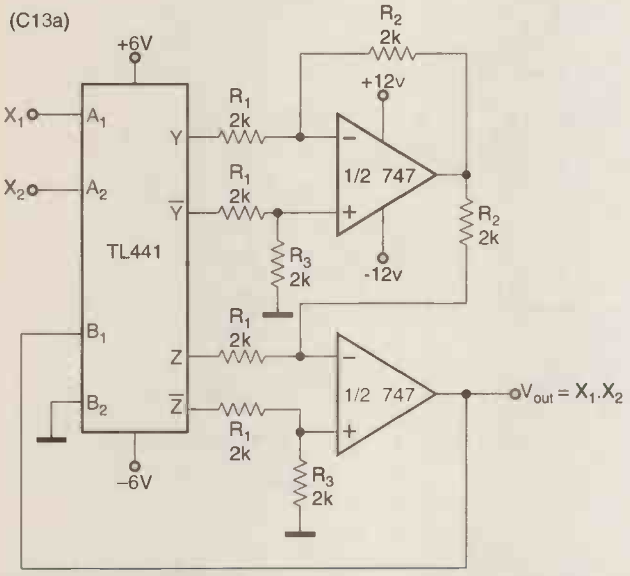
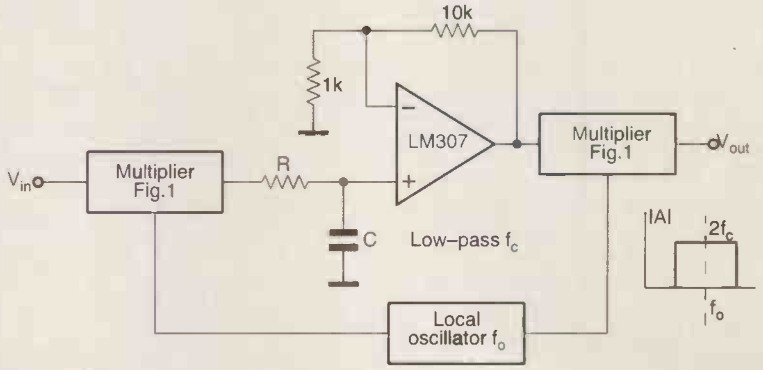


Fig. 1. A logarithmic amplifier used as a multiplier, which will also provide nth root or nth power output. Two such circuits are used in Fig. 2 to form a very high-Q notch filter, which is programmable.

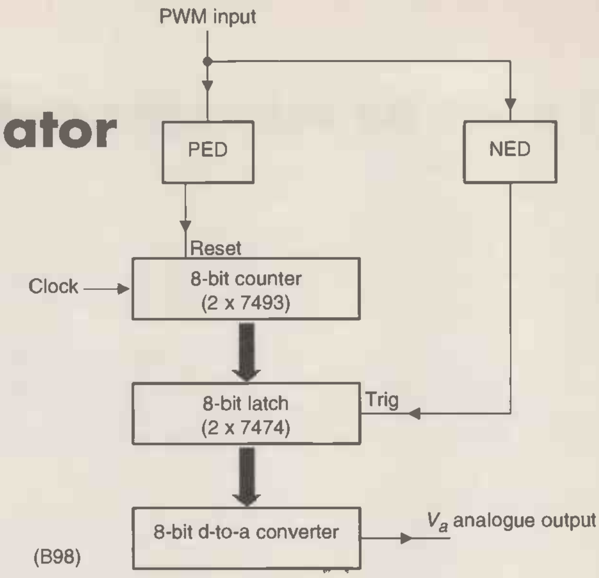


Linear pwm demodulator

Pulses from a pwm demodulator are converted to an analogue output that is directly proportional to the pulse width.

Positive and negative edge detectors were described in June 1998, p. 475. Here, the positive edge detector resets the counter and the negative edge detector triggers an eight-bit latch fed by the counter which, in turn, feeds a digital-to-analogue converter to produce the output analogue.

K Balasubramanian
Husseyin Camur
European University of Lefke
Turkish Republic of Northern Cyprus
B98



Simple and linear pulse-width-to-analogue converter.

Low-loss active diode

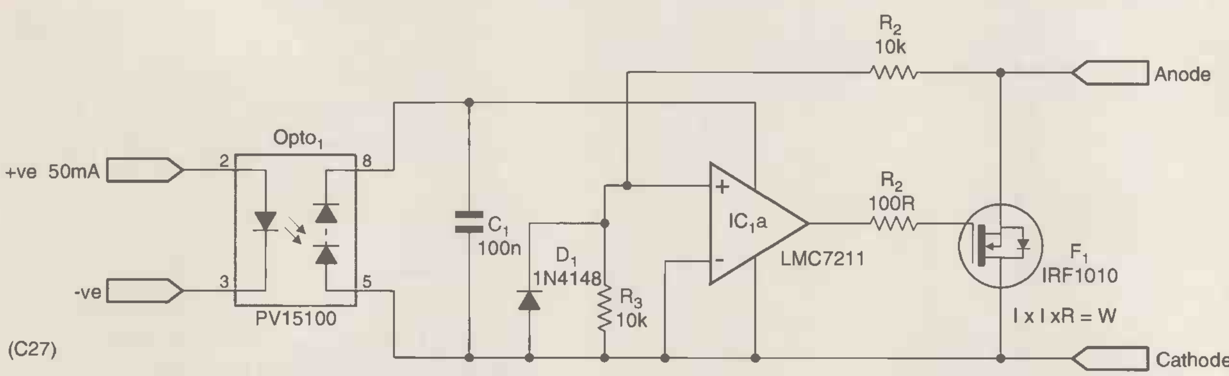
Since all diodes lose power as heat, this circuit was developed to reduce the loss and consequently the size of heat sink necessary. In the original large 400Hz, six-phase power supply, each diode dissipated 18W. With this active diode design, the loss is reduced to 3.6W.

Cmos comparator *LMC7211* by National Semiconductor senses that the anode voltage is high with respect to the cathode, its output turning the fet hard on. All power mosfets conduct in the reverse direction, although the V_f of the body diode inhibits the use of the effect; in low-voltage fets the problem is less. As the anode voltage falls at each half cycle, the fet turns off again.

The isolated supply comes from a photovoltaic coupler, the only high peak current needed being to turn the fet on. This can be supplied by the charge from C_1.

If a large current is needed to charge a reservoir capacitor at startup, the body diode prevents short-term overheating since its V_F is 0.7V.

Colin Wonfor
Bay Designs Consultants
Dunfermline,
Scotland,



Active diode circuit reduces power dissipation in a large power supply from 216W to 43.2W.

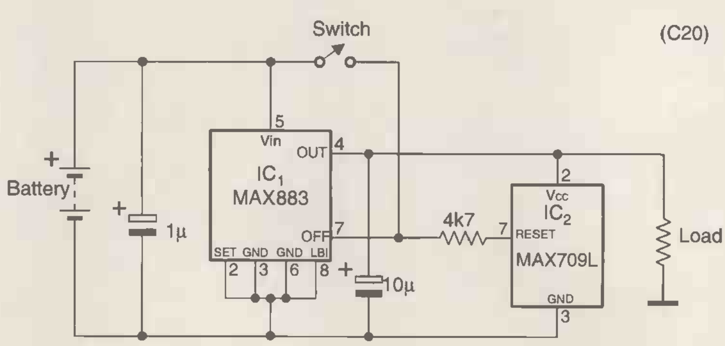
Positive regulator shutdown in battery systems

In portable equipment, a linear regulator often runs from the battery voltage, voltage monitoring circuitry shutting the regulator down if its output reaches the drop-out voltage. This disconnects the load, which allows the battery voltage to recover slightly, which causes the monitor to turn the regulator back on and so on...

The diagram shows a way of avoiding this chatter. The *MAX709L* is an inexpensive microprocessor supervisor used here to monitor the regulator output; when this reaches the supervisor's internal threshold of 4.65V, the supervisor's reset output turns the regulator off and removes the supply to the supervisor, reset remaining low. Close the switch momentarily before applying power.

Other versions of the supervisor with different thresholds are available.

Nigel Brooke
Maxim Integrated Circuits
Reading
C20



To prevent chatter when battery voltage falls below the threshold of the voltage monitor, the regulator turns off and remains off.

Parallel port as microprocessor bus

With any modern pc, this circuit may be connected to the parallel port to form a complete, eight-channel, 2kHz/channel data acquisition system costing less than £35. It is based on the National Semiconductor *LM12458* programmable 'datac', which has a 12-bit-plus-sign analogue-to-digital converter, an eight-channel multiplexer, a 32-word fifo buffer and a programmable ram to allow control of input and watchdog modes.

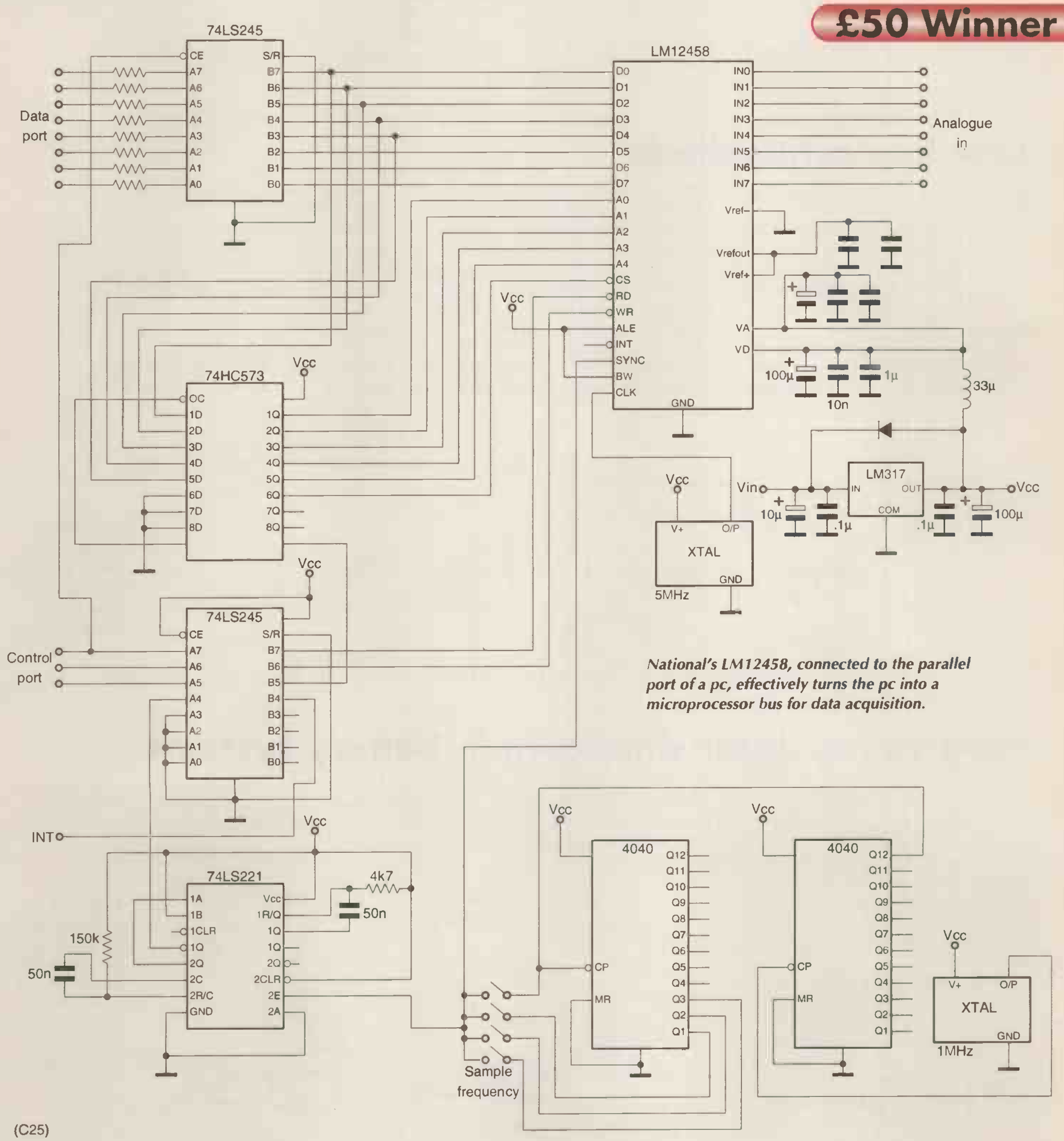
The *12458* is intended to run with a microprocessor and with the circuit shown connected to the pc parallel port, the chip 'sees' the pc as a microprocessor bus. The ram in the *12458* is first programmed and conversions timed by an oscillator driving flip-flops to give the required sampling frequency.

A *74LS221* dual monostable sends a pulse to the pc, triggering IRQ7 to signal that data is ready to download from the fifo – the *74HC573* latches an address to allow the selection of different registers in the *12458* for read and write.

A software virtual device driver handles communication with the circuit in a Windows environment; this software and a board layout may be obtained from David.Burke@UCD.IE.

David Burke
University College
Dublin
C25

£50 Winner



National's LM12458, connected to the parallel port of a pc, effectively turns the pc into a microprocessor bus for data acquisition.

£50 Winner

Monitoring catalytic converter operation

Dashboard led indicates rich or lean running of a vehicle's engine, avoiding damage to its catalytic converter.

Vehicles fitted with catalytic converters must achieve complete combustion to avoid damage or degradation of the converter. This circuit indicates rich or lean running by a bicolour led on the dashboard.

An oxygen sensor fitted to the exhaust detects an excess or deficiency of oxygen, denoting lean or rich running, its output consisting of a rectangular wave between 0.8V (rich) and 0.2V (lean) at very high impedance and at a frequency of around 1Hz. In **Fig. 1**, IC_1 takes the sensor output and produces a square wave, D_1 showing the fact; the preset copes with various sensor levels. Oscillator IC_2 drives the bicolour led in a 50:50 duty cycle, which turns on both leds and gives the effect of yellow.

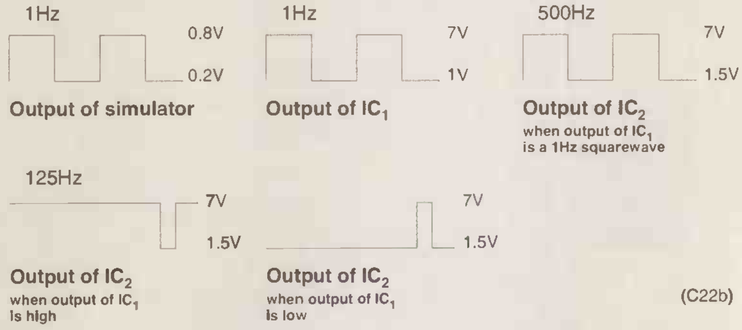
After filtering, output from IC_1 modulates the oscillator duty cycle according to the action of the sensor, causing either the red or green led to glow – red for rich, green for lean. A steady throttle opening shows both leds to give yellow.

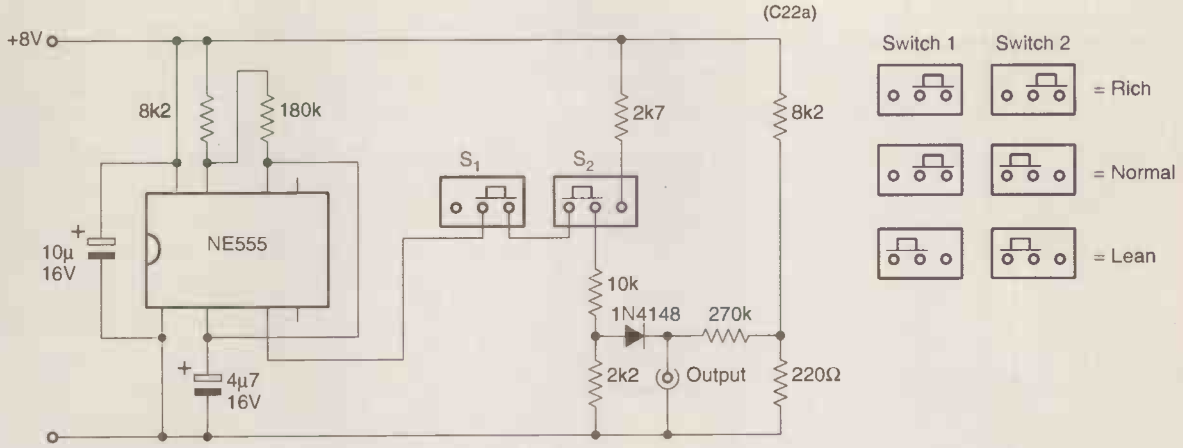
The sensor output appears on only one of the possibly four wires at high impedance and care is necessary to avoid deforming the signal.

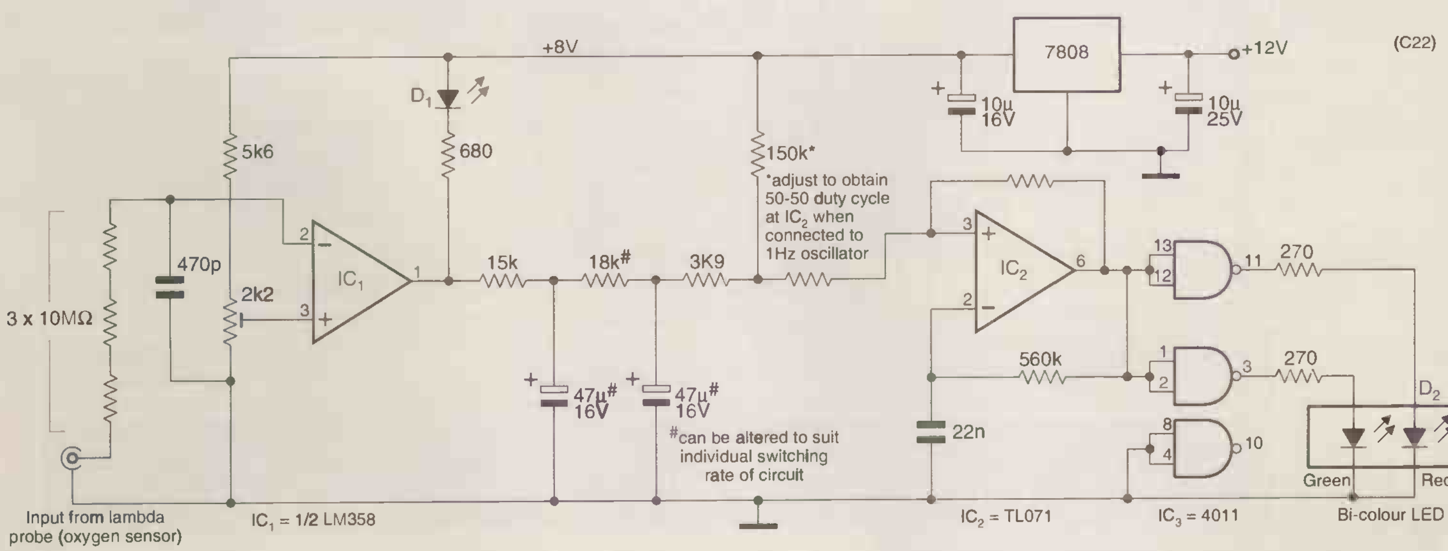
Figure 2 shows an oscillator to simulate the sensor action, which may be used for testing the circuit.

One further point — the exhaust pipe can reach temperatures in the region of 600°C!

K V Samson
Thornton Cleveleys
Lancashire
C22







Adjustable positive/negative voltage reference

Negative voltage references are not common. Most are positive types of 5V or 10V. This circuit provide either polarity and may be adjusted from –10V to 10V.

A +10V fixed reference with a temperature coefficient of 10ppm/°C provides the input to the variable-gain amplifier whose gain is variable from –1 to 1. Its output is determined by

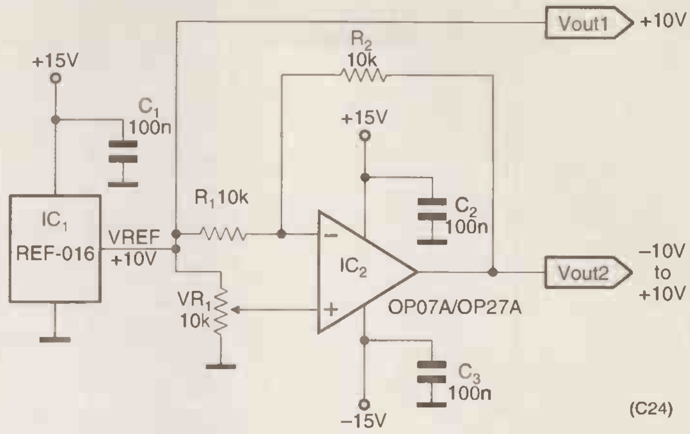
$$V_{out}=V_1(1+R_2/R_1)-V_{ref}(R_2/R_1),$$

so that if $R_1=R_2$ and V_{ref} is 10V, V_{out} is $2V_1-10$.

Moving the slider of the preset from bottom to top varies V_1 from 0V to 10V, V_{out} changing from –10V to 10V.

Resistors $R_{1,2}$ must be matched and care should be taken to ensure low input offset voltage and drift in the op-amp. Both types suggested have input offset of 10μV, drift of 0.2μV/month and drift with temperature of 0.2μV/°C.

V Manoharan
Naval Physical & Oceanographic Laboratory
Kochi India
C24



Not only providing a rarely found negative voltage reference, this circuit is fully adjustable from –10V to 10V.

1μs, 16-bit analogue-to-digital converter

For fast a-to-d conversion, a flash device is the best choice. But the cost of such a device of more than six bits becomes excessive, since each extra bit doubles the complexity.

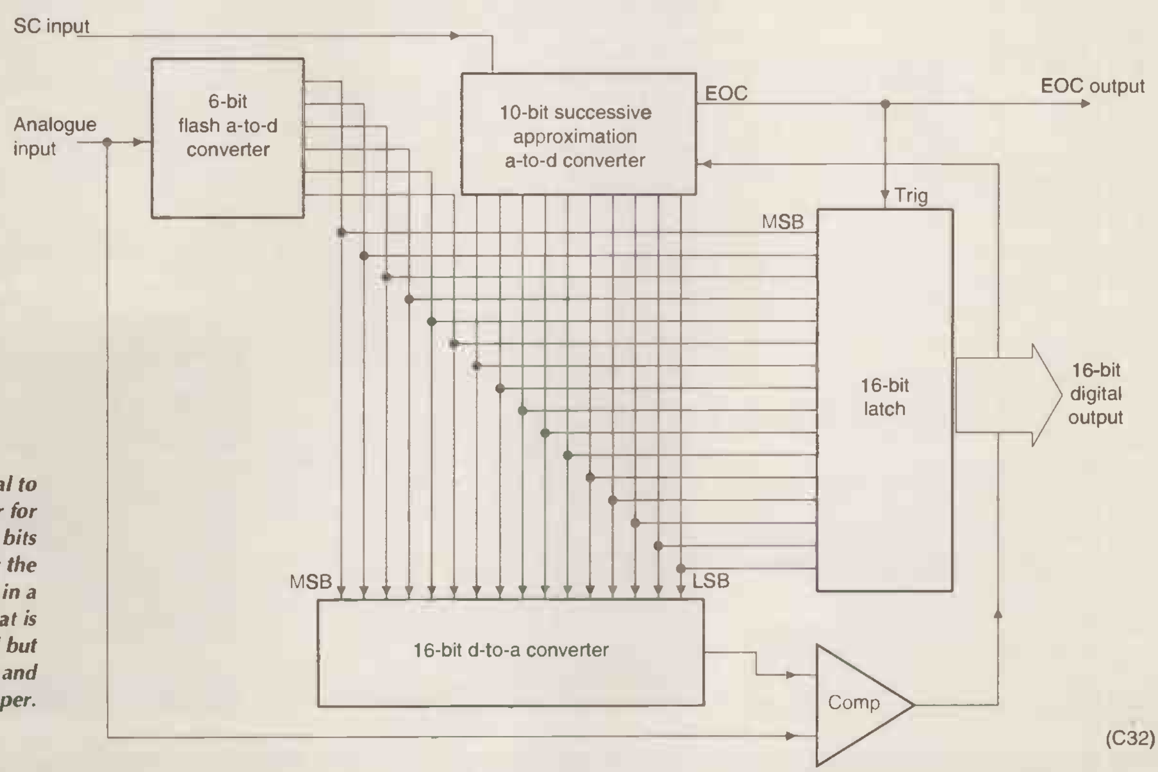
On the other hand, successive-approximation converters are somewhat slower, but a one-bit increase in capacity only increases conversion time by the period of the internal clock, so that a 10-bit, 10MHz converter converts in around 1μs and 1.6μs for 16 bits.

By combining a 20ns 6-bit flash converter with a 10-bit successive-approximation type, to obtain a 16-bit converter, conversion time is still about 1μs.

As analogue input is applied to the flash converter, output appears in 20ns and forms the six most significant bits, the ten least significant bits coming from the successive-approximation a-to-d converter. The start-conversion input to the successive-approximation converter triggers it. Output from the d-to-a converter is compared with the analogue input and the comparator output used to control the s-a a-to-d converter. After ten clock periods, the s-a produces an end-of-conversion signal and sets the latch to produce the combined digital output.

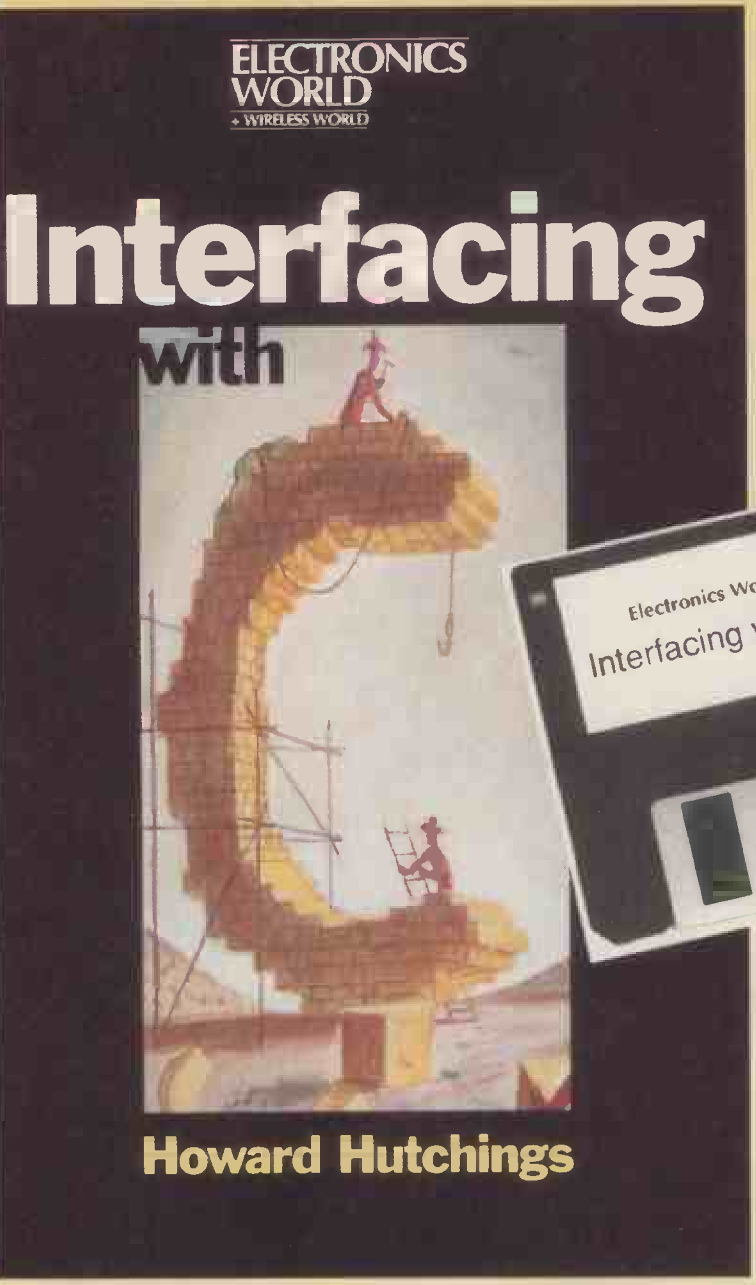
Conversion time of the circuit is therefore that of ten periods of the s-a a-to-d converter internal clock, whether the converter is an s-a type or a counting a-to-d converter.

K Balasubramanian
H Camur
European University of Lefke
Turkish Republic of Northern Cyprus
C32

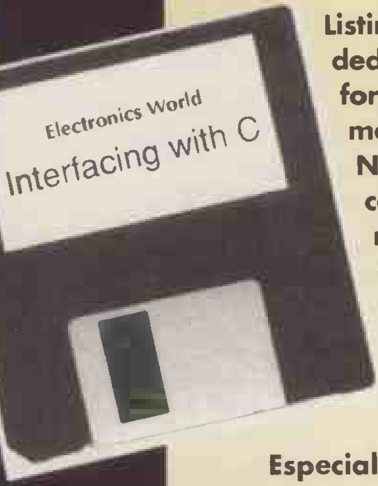


Using a fast digital to analogue converter for the most significant bits and a slower one for the least results in a combined circuit that is still acceptably rapid but less complex and cheaper.

Interfacing with C

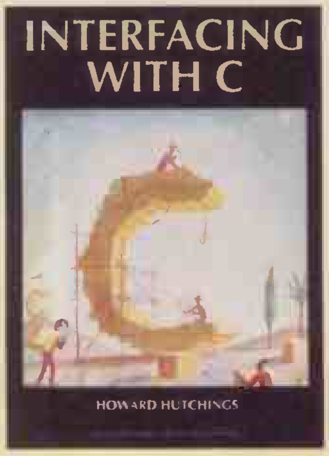


Without an engineering degree, a pile of money, or an infinite amount of time, the revised 289-page Interfacing With C is worth serious consideration by anyone interested in controlling equipment via the PC. Featuring extra chapters on Z transforms, audio processing and standard programming structures, the new Interfacing with C will be especially useful to students and engineers interested in ports, transducer interfacing, analogue-to-digital conversion, convolution, digital filters, Fourier transforms and Kalman filtering. Full of tried and tested interfacing routines.
Price £14.99.



Listings on disk – over 50k of C source code dedicated to interfacing. This 3.5in PC format disk includes all the listings mentioned in the book Interfacing with C. Note that this is an upgraded disk containing the original Interfacing With C routines rewritten for Turbo C++ Ver. 3. Price £15, or £7.50 when purchased with the above book.

Especially useful for students, the original Interfacing with C, written for Microsoft C Version 5.1, is still available at the special price of £7.50. Phone 0181 652 3614 for bulk purchase price.



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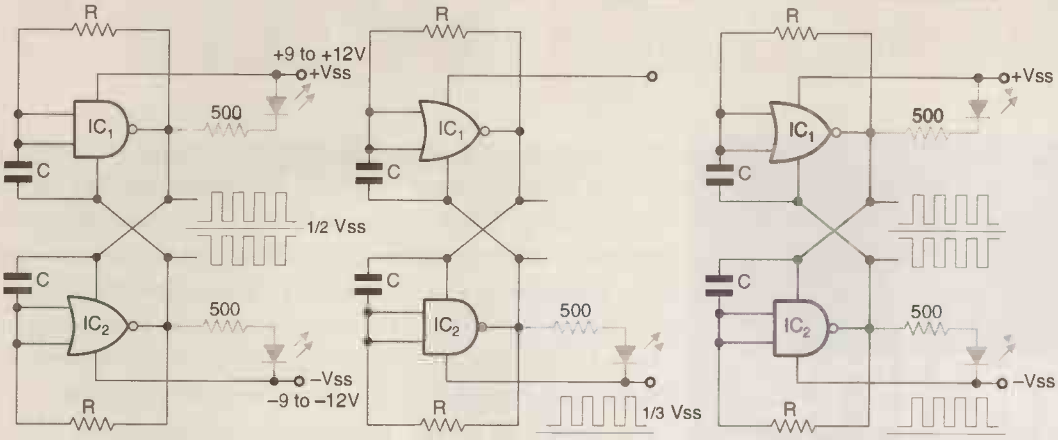
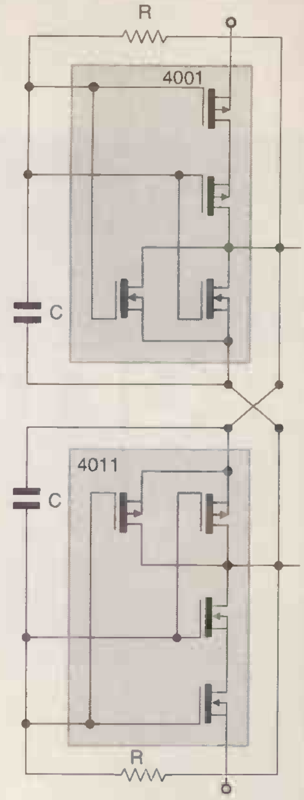


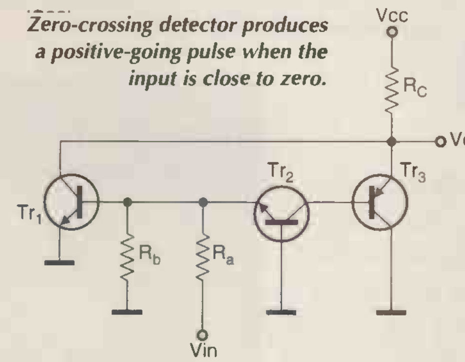


Three two-gate oscillators

Oscillators in **Figs 1-3** use one element from a *4001* and one from a *4011*. They look a little like ordinary cross-fed *RC* types, but in this case the output of each gate in Figs 1, 2 is used as the supply for the other; in Fig. 3, the negative supply for IC_1 is the positive supply to IC_2. The frequency of the symmetrical output square wave is around 1kHz when *R* is 1MΩ and *C* 1µF, the layout of the two ics being mirror images of each other.

Vasiliy D Borodai
Zaporozhje
Ukraine
C21

Elements in 4001 and 4011 devices are mirror images, leading to symmetrical outputs in these novel oscillators.



Zero-crossing detector produces a positive-going pulse when the input is close to zero.

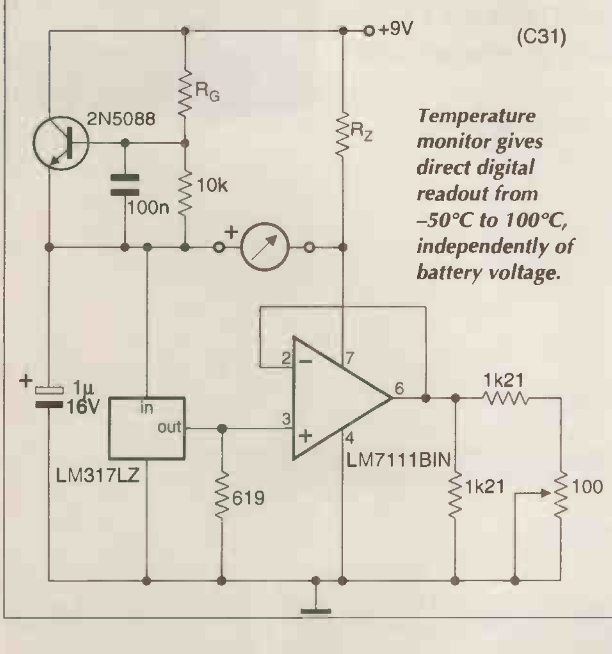
Zero-crossing detector

Output voltage from this simple zero-crossing detector is at V_{cc}; at all other times it is at $V_{CE(sat)}$ of Tr_2 or Tr_3.

With a positive input large enough to turn Tr_1 on, output is held low and when it is sufficiently negative to turn Tr_2 on, output is still low. Only when neither transistor conducts, the input being close to zero, is the output high.

On a positive-going edge, gain is set by the beta of Tr_1 and on a negative-going edge by the beta of Tr_3, so that rise and fall times should be fairly equal with typical transistors. The input resistors may be adjusted for the required switching threshold.

Gregory Rubinstein
Bogotá
Colombia
C28



Temperature monitor gives direct digital readout from –50°C to 100°C, independently of battery voltage.

Temperature monitor with 0.1°C resolution

Controllable gain and zero offset give a linear output to a digital meter of 10mV/°C, using a surface-mounted transistor as the sensor to obtain a rapid response at low cost.

Resistor R_G determines the factor by which normal V_{BE} is increased – in this case from –2.1mV/°C to –10mV/°C while operating from the constant-current sink formed by the *LM317LZ* voltage regulator with a 619Ω load. The 1.25V reference from the op-amp follower is also used as a current sink, adjusted by the 100Ω trimmer.

If R_z is now made 1.5kΩ, meter voltage is zero at 0°C and, since both ends of the meter are referred to V_{cc}, it is insensitive to battery voltage between 6.5V and 9V. Resolution using a digital meter is 0.1°C from –50°C to 100°C. Power used is less than 40mW.

John A Haase
Colorado State University
Colorado
USA
C31

£50 Winner

LETTERS

Letters to "Electronics World" Quadrant House, The Quadrant, Sutton, Surrey, SM2 5AS
E-MAIL jackie.lowe@rbi.co.uk

Radio 4's noisy floor

Charles Coultas is correct that the 'Today' program on BBC Radio 4 suffers from an excessively high noise floor in his February issue letter.

This has been going on for some time. Listening on precision speakers, it is easy to determine that the source is an inadequate air-conditioning installation. The blade passing frequency of the blower adds a dominant tone to the broad-band noise and the comb filtering due to standing waves in the ducting can be clearly heard.

There is no doubt that the studio concerned doesn't meet the BBC's own standards. I have a high regard for the BBC's technical staff and it is inconceivable that they don't know about the problem.

This suggests that the reason nothing has been done is political or financial. This is consistent with the BBC refusing to reply to Mr Coultas' justifiable complaint – a deplorable attitude.

I suggest that Mr. Coultas write to the Director General and to the *Radio Times*.

John Watkinson
Burghfield Common

Charles Coultas asks what the 'rumble' is on BBC Radio 4 long wave in the February issue Letters column.

This sounds to me like the long-wave version of the Radio Data System, RDS. This encodes binary data for transmission on the BBC Radio 4 carrier at 198kHz. In brief, the data, at 25bit/s, is biphase modulated onto a 25Hz digital carrier which then phase-modulates the 198kHz carrier at ±22.5°. The combination of low data-rate and low angle of modulation is supposed to ensure that there is no interference with the audio signal – but perhaps this is what Mr Coultas was detecting?

There are 30 blocks of 50 bits of data, which are repeated every minute. The last block before the minute contains data and time information. All blocks include a cyclic redundancy check word.

For an example of a typical receiver design, see: GEC Plessey Semiconductors, "Low-cost 198kHz Radio Data Receiver", Application note AN86. This was published in *Electronics World*, 99 (1692), pp. 960-1, Nov. 93.

The long-wave RDS does not carry the same information as the VHF system, which uses a higher data rate. This takes a bit stream at 1187.5Hz, and generates from this a DPSK signal (i.e. it is differentially encoded and bi-phase modulated). This signal generates raised-cosine pulses that are DSBSC modulated onto at 57kHz sub-carrier.

This was also described in *Electronics World* a few years ago, in an article by S.J. Parnell, 'Decoding RDS', *Electronics & Wireless World*, 95 (1636), pp. 148-152, Feb. 89.

David Gibson
Design Engineer, Microsystem Solutions
Leeds

Charles Coultas' letter in the Feb 99 issue mentions a low frequency rumble on the today programme.

I too have heard it while sitting in the Radio Theatre (formerly Concert Hall). It sounds like an underground train, which it almost certainly is as the Bakerloo line must pass close to Broadcasting House.

Mystery solved?

John Winn
Upminster

A window of misunderstanding

Mr Dennis (February, 1999) also demonstrates a certain lack of understanding.

At no time did I say that I was trying to run Windows 95 on a 33MHz 386 and 4MB of ram; that would have been, as I said, a bit limiting!

I 'upgraded' from that to the new one, which has a 32MB ram and runs at 166MHz.

Philip Darrington
Appledore
Kent

Shocked, I am

Regarding EMC and the problems experienced by Mr Elvis, there are several answers to his problems.

Firstly the EMC legislation is hardly worth the paper it is written on. I have experience on this for my own pet hate is EM pollution.

In this area, electric fences are extremely popular during the grazing seasons with the result that the long and medium wave broadcast bands are rendered useless.

These fence energisers resemble a

Ionisation chamber

In my letter in the October 1998 issue, entitled 'Radiation answers,' I mentioned the use of an ionisation chamber. I synthesise here below how the chamber works.

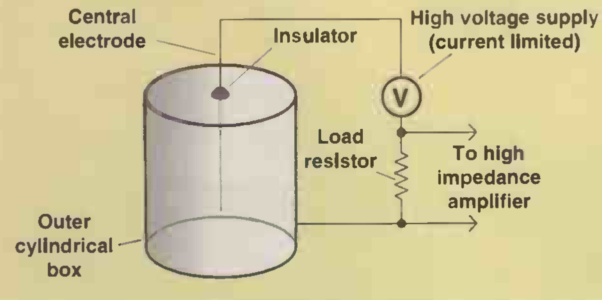
The chamber, outlined in the sketch, consists of a cylindrical metal box, at the centre of which a very highly insulated electrode is brought.

A high DC potential is applied between the box and the electrode by a high impedance supply in series with a large resistor. The voltage applied – in contrast with Geiger-Muller counters – is far from the break-down voltage of the gas inside the box, but high enough to set up a strong field. This voltage causes any ion existing within the box space to be captured by the electrodes. Symmetry is very important.

The tiny current arising from ion capture is measured across the load resistor by an electrometer amplifier and is directly proportional to the number of ions captured.

The device is very simple, but versatile. A radioactive sample could be enclosed in it and its total radiation over the spherical space surrounding (or 4π) will be measured.

Alternatively, a suitable window of very thin metal sheet or metallised plastic can be used as an input window, replacing part of a wall or of the bottom. This alternative is suitable for measuring larger radiation sources. Changing the window type and thickness offers wide discrimination between radiation types and energy.



There is a wide scope for clever solutions in the design of the chamber itself to avoid current leaks and to limit the field gradient at the passage of the central electrode. The electronics associated will be also challenging.

Unfortunately I am not a specialist in radiation measurement, but information on this topic can be found in open literature and textbooks on the subject. You should be able to find dimensions, voltages, tips for insulation and characteristics of the devices.

I have seen an ionisation chamber being used in a radioactive laboratory that was no larger than a fountain pen. It was in form of a pen, and intended to be carried in a pocket.

Inside it, gold covered quartz fibre acting as central electrode was charged at high voltage against the walls when 'zeroing' the device. During measurement, the quartz fibre also acted as an electrometer: its deflection against a small internal graduation was checked by means of a small lens system at the lip of the 'pen'. It was mostly a safety device, of modest precision, but very simple indeed.

Finally, there are other potential radiation sources that I did not mention in my earlier letter. Uranium salts are commercially available at specialist chemical suppliers. They should be easily purchased in small quantities.

As a pure chemical, the radiation will be only that of uranium, as quoted in literature, with the exclusion of the rest of the decay chain.

Health and safety can be cared for by using one of the oxides, which are almost totally insoluble. Even so, you should avoid breathing in the powder. Even better will be pure thorium oxide, which is a refractory untreatable oxide. The same safety precautions apply.

Dr G Imarisio
Menton
France

capacitor-discharge ignition system: most will produce a 'fat' spark and it is claimed that the premier models will 'energise forty miles of fence and kill back vegetation'.

Some years ago I wrote to the European Parliament regarding the interference that these fences cause. I also highlighted their lack of compliance with the EMC Directive, and requested that it be made compulsory for low pass filters to be fitted.

I am sorry to report that the response was pathetic and derisory. Although I did receive a large folder of waffle, it was evident that farmers must not be upset at any cost.

On a practical basis it would appear that equipment can easily be made to comply with the directive. But once you connect wires to it, it is a different story.

Help is at hand though, in the form of the book 'EMC for product designers' by Tim Williams. I have no connection with the author, but I would recommend the book as good grounding in the subject.

Finally Mr Elvis's relay problem can be solved by fitting recirculating diodes across the coils. Standard or slow recovery types are best. The 1N400x range is both suitable and economic.

D Benyon
Bude
Cornwall

Missing charge

In the January issue's letter column, Mr Cox, seeks a physical level explanation for the 'lost' energy when two capacitors share a charge, and then uses an idealised zero-resistance model which does not conform to physical reality.

A proper calculation shows the energy dissipated in the switch and interconnection resistance is half the original energy – a value that is unaffected by the precise resistance value.

If the resistance is zero, the initial current is infinite, and the time-integrated power, which is the energy dissipated in the resistance is still a finite $^1/_2CV^2$.

Consequently both energy and charge are conserved to the great comfort of physicists everywhere.

Dr A M B Shaw
Baldock
Hertfordshire

Brian Cox's thought experiment has instantaneous voltage changes across its capacitors. Charge in a capacitor is proportional to the product of the voltage and capacitance, or:

$q=c.v$

With a fixed capacitance, the rate of change of charge is proportional to the rate of change of voltage, or:

$dq/dt=c.dv/dt$

Rate of change of charge is current, so Mr Cox's experiment invokes infinite current. It is not possible to connect the capacitors directly without loosing energy in the resulting bang.

The two capacitors may be connected without a bang using a series inductor which does allow instantaneous voltage changes across its terminals. Doing so causes the voltage across C_1 to drop as charge flows across, building up current in the inductor.

The current reaches a peak when the capacitor voltages are equal. Energy stored in both capacitors is then a quarter of the original value, and the remaining half is stored in the magnetic field of the inductor. The current then falls to zero as the voltage across C_1 drops to zero and the voltage across C_2 rises to the starting value.

This oscillatory process then reverses, repeating *ad infinitum* since my thought experiment ignores loss components of resistance, radiation, dielectric, hysteresis, etc. But at least it doesn't cause a bang.

Chris Ward
Via e-mail

Did you write in?
Brian Cox's letter on capacitor discharge in the January issue prompted an unprecedented level of response. Bryce Smith's letter on light gates also had a surprising effect on you. All of the replies were good reading, and some were so comprehensive as to merit the title 'article'. Space permitting, more response to Brian's letter will be published later. Many thanks to all of you who have written in. Ed.

Problem ironed out

In his letter 'Filament failure' in the the January issue, Mr Ziemacki mentions the barretter but fails to realise that the essence of this device was that it used an iron filament in a hydrogen atmosphere. It can be designed to work between about 200mA and several amps by varying the gauge of wire.

A typical device maintains a constant current within perhaps 1% over a range of 95 to 165V. The use of an iron wire means that it must be kept away from magnetic fields which could cause the filament to vibrate, with detriment to its life, its characteristics, or both.

Although barretters dissipated a deal of heat, I always considered them more reliable than the series resistor used in valve television sets.

J C Taylor
Heywood
Lancashire

Rusty diodes

There has been discussion in recent years over the linearity of cable resistance – in particular the existence of oxide diodes and their effect on audio performance.

I have come across an application note from Microwave Associates that suggests that such non-linearity does exist in rf connectors. It is also a concern in high capacity cell phone systems.

However the company makes it plain that the non-linearity is only an issue with high capacity systems where several transmitted and received signals share the same physical channel, and where IMD levels of –160dBc – ie. 0.000001% or ten parts per billion – are required.

I think we can safely say that this has little or no relevance to hifi. The document in question is 75.pdf and it is available at www.macom.com. The easiest way to find it is to do a search using 'intermodulation'.

Phil Dennis
School of Physics
University of Sydney
Australia

Vision by radio

I greatly enjoyed Don McLean's story of his inspired recovery of video images from early Baird 30 line television transmissions. And I have no doubt that Baird was the

And the winners are...

Here are the winners of the two competitions we ran recently. Sincere thanks for all your feedback on favourite topics. Circuit ideas were most popular, followed by audio design, and then rf design.

Audiophobes note that this issue is a little audio heavy. This is not indicative of a change of direction. I didn't anticipate that Ian Hickman would offer me an article on audio distortion at the last minute. But could you have refused such an enlightening account? Ed.

Grundig oscilloscope winner:

David Paterson, Glasgow

Multimeter winners:

Dominic Steele, Altrincham
Jose Cavassi, Argentina

Factfinder winners:

Brian J Aitken, Stevenage
Gill Rickards, Charfield, Gloucestershire
John Winn, Camberley, Surrey
Peter Meinertzhagen, Sevenoaks, Kent
David Reid, Oldham, Lancashire
Doug Webster, Ampthill, Bedfordshire
Huw Jones, Llantrisanat, Mid Glamorgan
R J Philips, Bassingbourn, Hertfordshire
Peter Ferrell, Orpington, Kent.
C M Taylor, Shaw, Lancashire.

catalyst who made broadcast television a reality.

That said, I felt it was unfair to dismiss the work of other pioneers using film and silhouettes as not 'true television'. This debate has run since the late 1920s, when the Baird lobby was economical with the truth about rival experimenters to enhance his priority claim.

To me, television is the instantaneous transmission of moving images between two points. There is no doubt that Baird's transmission of images of real objects using reflected light was technically more difficult, but true television existed before he demonstrated his advance in the art.

I consider the real inventor of television was Francis Jenkins, an American motion picture technologist who laid all the foundations of practical television. More importantly, he recognised the true entertainment value and scope of the new medium. This can be clearly seen from the 1925 picture attached, which shows a television more like today's than any Baird Televisor.

In his book 'Vision by Radio', 1925, Jenkins outlined and demonstrated an the elements of a practical television system, which he said was capable of handling picture modulation signals in excess of 1MHz to give the image quality needed for home entertainment.

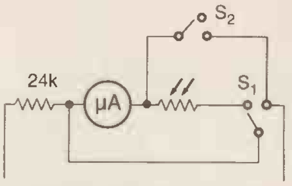
Without in wishing to devalue Baird's achievements, the tight definition of 'true television' as the transmission of images lit by reflected fight is illogical. We might as well define true radio as transmitting speech and music rather than morse, so the inventor of the radio was Fessenden in 1906 – not Marconi in 1895.

Anthony Hopwood
Upton-upon-Severn
Worcestershire

Jeez – I told you we'd be able to pick up Baird's tv signals. This one's one of them there whacky corn circles that the Brits are always on about.

I wired into this, and...

This is a brief reply to Jean-Marc Brassart's little circuit puzzle. A



neat little puzzle, but his estimation of how long it would take to solve is woefully extravagant.

I would expect someone with an interest in electrical/electronics to solve it in less than ten minutes. I took (I think) less than 5 minutes. So I expect Jean Marc to be very surprised.

Andrej Chomyn
Via e-mail

High-voltage fuses found

In the February issue, I noticed that Mr Gentle was having problems obtaining high voltage fuses as spares for a microwave oven. He might care to contact CPC in Preston, tel. 01772 654455. This company stocks seven values of high voltage encapsulated fuses in various ratings from 500ma to 1A.

The devices have a rated voltage of 5kV and they are fitted with leads ending in 6.3mm right angle female spade connectors. The catalogue price is £2.45 for individual fuses and on small orders will also add 3.99 p+p before also including VAT. This represents a significant reduction from the mentioned £50.00 he is supposed to have been quoted for the alternatives – a high proportion of the replacement cost of the complete oven.

Dave Turtle
Erith

Lighting emergency

In George Goh's emergency lighting arrticle in the January issue, details of the transformer were omitted – sorry. For 2.4V operation, use an FX3440 core with 0.55mm spacer or FX3670 with 0.65mm spacer on a DT2484 coil former. For the first winding, use 500 turns of 0.18mm wire wound neatly. Use insulating tape then bifilar wind the three turns each of W_2 and W_3 using 0.5mm wire. Finally, apply the three turns of W_4 using 0.31mm wire.

For operation at 4V, use either of the same cores but with 0.34mm and 0.45mm spacers respectively. Reduce W_1 to 400 turns but increase $W_{3,4}$ to 4 turns. Winding W_4 stays the same. The core spacer must made from a non-conducting material.

Measuring Yagis

In the December issue, in the article on measuring Yagis, the difference path between direct and reflected wave should have been:

$$r_o=((h_t+h_r)^2+(d)^2)^{1/2}-((h_t-h_r)^2+(d)^2))^{1/2}$$

In both terms of the above equation the square of the distance is used instead of the distance, in accordance with Pythagoras' law.

The receiving area of the dipole is $0.131\lambda^2$. Also in this case the square of the wavelength against wavelength is used.

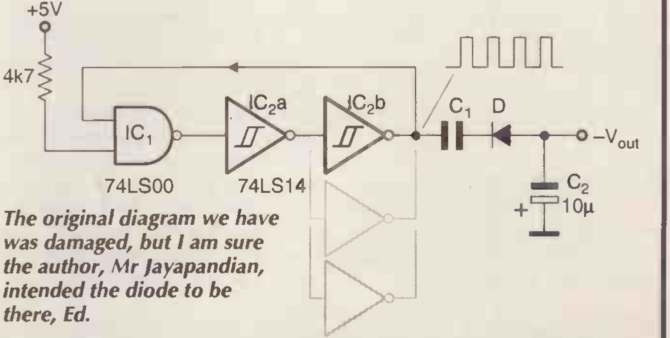
Marco Arecco
Via e-mail

Negative voltage converter

In Circuit Ideas, January 1999, the idea 'Negative voltage converter' will not work. The rectifier circuit needs a path to ground for positive half circles of the clock signal so that C_1 can charge. This is prevented by diode D, but adding a second diode provides such a path.

The revised circuit charges capacitor C_1, when the clock signal is positive, through diode D_2. During the negative half cycle, when the clock signal is at ground potential, C_1 discharges and creates a negative current flow. Diode D_2 is reverse biased, so does not conduct. The negative current flow passes through diode D and produces a negative voltage at the output, assuming that the load provides a dc path to ground.

Steve Winder
Ipswich
Suffolk



The original diagram we have was damaged, but I am sure the author, Mr Jayapandian, intended the diode to be there, Ed.

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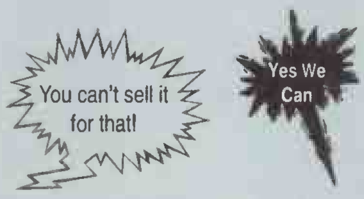

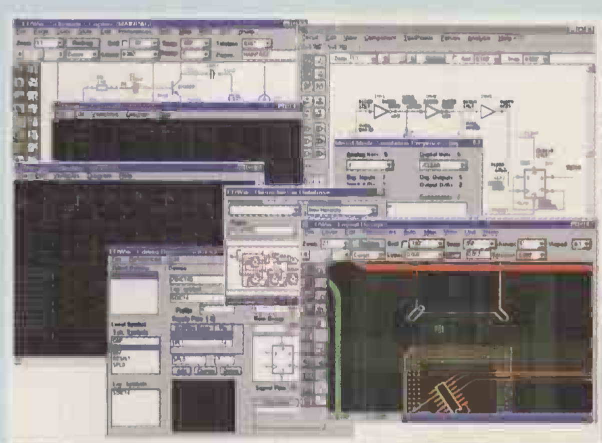

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AMP. Tel., 0181 9542356; fax, 0181 9547467.
Enq no 501

Data converters

DVD DAC. AKM's *AK4393* is a 24-bit, 96kHz sampling, stereo d-to-a converter that complies with DVD standards, having a dynamic range of 120dB and sampling at 32, 44.1 and 48kHz as well as 96kHz. Outputs are filtered on-chip by a switched-capacitor filter that tolerates clock jitter of several tens of nanoseconds, since output charge packets are determined by an external voltage reference and not the clock. No exotic pll is therefore needed and neither is level conversion because the digital interface is at ttl levels.
Asahi Kasei Microsystems Co., Ltd. Tel., 01923 226988; fax, 01923 226933.
Enq no 502

Discrete active devices

Switching dual diode. Rohm offers the *BAV9U* surface-mounted dual diode package, which exhibits a peak reverse voltage of 90V and maximum repetitive forward current of 600mA; at 200mA, forward voltage is 1.05V. Power dissipation is 225mW and surge current rating is 4A. Junction temperatures between –65°C and 150°C are accepted and reverse recovery time is 20ns.
Rohm Electronics UK Ltd. Tel., 01908 282666; fax, 01908 282528; web, www.rohm.co.jp.
Enq no 503

Displays

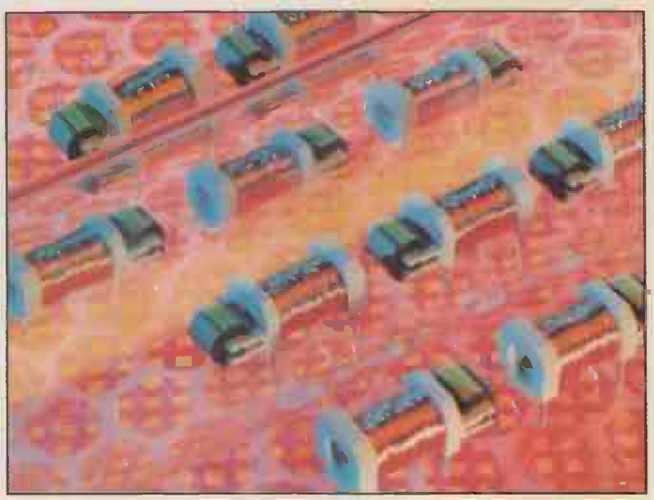
Serial-to-lcd interface. As part of the *EDE* range of "building-block" ics by E-Lab Digital Engineering, the *EDE702* serial-to-lcd interface ic allows any size of text display to be used from only one pin of a microcontroller, instead of the usual eleven. It also eliminates the software for latching, writing and control since it provides a standard serial data interface. Other units in the range are the *EDE1400* parallel printer driver that takes serial data in; the *EDE1200* stepper-motor driver providing full control in any mode; and the *EDE300*, which controls external devices via a pc when connected to its serial port.
Dannell Electronics Ltd. Tel., 01376 347415; fax, 01376 550019; e-mail, sales@dannell.co.uk; web, www.dannell.co.uk
Enq no 504

On-screen display module. LS Designs has a range of on-screen display modules to superimpose text directly on composite-video signals. Four units in the range provide displays from basic time and date information to serial-controlled text. They are on single-in-line boards, they need few external components and special versions can be provided for specific applications.
LS Designs. Tel., 0115 9324488; fax, 0115 9325588; e-mail, info@lsdesigns.co.uk; web, www.lsdesigns.co.uk
Enq no 505

Hardware

Pentium II cooler. Combining the Sunon *Cap Fan* with a heat sink designed by Thermalloy has enabled the thickness of this Pentium II processor cooler to be reduced to 18mm, while its claimed performance is 150% more efficient than standard Pentium II types. Exhaust of the warm air is over 360° and the fan motor has no direct contact with the heated area to promote long life. The cooler has fixing clips.
Thermaco Ltd. Tel., 01684 566163; fax, 01684 892356; e-mail, thermaco@compuserve.com
Enq no 507

Sealed, cast housings. Densitron has a new design of equipment housing that not only halves tool costs but produces a cast-alloy housing complete with heat sink and rf seal as a single piece for vhf use. The rf sealing is achieved by a system of closed cells inside the housing and an automatically dispensed rf sealing gasket. The housings are nickel-plated, machined, stove-enamelled and sealed to IP54.
Densitron Europe Ltd., 01959 700100; fax, 01959 700300; e-mail, sales@densitron.co.uk; web. www.densitron.co.uk.
Enq no 508



Magnetic indicators. With an eye on aerospace and medical usage, Electrodynamics has introduced the *C125* single-coil, latching, non-volatile indicator, which operates in the –40°C to 134°C range in 100% relative humidity and in a pressure of 30lb/in^2. This device is meant for fault indication in poor conditions and low ambient lighting. It comes in 3V, 6V and 12V versions and responds to a 50ms or longer pulse to latch the drum and exhibit a red, yellow, green or white face.
Relec Electronics Ltd. Tel., 01929 555700; fax, 01929 555701; e-mail, sales@relec.co.uk
Enq no 506

Linear integrated circuits

Rail-to-rail comparators. Two SOT23-5 rail-to-rail cmos comparators by Micrel are designed to operate from 2.2-10V and are for use where space is limited, being five-pin devices. *MIC7211* has a conventional output stage and the *MIC7221* an open-drain output; both exhibit a common-mode range to exceed the rail voltages. Supply current is 7μA and response time under 5μs.
Micrel Semiconductor Europe. Tel., 01635 524455; fax, 01635 524466; web, www.micrel.com
Enq no 509

Materials

Shielding gaskets. *Combination Gaskets* from Warth combine ME and MS electromagnetic shielding strips bonded in parallel to a closed-cell neoprene or silicone sponge elastomer. Shielding is in excess of 128dB between 1MHz and 100MHz. In addition, the gaskets provide sealing to IP65 against water and dust. Operating temperatures are –60°C to 200°C for the silicone types. To help with mounting, pressure-sensitive adhesive can be supplied.
Warth International Ltd. Tel., 01342 315044; fax, 01342 312969; web, www.warth.co.uk..
Enq no 510

Memory

Low-cost flash. New Atmel flash memories for use in pcs and consumer equipment are announced. *AT49F512, AT49B512* and *AT49F516* are 512K devices and the *AT49F4096A* a 4Mbit type. All are suited to use in graphics cards, mass storage drives and DVD players. The *512*s are organised as 64K by 8, the *516* as 32K by 16 and the *4096* as 256 by 16, all *512*s allocating 8K for boot block and 56Kbyte for main memory, while the *4096* provides a 16Kbyte boot block with programming lockout, two 8Kbyte parameter blocks and a 480Kbyte main memory block.
GD Technik Ltd. Tel., 0118 9342277; fax, 0118 9342896.
Enq no 511

133MHz fifos. IDT's *SuperSync II* first-in-first-out memories are said to be the first to achieve 4Mb density and to run at 133MHz. They also only take 35mA from 3.3-5V rails and come in densities of 126Kb-4Mb. In addition to conventional bus configurations, these devices provide ×9/×16 bus matching on read and write ports. Other features include zero-latency transmission, eight preselected default offsets for the almost-empty and almost-full flags

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and selectable async./sync. programmable flag modes.
IDT Europe. Tel., 01372 363339; fax, 01372 378851.
Enq no 512

Microprocessors and controllers

Embedded Pentium conversion. Hitex has produced a conversion board to allow developers to incorporate the new 0.25μm Intel *Pentium MMX* processor in existing and future embedded applications. The board may be plugged onto a standard Pentium processor and contains all 3.3V to 2.5V voltage converters and level shifters needed for the conversion. The Hitex *DProbe PENTIUM* emulators support the new 2.5V form.
Hitex (UK) Ltd. Tel., 01203 692066; fax, 01203 692131; e-mail, sales@hitex.co.uk; web, www.hitex.co.uk.
Enq no 513

New PICs. *PIC16F627/8* are new flash microcontrollers by Microchip and are intended to provide an entry to more complex embedded control. Both have a 4MHz clock, precision comparators, a high-speed usart and a capture/compare/pwm module. There are 1024 by 14bits and 2048 by 14bits of flash program memory, 224byte of data ram and 128byte of data eeprom. Other features are a working voltage of 2-5.5V, a 20MHz maximum operating frequency, brown-out reset, a 1μs single-cycle instruction time at 4MHz, a watchdog timer and three others and 16 i/o pins. Both micros are supported by the *MPLAB-ICE* emulator and the *PICstart Plus* development system and come in 18-pin pdip, soic, ssop and windowed dip packages.
Arizona Microchip Technology Ltd. Tel., 0118 9215858; fax, 0118 9215835.
Enq no 515

Peripheral-rich micro. Dallas Semiconductor has announced the *DS87C550* eprom high-speed microcontroller, which has an analogue-to-digital converter and pulse-width modulation on the chip. Its processor is the fastest 8051 type with extra circuitry, although still compatible with the standard 8051. Processing speed is up to three times faster at the same clock speed, using four cycles instead of twelve to process an instruction. The a-to-d is a 10-bit type taking up to eight inputs and having a window function to allow the conversion to proceed with no processor interruption until a value of interest is found. Four pwm channels are provided, two being cascaded for 16-bit resolution. Many more features are incorporated – registers and comparison registers, an 8Kbyte eprom, power management, timers and radiation reduction.
Dallas Semiconductor Corporation. Tel., 0121 782 2959; fax, 0121 782 2156.
Enq no 516

Power semiconductors

Rf power transistor. Ericsson's *PTF10112* n-channel rf enhancement-mode fet power device, which uses the Goldmos technique, is meant for use in CDMA and TDMA applications in the 1.8-2GHz band. Minimum output is 60W at 1dB compression and forms a viable alternative to *MRF286* types. Gain is around 3dB higher than bipolar equivalents and it has better stability. Minimum power gain is 12dB at 1.95GHz within ±0.3dB from 1.93GHz to 1.99GHz Class AB, two-tone, third-order intermodulation distortion is –40dBc at 25W pep. Load mismatch tolerance is 10:1.*Ericsson Components AB. Tel., 01793 488300; fax, 01793 488301*
Enq no 514

Motors and drivers

Stepper drivers. Two new dual stepper motor drivers by Ericsson, the *PBL37712/3*, are based on the *PBL3771* but now offer higher motor voltage, lower power dissipation and more efficient packages. Output to the motor may be up to 60V, the *37712* providing 750mA continuously per channel and the *37713* up to 900mA. These are dual-channel, switched-mode, constant-current choppers – one for each winding of a two-phase stepper motor and, as well as microstep operation, give full and half stepping modes; both work with the company's *PBM3960* controller. Slow or fast current decay in the output stage is selectable by logic level from the controller to give better positioning and less noise at high stepping rates.
Ericsson Components AB. Tel., 01793 488300; fax, 01793 488301.
Enq no 517

Optical devices

Led modules. Rohm's family of high-brightness modular displays is now expanded with the addition of a compact, 256-dot, three-colour type using surface-mounted chips and complete with the driving and control circuitry. These *LUM-256* modules, measuring 96 by 96mm, provide a 16 by 16 resolution, with a dot size of 2.1 by 2.3mm pitched at 6mm. Colours available are red, green and orange. Modules may be stacked in either direction to form larger displays. Current taken is 1.8A and there is an asic driver/controller with a display data memory large enough for two screens. Typical brightness is 100cd/cm^2 and a fine-control allows matching between units.
Rohm Electronics UK Ltd. Tel., 01908 282666; fax, 01908 282528; web, www.rohm.co.jp.
Enq no 518

Oscillators

Voltage-controlled crystal oscillators. Compact 14 by 9 by 4mm oscillators by C-MAC in the *CFPV-1000 Series* are meant for use in timing circuitry in applications such as telephone switching and transmission equipment. They provide voltage control up to ±200ppm over the 4.096MHz-155.52MHz frequency range. In J-lead packages, these devices are supplied on tape and are usable with pick-and-place and reflow soldering. Standard tolerance is within ±25ppm over the range –20°C to 70°C or ±50ppm down to –40°C and up to 85°C. Ageing is under ±5ppm in the first year and within ±15ppm in ten years. Output drives Hcmos and ttl, with the option of ecl/pecl.
C-MAC Quartz Crystals Ltd. Tel., 01460 74433; fax, 01460 72578; e-mail cfp@europe.cfpwww.com; web, www.cfpwww.com.
Enq no 520

Passive components

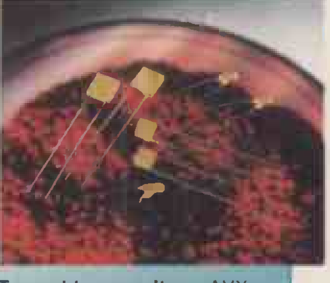
Pulse transformers. Timonta's *IT Series* high-voltage, high-insulation pulse transformers are said to be 30% smaller than conventional types. They come in through-hole and s-m form and have an insulation rating of 3.2kV, with small coupling capacitance. They are meant for use in the control of semiconductors and have an unlimited service life.
Timonta UK. Tel., 01929 555800; fax, 01929 555801; e-mail, sales@timonta.co.uk.
Enq no 521

Protection devices

I/o protection. Semtech's *LCDA15C-6* is a transient voltage suppressor for the protection of multi-mode transceivers in telecomms, networking and wans. It will protect up to six I/o lines or three pairs working at 5-15V in all multi-mode levels. Capacitance is under 15pF per line to make the device suitable for high-speed interfaces and the clamping voltage is low to avoid stressing the protected device. Surge rating is 400W in an 8-20μs pulse and the low inductance protects against overvoltage caused by lightning and hot plugging; esd protection is up to 25kV.
Semtech Ltd. Tel., 01592 773520; fax, 01592 774781.
Enq no 522

Transducers and sensors

Doughnut load cells. Control Transducers' has the *Model PG* range of load washers for the measurement of forces such as bolt stresses, overloads, clamping forces, die loads, etc. These are self-contained, calibrated load cells designed for fitting directly onto the component. Circuitry is a full Wheatstone bridge with the strain elements fixed to the load column in such a way as to promote maximum linearity and temperature compensation. Operating temperature range is –10°C to 65°C with compensation extending an optional 200°C. Repeatability is ±0.5%, non-linearity and hysteresis better than ±0.2%, with an output of 2mV/V up to 20V input. Capacity range is 100 to 100 000kg.
Control Transducers. Tel., 01234 217704; fax, 01234 217083.
Enq no 519



Traceable capacitors. AVX offers the *MR05/06* and *TAP* ranges of traceable capacitors with documented CECC release. *MR* series types are radial, multilayer ceramics in epoxy cases, in three types of dielectric and two working voltages, while the *TAP* models are dipped tantalum components with radial leads, operating at voltages from 6.3V to 50V and in the –55°C to 125°C temperature range.
Farnell Components Ltd. Tel., 0113 263 6311; fax, 0113 263 3411, web, www.farnell.com.
Enq no 517

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

Circuit-breaker replacement. Teledyne's *PC Series* of solid-state, optically isolated power controllers replace conventional electromechanical circuit breakers in some applications, reducing cost, size and weight and enhancing reliability. They come in 28V dc at 2-15A or 270V dc at 1-10A versions, giving low on resistance and provide complete short-circuit and current overload protection, with status outputs for trip and load voltage to allow monitoring.
Teledyne. Fax, 01634 863494.
Enq no 524

Switches and relays

Four relays – one package. Teledyne's *EFRQ* series of four-pole relays are industrial solid-state units and are effectively four relays in a single housing. The relays have scr output handling 55A at 1.2kV and use optical isolation between control circuits and output to reduce transients. Teledyne's Powertherm process of thermal management increases the efficiency of heat dissipation and reduces the stress caused by different expansion rates.
Teledyne. Fax, 01634 863494.
Enq no 525

Movement switch. From Assemtech comes the *MS24* movement detection switch, which is a non-mercury type intended for use in anti-tamper and interference detection. It has gold contacts and a sealed metal body. It is not sensitive to mounting position. The switch's sensitivity to vibration allows it to detect the starting of motors or other equipment. Normally, the contact may be open or closed, vibration or movement causing the contacts to open and close repeatedly, the output being damped if necessary to reduce sensitivity. It is suggested that battery-powered equipment may use the switch as a wake-up device from sleep mode.
Farnell Components Ltd. Tel., 0113 263 6311; fax, 0113 263 3411, web, ww.farnell.com.
Enq no 526

EQUIPMENT

Communications equipment

Tunnel antenna. With a view to providing better and cheaper communications in tunnels for security and emergencies, European Antennas has introduced a broad-band antenna for single-point mounting to cover the 400MHz-2GHz frequency band with 4-7dBic gain, being a lower-cost alternative to leaky feeders. It is only 420mm in diameter and uses circular polarisation; tests have shown its range to be an improvement on earlier methods. Its plated aluminium housing and glass-fibre radome withstand corrosive pollution.
European Antennas Ltd. Tel., 01638 731888; fax, 01638 731999; web, www.european-antennas.co.uk.
Enq no 527

Production equipment

Conductive storage. TBA Electro Conductive Products has announced the availability of a moulding and fabrication service for conductive storage boxes and bins, in which a customer may specify inserts and dividers and box dimensions. Materials used are conductive PP, HDPE, PA6 and PS including carbon blacks.
TBA Industrial Products Ltd. Tel., 01706 47718; fax, 01706 46170; e-mail, info@tbaecp.co.uk; web, www.tbaecp.co.uk.
Enq no 528

Power supplies

65W "smallest & lightest". The *Eos ZVC65NT* 65W power supply is claimed to be the smallest and lightest 65W unit available, measuring 115 by 60 by 28mm and weighing 250g. Zero-voltage and current switching provides 89-91% efficiency and a 5.2W/in^3 power density. There are supplies to accept 90-264V ac with standard outputs of 12-48V, all having active power factor correction and a 15ms hold-up time. They comply with all the relevant standards for safety and emi.
Acal Electronics Ltd. Tel., 01344 727272; fax, 01344 424263.
Enq no 529

"Fastest" dc-to-dc converter. Claimed by Semtech to be the world's fastest converter, the *SC1144ABCS* will meet demands for a load increase of 5A to 20A in 500ns. It is a selectable, four-phase controller for advanced processors, for example Intel Pentium-based servers and workstations. Oscillating at 8MHz, the pwm controller for multi-phase buck converters gives drive for two, three or four phase working, a 5-bit programmable d-to-a converter giving good regulation. Output is 1.3V-2.05V in 50mV steps and 2V-3.5V in 100mV steps.
Semtech Ltd. Tel., 01592 773520; fax, 01592 774781.
Enq no 530

Radio systems

GSM transceiver. TDK has the *GSM900/DCS1800* calibrated radio transceiver module for the GSM market, as an entry module or as an upgrade to dual-band operation. It complies with GSM phase-2 specifications, meets GSM power class 4 at 2W and DCS power class 1 at 1W and supports inter-band handover. Used with a base-band system, the module provides all transmit and receive circuitry for dual-band GSM. Applications include mixed systems such as a combined GSM/GPS or GSM with personal communication, in addition to providing GSM functions in a laptop pc or notebook. This device was designed in partnership with TTP Communications of Cambridge.
TDK UK Semiconductor Corp. Tel., 0181 4437061; fax, 0181 4437022; e-mail, europe.sales@tsc.tdk.com; web, www.tdksemi,demon.co.uk.
Enq no 531

Power pulse generator. Models *2430* and *2430-C Digital Source Meters* are announced by Keithley for the production test of active or passive components needing transient power pulses. The instruments put out pulses with widths of 300μs to 2.5ms at up to 10A at 100V. In addition, *Model C*

Test and measurement

Inductance analyser. Wayne Kerr's *IA3255* analyser offers the functions selected as being in most common use: *L*, *Z*, R_{ac}, R_{dc}, phase, *Q*, turns ratio, *C* and dissipation factor. Its ability to measure using a range of voltages allows the measurement of air gaps, core material and turns, the low-level dc resistance test avoiding overheating and magnetisation. There is ac drive level to 10V, dc bias from 0.1mA to 1A, connection to the component by four-terminal Kelvin leads, high-speed, GPIB control, automatic level control and on-screen absolute or relative indication. Basic accuracy is ±0.5% and there is self calibration for consistency.
Wayne Kerr Electronics Ltd. Tel., 01243 825811; fax, 01243 824698; e-mail, sales@wayne-kerr.co.uk.
Enq no 532

Emissions tester. Schaffner EMC has introduced a range of emissions-test equipment – *ProfLine 6000* – comprising six equipments for those needing to test to Euro Norms, FCC and CISPR emc emission standards. Each comes with the *SCR 3000* series receiver covering 9kHz-2.6GHz, one for CISPR requirements to 1GHz and the other for applications such as mobile telephones and microwave oven monitoring. Both are CISPR compliant and are fitted with IEEE488 and RS232 for automatic control. The receivers have internal storage of transducer factors and limit lines and also removable memory cards for data and device settings. Software is supplied.
Schaffner EMC Ltd. Tel., 0118 9770070; fax, 0118 9792969.
Enq no 535

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

has a contact check circuit to verify contact with the component being tested in under 350μs – a facility needed in fast production test in which contacts have a tendency to degrade. Each has a 5.5-digit multimeter and digital i/o lines and comparators for fast parts binning when used with handlers; there is also memory for test sequences. The instruments will provide continuous voltages from ±5μV to ±100V dc and measure voltages to within ±0.012%. Current sourcing and measurement is also provided.
Keithley Instruments Ltd. Tel., 0118 9575666; fax, 0118 596469.
Enq no 534

Electronic load. Start Spellman's electronic load handles inputs of 75-10000V dc in either polarity and is an active, solid-state type, the load value being varied by front-panel control or remotely by an analogue 0-10V dc input. Power is dissipated by element cards in a backplane carrying fets, an arrangement allowing best power transfer into cooling air. There is protection for single-card failure and fan failure, power, current and over-temperature. Maximum load current is 2.5A, input power being limited to 20kW. The unit measures 600 by 800 by 980mm high with its castors, and weighs 100kg.
Start Spellman Ltd. Tel., 01798 873986; fax, 01798 872479; e-mail, hvsales@start-spellman.co.uk.
Enq no 539

COMPUTER AND DATA HANDLING

Computers

Embedded pcs. Inside Technology of Denmark announces a family of embedded pcs based on the Cyrix *MediaGX* processor chip set. There are three types in the family: *586LCD/GXm, 586LCDGXm*^{Plus} and *686LCDCXm*. The two *586*s are based wholly on the *MediaGX* chip set, both using the integrated graphics controller and providing Ethernet support, *DiskOnChip* flash disk to 72Mb and interfaces for ISA, PC/104 and USB. In addition, the *Plus* model supports *Compact Flash* to 48Mb, on-board *PanelLink* for remote display control and *SoundBlaster 16*. It also has four serial ports instead of the standard two com ports. The *686* model has, in addition to the *MediaGX*, a C&T *69000* graphics controller for better performance with flat-panel displays. It also copes with 300MHz clocking and a YUV interface for direct video input.
Inside Technology A/S. Tel., 0045 45761016; fax, 0045 45761017; e-mail, inside@inside.dk; web, www.inside.dk.
Enq no 538

Computer board-level products

Analogue i/o coprocessors. Datel has two additions to the *PCI-431* family, the *PCI-431D/L*, which are analogue i/o digital dsp coprocessor boards for the PCI bus, offering true multi-level concurrent coprocessing. A local fifo a-to-d memory and a bidirectional PCI bus fifo allows analogue samples to be stored while dsp maths is continuing and previous data blocks are sent to the pc. Model *D* has sixteen single-ended, 14-bit a-to-d channels with parallel sampling at up to 300kHz/channel, while the *L* has a similar number of of 12-bit channels sampling at up to 600kHz/channel. A user clock can be used or an on-board frequency synthesiser will give a-to-d clocking. Several on-board sub-controllers allow the dsp to process blocks while the a-to-d section samples and stores.
Datel (UK) Ltd. Tel., 01256 880444; fax, 01256 880706; e-mail, datel.ltd@ge.geis.com; web, www.datel.com.
Enq no 540

Audio analyser interface. As an option for the Audio Precision *Portable One* range of audio analysers, Thurlby Thandar can now supply a GPIB interface for both versions of the instrument. The interface controls all the operation of the instruments including the recently introduced digital audio measurement in the dual-domain version for which Visual Basic sample source-code programs are supplied. The interface is also available as an upgrade.
Thurlby Thandar Instruments Ltd. Tel., 01480 412451; fax, 01480 450409; e-mail, sales@ttinst.co.uk..
Enq no 537

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

Development and evaluation

68HC12 debugger. Hot insertion is the feature of the Noral Micrologic *Flex-BDM/68HC12* handheld background debug tool, allowing connection to a live, embedded target with no need for system reset in systems that must operate continuously with zero down time. It operates with all members of the family of processors and is meant for the location and fixing of problems that vanish at reset. The tool may be used with the company's *Flex* debugger software to give similar functions used during initial development, including viewing the original C code, reading and modifying variables and registers and single-stepping source code from all memory areas including flash and eeprom.
Noral Micrologics Ltd. Tel., 01254 682092; fax, 01254 680847.
Enq no 540

Mass storage

120MB floppy drive. Panasonic's 3.5in *SuperDisk120MB* floppy disk drive is now available as an upgrade package – cables, media, mounting accessories, software and a manual. The drive takes Imation and Maxwell disks, but is read/write-compatible with existing 1.44MB and 720KB 3.5in disks. It measures 101.6 by 150 by 25.4mm.
Panasonic. Tel., 0800 444220.
Enq no 541

Software

Electromechanical component analysis. Densitron software for analysing the behaviour of electromechanical components uses finite element analysis to allow users to predict the behaviour of designs before they are made, pin-pointing areas likely to need modification. After programming with the design details, the software measures force and torque against displacement or current or both, modelling the magnetic field intensity to validate the choice of materials.
Densitron Europe Ltd., 01959 700100; fax, 01959 700300; e-mail, sales@densitron.co.uk; web. www.densitron.co.uk.
Enq no 542

Thermal management. *Flotherm v. 2.1* by Flomerics now has five major improvements. There is a 1000-times-faster radiation exchange-factor calculator; automatic calculation and setting of characteristic velocity and length scale on a cell-by-cell basis; automatic block correction for temperature to reduce manual setting errors; a conjugate-gradient solver for pressure to improve convergence for problems involving pressurised conditions or unstable airflows; a faster solid modelling engine to ACIS v.4.0 for processing data from *mcad*; better graphics for low-end pcs and workstations; and a better database.
Flomerics Ltd. Tel., 0181 9418810; fax, 0181 9418730; e-mail flomerics@flomerics.co.uk; web, www.flomerics.com.
Enq no 543

PUBLICATIONS

Memory. NEC has reorganised its cd-rom memory catalogue to make it easier to drive. You now get taken to the relevant device promptly. The cd contains selection tables, data sheets and manuals, with application notes on synchronous dynamic and graphics ram. Additions this time are double-data-rate sdram and high-density 256Mb sdram; others are mcp combining sram and flash, and combo memory having sram and mask rom. The cd has Acrobat, in case you haven't. And it is free.
NEC Electronics (UK) Ltd. Tel., 01908 691133; fax, 01908 670290.
Enq no 544

Computer measurement & automation. National Instruments has its 1999 *Measurement and Automation Catalogue* of equipment concerned with computer-based measurement. It contains tutorials on data acquisition, applications software, GPIB, VXI and communications. New products include LabVIEW, new PXI/CompactPCI modules, toolkits for the development of IVI drivers and the newest computer-based instruments.
National Instruments UK. Tel., 01635 572400; fax, 01635 524395;e-mail, info.uk@natinst.com; web, www.natinst.com/uk
Enq no 545 ■

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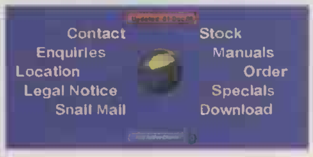

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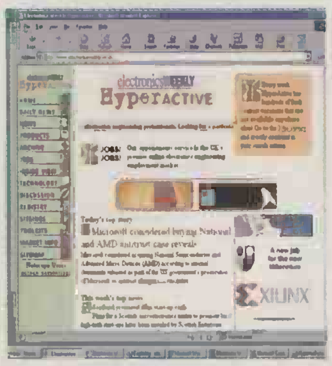

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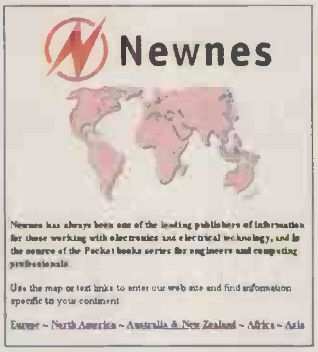

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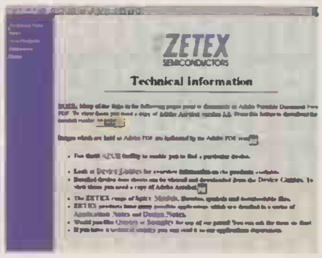

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Contact Mark Wheeler for more information.

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Contact Mark Wheeler for more information.

RF STANDARDS ENGINEER ~ Surrey to £30k

Working within a new group, you will be ultimately responsible for setting in place procedures, policies and strategies to comply with international regulations for mobile comms equipment. You should be qualified to HND standard and have several years experience in a similar environment, ideally in 3rd generation mobile technology. Quote WW9808-82.

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Contact Rich Wootten for more information.

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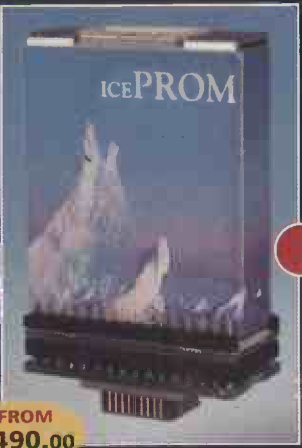

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