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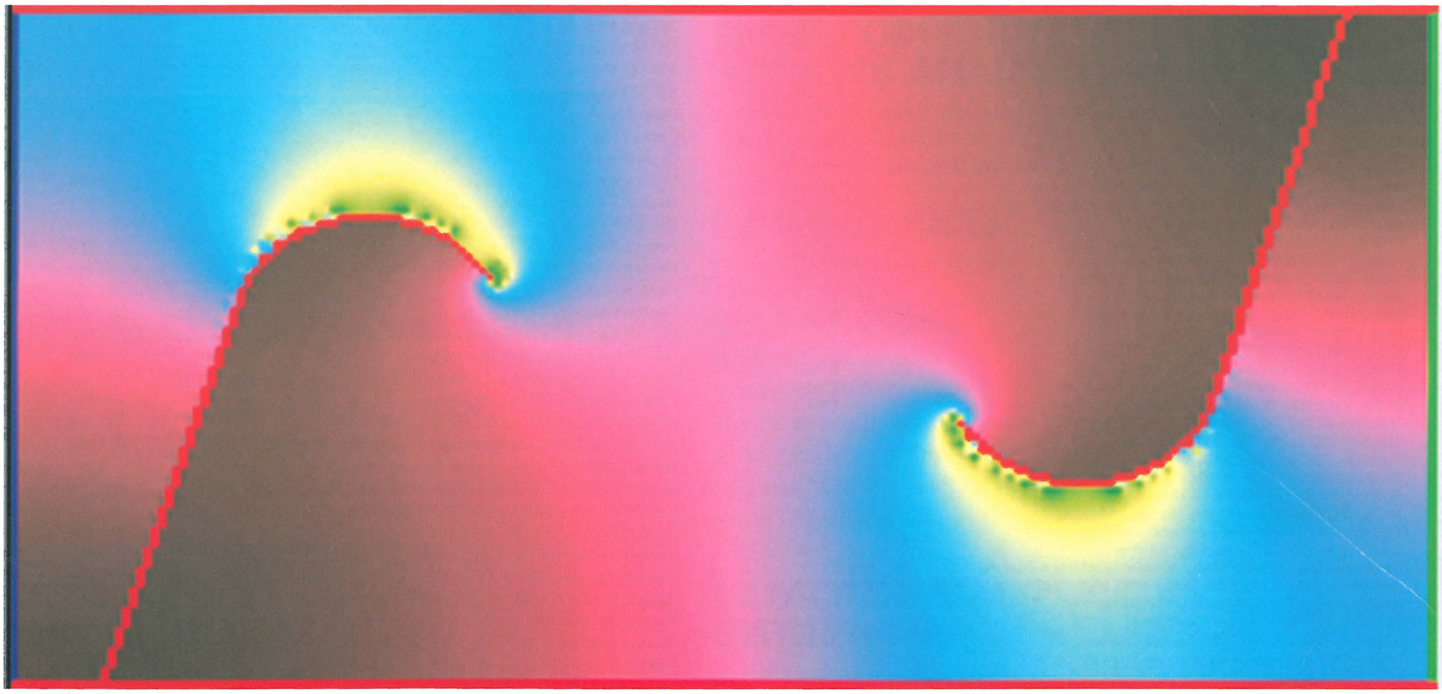
ELECTRONICS WORLD

DECEMBER 2003 £3.25

Planar resistors' stress



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Too much regulation?

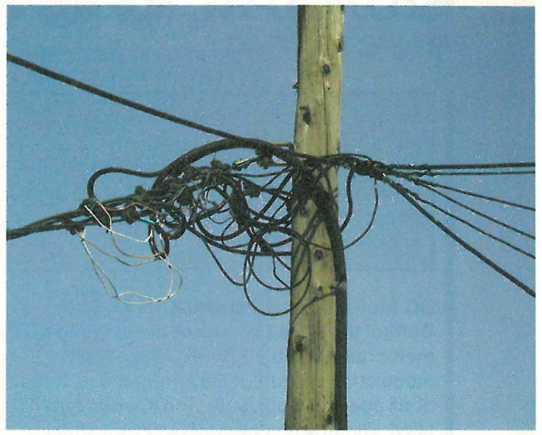
I've been following the letters in the last few months concerning EMC and CE marks. Reader consensus seems to be about 50-50 on whether in fact there is a conspiracy or not. My own opinion is that I am sure the regulations do some good – but is it too little for the cost to the consumer. Does the consumer get his/her money's worth? I don't think so. Putting aside industrial, military and transport electronics for a moment, my own experiences are that the things that traditionally cause interference still do. If I want to listen to AM radio, I must make sure I'm nowhere near my TV or fluorescent lighting. If I'm using a sensitive microphone amplifier, I must make sure there is not a refrigerator on the same power circuit. My mobile phone (only spewing a few watts at very high frequency) will interfere with anything audio I own. And so it goes on – so regulations for the aforementioned interferers don't seem to work or they are not worth the paper they are printed on.

When it comes to industrial gear – in particular when life is at risk if anything went awry – I can see some sense. Although quite what it is that comes out of a CD/MD/DVD player that can affect an aircraft I can't imagine. But most flights these days ban them. And all this when the jury is still out on links to cancer from overhead power lines and transmitters. Something's not making sense.

If you read last month's leader, you'll know I went to Rhodes on holiday. Whilst there I spied a fascinating pole mounted power distribution system. Looking closely and also working out roughly the load on what appears to be a 125A feeder – I suggest that the latest IEE regs were not followed. But does it really matter? The pole has been there for years and there was no evidence of overload or indeed any other problems. So, does it matter that we sometimes don't follow the advice of the gurus? In this instance obviously not.

Wireless

Last month I suggested that G3 franchise holders ought to sell to the business fraternity and low and behold, Motorola have just announced that they are working on a network card that will hook into a Wi-Fi network if available and if not – seek out



a G3 connection. Well done. Perhaps the porn industry won't be the 'killer app' for G3 after all.

Welcome

I'd like to welcome Caroline Fisher to our little *EW* team. Caroline has taken over from Jackie and will be your first point of contact for all things administrative. So, for those of you who were wondering if you'd ever get a response from us – hopefully you will soon!

Phil Reed

New editorial and advertising address

The Highbury Business Communications office previously at Cheam, Surrey has moved to Swanley in Kent. All correspondence intended for the editorial and advertising departments should be addressed to:

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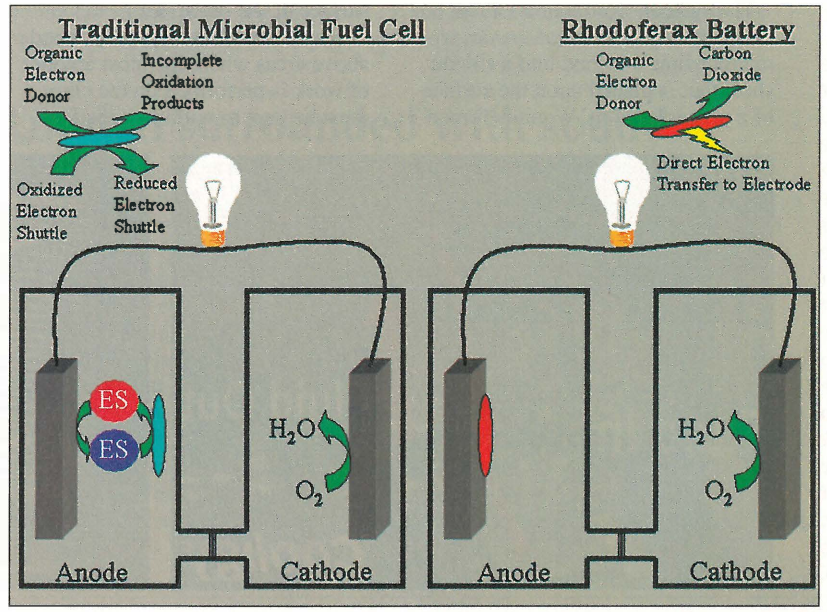
Bacteria makes electricity from sugar

Sugars can be converted to electricity with an efficiency higher than previously known, claim researchers at the University of Massachusetts Amherst.

Professor Derek Lovley has discovered a micro-organism that is capable of stable, long-term electricity production by oxidising carbohydrates - but it is early days. "I don't want to give the impression that it's 'Back to the Future,' where we stuff a banana in the engine and go," said Lovley, "but it's a pretty good leap from where microbial fuel cells were before."

Lovley's cell produces 600mV at between 600 and 800μA.

The organism, *Rhodoferax ferrireducens,* transfers electrons directly onto an electrode as it metabolises sugar, producing carbon dioxide as a by-product.

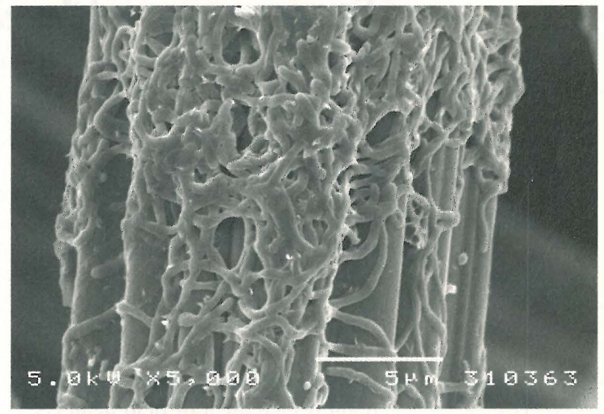


"There's been a lot of interest in microbial fuel cells trying to convert sugar into electricity," Lovley said. "But in the past, they've converted ten percent or less of the available electrons, and we're up over 80 per cent. And previous attempts to convert carbohydrates to electricity have required an electron shuttle, or mediator, which is typically toxic to humans."

This organism doesn't require a mediator because it attaches directly to the surface of the electrode, said Lovley: "That's one of the big advances. People have done it without a mediator before, but their recovery of energy was less than one per cent. In the end, the electrons in the fuel cell are transferred to oxygen, so what we are really doing is putting a wire in between the microbe and the oxygen and harvesting this electron flow that otherwise would just go directly to oxygen."

Rhodoferax was isolated at the university from aquifer sediments in Virginia. "We found that it had the unique ability to oxidise sugars with the reduction of iron oxides," Lovley said. "This was of interest to us because last year we reported another group of iron reducers, known as *Geobacter,* could transfer electrons to electrodes. We reasoned that *Rhodoferax* might be able to do the same thing, which proved to be the case."

In theory, a cup of sugar in a fuel cell could produce 60W for 17 hours.



The organism Rhodoferax shown on an electrode.

Opcouplers will use silicon

Silicon - great for ICs, but terrible at emitting light. That view may soon change as STMicroelectronics plans to sell optocouplers made using conventional silicon.

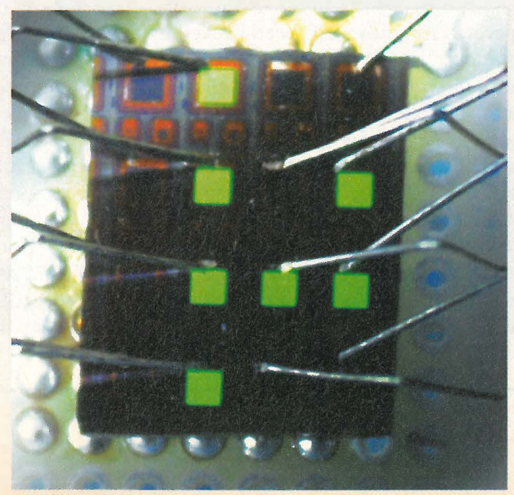
The French/Italian chip firm has demonstrated light emitting silicon, and says the efficiency is better than more expensive gallium arsenide.

Moreover, the devices could be integrated with power electronics and control circuits, reducing the number of packages in applications such as motor control.

ST's emitters avoid using silicon's indirect bandgap by embedding rare earth elements, such as erbium, into a layer of silicon dioxide. When charge is injected into the SiO_2 layer it excites the erbium. Photons are released, in erbium's case, at around 1.5μm.

Power output is claimed to be 1mW per mm^2 of silicon. More photons are emitted, at a set current, than conventional LED materials such as AlInGaP and AlInGaN, claimed ST.

STMicroelectronics has produced light from silicon by doping with rare-earth materials. This is not new, many research teams have done is before but, unlike most attempts, ST's devices are easily visible - as Electronics World witnessed during a visit to the development labs in Catania, Sicily. The emitters have been used to construct working all-silicon opto-isolators.



Soothing the hot spots

Technology developed at Stanford University in the US has been applied to the cooling of microprocessors, which could exceed 100W next year.

The system, from a firm called Cooligy, uses a series of microchannels etched into a silicon sheet that is placed upon the surface of a processor chip. Water is forced through the channels by an "electro-kinetic" pump, said the firm.

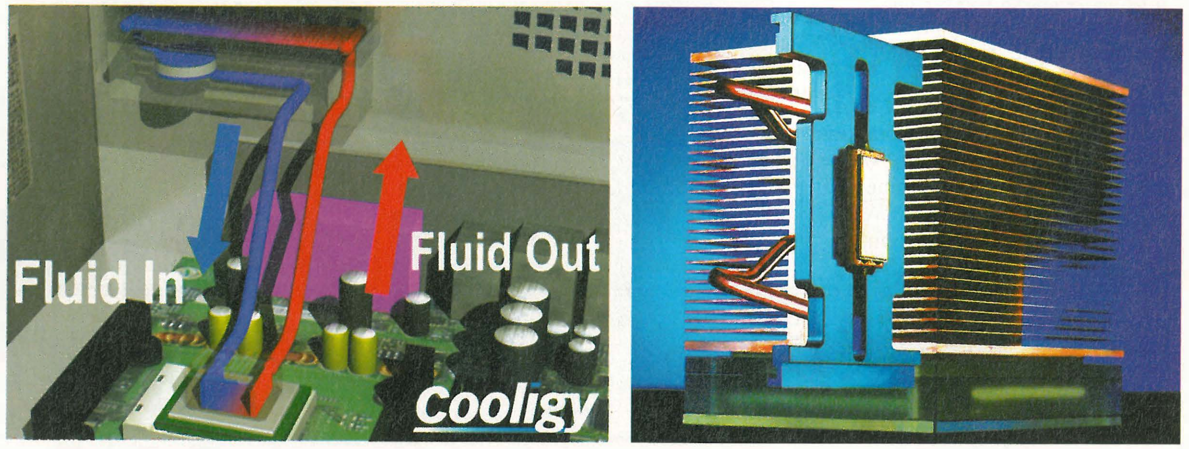
The advantage of this technique, versus heat sink and fan cooling, is it copes better with hot spots on the surface of the processor.

"These hot spots, typically found above areas where the most amount of work is performed on the chip, must be kept to within a specified temperature to ensure high performance and reliability," said the firm.

It claims to be able to remove up to 1,000W/cm^2.

Cooligy said its heat sinks would be attached to the processor die at the point of packaging. It expects to start supplying test systems to computer manufacturers this year.

The photos show the microchannel heat collector attached to a mounting plate that connects the heat collector to the CPU. Fluid flows through the collector, back to a radiator that transfers heat to the air, then into a pump located below the radiator. The pump moves the fluid back through the microchannel heat collector, completing the sealed loop.



Super magnet breaks field record

A superconducting magnet has generated a magnetic field of 25 Tesla for the first time.

In the experiment, carried out at the US National High Magnetic Field Laboratory, a 5T high temperature superconductor (HTS) 'insert' coil was positioned in an existing 20T magnet.

The HTS insert coil broke at least seven world records, claims the lab, including the highest field generated in a superconducting magnet and highest increment of field in an HTS insert of useful size. These records were previously held by Japanese industrial scientists.

"This is a critical and essential technological breakthrough for high temperature superconducting materials for state-of-the-art magnets," said project leader, Dr Justin Schwartz.

The lab worked with New Jersey-based Oxford Superconducting Technology.

"The drive for ever higher fields in commercial NMR spectroscopy magnets was a compelling motivation for Oxford's investment in this achievement, and we look forward to using the technological advances demonstrated in our high field business," said Dr Ken Marken, project leader at Oxford.

Oxford supplied long-lengths of Bi-2212 superconducting wire for the program and both organisations "spent much time on conductor development, conductor characterisation, coil winding studies, and the testing of coils," they said.

Capacitive coupling is fast

Scientists at Sun Microsystems have invented a technique for passing high speed data between chips without using a direct electrical connection.

In fact the method uses capacitive coupling between closely spaced pads to transfer data from one die to another. Sun says that in tests a single channel could reliably send data at 1.35Gbit/s.

In fact the firm has manufactured test chips with 16 channel links, capable of transferring data at 21.6Gbit/s. At this speed the bit error rate was better than 10^{10}, claimed the firm.

Links made between chips in this way are a factor of 60 times denser than using wires.

The technique was invented by Ivan Sutherland, a senior engineer at Sun who also invented the micropipeline method of asynchronous logic.

A transmitter is an inverter directly driving the pad, measuring around 35x35μm. The receiver's pad makes up the other half of the capacitor, which feeds to back to back inverters.

The smallest pads that gave reliable transmission measured 25x25μm, said Sun.

IEE merger backed by Government

The proposed merger between the Institution of Electrical Engineers (IEE), the Institute of Mechanical Engineers and the Institute of Incorporated Engineers has been backed by the Government.

"This vitally important development reflects the fact that there is an increasing convergence between the disciplines within engineering, and I am sure it will unify and strengthen the profession as a whole," said Lord Sainsbury, minister for science.

"Such an institution would undoubtedly have a stronger voice and therefore be more successful at promoting and representing the engineering sector."

The IEE itself has indicated that the merger is more likely to happen than not. The previous president of the Institution, Professor Mike Sterling, said earlier this year: "Most of the comment and questions concentrated on how to proceed rather than whether we should."

All three organisations are carrying out consultation with members. A final vote on the proposed merger will be carried out in the autumn.

"Both members and their employers would find such a body more relevant to the first decade of the 21st century," said Sterling.

Digital TV too complicated, says DTI

A study published by the Department of Trade and Industry has warned that many UK consumers are not able to use digital TV systems.

The Government's E-commerce Minister, Stephen Timms, said: "Today's digital TV equipment is confusing and difficult to use."

According to consulting firm Generics, which carried out the DTI's research, over seven per cent of the UK population cannot use a digital set-top box or TV, even for simple everyday viewing. This compares to under three per cent for analogue TVs.

"The UK leads the world in take up of digital TV, and we must not squander the opportunity to make the most of this advantage. This report provides a wake-up call to the industry," said Timms.

Dr Jeremy Klein, Generics project leader, outlined the problem: "We now have a pretty good idea of where the problems lie. Compared with analogue TV, digital TV provides many more useful features; but you can only access those features by using the remote control and on-screen displays.

"Our research indicates that unless improvements are made, then about two million people will not easily be able to use digital TV in its current form."

Much of the technology for digital set-top boxes comes from the PC world. "That's fine if you've had experience of PCs, but not everyone has. Some people simply cannot understand how to work the equipment and are scared that they will make mistakes," said Klein.

"It's fine to press the red button", claimed Kay Sinclair, Generics' product design expert, "but it's what happens next that confuses people."

If you are in an interactive service and you want to go back to the top menu, then every broadcaster does it a different way, she said.

Manufacturers should get together and set design and use standards, the Government said.

London surrounded with sound

A five-channel, surround sound audio broadcast trial has started in London, with UK firms providing the receiving equipment.

Radioscape is supplying much of the core broadcast equipment, based on the digital audio broadcasting (DAB) standard. Receivers come from Radioscape and Imagination Technologies.

The six month pilot scheme sees Capital Radio broadcasts using Microsoft's Windows Media Audio 9 format, which can squeeze 5.1 audio into a 128kbit/s Internet protocol stream.

NTL Broadcast is proving the multiplex for the trial using L-band (1.4GHz) transmission.

"The high quality and compression efficiencies of Windows Media 9 Series make 5.1-channel surround sound over DAB a reality," said Simon Mason, head of new product development at NTL Broadcast.

The Radioscape receivers are two PCI-bus cards. Imagination is supplying DAB receivers that output the five channel data to a PC via USB cable.

2.4GHz band not congested

A Radiocommunications Agency report shows that the 2.4GHz band remains relatively free from activity in the UK, despite warnings it would be saturated by wireless LAN and Bluetooth.

The report, from Mass Consultants, said "the use of 2.4GHz services appears to be very widespread, although the recorded levels of activity were generally low, both in terms of signal strength and the proportion of the time that signals were present".

The firm carried out private sector monitoring in Cambridge and public sector tests in schools, hospitals and Heathrow Airport. All areas were covered extensively by wireless LAN.

In fact the main contributor to the band was microwave ovens, while movement detectors were commonly found at low signal strengths.

No cases of wireless LAN congestion were observed, said the firm. No out of band emissions were observed and power levels were within the designated limits.

Light emitting handbag

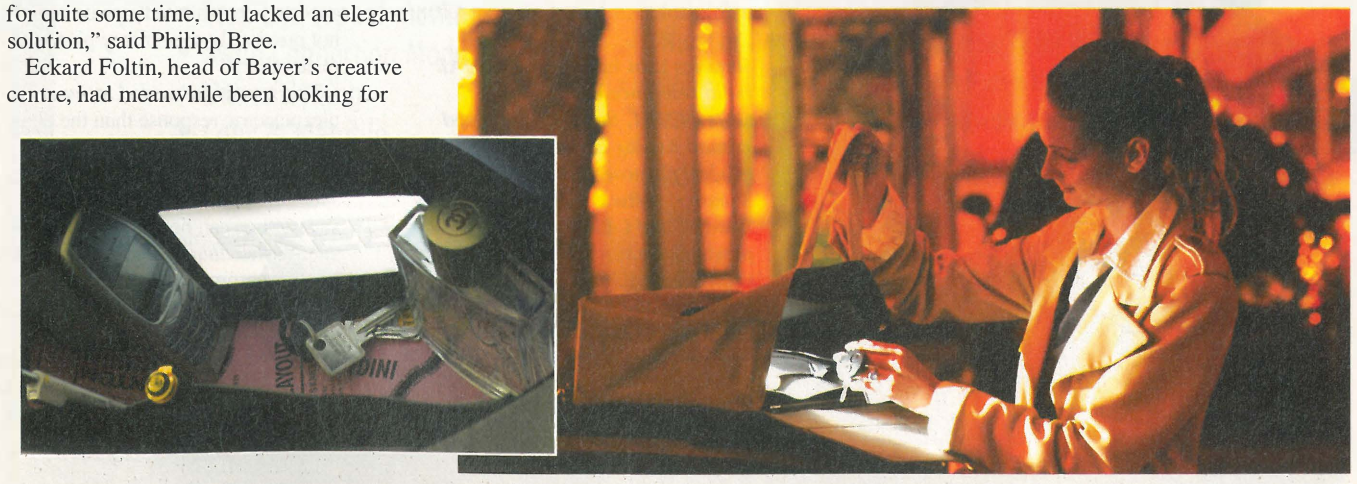
Bag specialist Bree and Bayer Polymers have teamed up to produce a prototype self-illuminating handbag.

"We had been toying with the idea of illuminating the dark insides of handbags for quite some time, but lacked an elegant solution," said Philipp Bree.

Eckard Foltin, head of Bayer's creative centre, had meanwhile been looking for another use for the firm's dashboard and headlining illuminating electroluminescent (EL) technology.

The two met, and the result is a bag with a 7 x 16 EL film embossed with the Bree logo that lights up two compartments at the touch of a button.

"In less than five years, interior light will be just as common in handbags as mobile telephones are today," said Bree.



European 65nm CMOS disclosed

Philips and Belgian research organisation IMEC have released details of the 65nm CMOS process they are jointly developing.

"The completion of fabrication of 65nm CMOS devices with good electrical performance marks the second milestone within the strategic partnership between Philips and IMEC," said IMEC.

65nm is the next step after 90nm, the most advance CMOS process in production.

The organisations formed an alliance at the beginning of 2000 to explore processing and integration steps in CMOS. Work on 65nm began in early 2002 after achieving the first milestone: 90nm CMOS.

The 65nm technology is based on a scaled version of planar 90nm bulk CMOS.

Devices feature 45nm gate length, equivalent oxide thickness of 1.4nm, 100nm thick polysilicon gates and sub-20nm junction depths. "Gate dielectric recipes were optimised through plasma nitridation of ultra-thin oxides for reduction of gate leakage and suppression of boron penetration," said IMEC. "Shallow source/drain engineering was performed using ultra-low energy implantation in combination with germanium pre-amorphisation and fluorine co-implantation (PMOST) and fast ramping high-temperature spike anneals."

Low-temperature deposition techniques were introduced in the back-end for spacer, salicide blocking and pre-metal dielectric layers to avoid excessive dopant diffusion and de-activation.

Finally a two-step nickel salicidation was integrated to improved control of line width effects as well as reduced junction leakage and contact resistance.

Drive currents of $790\mu A/\mu m$ for NMOST and $355\mu A/\mu m$ for PMOST were obtained at Vdd=1V and an off-state current of $100nA/\mu m$.

Devices exhibit good short channel effects control.

"The achieved electrical performance, which compares favourably with results from other companies, demonstrates that a successful step has been made in the joint exploration of the 65nm technology at IMEC and Philips Research," says Dr Carel van der Poel, senior v-p of Philips Research.

Credit cards get smart

UK consumers are beginning to receive credit and debit cards containing secure microcontrollers as part of the national Chip and PIN programme.

The replacement of magnetic stripe cards has begun in earnest, in a bid to cut the UK's annual fraud bill of £425m.

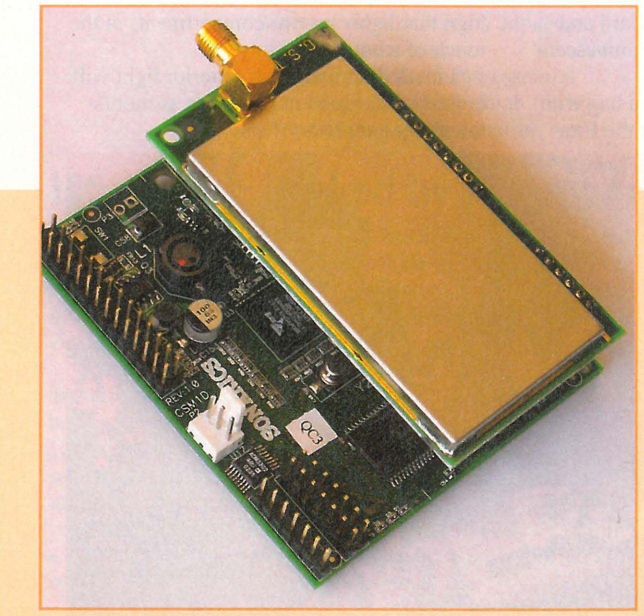
Replacing the country's 122 million cards, 850,000 shop terminals and 40,000 cash machines will cost the UK banks around £1.25bn.

Chip and PIN was trialed through the summer in Northampton with over 200,000 cards being issued and 1,000 retailers set up with card readers. In a survey, four fifths of users were said to be in favour of the scheme.

"I am encouraged that the lessons learnt in the trial will be taken forward as the scheme is rolled out across the country, so that the majority of plastic card transactions will be chip and PIN by 2005," said Hazel Blears, minister for crime reduction and policing. "As well as fighting fraud, Chip and PIN has also proved to be an efficient, secure and customer-friendly system."

APACS, the Association for Payment Clearing Services, has set a deadline of 2005 for a complete switchover to the smartcards. By the end of this year 20 per cent of UK cardholders will be using the cards.

In 2002 the UK banks lost £425m to card fraud, the majority of which was to counterfeiting (£148m). Card-not-present fraud cost £110m, while theft using stolen or lost cards cost £108m.



Sonarics Labs has unveiled a DAB radio reference design.
Called CSM1, the design is based around Analog Devices' $5 Blackfin general purpose DSP. Running on this, Sonarics' software implements DAB Band III and L-Band decoding, MP3 playback from a flash card and digital sound recording. The evaluation module in the picture is available for £199 ($299) and is 76 x 66 x 15mm. Sonarics estimates the parts would cost $25 in production.

www.sonarics.com

Superlattices transducer

Improved ultrasound transducers could spring from theoretical computer-based studies at the University of Arkansas.

"We can design new materials based on our predictions," said researcher Igor Kornev.

Using a computer model first described in 2000, Kornev and fellow researcher Laurent Bellaiche looked at hypothetical ferroelectric superlattices made of layers of lead zirconate titanate (PZT) with different titanium compositions.

In particular, superlattices with between one and six layers of 44 per cent titanium PZT alternating with layers of 52 per cent titanium PZT.

The average titanium composition of these is 48 per cent - the composition at which normal - disordered - PZT exhibits a huge piezoelectric response.

With six layers of each, the superlattice exhibited a phase transition not previously seen in any piezoelectric material.

This transition created an even larger piezoelectric response than the phase transition known in the disordered material.

In addition, they found that the superlattice can be stuck in a higher energy state than the ground state, which implies commonly used and assumed statistical laws are not always valid, said the team.

"These superlattices are thus important not only for technological applications but also from a fundamental physics point of view" Kornev said.

Better audio and smaller PCs from VIA

PC component maker has introduced a new audio chip, aimed at home entertainment PCs.

Called Eight-TRAC Audio, the device complies with AC'97 revision 2.3, supports 8 channel outputs, and up to 20-bit resolution with 96kHz sampling rates.

Hardware down-mixing allows PC users to play 6-channel audio with two or four speakers and the analog mixer circuitry includes stereo processing to provide 3D surround sound effect for stereo media. A high-quality headphone amplifier is also included on the chip.

Automatic jack detection allows users to connect a record or playback audio device to any jack. The chip will detect this and the user can then configure the correct I/O to the jack in use through the PC.

VIA also announced a smaller PC motherboard format.

The successful 17 x 17cm mini-ITX PC motherboard format was initially promoted by the firm 18 months ago and it is now mooting a full-function PC on a 12 x 12cm board - dubbed nano-ITX.

It is aimed at "the next generation of smaller, quieter, digitally intelligent home, office, mobile, industrial and commercial devices", said VIA.

www.via.com.tw

VIA Eight-TRAC Audio chip

AC97 rev 2.3 compliant
96KHz sampling
20-bit ADC and 20-bit DAC
>95dB signal/noise
7.1ch outputs
96kHz S/PDIF output
Direct CD input to S/PDIF output
Integrated headphone amp
3.3V or 5V analog power
3.3V digital power
48-Pin LQFP package

Laptop batteries can out-perform specialist traction batteries when it comes to electric vehicles.

Laptop batteries can out-perform specialist traction batteries when it comes to electric vehicles.

Californian firm AC Propulsion recently revamped its tzero prototype car to make the 'super LIght versION'. A move from lead-acid batteries to lithium-ion (Li-ion) saved 230kg and tripled the vehicle's energy capacity.

Power comes from 6,800 65 x 18mm diameter (18650 size) Li-ion cells - as used in laptop battery packs. "The market for big cells is small so they cost too much," said company president Tom Gage. "The small cells for the tzero cost less, in total, than the nickel-metal hydride battery in the Toyota RAV4 electric vehicle, and they hold twice the energy."

Gage look into getting 'vehicle' cells made. "We got a quote from one battery company for a Li-ion pack made from 100 much larger cells," he said. "Their price was ten times higher, and neither the energy or the power were as good as we get from the small cells. If you want to start building electric cars right now, as we do, you have to have a commercial battery. Right now, 18650s are the only game in town."

Tzero weighs 900kg and will drive 250 miles in 75-80mph traffic. "On any type of standardised drive cycle it will go over 300 miles," said Gage. Its best 0-60mph time is 3.6s.

www.acpropulsion.com

Correction
The UK's most powerful computer, HPCx, is not located in Oxfordshire as we reported in the September edition of *EW*, but Cheshire, and is part of Daresbury Laboratory near Warrington. More information about this facility can be found at: www.cse.clrc.ac.uk/hpcx/index.shtml.

Carbon shines perfect light

Carbon nanotubes are "ideal photon emitters", said researchers at the US' University of Rochester.

"The emission bandwidth is as narrow as you can get at room temperature," said professor Lukas Novotny of the university's optics department.

Precise, discrete, wavelengths are emitted by the tubes, unlike the wider band output of most materials at room temperature.

The team was using confocal microscopy, illuminating a single nanotube with a focused laser beam to see what was re-emitted by fluorescence.

"The emission wasn't just perfectly narrow, it was steady as far as we could measure," said researcher Todd Krauss.

Molecules, said Rochester, usually emit their photons for a certain time and then cease, only to resume again later. The tubes that Krauss and Novotny measured remained steady to the limits of their instrumentation. "This is very exciting because for any application in quantum optics, you want a steady and precise photon emitter," said Novotny.

Narrow steady emissions could help with the development of single photon emitters - used in quantum cryptography.

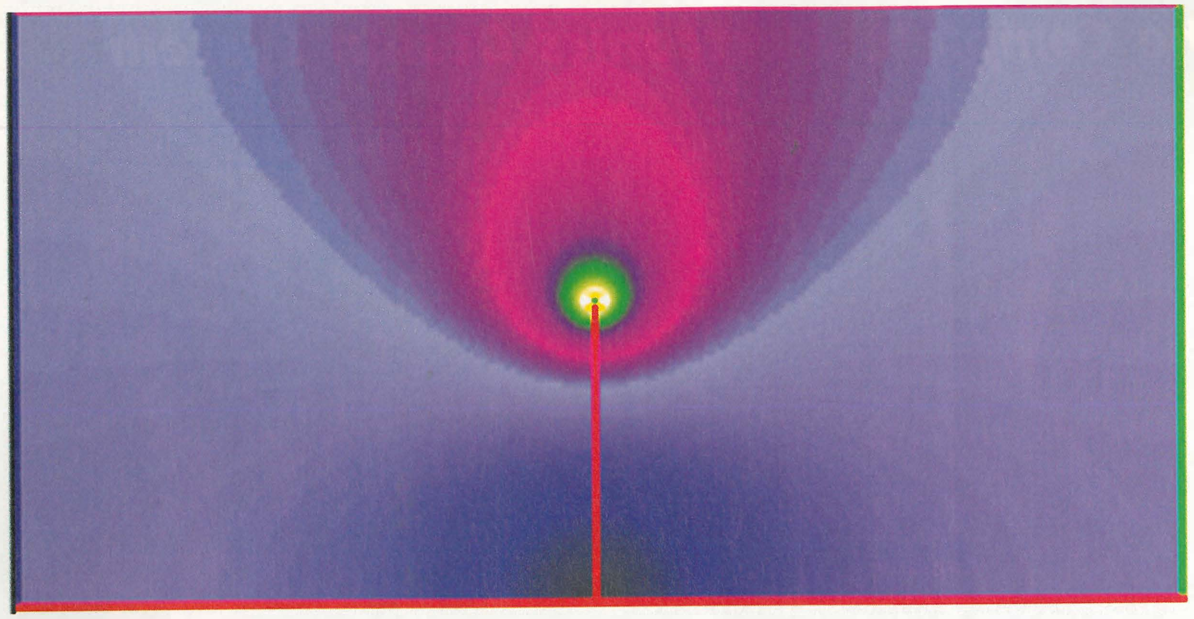


Fig. 1. Gradient plot of a plunge cut.

Reducing the stress in planar resistors

A well-designed resistor should have a flow pattern that is smooth and gradual. And choosing which track pattern would be most suitable for high stability resistors is also very important. Leslie Green (CEng MIEE) takes us through some of the pitfalls

In the first part of this article, the measure 'stress ratio' was introduced to give a quantitative rule for choosing which track pattern would be most suitable for high stability resistors. In this last part of the article the subject of trimming is discussed. Without careful trimming, all the work that went into designing a stable resistor pattern would be wasted; the trimming range is required to be so great that it has a strong influence on the final stress ratio in the trimmed resistor.

The stress ratio is so important to this discussion that it is repeated again below:

$$\text{Stress Ratio} = \frac{\text{Peak Electric Field Strength}}{\text{Mean Active Field Strength}}$$

Regions in the distribution which have a field strength of less than 5% of the peak field strength are not taken into account when calculating the mean field strength, hence the term 'mean active field strength'.

Trimming

The problem with the resistor design so far is one of accuracy. It is very difficult to control the material of the film and its thickness accurately. Without some form of trimming the resistor would typically have a tolerance of around ±19%. Given that trimming techniques consist of making cuts in the film, it is more natural to express this as a one sided tolerance of the form +0% –30%. The resistor is then trimmed *up* to the desired value.

You might think that there is an error in the above paragraph because from ±19% you might have expected to go to +0% –38%. The answer is that large percentages don't behave in a nice additive way.

Trimming is of major importance to manufacturers and users alike; it makes the difference between a good, stable resistor, with excellent voltage withstand properties, and a poor resistor not having these qualities.

Trimming Techniques

The best possible way to trim a resistor is to uniformly thin down the film. Remember that the resistance of the film is inversely proportional to its thickness. Unfortunately this is not as easy to achieve in practice, as it is to consider theoretically. Possible techniques include surface abrasion, wet etching or gaseous-phase dry etching. These are all difficult and expensive processes, particularly when you consider that a *dynamic trim* is the optimum method. By dynamic trim I mean that the resistor is being measured whilst it is being trimmed. Otherwise you can imagine having to guess how long to leave the resistor in the etching tank to achieve the desired amount of trimming. Amongst these three trimming techniques, as far as I know, only dry etching is currently being used commercially.

And now we go from the very best techniques to one of the worst. One of the worst ways to trim a resistor is to put a laser cut partly through the middle, perpendicular to the current flow. This is shown in **Fig. 1.**

With electrodes on either side this rectangular element we should have a resistance of two squares. By cutting half way through it at the middle, the resistance is increased to 2.454 squares. This is horrible in terms of the peak electric field intensity, as the gradient field plot of Fig. 1 shows. The stress ratio is 7.09.

The straight cut at right angles to the current flow is known as a plunge, a plunge cut or a P-cut. It is not only lousy in terms of the resulting stress ratio. It is also difficult to get accurate trimming, because the percentage resistance change per micron of cut length increases as you cut further into the film.

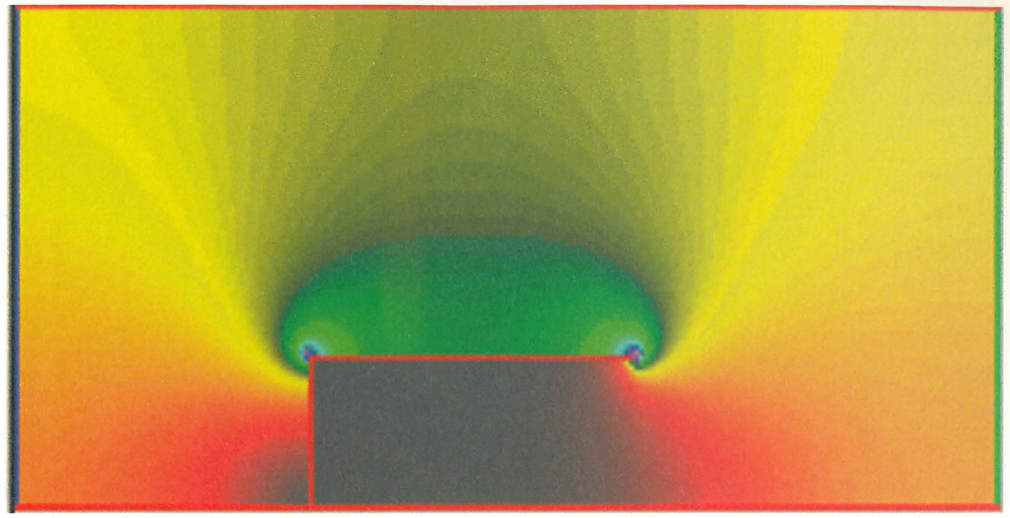


Fig. 2. Gradient field plot of an L-cut.

Laser Cutting

Laser trimming of resistive films is a detailed technology in its own right. The laser is not a continuous beam, as you might have expected, but is a series of short bursts of intense energy at a low duty cycle.

Each short pulse evaporates the material in a small circular region, but the edges of the 'cut' are not distinct. The laser beam has a finite focus in terms of its intensity, so that there is a small region around the edge of the hole where the resistive material has been overheated but not evaporated.

As you can imagine, this region is not an ideal place for high current densities. It is also more likely to drift in resistance value, and if it is contributing more than its fair share of resistance to the overall resistance, then the resistor will not be as stable as it should be.

To get a cut line in the resistor, the beam is stepped to a new position, designed to overlap the previous position by as much as 90%. This gives a clean cut, also called a *kerf*, in the film. Another problem associated with this cut is micro-fractures [1]. The resistive material is being heated sufficiently to evaporate it; although only a small amount of material is being removed, the surrounding area still gets heated significantly. This results in micro-fractures spreading away from the lased path. These fractures will spread with time and are one cause of the resistance increasing after the trimming operation.

For this reason the manufacturer has to use predictive trimming to set the value lower than the final required value, so that the resistor will drift up to the correct value a few tens of hours after the trimming is complete.

Another problem with the laser trimming technique is that a narrow laser cut in a relatively large sheet of resistive material allows significant distributed capacitance across the resistor[2]. When used in an attenuator, such a resistor cannot be compensated to give a response that is flat to within a few percent.

Symmetry

It is evident from the previous plot that the field is mirror symmetric about the central cut. This symmetry is useful in terms of the accuracy of the finite element analysis. Because of the symmetry, it is actually only necessary to simulate half of the resistor. In this way there are twice as many simulation elements used in each direction, giving 4× the resolution in terms of the number of elements.

It is a general principle of any sort of computer simulation to take advantage of symmetry whenever possible, to either improve accuracy or reduce the simulation time. Unfortunately the L-cut of **Fig. 2.** which is used because it is easier to get a fine trim than with the P-cut, wrecks the symmetry. However, throughout this article I have not made use of any available symmetry, in order to make the resistor designs easier to understand.

The resistance is increased by taking the cut parallel with the current flow, forming an L shape. This pattern has a resistance of 2.45 squares and a stress ratio of 3.48. The L-cut therefore gives a considerably better stress ratio for the same resistance as the P-cut. The only possible drawback is that the length of the cut is longer.

Now the cut on the film has been shown as being very narrow. This would apply to a laser cut, typically around 25μm, on a relatively large thick film resistor. On a resistor of 0603 size, the simulated cut would appear considerably wider. This would reduce the distributed capacitance and the field stress ratio.

For a larger thick film resistor another method is to use an air abrasion cut. This is wider than a laser cut and therefore reduces the stress ratio and the distributed capacitance; the penalty is increased cost because the machine is slower.

Obviously what we would like to do is to remove whole strips of the resistive material parallel to the current flow. This just is not feasible with a laser because the trim time would be enormous and the resistor would overheat. Clearly, since the length of cut determines the trim time and therefore the trim cost, this has to be balanced against the achievable accuracy and stress ratio achieved.

The User's Problem

You may not be designing the resistor, but you do need to understand what can happen in routine production. If you approve

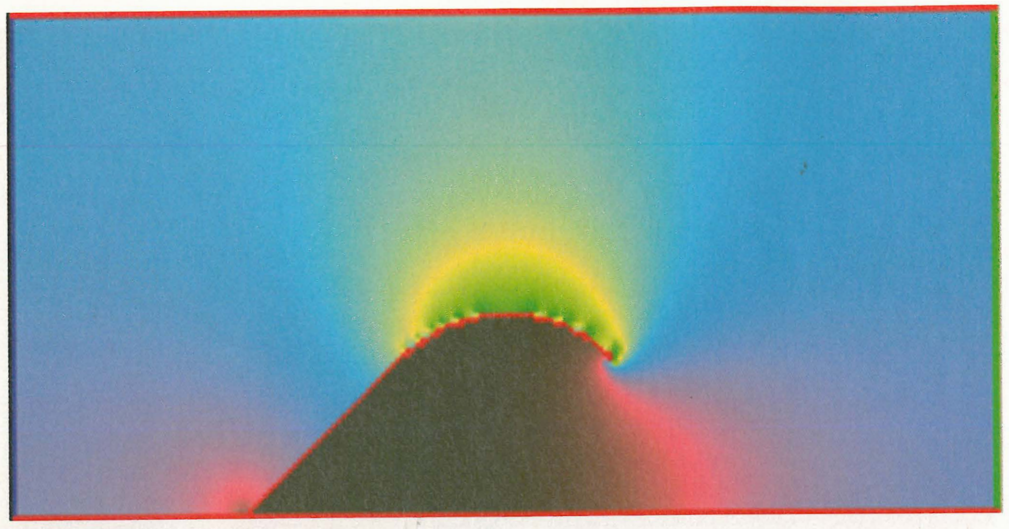


Fig. 3. Above gradient plot of a lazy-J cut.

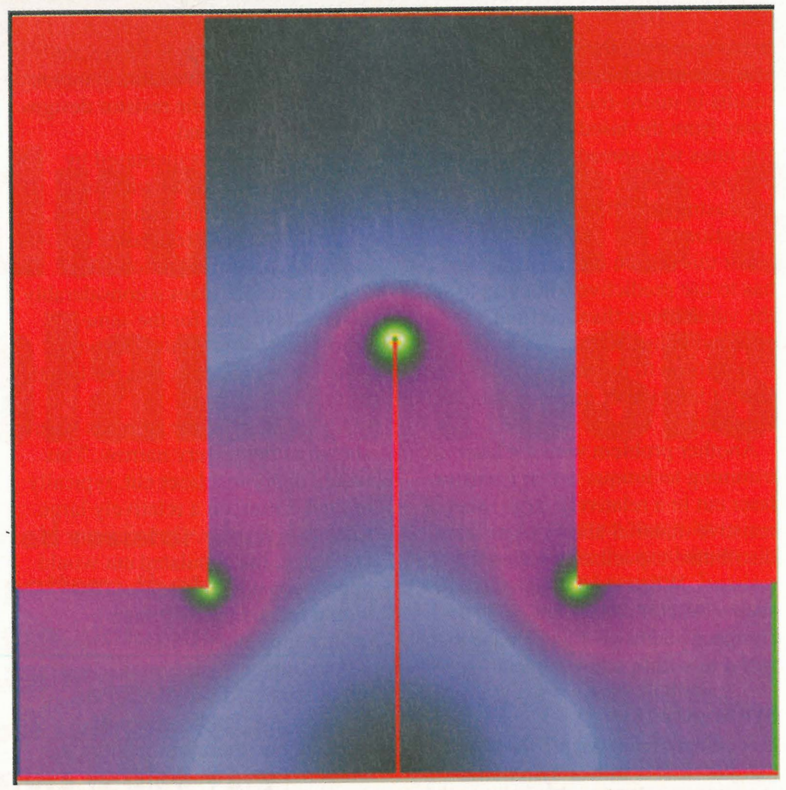
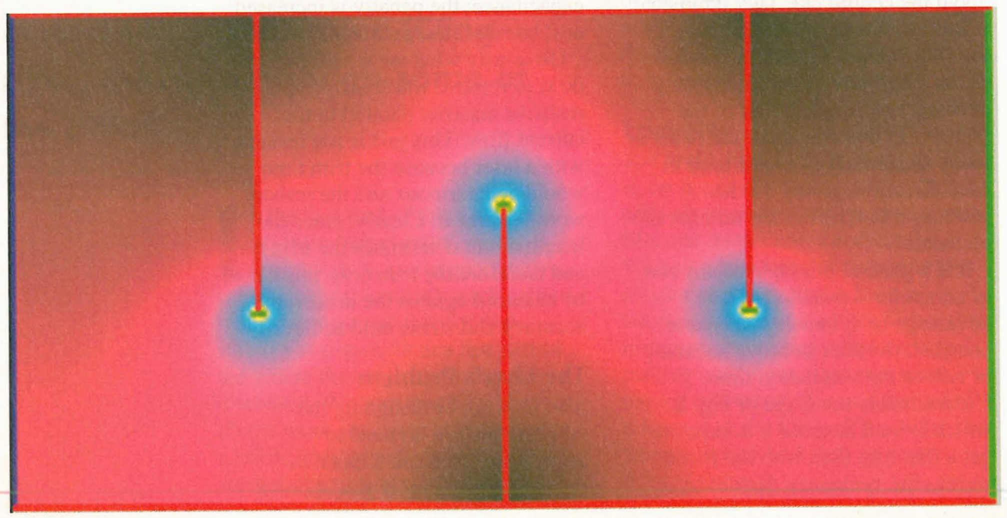


Fig. 4. Gradient plot of a top hat pattern. The orange area is the (insulating) substrate.

Fig. 5. Below gradient plot of a serpentine trim.



the design of custom resistors based on one sample batch, you can get caught out. Suppose the prototype batch happened to have high sheet resistivity. This would mean that the resistors would not need to be heavily trimmed. Thus any distributed capacitance effects and voltage breakdown effects would not necessarily be evident. Then, when you are in routine production, you get a batch where the sheet resistivity is low and all the nasty problems surface. This is why a user would need to consider what the manufacturer was doing in the design of the resistor.

Other Cuts

The L-cut can be enhanced by a P-cut at the 'open' end. When the plunge does not intersect with the L, a fine trim is achieved and the stray capacitance across the cuts is reduced.

If the plunge intersects the L, the path becomes continuous; a section of resistive material is isolated and it becomes a box cut.

Looking at the stress patterns on the P-cut and the L-cut, it is clear that all the problems come at the sharp corners. Looking back in this article at how the stress in the square corner problem was solved, a new cut is suggested. This consists of a sloping line which ends in a curved path. We could call this new cut a lazy-J as shown in **Fig. 3.**

The resistance is 2.52 squares and the stress ratio is 2.59. This makes it better than the L-cut. To get a finer trim, a sloping line should be cut up from the outside towards the open end of the arc. If this cut were continued, the shape of the cut would be a mirror symmetrical round-topped triangle. The fine trim cut also helps to reduce capacitance across the cuts, by reducing the potential difference across them.

Dynamic Circuit Trimming

The previous trimming techniques have been to get the final resistor to a predetermined value. Another possibility is to trim a circuit to a defined operating point by adjusting a resistor appropriately. This might be done for a hybrid circuit, for example, where it would be unacceptable to use a pot.

Because we are trying to emulate the range of a pot, the trimming range of the resistor needs to be considerably increased. In this case the top hat and serpentine cut can be used.

Figure 4 is one form of 'top hat' trim; it is good for making larger resistance changes, but it suffers badly from the electric stress problem, with a stress ratio of 6.16 in this simulation. Another method of getting greatly increased resistance is the serpentine trim of **Fig. 5.** This is just a series of interlocked plunge cuts.

This example has a resistance of 4.75 squares, which is a considerable 'trim' from the starting value of 2 squares. Again the stress ratio is very poor at 7.22. A better method is to use a lazy-J serpentine cut, shown in **Fig. 6.**

Figure 6 has a resistance of 5.30 squares and a stress ratio of 3.75. This new cutting pattern is therefore considerably better than the old serpentine cut. The top hat pattern is considerably more difficult to improve. First the basic shape of the corners is changed by pushing them inwards, as was done earlier on the single corner section. Then the top of the cut needs to be made circular as shown in **Fig. 7.**

This gives a resistance of 7.24 squares with a stress ratio of 3.45. The circular cut on the end of the plunge needs some explanation. This is not as infeasible as it might at first appear. Once the plunge is past the 'brim' of the top-hat, the change of resistance with cut depth is easily predictable. The fringing part of the field is relatively constant because the height of the hat can be made much larger than the cut depth.

It is therefore also true that the circular artefact on the end will have a relatively constant effect on the resistance and so it is possible to predict when to start the circular part of the cut. A fine trim can be done by a P-cut into the side of the hat, some distance above the circular cut.

Link Cutting

An even better way of getting large trims without affecting the stability of the resistor is to use link cutting. In one method the resistive film is used to form short links that bypass larger loops or ladders. When the link is cut, the current has to pass through the longer loop, thereby increasing the resistance.

These methods are very prone to the problems of stress in corners and can in fact be enhanced by the corner smoothing techniques mentioned earlier.

The key advantage of these link cutting methods is that the resistive film is completely cut away. Thus the resistive material which has been overheated around the edge of the cut is no longer used to carry current.

Another method to overcome the trimming problem is to have strips of conductive material under the resistive bar, following the equipotential lines as shown in **Fig. 8.** These conductive strips can be connected to each other with laser cuttable strips and the resulting pattern will have a stress ratio approaching 1.

Notice that this is an equipotential plot; the gradient plot would show nothing because the gradient is the same throughout. The capacitance of the bars will not be as significant as you might at first imagine, simply because there is very little potential difference between them.

Conclusion

There are many factors that affect the stability of a planar resistor. The initial shape of the resistor is important in order to give a low stress ratio and therefore the optimum performance from a given technology. Trimming a resistor with a laser is problematic. As far as the film integrity is concerned, the laser cut should be as narrow as possible. This minimises the heating of the film and therefore reduces the micro-cracks that form around the cut. The

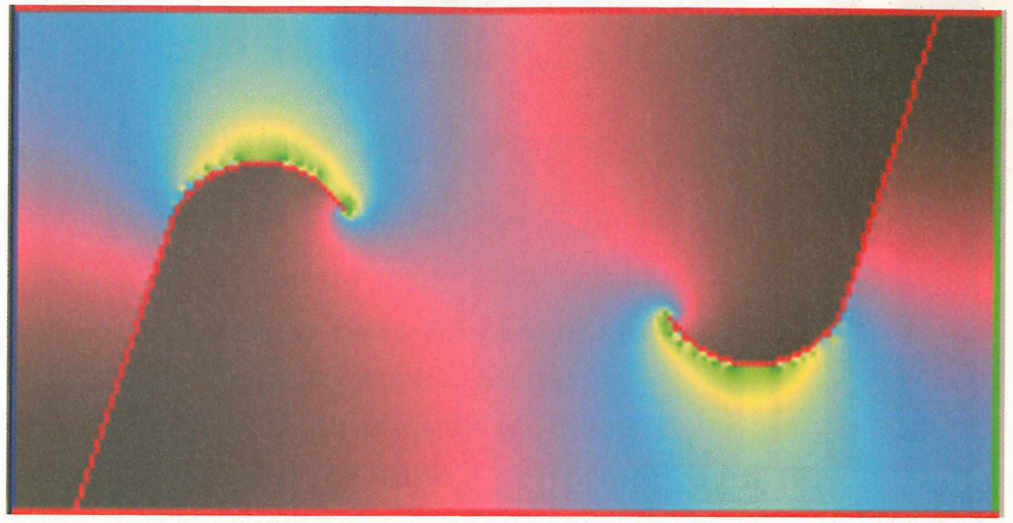


Fig. 6. Gradient plot of an improved trim method, a lazy-J serpentine trim.

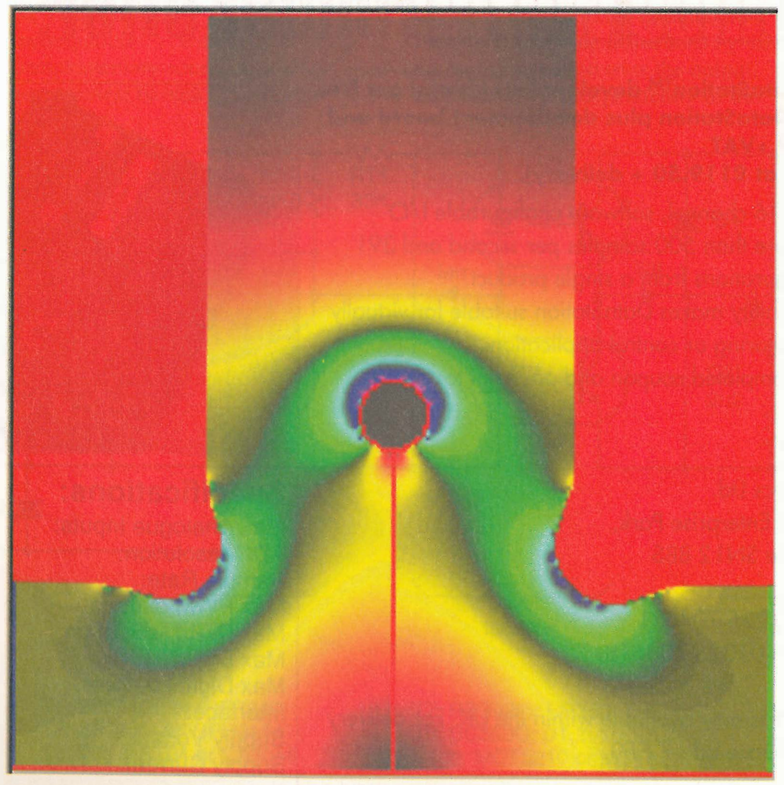


Fig. 7. Gradient plot of an improved top-hat trim.

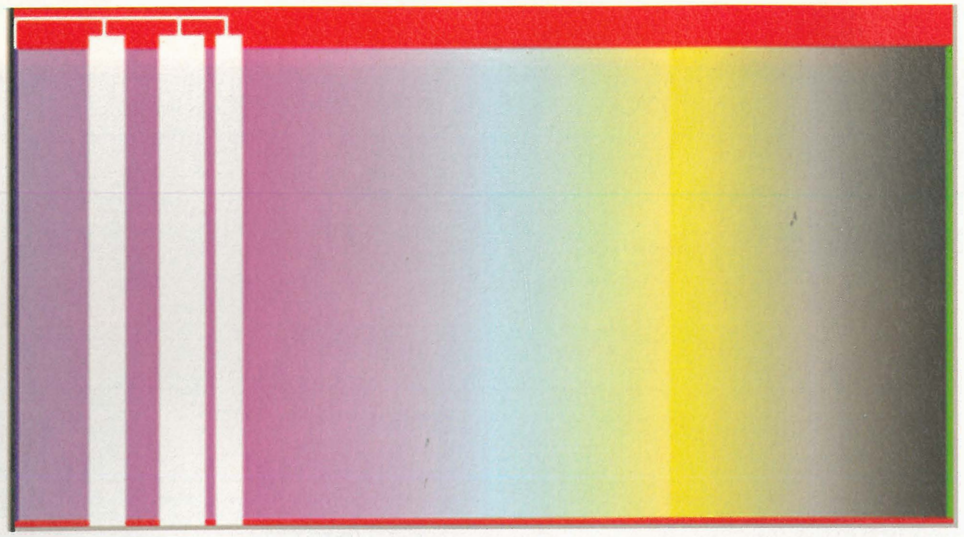


Fig. 8. Equipotential plot of the ultimate in stress-free trimmed resistors. The white strips are conductive material either over or under the resistive film.

disadvantages of this are that the parasitic capacitance across the cut is higher and the stress ratio is worse.

It is very easy for the micro-fracture problem to be an order of magnitude, or more, larger than the effect due to the stress ratio. Thus the stress ratio has greater importance when the micro-fracture problem is dealt with. The micro-fracture problem and the overheating of the film around the edges of the laser cut are both dealt with by 100% cuts of individual current paths. This allows the benefits of the stress ratio improvements to be realised.

It is not possible to verify the performance of a custom designed resistor based on a prototype that happens to have high sheet resistivity. The fact that it has not been heavily trimmed means that its voltage withstand capability, long term stability, 1/f noise and AC performance will be superior to a future part which is made from a lower resistivity material.

A possible solution to this problem is to get the manufacturer to trim such a part up to the maximum possible adjustment range. This will make the resistor the wrong value by up to 30%, but may give a more representative sample in terms of the adverse effects mentioned previously.

The 2-dimensional field patterns in planar films are very beautiful to look at when seen in full colour. Unfortunately the gradient patterns are at their most beautiful when the stress ratio is the worst. Thus a truly beautiful resistor design has a very plain looking gradient plot.

A well-designed resistor has a flow pattern that is smooth and gradual. Sharp lines and angles need to be avoided. If you look at the equipotential plot, you can see where the current is flowing; it always flows at right angles to the equipotential lines. This is an area where artistic ability can improve electrical performance. Thus a beautiful resistor has technical as well as artistic merit.

Interested readers can download demo field plotting software from www.logbook.freeserve.co.uk

References

1. Mechanism and Control of Post-Trim Drift of Laser-Trimmed Thick-Film Resistors by J.Shah & L.Berrin: IEEE Transactions on Components, Hybrids and Manufacturing Technology. Vol. CHMT-1, No.2, June 1978, pp 130-136.
2. Parasitic Capacitance Effects of Planar Resistors by S.Demurie & G.DeMey: IEEE Transactions on Components, Hybrids and Manufacturing Technology. Vol. 12, no.3, September 1989, pp 348-351.

Autobias for mosfet audio output stages

It's said that biasing vertical d-mosfets in a class-AB output stage is less critical than biasing their bipolar counterparts. So many designers are content with the classical V_{BE} multiplier as bias generator. However, the accuracy needed for utmost performance (in terms of cross-over distortion and quiescent dissipation), cannot be provided by such a circuit, even when it is thermally coupled to one of the output devices. Edmond Stuart explains

Several factors may contribute to the lack of accuracy:

1) Mismatch between relative temperature coefficients of mosfets and bjts as consequence of the variability of the gate threshold voltage as well as the temperature coefficient of V_{GS}.

2) Thermal delay and attenuation of the coupling between output device and sensing element.

3) Drivers - if included - that operate at a different temperature.

4) Long-term drift of threshold voltages as a result of ageing[1].

5) Errors in adjusting the bias level for each individual amplifier.

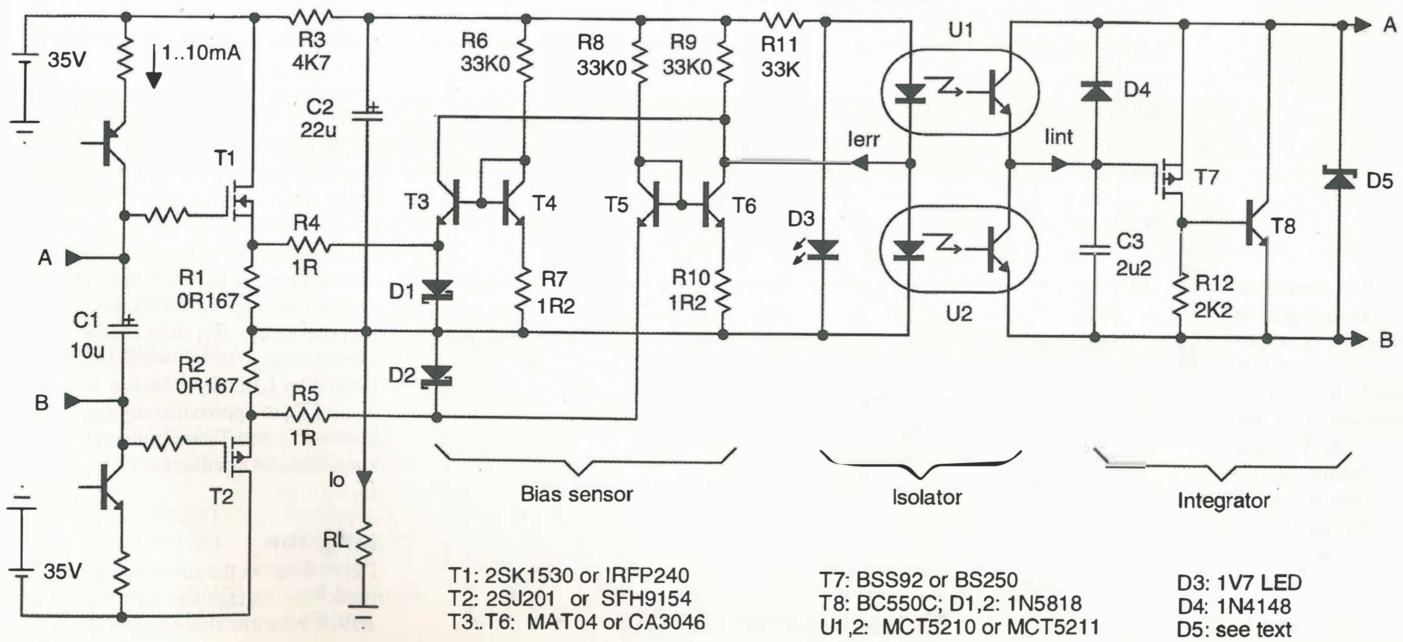
So it seems natural to replace the V_{BE} multiplier - which in fact provides a kind of error feed forward[2] - by a control loop based on feedback of the bias current itself. In the past, several attempts has been undertaken in this direction, but none of them seem to me suitable for high-end applications, as they are intrusive also on other parts of the amplifier. This could raise distortion[3,4], complicate HF compensation[5,6] or be incompatible[3,4,5] with a complementary source follower arrangement (which I prefer), or could be too complex[7]. Nevertheless, reference 5, ingenious in its own right, inspired me to a re-design that overcomes these shortcomings.

The new design comprises three sections: a bias current sensor, an isolator and an integrator. Each of them will be discussed below in detail.

Bias sensor

The bias sensor's purpose is to detect any deviation from the nominal bias level without being influenced by the current distribution over the output transistors, i.e. independently of the

Fig. 1. Circuit diagram of the autobias generator connected to a typical mosfet output stage



current delivered to the load (R_L). This is accomplished by sensing the voltages across the source resistors of the output stage and passing them to a non-linear network, comprising two current mirrors (transistor pairs $T_{3,4}$ and $T_{5,6}$ respectively). Two equal reference currents are supplied to the inputs of the mirrors via R_6 and R_8. Since the voltage across each source resistors adds an off-set to V_{BE} of T_3 and T_6, the currents reflected by them will be lower than the reference.

Under quiescent conditions, this offset is such that each mirror reflects only 50% of the reference current. As dictated by the laws of physics, this condition is met if the offset voltage is 18mV (at room temperature). Together with R_1 and R_2, this 18mV defines the quiescent current of the output stage (e.g. 100mA if R_1=R_2=0.18Ω). To maintain this condition the reflected currents are summed together and subtracted from a third reference current supplied by R_9. The resulting difference, I_{ERR}, tells us whether the output stage is under, correct or over biased, thus I_{ERR} can be used as a feedback signal, **Fig. 2.**

Next, what happens in the presence of small or medium signals? This is illustrated by the middle curve of **Fig. 3**. It shows the relationship between error signal and output current at the nominal bias level. As one can see, the crux is that *the error signal stays very close to zero*. Apparently, the non-linear behaviour of the mosfets, in particular in their weak and moderate inversion region, matches the characteristics of the bias sensor quite well. The other curves show the error signal if the output stage is forced to an under - or over-biased state. Beyond output currents of ca. 0.6A the error signal is pinched off. This looks like a disadvantage, but it turned out to be beneficial, as explained below.

Finally, what happens in the presence of large signals? Suppose T_1 carries a large current and T_2 is turned off. In this case the reflected current in T_3 is zero, while in T_6 it is 100%. Summed together and subtracted from the third reference, the resultant error signal is again zero. This is exactly what we want, as an output stage operating in class B provides no information about the quiescent current, thus the error signal has be pinched off in order to preserve the charge of the integrator's capacitor (C_3).

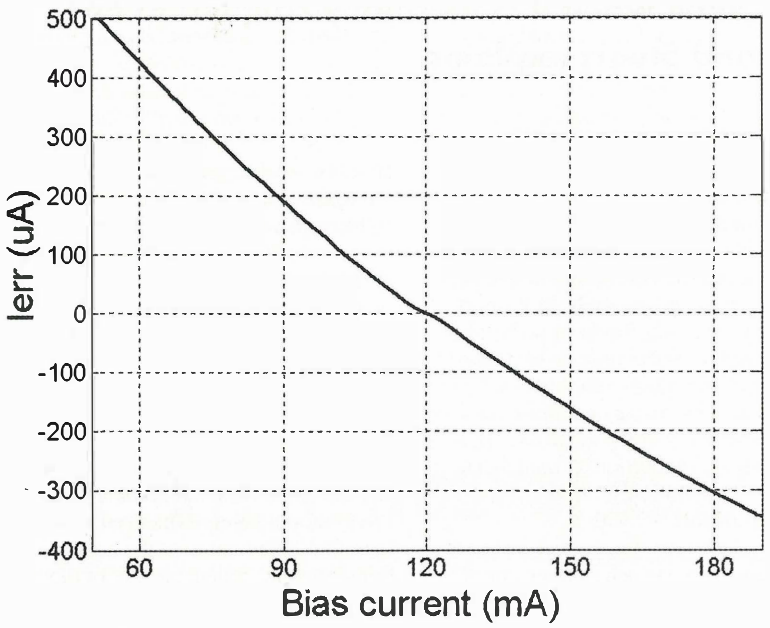


Fig. 2. Simulated error signal as function of bias current (I_{REF}=1mA, $R_{1,2}$=0.167Ω, RL=∞).

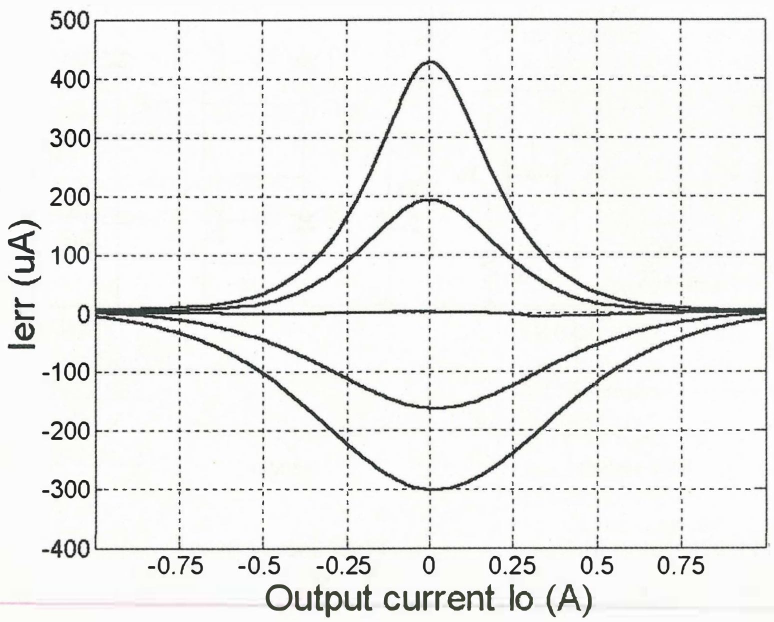


Fig. 3 Simulated error signal as function of output current at bias levels (from top to bottom) of 60, 90, 120, 150 and 180mA. Notice that at 120mA this signal stays close to zero.

Since music has a high peak/average ratio - some 20dB - the average signal level - even at maximum volume - is well within the capture range of the bias sensor. Sine waves at full power give no trouble either, as the relative time traversing the capture region is long enough to let the control loop do its work. However, a large square wave pushes the output stage continuously in class B and no error signal is produced at all, leaving the integrator in an undefined state.

Isolator

To avoid any adverse interaction between common mode and differential signals at the gates (node A and B), an isolator has to be inserted somewhere inside the servo loop. Putting it between bias sensor and integrator greatly simplifies the circuit, as the integrator can now simply use the bias voltage as supply. Given the bipolar nature of the error signal, two opto-couplers (U_1, U_2) are needed, one for charging, the other for discharging C_3. They are specified for operating at low currents (<1mA). Apart from their primary task (isolation), they serve one more purpose: masking the tiny deviations of the error signal, as can be seen at the middle curve of Fig. 3. The reduced transfer ratio at very low currents from which any opto-coupler suffers (see **Fig. 4**), meets this purpose nicely. R_{11} delivers the supply voltage to U_1, while being limited by LED D_3 reducing V_{CE} of T_3 and T_6 to approximately the same level as T_4 and T_5 and preventing simultaneous conduction of U_1 and U_2.

Integrator

Depending on the mosfets actually used, bias voltage can vary from 2 to 10V. To handle this range it leads almost automatically to the kind of topology, as shown in Fig. 1. In spite of its simplicity, this integrator, or to be more precise - integrating shunt regulator, exhibits a dynamic output impedance that is low enough (<2Ω) to cope with AC currents from the driver stage. In order to exclude interaction at AF, integrator capacitor C_3 is rated such that the unity gain frequency of the servo loop falls below the audio spectrum, somewhere between 1 and 10Hz, depending on the transfer ratio of the opto-couplers. D_4 discharges C_3 during switch off and protects the gate of T_7. For reliable operation, low leakage at the integrator input is essential, so D_4 should be protected from light. Zener diode D_5 is rated at the maximum expected bias voltage plus a small margin and should be adapted to fit a particular design. If some component fails or if nasty test signals have been applied, this diode protects the output stage against excessive common mode currents.

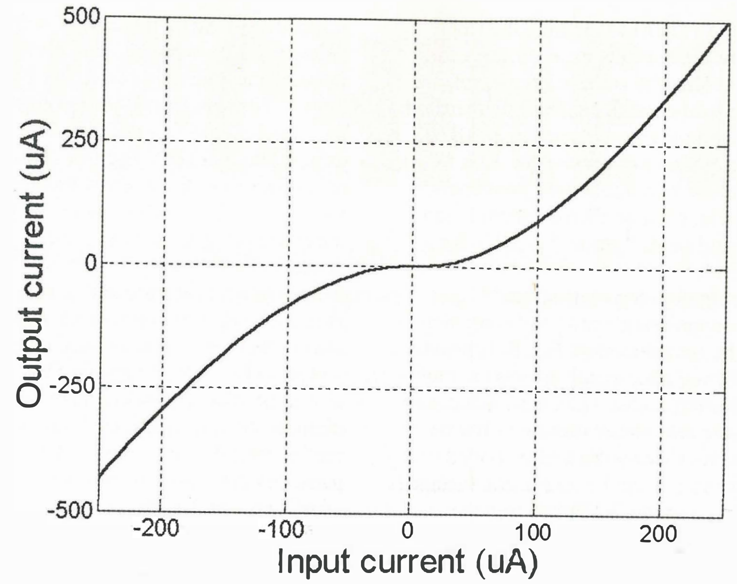


Fig. 4. Transfer function of the isolator.

Accuracy

The bias level is very sensitive to mismatches of the transistor pairs and reference currents. Base-emitter voltages T_3 T_4 T_5 and T_6 respectively should match at least within 0.5mV. A quad transistor like a MAT04 or CA3086, selected on low Vos, meets this requirement. For the same reason, R_6, R_8 and R_9 should match at least within 0.5% as well as the equivalent emitter series resistors; hence R_7 and R_{10} are rated slightly higher than R_4 and R_5. Since a MAT04 is equipped with small reverse connected diodes between base and emitter, Schottky diodes D_1, D_2 are added to protect them.

Now we come to a moot point: the voltage of 18mV across R_1 and R_2 which all relies upon, varies linearly with the absolute ambient temperature*. Of course, it varies much less than the junction temperature of the output devices and thermal runaway is precluded, but still it is not constant. It is not yet clear to me whether this should be regarded as flaw or feature, as one could argue that the decreased transconductance of mosfets at elevated temperatures just needs an increased bias level. Interestingly, a bias control IC from Linear Technology[6] shows the same temperature dependence, which could not be explained by an inherent shortcoming of the basic circuit. So I concluded that this property has been added on purpose. Asking why, Linear Technology was unable to give a satisfactory explanation. If anybody could shed light on this matter, please let me know.

* $V_{BE} = V_T Ln2$, where $V_T = kT/q$, the thermal voltage (25.86mV at 300K).

Experimental results

To see if the circuit is generally applicable, I tested it on several combinations of mosfets, all capable of delivering 12 to 20A, but of different types and brands. To minimise temperature effects, measurements were done at a reduced supply voltage of 2x16V, the mosfets mounted on a large heatsink with forced air cooling and at a frequency of 1kHz. Static measurements were done at an even lower voltage, 2x7.5V. Since these were very time consuming, I have done this only in case 1 and 2.

In the first instance, dynamic behaviour of bias current was observed by means of an oscilloscope, but changes at various output levels were hardly visible and difficult to quantify, except in case 1, which showed an increase of 5% at maximum output power. Instead, I

Ripple amplitude of the error signals measured at $V_O = 8V_{pp}$ and 1kHz as well as estimated ripple on bias voltage (V_{RPL}) at 20Hz.

Case	Type	Manufacturer	R_L (Ω)	I_{ERR} (μA $_{eff}$)	I_{INT} (μA $_{eff}$)	V_{RPL} (mV$_{eff}$)
1	IRFP240 IRFP9240	Int. Rectifier Idem	4 ∞	15.9 62.4	3.3 157.0	12.9 568
2	2SK1530 2SJ201	Toshiba Idem	4 ∞	4.9 3.2	<0.1 <0.1	<0.4 <0.4
3	IRFP240 FQA12P20	Intersil Fairchild	4 ∞	14.2 5.0	1.3 <0.1	4.7 <0.4
4	IRFP240 SFH9154	Intersil Fairchild	4 ∞	7.2 5.6	0.2 <0.1	0.8 <0.4
5	FQA19N20 FQA12P20	Fairchild Idem	4 ∞	11.6 5.1	0.7 <0.1	2.5 <0.4

used a DVM to measure the ripple amplitude of the error signal before and after the isolator under load and no load conditions. Next, I estimated the ripple-on-bias voltage at 20Hz, according to $V_{RPL} = I_{INT} / (2 \pi f C_3)$, instead of a direct measurement at 20Hz, because thermal modulation could be disturbing. See table for results.

The first trial was rather disappointing, not to say confusing. The error-function, **Fig. 5**, is heavily skewed and ripple currents are high (see table, case 1). Transconductances were reasonably matched - within 20 %, so something else spoiled it. It appeared that the output conductance (G_{OS}) of the IRFP9240 was the culprit. At a drain current of 125 mA, G_{OS} is about 5mA/V, while the IRFP240 shows a G_{OS} of only 0.4mA/V (corresponding to an Early voltage of 25V and 312V respectively). So an increase of output voltage of 1V - without load - will increase the quiescent current by 4.6mA. No wonder that the error function is skewed. At higher drain currents the IRFP9240 behaves better: at 1A for instance, the Early voltage raises to ca. 75V. This explains why the ripple on I_{ERR} becomes much smaller when the output stage is loaded with a low impedance. However, speaker impedances are not always that low – at resonance up to tenfold, so a no-load condition has also to be taken into account. Without blaming the manufacturer, I cannot recommend this mosfet pair. After all, these devices were designed for switching, not for driving loudspeakers.

In the next trial I used a complementary pair from Toshiba, especially intended for linear applications: 2SK1530 and 2SJ201. Due to closely matched transconductances (within 5%) and high Early voltage (over 300V) for both N- and P-channel parts, the results were far better. The error function, **Fig. 6**, is in accordance with the simulation, although skew is slightly higher and in the opposite direction. Ripple currents were hardly measurable.

In the last three cases I tested several other samples (courtesy of Fairchild) which are less expensive, but, as in case 1, primarily targeted for fast switching. Results were almost as good as in case 2 and I see no reason not to use these mosfets, except that the higher gate threshold voltage reduces the maximum output power somewhat, that is, without using a boosted power supply for the drivers.

I have also investigated a few combinations of two 20A N-channel and three 12A P-channel devices. Because no improvements were seen, I will not discuss them any further. Using bjts instead of mosfets will probably not work at all, as Spice simulations were very discouraging. For lack of Spice models, lateral d-mosfets have not been investigated.

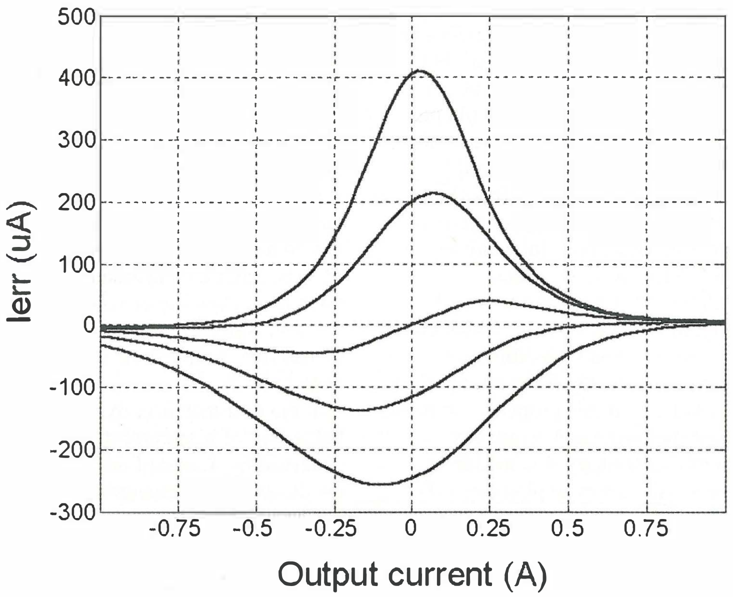


Fig. 5. Same as fig. 3, but measured on a IRFP240/IRFP9240 pair at bias levels of 57, 85, 118, 142 and 171mA.

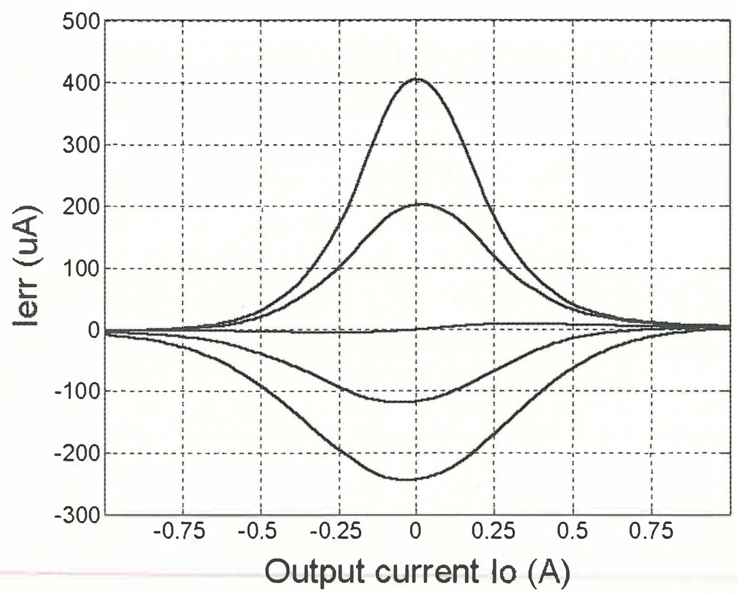


Fig. 6. Same as fig.5, but measured on a 2SK1530/2SJ201 pair.

Conclusion

Provided that output devices are selected with some care, in particular with regard to trans- and output conductance, the proposed circuit comes up to all expectations. Since the circuit acts only on the bias voltage and is not intrusive on any other part of the amplifier, it should be easy to incorporate into new or existing designs like mentioned in ref. 8 and 9.

References

1. Finnegan, T, 'Going linear with power mosfets, part 2', *EW*, Sept. 1992, p.781.
2. Self, D, 'Thermal dynamics in audio power', *EW*, May 1996, pp. 410-415.
3. Roehr, W., 'The autobias amplifier', JAES, April 1982, pp. 208-216.
4. Siliconix, 'Mospower Application Handbook', Chapter 6, pp.105-110
5. Gevel, M. van de, 'Audio power with a new loop', *EW*, Feb. 1996, pp.140-143.
6. Datasheet LT1166, Automatic bias system, Linear Technology.
7. Brown, I., 'Opto-bias basis for better power amps', *EW+WW*, Feb. 1992, pp. 107-109
8. Hitachi Mosfet Handbook, Section 6.1, pp. 143-151.
9. Stochino, G.,'300V/μs power', *EW*, April 1997, pp.278-282

TIME MACHINE 2

Accurate time measurement on a budget by John Morrison. In this the second part of John's article, he describes the circuit and gives us the source code.

The 16F84 has 13 independent I/O pins. These can be configured individually by the software to be inputs or outputs. When configured as outputs they can drive LEDs directly.

In this design we require 10 outputs to drive the bar graph display and one input to read the pulse to be measured. The timer runs from the clock generated by the 4Mhz xtal, this is divided by 4 internally. Using the maximum pre-scale of divide by 256 we have a counter that runs at 3906Hz.

The timer is only 8 bits wide but 3906 decimal requires 12 bits, and this is where timer interrupts become useful. For those not familiar with microcontrollers, an interrupt can be hardware or software generated. This will divert the controller to a preset location in memory where it will process the instructions until it finds a 'return from interrupt', it then returns to where it left off originally.

So we set the timer to generate an interrupt every 256 counts, and write an interrupt routine to increment a memory location. At the end of our pulse count the top 4 bits in interrupt counter plus 8 bits in timer counter should equal 3906 for a 1 second pulse.

Source Code

The complete source code is supplied so that you can modify it to suit your needs.

For example if you wish to measure a 10Hz pulse width the count expected would be 390. This is 0186 hex so just change the subtract numbers in the display routine. ■

```
; Bar Graph Clock Calibrator.
; Pic 16f84 4 Mhz Xtal.   Fuse=3FF9
;---------------------------------------------------------
; Timer0 + timsb (16bits) contain counter (3609 cps)
inpin       bit         porta.2
;
timer       equ         01          ;pic timer address.
timsb       equ         0c          ;interrupt counter
msbcnt      equ         010
lsbcnt      equ         011
;---------------------------------------------------------
            jmp         main
            org         004
intvect     incf        timsb       ;come here on iterrupt.
            bcf         intcon,2    ;clr toif
            retfie
;---------------------------------------------------------
; BarGraph table 0 - 7 ( 8 Bar dots)
table       addwf       02
            tablw       07f,0bf,0df,0cf,0f7,0fb,0fd,0fe
;---------------------------------------------------------
main        movlw       0fc
            tris        porta       ;a0/1 outputs.
            movlw       00
            tris        portb       ;all B as outputs.
            movlw       07
            option                  ;pre-scaler div 256
            movlw       0ff         ;switch off LEDs
            movwf       porta       ;on both
            movwf       portb       ;ports.
            bsf         intcon,5    ;toie  Enable timer Int.
            bsf         intcon,7    ;gie   Enable Global Int.
mloop       call        read
            call        display
            goto        mloop
;---------------------------------------------------------
read        btfsc       inpin       ;wait for inpin goes low
            goto        read
            movf        timer,w     ;get low 8 bits
            movwf       lsbcnt      ;put to result low.
            movf        timsb,w     ;get high 4 bits
            movwf       msbcnt      ;put to result high.
            clrf        timsb       ;Clear Int count
            clrf        timer       ;Clear Timer count.
till_high   btfss       inpin       ;wait for inpin  goes high.
            goto        till_high
            return
;---------------------------------------------------------
display     bsf         porta,0     ;switch off
            bsf         porta,1     ;LED display
            movlw       0ff         ;before calculating
            movwf       portb       ;bar graph position.
;----- BarGraph centre=0F42 (3906 decimal). ---------
            movlw       03d         ;subtract 3901
            subwf       lsbcnt      ;from result to
            btfss       03,00       ;leave a
            decf        msbcnt      ;value of 5 (centre bar)
            movlw       0f          ;if  the result
            subwf       msbcnt      ;was 3906.
            btfss       03,00       ;chk carry flag
            goto        fast        ;if  clear 'out of range'.
            movlw       10          ;subtract 10
            subwf       lsbcnt,w    ;from result
            btfsc       03,00       ; check carry if set
            goto        slow        ; 'out of range'.
            movf        lsbcnt      ;dummy move, get flags
            jz          fast        ;'out of range'
            decf        lsbcnt      ;ans=ans-1
            jz          d3          ;if ans=0 light segment 0
            decf        lsbcnt      ;ans=ans-1 to make
            movf        lsbcnt,w    ;look up table work.
            call        table       ;change number to bar value
            movwf       portb       ;light bar segment.
            return
fast        bcf         porta,1     ;light top right bar segment
            return
d3          bcf         porta,0     ;light 1 left from top right segment
            return
slow        bcf         portb,0     ;light bottom left bar segment
            return
```


```
:100000001028FF3FFF3FFF3F8C0A0B1109008207BA
:100010007F34BF34DF34CF34F734FB34FD34FE3467
:10002000FC306500003066000730620OFF3085005C
:10003000860 08B168B171E2029201B2805191E28C9
:100040000108910O0C0890008C018101051D2628F3
:10005000080005148514FF3086003D309102031C12
:1000600090030F309002031C46280A301102031837
:100070004A2891080319442891030319482891O339
:10008000110807208600080003lD4828851008OO75
:100090000510080006100800FF3FFF3FFF3FFF3F2D
:00000001F
```

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An introduction to network analysis

Computerised circuit simulators are useful tools, but they are not infallible. Here, John Ellis provides an insight into how network analysis works, with the aim of giving you a better idea of how to assess the usefulness of the results of circuit simulations. In the second part of this article, John will also outline how you can produce your own basic simulation tools.

Today, circuit simulation is such an integral part of electronic design – whether for integrated circuits, discrete designs or even printed circuit boards – that the underlying principles are not often considered. This is an indication that the design process, and technology, is commercial, competitive and industrialised where the principles have become secondary to designing new circuits or products that put transistors to use.

Specialist software has become available to enable circuits with thousands or millions of transistors to be simulated with relative ease. The price that is paid for this commercialisation is that the simulation software also has a price tag. To an extent, only companies can afford to pay for them.

Yet the principles of simulation are quite straightforward. It is possible to write programs on a PC to address some of the simpler tasks without too much difficulty – particularly for small-signal analyses. Transient analyses over large voltage swings causing saturation are more difficult.

The SPICE – Simulation Program with Integrated Circuit Emphasis – program[1] is perhaps the most widely used simulator. Although a public domain program, Berkeley lists charges of \$150 for version 2 listings and \$250 for version 3 on their web site – at least as of May 2000. Commercial versions make it easier to use, but are similarly, or more expensively, priced.

This set of articles introduces the simulation task from circuit specification to methods for solving the equations, and illustrates the solutions for some example circuits. As such the principles described are not new: the purpose of this article is to provide an overview of the simulation process.

Furthermore, the program methods here are, it has to be emphasised, quite basic and do not equate to a full commercial simulator. A commercial simulator will have a graphical user interface, or GUI, accepting a circuit diagram for the input which is drawn more or less as normal. With the simulator described here, you will have to enter the equations for the nodes manually.

A commercial simulator will have robust algorithms which will deal with extreme non-linear behaviour in transistors. For example, while the basic exponential equations can be handled without much difficulty, in saturation, the gain rapidly collapses, making the collector-to-base junction become far more significant than in the normal active mode. The algorithms here are somewhat basic, but respond to short time-stepping.

In this article, I have limited discussions to resistors, capacitors and the well-known SPICE -type of model of the bipolar transistor. Bipolars form the bulk of most discrete circuit designs, but MOSFETs are dominating the transistor and IC market in many areas and perhaps should be considered in a separate article.

The bipolar SPICE model has served very well for many years since its introduction (*op cit*). It continues to describe the types of transistor used in amplifiers, such as the BC547, BD139 and 2N3055 (epi) devices quite well. It is today regarded as somewhat lacking for very high speed transistors, such as used in the mobile phone industry, which have f_Ts of 10GHz or more, but it is to its credit that it has withstood the test of time for so long.

How to simulate a circuit

There are several steps to simulating a circuit. First, the circuit has to be described in terms of its components. Then, expressions are required for each of those components to describe the electrical behaviour in terms of voltages and currents. Lastly, the resulting set of equations has to be solved in a self-consistent manner.

Starting with the circuit diagram, every interconnection point, or node, is given a number. Often the circuit is also specified as a 'net list'.

In the SPICE model, a node is simply listed as a number with the related node numbers given as appropriate to the component, followed by a letter for the component type – such as R for resistor – and finally its value. The result is a set of nodes with the components described between each, leading to a set of equations describing the electrical behaviour with, usually, one unknown voltage per node. Hence the number of equations required is dictated by the number of interconnections in the circuit.

There are two approaches to simulation that provide complementary information about a circuit. These are the frequency-domain and time-domain methods. In the simulation world, the approaches do not give equivalent information.

The frequency-domain method is based on an AC small-signal model, while the time-domain approach uses discrete time steps. The frequency-domain method gives the frequency response of a circuit, but no absolute values. This is because all equivalent impedances are by definition fixed and do not change with voltage.

The time-domain approach will provide large-signal behaviour, distortion characteristics, and transient information for – in principle – any arbitrary input wave-form. The frequency-domain method is useful for checking whether an amplifier has a flat response, or whether there are some peaks or other surprises in its performance, while the time-domain solution will provide absolute distortion and other information, but for a pre-defined input wave-form.

Time-stepped simulation will thus provide the most detailed analyses of circuits. For long complex wave-forms though, it may take a while as there would be many calculations to make. For example if the response over a 1 second period were needed, but time steps of 1μs were required for accuracy, at least 1 million calculations would have to be made.

In some simulations, the time steps taken need to be varied according to the changes occurring in a circuit, so that where nothing much changes the time steps can be widened, and *vice versa*. This usually requires an iterative approach, possibly with 'trial and error' so that if a time step is taken which is too large to resolve accurately, finer time steps can be taken from the previous solution.

Component descriptions

Resistors. Resistors are almost too trivial to mention, but there are some considerations to make concerning the formulation of the model. In a circuit, two nodes N_1 and N_2 with a resistor between them, **Fig. 1**, have a description for the current which is just

$$i = \frac{V_2 - V_1}{R} \qquad (1)$$

where V_1 and V_2 are the voltages on the nodes and R is the resistance. Current is taken to flow in the direction 'there' to 'here', so if node 1 were 'here', the current is as given in equation 1.

Capacitors. Capacitors are described in two ways, either as an impedance, for the frequency-domain analysis, or using a differential, for time-domain analysis. The impedance method uses the expression

$$Z_c = \frac{1}{2\pi fC} \qquad (2)$$

Here, Z_c is the impedance of the capacitor, f the frequency, and C is the capacitance.

The differential uses

$$i = C\frac{dV}{dt} \qquad (3)$$

where C is the capacitance and dV/dt is the rate of change of voltage across it with respect to time. In **Fig. 2**, on nodes N_1 and N_2, for example, the rate of change of voltage with time is

$$\frac{dv}{dt} = \frac{(V_2 - V_1)|_t - (V_2 - V_1)|_{t-1}}{dt} \qquad (4)$$

where t is the time at the current time step; t–1 is the previous time step, and dt is the difference between the time steps. The current is then

$$i = C \times \frac{(V_2 - V_1)|_t - (V_2 - V_1)|_{t-1}}{dt} \qquad (5)$$

Because the previous time-step solution leaves the capacitor with a charge on it, it is a little simpler to write equation 5 thus

$$i_c = \frac{C(V_2 - V_1)}{dt} - \frac{Q|_{t-1}}{dt} \qquad (6)$$

where $Q|t-1$ is the charge on the capacitor at the previous iteration (t–1).

Inductors. I have not simulated any inductors here, but it is perhaps possible to describe inductors in a similar fashion to the capacitor. The small signal approach is very easy and uses

$$Z_l = 2\pi fl \qquad (7)$$

For the transient simulation, instead of a stored charge, there is a stored magnetisation which for want of any better symbol I designate by H. Then for a change in current the induced voltage

$$V = -L\frac{di}{dt} \qquad (8)$$

Following the same time steps as for the capacitor

$$V = -L\frac{i_t - i_{t-1}}{dt} \qquad (9)$$

and the stored magnetisation

$$H = L\frac{i_{t-1}}{dt} \qquad (10)$$

so

$$V = -\left(L\frac{i_t}{dt} - \frac{H_{t-1}}{dt}\right) \qquad (11)$$

For any change in current, H will change, and if the current were to become constant, there could still be a stored energy represented by H. At the next time step H is updated by $V.dt$ – rather than i.dt for the capacitor charge – which for a constant current will not alter H. This correctly gives an induced voltage if, for example, the current were to be switched off.

Note that the current must be referenced towards the node to obtain the correct signs.

Transistor models

Transistors are rather more complicated. The most widely used model is the bipolar algorithm used since the early 1970s for SPICE. Actually, SPICE is a circuit solving environment, while the individual components are described using device models.

The bipolar transistor model is based on the Ebers-Moll formulation but extended by Gummel and Poon[2]. There are several equations to describe a transistor, which account for the various physical effects which occur. These can be found in SPICE manuals, or the SPICE code from Berkeley, and are discussed in bipolar device books[3,4]. In the following discussion, SPICE model really means 'the bipolar model used in SPICE'.

In a basic SPICE bipolar formulation, around forty parameters describe the transistor. Each transistor will have its characteristics described by a set of SPICE parameters known as the SPICE model. Most manufacturers provide the SPICE model values for their transistors.

In addition to the SPICE parameters, each transistor requires an additional set of variables to describe the particular device's operating conditions. For example, the SPICE model will provide a fixed value of emitter and collector resistance internal to the device – basically the silicon limiting resistances – and a saturation current for the junctions.

A particular transistor will need to refer to these fundamentals, which will vary for each type of transistor

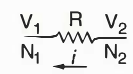


Fig. 1. Resistor from point of view of node 1.

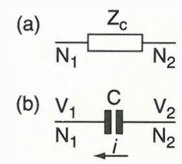


Fig. 2. Two views of a capacitor. Component (a) is for small-signal analysis while (b) is for transient analysis.

used, but also to the voltages on the device such as V_{be} and V_{cb}, which may be different for each particular transistor.

Formulating in C

Using C for the simulation program, the two sets of data required to describe a transistor can be accessed easily using pointers.

Pointers can be set up to refer to the model file and particular variables by defining double precision pointers *trmodel[n] and *trvar[n], where n is a number equal to or larger than the maximum number of transistors required. Alternatively, double-deferred pointers can be set up for a true 'unlimited' simulation.

Now, for a particular transistor m the model pointer, trmodel[m], is set to point to the model file, from which the forty or so SPICE parameters are referenced. Thus more than one transistor may refer to the same SPICE file.

The individual variables however, must be set separately for each transistor which are referenced from the pointer base trvar[m], where m is again the number of the particular transistor in the circuit. Thus a three-transistor circuit using two types of transistor will require two SPICE files.

If the first and last transistor were a BC547, trmodel[0] and trmodel[2] should point to the same BC547 model file but trmodel[1] points to a BC557 file. Individual parameters are referred to by name, which is actually pre-defined as an index. To accomplish this, each SPICE parameter is equated to an integer number, in sequence. For example, r_e might be set to 20, meaning that the SPICE model parameter 'RE' is the 20th parameter from the model base trmodel[#].

The parameter is accessed using trmodel[0][re]. Then, the individual variables will be accessed using a similar set of references such as trvar[0][vbe].

A snag is that it is not always easy to remember, at first, which parameters are individual transistor variables – like the operating voltages – and which are model parameters – like I_{sat}, r_e, r_b. Both are needed to describe a transistor in a circuit.

It was not the intention to describe the SPICE equations in this article. However, some discussion to illustrate the type of calculations SPICE performs is worthwhile.

The fundamental expression for collector current for a given base-to-emitter voltage V_{be} is

$$I_c = I_{sat}\left(\left(\exp\frac{V_{be}}{nf \times V_{th}}\right) - 1.0\right) \qquad (12)$$

where I_{sat} is the saturation current for the device, V_{th} is the thermal voltage kT/q, (k is Boltzmann's constant, q the magnitude of the charge on an electron and T is absolute temperature) and nf is the ideality term.

For some first-order simulations, using the transistor in the forward active region, this may suffice. In fact, this is why I always refer to a transistor as a voltage controlled device. Strictly, it is, despite the term 'current mirror' used as a current amplifier.

SPICE adds similar expressions to equation 12 for the collector-to-base voltage to reflect the second junction.

There are also additional terms for the collector to base diode – reflecting the extrinsic collector to base diode – and reverse gain.

The basic operation is fairly symmetrical in terms of applied voltages though the forward and reverse parameters will usually lead to quite different results between forward and reverse bias. This basis for transistor modelling was proposed by Gummel and Poon (*op. cit.*), who included a modification for I_c, q_b, to describe gain fall-off at high currents from high level injection.

Base current comprises four terms. The first is the forward current from equation 12 divided by the forward gain parameter β_F. The second is a low-current term while the third and fourth are terms for the collector to base diode. The third is the collector reverse current as described for the collector – the collector to base diode currents are the same but opposite signs – divided by the reverse gain and the fourth the low current gain characteristic. The collector and base current account for some dozen or so parameters.

Once the DC operating point is established, the capacitances are determined from equations describing the junction capacitances and transit times. These control the frequency response.

The two components making up a capacitance in a junction are the depletion capacitance, which varies with bias voltage with a power law usually between the ideal half (square root) and a less ideal one quarter. The depletion capacitance uses a standard expression

$$c_j = \frac{c_{j0}}{\left(1 - \frac{V_j}{V_{j0}}\right)^{m_j}} \qquad (13)$$

where m_j is the power, V_j the applied voltage, V_{j0} the built-in voltage and c_{j0} the capacitance for zero bias. The parameters V_{Jx}, M_{Jx} and C_{Jx} where x is for E and C, for the emitter or collector, are supplied in the SPICE model file. An integrated circuit transistor also has a third junction to the substrate, designated by S.

For high reverse biases, V_j is negative and thus decreases the capacitance while for forward bias the term V_j/V_{j0} approaches 1. To stop a numerical overflow as well as generating an unrepresentatively large capacitance, a term F_C limits the effective bias to a fraction, maybe 90%, of V_{j0}. This parameter, as with all the others, is characterised to give the best fit to the transistor by the manufacturer.

At the same time, however, there is an increasing capacitance arising from stored charge – current carriers – within the transistor. This is expressed in terms of forward transit time (all carriers take the transit time to cross) and increases in proportion to the current and is the so-called diffusion capacitance. The net junction capacitance is the sum of the depletion and diffusion capacitances.

There are terms for the base and collector junction capacitances, and terms for the transit time as a function of temperature. The collector to base capacitance is split into two terms separated by the effective base resistance, and all of these terms add up to the forty or so in the model.

The transistor equivalent circuit is quite relevant to the discussion on the model. There are two shown in **Fig. 3(a)** and **(b)** for the standard and small-signal models respectively. The main difference between these is that the small-signal model contains equivalent resistances for the input and output impedances, which are not included in the standard model.

The small-signal model requires these impedances to be determined from the differentials of the DC equations. It will provide relative gain as a function of frequency. The large-signal model will calculate the currents and voltages for each time step and does not need to know these 'effective' resistances.

In effect the large-signal model is a series of incremental small signal model changes and will accommodate the 'large signal' behaviour automatically.

In these equivalent circuits, V_{be} and V_{cb} are the applied base to emitter and collector to base voltages respectively. Internal resistances of the transistor are described by r_{bb}, representing the external to intrinsic base resistance.

The resistance arises because the base current has to flow laterally in the base. It is a measure of the resistance of the base region, **Fig. 4**. Sometimes this is called 'rbb′', but the SPICE equivalent circuit usually refers to it as 'rbb'. SPICE uses two terms called 'RB' and 'RBMIN' to account for the change in r_{bb} with bias.

Resistance 'RB' is the value of the base resistance under zero bias, normally its maximum value, while 'RBMIN' is the lowest value that r_{bb} can have. An expression relates r_{bb} to 'RB' and 'RBMIN'.

Resistances 'RE' and 'RC' represent the fixed resistances associated with the contacts and diffusion resistances, and 'r0' the output resistance which relates roughly to the Early voltage in the large-signal model. Collector-to-base capacitance is split into two which are lumped into the intrinsic (c_{bc}) and extrinsic or external base (c_{bcx}) contact.

To illustrate the difference between the small and large signal models consider a BC547B biased at 2mA. The DC conditions may have V_{be}=0.64V for both models, and i_b=6.7µA. A small change in V_{be} (say 1mV) leads to a change in base current of 25nA.

The large signal model will calculate the new base current for a given voltage at a particular time step, whereas the effective input impedance is a resistor of 1.0/25nA or 4kΩ. This input impedance is h_{ie}, which is just the small signal change of base current for a small change in base voltage.

The value of h_{ie} used in the small signal model has to be determined for the particular bias point of the transistor. The input impedance h_{ie} is dependent on the transistor bias, as is h_{fe}, the forward gain; g_m, the forward transconductance and c_{bdiff}, the diffusion capacitance. So for any small signal model these must be first calculated from a static or DC solution and either then perturbing these by a small amount to determine the small-signal parameters (numerical differentiation), or evaluating the differential directly.

A DC solution is also required for the transient model in order to establish the starting conditions. So it follows that a DC solution is a first step once the circuit has been defined for either simulation.

A DC solution

The DC problem is easier to consider as it uses a very basic equivalent circuit that has no capacitors in it as shown in **Fig. 5**.

The base and collector currents are shown as current sources. Resistors R_E and R_C can be lumped in with the emitter and collector load resistances. This reduces the number of unknowns in each transistor circuit to essentially two: the base current and base voltage. Formulation of the equations to write the emitter voltage in terms of I_e is necessary though. This is $(1+h_{fe})i_b$, and R_E, and the base voltage (V_E=V_B–V_{be}), and similarly for the collector to base voltage.

The DC solution generally has to be iterated to obtain the self-consistent solution which meets both the circuit requirements and SPICE model equations for those bias points.

One way to solve the DC problem is, having set the model for each transistor in the circuit, to guess the bias voltages V_{be}, V_{cb}, and gain. Then, the SPICE model is called which provides the collector and base currents for those bias conditions.

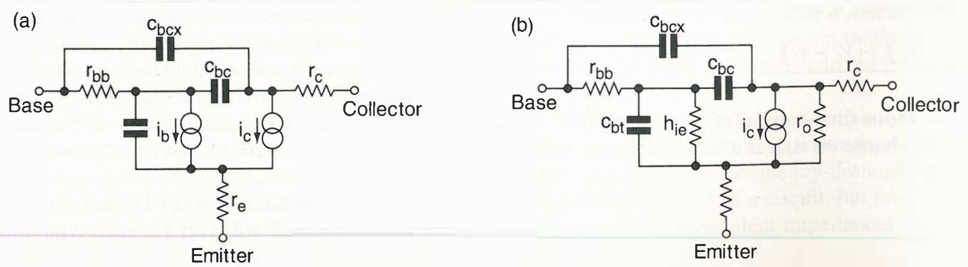
For the next step, these values are stored temporarily. Writing the matrix in terms of gain and the base and collector voltages being 'known' quantities, the circuit conditions are calculated. This leads to a collector and base current being defined which is closer to the circuit values than perhaps the original SPICE calculation.

Now the calculations are iterated. The collector current from the circuit simulation is compared with the current from the SPICE simulation. If the current from SPICE is lower than the circuit current, the base-emitter voltage is increased; and if higher, reduced.

The new collector-base voltage corresponding to the circuit conditions is used, basically adjusting for the new base voltage. Then another loop comprising a SPICE calculation followed by a circuit simulation is executed. Again the currents are compared and will eventually converge providing the base voltage adjustments are set accordingly. This approach is a type of relaxation method with a search test included.

One iterative method is to use a pure 'binary search' whereby the base voltage is adjusted up or down by a difference value which is then halved, so that the adjustments become smaller as the convergent value is approached, for each input condition. This should reach any desired accuracy within a finite number of iterations,

Fig. 3. Two hybrid π models of the transistor. In a) is the standard model, which is suitable for large-signal analysis while b) shows the common small-signal model.



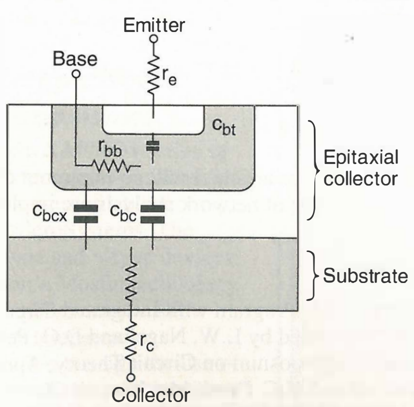


Fig. 4. Diagram of bipolar transistor showing model parameters. Total base-emitter capacitance is c_{bt} while r_c and r_e are shown partly outside the device to represent contact resistance from the metal to the semiconductor.

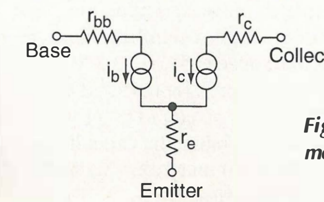


Fig. 5. Simplified model for DC analysis.

typically 8, giving 2^8 reduction from the original difference. Another is to use the fact that the collector current is exponentially dependent on base voltage and adjust the base voltage by the voltage

$$dV_{be} = V_{th} \log \frac{I_{c(C)}}{I_{c(S)}} \quad (14)$$

Here, $I_{c(C)}$ is the current determined from the circuit and $I_{c(S)}$ the SPICE model current. Component dV_{be} is added to the base voltage so that if the SPICE calculation is below the circuit current the voltage will increase V_{be}. This is usually able to resolve the two conditions within four or five iterations, but will take more at high or low currents when the exponential law of the junction changes, unless this is also tracked through successive iterations to provide a better predictive adjustment.

At this point we can consider the small-signal model.

Small-signal model

The small-signal AC analysis technique begins by determining the impedance of each component in the model. A 'frequency response' will require the gain and phase to be calculated for a number of discrete frequencies over a band of interest.

Each solution is calculated using an AC (sinewave) signal so that components such as capacitors can be represented by an impedance at that frequency. By carrying out a number of these simulations over the desired range the bandwidth of a circuit can be determined, along with any untoward frequency response being highlighted.

Complex numbers. In any reactive component, the voltage will be out of phase with the current. The current and voltage can be represented by an x-y graph where y is current and x voltage. The resultant impedance is the vector sum of the voltage and currents as shown in **Fig. 6** for a capacitor, where the current leads the voltage.

Other textbooks may plot the current on x and voltage as $-jy$, but the important point is the phase relationship. I prefer to keep voltage on x as the independent variable. Arguably for a capacitor the current is the independent variable.

Impedance of a capacitor is Z_c as given in equation 2.

In a composite circuit containing resistors and capacitors, the impedance has to be obtained from the vector resultant. For a single resistor and capacitor, this is trivially the square root of the individual impedances squared. For several components, this approach rapidly becomes unwieldy.

It has been known for a long time that complex numbers can be mapped onto an x-y graph where y represents the imaginary term, resulting in an exactly equivalent vector diagram to the simple impedance graph just mentioned. But now any number of impedances can be handled by following the rules of adding complex numbers.

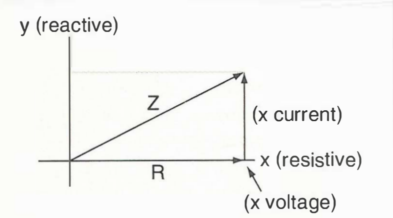


Fig. 6. Vector sum of current and voltage in a network.

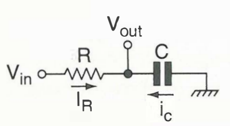


Fig. 7. Low-pass filter showing nodal currents.

Each impedance is then represented by a complex number comprising a real and imaginary term, represented by $x+jy$ where j is the square root of -1. The rules of complex number arithmetic are straightforward if not quite as simple as ordinary arithmetic. Really, complex numbers make calculations easy.

A capacitor is represented by $1/(j\omega C)$, or $-j/(\omega C)$ to be more useful. This maps the capacitor onto the imaginary axis in the — direction.

To illustrate the use of complex numbers a basic resistor-capacitor low-pass filter circuit as shown in **Fig. 7** is simulated. Writing the nodal equations there are just V_{in} and V_{out}, effectively one unknown. Across the resistor and capacitor junction is the resistor current

$$i_r = \frac{V_{in} - V_{out}}{R} \quad (15)$$

and the capacitor current

$$i_c = \frac{V_{gnd} - V_{out}}{Z_c} = -\frac{V_{out}}{Z_c} \quad (16)$$

Note that we consider the node at V_{out} with all currents written entering the node as shown in Fig. 7 such that we can write the sum of all currents to be zero. This is only Kirchhoff's current law.

In this example we could also have written $i_r{=}i_c$, but note that i_r and i_c have 'directions'. If we use $i_r{=}i_c$ the directions are the same, but writing $i_r{+}i_c{=}0$ requires that the current flows are towards each other.

In more complicated circuits with several components connected to one node it is appropriate to consider all currents entering that node and equating them to zero.

Summing these currents and setting them to zero gives

$$V_{out}\left[-\left(\frac{1}{R}+\frac{1}{Z_c}\right)\right]+\frac{V_{in}}{R}=0 \quad (17)$$

This expression has the form which will be used in all subsequent simulations. In this case V_{in} is known and is moved to the right-hand side to give

$$V_{out}\left[-\left(\frac{1}{R}+\frac{1}{Z_c}\right)\right]=-\frac{V_{in}}{R} \quad (18)$$

Using ordinary numbers, the only way we can combine the two impedance terms is by the vector sum. Using complex numbers we can add them directly. The complex version of a resistor is $(R, 0)$ where the two terms represent the real and imaginary parts, in that order, while the complex impedance of the capacitor is $(0, Z_c)$.

In the above equation we have inverse impedances. Defining the complex impedances

$$z_{r(real)} = R \quad (19a)$$

$$z_{r(imag)} = 0 \quad (19b)$$

$$z_{c(real)} = 0 \quad (20a)$$

$$z_{c(imag)} = \frac{-1}{2\pi fc} \quad (20b)$$

we can write

$$V_{out}\left[-\left(\frac{1}{z_r}+\frac{1}{z_c}\right)\right]=\frac{-V_{in}}{z_r} \quad (21)$$

In the second part of this article, I will go into more detail about how the concepts of network analysis are implemented in software. ■

References

1. SPICE, Simulation Program with Integrated Circuit Emphasis, introduced by L.W. Nagel and D.O. Pederson, 16th Midwest Symposium on Circuit Theory, April 1973
2. H.K. Gummel and H.C. Poon, 'An Integral Charge Control Model of Bipolar Transistors', *Bell System Technical Journal*, 49, 827, 1970.
3. P. Ashburn, 'Design and Realisation of Bipolar Transistors', Wiley, 1988
4. D. Roulston, 'Bipolar Semiconductor Devices', McGraw-Hill, 1990.

NEW PRODUCTS

Please quote *Electronics World* when seeking further information

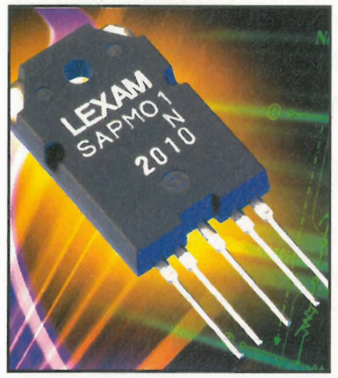
Fast Ethernet switches

Zarlink Semiconductor has announced availability of fast Ethernet switching chips aimed at supporting high-speed multimedia applications such as streaming video and VoIP (voice over Internet protocol). The six-device ZL50408 family consists of eight-port Fast Ethernet switches with a Gigabit uplink, as well as five and nine-point switches. Available in managed or lightly managed options, the switches provide full wire-speed forwarding at layer two and classification at layers two through four. The Gigabit uplink versions - the ZL50408/407 devices - are expandable to 16 ports. The family provides fine-granularity rate control - down to 16kbit/s increments - on both ingress and egress ports. The switches support QoS and access features, such as congestion management at the input and output of each port, patent-pending port security and filtering, IEEE's 802.IX Extensive Authentication Protocol, 4K VLAN (virtual local area network), 4K IP multicasting, advanced statistics monitoring, and link aggregation with the capability to trunk ports across chips.

Zarlink
www.zarlink.com
Tel: +44(0) 1793 518000

Heat compensated audio transistors

The Sanken SAPMO1 series of temperature-compensated audio transistors are available from Allegro MicroSystems. The 150V p-type and n-type devices use Sanken's Mosfet technology to offer highly accurate and responsive temperature compensation through the use of on-chip diodes. In addition, they feature built-in push/pull circuitry that eliminates the need to trim the idling current in audio amplifiers using external components. Absolute maximum ratings for the



SAPMO1 series are: drain-source voltage 150V; gate-source voltage ±20A; and pulsed drain current ±80A. Maximum power dissipation is 150W at 25°C.

Allegro
www.allegromicro.com
Tel: +33(0) 4 50512359

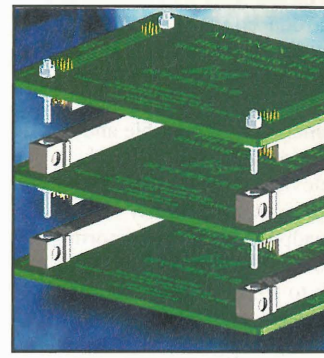
Prober retrofit kit for wafer ID

Cognex has announced the In-Sight 1700 series prober retrofit kit. The kit features the 1700 series wafer readers, which read alphanumeric and 2D matrix codes for the tracking wafers through the production process. The kit comes with all hardware, software, and installation instructions. The wafer reader's algorithms and electronically-controlled lighting improve wafer ID efficiency by reducing no-reads on hardmarked, softmarked, or even super-softmarked codes that have been degraded by process effects. The ability to read new compact code standards, while still being able to read older bar codes, enhances prober versatility, said the firm. Ethernet communication allows for remote setup, data access, and process monitoring on the test floor.

Cognex
www.cognex.com
Tel: +33(0) 1908 206033

4A PCB connectors stack up together

Hypertac Interconnect has added a stacking option to its standard range of HPH high-density PCB connectors. A minimum gap of 9mm between PCBs can be achieved by using a low-profile unshrouded pin carrier male and standard female connector, in comparison to full height

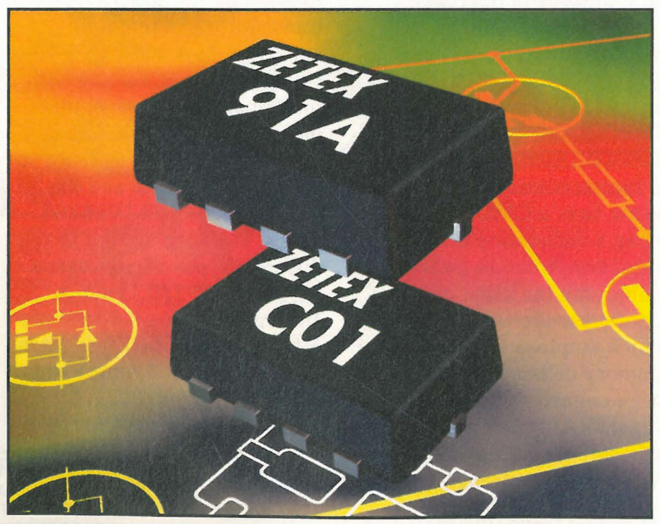


version of 16mm. Stainless steel hardware with optional polarising is available on all variations to discriminate mating connectors from one another, whilst providing a guiding system for correct mating, even in blind applications. The connectors are self-jigging when used in multi position applications. The guiding hardware is pressed in to specifically placed mounting holes with the connector fitting around this. Both the insulator shroud and extended guides provide protection against contact damage during manufacturing.

Hypertac
www.hypertac.com
Tel: +33(0) 8450 8033

Transistors for fet drivers

Complementary dual bipolar and Mosfet parts have been introduced by Zetex in its 3mm x 2mm x 1mm micro leaded package. Used in push-pull circuit topologies,



the transistor pairings create low cost, high performance power gate drivers. Providing the requisite high pulse current and fast switching, the ZXTD4591AM832 offers a 40V rated NPN and PNP combination collector current of 2.5A and a maximum voltage of 500mV. Specified up to 2A, the gain of the two transistors is also high, respectively 200 and 160 at 1A collector current. The Mosfet equivalent ZXMC3AM832 package houses complementary 30V Trench Mosfets that combine low on-resistance with enhanced rise and fall times

Zetex
www.zetex.com
Tel: +44(0) 161 622 444

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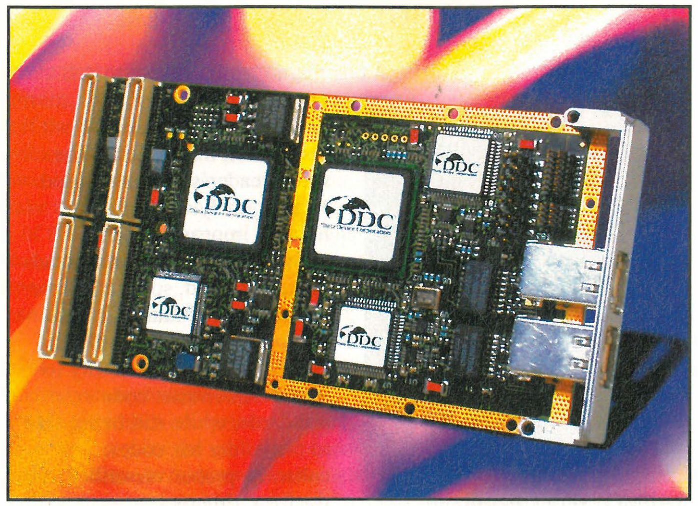
Stereo headphone DAC has low power

Wolfson Microelectronics has introduced the WM8759, a low-power 24-bit stereo DAC with integrated headphone driver. It is suited for use in the next generation of portable and home music players, and digital televisions. The WM8759 provides up to 50mW headphone power, supporting 16- to 24-bit word data inputs at up to 192kHz sampling rate. Operating on split analogue/digital power supplies, the device allows power consumption down to 20mW on 2.7V supplies, less than 10μA in standby, but supporting large output power from the headphone driver. The device has been rated at 100dB signal-to-noise ratio (SNR), "A" weighted at 48kHz with –88dB THD driving a line load and –72dB THD driving 16Ω headphones. The WM8759 includes a hardware control interface for selection of audio data formats, a serial interface port, digital interpolation filters, and multi-bit sigma delta modulators.

Wolfson Microelectronics
www.wolfsonmicro.com
Tel: +44(0) 131 272 7000



Fibre access with redundant architecture

Data Device Corporation has introduced a series of 2Gbit/s Fibre Channel network interface controllers (NICs). The FC-75000 Fibre Access NIC features a dual redundant architecture with autonomous failover or dual independent channels, low memory to memory message latency, deterministic autonomous message scheduling, and built-in avionics upper layer protocols on conduction cooled PMC card making it ideally suited for the most rigorous military applications. The series of conduction cooled Fibre Channel NICs operate over a wide –40 to +85°C temperature range.

DDC
www.ddc-web.com

40in. LCD for TV and display information

Torisan Sanyo has bought out an improved version of its 40in. TFT LCD module for television and public information display applications. The TM396WX-71N32 is lighter by 2.3kg and offers a response time of 8ms making it suitable for display of television and other video format images without streaking or blurring. The panel offers a full colour display of up to 16.7 million colours with a resolution of 1280x768 (WXGA) and a contrast ratio of 600;1. Luminance of 500cd/m^2 combined with its contrast make it suitable for use in areas where the ambient light levels might wash-out other displays. Minimum backlight life is 50,000 hours, reducing lifetime costs when compared with alternatives such as plasma displays, claims the company. Plans exist to develop much larger and improved versions of TFT LCD module in the future for these applications.

Torison Sanyo
www.displaze.com
Tel: +44(0) 1296 469770

DSL platform gets DSLAM1.1 data path

Wintegra has added a DSLAM 1.1 data path software release as part of its DSL platform which is aimed at DSLAM chassis-based line cards and uplink cards. Using the fabless firm's internal packet processing engines the DSLAM 1.1 data path software release provides advanced data path features such as multicast, NAT, VLAN support and enhanced deep packet classification, all with scalable performance. It is factory hardened and provided as a shrink-wrapped package that is royalty free and requires no up-front NRE fees.

Wintegra
www.wintegra.com
Tel: +44(0) 1698 404885

16Mbit SRAM cuts size in half

Renesas Technology has a range of low power 16Mbit SRAMs with a chip size of approximately 32mm^2. The small die size is achieved through combining an SRAM cell using a thin film transistor and a DRAM cell using a stacked capacitor. First devices in the range comprise the 16Mbit RILA1616R series (1.8V version) and RILV1616R series (3V version). Dubbed SuperSRAM, the memory cell uses a 0.15μm process and it is approximately half the size of the firm's CMOS SRAM using a conventional six-transistor structure (when employing the same process). Unlike pseudo static RAM which employs DRAM memory cells and is used in large-capacity applications, SuperSRAM does not require refreshing, said the company. As with conventional SRAM, information stored in a memory cell is automatically maintained by means of the load transistor and driver transistor. Data retention current is 1μA at 25°C. Two external voltage versions of the SuperSRAM are available on a metal mask option basis: the 1.8V (1.65V to 2.3V) RILA1616R series and the 3V (2.7V to 3.6V) RLIV1616R series. Both are housed in two different types of package, a 52-pin TSOP (10.79mm x 10.49mm) with a 0.40mm pin pitch, and a 48-ball fine-pitch BGA (7.5mm x 8.5mm) with a 0.75 ball pitch.

Renesas
www.renesas.com
Tel: +44(0) 1628 585161

Power Mosfet controller for 42V automotive systems

The A3925 power Mosfet controller from Allegro MicroSystems is for use in 42V automotive applications involving high-power motors. It provides six high-current gate-drives capable of driving a wide range of power N-channel MOSFETs. Bootstrap capacitors provide a steady supply voltage over a varying battery input

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range. Direct control of each gate output is possible via six TTL compatible inputs. A different amplifier with two sample-and-hold outputs is integrated to allow accurate measurement of the low-side current in a 3-phase bridge. Two diagnostic fault outputs can be continuously monitored to protect the driver from short circuits to battery or supply, bridge-open, all undervoltage conditions, and thermal shutdown. Operating temperature range is –40 to +135°C.

Allegro Microsystems
www.allegromicro.com

Buck bias regulator with 75V input

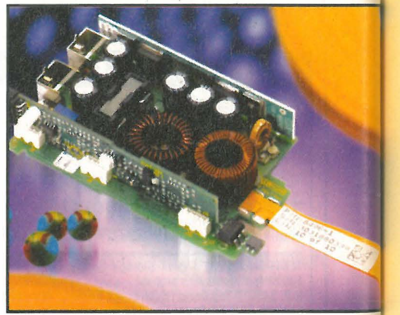
National Semiconductor is offering its smallest high-voltage buck bias switching regulator to satisfy housekeeping or bios power needs in next-generation communications, automotive –48V distributed and battery powered systems. The LM5007 is a buck bias regulator which steps down a high-voltage (up to 75V) primary-side power supply and produces a low voltage (10V typical) bias supply for secondary-side control devices. The device contains an 80V n-channel power Mosfet rated at

0.7A peak that can be switched at high frequencies (up to 500kHz), allowing the use of a small output filter to complete a bias supply design that sources up to 0.5A continuous load current. The device is available in a 4 x 4mm 8-pin chip-scale package and an MSOP-8 package. According to the supplier, the control scheme deployed in the LM5007 can eliminate the need for loop compensation while offering a very fast transient response using an ON-time that is inversely proportional to the input line voltage(V_{in}). This produces a relatively constant and easily filtered switching frequency. An intelligent current limit is implemented with a forced OFF-time, which is inversely proportional to V_{OUT}.

National Semiconductor
www.national.com
Tel: +44(0) 870 242171

Programmable output power module in slot

Lambda has expanded the output options for its Vega series with the addition of two wide-range programmable output modules. The W2 and W5 modules provide designers with a programmable output of 0.25V

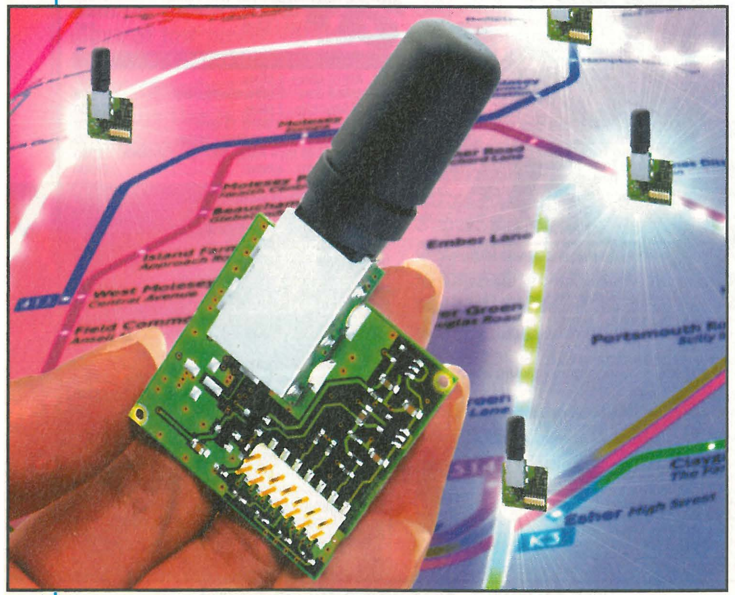


to 7V at 30A and 0.25V to 32V at 8.5A respectively. The modules occupy a single slot on the Vega chassis. They offer a choice of fixed or tracking overvoltage protection and can be fitted with fast-on or screw terminal output connectors. The modules also offer a choice of either resistance programming of the output, between 0 and 32kΩ, or voltage programming of the output, between 0 and 5V. Both programming types are available in four variants: inhibit with fixed current limit; inhibit with program current limit (0-5V); enable with fixed current limit; and enable with program current limit (0-5V). Power density is $0.35W/cm^3$ and there is no minimum load requirement.

Lambda
www.lambdaeu.com
Tel: +44(0) 1271 856666

GPS receiver with broad beam antenna

Sarantel has introduced SmartAntenna F02, its latest integrated antenna-receiver for global positioning applications. It combines the firm's omni-directional GPS antenna with Fastrax's Trax02/4 GPS receiver chipset. The antenna's GeoHelix design offers high levels of immunity to RF interference, simplifying the integration process, said the supplier. It measures 32 x 32mm and 10.8mm deep, weighs under 30g, and consumes 100mW at 2.7V in continuous operation. According to Sarantel, Fast acquisition times are a feature of the 12 channel iTrax02/4 receiver, which has a 32MIPS DSP core and dedicated GPS search engine. The use of a broad antenna beam width is designed to provide a more accurate GPS fix. The position fix is normally accurate to within 10 metres worldwide. The device's serial data interface (RS232) and 3.3V ground power connections are made via one standard 14-way header. It does not require a ground plane. Operating on the GPS LI-band (1575.42MHz) the GeoHelix antenna design is based on copper tracks, deposited on to a small ceramic cylinder, which are individually and automatically laser-trimmed for optimum frequency response. The antenna-receivers are fully mounted side-by-side in combined applications such as Bluetooth and GSM without loss of performance. A development kit is available which allows the more advanced user to make use of the pre-emptive real time operating



Sarantel
www.sarantel.com
Tel: +44(0) 1933 670561

Please quote *Electronics World* when seeking further information

100-tap non-volatile potentiometers

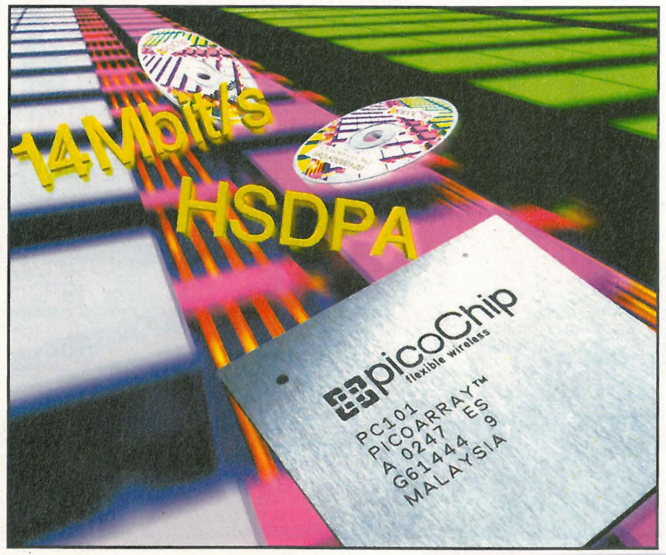
Xicor is offering a family of 100-tap non-volatile digitally-controlled potentiometers that will accommodate a voltage swing of between 0V and 10V for an increased dynamic range, making the devices suitable for applications such as offset and bias voltage adjustments in high voltage amplifier and regulator designs. The X9319 family of potentiometers features 100-taps with 99-segmented resistors and is available in 10kΩ and 50kΩ total resistance options. Adjustments to the wiper position are made using an up/down interface and the position can be stored in the internal EEPROM for recall during device power-up. According to the supplier, the up/down interface allows efficient wiper position calibration for reduced manufacturing cost in bias and control applications. Likely applications for this programmable device are high profile systems requiring gain, reference voltage and bias calibrations such as common mode biasing in RF power amplifiers and gain adjustments in audio applications. Other target applications include signal conditioning circuits to set zero offset and span correction for sensors and adjustments in process controls requiring parameter retention.

Xicor
www.xicor.com
Tel: +44(0) 1993 700544

3G Basestation design

PicoiChip Designs has announced its first high speed downlink packet access design (HSDPA). This is a packet-based mode for WCDMA Release 5 which increases data rates to up to 14Mbit/s for intensive multimedia services and has been dubbed by some as next generation 3G or 3.5G. The "basestation on a CD" design platform includes tested algorithms and source code for WCDMA FDD and HSDPA. The design platform combines a high-performance processor optimised for wireless, with a programming environment using standard ANSI C as well as system libraries. Based on the picoArray processor, it delivers 300GOPS and 30GMAC/s performance. In addition to WDCMA FDD and HSDPA, reference designs for TDSCDMA. 802.16 and other standards are under development. The system is also appropriate for any other advanced wireless technology.

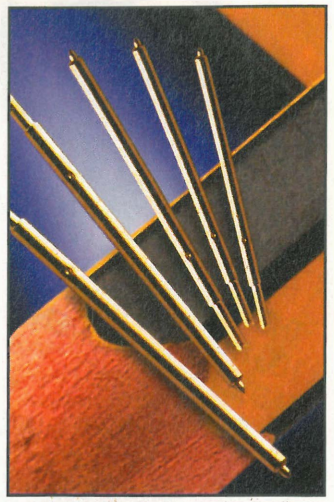
Picochip
www.picochip.com



IDE improves data visualisation

Green Hills Software, the supplier of real-time operating systems and embedded software development tools, has released the latest version of its integrated development environment (IDE) for embedded developers. Multi IDE 4.0 features new data visualisation, workspace management and low-level and bare-board debugging features which support software development activities, ranging from connecting to, exercising and testing new boards through advanced application debugging and project management. The IDE has also been extended to improve developer productivity over more aspects of the software development process, says the supplier. The Workspace Manager provides a graphical interface for managing sequences of commonly used actions within the IDE. Also the Multi Editor supports complete cross reference-browsing capabilities without the need for a compiled or linked program and it locates function prototypes included in header files so the user can see the required function signatures while typing, without requiring any previous configuration. Multi 4.0 will support PowerPC, ARM, MIPS, x86/Pentium, 68K/Coldfire, V800 and StarCore processor families as well as native development for Windows, Solaris, HP/UX and Linux.

Green Hills Software
www.ghs.com



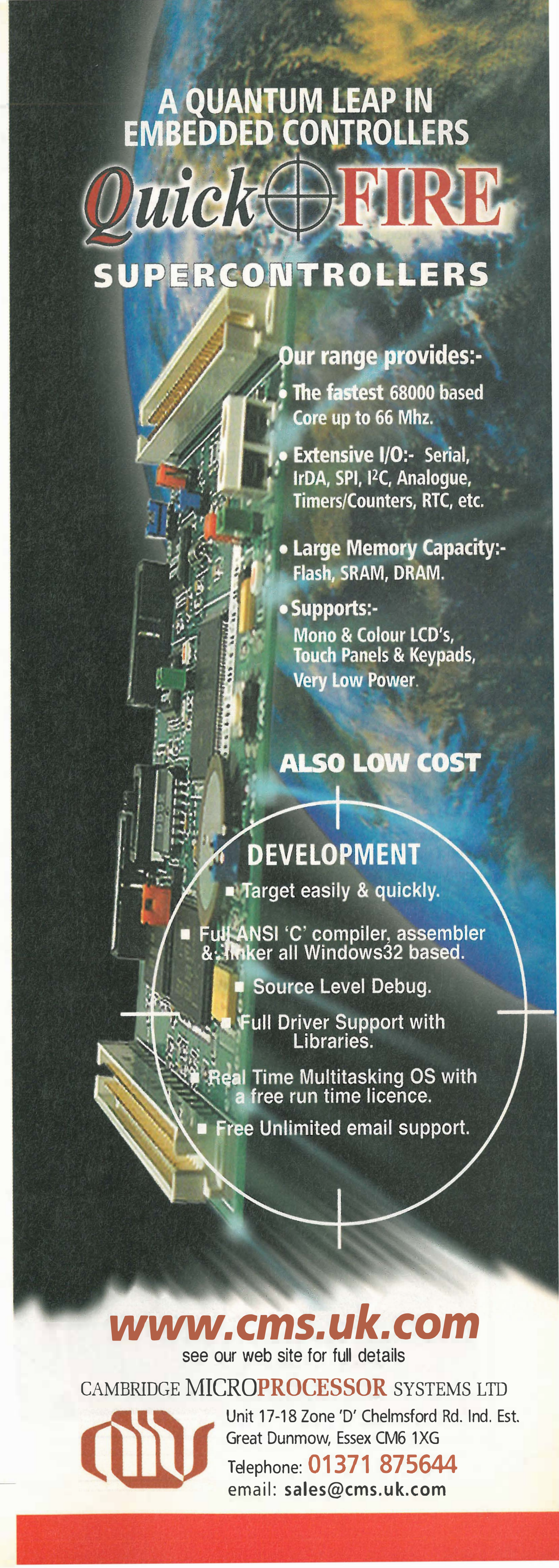
Ultra-fine pitch probe tests down to 0.5mm centres

The P706 from Peak Test Services is an ultra-fine pitch test probe for testing components at centres down to 0.5mm (0.02 inch). According to the supplier, the probe is specifically designed for testing boards using ball grid array, multi-chip modules and other fine-pitch packages. The P706 has a gold-plated 4-point crown measuring only 0.25mm in diameter, a working travel of 0.65mm and a spring force of 0.2N.

Peak Test Services
www.thepeakgroup.com
Tel: +44(0) 1462 475600

Isolated approach to POL converter design

Vicor has introduced its first in a range of isolated point-of-load (POL) power converters which is designed to sit on its factorised bus architecture. The power module supplier is responding to the need for more power rails driving widely ranging current levels on PCB designs with a new type of low current power regulator which can supply voltages ranging from 5V down to 1V scattered about the PCB at positions close to the point-of-load. Vicor's approach is to introduce a family of isolated point of load devices. It believes there is a problem with ground currents, generating unwanted noise with the more



Please quote *Electronics World* when seeking further information

traditional non-isolated device. Called the V-1 chip voltage transformation module (VTM), it achieves a response time of less than 1µs and delivers up to 80A in a volume of less than 0.25 cubic inch while converting 48V to 1.5V. The modules may be paralleled to deliver hundreds of amps at an output voltage settable from 1.0 to 1.8V DC, at full load. The firm's factorised power architecture is different to alternative intermediate bus architecture of other suppliers which feed non-isolated POL converters at lower bus voltages. Vicor maintains this approach is less efficient. The company says its VTMs have 1MHz bandwidth and can provide efficient bi-directional power flow with the load, limiting voltage excursions due to instantaneous load surges or dumps. The open loop output resistance, Rout, of the V048K015T80 VTM is approximately 1.3mΩ. The BGA package supports in-board mounting with a low profile of 0.16 inch (4mm) over the board. A J-leaded package option will support on-board surface mounting with a profile of 6mm over the board. Outline dimensions are 32 x 21.5 x 6mm.

Vicor
www.vicoreurope.com

Oven controlled crystal oscillators for all synchronization

C-MAC Micro Technology has a range of single oven temperature-controlled crystal oscillators. The CFPO-D03 single oven TCXO series is suitable as a frequency source and time keeping reference for all synchronization systems, including GPS based equipment.

The device is designed to provide a holdover performance of better than 7µs over 24 hours in stable ambient conditions and a frequency stability better than 2 x 10^{-10} peak-to-peak over an operating temperature range from –20 to +70°C. Package size is 51.0 x 41.0 x 19.0mm.

C-MAC Micro Technology
www.cmac.com

Mixed signal test in PC format

National Instruments has announced a suite of 100Msample/s PXI instruments intended for the prototyping and test of mixed-signal devices and systems. It includes 100 and 50MHz digital waveform generator/analysers (NI PX16552 and NI PX16551), a 100Msample/s, 16-bit arbitrary waveform generator (NI PX1-5421), and a 100Msample/s, 14-bit high-resolution digitiser (NI PX1-51220. The modules are designed to be used with the 100MHz clock and frequency generator (NI PXI-5404) and 500MHz switching module (NI PXI-2593) which were announced earlier this year.

Designed to run with the firm's LabView 7 Express graphical development software and the interactive NI Digital Waveform Editor, the instruments will also integrate with third-party software simulation tools, such as standard VCD files from FPGA simulation packages for test execution in LabView, LabWindows/CVI or other development environments. The digitiser, arbitrary waveform generator and digital waveform generator/analysers are built on a synchronisation and memory core architecture developed by the firm for its mixed signal instrument modules. Onboard memory is up to 512Mbyte. In addition, the 5421 arbitrary waveform has a close-in spurious free dynamic range of 91dB. The digitisers capture signals with increased fidelity - 64 times the resolution of traditional 8-bit instrumentation, said the company. The digital waveform generator/analysers provide programmable voltage levels from –2.0 to 5.5V with the 10mV resolution necessary for testing devices that use different levels or for characterising how a given device performs under changing conditions.

National Instruments
www.ni.com

Integrated connector modules

Pulse has introduced 12 integrated connector modules, for use in ADSL and cable modems, set-top boxes and video-on-demand equipment.

The modules combine magnetics with the RJ45 connector, The Starjack series is IEEE802.3 compliant and offers AutoMDIX compatibility with four parts designed for 10baseT applications and eight for 10/100baseTX. The RJ45 module includes an optional resistor capacitor noise cancellation circuit with alternative shield configurations for improving system compliance to worldwide emc standards. The components are offered in single-port (1x1), tabdown configuration with or without LEDs. They are suitable for Cat 5 and 6 Fast Ethernet or UTP cable. The internal magnets are 100 per cent electrically tested for Hi-Pot and functionality delivering at least 1.5kVrms (typically 2kVrms) isolation and they operate from 0 to 70°C.

Pulse
www.pulseeng.com
Tel: +44(0) 1483 401700

Unidirectional pressure transducer

Kulite is offering a unidirectional differential pressure transducer for measuring low differential pressures. This digitally corrected miniature pressure transducer is for use in air speed measurements using pitot tubes. It can also be used for flow measurements. The ET-3DC-312 has a full scale output of 5V DC, with a total error band of 0.5 per cent over 0 to 100°C and a bandwidth from DC to 2.5kHz. The device can withstand 100 per cent relative humidity, a peak linear vibration of 50g (sine 10 to 2,000Hz) and a mechanical shock of 100g. ■

Kulite
www.kulite.co.uk
Tel: +44(0) 1256 461646

Fact: most circuit ideas sent to *Electronics World* get published

The best circuit ideas are ones that save time or money, or stimulate the thought process. This includes the odd solution looking for a problem – provided it has a degree of ingenuity. Your submissions are judged mainly on their originality and usefulness. Interesting modifications to existing circuits are strong contenders too – provided that you clearly acknowledge the circuit you have modified. Never send us anything that you believe has been published before though.

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

Clear hand-written notes on paper are a minimum requirement: disks with separate drawing and text files in a popular form are best – but please label the disk clearly. Where software or files are available from us, please email Caroline Fisher with the circuit idea name as the subject.

Send your ideas to: Phil Reed, Highbury Business Communications, Nexus House, Azalea Drive, Swanley, Kent, BR8 8HU *email ewcircuit@highburybiz.com*

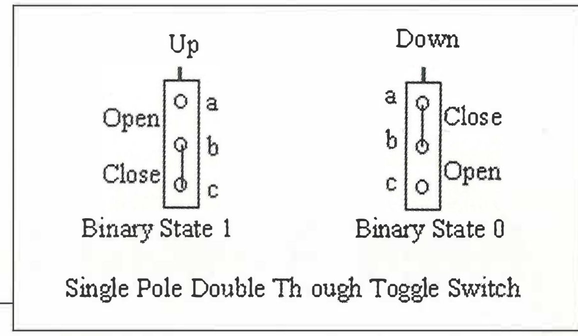
Simple code lock

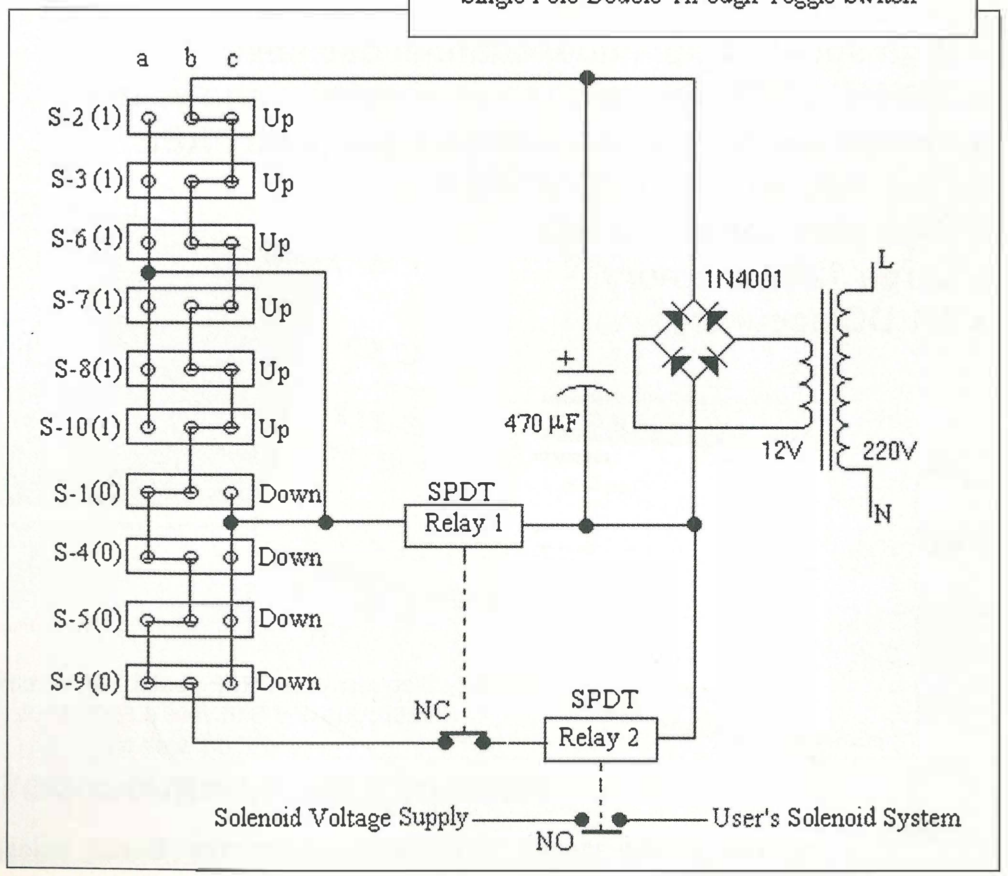
This code lock makes use of toggle switches to generate a preset binary code that activates a solenoid to open the lock **Fig. 1.** The circuit is designed in such a way that any wrong switching will cause interruption of the power supply to the solenoid and will keep it de-activated. For convenience, the switches with their toggles up are assigned binary code '1', while switches with toggles down are assigned binary code '0'.

The '0' (toggle down) and '1' (toggle up) states of these switches are shown in **Fig. 2.** For switches with toggles up (state 1) to conduct current, terminals b-c are used. For switches, with toggles down (state 0) to conduct current, terminals a-b are used. The central terminals, 'b' of all these switches are connected to + terminal of the DC supply. It can be seen Fig. 1. that in order to energise relay 2, the toggles of the switches number 2, 3, 6, 7, 8 and 10 must be up (binary state 1), and the toggles of the switches number 1,4,5 and 9 must be down (binary state 0). With the relay 2 energised, the user's solenoid system is activated to open the lock. If any of these switch(es) is/are in a wrong state, relay 1 is energized and will interrupt the dc supply of relay 2, and the solenoid system is not activated at all.

The code, which I set in my circuit, was 0110011101 as shown in Fig. 1. But re-arranging these switches can set any code. Total combinations of a ten-digit binary code come out to be more than 1000. Each addition of a switch doubles the number of combinations that could be set and thus, makes it more and more difficult to be assessed by someone else. It is advised to use more switches to make the combination more difficult.

Ejaz ur Rehman
Islamabad
Pakistan





Staircase waveform generator

A 555 timer configured as an astable multivibrator drives the programmable staircase waveform generator shown in **Fig. 1**. This multivibrator can be reset using switch S_1.

Output from the multivibrator feeds a presettable decade up/down counter through the push switch S_4 and rotary switches S_5 and S_6.

On the 74192 counter, inputs CP_U and CP_D are the clock up and down inputs respectively. The rotary switches are coupled to ensure that clock pulses feed only one of these inputs at a time. They are wired such that the unused clock input is pulled high.

Counter outputs are $Q_{0\text{-}3}$ and S_2 provides a reset facility. Push switch S_3 is added to allow parallel data to be loaded into the counter inputs $D_{0\text{-}3}$.

Terminal-count outputs TC_U and TC_D are normally high so the monitor LEDs are off. When the counter is receiving clock pulses via CP_U and the count reaches 9, the TC_U output goes low on the next high-to-low transition of the clock, lighting LED_1. Output TC_U remains low until the CP_U input goes high again. Similarly, LED_2 lights when CP_D is clocked down to zero.

Outputs from the counter feed the decoder shown in **Fig. 2**. This decoder is configured as an digital-to-analogue converter.

Initially, the op-amps are adjusted for minimum offset. Diode D_1 doesn't start to conduct until its associated output rises above 0.7V. Diodes D_2 and D_3 clamp the output voltage at 1.4V.

The binary-weighted resistors follow the relationship:

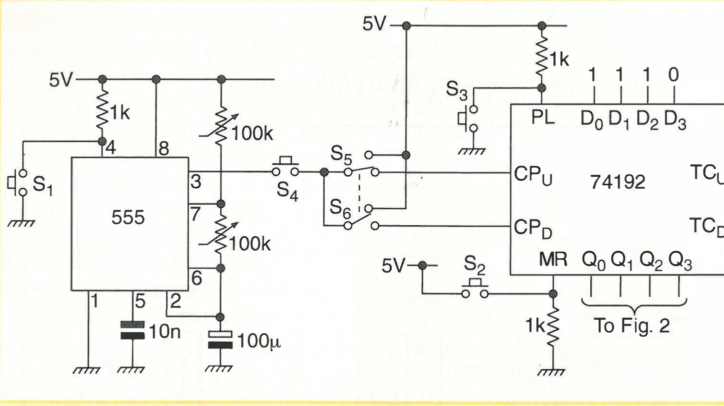
$$R_{in} = \frac{R_f \times V_c}{V_o}$$

$$= \frac{10k \times 1.4V}{1V} = 14k$$

Gain of the final op-amp can be adjusted to give the desired staircase characteristic. By using S_3 and loading data into the counter, the output can be made to start from any preset value. The minimum voltage of the staircase can be set using potentiometer Z at the bottom of the resistor ladder.

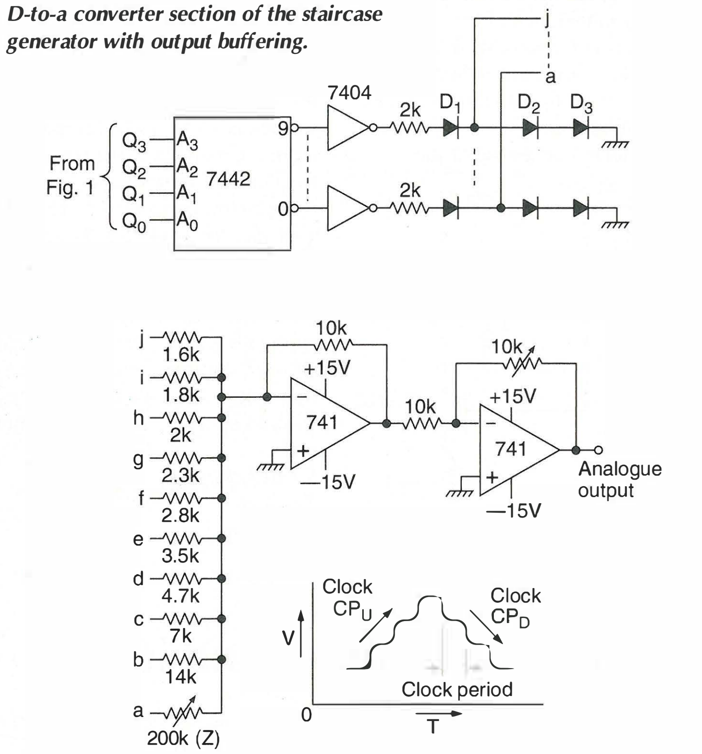
Figures 3, 4 and **5** show the waveforms created with the components shown. Operation of the D-to-A converter is explained more fully in an article by me in the *Journal of the Instrument Society of India*, Vol. 18, 1988 p. 295.

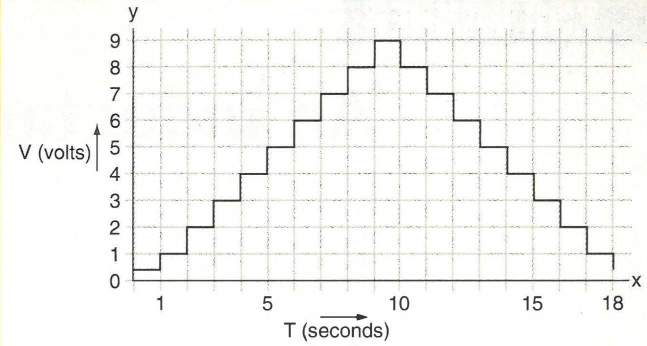
V. Gopalakrishnan



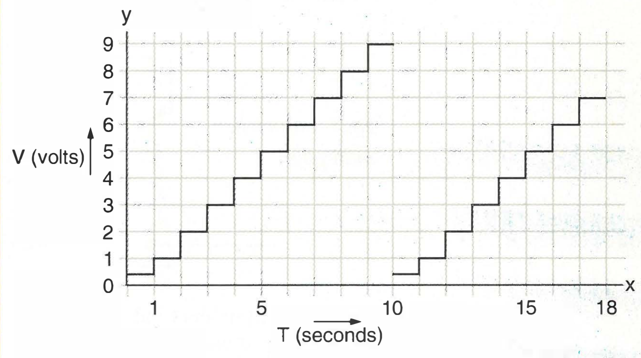
Clock and decade counter sections of the staircase generator.

D-to-a converter section of the staircase generator with output buffering.

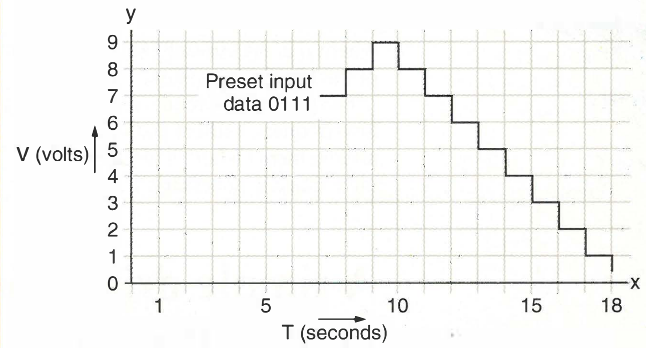




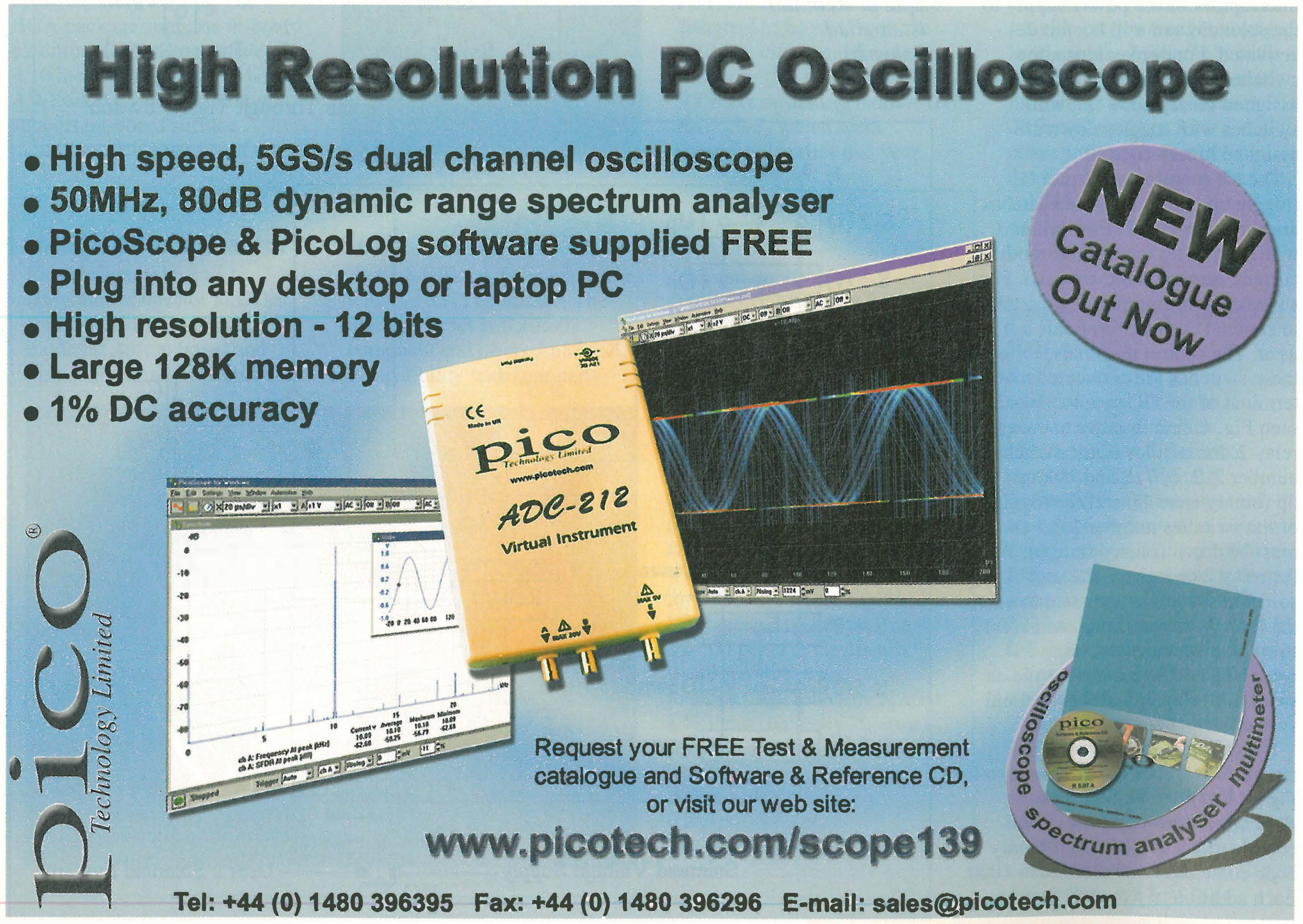
Output waveform when the circuit is used for producing a triangular waveform.



Output waveform when the circuit is used as a staircase generator.



By loading the counter with preset data, the ramp can be made to start at any voltage.



Voltage-controlled capacitance/inductance

With a transconductance op-amp such as the XR13600, it is possible to use the transconductance, g, to produce a simulated capacitance or inductance, as shown in the diagram.

Such a circuit can be considered to have three modes of operation. Firstly, with $Z_1=R$ and $Z_2=R_1$ the output resistance is given by:

$$R_{out} = \frac{R + R_A}{gR_A}$$

With $Z_1=R_1$ and $Z_2 \rightarrow C$, the inductance is given by:

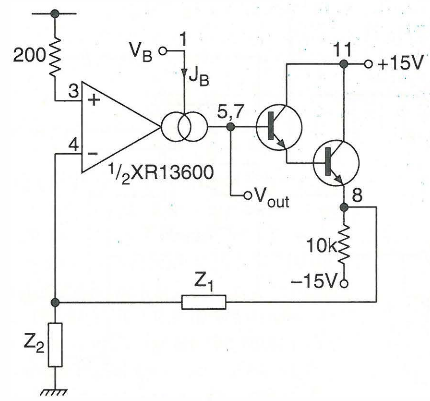
$$L_{out} = \frac{CR_1}{g}$$

Finally, with $Z_2=R_2$ and $Z_1 \rightarrow C$, the capacitance is given by:

$$C_{out} = gCR_2$$

Here, $g=19.2I_B$, hence resistance, inductance and capacitance can be controlled by altering only voltage V_B.

Kamil Kraus
Rokycany
Czech Republic



Using a transconductance op-amp, one simple circuit can act as a voltage-controlled resistance, capacitance or inductance.

£50 WINNER

An inductance multiplier

It is known that the application of large inductances in electronic circuits is always undesirable because they have large size, large weight and large price.

The proposed multiplier of inductance can be used in order to replace a large inductance coil by a small one. The circuit of the multiplier of inductance is shown in

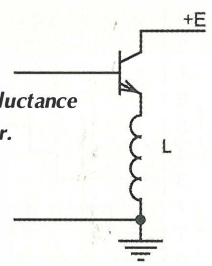


Fig.1. Inductance multiplier.

Fig.1. The equivalent inductance of the circuit is found to be

$L_{eq} = (\beta + 1)\,L,$

where β is the current gain coefficient of the bipolar transistor.

The proposed circuit can be used in low-frequency filters and other arrangements where a large inductance is necessary. For example, it can be used in a low-frequency oscillatory circuit as it is shown in **Fig.2.** The oscillatory circuit consists of the 1nF capacitor and the equivalent inductance of the multiplier. The field-effect transistor is used to ensure the necessary bias current of the bipolar transistor. The output incremental resistance of the field-effect transistor is very large, so it does not shunt the circuit. The equivalent inductance of the multiplier is equal to 0.4H in this case, i.e. the equivalent inductance is 400 times larger than the inductance of the applied coil.

The frequency response of the

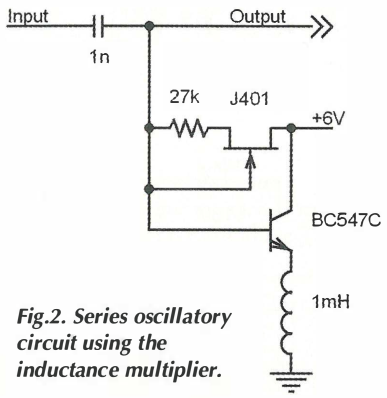


Fig.2. Series oscillatory circuit using the inductance multiplier.

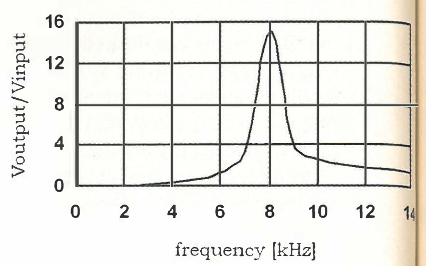
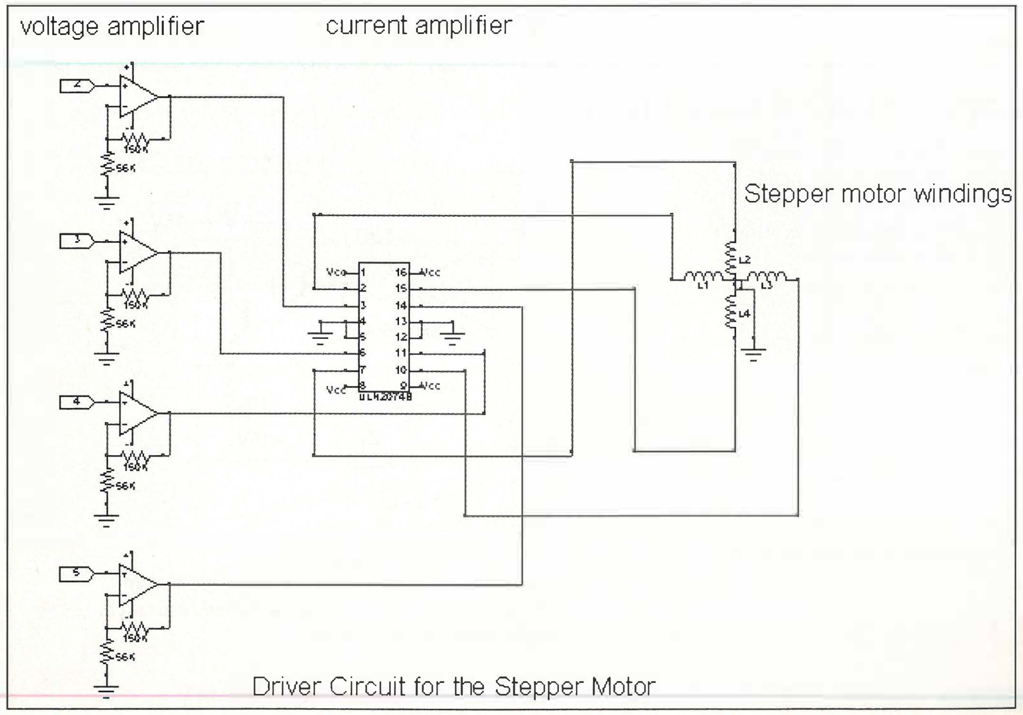


Fig.3. Frequency response of the oscillatory circuit.

oscillatory circuit is shown in **Fig.3.** It is easy to see that the output AC voltage is 15 times larger than the input AC voltage at the resonance frequency. Consequently the Q-factor is approximately equal to 15. It is also easy to check that the resonance frequency of 8kHz really corresponds to the inductance of 0.4 H and capacitance of 1nF. Therefore the application of the proposed circuit allowed getting a low resonance frequency of the oscillatory circuit without applying a large inductance coil.

S.Chekcheyev
Tiraspol
Moldova
Russia

A simple driver circuit for stepper motor and its control through a PC



In the circuit shown below a 12V, 1.5A, 10kg - cm torque stepper motor is interfaced to the PC via its parallel port. This is done in order to automate the motion of the stepper motor. This circuit is mainly IC based which makes it easy for construction, has fewer components and is also cost effective.

To move the stepper motor, a proper sequence of output bits from the PC parallel port (25 pin D connector) is obtained. The parallel port consists of 25 pins but we make use of only four data pins (2 to 5) and one ground pin (25) of the port 378 (hex) of LPT1. In the circuit only 4 of the 25 pins are shown. Pin 25, which is grounded, is not shown. For clockwise rotation output bit sequence 0001, 0010, 0100, 1000 is required. The voltage levels corresponding to logic 0 and logic 1 are insufficient for driving this stepper motor and hence need to be amplified. This is done by configuring the op-amps (741) in the non-inverting mode to provide a gain ~4. In the circuit diagram the power supply connections for the op-amp are not shown i.e. Vcc = +12V, Vee = -12V. The IC ULN2074B (Vcc +12V), a darlington transistor array, is used for current amplification.

The IC pins 4, 5, 12, 13 are connected to a heat sink and grounded. The voltage pulses obtained from this IC are then used to drive the stepper motor. Two programs in 'C' language control the stepper motor. The first program (contin.c) is used when the motor needs to be continuously rotated and the second program (handcrl.c) moves the motor in a step-by-step manner. In the first program the motor can be moved at user selected speeds between 0.3 – 8.0rpm. The direction of motion, clockwise/counter clockwise is also user selectable by pressing the 'c'/'a' keys when prompted by the program. The calibration factor declared as a variable 'calib = 18750' in this program is used to calibrate the speed of the stepper motor. This calibration factor may vary from PC to PC and needs to be determined before using the program. In the handcrl.c program the up arrow and the down arrow keys are used to rotate the motor in the counterclockwise or clockwise direction respectively, the motor moves by one step by pressing the key once.

S. Tauro, M.A.N. Razvi
Mumbai
India

Program for continuous rotation

```
/* contin.c*/# include<conio.h># include<dos.h>void
cdelay(float);void  ccdelay(float );int a[4] = {1,2,4,8};main(){ int
n; float rpm; int calib = 18750; char ch; clrscr(); printf("\n Enter
speed in RPM ");
 scanf("%f",&rpm);
 printf("Please select the direction cw/ccw :-   ");
 ch = getche();
 if(ch == 'c')
    {
      if((rpm >= 0.3) && (rpm<8))
            {cdelay(calib/rpm);}
          else if(rpm >8)
            {printf(" Too fast ");}
          else if(rpm<0.3)
            {printf(" Too slow ");}
    }
 else if(ch=='a')
         {
           if((rpm >=0.3 ) && (rpm<8))
             {ccdelay(calib/rpm);}
           else if(rpm >8)
              {printf("Too fast");}
           else if(rpm<0.3)
              {printf("Too slow");}
         }
}
void cdelay(float rpm)
   {
    int n =3;
     while(!kbhit())
       {
           outportb(0x378,a[n]);
           delay(rpm);
           n = n-1;
           if(n<0){n=3;}
       }
    }
 void ccdelay(float rpm)
    {int n=0;
     while(!kbhit())
      {
       outportb(0x378,a[n]);
       delay(rpm);
       n = n+1;
       if(n>3){n=0;}
      }
   }
```

Program for Stepwise Movement

```
/* handcrl.c*/
# include<conio.h>
# include<dos.h>
main()
{
    char key,key1;
    int a[4] ={ 1,2,4,8};
    int i=0;
   while( (key=getch()) != '\r')
      {
        if(key==0)
        {
          key1=getch();
           if(key1==72) /* extended code for up arrow key */
             {
               outportb(0x378,a[i]);
               i = i+1;
               if(i >3)
                 {i=0;}
             }
          else if(key1 == 80) /*extended code for down arrow
key */
               {
                  if(i < 0)
                    {i=3;}
                  outportb(0x378,a[i]);
                  i = i-1;
               }
        }
      }
}
```

A fast accurate differentiator

Op-amp based differentiators have a number of problems such as high output noise, ringing and instability, and severely limited speed of operation due to the finite open loop bandwidth of the op-amp. These limitations have effectively excluded their use in fast instrumentation and measurement systems.

The active differentiator circuit shown in **Fig. 1.** is inherently stable, has very low output noise and can deal with input signal slew rates up to about 1000V/µs with high accuracy and even beyond 5000V/µs with reduced accuracy. **Fig. 2.** shows the performance of the circuit. For the slew rate tests above 2000V/µs, the power supply voltages were increased from those shown in the circuit.

Q1 forms an emitter follower to buffer the input and to provide a low impedance source to the capacitor, C1. Q2 and R3 act as a current to voltage converter. The relatively high standing current in Q2 gives it an emitter input impedance of about 1.4 ohm, so most of the capacitor current flows into Q2 emitter with only a small amount flowing through R2. This common base stage Q2 gives very fast response to capacitor current changes. The 50 ohm collector output resistor, R3, was chosen to match a 50 ohm system for high-speed work, but could be made higher to achieve a larger output with only a small effect on speed performance.

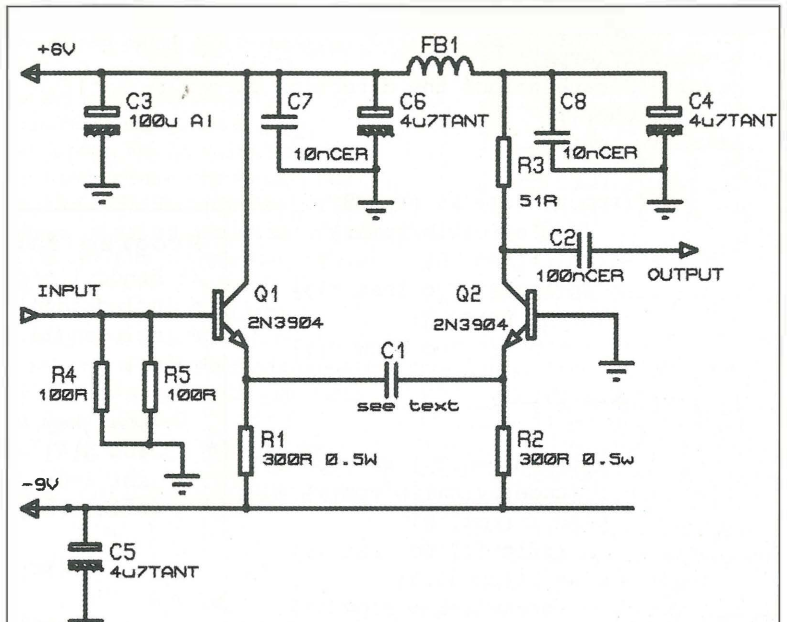


Fig. 1.

The circuit output is given by

Vo = R3*C1 *Input slew rate

Where the input slew rate is in V/s. The output is a scaled version of the true differential of the input signal. For input signal slew rates of up to 25 V/µs, C1 should be about 1000pF. For slew rates greater than this, C1 should be reduced to ensure that Q1 can provide sufficient current into the capacitor without loading the source too much.

As the circuit does not rely on a high gain amplifier for its operation, output noise is very low. With the capacitor value at 1000pF, the 'no signal' output noise is less than 1mV peak to peak measured with a 350MHz scope.

It should be noted that, in contrast with RC passive differentiators, the circuit's output response is related to the actual differential of the input waveform. This means that the circuit can be used to measure accurately the linearity of ramp waveforms or observe small rapid changes in signals. With small values of C1, it can be used to generate very fast rise (~1ns), short duration pulses from slower input signals.

For good high frequency performance the circuit should be constructed using RF techniques on a ground plane. As the output is taken effectively across R3, the circuit is sensitive to noise on the positive supply rail and so it should be very well decoupled as indicated.

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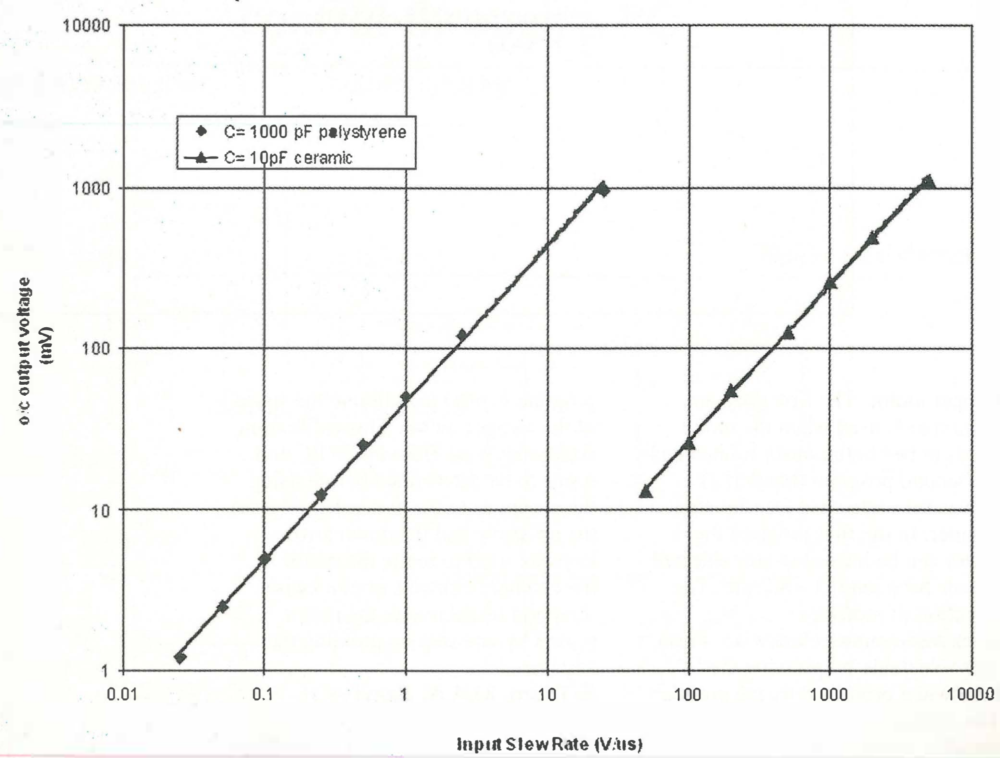
Fig. 2. Measured performance of differentiator.



Unusual application of comparators as excellent high speed linear amplifiers

A comparator is essentially a high gain, high slew rate amplifier with excellent offset and drift characteristics. An internal compensating capacitor is not provided at the manufacturing stage to significantly improve the requirement of slew rate.

The comparator is an element of pulse width modulator, peak detector, delay generator, switch drivers, A/D converters etc. However one might not have seen the comparator being used as linear amplifier with excellent high frequency and good output drive capability.

In order to use the comparator as an op-amp, one has to externally provide the frequency compensation and choose the appropriate value of open collector pull up resistor.

The LM139/LM239 being the most popular and easy to use quad comparator, is chosen to show how it can be configured as a non-inverting amplifier. Similarly the LM111/LM211, another precision popular comparator, is used to show how it can be configured as an inverting amplifier. Standard connections are shown in **Fig.1.** and **Fig. 2.**

Comparators do not have internal provisions for compensation by external components; therefore compensation must be applied externally at the input of the device. The R1, C1 network provides the external frequency compensation at the input. A small value of C2 is introduced across R3 to prevent very high frequency oscillation and to reduce the gain of the amplifier outside the frequency range of interest.

The feed back network R3 & R2 sets the closed loop gain at 1+R3/R2 in the case of a non-inverting amplifier and at -R3/R2 in the case of an inverting amplifier as shown in the Figs 1 & 2 respectively. For the values indicated the closed loop gain works out to 5 for both of the circuits.

The value of R4 tied to the +15V supply, not only affects the positive swing, but also the drive (current sourcing) capability. The higher the value of R4, the lesser the positive swing and the lesser the output drive capability. Therefore it is suggested to use R4 ≤ 820 ohms, so that the output can have a maximum linear swing of + or -13V when operated at + or -15V.

The circuits work very well both for low and high level signal. The amplifiers even respond linearly to a square wave input of up to 100kHz easily and can safely drive a load greater than or equal to 2K at + or- 13V.

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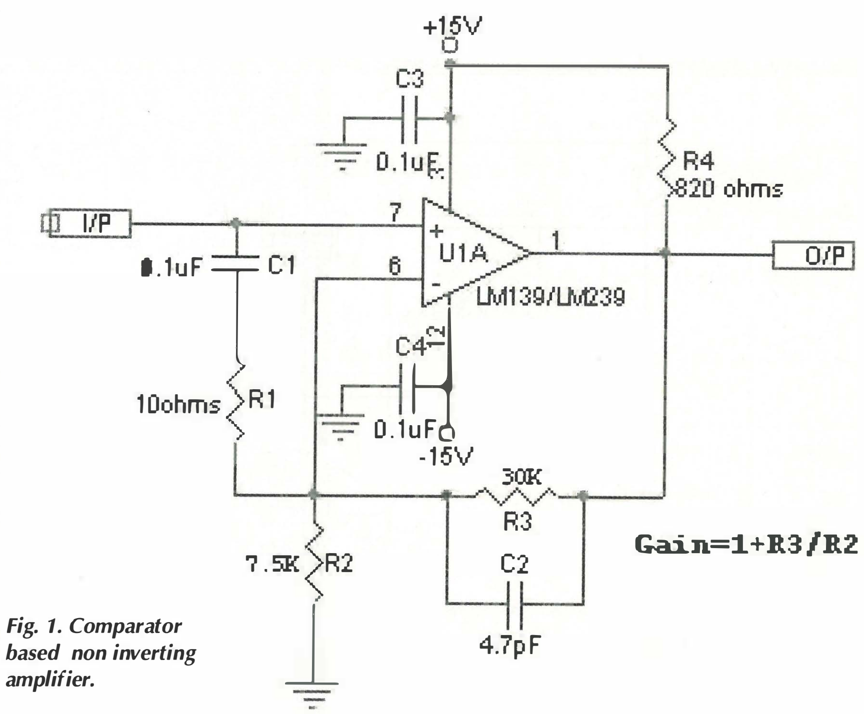

Fig. 1. Comparator based non inverting amplifier.

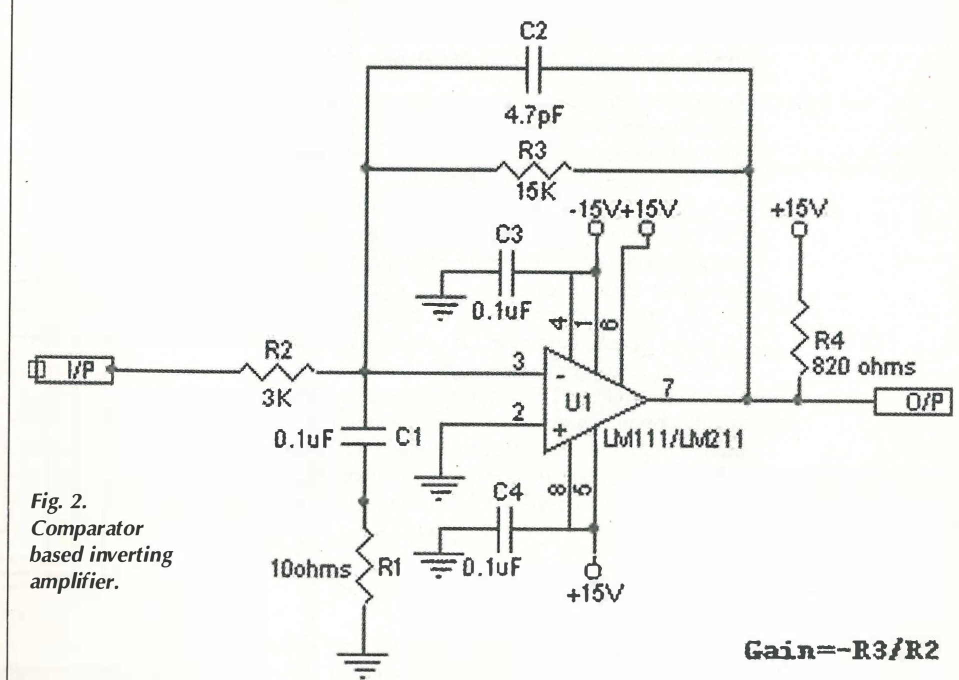

Fig. 2. Comparator based inverting amplifier.

Cut relay power to a quarter

Electro-mechanical relays are cheap and easy to use but unfortunately waste a large amount of power in their coil. Because of the magnetic hysteresis, the full drive voltage must be applied to excite the relay but only one half of this voltage is needed to keep it held.

The circuit shown takes advantage of this property and has been designed to fulfil the requirements of various supply voltages and control polarities (figure a = positive control, figure b = negative control). Vcc is the supply voltage and the relay has an operating voltage of 2 Vcc. In the OFF state, capacitor Cl is charged to Vcc through D1, R1 and the conducting Mosfet (Trl at fig. a, Tr2 at fig. b). When switching to the ON state, Mosfets commute so that C1 is connected in series with the supply and the voltage across the coil rises to 2 Vcc for a few milliseconds. When C1 is discharged, the coil voltage drops to Vcc thus reducing the power consumption.

Relay's specifications exhibit a coil resistance that is about four times higher when the operating voltage is double (FINDER: 55Ω@6V, 220Ω@12V, 900Ω@24V) hence the power is cut to a quarter.

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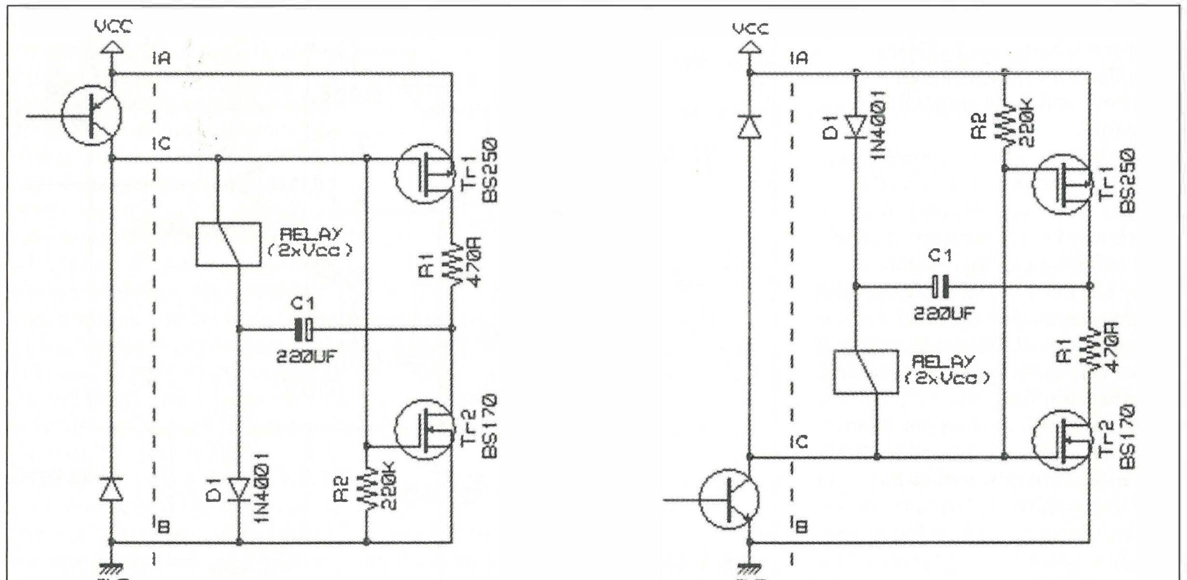


Fig.a : positive control

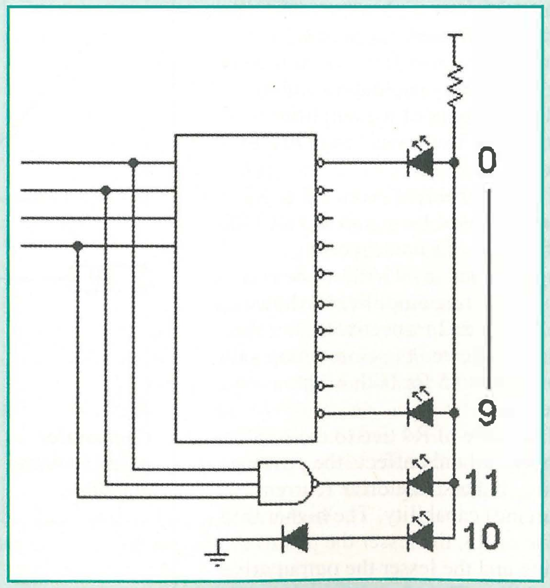
Fig.b : negative control

'None of the Above' decoder

This circuit idea can save a gate or two, which may help a design 'just fit' in available resources. It relies on the difference between V_{OL} (or V_{sat}) of the drivers and V_f of the diode being greater than the difference in V_f of an "on" and an "off" LED. Most individual LEDs go from dark to bright within 500mV, but there is significant V_f variation between types and colours, so beware when mixing them. The schematic shows the idea applied to turn a 1-of-10 decoder into a 1-of-12 with just one more gate. Of course, the same idea works for fewer (or more) outputs, such as Red/Yellow/Green LEDs for model traffic lights, or a standby/on indicator (a neat use for a common-anode bicolour LED, if only somebody made them!)

By the way, does anyone else remember destroying early Nixie decoder/drivers by turning all the outputs off?

Peter Horn
By email



Op-Amp and resistor distortions

In the last article of this series, Cyril Bateman uses his real-time distortion measuring system to explore means to reduce distortions in IC op-amp circuits and investigates distortions in resistors and potentiometers

Having completed the design for my very low distortion fixed output oscillator, part of the equipment for my original *Capacitor Sounds* series, I needed to provide a variable level output, able to develop an undistorted 6V test signal across my near perfect 1μF reference capacitor. My original potentiometer and non-inverting unity gain output amplifier design distorted badly driving a 3V signal into a 600Ω resistive load. This problem was solved by using an NE5534AN op-amp as a variable gain inverting amplifier, with a 15.4kΩ input resistor and a 25kΩ conductive plastic potentiometer for feedback. This inverting, variable gain output stage and potentiometer, added almost no measurable distortion driving a 600Ω resistive load, but did distort with a capacitive load.

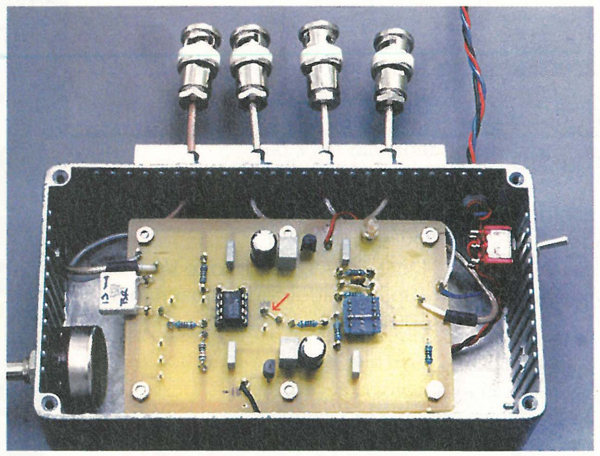


Fig. 1. This test PCB, attached to my real-time hardware distortion analyser, was used for more than 75 distortion measurements of the IC op-amps and test circuits in this article, simply by unplugging ICs. Switching the link shown arrowed, changes from the 'dual' amplifier position shown to 'single' using the 'A' section only of the IC. Replacing the DIL header with an IC, changes from measuring U7 to the two amplifier circuit, U7 and U8.

Clearly for my capacitor measurements, I needed to design a very low distortion, more powerful, buffer output stage. Searching my bookshelves and back issues of *Electronics World* I found nothing, but on the internet I found a short series of articles by Walt Jung, "Op-Amp Audio" originally published in the US magazine *Electronic Design* from September to December 1998[1]. In this he suggests using a gain stage and separate output buffer. Apparently he had successfully used the Analog Devices AD811AN, a current feedback video amplifier, as an audio output buffer. Using an OPA134 gain stage with this AD811AN output, I could develop an undistorted 6V signal at 1kHz across my near perfect 1μF reference capacitor from a 100Ω source impedance.

A similar test signal at 100Hz across larger capacitors needed more current than the AD811AN could provide. Further searching found a novel circuit for an exceptionally accurate, active feedback amplifier developed as input buffer for a 16 bit ADC, in *Electronic Design* April 2001[2]. A similar arrangement could drive the more powerful output stage needed for my 100Hz test equipment[3]. Then, whilst busy developing circuits and measuring capacitor distortions, time did not permit exploring these solutions in more detail for general use. Now two years later, using my standalone distortion tester[4], I could at last begin. **Fig. 1**

Active Feedback Amplifier

Many low level audio systems use unity gain, voltage following ICs as buffers between stages, it being often claimed such circuits can output up to 10V AC using ±15V supply rails, but measurable distortions are produced with much smaller signals. This novel active feedback amplifier, developed as a 16 bit input buffer, used both sections of a dual op-amp, the first amplifier section to drive the load as usual, the second stage to provide distortion cancelling active feedback instead of the usual feedback resistor. The idea being that having two errors of equal value but opposite sign, the feedback signal error would cancel the forward gain error[2]. **Fig. 2**

Initial tests measuring the input - output voltage differential of an AD712JN using my differential scope probe[5] confirmed that this arrangement did reduce errors. Intended for use as a unity gain buffer, I wondered whether it could be adapted for use in the gain of two buffer I now needed. A few initial measurements confirmed this arrangement could provide gain and improve performance. Initially it seemed an almost ideal distortion reducing panacea, except that some ICs I tried did not work at all well in my gain of two circuit.

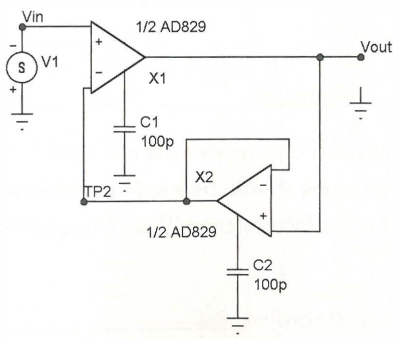


Fig. 2. The schematic from the "Active Feedback Amplifier Enables High-Performance A-to-D Conversion" article[2] found while accessing the Electronic Design web site.

Op-Amp distortion tests

Most op-amps provide very large open loop gain, typically 100dB at low frequency, allowing use of substantial feedback to reduce distortion. However this gain reduces rapidly with frequency such that by 1kHz, the open loop gain has reduced by 20dB and output distortion is increasing. With small audio signals and light loading this may not present a problem but with increasing amplitude and heavier circuit loading, problems do emerge. Capacitance to ground compounds these difficulties and can even result in oscillations.

The 'direct' input to my notch filter presents a high resistance in parallel with a 10.2nF capacitance, which with the 600Ω to ground in my test PCB[6] provides a difficult 575Ω and parallel 10.2nF test load, exceeding that expected in an audio circuit. I decided to use this load to explore how popular audio op-amps behaved. Would using the second stage of a dual IC as an output buffer or the Walt Jung external buffer permit larger amplitude undistorted signals? To make certain of a stable performance at all signal levels, I decided to use my test PCB to measure distortion with a 1V test signal, then increase the signal in 1V steps to 6V or until the amplifier distorted. **Fig. 3.**

Single Amplifier circuit

For many years the TL072CP, MC4558TPI and NE5532AN dual amplifier ICs have been used in audio systems. With a DIL header to bypass U8 and taking the output from U7A using one half of a TL072CP, its unloaded second section simply voltage following the first section's output, I wanted to see what low distortion signals with a gain of two, could be driven into my test load. **Fig. 4.**

The other two ICs worked rather better, the MC4558TPI producing 0.00228% distortion at 4V, but the NE5532AN was seven times better, just 0.00032% distortion driving a 4V signal into this difficult test load, the best of these older op-amps. From earlier measurements I already knew the expensive AD797 could provide large amplitude low distortion signals, so for this article I wanted to explore less exotic devices.

To minimise distortion with any IC it is essential to match as closely as possible the impedances 'seen' at its inverting and non-inverting inputs, otherwise, as explained in the Walt Jung papers, it will generate increased second harmonic distortion. The AD797 is able to produce exceptionally low distortion, but is sensitive to small impedance differences between its inverting and non-inverting inputs.

Although not claiming any particular distortion performance, in the past I found the BiFET AD712JN behaved well when driving adverse loads. Tested as above I measured 0.00162% distortion, rather better than the MC4558TPI and TL072CP but worse than the NE5532AN. A JFET input TLE2072CP measured 0.00142%, much better than the old TL072CP and slightly better than the AD712JN while an OP275G with its Butler Bi-polar/JFET input stage, intended for audio circuits, measured 0.00088% distortion. The Burr Brown FET input OPA2134CPA, part of their 'SoundPlus' range designed for low distortion audio, measured 0.00036% to equal the NE5532AN performance. **Fig. 5.**

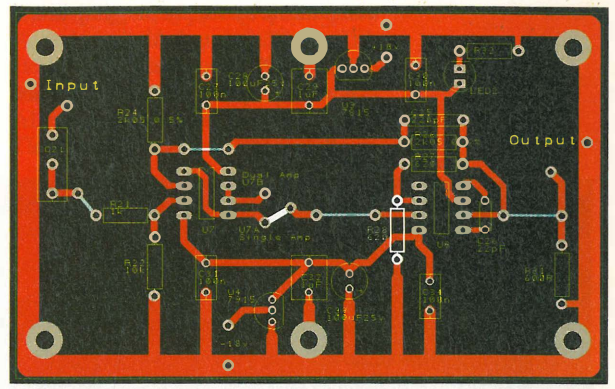
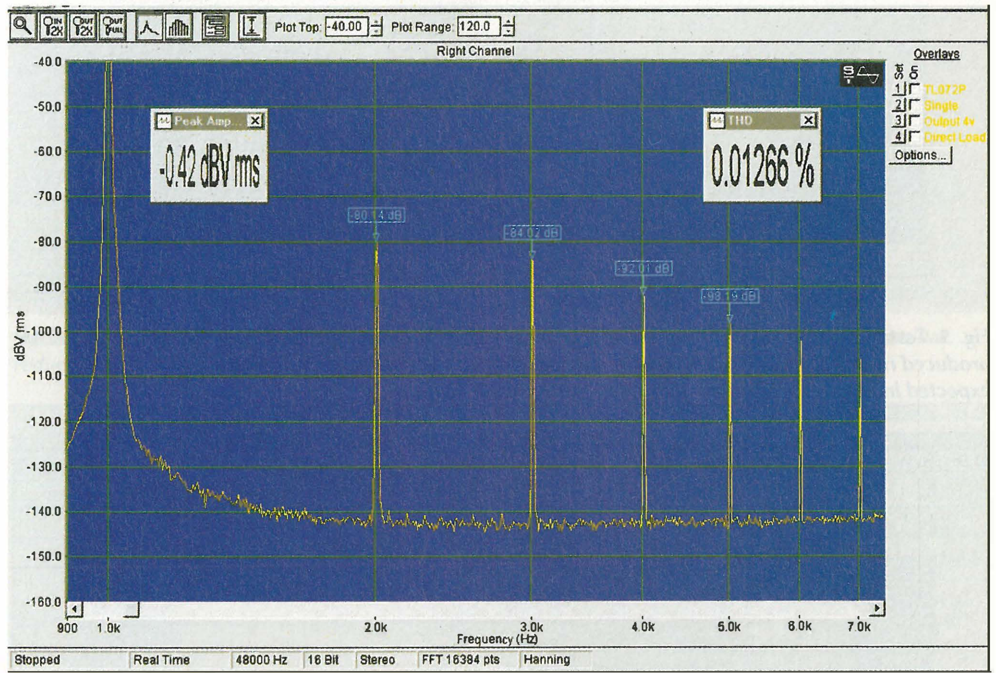


Fig. 3. The test PCB and component values used for this article. The link which changes from measuring the 'single' to 'dual' configurations is highlighted in white. Resistor R28, highlighted in white, must be removed when using an NE5534AN or similar amplifier also the DIL header for U8. With a current feedback AD811AN for U8, resistor R28 is required, so should be refitted.



Dual Amplifier

Having established a distortion baseline for a single stage amplifier driving 4V into my test load, would a gain of two version of the dual amplifier active feedback design, with output now taken from U7B, work any better? The heavy output currents would be removed from the input gain stage, but being in the one package, would thermal or capacitive feedback present new problems, increase distortions or even result in oscillation?

I decided to start by trying the worst performing of the above amplifiers, for that should more clearly show any improvement, as reduced distortion or increased drive level. The TL072CP in this 'dual' arrangement could not provide increased drive, but distortion at 4V output reduced dramatically from 0.01266% to 0.00041%, almost equalling the best of the dedicated 600Ω capable audio op-amps. **Fig. 6.** With such a dramatic improvement, I wondered how the other op-amps would perform using this circuit and

Fig. 4. Single amplifier distortion measured using the 'A' section of a TL072CP driving into my 575Ω 10.2nF test load. For this IC the 4V nominal test voltage had to be reduced to 3.8V.

components by simply plugging in a different IC. Strangely the MC4558TPI, which had easily outperformed the TL072CP in my first tests, also improved but by a far smaller margin, from 0.00228% as a single stage to 0.00062% in this dual circuit. However, this IC could now almost drive a low distortion 5V signal into my load.

The NE5532AN also improved from its original, equal best single stage performance, to an amazing 0.00022% at 4V, almost halving the best single stage results. In addition it could now easily drive a full 5V low distortion signal into my test load. In like fashion the AD712JN also could drive a 5V signal at 0.00073% and a 4V signal with just 0.00032% distortion. **Fig. 7.**

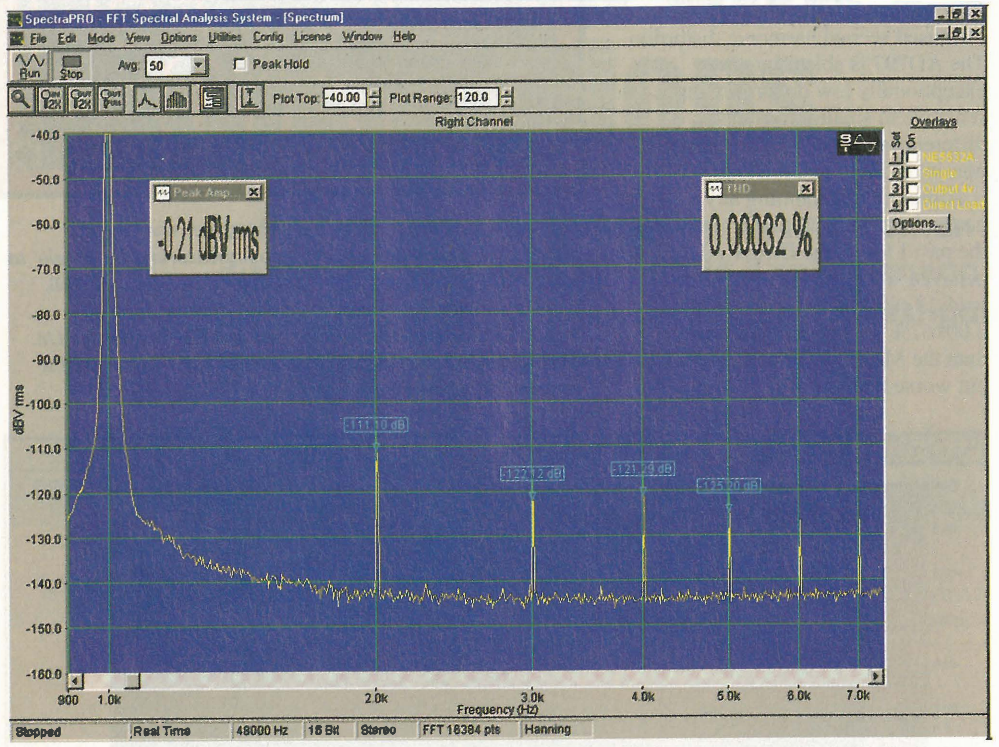


Fig. 5. Tested at 4V output, but otherwise exactly as Figure 4, this 'single' amplifier test of an NE5532AN produced remarkably little distortion driving this difficult test load, a heavier load than would be expected in any real world circuit or interconnect cable loading.

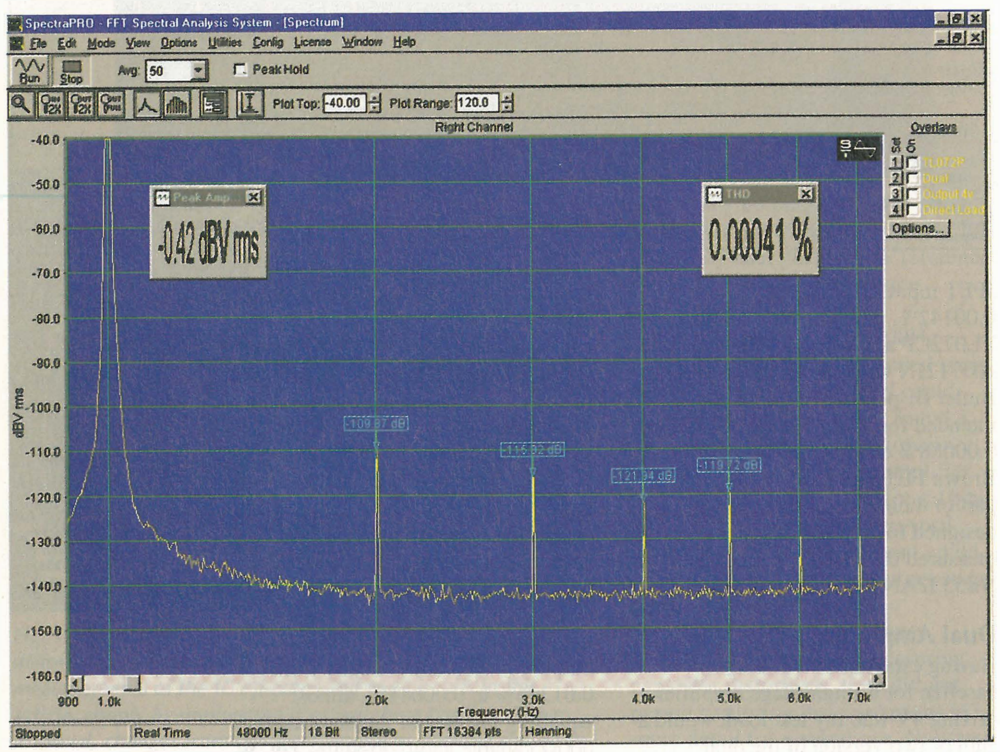


Fig. 6. The TL072CP of Figure 4, tested in the 'dual' amplifier circuit using its 'A' half for gain and 'B' half as a voltage follower driving the test load. Distortion has dramatically reduced from 0.01266% to 0.00041%.

Whether a feature of the op-amps themselves or my test circuit, the TLE2072CP, OPA2134CPA and OP275G were unusable in this configuration, so after all it has failed to become the hoped for universal palliative. Exactly why some ICs performed so well in this circuit and others were unusable is not clear.

Perhaps using an external load bearing buffer op-amp as proposed by Walt Jung would work better. This two IC arrangement is more expensive and requires larger printed board area, but in small quantities it could prove less expensive than using say a single AD797. I decided to explore this option, using the identical test set up, test load and PCB test circuit by replacing the bypass DIL header with an IC. I knew the AD811AN worked well in this circuit position, but how would an NE5534AN perform?

Two amplifiers

Starting with a 1V test signal and increasing in 1V steps as before, I tried an NE5534AN as the output stage with various amplifier gain stages. With R28 removed, the NE5534AN output stage works as a unity gain voltage follower. Taking the output once more from U7A, the 'A' section of the first op-amp provided the gain of two. Its unloaded second section following the first section output but was otherwise inactive. Using the NE5532AN as the first amplifier, at each test voltage significantly less distortion was measured compared with the same NE5532AN used alone, whether as a single amplifier or in my dual configuration. Furthermore, with the drive signal into my test load increased to 6V I measured just 0.00017% distortion. At all lower test voltages, a similar or slightly lower distortion was measured, an amazing result. Clearly removing the output stage's thermally conducted heat from the gain stage was beneficial in reducing distortion. **Fig. 8.**

Even more amazing was that the TL072CP, which had performed less well on its own, with the NE5534AN output, was able to drive a 5V signal with only 0.00044% distortion, into the test load. The MC4558TPI also improved and was able to drive a 6V signal at 0.00031%. With this success I decided to refit R28 so I could use an AD811AN output buffer to compare directly with these NE5534AN results.

The NE5532AN which had worked so well with the NE5534AN output buffer, partnered now with the AD811AN generated 0.00308%, ten times more distortion than when measured as a single amplifier. Since this was the last but one combination of those tested and the final combination worked perfectly, this distortion must result from a particularly unhappy combination of IC and test load characteristics. However, all other combinations I tried worked extremely well with this AD811AN and 5V output. The TL072CP improved to 0.00022%

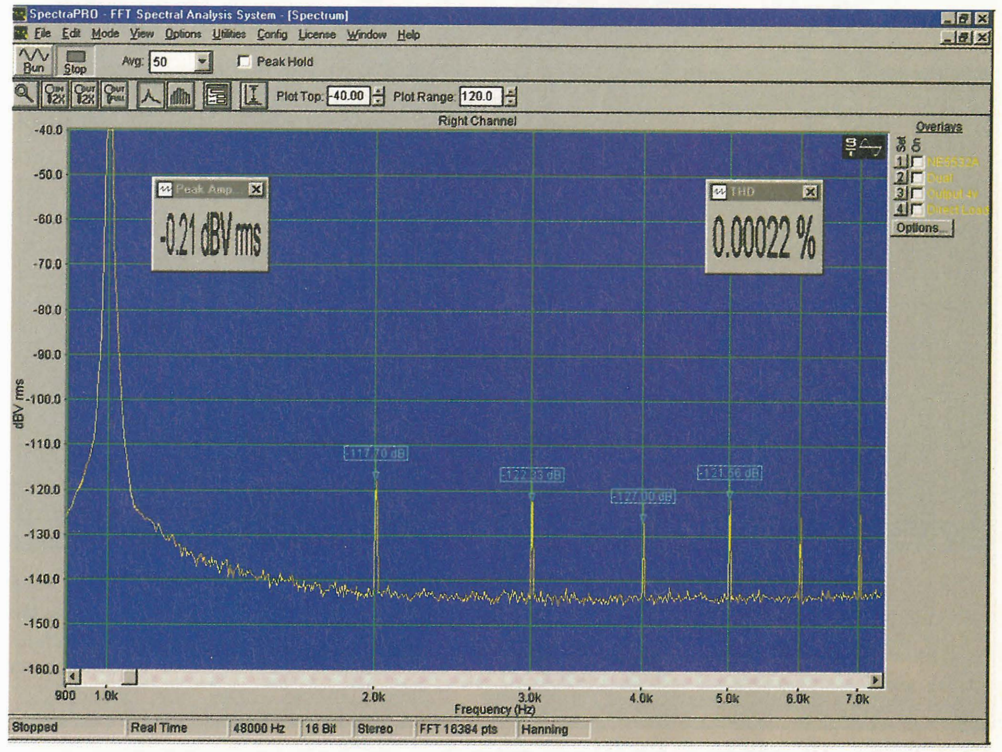


Fig. 7. Retesting the Figure 5 NE5532AN in the 'dual' amplifier test circuit as Figure 6, distortion has reduced again to 0.00022%, 50% less than the best 'single' amplifier of those tested

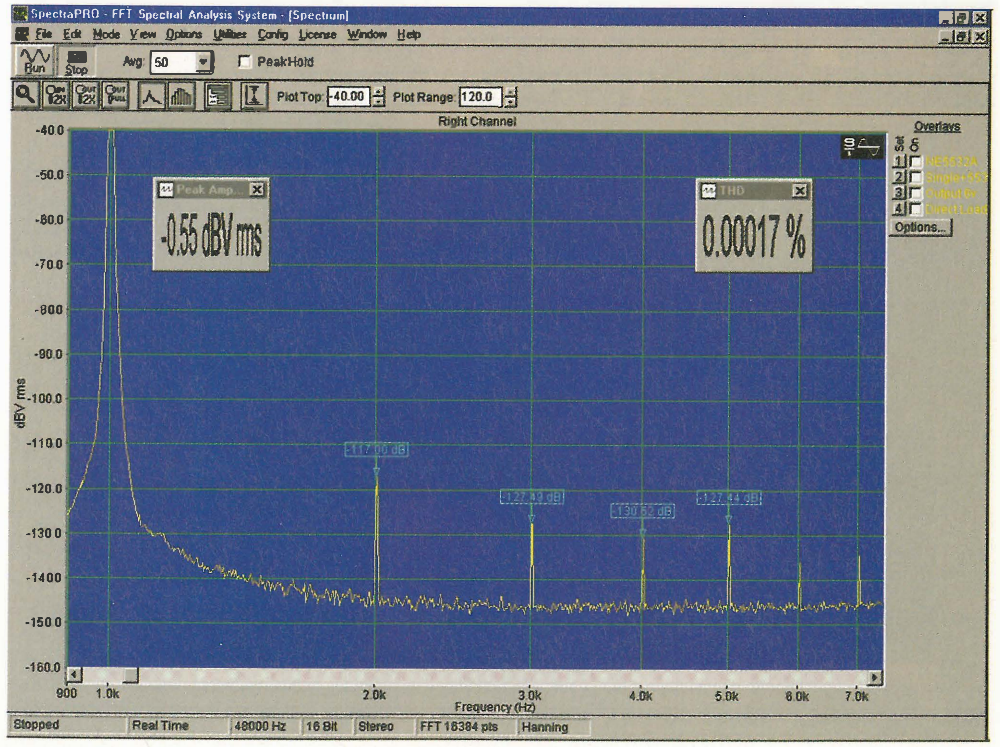


Fig. 8. Removing the DIL header and R28 to use two separate ICs rather than the 'dual' arrangement of Figures 6 & 7. Retesting the Figure 5 NE5532AN 'A' section with an NE5534AN for U8 removed the test load thermal effects, reducing distortion to just 0.00017%, halving that measured with the best performing 'single' IC

distortion, half that found when this IC was used with an NE5534AN. The OP275G and MC4558TPI improved more to 0.00016% and 0.00014% distortion respectively. Best of all, the OPA2134CPA with this AD811AN output, measured a remarkable 0.00010% at 5V output and could even manage 0.00011% distortion at 6V output, approaching the distortion measuring limit of my equipment. **Fig. 9.**

Op-Amps - Conclusions

Clearly, while the dual amplifier arrangement worked well, following the Walt Jung advice[1] to physically separate the gain and output driver stages can produce exceptionally low distortion figures into an adverse load, for many perhaps most combinations of gain and driver ICs.

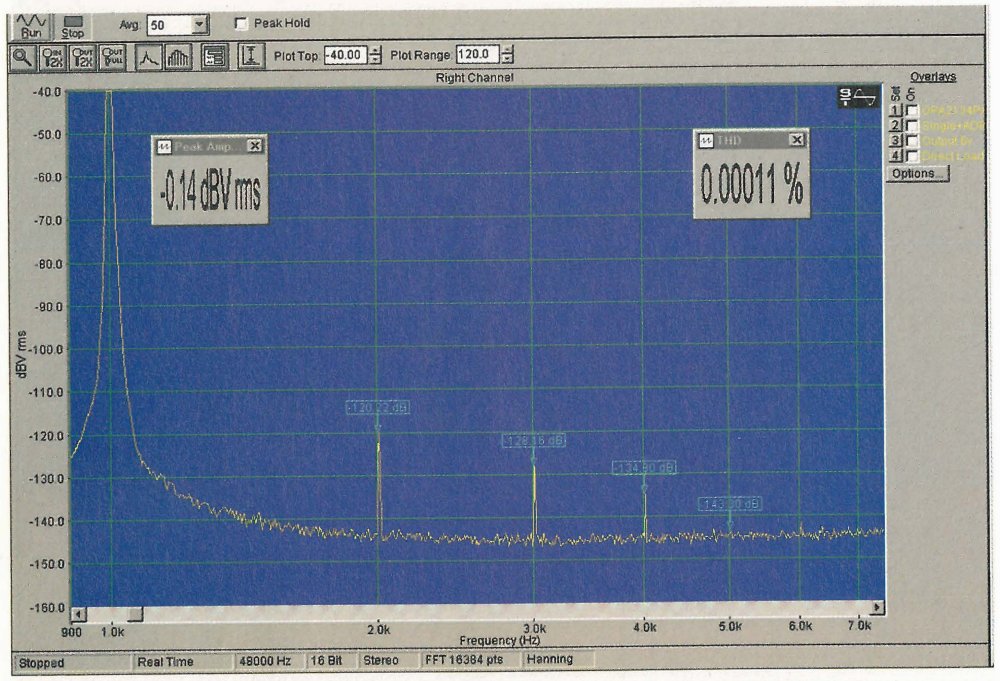


Fig. 9. Refitting R28 and using an AD811AN current feedback amplifier for U8, this Burr Brown OPA2134CPA, the joint best 'single' amplifier tested, reduced its distortion from 0.00036% at 4V output to this remarkable 0.00011% distortion at 6V output.

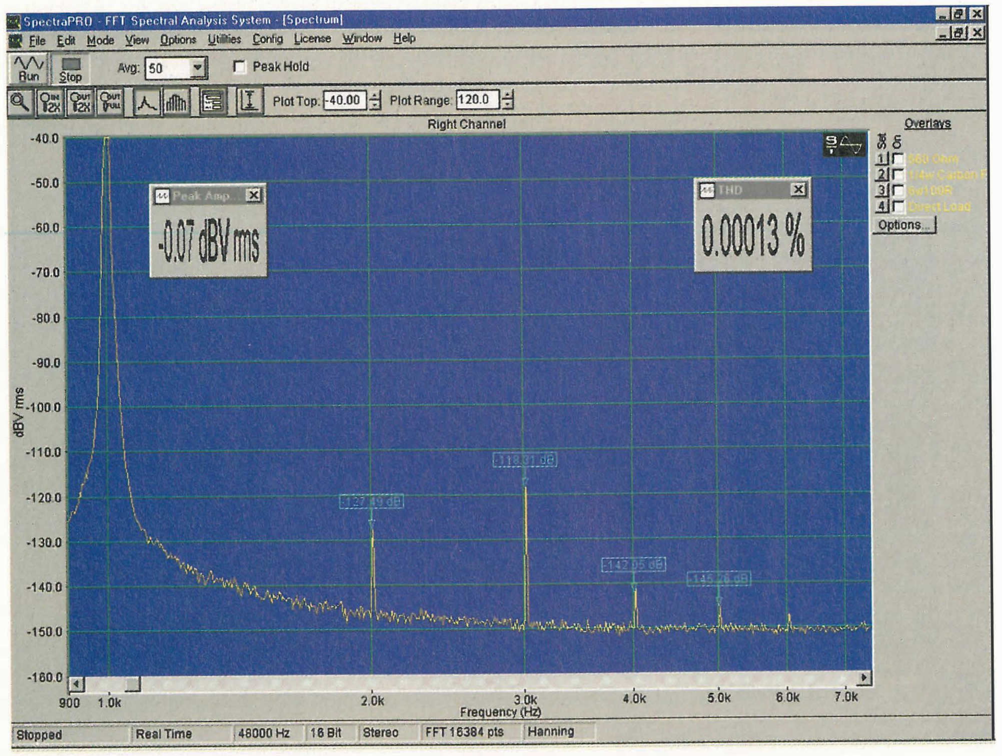


Fig. 10. This 20 year old 0.25 watt carbon film resistor made with a ground, not laser trimmed, spiral, produced 0.00013% distortion when loaded to 25% rated power. The second harmonic for a same make 0.5 watt resistor loaded to 12.5% rated power, measured 2.3dB better. Distortions from a modern laser spiralled, low cost 1% 0.5 watt metal film resistor, were too small to be measured.

Resistors

Many readers have written requesting advice about the resistor distortions, much publicised in magazines and internet discussion groups and based on subjective tests, not measurements. They were concerned about voltage and temperature coefficients and the effect of magnetic and non-magnetic leadwires.

I believe distortion from carbon composition and to a lesser extent carbon film resistors can be a problem, but expected modern laser spiralled 1% metal film resistors would not produce any measurable distortion with my equipment. Today no sensible audio design would use carbon composition or carbon film resistors.

Every resistor exhibits a temperature coefficient and a very small voltage coefficient, specified according to international standards and test methods. BS and CECC specifications demand 'true values', so test instrument uncertainties must be added to the component's measured values in any published claim. Consequently a resistor specified as 50ppm temperature coefficient, may in practise exhibit less than 30ppm deviation.

In circuit, resistor body core temperature will increase above local ambient according to the power dissipated. The body temperature of a typical 0.25W resistor with 25% rated loading, increases some 6°C above local ambient, but temperature coefficient with a steady temperature rise does not produce distortion. To generate distortion with an AC signal, resistor core temperature must track the AC signal. Every resistor has some mass and thermal inertia so its core temperature cannot instantly change. Metal film resistor temperature and voltage coefficients with modest AC signal loading generate little or no measurable second harmonic distortion, even with low frequency signals.

In past years when 5% carbon film resistors were standard, miniature high speed grinding wheels were used to cut a groove in the resistive film, to trim to value. The resultant spiral cut through the resistive element, into the surface of the exceptionally hard resistor core, usually had ragged edges and varying width. In places a poor grind could leave minute semi-conducting bridges across the cut, resulting in increased third harmonic distortion. Today 1% tolerances require laser cutting equipment. Lasers cut clean, consistent, spirals, virtually eliminating this source of distortion.

The termination between lead wire and resistor element for almost all low wattage resistors relies on a pressure contact between the end cap and the resistor element. Unless adequate contact can be assured after soldering the resistor into circuit, this presents a potential source of third harmonic distortion. Some audio specialist companies have used non-magnetic end caps to counter the 'magnetic' discussions. To maximise the contact pressure it is essential the thermal expansion coefficients of end cap and resistor body are matched using a high tensile strength, elastic metal. For these reasons I prefer to use plated steel end capped resistors with tinned copper leadwires, believing any magnetic field effects due to the tiny currents in most resistors, flowing through this end cap, are preferable to third harmonic distortion from poor end contact pressure. My equipment can only stress a resistor to some 6V and read distortions above -120dB. To stand any chance of realistically measuring distortions in 1% metal film resistors, much larger pure test voltages, loading the resistor to perhaps 50% power and measurements down to -135dB or better are needed.

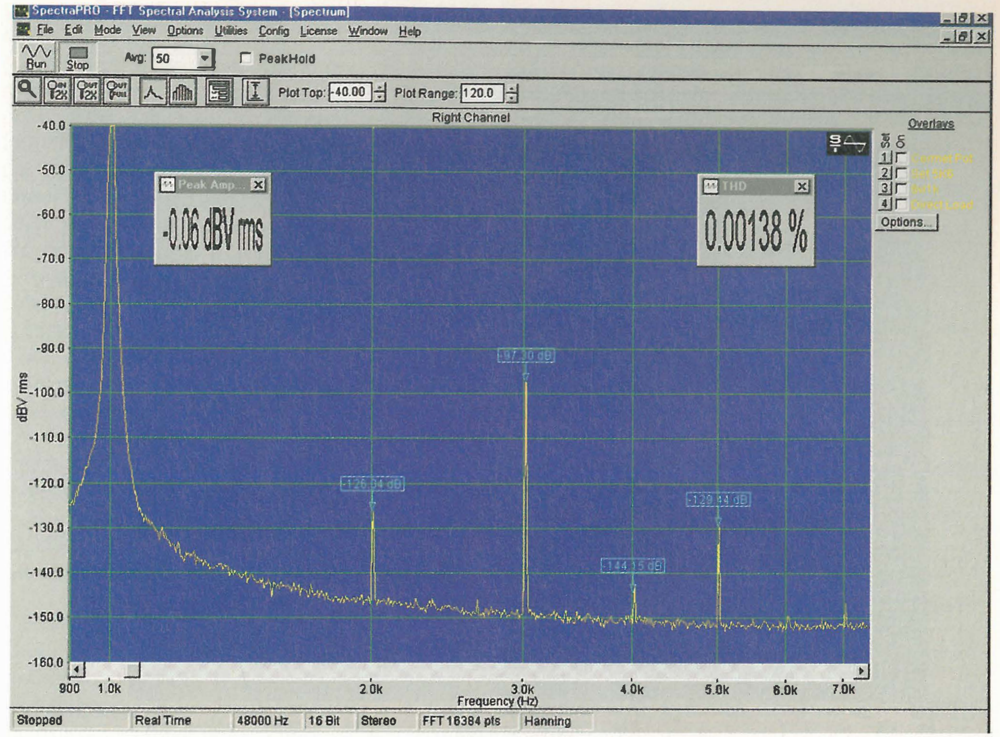


***Fig. 11.** This multi-turn cermet trimmer, set as a 5.6kΩ variable resistor and tested with a 6V signal from 1kΩ source impedance, generated this enormous -97dB third harmonic, 0.00138% harmonic distortion. Tested exactly the same a low cost carbon control produced 0.00129% while a conductive plastic control and 10-turn wirewound generated only 0.00009% and 0.00007%.*

I no longer have any carbon composition resistors but do have a number of 20 year old, ground spiral, carbon film resistors. I decided to see whether my test equipment might find these produced more distortion than modern low cost 1% metal film types. Using a 6V test signal, I measured some 56kΩ with 1kΩ source impedance, 5.6kΩ also using 1kΩ source and finally some 560Ω resistors using 100Ω sources. Naturally resistor current through the 56kΩ parts was minuscule so it was no surprise to find all types, carbon film and metal film measured almost identically, near my equipment's basic distortion.

At 5.6kΩ I found one particular carbon film resistor measured 0.00011% compared with the metal film types at 0.00007%. At 560Ω, because the resistors were passing 10mA through current and dissipating 65mW, larger differences were noticed. I now found two carbon film resistors measuring increased distortion. One, a quarter watt part measured 0.00013% and a half watt 0.00010%. In comparison low cost 1% metal film resistors measured 0.00007% as did a 0.5% Welwyn RC55, near the baseline distortion of my equipment, at these settings.

Second harmonic for all four resistors measured -127dB, the metal film third harmonics measured -125dB while the carbon film third harmonics measured -118 and -120dB respectively, all higher harmonics remained below -140dB for all types. **Fig. 10.**

Fixed Resistors - Conclusions

Provided a resistor is loaded to 25% of its rated power or less, modern 1% metal film resistor distortion is small, typically less than 0.0001%, smaller than almost any other active or passive component, which may be used in an audio system.

Distortions found with the 1% metal film resistors used for this article are small and cannot be properly measured at 6V using my less than 1ppm distortion equipment.

Volume controls - trimmer resistors

Almost as many words have been written about noisy carbon volume controls as for distorting capacitors, but I have seen little about distortion from volume controls or pre-set trimmers. As seen in this series, third harmonic distortion in capacitors and resistors is usually caused by non-Ohmic contact resistances, surely the wiping contacts used in volume controls and pre-set trimmers must produce similar distortions. Recalling the problems I had with my original oscillator variable output stage, I decided to explore further.

Unlike other variable resistor types, a multi-turn wire wound at AC will exhibit a reactive phase angle in addition to its claimed DC resistance value. Depending on its design, construction and the test frequency, it may appear either as inductive or capacitive. I tested my stocks and without exception all were capacitive at low frequencies, measuring typically 100pF, becoming inductive at higher frequencies. This reactance may cause problems in some circuits.

Using the 6V drive at 1kHz from my equipment, I first connected some 10kΩ potentiometers and multi-turn pre-set resistors to make 5.6kΩ variable resistors, passing some 1mA through each wiper. I used a 10-turn wirewound, a 20-turn cermet trimmer, a low cost carbon and a conductive plastic volume control. Not surprisingly the 10-turn wirewound measured 0.00007%, my equipment baseline distortion, the conductive plastic was almost as good at 0.00009%, the difference being a 5dB increase in third harmonic distortion. When I tried the low cost carbon volume control I expected and found increased distortions, now measuring 0.00129%, 14 times greater distortion than the conductive plastic volume

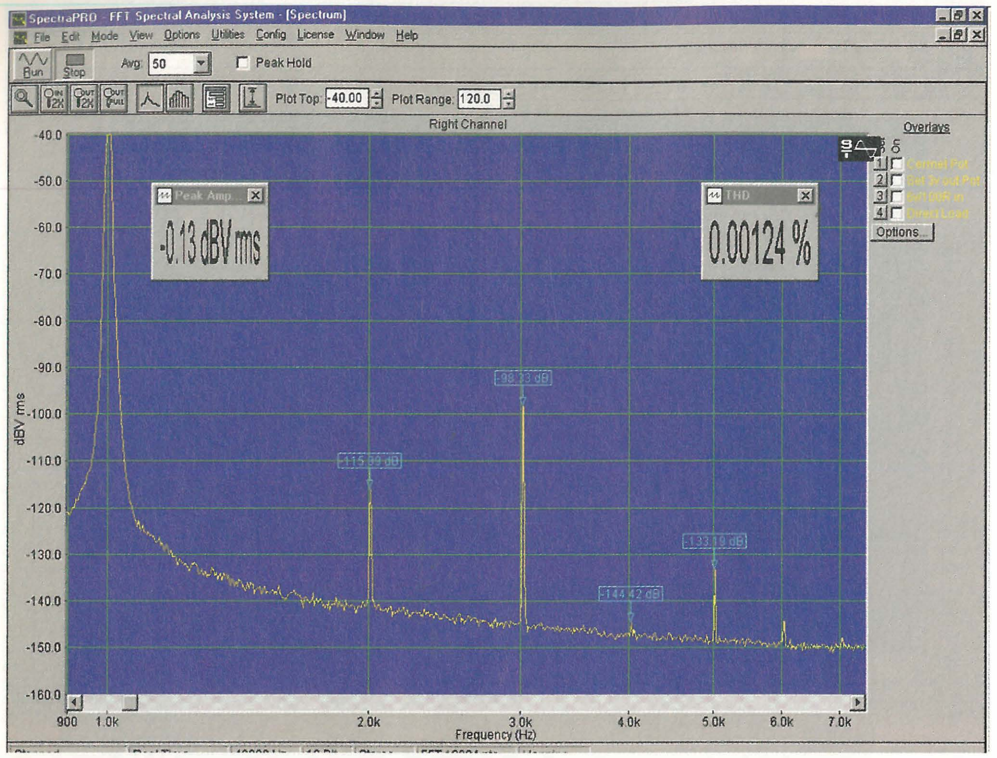


Fig. 12. Re-connected as potentiometers to output a 3V test signal drawing 225μA through their wipers, produced a similar pattern of distortion. The cermet control with 0.00124% distortion was worst; the low cost carbon was much better at 0.00039%, the conductive plastic and wirewound measuring just 0.00009% and 0.00005% respectively.

control. Second harmonic was -117dB, third -98dB, fourth -137dB and fifth -121dB.

Finally, the multi-turn cermet trimmer which measured an enormous 0.00138% distortion, worse even than the inexpensive carbon control. While the second and fourth harmonics remained near my measurement baseline, its -97dB third harmonic dominated distortion, more than 31dB worse than measured on the wire wound control. **Fig. 11.**

Used as a potentiometer

While the above test reasonably simulated use as a variable resistor, many potentiometers and pre-sets are used as potential dividers or volume controls. To simulate this requirement I connected my 6V test signal to one end terminal, the other end to ground, then set the wipers to measure a 3V output signal. To ascertain the effect of wiper contact linearity, each control was tested twice, once with my notch filter input switched to 'pre-amp' for a negligible 10μA wiper current, then switched to the 'direct' position, a 13.5kΩ resistance in parallel with 10.2nF capacitance, drawing some 225μA through the wiper.

With the 10μA wiper current, the 10T wire wound measured 0.00006%, the carbon and conductive plastic controls 0.00007%. The cermet trimmer third harmonic increased by 16dB to measure a distortion of 0.00037%. Clearly this increase results mainly from the cermet resistive element, not the wiper contact which was passing only 10μA of current compared with 600μA through its element. Distortion was third harmonic at -109dB, second -120dB.

To determine how increased wiper current might be a factor, I re-measured each with the pre-amp switch set to 'direct', for 225μA wiper current. The wire wound and conductive plastic controls changed little, reading 0.00006% and 0.00009% respectively. The low cost carbon control measured 0.00039% distortion, indicating its wiper made reasonable contact, whereas the cermet trimmer measured very badly, at 0.00124% its distortion was dominated by a -98dB third harmonic. **Fig. 12**

Variable resistors and potentiometers - conclusions

Clearly to minimise distortion, the lowest possible Ohmic values should be used and variable resistors, potentiometers and pre-set controls must be subject to the smallest possible through and wiper currents. Particular care must be taken to avoid passing capacitive load currents through the wiper contacts, which could result in unexpected tone control distortions.

For almost all applications, a conductive plastic control will produce low noise and distortion while avoiding any reactive loading problems which may result when using a wire wound control. When a cermet type control must be used, it is essential to make certain it is subjected only to small voltage drops with small currents passing through the element and none or very little current is drawn through the wiper.

Conclusions

This series has shown how using low cost self build equipment and simple test methods, one can easily measure the distortions generated by most components used in modern audio systems as well as complete amplifiers, in the hope many readers will replicate these measurement methods. Gain understanding, especially of capacitor functions and help to eliminate many popular misconceptions. Improving our knowledge base by using real measurements to replace subjective opinion. ■

Contacts:
WinAudioMLS Pro http://www.dr-jordan-design.de
SpectraPlus232 http://www.soundtechnology.com

References

1. Op-Amp Audio. Walt Jung, *Electronic Design*, September 1 to December 14, 1988. http://www.elecdesign.com/content/ 3004, 2800, 1474&1518.html
2. Active Feedback Amplifier Enables High-Performance A-to-D Conversion. Moshe Gerstenhaber & Chau Tran, *Electronic Design*, April 2, 2001
3. Capacitor Sounds. C. Bateman, *Electronics World*, January 2003
4. Capacitor Sounds II. C. Bateman, *Electronics World*, September 2003
5. Differential-in 100MHz scope probe. C. Bateman, *Electronics World*, December 2001
6. Capacitor Sounds. C. Bateman, *Electronics World*, September 2002

FFT Software

Throughout my *Capacitor Sounds* series, except the first two articles, I used the SpectraPlus232 software for my distortion plots. This software is easy to set up and has served well. However some readers have asked whether lower cost software might be used, since with a full set of options it becomes expensive.

I have now found two alternatives. Provided the reader can accept not having the on screen THD% display, all other facilities I used are provided by purchasing only the Spectra base module, almost halving the cost. The on screen THD% option can be purchased later.

My second alternative is "WinAudioMLS Pro", I evaluated version 1.66, a new version having its microphone correction ability updated for use with my test equipment, or a conventional microphone. It can be obtained from the Dr. Jordan web site.

As standard this software provides a THD+N display and cursor controlled readout of harmonic levels. It accepts the microphone correction file, essential when using my notch filter/pre-amplifier assembly. In addition to all the features needed for my measurements it also provides an MLS measuring facility. This can be used to measure loudspeaker and room responses as well as the impedance and phase of low impedance components, especially those used in loudspeakers. All this for less cost than for the basic SpectraPlus232 module, makes this software well worth your evaluation.

This software also has a range of additional cost upgrade options, but I found the base WinAudioMLS Pro version with their THD% option, sufficient for my needs.

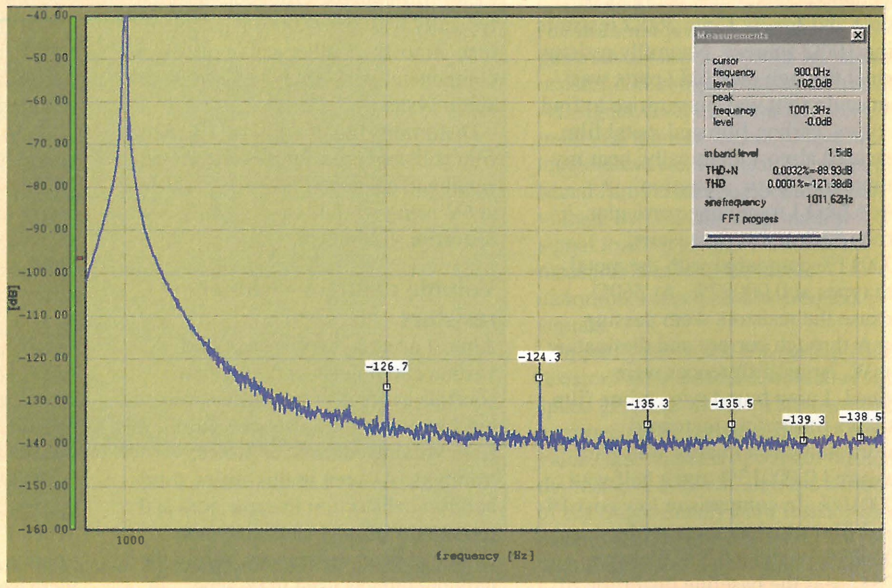


Fig 13. The Dr Jordan software, measuring a 511Ω resistor at 1V and 1kHz.

LETTERS to the editor

Letters to "Electronics World" Highbury Business Communications, Nexus House, Azalea Drive, Swanley, Kent, BR8 8HU
e-mail EWletters@highburybiz.com using subject heading 'Letters'.

Defence of Mr. Miller continued

I would like to clarify my June 2003 letter regarding Miller compensation, in light of Mr. Graham Maynard's and Mr. John Ellis's responses to said matter.

Mr. Maynard noted that Mr. Ellis published graphs of 2mV spikes for the PLIL case verses 25mV spikes for the Miller compensated case and suggested that I was unaware of such graph. Fortunately, I had not had any Guinness that day, so this suggestion is somewhat strained. He then made an elementary explanation as to why such behaviour might, for those unskilled in such matters, result in degraded audible performance. Indeed, this was despite the fact that, by his own admission, he also suggested that such spikes would not have been measurable in a THD distortion test set-up. I certainly agree that 25mV is much larger than 2mV, however, I am unaware of any convincing or credible evidence that such microsecond width spikes would actually be audible, despite being visible on a scope. This is a view often held by the "golden ears brigade" which, arguable, is in an effort to extract rather large quantities of cash from the uninitiated.

Mr. Maynard also made an assertion that I considered Miller compensation "essential". It would appear that Mr. Maynard may have been on the Guinness himself whilst reading said article. I made no such claim. There are indeed, other very well known and very well used alternatives to miller compensation. For example, a common technique in current feedback amplifiers[1] is to compensate by one capacitor from the high impedance gain stage output to AC ground.

Mr. Maynard also pointed out that he failed to notice the ambiguity in the simulation graphs. This will, hopefully be rectified by the following. It was, and is still, not clear as to the exact method as to how the graphs were made. As I noted, it is important to break the loop in the correct place. It is quite common for the inexperienced to perform loop analysis incorrectly, as a correct loop analysis is not necessarily trivial. For example Dr. Middlebrook[2] has studied this issue extensively. In summary, it can be quite difficult to break the loop without ensuring the correct loading on each side if the loop. There may be significant interactions. In addition, Mr. Ellis article did not specify exactly were the loop was broken, which can be quite crucial. The exact details of the loop gain measurement need to be specified in order to make any conclusions as to the validity to the results.

To continue, I certainly agree with Mr. Maynard that there are many without the experience to competently design amplifiers and may well use Miller compensation incorrectly. However, there are also many experts who have no such problem. In addition, there are also those that are prone to use such terms as "high amplitude transparency" intermixed with various Star Trek technical terms in an effort to mislead or obscure the real issues, or because that do not actually understand the real significance of these terms themselves.

Regarding Mr. Maynard's query on the *MOSFET 1000* amplifier, which was, of course, and no surprise here I would gather, designed by myself. It used a trivial Miller compensation scheme utilising a mere 8 transistors for the complete driver design, excluding the output power mosfets. It achieved <0.005% THD at 20kHz at 8 Ohms. The only other compensation was the standard RC Zobel network and the standard parallel LR in series with the output.

I do agree with Mr. Maynard that some writers do indeed fail to consider many aspects of their subject matter. However, there are also those that have considerable experience, such that those with only a passing acquaintance often misunderstand the finer and more subtle points being presented by individuals who do have such experience. I also note that Mr Maynard is not acquainted with myself, further information may be obtained by reference to my AnaSoft Web Director entry in this magazine:-)

In reply to Mr. John Ellis's response, I certainly agree with Mr. Ellis regarding the assertion that some amplifiers may well have been designed rather poorly with regard to slew induced distortion. However, his arguments and technical rationale in his letter are very well known and completely understood by many, many, professional amplifier designers and have been so for many years, indeed going way back to the likes of J. Linsley Hood and Peter Baxendale, well known prior regulars to this magazine I might add. Mr. Ellis seems to be implying that all amplifier designers are not the full shilling. There is nothing new here at all. The reality is that this is a solved problem and a dead issue. As I suggested in my first letter, is relatively straightforward to design audibly perfect amplifiers with Miller compensation e.g. without the input overloading etc. Mr. Ellis appears to be comparing apples with oranges. That is, comparing a good PLIL amplifier, with a bad Miller compensated amplifier. Mr. Ellis also comments on the addition of a low pass filter to avoid slew limiting, so I will address this by noting that for reference, the *MOSFET 1000* had a full power bandwidth of 200kHz, did not require, and had no input filter.

Mr. Ellis then addresses my comments on the loop gain analysis. Unfortunately, he still fails to address the fundamental criticism. Exactly how was the graph obtained? Where was the loop broken? What steps were taken to ensure that loading effects were accounted for correctly? He appears to be suggesting "..by performing the subtraction..." that one can determine a valid loop gain plot from a suitable subtraction of the 1 from the closed loop plot, as seen from the input signal. This is a very well known error, and was one of the issues that was being addressed in my original letter. The gain determined from the signal input is simply not the same gain as that around the feedback path. It is quite common for these two gains to be significantly different, such that the signal input derived loop gain shows stability, when in fact, the real loop gain as seen by the feedback loop, shows, and is, unstable.

Mr. Ellis then goes on to point out that he considers that the article was objective. While there was a passing nod to impartiality, it appeared to present the case from the advantage of the PLIL point of view. Furthermore, I clearly quoted two statements by Mr. Ellis, that were indeed contradictory, that is, his claim that their was an "improvement in linearity" for the PLIL, yet his results, further supported in Mr. Ellis' own table in his reply to my letter, showed worse linearity.

In closing, Mr. Ellis' claim that competent Miller compensated amplifiers are not standard practice is ludicrous. Indeed they are, and have been for well over 20 years, probably 30. I would estimate that there are 1000's of amplifier designs out there with golden ear specifications, using Miller compensation. I would suggest that Mr. Ellis actually investigate what the facts actually are. His overall inferred implication that 100's of amplifier designers are clueless says much.

Kevin Aylward
Peterborough
UK

References:

1 "The current feedback myth"
2 Dr. Middlebrook, http://www.rdmiddlebrook.com/

Walt Disney University

Perhaps Brian Corbett would like to tell us just what he means by a 'Mickey Mouse' degree. Or is it just an all purpose term of denigration he has picked up from the press and politicians? Perhaps he means 'media studies' and the like. If he does then I suggest a bit of a re-think might be needed.

Media studies courses were developed at the old polytechnics more than twenty years ago. The people who undertook the early courses are now in their forties and fifties, and many have gone on to successful careers in broadcasting. That was the great strength of polytechnics and similar institutions. They could develop worthwhile vocational courses without being forced to call them degrees. Abolishing the polytechnics took away that option.

In England we have a very poor understanding of exactly what we mean by vocational courses. Studies in law, medicine or veterinary medicine are not seen as vocational and are acceptable to the chattering classes as worthy of being called degrees. Mathematics, physics, chemistry and biology will just about pass muster provided they are studied at a 'good' university. Studying engineering, electronics, computer science or applied anything, is a sure fire way to be seen as just about one step up from the 'drawers of water and hewers of wood'.

With this kind of snobbery around do we really need Brian Corbett casting around for someone to look down on?

Dr. Les May
Rochdale
Lancashire
UK

Wideband buffers

Many thanks to Dewald de Lange for his comprehensive article, 'Flat, wideband buffers' in *EW* October, 2003. He certainly clarified issues that have given me fits. If only I'd had this information 35 years ago when we all were building op-amps from bits and pieces!

Despite the continuing abundance of linear integrated circuits in a world gone digital, discretion is said to be the better part of valour, and often a design using discrete components has decided advantages over its monolithic counterpart. I would love to see more articles extolling the virtues of a simplistic approach to circuit design.

Jim Wood
California,
USA

Test failure

It appears that I would not be a likely recruit for C. Bateman & Co. I tried Cyril's cube-of-resistors puzzle (*Letters*, September 2003) and I must confess that it took me considerably longer than the required couple of minutes. To make myself feel better I showed it to three other engineers. Engineer 1 muttered something about having to see a man about a dog and departed. Engineer 2 rather irritatingly solved the problem in about five minutes. Some time later Engineer 3 alleged that I had been conceived out of wedlock and said that he would be able to do it with Kirchhoff's Laws and simultaneous equations but he hadn't the time. He reappeared the following morning with a solution similar to Engineer 2's. At this point, before hastily retreating, Engineer 1 asked what would happen if the resistors all had different values. I was able to work out the answer much quicker this time: the person who had posed the question would be in danger of having their own resistance determined by a mob armed with the electrician's Megger. (A clue for anyone still struggling: short together any points which are at the same potential.)

Pete Fry's letter remarked on school science lessons and reminded me of a question I used to ask sandwich-course students. I thought it would indicate their ability to apply theoretical knowledge to a practical situation. I got it from a MENSA magazine. (As you have probably guessed by now, the magazine was someone else's.) Suppose that two metal balls have an identical weight, diameter, and surface finish. One ball has a lead core surrounded by aluminium, and the other an aluminium core surrounded by lead. How does one tell which is which without damaging the balls? I had to abandon this question when my son completed his 'A' level courses in maths, further maths, and physics without having been taught about moments of inertia. A university lecturer told me that this is now quite normal. This seems to me to leave a gaping hole in students' understanding of a world which contains numerous rotating objects, and to be a bad thing for a nation which relies increasingly on its technical ability and inventiveness.

On one more topic, I found the article "The Cathode" interesting, particularly the bit about the forming process for oxide-coated cathodes.

PCB help wanted

I seek the help of readers who may be familiar with my problem. To design my double-sided PCB's, I use a homemade program that in the end generates two drawings in bit-map format. Then, via the commercial program Paint Shop Pro version 4, I can print the layout of the component side and the solder side of a double-sided PCB. To register one drawing with respect to the other, I use markings on the four corners of each drawing. On one drawing the markings are open squares and on the other the markings are solid squares that fit exactly into the open squares. To register the drawings I put them face to face and I found that the markings do not register. When I put the drawings together face to back, in the same fashion as they come out of the printer, the markings do register. It turned out that vertical lines are not printed perpendicular to horizontal lines. Blaming my old ink-jet printer, I took the bit-map files to a print shop to have them printed on a state-of-the-art laser printer. Their printouts however showed the same defect. I would be very much obliged if somebody can explain to me what causes this error.

Chris Schuur
Nuenen
The Netherlands

When I worked in T.V. servicing many years ago, the workshop had a box of tricks called a tube booster. This was sometimes able to rejuvenate cathodes which had lost their emission. If I remember rightly, the booster put an excessive current through the heater and a large positive voltage on the control grid. Presumably the effect was similar to the forming process, removing the oxygen from any residual oxide on the cathode and leaving exposed barium behind. I can't help wondering if the success rate would have been higher if the tube had been left for some time before being operated, so that the oxygen could be absorbed by the getter.

Hugh Mirams, G8UTW
By email

Dinosaurs and Crosstalk

R Harris makes serious errors in his letter "Dinosaurs" in the September issue of *EW*, p54.

Since in my June article I wrote; ".... coarse grain arrays made up of a small number of powerful processors have discredited rather than promoted large scale (fine grain) array processors," he should not have written about failure of Transputer (powerful) arrays discrediting my promotion of an array of one million processors, because I had already said so.

Harris's second error is to write within the paradigm of separation between management and technocracy, with the technocracy subservient. We have just spent half a century demonstrating that such an arrangement fails, and I have written books and articles about its failure; see my book *Computer Worship*, (pub. Pitman 1973), or my article 'The New Bureaucrac', *Wireless World* December 1982 at http://www.ivorcatt.com/31.htm , or indeed my June 2003 article, which Harris is supposed to be commenting on. Harris, willy-nilly, writes as if it will always be thus; ".... make the transition to management ....; technical side of the fence ....". The error some technocrats make is to assume, in their ignorance, that management is a challenge. Compared with hi-tec activity, it is trivial, as I know from experience. Hi-tec activity contains within it all the challenges of management, so that the challenge of management is a subset of the challenges posed by high technology. That is the reason for the nervous rearguard by management against hi-tec, and the incessant propaganda that Harris parrots, that technocrats would not be able to manage. The recent major case of such propaganda was to try to blame an engineer for the collapse of GEC after Weinstock had systematically rooted out GEC's technical (a middle managerial) infrastructure, so that it was bound to collapse when the cold war 'defence' scam disappeared. The journalists who blamed an engineer were not technocrats.

In his letter, "Design for EMC", *EW* Nov.03, p53/54, Ian Darney recommends his faulty article in the August 1998 issue and his earlier article in May '01, in both of which he in turn recommended certain faulty software to calculate crosstalk in digital systems. Unfortunately both Ian Darney and those who supply the software betrayed their lack of grasp of the subject in Figure 11 in Darney's Aug '98 article. The software output proves that he and they do not know that in the configuration shown, the crosstalk (noise) is flat topped, not the damped sine wave which they show. You can see this in the oscilloscope photographs I took of such cases and published in IEEE Trans. Comp. Dec. 1967. The whole industry has ignored my exciting discovery of the two modes of propagation and my rigorous proof, leading to simple graphs for reading off the maximum crosstalk amplitude for any configuration of printed circuit wires. These can now be found on the www via www.ivorcatt.com/34.htm.

As to "De-bounce II", the letter by Ronald Ogilvie on the same page, I have gone back to the letters etc. that he refers to. Certainly, Yong's circuit is nonsense. However, there is a second problem, which is 'The Glitch'. This hazard, also called 'synchroniser' or 'arbiter', has to be dealt with by circuitry which also solves de-bounce. In 1961, when I complained to a designer of the £5 million Ferranti Atlas Computer that it would crash because it lacked circuitry behind a mechanical switch to deal with the glitch, he replied that this did not matter because the computer was so unreliable anyway. Too get a feel for the money, my graduate salary was less than £1,000.

Later, I was the first to publish on 'The Glitch', see IEEE Trans. Com. Feb.1966, p108. Although the subject was and remains taboo, I published in the IEEE by giving it a misleading title. (Repeated in my self-published 1980 book *Digital Electronic Design vol. 2*, p281. Send large s.a.e. to me via *EW* for those 23 pages). It is also discussed in my book *Computer Worship*, p94, and was then picked up by the *Daily Telegraph*, 5 Feb.1974, "Computers sent mad by 'The Glitch'".

Later, Wormald claimed to have solved the insoluble problem of 'The Glitch', but he recanted when I went after him. His recantation, in IEEE Trans. Com. Oct 1979, ended; ".... Obviously the situation needs understanding by a much wider circle of the computing fraternity than the small proportion of engineers who have been concerned so far." Since then, the problem has been ignored/suppressed for a further quarter century, so that computers can continue to crash. Chris Penfold was commissioned to write a play about the suppression, and wrote the script, but it was cancelled before shooting.

Ivor Catt
St Albans
Hertfordshire

Volks radio receivers - Germany 1930's

I read the *EW* August article on 'Radio Receivers of the Third Reich'. As I examined the schematic that was shown on page 17, I noticed how extremely primitive it is. This is one of the crudest receiver circuits that was commercially produced after 1929 (the year the superheterodyne came out in America). The Germans obviously intending to make a mass produced radio that was as cheap as possible , your article's propaganda about the Nazi censuring, notwithstanding. In any case I noticed that the output stage was directly connected to the speaker and that the power amp stage had a directly heated cathode , which combined would have made for a very noisy speaker - 50Hz tone from the AC line.

I was thinking, there was a method used in dynamic speakers called a 'hum-bucking coil'. This coil was wrapped around the field coil of the speaker. The hum from the speaker would induce a counter-EMF in the H-B coil and cancel out this 'waste noise'.

Could the Germans have used that in their radio receiver sets to nullify the 50 cycle power line hum from the lousy circuitry they used ? ? ?

Chad Castagana
Woodland Hills
California
USA

Fluorescent Starter

October's *Circuit Ideas* on 'Fluorescent Starter Circuit' reminded me of working on lamp dimming circuits in the 1960s. We found that it was necessary to keep the heaters alive and used a double secondary transformer to heat the two cathodes and so dispensed with the starter. I seem to remember 9 volts but I have been using 6.3 volts in several fittings at home for over 30 years. These have given me nearly instant starting without flicker and usually the light gets too poor before the tube fails completely. Dimming circuits work well but must have a flywheel action to cope with the back EMF from the choke otherwise the dimming range is poor.

Albert Lardeur
Chaldon
Surrey
UK

Cyril's quiz answer

The answer to my quiz is all too simple provided you spot the importance of the circuit's symmetry. This is made easier by assigning resistor and junction node numbers, as in the amended figure.

Starting from point A, we have three same value resistors, each connecting to a pair of resistors of the same value, shown as junctions 2, 3, 4. One resistor of each pair then connects to one of the three resistors which lead out through point B, shown as junctions 5, 6, 7.

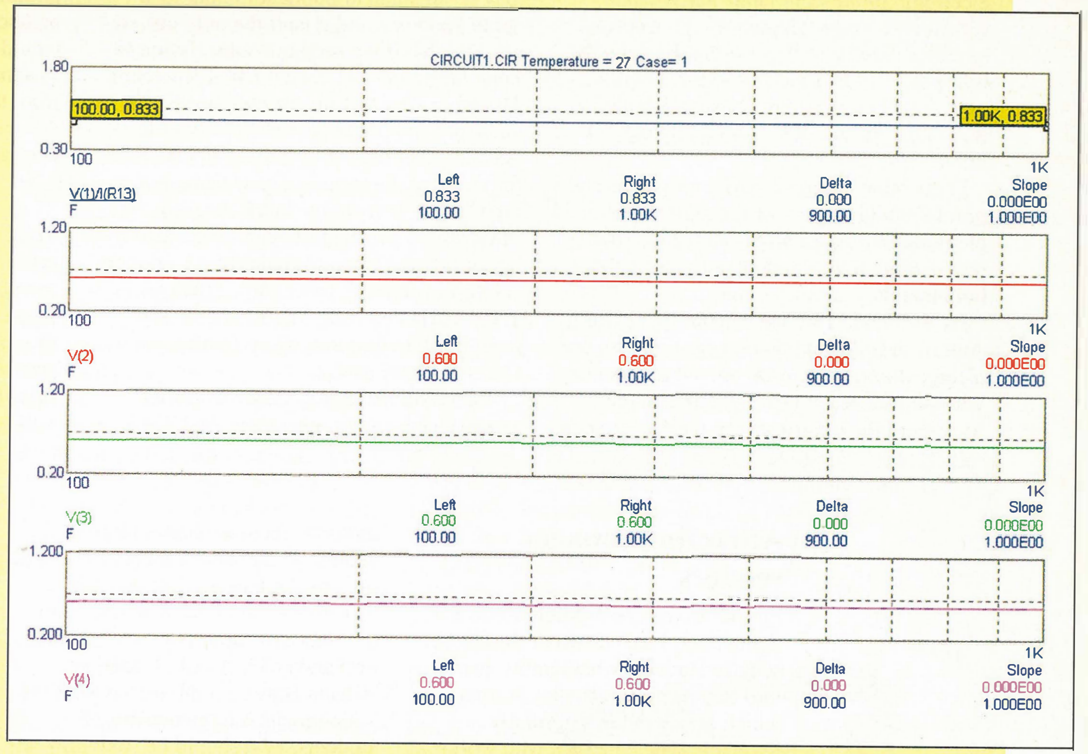
Hence each of the junctions 2, 3, 4, sees the same source and load currents, so these three junctions are equipotential points. In similar fashion, junctions 5, 6, 7 are also a set of three equipotential points, but have a different voltage from the first set. Hence we can short junctions 2, 3, and 4 together without any current flowing in the short. Likewise junctions 5, 6, and 7.

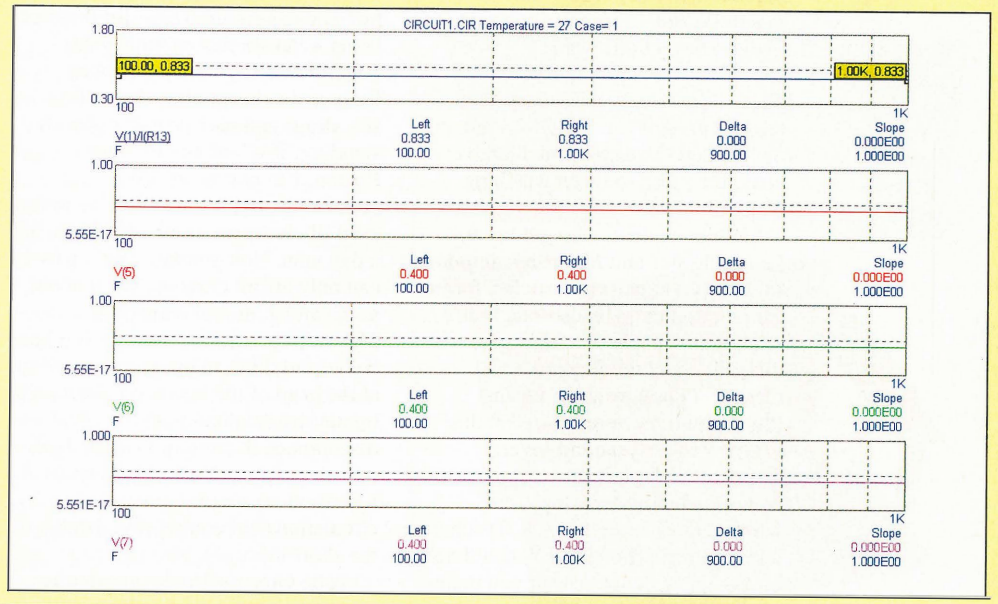
Equipotential points can be inter-connected without contravening the 'Kirchoff' law as in the rearranged figure. Hence by inspection we have 1/3 + 1/6 + 1/3 = 5/6 or 0.833 Ohms which is the answer.

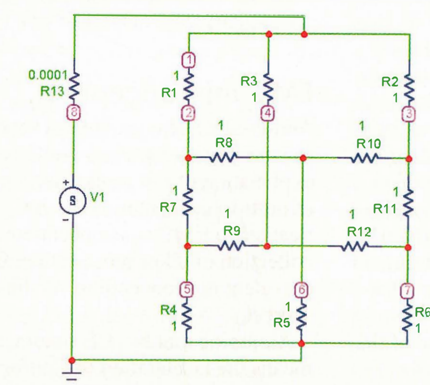
If proof is needed, a Spice simulation can be made by adding a very small current sensing resistor R13, 0.0001 Ohms, as shown in the schematic which also clearly shows the above symmetry and node junctions, this R13 is much too small to affect the calculated values.

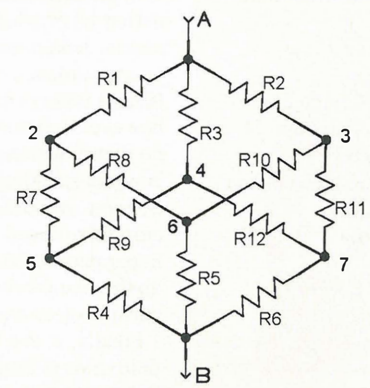
I have also attached MC6 simulations showing the overall circuit resistance of the original figure as 0.833 Ohms and two groups of equipotential points at 0.6V and 0.4V, using a 1V signal as stimulus.

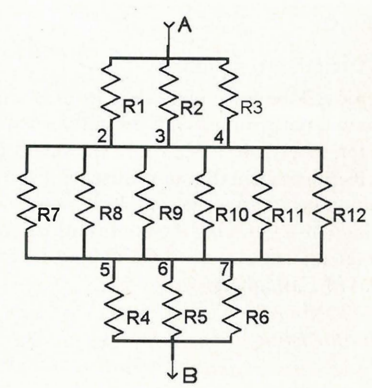
Cyril Bateman
Acle
Norfolk
UK.











US rant

In October *Circuit Ideas* featured a little electronic fluorescent lamp starter from contributor Henry Maidment. It's a cute circuit. I assume in the text that P3 actually refers to R3. I assume that in the diagram, one of the two different resistors labelled R1 is also, in fact, R3 — probably the 15k item.

I know that editing contributor pieces and proof reading are two of the least pleasurable tasks in all of publishing, but please remind the residents of your galley-hold that they are important.

By the way... I'm one of your loyal North American followers. Each year I remind our technical library to re-up our subscription to your journal. Each year I get a message back from the library saying the *Electronics World* is an amateur publication, and a British one at that. In response I send off one of two saved emails. One says that *EW* may be an amateur publication, but its a damn good one and it isn't the only one we get, and that if we keep our subscription to *Time Magazine* and cancel *EW*, I'll scream. The other says that the articles on RF and audio are so relevant to our field (wireless telecom) that the subscription has real value for many of the technical staff here. And as far as being British, the last I checked Maxwell's Laws hadn't been overturned by our Supreme Court, so aside from having to convert everything from 240V 50Hz to 120V 60Hz and from Mains to Line and from Earth to Ground, we're finding your material pretty useful.

Two wish list items... Your amplifier articles have taught me a great deal. I'd love to see a high performance utility audio amplifier design built on a modern IC such as TDA7294. I'm fascinated by studio photoflash systems, such as the Broncolor or Ascorlight systems. Any chance you would publish a studio/lab strobe flash system showing how they work — perhaps from the same author who did the inverter design in your current number.

Richard W. Davis
USA

Your error spotting is absolutely correct – and I have no idea how the errors got through. In my (feeble) defence the text was OCR'd and the diagram was re-drawn, which is a bit unusual in is these paperless times. And I'd be pleased to hear from any potential authors on the subjects you mention.-Ed

Attracting younger readers

Further to the correspondence in *EW* September, I asked two of my former science students what tempts them into buying an electronics journal, which they wouldn't normally purchase. One, aged 35, who works in a radio and TV repair shop said without hesitation, "free software...with 14 day delete." Nestlé is currently offering a free music mixing PC CD ROM, – but not the Golden Grahams, which are very tasty, the more so when watching baseball.

Another student, who got his A-Level Physics and Maths result today, said "bits and pieces...articles, for/on car electronics". He also said that "the Maths (paper 3) was very difficult...and the Physics a bit messy." I know what he means! Physics entries were down 3% this year w.r.t. last year and several, different explanations were given in News media this evening – but, whatever? The trend is real. Teachers and lecturers who read *EW* could help by asking students to send you their views and interests and what might motivate them to choose physics against an increasing range of options. Otherwise, UK physics is headed for the minor leagues! I saw the 'unassist triple-play' by Furchal on Sunday TV 5 (S.L. Cards' vs. Atlanta Braves) – the first since 1984 – along with a large number of students, who should be studying – a ha? The exams are over – for the time being – but studies recommence Sept./Oct. along with ice-hockey, footy and a dozen other distractions – sex, drugs and rock & roll, not with standing. If it's of any interest, Pigeon; I'm not on any GP medication, at present; and I've never used illicit drugs; or inhaled. Fags, 63 a day man. Non-smoker, that's why I can only afford crayons. What about you?; and your real name (*EW*, March, page 23, 'No bottle'). It might be helpful, Phil, to put your advice up at the head of the letters columns on a regular basis, along with the usual disclaimers, that many journals find necessary – for obvious reasons. Libel actions might increase circulations but could prove fatal in the short-term.

Leslie Green's article on calculus was excellent and indicative perhaps?, of what should form a regular feature in *EW* intended for young students. Non-linear dynamics (Chaos theory) must be included, however, because of its universality – no theory which avoids non-linearity is worth spending too much time on. Sohiton waves, for example, are currently treated using NLPE (Non-linear partial differential equations) in dissipative processes, which are the norm in electronic systems.

Finally, at last there is an end of the field theory! Professor Jacob Bekenstein has stated[1] that "field theory must give way to a theory that restricts the number of degrees of freedom" such as an 'information gathering and utilizing holographic universe(s?)', which Everett, deWitt, Gell-Mann and Hartle, Bohm et al have proposed since about 1970. Bohm and Hiley[2] also suggested that Everett's model should really be seen as a "many-minds interpretation" rather than a 'many-words model'. Support for the mind-model is given in a superb paper by Professor William tiller and Dr. Watter E. Tibble Jr.[3], kindly sent me by Dr. Giovanni Orlando, who is co-operating in their research. Hopefully *EW* readers will be able to see details of their methods and findings at an early opportunity!

Tony and Jadwiga Callegari
(Ages; 63 and 57)
Much Hadham
Hertfordshire
UK

References

1.*Scientific American*, August 2003, p55 'Revolution'.
2.*The Undivided Universe*, D.Bohm, B.J. Hiley.
3.*Mat. Res. Innovat* (2003) 5; 21-34, W.A. Tiller, W.E. Pibble Jr.

Detention Green

I enjoyed the article and tests from Leslie Green. There are two typographical errors in the answers on Page 51 (September 2003). Slew rate should be 26.67 volts/microsecond - not millisecond and the mean power should be 25.75 watts not ohms!

I am also enjoying the contributions from Cyril Bateman and the ever-lively letters pages.

David Callaghan
Watford
Hertfordshire
UK

EMC misconception

Andrew Denham provides a service to your younger readers with his explanation of the centimetre and jar as units of capacitance. But his treatise on EMC is a concentrated collection of all or most of the over - prevalent misconceptions on this subject.

Assuming that by 'CE statement' he means the Declaration of Conformity, there is no scope at all for any 'carefully-worded paragraph'. The DoC is a bald statement that the equipment conforms to the relevant, named, standards.

Next, he refers to the application of tests being 'selective', as if that is not good, but then inverts his position in saying that a kettle has to be tested for all sorts of irrelevant phenomena. It doesn't: it is an established ruling that irrelevant testing is not required. In fact, no actual testing at all is demanded: all that is necessary legally is that the DoC is true.

The torch example is another in the same line as above: a simple torch needs no EMC assessment, let alone testing, and doesn't legally need a CE mark, although many manufacturers apply one so as to prevent questions as to why there isn't one, from people like Mr. Denham, who sound off from a position of not knowing the facts.

However, the torch with an inverter definitely *does* need to be assessed, and probably tested for emissions only, since it's unlikely that the applicable immunity test levels would produce any unfavourable effect. The decisions about testing are the 'responsibility' of the manufacturer, but there is plenty of advice available, some of it even free.

The text about detachable mains leads is utterly ludicrous. The product *has* to have a mains lead attached while it is being tested, so any effects due to that lead *are* included in the test results. Any CE marking on a mains lead substantially refers to the Low Voltage Directive, not the EMC Directive.

The passage on plug-top power supplies is equally surreal. If a product is sold with its power supply, they are assessed and tested together. If a product is sold without a plug-top power supply, but one can be attached, it is assessed and tested with a representative power supply. In any case, non-switching plug-top supplies are CE marked for electrical safety rather than EMC.

True to form, Mr. Denham trots out the 'faceless men in Brussels' cliché. In fact, the EMC and safety standards are written by practising engineers (me, for instance) from manufacturing industry, the electricity suppliers and academia. There are no people from the Commission involved, except an EMC expert who spent most of his career in industry and now has an advisory rôle.

If it were true that industry, left to itself, always made products 'with minimal interference radiation and absorption problems' Mr. Denham and his confrères would have no trouble in meeting the EMC requirements, so his protests would be without foundation. It's precisely because it's not easy to design and manufacture such products that testing, self-certification and regulation are necessary.

The idea that individual consumers have an effective part to play in EMC regulation is not entirely unrealistic. It is, for example, a justification for no test for immunity to electrostatic discharges (ESD) appearing in the EMC immunity standard for television receivers, EN55020. If a receiver were marketed that had poor ESD immunity, the return rate under guarantee would demonstrate to the manufacturer the error of his ways. But this reasoning doesn't apply to radiated or conducted emissions, which affect other equipment, not the receiver that is the source.

John Woodgate

Oh, 'O'

May I point out a small typo on P52 of the November issue? You print OC as though the 'O' was a letter of the alphabet. As you remember well the 0C series you will also remember such things as the 2A3, the 5U4, the 6V6, the12AT7, etc., and so will have an excellent opportunity to instruct the younger readers in what that '0' really meant.

J. I. Anderson
Edinburgh
Scotland
UK

Well, I stand corrected. All these years I've thought that the '0' (zero) was in fact the letter 'O'. I remember the 12AT7 etc. and also the ECC83, AF117 and the like and naturally assumed 'O' was 'O'. For readers that did not know (and I'm really hoping that I'm not alone here) the 0 (zero) prefix predates the common 'Pro-Electron' numbering system that was used for things like the AF117, AC128 and the ubiquitous BC108/9. It appears that the in the early numbering days, transistors were treated as valves with a zero heater voltage (as the first letter of any valve numbered under the UK system denoted its heater voltage and/or current) – hence the leading zero in 0C71. Thanks to the British Vintage Wireless Society web site for the answer. A full description of transistor numbering can be found at: www.bvws.org.uk/405alive/tech/valvenos6.html - Ed.

HELP WANTED

I have a Kikusui COS 6100M oscilloscope with a dead tube: I'd like to obtain working tube or similar dead model with good tube or offer the scope to a good home.

Mike Law, bcd.audio@btinternet.com

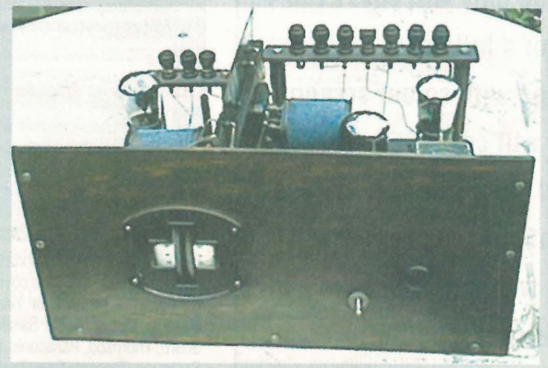
Old radios again

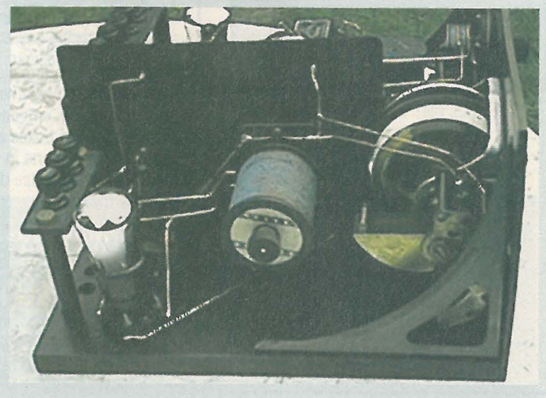
In the October EW, I asked for help in identifying an old radio – well I've finally got some pictures to jog readers' memories.

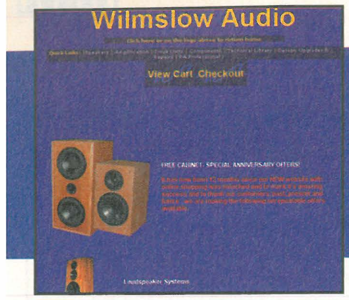
The set was a three valve TRF design with no identification marks apart from the component manufacturer's names and I would really like to know who made it and when. The receiver is built on a half inch thick wooden base board of side 12 x 14". It has an ebonite panel, 14 x 7", with four controls, i.e. LT switch, reaction and twin edge-wise tuning controls with scales marked 0 to 180.

I look forward to solving this mystery.

Chas F Fletcher. *G3DXZ*
g3dxz@thersgb.net







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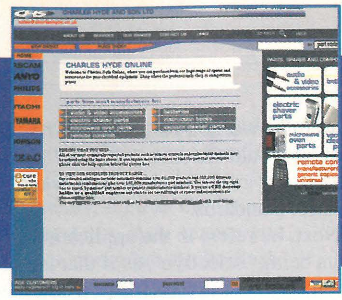

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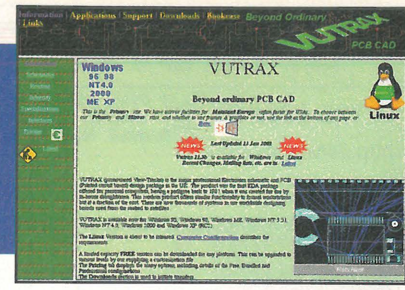

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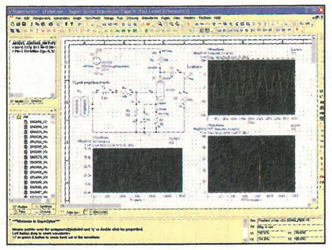

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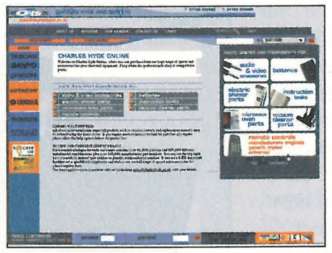

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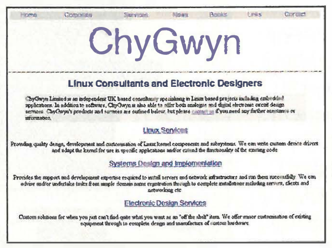

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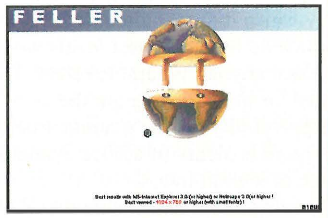

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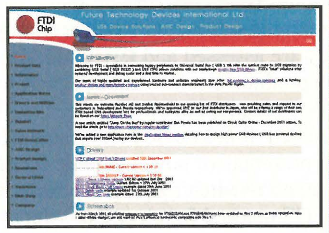

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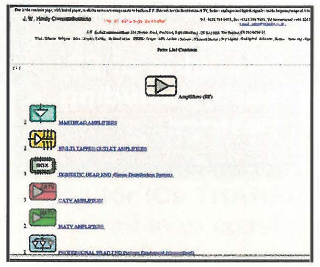

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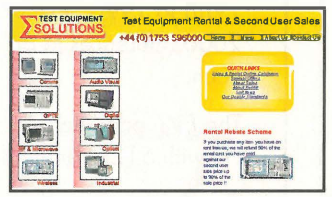

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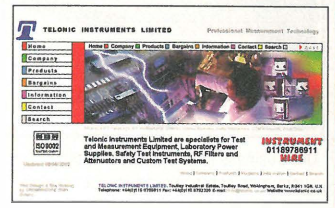

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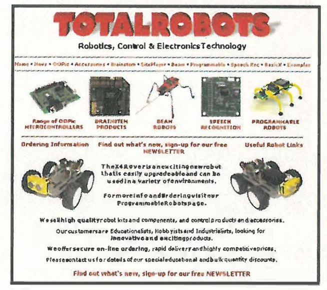

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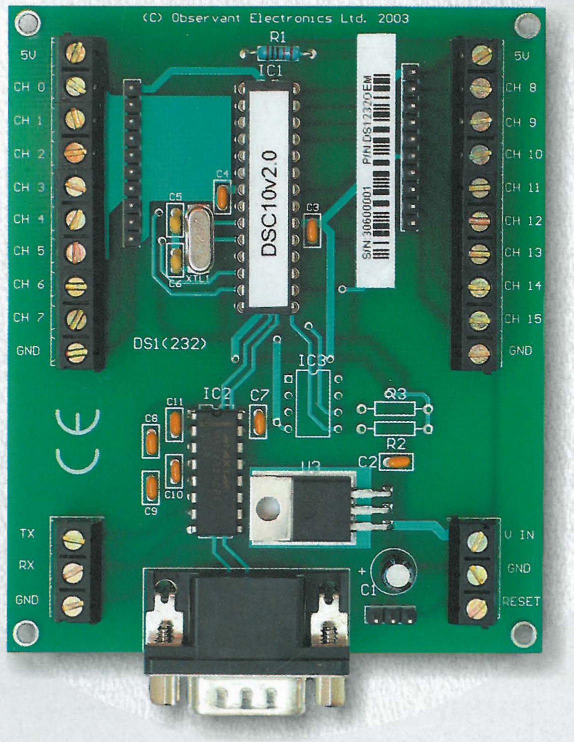

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