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<table>
<thead>
<tr>
<th>FLASH code ROM</th>
<th>8951</th>
<th>8952</th>
<th>1051</th>
<th>2051</th>
</tr>
</thead>
<tbody>
<tr>
<td>4K</td>
<td>8K</td>
<td>1K</td>
<td>2K</td>
<td></td>
</tr>
<tr>
<td>RAM</td>
<td>128</td>
<td>256</td>
<td>64</td>
<td>128</td>
</tr>
<tr>
<td>I/O</td>
<td>32</td>
<td>32</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Timer/Counter (16 bit)</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Serial Port</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Interrupt Sources</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Pins (DIL/PLCC)</td>
<td>40/44</td>
<td>40/44</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Special features</td>
<td>Timer 2</td>
<td>Comparator</td>
<td>Comparator</td>
<td></td>
</tr>
<tr>
<td>Price (1-24)</td>
<td>£14-85</td>
<td>£16-95</td>
<td>£4-70</td>
<td>£5-85</td>
</tr>
</tbody>
</table>

---

*Offer includes one AT89C1051, one AT89C2051 and one IC extractor tool.
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**CIRCLE NO. 101 ON REPLY CARD**
## CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>917</td>
<td>POWER-SAVING REGULATORS</td>
</tr>
<tr>
<td>918</td>
<td>REFLECTIONS ON OPTO-ELECTRONICS</td>
</tr>
<tr>
<td>922</td>
<td>INTERNET MODEM</td>
</tr>
<tr>
<td>922</td>
<td>INTERNET MODEM</td>
</tr>
<tr>
<td>930</td>
<td>A NEW DIRECTION IN MAGNETIC SENSING</td>
</tr>
<tr>
<td>938</td>
<td>CONTROLLING AUDIO DYNAMIC RANGE</td>
</tr>
<tr>
<td>952</td>
<td>SURROUND SOUND STANDARDS POLARISE</td>
</tr>
<tr>
<td>954</td>
<td>ISOLATING RS-232</td>
</tr>
<tr>
<td>960</td>
<td>DEEPER INTO DC ANALYSIS</td>
</tr>
<tr>
<td>964</td>
<td>MAXIMISING POWER TRANSFER IN CLASS-C</td>
</tr>
</tbody>
</table>

### Magnetic sensors offer
EW+WW readers can obtain 20% discount on a new three-terminal magnetic sensor capable of detecting down to 10nT. See pages 930 and 933.

### REGULARS

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>907</td>
<td>COMMENT</td>
</tr>
<tr>
<td>908</td>
<td>NEWS</td>
</tr>
<tr>
<td>912</td>
<td>RESEARCH NOTES</td>
</tr>
<tr>
<td>943</td>
<td>CIRCUIT IDEAS</td>
</tr>
<tr>
<td>956</td>
<td>LETTERS</td>
</tr>
<tr>
<td>983</td>
<td>NEW PRODUCTS</td>
</tr>
<tr>
<td>994</td>
<td>APPLICATIONS</td>
</tr>
</tbody>
</table>

### Next month:
Electronics in engine management, New thoughts on distortion, Interfacing GPS.

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"Moving from schematic to layout could not be easier" review of Quickroute 3.0 in Electronics World & Wireless World Jan 95

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PhoneDay fiasco

Responding to criticisms from BT and Mercury that he is accountable to nobody, Don Cruickshank, director-general of telecoms watchdog agency OFTEL, has belatedly admitted that his decisions would be better made by a committee and in public. This dramatic conversion comes too late, however, to reverse one of his department’s biggest mistakes — this year’s National Code Change.

Peripheral as this might sound to you, it’s not because you paid for it. You and other UK phone users shelled out £3,250 million in return for a change which did not even solve the most urgent problem — the imminent exhaustion of phone numbers in several UK cities (cost estimate courtesy of the Telecommunications Managers Association). Despite Don Cruickshank’s proud boasts on television of new numbers which would not change again in our lifetime, the likelihood is that we shall need new ones well before the end of the decade — let alone our lifespan.

According to Oftel’s consultative document, Numbering: Choices for the Future, the new code plan is a numbering scheme for the 21st century. Given that the European Telecommunications Office has not yet come to a decision on a pan-European numbering scheme, it would appear that our 1995 plan is already out of date. At this stage it is also difficult to predict the extent of the demand for location-independent numbers occasioned by personal numbering and UPT, the mixed wire-line and radio-based universal personal telecommunications service also known as ‘one person, one number’. All these require a total re-think of phone numbering, as will pressures for pan-European number harmonisation.

PhoneDay was a wasted opportunity therefore. Oftel deliberately chose to ignore specialist advice, while refusing to provide statistical information to experts who questioned its machinations. Subsequently the department came up with an even more ill-conceived scheme for adding new codes beginning with 02 and this time reaction was so negative — with operators like BT and Mercury distancing themselves from the plan — that Oftel had to think again. It is peculiarly coincidental that the architect of all these hair-brained schemes has been removed from the post of numbering-scheme manager. It is also notable that one of Oftel’s officers most responsible for pushing through the code change and who made several statements which have since been proved wrong left for another government department.

Phone users have just cause for grievance with this inelegant arrangement. Londoners have already suffered two code changes since 1990 and it looks highly likely that a third will be necessary well before the decade is out. Even more lamentable is the lack of consultation. For reasons of ‘commercial confidentiality’, Oftel will not reveal statistics on number distribution and utilization. The department also refuses to make available numbering allocations inside area code groups, except to network operators, making it impossible to validate its judgements and projections or for large users to plan new facilities.

Don Cruickshank’s offer to make Oftel more accountable is welcome but must be scrutinised.

Earlier this year powerful arguments were expressed for delaying the introduction of a new national numbering plan but Oftel took the view that “details of the new numbering scheme cannot be debated indefinitely.” Observers contend there was no debate at all and in the absence of an open forum or even a situation where all telecoms industry interests are represented, it is hard to suppress the feeling that Oftel has not served phone users well in manipulating what is a scarce national resource.

There are signs that a change of attitude in Oftel will now produce a more effective régime; this is to be welcomed but it will not recoup the wasted £3 billion.

Don Cruickshank’s decisions would be better made by a committee and in public

Back in 1992, the then chairman of TMA, Nick White, expressed the view: “The topic of telephone numbering and code changes does not attract widespread attention but the planned changes are widespread and will hit every customer’s pocket. Therefore any changes must be optimised by an expert planning and consultation process to minimise the cost of the changes to the customer and to deliver a solution that will last well into the next century.” It is as valid now as it was then.

Andrew Emmerson
Digital TV a bit nearer

Europe appears to be favouring a digital terrestrial TV scheme based on a 2000 carrier modulation scheme, increasing the likelihood that the UK will meet the challenge of employing a service by late 1997, as proposed by the recent government's white paper.

Last week's meeting of the European Digital Video Broadcasting (DVB) project addressing digital terrestrial television concluded with the setting up of three adhoc groups. The first group is to produce a document transferring the current 8000 carrier-QAM draft proposal to one based on 2000 carriers. The second group, comprising Deutsche Telekom and NTL, will independently appraise the offshoot 2000 carrier differential amplitude modulation scheme, 2000-DAPSK, while the third will investigate the feasibility of a scalable 2000-8000 system, allowing 8000 carrier transmissions to be decoded by a 2000-QAM receiver.

Bob Anderson, Motorola's consumer segment manager, commenting on the meeting's outcome, said: "In effect, the current system is coming nearer to being internationally adopted." Roy Rubenstein, Electronics Weekly

Canada goes for DAB

Europe's digital audio broadcasting (DAB) system, based on the Eureka 147 implementation, is a step closer to becoming an internationally adopted standard. Canada is to adopt the system following the BBC's decision to introduce a DAB service later this year in the Greater London area.

"It is the strongest and probably the most known system," said John Lee, manager for networks and technology at the Canadian Broadcasting Corporation. In the meantime the US is testing eight additional systems before it decides on a national standard. The nine systems provided with Eureka 147 uses the coded orthogonal frequency division multiplex modulation technique specifically designed for interference-resistant transmission by portable and mobile receivers.

"Eureka 147 does very well in audio quality and multipath tests. Others don't do well in multipath but do well in audio quality," said one EIA spokesperson.

Although the DAB service is favoured in many countries including Australia, Israel and China, high-volume production of DAB receivers, which should lower prices and sizes, has not begun yet.

Grundig currently manufactures 4000 to 6000 sets per annum, but hopes to increase volumes next year. Receivers are expected to be widely available to consumers by 1997.

Canada will provide a DAB service in the L-band (1452-1492MHz), whilst the UK will use the vhf band (217.5-230MHz).

Svetlana Josifovska, EW

Standards delay video disk

The launch of digital video discs -- DVDs -- is to be delayed following the recent agreement of a common standard by the two opposing alliances led by Toshiba and Sony/Philips respectively.

The Super Density -- SD -- alliance, led by Toshiba, had originally scheduled the launch of its format for June 1996, but due to necessary design changes, incurred by the newly adopted standard, this launch will be postponed by at least three months. Nevertheless, DVDs are expected to soon start raising revenues for the consumer electronics industry. The impact will be even greater with the arrival of other consumer electronics systems, such as high-resolution widescreen tvs, audio speakers and amplifiers which will support Dolby AC3 discrete five-channel soundtracks, that DVDs will spur.

The 'new' DVD format will incorporate the best features from both the Super Density CD and Multimedia CD. It will be a two-side, double-layer CD with a substrate thickness of 0.6mm and capacity of 4.7Gbyte per layer giving 18.8Gbytes per disc. Signal modulation will be based on the efm Plus technique adopted from Multimedia CD technology, and will use Reed-Solomon error correction.

Electronic Industries Association (EIA) for testing are AT&T's In-Band/Adjacent-Channel (IBAC), AT&T/Amati Communications Corporation's Inband/On-Channel (IBOC), Eureka 147's DAB system, one AM and two FM implementations of IBOC from USA Digital Radio, and AT&T/Amati Communications Corporation's Inband/On-Channel (IBOC), Eureka 147's DAB system, one AM and two FM implementations of IBOC from USA Digital Radio, and Voice of America/Detroit Laboratory's new-band/direct-broadcast satellite system.

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Svetlana Josifovska, EW

SD-18 Disc: Double Sided, Dual Layer = 18GB

Dual Focus Pick-up

Dual Layer

Double Sided

Dual Focus Pick-up

Typical applications: Two audio tracks per layer, dual享受 from the highest video storage capacity on one disc. This disc is ideal for feature films or larger character applications.
GI wants Pace

Sources close to General Instrument (GI) have confirmed it is targeting UK satellite and cable receiver maker Pace Micro Technology in a takeover bid. Talks are taking place and GI is confident a deal will be struck this week.

GI, which is one of the largest American cable television equipment suppliers, sees an opportunity to capitalise on Pace’s strong presence in digital TV decoders. There was no official comment from GI’s corporate headquarters in Chicago.

A deal had been expected sooner but the two firms have had difficulties agreeing a price. GI believes Pace leaked details of the talks in a bid to boost the value of the company. Reports indicate the wrangling centres on a price of £120m.

GI has pushed its alternative DigiCipher II digital compression system but has lost out to the MPEG-2 scheme as broadcast standards have been finalised.

GI has pushed its alternative DigiCipher II digital compression system but has lost out to the MPEG-2 scheme as broadcast standards have been finalised. Pace started eleven years ago by selling modems from one of the founder’s bedrooms. Last month Pace sold its modem manufacturing business to its management team for £3m. Pace wished to concentrate on its digital TV business although the modem company, Pace Micro Communications continues to operate from the Saltaire site.

New light on optical switching

Optical routers with femtosecond switching speeds are the goal of research by Hitachi and Cavendish Laboratories, in Cambridge. The pioneering work uses delayed, short duration, light pulses to improve optical semiconductor switching characteristics by over three orders of magnitude.

Optical switches use light to control the conducting state of the semiconductor material. “This interaction of light creates electrons and holes which exist in the material for up to a nanosecond until recombining naturally,” said Dr Jeremy Allam, the project’s group leader. It is this duration that limits the switching speed since the material’s state cannot be changed until the carriers recombine.

The task employed by the group is to follow the controlling light pulse with a carefully delayed, second one. This accelerates the overall recombination rate, even though the delayed pulse introduces yet further electrons and holes.

“The idea’s novelty is in exploiting the phase of electrons. Electrons and holes remember for some 10ps the oscillations generated by the light field. By synchronising the second light pulse, destructive interference results,” said Dr Jeremy Baumberg, a researcher at Hitachi Cambridge Lab.

Applying this technique at 4K (−269°C), up to 70% of the carriers recombine within 100fs. The reason why a percentage of the electrons still remain is unclear.

Dr Baumberg believes that the achieved performance can be demonstrated at 70K. Using quantum dot semiconductor structures, the operating temperature is likely to be pushed up further still. Moreover, by implementing delayed light pulses on a chip’s surface, greater robustness to vibration and thermal drift is expected.

Roy Rubenstein, EW

Siemens has produced a new detection system for the front-passerenger airbag. It improves the safety of children placed in rear-facing child seats. The system only triggers if a person is sitting in the front passenger seat. If a child seat is mounted on the seat, occupied or not, triggering of the airbag is prevented. Required signals come from a pressure-sensitive force-sensing resistor foil responding to a pressure of 12kg or more.

Three-fold increase in optical switching speed – bringing switching capability to femtosecond levels – could be possible thanks to research by Hitachi and Cavendish Laboratories.
2.5THz receiver is a stage nearer commercial application

A team at the Rutherford Appleton Laboratories claims to have made the first waveguide based radio receiver to work at 2.5THz. Other receivers have been made that work at this frequency but these have been based on less robust structures that do not have well defined directional characteristics.

The receiver is based around a Schottky diode mixer and a tiny horn antenna which are connected by a waveguide only 100µm wide by 25µm high.

The horn and waveguide are made by electro-forming. Fabrication begins with a ‘former’ that is machined to be the same shape as the desired interior of the horn and waveguide.

This is thickly electroplated, then the former is dissolved leaving the complete electroformed antenna.

The finished assembly is 3mm long and is held above the chip containing the Schottky diode.

A far-infrared laser is used as a local oscillator for the receiver. The laser output is directed onto the diode which mixes the optical and incident Radio-frequency energy down to more ‘conventional’ frequencies.

The receiver is not just a scientific curiosity. It has been developed to detect decimillimetric radiation from molecules in the atmosphere as a way of assessing pollution levels and ozone depletion.

Another mixer, based on a superconducting tunnel junction, can be used to raise the signal to noise ratio at the expense of a 1THz maximum frequency.

Mobile phone chip-count reduced

Analog Devices will introduce one of the most highly integrated GSM mobile phone designs next year with the appearance of its two-chip baseband chipset.

The company is currently selling the AD20nsp410 three-chip GSM baseband design, but according to Jurgen Krogh, marketing director for wireless communications products, a two-chip design will be introduced in the first quarter of 1996.

"Within four to five months the 410 design will move to two chips," said Krogh. The new chipset, to be called the AD20nsp415, will include the AD7015 baseband codec from the 410 chipset, and the speech and channel coders, as well as channel equaliser and H8 microcontroller.

In addition, Krogh said that Analog would have a two-device rf front end design which will be suitable for both 1.8GHz and 1.9GHz frequency rates.

Analog, which has developed a full software and hardware GSM reference model with UK developer the Technology Partnership, intends to support the proposed enhanced full rate speech coder design when approved by ETSI possibly next month.

Krogh, who believes that Nokia’s EFR proposal is the favoured design, admitted there would be a small premium on enhanced rate designs which improve speech quality, largely due to increased memory requirements.

Quieter digital cellular

Mobile phone technology developer Qualcomm has demonstrated a low noise rf front end for its CDMA digital cellular system using superconducting cryo-electronic technology.

The Californian pioneer of the CDMA – code division multiple access – radio protocol, which is competing with GSM-based systems in the US digital cellular market, used a cryo-electronic rf circuit developed by Superconducting Core Technologies (SCT) in a 2GHz PCS radio test. The company claims a 6dB improvement in the rf circuit noise figure.

Qualcomm used Colorado based SCT’s refrigerated cryo-electronic radio circuits in a basestation receiver which included narrowband, multipole filters made from superconducting materials, and a cryogenically-cooled low-noise input amplifier. High temperature superconducting circuits work above the 77K boiling point of nitrogen and so each basestation required its own refrigeration compressor.

The CDMA spread spectrum digital radio system relies on the sensitivity of the receiver much more than TDMA-based GSM systems. Because the CDMA radio signal is spread across the entire frequency band and not confined to narrow radio channels, it can be close to the noise floor of the receiver.

A 6dB improvement in the sensitivity of the basestation receiver, according to Qualcomm, will improve system performance in the presence of interference from reflected signals. Qualcomm, which is obviously aware of the competitive situation in the US digital cellular phone market, claimed that noise performance improvement could ultimately reduce the number of basestations required in PCS networks by up to 50 per cent.

Richard Wilson, Electronics Weekly

UK semi billings up...

UK semiconductor billings in August were significantly above the seasonal average and new orders also hit a record high in July for the first time, according to the SEMI’s Semiconductor Manufacturers’ Association.

There has been a prolonged period in which demand has exceeded supply," said SEMI statistician Malcolm House. "At present, this very strong demand cannot be satisfied due to capacity limitations.

"The full rate speech coder design when approved by ETSI will be called "The 410"," said Krogh. "It will be a low noise rf front end design which will be suitable for both 1.8GHz and 1.9GHz frequency rates."

Analog, which has developed a full software and hardware GSM reference model with UK developer the Technology Partnership, intends to support the proposed enhanced full rate speech coder design when approved by ETSI possibly next month.

Krogh, who believes that Nokia’s EFR proposal is the favoured design, admitted there would be a small premium on enhanced rate designs which improve speech quality, largely due to increased memory requirements.

...while US billings are down

The Semiconductor Industry Association’s barometer of the health of the chip industry, the book-to-bill ratio, fell in August but demand for semiconductors still remains high.

The August book-to-bill ratio was 1.18 compared with 1.23 in July. The SIA said that US chip makers shipped $3.88bn worth of chips in August compared with $3.78bn in July and $2.8bn for the same period last year.

New orders dropped by 1.3% in August to $4.5bn compared with July orders of $4.64bn. While the book-to-bill ratio was slightly down in August, the SIA says that chip demand remains high.

Record demand for chips has led to shortages, especially in PC related areas, which are not expected to ease until the first quarter next year.
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Sucking life into control technology

Better pumps and improved motor control systems for robots are the goals of research at Georgia Institute of Technology and Emory University—from work being carried out into leeches.

Neuromorphic analogue VLSI circuits—circuitry based on biological systems—have modelled the circulatory and swimming neurosystems of the leech. Previously, most neurosystem modelling with analogue VLSI has been in the area of sensory systems—for example, visual processing in the retina or auditory processing in the cochlea.

But little has been done with VLSI in modelling motor systems. Similarly, although many mathematicians and biologists are studying biological motor systems, few research groups are doing circuit modelling of them.

The Georgia and Emory workers picked on the leech because its swimming and circulatory control systems contain a fairly large but manageable number of neurons. This is important if researchers are to depict behaviour on both the cell and system levels, in real time.

The neurons are also part of reasonably regular, repetitive structures. The circuitry and connections in each segment are almost identical to those found in every other segment. Motor systems of the leech are also well known.

The leech’s movement is itself quite interesting. Each of 20 segments in the animal houses motor controllers for swimming, and the controllers work together to cause the leech body to move. The kind of oscillation they induce produces a constant phase lag.

“If you think of the position of the body as a big sine wave, each stage is a little bit out of phase of the one behind it. It’s just like a wave moving down the body,” says Steve DeWeerth, assistant professor in the School of Electrical and Computer Engineering at GeorgiaTech.

When leeches move faster, they keep the same phase, they just increase the frequency.

Solar drive will take Nasa into deep space...

Launch of a small Nasa spacecraft destined for a fly-by of an asteroid and a comet in 1998 will be the first to rely on solar electric propulsion for its main source of thrust, rather than conventional solid or liquid propellant-based systems.

Propulsion-related technology for the mission is currently under development by two separate programs run by Nasa and the US Air Force Ballistic Missile Defense Organization.

Thrust during the mission will be generated by one 300mm diameter ‘ion-drive’ thruster, which expels from the spacecraft a high-velocity beam of xenon gas that has been ionised using the electricity produced by solar arrays.

Ion-drive systems should be much more efficient than chemical propulsion systems, which typically require two or more chemical propellants for fuel and oxidiser.

Smaller versions of such thrusters have been used occasionally on Earth-orbiting satellites for adjusting spacecraft attitude or executing small orbit changes, but no space vehicle has yet employed solar electric propulsion as its primary means of thrust.

The idea has actually been around for some time, and the dramatic benefits of ion propulsion for a wide variety of deep space missions have been appreciated. But Nasa science mission managers have never felt that the technology was mature enough to be used.

But the 1998 craft, part of the New...
Millennium programme – will bring full-scale solar electric propulsion out of the lab and into space – once and for all.

The craft is also expected to test a variety of advanced technologies that may find their way onto ambitious deep space and Earth-orbiting missions planned by Nasa for next century.

For example, a miniaturised deep space antenna and related telecommunications equipment, advanced solar arrays and lithium ion spacecraft batteries, and low-mass spacecraft structures.

The instrument pay-load will include a miniaturised imaging spectrometer that will make chemical maps of the target asteroid and comet. New mission operations techniques are promised to give the spacecraft independent decision-making abilities – unprecedented for such a deep space mission.

“These technologies represent significant leaps over the existing state of the art for deep space vehicles,” says Kane Casani, New Millennium programme manager at the Jet Propulsion Laboratory. “We’ll have a very capable yet very advanced flight computer as well as a prototype multispectral science instrument that is at most a tenth of the mass of similar instruments on the Voyager probes. The autonomous navigation capabilities will deliver performance equivalent to sailing a ship across the Atlantic Ocean hands-free while arriving at the port in Europe a few steps away from the dock.”

Depending on the launch date, the primary asteroid and comet fly-by mission is expected to last 12 to 18 months.

...And up into the clouds:

A Nasa pilotless, remotely-controlled aircraft, using the Sun’s energy to fly to stratospheric altitudes, has achieved a milestone flight demonstration that could lead to better understanding of the upper atmosphere – and the effect of greenhouse gases on Earth’s environment.

Pathfinder is one of several pilotless prototype research vehicles under study by Nasa, and the flight at Nasa’s Dryden Flight Research Center was the first in a series of high altitude tests of the solar-powered aircraft, developed by AeroVironment.

During the near 12-hour mission, Pathfinder – controlled from a ground station – reached an altitude of 2385m, a new record for a solar-powered aircraft.

The all-wing aircraft, weighing less than 270kg, is being evaluated by a Nasa-industry alliance in a programme to develop technologies necessary to operate pilotless aircraft at altitudes of up to 4700m on environmental sampling missions lasting up to a week or more. Previous holder of the solar aircraft record of 660m was the Solar Challenger, also built by AeroVironment Inc. The company also developed the human-powered Gossamer Condor and Gossamer Albatross lightweight aircraft.

From Albert Hall to Albert Terrace

How would you like to experience your favourite music, at home, as though you were sitting in one of the best seats at the Royal Albert Hall. Or perhaps you’d like to travel a little further. How about putting your feet up at Carnegie Hall?

Such a venue choice could soon be possible if the work being carried out by Ducksoo Lee in the Image & Media Lab at LG Electronics, and Koengmo Sung, at the Department of Electronics Engineering at Seoul National University is taken up.

The two researchers have developed a sound field processor system designed to create the aural impression of a concert hall at home, using normal recording tapes or cds. Listening tests are reported to show an increased spatial awareness with the created sound – generally preferred to the original sound.

Researchers have experimented before with adding concert hall data into recordings but these have been limited by specialist hardware required. Other approaches have been to create reflections by placing a number of loudspeakers in the room. But most of the sound processing systems of this kind are based on single-point source models to create the reflections.

Digital signal processing technology needed to bring concert hall effects into your front room.
Lee and Sung propose ('Sound Field Processor for Creating Virtual Concert Hall Impression in the Home,' IEEE Transactions on Consumer Electronics, Vol 41, No 2, pp.273-281) an enhanced sound field processor system that makes optimal use of the two channel information contained in conventional stereo recordings, in a four-speaker system. Firstly, they obtained the reflection data of a real concert hall by ray tracing simulation with two sound sources to create the reflections originating from the left and right channel.

These data are then processed as 'panning' information, which will act to give the impression of the image source moving from speaker to speaker.

A digitally processed sound field processing unit creates the reflections and reverberation signal from the two channel input signal. Left and right input signals, digitised with a sampling frequency of 44.1kHz, are stored separately in the delay lines, then multiplied by gain coefficients to build up the sound, sample by sample. Panning signals from the front left/right channels are mixed with the direct sound, while only panned information is routed to the rear channels.

In the current system, the coefficients of several concert halls are stored, while room parameters such as initial time delay, size of hall and 'liveness' can be changed to alter the listening effect.

Obviously painstaking fine-tuning by a listener is still necessary to get that perfect concert hall effect in the front living room. But at least the drinks are cheaper...

### Optical gyro puts motorists on the map

Global positioning satellite technology, as the basis for navigation systems, is pretty popular at the moment. Unfortunately, for navigating a car, gps has certain serious shortcomings - it suffers signal blocking due to tall buildings, and its location results are really too noisy to identify a street.

But three Japanese researchers at Hitachi have demonstrated a practical automotive navigation system using a prototype optical gyroscope in combination with a map-matching algorithm, that offers a practical alternative to gps. It also addresses many of the problems associated with current gyroscope navigation. In particular, the researchers say electronics have been used to restrict the resolution and bias error of the gyroscope, while a microcomputer can compensate for the scale error due to the optics.

Basis of the system is the fibre ring interferometer. Laser light is split into two beams by the coupler then launched into the 300m fibre loop (10cm in dia) from different fibre ends so as to propagate in different directions. After circulating in the fibre loop, the two beams combine into an interference beam. According to the Sagnac effect, the two beams experience a different phase shift when the system is rotating, so a rotation-dependent change results in the interference pattern.

In a test, the researchers were able to show ("Optical Fiber Gyroscope for Automotive Navigation", IEEE Transactions on Vehicular Technology, Vol 44, No , pp.698-705) that a car containing the system could successfully track itself on a digitally-stored map. Run length was measured by a conventional speedometer and heading information was obtained from the gyro, constantly adjusted by the system so that the car's position matched up with a stored digital map.

A crucial test of the system was when the car turned into an area not detailed on the chart, effectively disappearing from the screen and being totally dependent on its sensors. The Hitachi team reports that when the vehicle did eventually turn into a mapped area, it once again appeared back on the map in precisely the right position.

### Mag-lev has profound effect on chips

Magnetic levitation technology, developed by MIT in the US, is being used to increase precision in integrated circuit production. The mag-lev technique, developed by David Trumper of the Department of Mechanical Engineering, offers the promise of extremely fast and accurate frictionless positioning of the silicon wafers on which integrated circuit chips are fabricated.

MIT has licensed the process to Integrated Solutions Inc (ISI), a developer of ultra-precise machines for semiconductor production, where it will be used in the design and manufacture of ISI's wafer stepper tool for printing integrated circuit patterns.

ISI engineers say they expect to be able to position stepper stages, on which wafers are photographically imaged, with accuracy measured at better than 10nm. Mag-lev technology will be used to replace the current fine set stage and long travel stages of a wafer stepper, capable of 200mm of travel, according to Larry Thomson of Integrated solutions. The MIT technology developments will be incorporated with a recently announced Crada (cooperative research and development agreement) for ISI to share mag-lev technology research results with Sandia National Laboratories.

Thomson says he has: "no doubt that this new mag-lev precision measurement and motion technology will have a profound effect on next generation semiconductor production equipment, such as wafer steppers, already under development."
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CIRCLE NO. 1118 ON REPLY CARD
Managing power

Dave Brotton and Dave Bradbury look at the design and application of energy-efficient power ICs.

What are some of the most important considerations for today’s modern systems? How efficient and how small can I make my product? This is particularly relevant to many battery powered systems.

While most IC manufacturers concentrate on ever more complex products the important area of power management is often overlooked. Advances in product requirements, for example, portable equipment such as mobile phones, demand smaller components which consume less power and extend battery life as much as possible.

Extending battery life

For power-sensitive applications, device quiescent current is important. Industry standard regulators – the LM78L and LM431 – commonly feature quiescent currents of 2mA and 400μA respectively. We have designed equivalents featuring quiescent currents of only 350pA and 35pA – representing a potential power saving of up to 11 times.

Elements of the ZR78L

Circuit design of the ZR78L three-terminal regulator, Fig. 1, is based on a bandgap reference, Tr1_5, which forms the core of the regulator. Closing the feedback loop around the reference is amplifier Tr6_9.

Output voltage of the regulator is programmed by tapping off from a resistor chain R13. The value of this resistor was chosen as high as possible to assist minimising the quiescent current of the circuit. The remainder of the device quiescent current is defined by the bias generator Tr11 to Tr15 which has been set as low as possible.

An important feature of the circuit is that its current is almost entirely determined by a VBE and a resistor. This means that it is largely independent of supply voltage leading to exceptional voltage regulation.

The final part of the circuit is formed by transistors Tr16_18 which operate as a thermal shutdown for the device. We find this device out-performs the typical competition in almost

Dave Brotton and Dave Bradbury are with Zetex

Fig. 1. Inside the ZR78L three-terminal regulator. The resistor ladder, for determining the output voltage during manufacture, is designed with as high values as possible to minimise quiescent current.

Fig. 2. Pinout of the ZR78L05C three-terminal, 5V regulator.
Table 1. Key specifications of the ZR78L05C

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>min.</th>
<th>typ.</th>
<th>max.</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{oc}$</td>
<td>output voltage</td>
<td>$I_{oc}=1$ to 200mA</td>
<td>4.875</td>
<td>5</td>
<td>5.125</td>
<td>V</td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>output current</td>
<td>$V_{oc}=7$ to 20V</td>
<td>4.8</td>
<td>5.2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{oc}$</td>
<td>line regulation</td>
<td>$I_{oc}=1$ to 200mA</td>
<td>0</td>
<td>10</td>
<td>40</td>
<td>mV</td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>load regulation</td>
<td>$V_{oc}=7$ to 20V</td>
<td>5</td>
<td>25</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>$V_{oc}$</td>
<td>quiescent current</td>
<td>$I_{oc}=1$ to 200mA</td>
<td>2</td>
<td>50</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>quiescent current</td>
<td>$V_{oc}=7$ to 20V</td>
<td>2</td>
<td>100</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>change</td>
<td>$f=10$ Hz to 10kHz</td>
<td>48</td>
<td>62</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>input voltage required to maintain regulation</td>
<td>$I_{oc}=5$ mA</td>
<td>7</td>
<td>6.7</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$I_{oc}$</td>
<td>average temperature coefficient of $V_{oc}$</td>
<td>$T_{j}=55$ to 125°C</td>
<td>0.1</td>
<td></td>
<td>mV/°C</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. A 7.2V rail from a 5V regulator. Since the maximum value for $R_2$ is governed by quiescent current and since a high value for $R_2$ is beneficial in terms of battery drain, a device with low quiescent current is desirable.

Fig. 5. In battery applications, where the generic 431 three-terminal shunt regulator may consume too much power, this high-performance alternative is useful. Its quiescent current is 50µA and the reference input current just 120mA.
pin of the device is not directly wired to the sense divider. Instead it has the led of an optocoupler in series which feeds error signals to the pulse width modulator of the power supply across the isolation barrier.

There are occasions when a reference with a large and closely defined temperature coefficients are required. It is vitally important that the specified terminal voltage of sealed lead-acid batteries is not exceeded during charging but ensuring this can be difficult due to large temperature dependence of the batteries voltage. By adding diodes with a known temperature coefficient to the reference input circuit of the ZR431, a reference with the same coefficients as the lead-acid batteries can be produced. Figure 7 shows a 6.9V reference which has a temperature coefficient of -1.7mV/°C, matching a three cell lead-acid battery pack terminal voltage temperature.

**Saving space**

Mechanical constraints in battery applications often mean that the circuits used should be as compact as possible. Traditionally, the ZR431 has been provided in a through hole TO92 package, however space saving requirements today are driving manufacturers to surface mount packages.

The commonest surface mount package for the industry standard LM431 has been SO8. Zetex part is available in the SOT23 package, which at just 3mm by 1.5mm offers a 75% saving in pcb space when compared to the alternative SO8. Not only that but just three connections are required to assemble the device onto the board.

Another feature of Zetex surface mount packaging capability comes into account where high dissipation may be expected but space saving is still important. Typically the LM78L standard devices have been made available for surface mount applications in the SO8 package. Thermal contrains for this package often limit the dissipation of the competitive parts. Zetex ZR78L series surface mount regulators can utilise the SOT223, 7mm by 4mm package, to utilise the SOT23, 7mm by 4mm package, to attain dissipation up to 2W perhaps three times the SO8 alternatives. This means you can use the regulators up to their 200mA load current limit with a wider range of input voltages not supported by alternative products.

**Low drop-out voltage**

Extension of battery life is all important to users of battery powered equipment. Of course quiescent current in the power management circuit is important here, but another consideration comes into play. As a battery runs down, so its output voltage falls. To ensure that the equipment continues to function as long as possible demands the battery regulator has the lowest possible dropout voltage.

Dropout voltage is the minimum input to output voltage differential required to maintain regulation. Our design approach produces regulators with exceptionally low dropout voltage - down to 35mV with 100mA load current.

**High-performance, low drop-out**

The Zetex low-drop-out device can be remotely shut down under direct low-power logic control. It also includes a low supply warning flag which goes valid when voltage across the regulator falls to below 300mV. At this differential voltage, the ZLDO still regulates correctly so the flag gives a warning of impending failure, not an alarm of failure occurring. This gives time for an orderly system shut down of battery powered microprocessor systems.

**Inside the low-drop-out regulator**

Critical to performance in this type of regulator is the pass device. Traditional linear regulators use an npn pass element - usually a darlington - to provide drive current. This results in an input to output voltage differential in the region 1.5 to 2V. Such a high voltage drop, at the level of drive current required, results in high dissipation.

Replacing the pass element with a pnp transistor reduces dropout voltage to the saturation voltage of the output device so greatly reducing the wasted dissipation in the regulator. Typically integrated output npn devices have given poor saturation voltages with hundreds of milliamps load current. In addition, relatively poor beta has resulted in high base current drive requirement and so high quiescent current.

In the configuration below, output device \( T_{f15} \) features very low saturation voltage - only 35mV at 100mA. The pass transistor also has a high beta, contributing minimally to the device total quiescent current of 600\( \mu \)A.

---

**Figure 7.** When charging a lead-acid cell, terminal voltage must not be exceeded. This circuit tracks the large change in terminal with temperature.
Following the success of 1994’s Writers Award, *Electronics World* and *Hewlett-Packard* are launching a new scheme to run from January to December 1995.

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November 1995  ELECTRONICS WORLD+WIRELESS WORLD  921
Phil Collins discusses the design of a 14.4kbit/s intelligent modem/fax card, ideal for Internet applications.

Highly integrated, Rockwell’s RC144 series of single device modem ICs handle data, fax and voice to 14,400 bits per second with few additional components. This design example shows how RC144 AT options develop into low-cost PC cards that are transparent in Internet applications and are capable of sustained data throughput of 57kbit/s.

Data compression and error correction facilities are integrated into the RC144 AT modem chips. The devices handles fax and data at rates of up to 14,400bits/s - i.e. V.32bis/V.17. In data mode - due to the integral compression and error correction facilities - it is possible to design a low cost, minimal-component modem capable of data throughput of up to 57,600kbit/s.

Figure 1 is a block diagram of the Internet modem for a parallel PC bus configuration. Alternative devices are available which allow a serial option Fig. 2.

RC144AC/AT modem family
From the basic RC144 device, there are twenty-four variants. One of the major options is serial or parallel interfacing. Further options are listed in Table 1.

While the table appears daunting, it is quickly explained. Suffix AT versions require the host computer to perform data compression and error correction for the modem. A package called WinRPI does this in Windows 3.1, Win95 already includes this software. Suffix AC versions use external static ram to enable them to perform the same error correction and compression. Another benefit of using the AC version is that MNP-10, the cellular data trans-

Specifications of the Internet modem design
- V.21 (300/300 bps)
- V.22 (75/1,200 bps)
- V.22 (1,200/1,200 bps)
- V.22bis (2,400/2,400 bps)
- V.32 (9,600/9,600 bps)
- V.32bis (14,400/14,400 bps)
- V.42 and MNP-2-4 error correction
- V.42bis and MNP-5 data compression
- Fax send & rec. to 144kbit/s (V.17)
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Fig. 2. Options of the RC144 fax/data modem chip allow interfacing to a pc COM port via a standard serial interface.

Table 1. There are twenty-four variants of the basic RC144 modem chip. One of the major options is serial or parallel interfacing.

<table>
<thead>
<tr>
<th>Model</th>
<th>ECC</th>
<th>Fax</th>
<th>Voice</th>
<th>US/World</th>
<th>RAM</th>
<th>ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC144ACFD-P</td>
<td>Built-in</td>
<td>No</td>
<td>No</td>
<td>US</td>
<td>32K</td>
<td>No</td>
</tr>
<tr>
<td>RC144ACF-P</td>
<td>Built-in</td>
<td>Yes</td>
<td>No</td>
<td>US</td>
<td>32K</td>
<td>No</td>
</tr>
<tr>
<td>RC144ACFW-P</td>
<td>Built-in</td>
<td>Yes</td>
<td>Yes</td>
<td>World</td>
<td>32K</td>
<td>128K or 8K</td>
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<tr>
<td>RC144ACFW-P</td>
<td>Built-in</td>
<td>Yes</td>
<td>Yes</td>
<td>World</td>
<td>32K</td>
<td>128K or 8K</td>
</tr>
<tr>
<td>RC144ATFD-P</td>
<td>Via host</td>
<td>No</td>
<td>No</td>
<td>US</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RC144ATFD-P</td>
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<td>No</td>
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Fig. 2. Options of the RC144 fax/data modem chip allow interfacing to a pc COM port via a standard serial interface.

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<td>RC144ACFW-P</td>
<td>Built-in</td>
<td>Yes</td>
<td>Yes</td>
<td>World</td>
<td>32K</td>
<td>128K or 8K</td>
</tr>
<tr>
<td>RC144ACFW-P</td>
<td>Built-in</td>
<td>Yes</td>
<td>Yes</td>
<td>World</td>
<td>32K</td>
<td>128K or 8K</td>
</tr>
<tr>
<td>RC144ATFD-P</td>
<td>Via host</td>
<td>No</td>
<td>No</td>
<td>US</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RC144ATFD-P</td>
<td>Via host</td>
<td>Yes</td>
<td>No</td>
<td>US</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RC144ATFW-P</td>
<td>Via host</td>
<td>Yes</td>
<td>Yes</td>
<td>US</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RC144ATFW-P</td>
<td>Via host</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>World</td>
<td>128K or 8K</td>
</tr>
<tr>
<td>RC144ATFW-P</td>
<td>Via host</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>World</td>
<td>128K or 8K</td>
</tr>
</tbody>
</table>

fer protocol is included.

Secondly, W versions are what Rockwell term 'world-class' products. This means that they can easily be configured for any country in the world, and be approved in that country. TDC provides Rockwell software called ConfigurAce which allows the various country parameters to be fine-tuned.

The use of 128K on-board rom allows multiple country selection to be performed, while 8K of rom provides only single country support. Normally, only 8K is used since the line interface needs to be changed for each country in a multiple-country version.

Versions suffixed RCV, for example the RCV144ACFW – add voice capability to the modem. There are extended AT commands which allow voice to be sampled and played back from the telephone line. With appropriate software – many fax packages include this facility – it is even possible to turn your pc into an answering machine. Voice mode also

Components for the Internet modem

Parts shown in bold type are required for the discrete line interface, and are not required when the Xecom DAA is used.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, L2, L3</td>
<td>IMO 41T70</td>
</tr>
<tr>
<td>R1</td>
<td>100R</td>
</tr>
<tr>
<td>R15</td>
<td>1k</td>
</tr>
<tr>
<td>R16</td>
<td>10R</td>
</tr>
<tr>
<td>R17</td>
<td>680R</td>
</tr>
<tr>
<td>R18</td>
<td>330R</td>
</tr>
<tr>
<td>R19</td>
<td>10k</td>
</tr>
<tr>
<td>R20</td>
<td>8k2</td>
</tr>
<tr>
<td>R21</td>
<td>1M</td>
</tr>
<tr>
<td>R22</td>
<td>56R</td>
</tr>
<tr>
<td>T1</td>
<td>116S</td>
</tr>
<tr>
<td>Tr1</td>
<td>BZB12</td>
</tr>
<tr>
<td>Tr2</td>
<td>ZVN305A</td>
</tr>
<tr>
<td>X1</td>
<td>35.2512MHz</td>
</tr>
<tr>
<td>XCOM,</td>
<td>Xecom XE0564SIP DAA</td>
</tr>
</tbody>
</table>

(Not needed for component line interface)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>18pF</td>
</tr>
<tr>
<td>C10</td>
<td>3.3nF</td>
</tr>
<tr>
<td>C11</td>
<td>10pF</td>
</tr>
<tr>
<td>C12</td>
<td>100nF</td>
</tr>
<tr>
<td>C13</td>
<td>100nF</td>
</tr>
<tr>
<td>C14</td>
<td>220µF</td>
</tr>
<tr>
<td>C15</td>
<td>22pF</td>
</tr>
<tr>
<td>C16</td>
<td>0.47µF</td>
</tr>
<tr>
<td>C17</td>
<td>10pF</td>
</tr>
<tr>
<td>C18</td>
<td>IN4148 NSC</td>
</tr>
<tr>
<td>C19</td>
<td>BZX79CV3</td>
</tr>
<tr>
<td>C20</td>
<td>BZX79C12</td>
</tr>
<tr>
<td>C21</td>
<td>IN4004</td>
</tr>
<tr>
<td>C22</td>
<td>AT27C010-70DC or AT27C64-70DC (70ns)</td>
</tr>
<tr>
<td>C23</td>
<td>RC144ACFW</td>
</tr>
<tr>
<td>C24</td>
<td>32 pin DIL 0.6in</td>
</tr>
<tr>
<td>C25</td>
<td>CD74HC7245E</td>
</tr>
<tr>
<td>C26</td>
<td>HY62256ALP70 (70ns)</td>
</tr>
<tr>
<td>C27</td>
<td>28 pin DIL 0.6in</td>
</tr>
<tr>
<td>C28</td>
<td>RC144ACFW</td>
</tr>
<tr>
<td>C29</td>
<td>68 pin PLCC</td>
</tr>
<tr>
<td>C30</td>
<td>TLC627</td>
</tr>
<tr>
<td>C31</td>
<td>4N35</td>
</tr>
<tr>
<td>C32</td>
<td>CD74HC704E</td>
</tr>
<tr>
<td>C33</td>
<td>ST24C02AB1</td>
</tr>
<tr>
<td>C34</td>
<td>PFC74HCT30P</td>
</tr>
<tr>
<td>J1</td>
<td>Jumper sockets</td>
</tr>
<tr>
<td>J2</td>
<td>3 way 0.1in pitch jumper connectors</td>
</tr>
</tbody>
</table>

November 1995 ELECTRONICS WORLD + WIRELESS WORLD 923
Complete 14.kbit/s fax/data modem for interfacing to the PC via an expansion slot. Due to integral data compression and error correction, the RC144 is capable of sustained data throughput of up to 57.6kbit/s.

NOTE: FOR XE0054P R10 = 638

C12 ONLY REQUIRED IF COMPLEX IMPEDANCE REQUIRED
817 ONLY REQUIRED IF TRANSISTOR GYRATOR USED

Some components will have the same number where used for either options.

RC144ACF
PARALLEL CARD

DRAWN
G. C.

CHECKED
APPROVED

DATE
25-8-95

ISSUE 5

NOTE: CIRCUIT HAS OPTIONS FOR GYRATOR TRANSISTOR OR FET,
DAA DISCREET OR ENCAPSULATED,
AUDIO AMP TRANSISTOR OR IC

SOME COMPONENTS WILL HAVE
THE SAME NUMBER WHERE USED
includes the ability to detect dual-tone multiple-frequency, or dtmf, tones allowing signalling and control to be performed from an ordinary telephone.

Versions with D in the part number are data only and do not include fax. The -P at the end of the part number indicates the chip is a parallel version for PC-card or PCMCIA designs. The alternative is -S, which specifies serial normally used in external desktop modems.

A board designed to take one particular parallel device will accept any of the devices with the -P suffix. This makes it possible to choose the feature set after the modem has been designed. Of course the same applies to the serial product family.

**Modem architecture**
As with all modems these chips comprise a number of basic building blocks.

**DTE interface.** This is usually either RS232 serial or parallel pc bus.

**Modem data pump.** The data pump is the heart of the modem. It is a fast digital signal processor which modulates and demodulates signals carried across the telephone line.

**Modem controller.** A microprocessor - the modem controller - handles the AT commands, data compression, line control etc. In this modem, both the data pump and controller are integrated into the one 68-pin PLCC package. Rockwell uses novel HyPAC technology which puts a number of different silicon die into a special leadframe providing the interconnects. This allows Rockwell to simply integrate the digital and analogue technologies into the one device.

**Table 2. The Internet modem card can be set for communication via any one of the four standard COM ports on the pc.**

<table>
<thead>
<tr>
<th>Port</th>
<th>Address High</th>
<th>Address Low</th>
<th><strong>COM1</strong></th>
<th>Address 3F8</th>
<th><strong>COM2</strong></th>
<th>Address 2F8</th>
<th><strong>COM3</strong></th>
<th>Address 3E8</th>
<th><strong>COM4</strong></th>
<th>Address 2E8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td></td>
<td>IRQ4</td>
<td>IRQ3</td>
<td>IRQ4</td>
<td>IRQ3</td>
<td>IRQ4</td>
<td>IRQ3</td>
<td>IRQ4</td>
<td>IRQ4</td>
<td>IRQ3</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. On the modem card, jumpers are provided for non-standard address and IRQ selections.**

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Function</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A4 address select</td>
<td>F</td>
<td>E</td>
</tr>
<tr>
<td>2</td>
<td>A8 address select</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>IRQ line selection</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>IRQ line selection</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>IRQ line selection</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

*Note that only one IRQ line should be selected at any one time.*

**Contacts and technical support**
TDC is the distributor for Rockwell and Xecom in the UK, and specialise in the supply of modern components to the communications industry. A manufacturing package is available from TDC which includes full documentation, and a disk with Gerber files, e-prom image etc. This package allows manufacture of this modem in volume at a minimum cost. Its price is £75 plus VAT and carriage. The 8K e-prom image for the UK is available free of charge on TDC's BBS, file name TDC144.HEX. TDC can also help with BABT approvals.

For readers wanting to produce small quantities or one-offs, Siskin Electronics, tel 01703 243400, can supply the pcbs, programmed e-proms and other parts.

Once you have the modem working, you can connect to Rockwell’s home page - http://www.nb.rockwell.com - to read about the latest developments in modem technology...You can even ask BaudMan - SuperHero of the SuperHighway - a question about modems.

The author can be contacted at TDC on 01256 332800, BBS 01256 57900, or via Compuserve on 100702,1162.

The RC144 contains three pieces of silicon, the DSP, controller and an integrated analogue device.

**Non-volatile ram.** Although not essential, this device is useful for storing frequently dialled telephone numbers and personalised configurations.

**Line interface.** This connects - and isolates - the modem to the telephone line. Most countries have different standards and connectors for telephone line connection, and of course it is illegal to connect a modem which is not approved for that country. The design here has not been approved for use in the UK, although it has been designed to be approvable.

You can choose between two types of line interface on the pcb - a discrete line interface made up of individual components (BABT approvable), or an encapsulated line interface manufactured by Xecom. The pre-built option replaces some 25 or so components - including the transformer and some special opto-isolators. The module provides all of the line isolation, ring detect and line hold functions.

**Designing a pc card modem**
The circuit is based upon a pc half-card design, and of course is dominated by the Rockwell chip. A 32K ram and 128K eeprom are provided for, with the latter being replaced by an 8K eeprom for the single country option.

The pc bus is a standard 8-bit ISA type, so should be compatible with most pcs. A 74HCT245 bi-directional buffer isolates the modem from the pc bus when it is not being accessed.

**The author can be contacted at TDC on 01256 332800, BBS 01256 57900, or via Compuserve on 100702,1162.**

---

**Table 4.**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>20Hz</th>
<th>200Hz</th>
<th>2kHz</th>
<th>20kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical hearing limits - 20Hz to 20kHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When communicating data over the public switched network, data rate is usually limited by the bandwidth of the telephone line, which is only designed to carry part of the voice spectrum. But data compression and error correction can provide significant benefits.
For communicating between the card and pc, the RC144 chip emulates a 16550 fast serial port. As a result, the modem appears as a COM port.

When setting up COM ports, it is important to be aware of COM ports already in use within the pc. If your pc already has COM1 and COM2, the natural selection is of course COM3. However, the standard setting for COM3 shares an interrupt with COM1, the outcome of which is an interrupt clash with some other device – usually causing lost data. It makes sense therefore to change the interrupt used from the default IRQ4 to, say, IRQ5.

Windows 3.1 allows you to set the new interrupt, but other packages may not. Check for these compatibility problems before suspecting something is wrong with the modem.

The modem incorporates expanded COM port setup facilities to allow for maximum flexibility. There are five jumpers on the board. Table 2 shows the standard dos configuration you should select for each port. The diagrams are shown with the edge connector facing down. Table 3 shows jumper functions for those who wish to use non-standard configurations.

The speaker allows for call progress monitoring. It has two drive circuit options. The lowest cost option is a single transistor amplifier using Tr2, R19 and R20. A link should be fitted in LK1 when using this option.

Better audio output is provided by using an LM386 amplifier, C14, R14, and C13. If no audio output is required, for example in an unmanned or embedded system, then these components can be left out.

Many more components are omitted when the Xecom DAA is used, but note that R10 needs to be changed to 6.8kΩ in this case.

Gaining approval

Although the modem described here is UK approvable, prospective manufacturers may wish to make use of a UK approval service offered by TDC. The modem can be approved and manufactured in your own name.

Those with experience of modem design will note the absence of a 2-to-4 wire hybrid. Remember that a telephone line is based on two wires, and both sides – transmit and receive – of a conversation take place simultaneously. For a modem to operate, the received signal needs to be isolated from the transmitted signal. In many modems this is performed externally using an op-amp, but on the Rockwell device, this circuitry is included.

A 24C02 non-volatile ram provides parameter storage for the modem. But if the modem is initialised every time by host software, this may not be required – again reducing cost.

This article is based on a Rockwell application note, a copy of which is available to modem designers from TDC.

### Key components for the 14.4kbit/s Internet modem described in the article on page 923 are available from Siskin for £49.95 excluding VAT. These components are the RC144 chip, a pcb, ready-programmed eproms and a technical manual. Note that the modem is based on the UK telephone standard. Please add £1.50 carriage with your order and make your postal order payable to Siskin Electronics. Credit card details should include type of card, card number and expiry date. Send the order to Siskin at Unit 1A, Hampton Lane, Blackfield, Nr Southampton, SO45 1WE, tel. 01703 243400, fax 01703 243500.

**Internet Modem – an Electronics World exclusive reader offer**

PC interfacing 14.4kbit/s modem includes error correction and compression to achieve sustained data throughput of 57kbit/s.
Elan E9D copier/programmer EPROM/EePROM editing and interface new boxed £110.00 c/p £16.00
Racal Dana 9301a R.F millivoltmeter true R.M.S.
AT&T Starlan 10 network hub model E
Astec SA 30-1306 +5 @2A +15 @1.8A -15 @.3A new boxed
Chessel 301 chart recorder
Switchcraft plug new qty discounts
Tektronix 7CT1N curve trace plug in
Tektronix 7A15A amp plug in£175.00 c/p £10.00
Tektronix 7853 dual time base plug in
HP 3551a Transmission test set
HP 7470a Plotter IEEE including interface cable
HP 1727a 275Mhz storage oscilloscope
Mains conditioner and UPS please ring
AT&T 60" graphics colour monitor terminal 25 pin D connector with keyboard
12" Mono VGA (paper white) chassis enclosed 240v
Sony 9" colour Trinitron KTM 1000ub data for RGB
NEC CMV 123ne 12" colour VGA/SVGA 800 x 600
Yuasa NP 10 6 6v 10ah sealed lead acid battery New
102 Key IBM compatible keyboard terminated to 6 pin mini-din type PS2 plug
68020 G compiler/assembler, originally developed to accompany
Motorolas 68020 and 68EG020 evaluation models
Our first C compiler/ossembler package
now supports floating point arithmetic
now supports level 2 source level debug output
to ease the path to full UK approval, Xecom Inc, line interfaces are the compact solution to PSTN connection. Other country versions are also available.

Digital Simultaneous Voice & Data
Operating at 28.8 kbps, DSVD is ideal for new and expanding markets like business presentations and interactive games - play and talk simultaneously on a single standard phone line!

SocketModems™
Rockwell SocketModems™ make integration of voice, data, and fax functionality a breeze. Connect with one of our BABT line interfaces for fastest time to market.
Radio Engineer's Pocket Book
by John Davies, 240pp, hardback
Order - ISBN 0 7506 1738 1
Price £12.99
Contains: Propagation; decibel scale; transmission lines; antennas; resonant circuits; oscillators; piezo-electric devices; bandwidth requirements and modulation; frequency planning; radio equipment; Microwave comms; information privacy and encryption; multiplexing; speech digitisation and synthesis; vhf and uhf mobile communication; signalling; channel occupancy, trunking; mobile systems; base station management; instruments; batteries; satellite comms; connectors and interfaces; broadcasting; abbreviations and symbols; tables and data; glossary.
Covers all aspects of radio and communications engineering from very low frequencies to microwaves, with particular emphasis on mobile communications. Wave principles and the decibel scale, instrumentation and power supplies, equipment types and encryption methods, connectors and interfaces, are all included in this book.

Audio Recording and Reproduction
Michael Talbot-Smith, 204pp, paperback
Order - 0 7506 1917 1
Price £12.99
Contains: Physics of sound waves; hearing; basic acoustics; microphones; loudspeakers; public address; stereo; simple mixing equipment; recorders; introduction to digital audio; music and sound effects; miscellaneous data.
This book gives a simple and straight-forward approach to audio techniques, detailing technical and practical information for those with no specific training in the subject.

Newnes Audio and Hi-Fi Handbook
by Ian Sinclair, 656pp, hardback
Order - ISBN 0 7506 0932 X
Price £60.00
Contains: Sound waves and acoustics; studio acoustics; microphones; sound synthesis; introduction to digital principles; compact disc technology; other digital systems - DAT, NICAM, DCC, MD - analogue tape recording; noise reduction systems; LP records; disc reproduction; tuners and radio receivers; preamps and inputs; voltage amplifiers/controls; loudspeakers and enclosures; Headphones; public address; in-car audio; interconnections; the future.
Covers a wide perspective of high-quality sound reproduction, including reproduction under adverse circumstances, from less conventional sources and with regard to the whole technology from studio to ear.

TV & Video Engineer's Reference Book
by Boris Townsend, 876pp, paperback
Order - ISBN 0 7506 1953 8
Price £40.00
Contains: Materials; components and construction; colour tv fundamentals; broadcast transmission; distributing broadband; DTS; tv studios; mobile and portable equipment; tv sound; tv receivers; servicing tvs; video recorders; teletext etc.; HDTV; other applications of tv; performance measurements.
Covers information on every aspect of modern broadcast technology. Of value to all practicing engineers and managers involved with broadcast, cable and satellite services.

Masts, Antennas and Service Planning
by Geoff Wiskin, 250pp, hardback
Order - ISBN 0 240 51336 3
Price £49.50
Contains: Antennas; antenna support structures; service planning.
Covers all aspects of information conveyance via radio-wave transmission. Invaluable to anyone planning for broadcast and mobile-radio coverage, or designing, installing and maintaining antenna systems.

Operational Amplifiers
by Jiri Dostal, 400pp, hardback
Order - ISBN 0 240 51337 1
Price £40.00
Contains: The operational amplifier; basic concepts; operational amplifier parameters; the operational circuit; the ideal operational circuit; analysis of the real operational circuit; static and dynamic errors in the frequency domain; dynamic errors in the time domain; input and output impedances; offset; noise; stability; good laboratory practices.
Provides an extensive treatment of applications and a practically oriented, unified theory of operational circuits. Provides the reader with practical knowledge necessary to select and use operational amplifier devices.

Cassette Recorders
by S W Amos, 384pp, paperback
Order - 0 7506 1999 6
Price £17.99
Contains: Semiconductors and junction diodes; basic principles of transistors; common-base and common-emitter and common-source amplifiers; common-collector and common-drain amplifiers; bias and dc stabilisation; small-signal af amplifiers; large-signal af amplifiers; dc and pulse amplifiers; rf and if amplifiers; sinusoidal oscillators; modulators; demodulators, mixers and receivers; pulse generators; sawtooth generators; digital circuits; further applications of transistors and other semiconductor devices.
This seminal work has now been presented in a clear new format and completely updated to include the latest equipment such as laser diodes, Trappatt diodes, optocouplers and GaAs transistors, and the most recent line output stages and switch-mode power supplies.

Logic Designer's Handbook
by Andrew Parr, 481pp, paperback
Order - 0 7506 0935 9
Price £39.00
Contains: Simplified data on a comparative basis of TTL and CMOS ics; storage devices; logic circuits; timers; counters; drivers; interface circuits; logic gates; definitions of ic characteristics; event driven logic; communication and highways; analogue interfacing; practical considerations; summaries by function of all relevant circuits; individual pin-out diagrams.
Easy-to-read, but nonetheless thorough, this book on digital circuits is for use by students and engineers, and is a readily accessible source of data on devices in the TTL and CMOS families.
The Art of Digital Audio
John Watkinson, 490pp, hardback
Order – 0 240 51320 7
Price £49.50

Contains: Why digital?; conversion; AES/EBU; digital audio coding and processing; digital compact cassette (DCC); advanced digital audio processing; digital audio interconnects; digital recording and channel coding; error correction; rotary head recorders; stationary head recorders; Nagra and data reduction; Digital Audio Broadcasting (DAB); the compact disc/midi disc.

New edition, completely updated to include all the latest developments, including DCC, the mini-disc and digital audio broadcasting.

Microphone Engineering Handbook
by Michael Gaylord, 384pp, hardback
Order – 0 7506 1199 5
Price £65.00

Contains: Microphone techniques; precision microphones; optical microphones; high quality rf microphones and systems; radio microphones and ir systems; microphone testing; ribbon microphones; microphone preamplifiers; stereo microphones; microphone standards.

Comprehensive and authoritative book for engineers, technicians, students and anyone else concerned with the design and use of microphones.

MIDI Systems and Control
by Francis Rumsey, 256pp, paperback
Order – 0 240 51370 3
Price 19.95

Contains: Introduction to principles and terminology; synchronisation and operating systems; digital recording and channel coding; MIDI timecode; MIDI transport; MIDI implementation of midi with peripheral devices; practical systems designs.

Second edition is updated and enlarged to take MIDI evolution into account. More examples of real implementations, more diagrams and the whole book has been rewritten to include a far greater practical element, to complement its existing technical strengths. Several completely new sections and complete chapters have been added including a new opening chapter as an introduction to principles and terminology; MIDI timecode; librarians and editors.

Loudspeaker and Headphone Handbook
by John Borwick, 224pp, hardback
Order – 0 240 51371 1
Price £35.00

Contains: This book brings together in a single volume every aspect of loudspeaker and headphone theory and practice in sufficient depth to equip students and practitioners alike with a solid working knowledge of the subject. A comprehensive technical reference on the theory and practice of loudspeaker and headphone performance, design and operation.

The Art of Linear Electronics
by John L. Hood, 400pp, paperback
Order – 0 7506 0868 4
Price £16.99

Contains: Electronic component symbols and circuit drawings; passive components; active components based on thermionic emission; active components based on semiconductors; practical semi-conductor components; dc and low frequency amplifiers; feedback negative and positive; frequency response; modifying circuits and filters; audio amplifiers; low frequency oscillators and wave-form generators; tuned circuits; high frequency amplifiers/oscillators; radio receiver circuitry; power supplies; noise and hum; test instruments and measurements.

This practical handbook gives a complete working knowledge of the basics and technology of linear electronics – with application examples in such fields as audio, radio, instrumentation and television.

Servicing Audio and Hi-Fi Equipment
by Nick Baer, 344pp, hardback
Order – 0 7506 2117 6
Price £25.00

Contains: Introduction; tools and test equipment; radio receivers; amplifiers; power supply circuits; portable audio; cassette deck mechanics; cassette electronics; turntables; system control; motors and servo circuits; compact disc; mini disc; digital audio tape, digital compact cassette; speakers, headphones and microphones; repair, addresses.

As a bench-side companion and guide, this work has no equal. Its purpose is to ease and speed up the processes of fault diagnosis, repair and testing of all classes of home audio equipment: receivers, amplifiers, recorders and playback machines.

EMC for Product Designers
by Tim Williams, 304pp, hardback
Order – ISBN 0 7506 1264 9
Price £25.00

Contains: What is EMC? standards; EMC measurements; interference coupling mechanisms; circuits; layout and grounding; interfaces; filtering and shielding.

Build Your Own PC
by Ian Sinclair, 256pp, paperback
Order – ISBN 0 7506 2006 4
Price 16.95

Contains: Assembly from scratch – mainly for masochists; fundamentals and buying guide; case, motherboard and keyboard; disk drive details; improvers and modifiers for graphics and video; DOS operation and hints; Windows; connecting printers; glossary.

Covers Building your own pc from scratch or from modules. Written at a level suitable for beginners and those with experience of computers or electronics. In addition, this work provides a useful guide for anyone wanting to save money by upgrading their pc themselves.
British company Speake & Co has developed a high-sensitivity magnetic field sensor operating in the ±50μT range. Having only three terminals and an output period proportional to field strength, the device is easy to interface. In addition, the device runs from a single 5V supply.

Unlike Hall-effect sensors, which are difficult to apply at these field levels because of their sensitivity to temperature, the FGM-3 sensor has a typical temperature coefficient of 0.003%/°C at around 25°C. Its operating temperature range is 0-50°C.

Output of the device spans -50kHz to -120kHz. As the lowest effective Nyquist sampling rate is about 50kHz, appropriate digital filtering can provide an ac field bandwidth from dc to around 20kHz.

Since the range covers the Earth's magnetic field, multiple sensors can easily be arranged to provide compass orientation, or full three-dimensional orientation systems, using the local Earth's magnetic field as a reference. Other applications include conventional magnetometry, ferrous-metal detection and vehicle re-orientation alarms.

Decoupling and power supply regulation
If long leads are used with the sensor, it is advisable to provide some local decoupling close to the sensor itself where possible. A 10µF electrolytic capacitor is suitable for this.

Since the sensor has a sensitivity of a few percent to power supply variations, it is necessary to provide it with some power regulation in most cases. For many applications, such as ori-
entation devices, a single fixed voltage regulator of the LM98L05 or equivalent type is adequate. However, for applications such as earth field magnetometry or where extremely small field variations are being studied, supply voltage variation needs to be reduced to a level which permits the temperature coefficient of the device to be the limiting performance factor.

Double regulation from 12-15V, first down to 9V and then to 5V, using the LM98L09 and LM98L05 provides a low-cost solution. Fig. 1.

Sensor calibration
For many applications, such as simple field detection or orientation measurement systems, calibration of the sensors is not necessary.

For applications that do need to measure field strength, a reasonably accurate calibration can be made using simple equipment. A single-layer solenoid can easily be made by close-winding enamelled wire on to a tube having an internal diameter large enough for the sensor to be inserted in it. The field inside a long solenoid is given simply by the product of the current flowing in it and the number of turns per metre with which it is wound. Both these items can be measured reasonably accurately, one, with a ruler, the other with an ammeter.

For most purposes, a winding at least twice as long as the sensor will give a good calibration, consistent with the likely turns/metre measurement accuracy using a ruler - provided its diameter is no greater than necessary. Single axis sensors are the easiest in this respect because they have a small diameter and can be inserted into a small diameter tube. The following should be helpful in the design of calibration coils.

First, the field at the centre of a cylindrical coil of the type suggested is given by:

\[ H = \text{geometry-factor \times turns/metre \times current} \]

where \( H \) is in A/m and geometry-factor is shown in Table 1.

Table 1. Factors needed to calculate field produced by the magnetic calibrator.

<table>
<thead>
<tr>
<th>Length/Geometry diameter</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.9906</td>
</tr>
<tr>
<td>6</td>
<td>0.9884</td>
</tr>
<tr>
<td>7</td>
<td>0.9900</td>
</tr>
<tr>
<td>8</td>
<td>0.9923</td>
</tr>
<tr>
<td>9</td>
<td>0.9999</td>
</tr>
<tr>
<td>10</td>
<td>0.9950</td>
</tr>
</tbody>
</table>

This permits calibration of the coil centre-field. The correction is small, somewhere between 0.5 and 2%, but may be worthwhile in appropriate cases.

Away from the centre of the coil the field falls off towards either end. On the assumption that the coil is twice as long as the sensor, Table 2 gives a factor for this reduction, at either end of the sensor, for various coil geometries. It also shows, in the third column, the percentage by which the field differs from being uniform along the length of the sensor, assuming that the sensor is centrally placed.

Table 2. Reduction factors to compensate for falling off of field towards the ends of the calibration coil.

<table>
<thead>
<tr>
<th>Length/Diameter</th>
<th>Reduction factor</th>
<th>Uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.9788</td>
<td>±0.29%</td>
</tr>
<tr>
<td>6</td>
<td>0.9847</td>
<td>±0.31%</td>
</tr>
<tr>
<td>7</td>
<td>0.9884</td>
<td>±0.45%</td>
</tr>
<tr>
<td>8</td>
<td>0.9910</td>
<td>±0.58%</td>
</tr>
<tr>
<td>9</td>
<td>0.9950</td>
<td>±0.86%</td>
</tr>
<tr>
<td>10</td>
<td>0.9999</td>
<td>±1.06%</td>
</tr>
</tbody>
</table>

The geometry-factor from Table 1 should be reduced by this percentage to arrive at a mean calibration factor for the coil, for the most accurate results.

Calibration currents required are modest. Since the usable range of the sensor is around ±0.5 oersted or 40A/m, a single-layer winding of 0.5mm enamelled wire, with a diameter of around 0.559mm, will only require 23mA to reach maximum calibration field strength.

In carrying out such a calibration with a solenoid coil, the coil and sensor should be aligned at right angles to the direction of maximum local field, as determined by the sensor alone. Where only relative field measurements are needed this can be done by simply aligning the coil and sensor in an east-westerly direction.

If an accurate zero field calibration point is required the sensor will need to be placed in a zero-field location, such as the inside of a small mumetal container, aligned east-west.

Measuring in the field
The simplest way of making field measurements is to use a frequency meter set for period measurement directly on the output of the sensor. In most cases, designers will prefer to dedicate some specific hardware to carry out the conversions automatically.

Hardware configurations can vary from minimal, battery powered meter-display detectors through to complex, multiple sensor, computer controlled data collection systems. The following notes describe some useful techniques.

Meter or chart-recorder outputs
Low cost equipment can be made by using a semiconductor frequency-to-voltage converter such as the LM2917. A circuit for a portable, direct reading instrument is shown in Fig. 2.

Since the field strength is inversely proportional to frequency, the output is not linear but over the ±0.5 oersted range the non-linearity is modest and provides an acceptably spaced meter scale. At higher sensitivities over a more limited full scale range, the non-linearity becomes increasingly negligible and gives an almost evenly spread scale.

Where the converter is unable to handle the highest frequency output, simple binary division in a prescaler will bring the sensor output into an acceptable range.

As an alternative to the diode pump type of converter, a phase locked loop can also be configured to provide similar performance.

Digital heterodyning
If the full range of the sensor is not required, such as in ferrous material detection or the measurement of small field fluctuations, a technique of digital heterodyning is useful.

This is not a true heterodyne process but is similar when used over small frequency ranges. It is more akin to the production of...
Sensors

aliasess by undersampling and gives very high sensitivity to small signal fluctuations. This makes it useful for detecting remote moving ferrous objects or for measuring Earth field fluctuations during magnetic storm activity.

The technique requires a stable but adjustable source of clock pulses of similar frequency to the sensor output. These are used to undersample the sensor output and produce a much lower frequency square wave. One easy way to achieve this is to use the sensor output as the D-input of a D-type bistable and the clock source as the trigger input, Fig. 3.

The sensor is used in a fixed position and the clock signal is set to a frequency close to the sensor frequency. Output of the bistable is a square wave of frequency equal to the difference between sensor and clock frequencies, similar to a heterodyne mixer. A small percentage change in the sensor frequency can cause a large percentage change in the bistable frequency. This can be converted to a voltage as before, for meter or chart recorder, but gives a large increase in apparent sensitivity without the need for high gain amplifiers.

The cmos oscillator above is more stable than most and is suitable for applications such as ferrous metal detectors. Some care is needed in decoupling both the oscillator and the sensor to prevent a tendency to frequency lock, if the highest sensitivity is required. However such an arrangement has successfully detected passing vehicles and a measure of its sensitivity can be obtained from the fact that it could pick up a motorcycle in the far lane of a three lane motorway from the grass verge.

More critical applications of Earth field or materials magnetometry need a more stable oscillator, such as a crystal controlled type, but a fixed frequency is normally adequate, since such instruments are not usually mobile.

The technique is equally applicable to ferrous object detection or counting of smaller objects passing on a conveyor belt, the sensitivity and range being adjusted to suit the individual system. In this context it is useful to remember that the field produced by a given magnetic moment falls off as the inverse square of the distance – not the inverse square. All of the above hardware approaches can be simulated by software in a computer or microcontroller, often resulting in minimal hardware to achieve sophisticated results.

Detecting the Earth’s field

A block diagram of a modest Earth field magnetometer, Fig. 4, uses the type of circuitry

Applying the sensor with computers and microcontrollers

The sensor’s large output pulse gives considerable noise immunity permitting the use of transducers sited at long distances from the main system.

Interfacing is simple in that it requires only one bit of a digital input port per measurement channel, the technique being to count input pulses for a fixed period on the device the frequency of the incoming signal. From this, the field can be calculated.

If faster response is needed, the time between successive edges permits direct determination of period, from which frequency can be calculated. With microcontrollers, this usually presents no problem, but with systems using many interrupts or extensive multi-tasking it may be necessary to buffer the input signals to deal with the high data rate. However this usually means no more than the addition of a single triple-counter i/o chip – even for three-dimensional orientation systems.

For applications such as Earth field magnetometry, where readings may only be required at relatively long intervals, simple binary division with a 12 or 14 stage divider will reduce the input period to a level where data rate ceases to be a problem to the computer. Alternatively, in such applications where the field variation is extremely small, digital heterodyning with a stable oscillator will also reduce the period but simultaneously maintain the high sensitivity, in hertz/oersted, to field variations.

For applications needing absolute field magnitude without any orientation sensitivity, it is necessary to use three orthogonal sensors and exploit the fact that the sum of the squares of the three signals is constant regardless of orientation. Provided that the zero offsets, channel sensitivities and linearisation are appropriate to the required absolute sensitivity, this will permit free movement of the sensor head while measuring small changes in absolute field. If the sensor is in constant angular motion, advantage may be taken of this to provide some level of auto-calibration of zero offset and channel sensitivity.

Where the sensor can be permanently fixed, only one sensor is necessary, the zero offset being adjusted to suit the local ambient field strength. This technique is appropriate to fixed ferrous metal detection systems such as conveyor belt counters, vehicle and ship passage detectors and materials magnetometry. A limit to the range of such systems results from the fact that the Earth’s field itself fluctuates at a low level continuously. The effective range is a function of the size or likely magnetic moment of the objects being detected – ships generally giving a larger range than vehicles or hand guns. Appropriate filtering of the input frequency variations will enhance range.

Where extremely high sensitivity is required it may be possible to use two sensors in a gradiometer configuration to cancel out the micro-fluctuations of the Earth’s field. However, this will not always increase range, since the gradiometer sensitivity falls off faster with range than the simple field sensor.

In this context, you should remember that the field produced at range by a magnetic moment falls off as the inverse cube of the range, so the gradiometer configuration will fall off as the inverse fourth power. However such systems may be useful as short range high sensitivity detectors and materials measurement systems. An example might be extremely small magnetic moment inert particles introduced into fluid flow systems for movement detection, such as chemical processing plants or animal internal fluid flow systems in medical research applications.

Fig. 2. Since the sensor provides an output whose period is proportional to magnetic field, adding a frequency-to-voltage converter produces a simple portable meter output instrument.
The sensor should be located in an east-west orientation and its mean frequency is measured. A crystal oscillator and binary divider are then selected to produce a frequency around 500Hz below the sensor frequency. The sensor signal and the divided clock are fed to a digital heterodyne circuit as described earlier.

Sensitivity of the FGM-3 is such that this arrangement will give a swing of about 0 to 1000Hz for a variation in field of around ±500y (1y is 10⁻⁵ oersted). This gives enough headroom for most magnetic storms likely to be observed. The exact range can, if required, be calibrated as outlined earlier.

Output of the digital heterodyne can be taken to a voltage-to-frequency converter for chart recorder use or to a computer to store or plot the data in whatever form is appropriate. If the sensor is calibrated, the results can easily be converted to angular or azimuth variations by dividing by the local horizontal component. This can be measured by a north-south oriented calibrated sensor. Output is variation in radians, which is readily converted to the more suitable minutes of arc.

A magnetometer of this kind needs to be installed in a location far removed from potential sources of magnetic field interference. Such sources are mains transformers and motor vehicles. Fortunately the inverse cube law mentioned previously helps considerably with this aspect.

One exception to this rule can be exploited in the initial commissioning of the equipment. If difficulty is experienced in finding an appropriate combination of crystal and binary divider to nearly match the sensor output, in the magnetically quiet location needed, the strategic placement of a small ceramic magnet, at a suitable range, can be used to 'pull' the sensor frequency instead.

**Materials magnetometer**

A setup with this kind of sensitivity is equally capable of being used as the measurement tool for the Earth's magnetic field, but the oscillator needs to be stable.

Normally, the FGM-3 sensors sell at £1.645 but as a special introductory offer to EW+WW readers, Speake & Co is making up to two sensors per reader available at the 20% discount price of £1.316 each – fully inclusive of VAT and postage.

The FGM-3 is a three-terminal sensor – ground, +5V and output – that produces a frequency between 50kHz and 120kHz. The period of this output represents magnetic fields in the range ±50μT. At 25°C, temperature stability is 0.003% – a significant improvement over non-compensated Hall-effect devices. Send your postal-order or cheque payable to Speake & Co Ltd to Speake & Co Ltd, Elvicta Estate, Crickhowell, Powys NP8 1DF, tel. 01873 811281, fax 810958. Please note that any queries about this offer, or the FGM-3 sensor, should be directed to Speake & Co, not EW+WW.

Please note that this offer applies to overseas readers, but excluding those in Canada and North America.

The FGM-3 outputs a frequency between 50kHz and 120kHz whose period represents magnetic fields in the range ±50μT and is highly stable with temperature.
in a classical Gauss-type materials magnetometer.

Figure 5 shows the usual configuration of this instrument. It comprises a controllable magnetising arrangement in the form of an air-cored solenoid in conjunction with a field measuring device. As shown, the arrangement is for low susceptibility specimens. Alternatively, an electromagnet type yoke can be used to reduce demagnetising effects with high susceptibility materials. The demagnetising field measured by this device is related to the magnetic induction in the specimen. Taking the magnetising coil through positive and negative cycles large enough to reach saturation in the specimen produces a measured field displaying the hysteresis loop characteristics of the sample. To avoid shearing the hysteresis loop, it is necessary to use a specimen with a small demagnetising coefficient.

Alternatively, an electromagnet type yoke can be used to reduce demagnetising effects with high susceptibility materials. The demagnetising field measured by this device is related to the magnetic induction in the specimen. Taking the magnetising coil through positive and negative cycles large enough to reach saturation in the specimen produces a measured field displaying the hysteresis loop characteristics of the sample. To avoid shearing the hysteresis loop, it is necessary to use a specimen with a small demagnetising coefficient.

Calibration is often carried out using a standard comparison sample of known demagnetisation coefficient and magnetic properties. The arrangement shown can also deal with the process of anhysteretic magnetisation if an alternating current source is superimposed on the d.c. supply. The more common a.c.-driven type of B-H loop tester has difficulty with this since it cannot measure static fields.

Similar arrangements are used by naval establishments under the name of fixed or portable ranges. These determine the efficiency of the various degaussing equipments with End Correction Coils.

Alternatively, use one with a known demagnetisation coefficient which can be corrected for, such as a cylinder.

For straightforward quantitative work distance r should be large compared to the magnetic length of the specimen if induction is to be measured. This requires high sensitivity in the detector. Comparative work and coercive force measurement are not so demanding.

SENSORS

Fig. 5. At the heart of this materials magnetometer is a controllable magnetising arrangement in the form of an air-cored solenoid. Demagnetising field measured by this device relates to magnetic induction in the specimen.
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Controlling dynamic range

Based on a chopped attenuator, John Linsley-Hood's audio processor expands and compresses by around 26dB with very low thd.

In an ideal world, music, speech or drama - when recorded and replayed, would be reproduced in similar surroundings, with identical sound-level intensities. In practice of course, this ideal is rarely achievable.

When performing live, popular music the artists have to make themselves heard in competition with the audience. Some information may be lost during quiet passages, but generally, reproducing such music presents few problems in audibility.

At the other end of the loudness scale - for example plays - the contrast between loud and quiet may be an essential aspect of the dramatic content. In this case, realism depends on the quiet parts being heard as effectively as the loud. For this purpose, desirable dynamic range would be at least 50-60dB.

In the performance of 'classical' music - particularly with a large scale modern orchestra in a well-designed auditorium - sound pressure levels ('spl' is in decibels referred to 2x10^-5N/m^2) can range from less than 15dB to greater than 100dB.

In a domestic environment, the situation will not be as favourable. Background sound-levels of a quiet room are likely to be around 25dB, while the tolerance limit of family and neighbours may demand that sound-pressure levels of loud passages are held significantly lower than 100dB.

For listening in a car, the background noise level when travelling on the open road is at least 55dB, and higher when driving in urban traffic. This would be acceptable for listening to loud music but hopeless for a radio play or orchestral concert.

In reality, there are mitigating factors. In most radio broadcasts there is a degree of dynamic-range compression, as well as peak level limitation. This is introduced to avoid overloading the transmitter systems. In programme material transferred to tape, there will be a significant amount of inadvertent maximum recording level compression. This is an inherent characteristic of the magnetic tape record/play system.

During the manufacture of vinyl records, a substantial amount of short-term peak recording level compression results from the recording engineer's manipulation of the level controls. This is needed to ensure that loud passages do not cause groove-to-groove breakthrough at recording levels. It is chosen so that quiet portions of the programme are adequately above the surface noise floor of the disc. For this reason there is a degree of dynamic range compression imposed both in the initial recording and in the user's subsequent copying on to cassette tape - often listened to in the car.
**CDs and dynamic range compression**

In CDs and, to a lesser extent, the digital compact cassette and Sony's Mini-Disk, digital signal processing has lowered the noise floor of recordings. It has extended the dynamic range available in the recording system to some 90dB. This range is even greater in some of the better machines.

Unfortunately, wide dynamic range recordings make unsatisfactory programme sources when the replay system is being listened to in a noisy environment such as an automobile, or when the listener has impaired hearing. Such situations benefit some form of dynamic range compression in the replay chain.

Conversely, if some form of external dynamic range control is available, this could equally well be used in more favourable conditions. One example is for expanding the range available from a standard vinyl disc, by making the loud passages louder or the quiet ones quieter — a process which would also reduce the audibility of the disc surface noise and turntable "rumble'.

**Controlling dynamic range**

I described a low-distortion, gain-controlled block based on a high-speed electronic switch in *EW+WW*, April 1995. This switch, outlined in Fig. 1 had on and off durations controlled by an externally applied dc voltage.

Using a switch in this way removes the transistor matching problems normally associated with high-performance attenuators. Over the

---

**Fig. 2. Audio compression and expansion system based on a low-distortion switched attenuator.**

**Fig. 3. Audio dynamic range controller incorporating a switched attenuator. The j-fet provides the attenuation, under control of square waves from oscillator, Fig. 4.**

**Fig. 4. Analogue signal conditioning provides a dc control voltage for the controlled oscillator based on a 4069 c-mos logic buffer.**
range 100Hz to 10kHz, the chopping attenuator achieves a third figure in the region of 0.005% for a 1V rms input.

With this arrangement, Fig. 2, system gain can be caused to change rapidly in response to a control voltage derived from the audio signal level. This voltage can be derived either from the signal present at the output of the gain controlled block - if peak level compression is needed - or from the signal input, where dynamic-range expansion is required: there would otherwise be positive feedback around the control loop.

Figures 3 and 4 show the circuitry of the gain-control and filter block, and the control voltage and rectangular wave generator.

Overall system operation
The system operates in dynamic-range compression mode by using the chopper fet, T1, to cut segments out of the audio signal waveform present at its drain electrode.

The duration of the chopped out segments becomes greater as the input control voltage fed to the oscillator becomes more positive. This happens as the size of the audio signal fed to IC6 increases - an arrangement which reduces amplitude of the output signal.

The converse effect is obtained if the rectangular waveform generator is connected so that duration of the chopped out segments increases as signal size decreases. This effect occurs if drive signal to the gate of T1 is taken from the oscillator Q output rather than the Q output.

Some form of threshold control, shown as RV2 in Fig. 2, is necessary when the circuit is used in its dynamic-range expansion mode. It would otherwise be possible for the circuit to suppress low-level signals entirely, unless some residual input voltage is fed to the CD4069 oscillator. Magnitude of this voltage can be chosen to set the minimum size for low signal-level transmission.

The 130kHz chopping frequency is well above the audible range, but it is necessary to remove notches due to the chopped out segments in order to recover the original distortion-free waveform. This is achieved by introducing two consecutive third-order Sallen and Key low-pass filter stages, IC2A and IC3A. These sit between the chopper stage and audio-frequency output.

Frequency response of this circuit, Fig. 5, gives about 90dB rejection of the switching waveform in the af output.

Implementing the controller
It is necessary to mount this unit in a metal enclosure to avoid interference with adjacent radio receivers. This occurs as a result of the fairly large hf signal voltage in the oscillator circuit, when the unit is used as an adjunct to an existing high-fidelity system. With this simple precaution, I have noticed no rf interference from my prototype.

For domestic use, a conventional IC stabilised ±15V mains operated power supply unit will provide all the necessary supplies. An led in series with the positive rail to the CD4069 provides an 'on' warning light.

For use in car, the positive battery supply will need to be supplemented with a -12V feed to the op-amps. This is best provided by a pcb mounting dc-to-dc converter such as a Newport NMF1212S.

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**Fig. 5. Frequency response of two consecutive third-order Sallen and Key low-pass filter stages between the chopper stage and af output. The circuit gives about 90dB rejection of the switching waveform in the af output.**
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This is a complete instrument, using an **ICL8038** to give sine, square and triangular waves up to 250kHz in four ranges, and can be made to operate down to 5Hz.

At the core of the circuit is the **8038** IC, whose frequency of operation is set by the linear pot. P₁ and the switched capacitors C₃,4,5,6. Resistors R₁,2,3,9 and the pot. R₁ set the bias on the **8038** internal charge pumps, R₁ being used to achieve symmetry of the output waveform and P₂ and R₁₀ adjusted for minimum distortion. Diode D₁, sprinkling of 150pF capacitors reduces the severity of interaction between triangle and sine outputs. Square output is symmetrical about zero volts and is not, therefore, useful as a ttl drive; Tr₂ is used as a level shifter and Tr₃ as an output emitter follower. RC components R₁₃,₁₅ and C₇,₈ improve rise and fall times. The triangle output of the ic is taken to emitter follower Tr₄ and then to a high-frequency op-amp, the **NE5539**, which has a 500MHz bandwidth, biased to zero by R₂₂,₂₃ and having a gain of 2.5. The sine output is ac-coupled to a further **NE5539**, which drives the two followers to obtain an output symmetrical about zero, set by P₄. This output drives the output stage.

**Emil Vladkov**

Sofia University

Sofia

Bulgaria

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CIRCLE NO. 122 ON REPLY CARD

944 ELECTRONICS WORLD + WIRELESS WORLD November 1995
Switch debouncer

This was meant to debounce the contacts of a semi-automatic Morse key, but has since been used for many other types of switch. It takes a pair of contacts and introduces no delay, apart from that inherent in the circuit, which is insignificant when used with mechanical contacts.

A pulse of around 30ms formed by \( C_2 \overline{R_3} \) removes the bounce when the contacts make. The pulse generated by \( C_3 \overline{R_4} \) performs the same function as the contacts open, \( R_3 \) and \( R_4 \) being varied as needed. \( I_{C1(a)} \) and \( I_{C1(b)} \) extend the duration of a short contact closure and \( I_{C1(d)} \) can be used to inhibit a second intentional closure for a time determined by the values of \( C_3 \overline{R_4} \).

Output comes from \( T_{R1} \)'s open collector, the transistor allowing level shifting, if needed, but \( T_{R1} \) and \( R_5 \) may be left out and the output taken from pin 3 of \( I_{C1} \). Supply voltage is adjusted to give the correct logic levels; the supply for the circuit shown is under 5V to about 18V.

\( I_{C1(c)} \) gives a beep when the contacts are closed or a shorter one if a \( CR \) is used before pin 9 of \( I_{C1} \). If \( C_3 \overline{R_4} \) are omitted and pins 8 and 9 of \( I_{C1} \) are connected, \( I_{C1(c)} \) gives an inverted output.

Ted Crowley
Invotron Ltd
Bray
Co. Wicklow

Switch debouncer, originally for a Morse key, has been used for many other applications, introducing no extra delay and producing a beep when contacts are made.

Mercury battery replacement

Mercury batteries in older light meters and cameras have had a very bad press and some manufacturers recommend simply using alkaline or silver oxide cells instead, even though the terminal voltage may not be correct. Placing an \( HP 5082-2835 \) Schottky diode in series with a 1.55V silver oxide cell reduces the output of the circuit to almost exactly the 1.35V of a mercury cell, due to the 0.25V drop across the diode at a typical load current of 0.1mA. Note that cameras usually have a positive chassis ground.

Someone could do the industry a service by packaging a Schottky in a little wafer to stack on a button cell or even to go inside it.

Michael A Covington
Artificial Intelligence Center
University of Georgia
USA

Instead of junking older photometers using banned mercury cells, use a Schottky and a silver oxide cell.
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Digital, programmable mark:space converter

With no effect on frequency, this circuit allows the digital programming of a rectangular wave duty cycle, in 1% steps, from 0 to 99% over a wide range of frequencies.

IC1a is a free-running oscillator driving a 12-bit down counter, IC5,6,7, directly and, by way of a synchronous decade rate multiplier IC3,4, the 12-bit up counter IC2.

A narrow pulse derived from the leading edge of the input signal loads the data from IC2 into the down counter and provides reset and clear for the up counter and rate multiplier. Data output N of the up counter is determined by the input signal period, by the rate input M to the rate multiplier and by the clock frequency, giving

\[ N = f \frac{M}{f_{in}}. \]

After data is loaded, the output at RCO goes high until the output of the down counter reaches zero, where it stays until new data is loaded. Since the loaded data is N and since the down counter's clock also comes from the oscillator, the output stays high for a duration

\[ T_1 = Nf \frac{f_{in}}{M}, \]

so the duty cycle at the down counter output is given by

\[ T_{d/c} = M. \]

Since neither \( f_{in} \) nor the clock frequency figure in this, the circuit is insensitive to both and depends solely on M.

As an example, if the output frequency is 500Hz, the rate is 0.25 and the clock runs at 500kHz. The maximum count in the up counter is 250, so the output pulse duration is 250/500kHz=0.5ms.

As the output frequency is 500Hz, the duty cycle is 25%.

Yongping Xia
Torrance
California
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Multiplying d-to-a converter

This is usable as a multiplying digital-to-analogue converter or as a triangle generator, given a counter to drive it.

Figure 1 shows the idea. Gain of this basic circuit is given by,

\[ G = \frac{2(R_v + AR)}{R_v + AR + (1-A)R} \]

If \( R_v = R \), gain becomes \( G = A \), so that if \( R \) changes from 0 to \( R \), gain changes accordingly from 0 to 1. With \( R_v = 0 \), gain is \( 2A - 1 \) and a change of \( R \) from 0 to \( R \) changes gain from -1 to +1.

The practical circuit in Fig. 2 uses a 4066 (IC3) switching the resistor chain to form \( AR \) and IC2 to provide \((1-A)R\). Data changing from 0000 to 1111 varies the gain from 0 to 1 with the shorting link open and from -1 to +1 with it closed. Driving the data inputs by means of an up/down counter gives a triangle at the output.

W Dijkstra
Waalre
The Netherlands

Voltage-controlled oscillator

Here is a low-distortion, variable-Q, voltage-controlled oscillator. A vital part of the circuit is the arrangement in Fig. 1, which provides the frequency control using a MPY634 multiplier. Since \( Z \) drives the inverting output of the amplifier, feedback is negative and the output voltage is given by,

\[ V_{out} = A(V_v/V_o)/SF - V_{out} \]

where \( SF \) is a scale factor, nominally 10V. When \( A \) approaches infinity, output voltage is \( V_{out} = V_vV_o/\text{SF} \), which may be written,

\[ V_{out} = V_v/sCR' \]

where,

\[ R' = RV / SF \]

and \( V_c \) is the control voltage.

In Fig. 2, cut-off frequency and \( Q \) of the state-variable filter, using the two integrators are given by,

\[ \omega_o = \frac{V_o}{RC/\text{SF}} \]

and

\[ Q = 1 + \frac{R_1R_2}{3} \]

So \( Q \) is adjustable to any value by varying the ratio \( R_1/R_2 \), with no effect on cut-off frequency. Feeding the filter output back to the input turns the circuit into an oscillator, in which integrator IC4 smoothes the rectified output to give a control voltage for the fet, whose variable channel resistance balances positive and negative paths for low distortion.

Kamil Kraus
Rokycany
Czechoslovak Republic

Fig. 1. Multiplier and integrator form part of state-variable bandpass filter, the frequency-determining element of the oscillator.

Fig. 2. Complete oscillator circuit, in which frequency is determined by \( RC \) in Fig. 1 and \( Q \) by the ratio of \( R_1 \) and \( R_2 \).
Simple programmable switcher gives 100W

We have used this power supply to give 100W at an efficiency of better than 70% and with ripple at about 50mVpk-pk. The control signal, $V_{DAC}$, sets output power, rather than voltage. Effectively, the circuit is that of a switching down-converter, using a commercial pulse-width modulator, the LM3578. The comparator accepts higher input levels than is normally allowed and is useful for series power supply current sensing.

High input-voltage comparator

Using a single power rail, this comparator allows the input voltage to exceed that specified for the op-amp in use. In this case, the circuit is used to sense the small voltage caused by a current drop in series resistor between a power supply and its load. Both inputs of the comparator in a basic circuit would be at or approaching the full rail voltage – in this instance 36V, far outside the permissible limits.

In the gating comparator shown, the voltage drop across the current-sensing resistor $R_s$ is taken to the inverting op-amp input, being divided by $R_{1,2}$, the reference voltage derived from the zener and its dividing chain going to the other input. When no gating pulse is present, this divider consists of $R_5,6$ and of $R_{6,8}$ when the gate pulse turns $T_1$ on.

Assuming that all the divider resistors are equal, differential voltage at the op-amp inputs is $V_{sup} - V_s = (V_{ref} - V_s)/2$; when $V_s$ exceeds $V_{ref}$, the op-amp output goes high. When the gate pulse appears, the differential voltage is approximately $V_{ref}$ and the output goes low.

Umberto Ruffina and Marco Villa
University of Pavia
Pavia
Italy

N I Lavrentiev
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Surround-sound standards polarise

Peter Willis looks at the pros and cons of two competing surround-sound standards – Dolby’s AC-3 and Europe’s MPEG-2.

Surround sound is set to enter a new dimension in the digital era, but differences between broadcasting standards in America and Europe could perpetuate the film studios’ use of the PAL/NTSC division to control the territorial release of new titles.

Dolby’s AC-3 system, demonstrated in Berlin and again at Live ’95 in London, has been selected by the American FCC as the standard for its digital television system. Soundtracks in AC-3 are already being included on NTSC versions of Laserdiscs, with 50 titles due out by the end of the year. Players, and outboard demodulators are becoming available.

Operating at 384Kbit/s, AC-3 is a 5.1 channel system providing totally discrete signals to each of the five speakers – left, centre, right and rear left and right – in a surround-sound set-up. The ‘.1’ refers to the optional subwoofer.

This standard won’t replace existing Pro Logic, but because it does not have to be mixed through a matrix, lateral diagonal effects become possible, and the sense of space is increased. It is however a multichannel system – not just five separate channels: the coder looks at what all the channels are doing together, enabling it to optimise the available bits, and to apply psychoacoustic principles. It also enables the datastream to be downmixed to four, two or one channel, with acceptable balance, as required.

And in Europe...

Europe, meanwhile, has chosen the Musicam-based MPEG-2 system for its Digital Video Broadcasting standard. This was inevitable, since backwards compatibility with stereo MPEG-1 – which can carry the two-channel Pro-Logic matrix – was a criterion.

MPEG-2 becomes a true five-channel system by adding an ‘Aux Data’ bistream carrying the centre and rear channels. Unfortunately this has the effect of depriving the MPEG-1-compatible Left and Right channels of vital information, notably dialogue, so the Aux Data has to be put through a matrix to restore the information. This, however, increases the apparent noise. As a result, the bit-rate has to be increased by some 40% to compensate, exceeding the available transmission limit. Not surprisingly, the people at Dolby see this as something of a bodge.

The real question, however, is what will go onto high-density MPEG-2 digital video discs when they start to be released next year. The SD group has publicly indicated that European discs will have MPEG-2 soundtracks. This would make for compatibility between players and broadcast receivers, but inhibit global traffic in pre-recorded discs. In fact, such is the capacity of the discs that they would have room for both soundtracks – provided the film studios don’t intervene.

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November 1995 ELECTRONICS WORLD+WIRELESS WORLD
Isolating
RS-232

Combined with opto-couplers, this pair of ICs isolates an RS-232 line to 1500V rms - without the need for an independent power source at the remote end of the link - as Douglas Clarkson explains.

An increasing level of connectivity between computers and electronic equipment - generally via the RS-232 COM port - provides a convenient universal approach to control and data logging. Many applications demand high noise immunity and isolation. Standards for telecomms and electrical safety often demand isolation between a computer and its remote monitoring subsystem or sensors. In many data-capture applications, optically-isolated digital interfaces are available.

Increasingly, the RS-232 interface provides control, in addition to data transfer. This development is, for example, incorporated into the Harris HI-7159A, where a single RS-232 line can control and abstract data from a 5 1/2 digit a-to-d converter.

When considering electrical isolation, distinction is usually made between the 'cable' ground and the ttl/cmos logic system ground, as in Fig. 1. Generally, isolation is achieved through optical coupling but some newer isolation interfaces take advantage of capacitive coupling.

With a mains powered pc, the ground signal of the RS-232 interface is usually tied close to the mains ground and is therefore not floating.

**Isolation criteria**

Not only is data passed across an isolation interface, but it is usually level shifted from the ±10V or so RS-232 levels into cmos/ttl logic levels for the external logic system and vice versa, Fig. 2.

The level of electrical isolation required determines the specific solution. For isolation up to 1500V rms, a device such as the Newport NM232DD provides two incoming and two outgoing lines. This component is a convenient device, having the dc to dc converter unit and photo-electric devices pack-

![Diagram](image-url)

---

**Technical support**
Maxim Components, Unit 3, Theale Technical Park, Station Road, Theale, Berkshire RG7 4XX, tel. 01734 30388, fax 305577. Newport Components, 4 Tanners Drive, Blakelands North, Milton Keynes, MK14 5NA, tel. 01908 615232, fax 617545.

A range of companies including Schott Corporation (type 67114760), Mini-Magnetics (type MM2357) and BH Electronics (type Q6471-1) also provide suitable transformers.

**Transformer alternatives**
Newport manufactures a range of transformers, outlined below, providing a range of isolation levels for use with the MAX250 and MAX251 chipset.

<table>
<thead>
<tr>
<th>Type</th>
<th>Isolation</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>76250</td>
<td>1500V rms</td>
<td>DIP6</td>
</tr>
<tr>
<td>76250M</td>
<td>1500V rms</td>
<td>SM28</td>
</tr>
<tr>
<td>76250HVR</td>
<td>2000V rms</td>
<td>DIP6</td>
</tr>
<tr>
<td>76250HVRM</td>
<td>2000V rms</td>
<td>SM28</td>
</tr>
<tr>
<td>76250KV4</td>
<td>4000V rms</td>
<td>DIP6</td>
</tr>
<tr>
<td>76250KV4M</td>
<td>4000V rms</td>
<td>SM28</td>
</tr>
<tr>
<td>76250EN*</td>
<td>4000V rms</td>
<td>DIP6</td>
</tr>
</tbody>
</table>

* a special designed for EN60950 approval.

---

![Figure 1](image-url)

**Fig. 1.** Distinction between 'cable' ground at the remote end of an isolated RS-232 system, and the logic system ground, which will typically be the 0V potential of a pc.

![Figure 2](image-url)

**Fig. 2.** RS-232 isolation systems usually involve both RS-232 and standard cmos/ttl logic levels.
aged together in a modest 24-pin module. A point worth noting with these devices is that when laying out a pcb, tracks in the mid-line zone under the device should be avoided.

A limitation of the 7N232DD is the electrical isolation achievable between components. If isolation greater than 1500V rms is required, it is necessary to separate logic components and the dc-to-dc converter transformer. The MAX250 and MAX251 and their associated discrete components provide a convenient option for constructing such a module.

If connections of the MAX250 and MAX251 are appropriately routed, it is the quality of the optical components – especially that of the dc-to-dc converter transformer – which determines the level of isolation achievable.

Circuitry for RS-232 isolation

Figure 3 outlines the Maxim chip set with 4N26 opto-isolators. Such a configuration should be capable of transmitting and receiving at rates of 19.2Kbit/s. Using the higher specification 6N136 with external pull-up resistors, rates of 90KHz can be achieved. This is also the case for 6N136, but their pin-out is different, Fig. 4.

Standard eight-pin devices in DIL packages usually have 0.3in row separation. The 6N136W set of opto-isolator devices are 0.4in wide and provide increased isolation protection.

In the MAX250, a pair of open-drain n-channel mosfets drive an external 1:1 isolation transformer in push-pull fashion at 150kHz and 50% duty cycle. This provides nominal voltage rails of +10V and -10V around the ground of the remote, isolated side. These rails power the transmitters and receivers in the MAX251. In addition, these supply lines can provide current for limited additional circuitry on the remote side.

All four driver outputs of the MAX250 source 7mA via internal current sources. They do not require limiting resistors when driving grounded opto-coupler leds or cmos/ttl logic inputs. RS-232 inputs and outputs of the MAX251 comply with all EIA RS-232 and CCITT V.28 specifications. Received outputs R1L and R2L source 7mA and can drive opto-coupler inputs without external current limiting resistors.

The MAX250 has a shutdown facility which activates when the shutdown input is high. On restoring the shutdown input low, the power rails establish themselves usually within 2ms. During shutdown, total power consumption of the chip set is around 50W – a convenient power saving option for battery equipment.

Figure 5 indicates a recommended pcb layout for the MAX250/MAX251 chipset with a generic transformer. A key design element is to prevent any tracks from crossing the isolation barrier. In the specified circuit, a single or double-sided board can be used. Thicker lines shown are on the underside of the board. Lines broken by a thin line can either go on the top board or bottom side, with jumpers where the thin lines appear.

Summary

The MAX250 and MAX251 are convenient building blocks for providing electrical isolation in excess of 1500V rms between RS-232 and ttl/cmos logic systems. Within this design framework, manufacturers are also developing higher isolation properties into both optical isolators and transformers in order to improve the levels of isolation attainable.
**LETTERS**

**Letters to “Electronics World” Quadrant House, The Quadrant, Sutton, Surrey, SM2 5AS**

**Shifting cultures**

David Manner’s may be correct in asserting that there is little chance of any Brit capturing the public imagination with what they are doing in electronics. Whose fault is that?

Sir Clive was adept at spotting opportunities for wringing the last drop of processing power from available technology, but it is difficult to UK electronics to seem more exciting than say, the innovation of putting sails on oil tankers.

Ignored in Britain the idea of sails has been thought good enough to raise Japanese interest. No doubt they will be ready to sell the technology back to us if given the opportunity.

Acom Computers is another example of British innovation ignored. The company’s ships are sold back to us in the Apple Newton, Samsung, TI, Sharp, IBM, DEC products, and GEC/Plessey produces ARM based products under licence.

Bill Gates is not the ‘richest man on the planet’ because of his technical brilliance. The UK media is ever willing to give him oodles of free publicity, while our home grown innovators are at best ignored. Even our technical and computing journalists seem to want to wait for another Sir Clive to come along, rather than to look at the technology and evaluate it for themselves.

**Les May**
Rochdale
Lancashire

In last month’s editorial I felt Dave Manners was too quick to write off the UK electronics industry. All is not lost in UK Electronics where, there are many fast growing, exciting entrepreneurial companies like my own emerging. The Electronics - and especially the Semiconductor Industry - is truly International. To be successful in this business you must think global, and the prize of success goes to a few winners in a particular space, it is important to apply and deploy your energies to ensure you are the world’s best in all you do.

Following through on this, all companies in electronics or information technology need to ‘partner for success’.

As the black and white films of ‘men in white coats’ show in the engineering companies of the early fifties it was appropriate to do everything yourself, design, machine shop, spray shop, drawing office, production of every detailed part.

Today however, low cost, short time to market and flexibility are key strategic weapons in being a global player. So it is necessary to harness your resources to be able to respond to rapid change. For example as the life cycle of a pc today is only eight months, it is important to launch your product on time, control your inventory and to be sure your next product is available and better than the competition.

Another trend of large corporations has been what I call ‘downsizing’ or the Americans call ‘right sizing’. This is the need in corporations to shed thousands of jobs in order to re-establish competitiveness from a cost point of view. Every electronics job today is a global job. In the West, we compete with our brain power and more automation with a hard working lower paid worker in a less developed part of the world.

It is vital that we concentrate in our research and development programmes on exploitation, job and wealth creation as the more esoteric research activities of the past. Thus in the European Fourth Programme the emphasis is rightly more market and exploitation orientated than previously.

**Robin Saxby**
MD, Advanced RISC Machines
Cambridge

**Delayed audio unjustified?**

Douglas Self has described Ben Duncan’s method of scientific enquiry as to take someone else’s circuit, alter it until it doesn’t work very well, and then rubbish the original. That is a pretty fair summary of his Delayed Audio Signals - EW&W May 1995 – which is largely a critique of one section of my Ironing Out Distortion - EW&W Jan 1995.

Readers can be assured that my original circuit for compensating low-frequency phase and group delay (as distinct from Mr. Duncan’s mutilation of 10) performs exactly as I claimed.

Mr. Duncan states that my phase-compensation method requires “…an exact ratio between three electrolytics…” In fact the original circuit contains two relevant capacitors, one only of which is an electrolytic. Everything Duncan says about tolerances should be divided by three for a start.

I don’t know where Duncan got the values he attributes to me in his Fig. 1. Inspection of any audio power amplifier circuit I have ever published will show that low-frequency phase-compensating capacitor – C4 in my Fig. 11 – is somewhere around 1-2µF, and circuit-board layouts show it to be a non-electrolytic type. Usually I lay this capacitor out as a main unit somewhat larger than the nominal value, plus a small parallel select-on-test tweak. This involves about five minutes’ work with a square-wave generator and oscilloscope at the initial setting up of an amplifier, and the whole question of tolerances becomes irrelevant.

Mr. Duncan’s approach to low-frequency group delay is to provide a gigantic time constant for the dominant pole; this is 1s in his Fig. 1 compared with 50ms for my unmutated original. It is a fact of life that real audio amplifiers are occasionally subjected to overdrive. It is also a fact that real audio waveforms are unsymmetrical.

When an amplifier is overdriven by an unsymmetrical waveform, excess charge accumulates on the low-frequency capacitors and this charge must dissipate before the amplifier returns to normal operation. My original recovers about 30 times faster than Duncan’s circuit. There was a reason for my choice of component values.

Duncan makes a number of other assertions which he should substantiate before readers take them seriously.

Please justify the statement that “…without hundreds of volts of LF headroom extension, Cherry’s phase compensation can in practice only be used once or twice.” Two parts to the answer please.

**Help someone hear**

Can anyone solve a problem that I have wrestled with for some time? I would like to help my mother, uniform sound amplification is not sufficient as they hear different frequencies at significantly different sound levels.

For people like my mother, uniform sound amplification is not sufficient as they have various degrees of hearing loss, to say nothing of the other checks and balances we often need to overcome a specific type of hearing disability, which she and many others suffer from. The right solution could dramatically improve her quality of life.

Conventional hearing aids help under ideal conditions but their ultra compact size obviously reduces their performance. For people like me, mono, uniform sound amplification is not sufficient as they hear different frequencies at significantly different sound levels.

If any reader is willing to rise to the challenge, I will gladly provide whatever information and help that I can.

**Haysen Sykes**
Bedlington
Northumberland
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- HP 8750A Storage Normalizer - £400 with lead + S.A or NA Interface.
Sallen & Key distortion

The well-known Sallen and Key active filter circuit appears as an 'application' in the data-sheets of low-distortion op-amps, such as the OPA2406 and the LM833, both dual devices. Distortions of 0.003% (3µV/√kHz) and 0.002% (20kHz) respectively are claimed.

The Sallen and Key low-pass shown here, with an Fc of 1kHz and Q of 1, 6, was intended to reduce the already low harmonic content of a 1kHz 1Vrms source, but had the opposite effect; for example, an OPA2406 section generated 270 ppm harmonic, and an LM833 section generated 150 ppm; raising the input to 2V gave 540 and 290 ppm.

Changing to a Rauch configuration – i.e. an inverting input – solved the immediate problem, a TL072 section did the job.

Further investigation showed that, in the straight follower connection, all these types add less than 2ppm, the distortion comes when there is resistance (impedance) in series with the non-inverting input – as there necessarily is in the Sallen and Key circuit.

The table shows some readings of the internally-generated second harmonic with a 10k input resistor only (less than one milliwatt of the data-sheet input resistance). Other resistor values give roughly proportional distortion.

To alleviate the mechanism may be, one must conclude that the Sallen and Key circuit is not generally usable for hi-fi, at least with these devices.

AD Ryder
Lancashire

Need we debate feedback?

In the October issue, p. 887, Doug Self calls for an informed debate on the amount of global feedback that can be considered safe in an audio power amplifier.

I must admit that I have a lot of time for Self and his powers of rational thought. I think the concept of a blameless amplifier is a useful one in an audio systems context. I admire his patience in dealing with the seemingly intractable supply of sloppy thinking which has been directed at him recently.

However, I am not sure that a debate is even necessary because there isn't a problem. All we are trying to do is amplify a waveform over a relatively small voltage and frequency range by electronic standards – a straightforward control problem.

Audio is not the only area in which feedback is used in a control system. These crop up in countless aerospace, marine, defence and industrial applications. Why is it that there is debate about the criteria for stability in these communities?

In reality, audio is seldom designed as a system. Too much effort is expended in one area and not enough in another. To debate amplifiers is missing the point. Today's amplifiers have been refined to the point where they can be blameless, yet they are invariably connected to loudspeakers which are as blameless as Atilia the Hun.

Most of today's hi-fi loudspeakers produce distortions, both linear and non-linear, which exceed those of amplifiers by orders of magnitude, yet they are never quoted. Try putting a squarewave into a loudspeaker and see what comes out – generally garbage.

I have yet to find a passive crossover which can meet the criteria of blamelessness. If you own a blameless amplifier with only one channel per loudspeaker you cannot hear blameless audio.

Cabinet resonances and other energy storage mechanisms add a layer of grime which swamps the non-linearity and the step response does not necessarily indicate what is on the other side; thus the seemingly inexhaustible supply of blameless amplifiers and any debate about them is a complete waste of time. All that can be done is to make them cheaper. As Self says, there are better things to do.

John Watkinson
FAES

Updates

Bigger bass smaller box

These are corrections to Fig. 1 of Jeff Macaulay's full-range loudspeaker design, 'Bigger bass, smaller box', which appeared in the June issue.

There are several resistors marked R93, R94. All of these are 10k except the Rp associated with A6. This is 22k. Capacitors C25, C26 are 10uF decoupling for the op-amps.

Resistors R103, R92, listed as 100k, were originally used to further decouple the op-amp supply pins. Due to persistent problems with 12V regulator parasitics, Jeff finally increased these to 2k2 and connected them directly to the supply lines.

Probing for switching losses

Due to typographical errors, the term mAs instead of µAs occurred several times in the article 'Probing for switching losses' in the October issue. All the errors occurred on page 832 and are as follows – 76.5mAs, line 35, 8mAs, line 48 and 8mAs/50 line 51. Apologies.
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ELECTRONICS WORLD+WIRELESS WORLD
November 1995
Owen Bishop looks at more aspects of dc analysis, including component value sweeping and the pitfalls of simulating oscillators.

Fig. 1. This schematic of a zener diode stabiliser was produced using the SpiceNet software. Node numbers are displayed (in red), except for the ground line, which is node 0. The Y-shaped symbol is an optional way of indicating a test point.

Fig. 2. Intuscope postprocessor software produces an oscilloscope-like display of the dc sweep of the zener stabiliser circuit. The zener, nominally 4.7V, produces a stabilised output at approximately 4.65V.

One useful feature of Spice is its ability to repeat the analysis while sweeping the values of components over a specified range. This allows the designer to check that the circuit is immune to variations due to component tolerances.

Temperature sweeps are used to confirm that circuit operation is reliable within a specified temperature range. Sweeping the value of a voltage source provides a convenient way of investigating the action of the simple zener diode voltage stabiliser of Fig. 1.

Nominal supply voltage (V1) is 6V, as shown in the IsSpice netlist, Table 1. For the dc analysis it is swept from 0V to 7.5V in steps of 2.5V. This more than covers a ±25% variation in supply voltage to the regulator. This netlist has a line beginning with the command 'include'. This is not a Spice command, which is why it is preceded by an asterisk, but is a direction to an IsSpice pre-processing routine to use the 'Diode.Lib' file to obtain the model for the diode.

Run the simulation, exit the analysis, then select Edit Text File. Clicking the 'Out' button displays the output file. As well as listing the netlist with the diode model expanded, the file has a table of thirty values of V(1) against V1, from which one might expect. Table 1 shows that V(1) is equal to V1 for all values of V1 up to 4.25V. From then on, current begins to flow through the diode and V(1) shows relatively small increases, finishing at 4.65V when V1 is 7.5V. The effect is best seen on the Intuscope display, Fig. 2.

Having seen that stabilisation is satisfactory with regard to supply voltage, the next step is to investigate the effects of varying the load. As well as a load resistor R2, Fig. 3 has an additional dummy voltage source, sometimes referred to as a current meter. Spice computes node voltages but not branch currents.

In a simple circuit such as this it is easy to read off the voltages at node 2, and use a calculator to divide by the resistance of R2. This gives the currents through R2 at each step of the sweep, but results of such calculations are not then available for plotting by the computer.

As noted last month, Spice calculates the currents through voltage sources. If there is an active voltage source in a branch, find the current by asking Spice to PRINT or PLOT I(Vname), where Vname is the name of the source. If there is no active voltage source in the branch, place a dummy source there. This adds a complication to the netlist, but is the only way to get Spice to calculate the required current.

Some Spice-based simulators automatically calculate current through all devices, and this manoeuvre is not necessary. There is no active source in series with R2, so the netlist, Table 2, shows a dummy source V2, voltage 0V. The new circuit has different
node numbers, so the stabilised output is now from node 2. The command to sweep V1 is the same as before, but the .PRINT command now includes the output voltage and the current through the dummy source.

Spice can plot two or more quantities simultaneously, but plots them all on the same scale. Because the magnitude of the current is much less than that of the voltage, they need to be plotted separately, using two PLOT commands. Incidentally, the PRINT command is not essential, because the plots show all that is required. The reason for including it is that Intuscope takes its data from .PRINT, not from .PLOT, and it is intended to use Intuscope after the analysis to show voltage and current on the same axes.

Running the simulation produces a plot of V(2), formerly V(1), almost identical to the previous one, shaped like Fig. 2. When V1 is 5V or more the current through R2 is steady at 46uA - this is to be expected as R2 has a high value. Return to IsEd, edit the netlist to make R2 equal to 8.2kΩ and re-run the simulation. The current is now a more-or-less steady 560uA, varying from 542uA when the supply is 5V to 565uA when the supply is 7.5V. Try for a greater output current by re-editing R2 to 4.7kΩ - stabilisation does not occur until the supply is 6V or more. Fig. 4. Intuscope plots the output voltage and current on the same axes but with different scales, Fig. 5.

Double sweeping
In dc analysis, Spice is able to sweep two voltage or current sources simultaneously. The two sources and the extent of their sweeps are defined in the command line. The first source, inner variable, is swept over its whole range at each step in the sweep of the second source, outer variable.

Figure 6 shows a circuit for finding the transfer characteristic of a mosfet by sweeping the drain and gate voltages and measuring the resulting source current. The netlist, Table 3, refers to the preprocessor to the mosfet library. Voltage V3 is the dummy source. Gate voltage V1 is swept from 3.5V in 0.2V steps. For each value of gate voltage, V2, drain-source voltage is swept from 0-5V in 0.2V steps.

The printout does not set out results in a way that can be readily interpreted, so a post -processor such as Intuscope is used to view them. This displays a set of curves, Fig. 7, showing the transfer curves of drain current against drain voltage for a number of different gate voltages. Curves from the lowest to the highest represent the drain current against source-drain voltage for each gate voltage from 3V (lowest curve) to 5V (top curve).

Satisfaction current increases with increasing gate voltage. Flat parts of the curve are more widely spaced for higher gate voltages showing that transconductance increases with increasing source current. The same method can be used to plot the transfer characteristic of different transistor types and certain other devices.

Simulating oscillators
The dc analysis of the astable circuit of Fig. 8, netlisted in Table 4, gives an insight into one of the pitfalls of simulating oscillators. At the beginning of an analysis, Spice assumes that all nodes are at zero voltage. Then it runs through a series of iterations to establish the actual voltages, with capacitors open-circuited and inductors short circuited.

To the simulator, all resistors of a given value and all transistors of a given type are identical. Consequently, dc analysis of a symmetrical circuit such as Fig. 8 results in symmetrical voltages at the dc operating point, Table 3. Plotting dc transfer characteristic of an NMOS transistor, using Spice's double-sweeping facility.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Plotting dc transfer characteristic of an NMOS transistor, using Spice's double-sweeping facility.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDBD06 - ZENER DIODE STABILISER, 4.7V</td>
<td>*INCLUDE DIODE.LIB</td>
</tr>
<tr>
<td>R1 1 3 1K</td>
<td></td>
</tr>
<tr>
<td>R2 2 0 100K</td>
<td></td>
</tr>
<tr>
<td>D4 0 3 DN750</td>
<td></td>
</tr>
<tr>
<td>V1 1 0 0</td>
<td></td>
</tr>
<tr>
<td>V2 3 2 0</td>
<td></td>
</tr>
<tr>
<td>DC V1 0 7.5 0.5</td>
<td></td>
</tr>
<tr>
<td>PRINT DC V1</td>
<td></td>
</tr>
<tr>
<td>PLOT DC (V1)</td>
<td></td>
</tr>
<tr>
<td>PRINT DC (V2)</td>
<td></td>
</tr>
<tr>
<td>PLOT DC (V2)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Load resistor and dummy voltage source, added to stabiliser Fig. 1. Source V2 has zero output, but is included so that the load current can be measured.

Fig. 4. With a low-value load resistor in circuit, current through the load rises as supply voltage is ramped from 0-7.5V, stabilising between 4.6µA and 4.7µA.

Fig. 5. An Intuscope plot shows how V(2), the output voltage at node 2 (curve 1), and I(V1) the output current through source V2 (curve 2), vary as supply voltage V1 is swept up from 0-7.5V.

Fig. 6. Circuit for measuring the transfer characteristic of an NMOS transistor. Drain-source voltage V2 is swept up from 0-5V at each stage of sweeping the gate-source voltage V1 from 3-5V. V3 measures drain current.
Fig. 9 Outputs (collector voltages) of the astable after it has been stimulated into oscillation by one of the techniques described in the text. After a 1ms settling period, V(2) becomes a square-wave, upper curve. V(5) is in antiphase to V(2), lower curve.

Table 5. Further iterations produce no further changes in the values, so Spice takes this to be the final solution. Because of manufacturing tolerances, such symmetry does not exist in real life. At power-up, the imbalance of the resistances, capacitances and gains causes a real circuit to take on one of its two possible asymmetrical states, with one transistor on and the other off.

As a dc operating point analysis, these results are acceptable, but problems arise when Spice is asked for a transient analysis. It begins by performing a dc operating point analysis and uses the results of this as a starting point for the transient analysis.

In Table 4, the netlist calls for a listing of the voltages at nodes 2 and 5, for a period of 100ms, sampled at 200µs intervals. Spice first of all carries out the dc operating point analysis, and prints the results as in Table 5, but calling it the Initial Transient Solution. A transient analysis which begins with a stable solution may not be able to get any further. In this example, the printout of the Transient analysis gives the expected results, the reason many be something unexpected, the reason many be something unexpected, the reason many be something unexpected.

Table 4. Netlist of the bjt astable, Fig. 8, set up for a transient analysis, with questionable outcome.

Table 5. An astable, Fig. 8, is in a symmetrical but metastable state at its operating point, as this analysis shows. This dc operating point solution is taken as the initial transient solution in a transient analysis.

Node Voltage
1 1.200000e+001
2 1.334727e-001
3 1.334727e-001
4 1.334727e-001
5 1.334727e-001

It is not necessary to provide values for every node but the more values provided, the easier Spice will find it to get the analysis working along the correct lines. Also, the more realistic the values supplied, the more quickly will the analysis converge on to the correct output. With the NODESET command added to the netlist, the Transient analysis gives the expected square-wave output at from both nodes 2 and 5, as shown by Intuscope display Fig. 9.

Fig. 10. This Mathematica-based sensitivity analysis of the filter in Fig 11 is adaptable to a wide range of circuits.
An alternative technique that may be used in circuits which contain semiconductors or switches is to specify that the device is to be in the 'off' state at the beginning of the analysis. This is done by adding the command OFF to the statement. For example, in the netlist of the astable, having deleted the .NODESET line, amend the Q1 line to

Q1 BC109C OFF

The Transient analysis then produces a square-wave output similar to Fig. 9, differing only in detail during the 1ms start-up period.

Another way around the problem, which is more applicable to other types of circuit, is to add a pulse generator to the circuit to 'kick-start' it into action with a single short pulse at time t=0. Having deleted the OFF command, add this line to the netlist.

V2 4 0 PULSE (0 120 00 1M)

This connects a voltage source between the OV line and the base of Q1. The source is defined as a pulse generator, with initial output OV, and a pulse value 12V. The next three parameters define the delay time, rise time and fall time. Delay time is zero so the pulse begins when the analysis starts.

The rise and fall times are given zero value, but a default value TSTEP, the time-step of the analysis, is automatically substituted. The PULSE command associated with Mathematica provides a simple and flexible routine for determining sensitivities, Fig. 10. After calling for the EE 'Master' routines to be loaded, it defines a function vo, which is the output voltage of the low-pass filter shown in Fig. 11. The parameters of the square-wave input are voltages Vt, t, and vi, the input voltage, and the values of the filter components shown in Fig. 11. The function is defined as.

\[ vo = vi \times \left(1 + \frac{rf + ra}{rc}\right) + s + 1/\text{rc} \]

A second function, sensitivity, is defined in terms of a function (func) and a specified parameter (param) of that function. The sensitivity is the first-order differential of the function with respect to the parameter, normalised by multiplying by the parameter and dividing by the value of the function.

The last step in the analysis is to call for a 3-dimensional plot of the sensitivity of vo, in decibels. The notebook has been set up to calculate the sensitivity of vo to capacitance over a range of frequencies. In the statement of parameters, ra, rf, r, and vi are given particular values, but c is left as a symbol. The term \( j \times 10^{6} \text{rad/s} \) is substituted for s - except that Mathematica uses I for j - with the result shown in Fig. 12, overleaf.

On the log frequency scale, numbers correspond to frequencies of 10^Hz. For example, '3' on the scale corresponds to 1kHz. It is seen from this graph that the circuit is relatively insensitive to variations in capacitor value when capacitances and frequencies are high.

This routine is easily adaptable to any other circuit for which the transfer function is known in symbolic form - simply substitute the parameters in the square brackets following vo. The sensitivity function is a general-purpose one applicable to all circuits. To obtain the sensitivity function, substitute actual values for all except one of the parameters. Figures in the first pair of curly brackets set the frequency range, and those in the second pair set the range of the parameter.

Modelling with Spice

Resistors, capacitors, voltage generators and several other component types are specified in a netlist by specifying their connections and values. Components with more complicated behaviour are specified either as subcircuits or as models. A bjt, for example, may be included as a subcircuit consisting of diodes, resistors, a capacitor and voltage-controlled current source.

The subcircuit is filed as one of a library of netlists and is incorporated into a circuit netlist simply by quoting its filename. This is a quick and simple way of modelling 'a transistor'. A sub-circuit is not necessarily defined for a specific transistor, but it is obvious that it can not be expected to behave exactly like any particular type of transistor, for example the BC109C used in the astable circuit of Fig. 8.

For greater precision, Spice provides algorithms for modelling specified types of components much more accurately. In Table 4, the model BC109C is called for, but parameter details are not given. All that is necessary is a reference to the library file in which these details are stored. When the output file is printed following an analysis, the model file is listed in full. In the case of the BC109C, this extra line appears in the output file.

\[ \text{MODEL BC109C NPN (IS=1.02E-14 \ NFE=1.0 BF=845) } \]

The model description gives the model name, followed by its type npn or pnp. Then a number of parameters are listed in brackets. A full Spice model of a bjt specifies 40 parameters, but it is not necessary for the user to assign values to all of these. Each parameter has a default value which is used when an explicit value is not specified.

The BC109C model lists 18 parameters of which only the first 3 are shown above.

Taking these as examples, IS is the saturation current in amps, NF is the forward emission coefficient and BF is the forward current gain.

Similar Spice models are used for diodes, jfets, mosfets, mesfets, and for high-precision modelling of resistors, capacitors, voltage sources, current sources and switches. Many semiconductor manufacturers publish Spice models for use by designers. Spice models give greater precision but they require more evaluation time than a sub-circuit model.
Maximising power transfer in Class-C

Researchers from Ontario challenge a recent statement that maximum power transfer does not occur under conditions of conjugate matching. Dennis Roddy, Oliver Buelow and Rob Williams* present their evidence.

A recent paper by Warren Bruene1 purported to show that maximum power transfer for a class-C amplifier does not occur under conditions of conjugate matching. This view has been challenged in correspondence between us, Bruene and Jack Belrose1. The following investigation was initiated as a result of this correspondence.

Maximum power transfer theorem and conjugate matching

Maximum power transfer theorem2 states that the average power transferred from a source to a load will be a maximum when the load impedance is equal to the complex conjugate of the internal impedance of the source, or \( Z_L = \bar{Z}_S \). Denoting the source impedance by,

\[
Z_S = R_S + jX_S
\]

and the load impedance by,

\[
Z_L = R_L + jX_L
\]

then conjugate matching requires that,

\[
X_L = -X_S \tag{3}
\]

and,

\[
R_L = R_S \tag{4}
\]

The first requirement is simply a statement of series resonance maximising current through the load. The second is obtained by equating to zero the differential coefficient of load power with respect to load resistance giving the \( R_L \) required for maximum load power.

Maximum power transfer theorem invokes very simple concepts with no question of its validity. However, it does imply that the source can be represented by an independent voltage source in series with a linear impedance, Fig. 1a) and Fig. 1b). A dual situation can be developed for an independent current source.

An independent voltage source is a source whose emf is independent of the current drawn from it. Linear impedance is an impedance which is independent of the voltage across it or the current through it. This is a common representation of an equivalent voltage source. In certain instances the source or internal impedance can be identified by some physical element within the source, for example the resistance of the electrolyte and electrodes in a battery.

The voltage equivalent generator described to this point is the key to the understanding of conjugate matching applied to amplifiers. However, the problem of establishing any equivalences between the actual circuit and the equivalent source has to be achieved entirely through external measurements.

If the results of terminal measurements can

---

*The authors are at Lakehead University, Ontario, Canada.
be manipulated into a form consistent with those expected from the equivalent voltage generator, then the source emf and impedance may be identifiable in terms of operating parameters of the amplifier. This is the approach used here for the class-C amplifier.

**Theoretical results for the class-C amplifier**

A thorough analysis of vacuum tube class-C amplifiers is given in a book by Heyboer and Zijstra\(^3\). This work is used as the basis for the following analysis.

The results are sufficiently general to be applied to class-C mosfet amplifiers. Two sets of device characteristics are required - the transfer characteristic, Fig. 2(a), and the output characteristics, Fig. 2(b). For convenience the notation is the same as that used by Heyboer and Zijstra.

These authors derive a number of functions related to the conduction angle shown in Fig. 2(a), and to the index \(k\) where the transfer function is described by,

\[
i = \frac{c}{\sigma_k}\sqrt{v, > 0} \quad \text{and} \quad v, < 0
\]

(5)

For mosfets where \(k=2\), the function of interest is given by eq.(3.23) in Heyboer and Zijstra as,

\[
f(\theta) = \frac{\sin \theta - 1}{\sin \theta - \cos \theta}
\]

(6)

The expression derived for power output, eq.(3.42) in Heyboer and Zijstra is,

\[
W_o = \frac{1}{2} \frac{\sigma_k f(\theta)}{1 + \sigma_k f(\theta)}\sigma_k^2
\]

(7)

In Heyboer and Zijstra, \(R_L\) is used to denote load resistance, \(V_a\) is the steady anode or plate voltage, and \(\sigma\) is the slope of the limit characteristic shown in Fig. 2(b).

Equation 7 can be rearranged as,

\[
W_o = \frac{V_a^2}{2} \frac{R_L}{\left(\frac{1}{\sigma(\theta)} + R_L\right)^2}
\]

(8)

By modelling the amplifier shown in Fig. 1b), where \(R_L\) is the load resistance corresponding to \(R_a\) of Heyboer and Zijstra, power output is,

\[
W_o = \frac{E_o^2 R_L}{R_L + R_a}
\]

(9)

Comparing equations 8 and 9 the equivalent source emf is seen to be given by,

\[
E_s = \frac{V_a}{\sqrt{2}}
\]

(10)

and the equivalent internal resistance by,

\[
R_s = \frac{1}{\sigma(\theta)}
\]

(11)

Internal elements of the equivalent source are given in terms of constant device parameters. This allows the amplifier to be modelled as an equivalent voltage generator.

**Computer simulation**

Since the object of the exercise is to find the load resistance which extracts maximum power from the amplifier, the circuit was kept as simple as possible. A single tuned circuit consisting of \(C\), \(L\), and \(R_L\) in parallel formed the output load.

Class-C bias was obtained from a separate fixed source with the input signal superimposed on this. The basic circuit is shown in Fig. 3. Initially, the simulations were carried out for a number of transistors - a 2N5400 bjt and IRF510 and IRF710 mosfets.

Early on, we found that forward biasing of the collector-base junction occurred in the bjt which obscured results. Also the current drive required for the bjt exceeded the capacity of

---

**Power transfer results for two mosfet types in a Class-C amplifier.**

Legend: \(i\)=subscript ranging from 0 to 5; \(R_L\)=load resistance in \(\Omega\).

<table>
<thead>
<tr>
<th>IRF710</th>
<th>(P_{CAPi})</th>
<th>(P_{SPICEi})</th>
<th>(P_{LABi})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Ω</td>
<td>0.46W</td>
<td>0.55W</td>
<td>0.13W</td>
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<tr>
<td>3.4Ω</td>
<td>0.65W</td>
<td>0.68W</td>
<td>0.33W</td>
</tr>
<tr>
<td>5Ω</td>
<td>0.81W</td>
<td>0.83W</td>
<td>0.5W</td>
</tr>
<tr>
<td>10Ω</td>
<td>1.2W</td>
<td>1.06W</td>
<td>0.62W</td>
</tr>
<tr>
<td>17Ω</td>
<td>0.97W</td>
<td>0.98W</td>
<td>0.40W</td>
</tr>
<tr>
<td>68Ω</td>
<td>0.38W</td>
<td>0.4W</td>
<td>0.09W</td>
</tr>
</tbody>
</table>

\(E_{DD}=7.5V, a=0.3S\) (IRF710), \(E_{DD}=7.5V, a=0.9S\) (IRF510)

<table>
<thead>
<tr>
<th>IRF510</th>
<th>(P_{CAPi})</th>
<th>(P_{SPICEi})</th>
<th>(P_{LABi})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Ω</td>
<td>2.8W</td>
<td>3.06W</td>
<td>0.5W</td>
</tr>
<tr>
<td>3.4Ω</td>
<td>3.4Ω</td>
<td>3.25W</td>
<td>2.1W</td>
</tr>
<tr>
<td>5Ω</td>
<td>3.02W</td>
<td>3.19W</td>
<td>1.9W</td>
</tr>
<tr>
<td>10Ω</td>
<td>2.21W</td>
<td>2.28W</td>
<td>1.3W</td>
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<tr>
<td>17Ω</td>
<td>1.65W</td>
<td>1.65W</td>
<td>0.95W</td>
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<tr>
<td>68Ω</td>
<td>0.47W</td>
<td>0.47W</td>
<td>0.41W</td>
</tr>
</tbody>
</table>

\(E_{DD}=5V, a=0.1\) (IRF710), \(E_{DD}=5V, a=0.6\) (IRF510)

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**November 1995 ELECTRONICS WORLD + WIRELESS WORLD**

965
our test equipment. Because of this, relatively low powered mosfets were chosen to suit the test equipment available.

Another consideration was that of keeping the circuit’s Q-factor constant. A value of 10 was chosen as being representative of practical values and an operating frequency of 1MHz was used. For high quality coils, dynamic resistance of the circuit is given, to a very close approximation by load resistance $R_L$. As a result, the expression for Q-factor is,

$$ Q = \frac{\omega}{RC_R} $$

In the simulations carried out in Microcap and PSpice, values were chosen to be close to the values used in the practical measurements. These are shown below.

**Calculated values for C and L for given $R_L$ values and a fixed Q of 10.**

<table>
<thead>
<tr>
<th>$R_L$ (Ω)</th>
<th>C (nF)</th>
<th>L (nH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>795.8</td>
<td>31.83</td>
</tr>
<tr>
<td>3.4</td>
<td>468.1</td>
<td>54.11</td>
</tr>
<tr>
<td>5</td>
<td>318.3</td>
<td>79.58</td>
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<tr>
<td>10</td>
<td>15.92</td>
<td>159.2</td>
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<tr>
<td>17</td>
<td>93.62</td>
<td>270.6</td>
</tr>
<tr>
<td>68</td>
<td>23.41</td>
<td>1,082</td>
</tr>
</tbody>
</table>

Power output was determined from the peak-to-peak voltage across the tuned load using,

$$ P_e = \frac{V_{PEAK}^2}{8R_L} $$ (13)

The limit-line slope was determined from the output characteristics for the two mosfets used. Resistance $r_{DD}$ shown in series with the $V_{DD}$ supply represents the internal resistance of the battery supply. A value of 0.41Ω was estimated for this in the simulations.

### Measured results

Circuit Fig. 3 was set up in the laboratory with commercially available values selected to be as close as practicable to the $R_L$ and C values shown in Table 1. Coils were wound to the required inductance. Peak-to-peak voltage across the tuned circuit was measured and the power calculated using equation 13.

For a given mosfet the results show the power curves all peak at about the same value of load resistance. For the IRF510, the theoretical value as given by equation 11 is 3.5Ω, and for the IRF710 it is 10.4Ω.

The simulated curves show the power peaking at the same value of load resistance as the theoretical and measured curves, but reaching considerably higher peaks. This may be a result of inadequate modelling of the effect of the series resistance of the battery source. Also, the effect of losses in the tuned circuit were ignored assuming that the dynamic impedance of the tuned circuit was much greater than the load resistance connected in parallel.

Accurate determination of the slope $\sigma$ was not easy as the individual curves peeled off rather gradually from the limit-line. The estimated uncertainty in $\sigma$ is about ±10%. The results clearly show however that peaking occurs at the predicted values of load resistance. Since the circuit was tuned to resonance for each measurement it can be concluded that the maximum power transfer theorem is valid for the class-C amplifier.

Finally, note that this investigation was limited to verifying the conjugate matching condition. No attention was paid to limitations imposed by voltage and power ratings of the transistors, or to the difficulties which might be experienced in practice in trying to achieve the necessary matching conditions.

In recent correspondence from colleague James Diggins\(^2\), who has designed class-C amplifiers ranging from 5-10kW, he states that he has never had to include the internal resistance in his sums. The exception was when it affected the Q of the tank circuit, when a guessed value was used.

### References


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\(^2\) Diggins, J., MBE, is a retired director from Racal Electronics Plc.
<table>
<thead>
<tr>
<th>Issue (Month/Year)</th>
<th>Quantity</th>
<th>Price</th>
<th>Total</th>
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Ian Hickman explains how to get the best out of opto-electronic emitters and detectors.

Opto-electronics has come a long way since the days of vacuum photocells with caesium or silver cathodes. Nowadays semiconductor photodiodes of silicon, gallium phosphide or GaAsP are almost universally employed, except in certain specialised applications, such as photometry, where photomultiplier tubes are often found.

Compared to early light sensitive cells, semiconductor photodiodes are small, inexpensive, stable and easy to use. However, there are a variety of types and a knowledge of their characteristics is needed if they are to be applied successfully.

Solid state photo-sensors

Silicon is the commonest material for photodiodes. It is used in various types covering the spectrum from ultra violet to infra red. Light energy impinging upon the diode creates hole-electron pairs, giving rise to a current. The more light energy, the larger the current, the ratio being a function of the material, and hence independent of the area of the diode.

Figure 1 shows sensitivities of some typical silicon photodiodes to light as a function of wavelength. It is clear that the sensitivity is greatest at longer wavelengths - in the infra red - with maximum sensitivity typically being in the range 0.5-0.6A per watt. At longer wavelengths still, sensitivity falls off rapidly. This is because each individual photon has insufficient energy to create a hole/electron pair in the material.

The formula relating the energy of a photon E to its frequency f, is $E=hf$, where h is Planck’s constant. From this it seems evident that once the photon energy was large enough to create hole/electron pairs – i.e. in the infra red – the response should remain constant or even increase with frequency. Energetic, very short wavelength, photons perhaps create more than one hole/electron pair. But in fact, as Fig. 1 shows, the reverse is the case. The reason becomes clear when the detailed operation of a silicon photodiode is considered.
How silicon photodiodes work
Figure 2a) shows—diagrammatically and not to scale, for clarity—the cross section of a typical planar diffused silicon photodiode. Incident light creates hole/electron pairs.

Under the influence of the potential barrier represented by the depletion layer, electrons liberated in the P layer migrate to the N layer while holes created in the N layer move in the opposite direction, Fig. 2b). This creates a current which flows through the external circuit if the diode is short-circuited, or notionally through the diode itself. If the diode is open-circuited, this establishes a voltage across it, Fig. 3a). Thus the diode can be represented by the equivalent circuit of Fig. 3b).

When load resistance $R_L$ is open circuit, the illumination causes a voltage across the diode. As with any diode this is logarithmically related to current, and shows a temperature coefficient of about $-2mV/°C$. Consequently, open-circuit operation is unsuitable for light intensity measurements.

By contrast, in the short-circuit case, the current $I_L$ due to the internal gain—up to $\times 100$—enables the diode to be used in a Fig. 4a) type circuit, with a much lower value of $R_L$ compared to a normal photodiode.

Small-area silicon avalanche diodes, operated with $R_L=500\Omega$, can achieve a cut-off frequency in excess of 1GHz, due to their low junction capacitance of around 2pF. Other types include Schottky junction photodiodes fabricated in GaP or GaAsP, offering high sensitivity well into the ultra-violet region.

Returning to the variation of sensitivity with wavelength, Fig. 2a) indicates that longer wavelength radiation penetrates further into the material than shorter wavelength radiation, due to absorption. The shorter the wavelength, the greater the degree of absorption of light within the surface diffusion layer, leading to reduced sensitivity, since most photons do not reach the depletion layer. In silicon photodiodes with enhanced ultra-violet sensitivity, therefore, the surface diffusion layer is made very thin. As a result, the depletion layer is very close to the surface.

Using silicon photodiodes
Figures 4a) and b) show two ways of operating silicon photodiodes in the current measuring mode, i.e. with and without reverse bias. In Fig. 4a), reverse bias results in fast response to light pulses, making the arrangement attractive for high speed data links.

On the down side, linearity is poorer, noise of $I_L$ due to the internal gain—up to $\times 100$—enables the diode to be used in a Fig. 4a) type circuit, with a much lower value of $R_L$ compared to a normal photodiode.

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DESIGN BRIEF

greater and leakage via $R_{an}$, Fig. 3a), results in a dark current in the absence of illumination, although $R_{an}$ is typically in the giga-ohm range. The arrangement of Fig. 4b) requires no bias source, and is very common. The high gain of the op-amp ensures a near perfect virtual earth, resulting in no voltage appearing across the diode and hence no dark current. However, the op-amp's bias current at the inverting input has to be supplied via $R_{i}$. As a result, if $R_{i}$ is made large in order to secure high gain and high sensitivity, then an op-amp with very low input bias current is necessary.

Sensitivity of silicon photodiodes, illustrated in Fig. 1, is the steady state or dc response. It varies as a function of the wavelength of the light as shown. However, the ac response, when the intensity of the light varies at some frequency or other, is a little more complex. This is due to a characteristic of silicon already mentioned.

The transit time of carriers liberated within the depletion layer is determined by the potential gradient therein. In turn, the gradient is set by the voltage across the layer. This may be the band gap voltage in a Fig. 4b) type circuit, or an externally applied bias as in Fig. 4a). But carriers liberated outside the depletion region are not subject to this potential gradient and hence take much longer to diffuse to the anode, or to the cathode as the case may be.

Response is slower at infra-red

As Fig. 2a) illustrates, longer wavelength radiation penetrates more deeply into the silicon. As a result, energy in the infra-red may release carriers in the bulk of the material, having passed right through the depletion layer before creating hole/electron pairs. Thus when infra-red illumination first strikes the diode, current due to carriers liberated in the bulk region appears at the terminals later than the component of current due to carriers liberated in the depletion region. At shorter wavelengths, where the luminous energy does not penetrate so deeply, this effect is much reduced or even absent entirely.

Response speed of a photodiode, expressed as the rise time $t_r$ is determined by three factors. Time $t_r$ is related to cut-off frequency $f_c$ by the approximate relationship $t_r = 0.35/f_c$. The first of the three factors is the time constant formed by the diode terminal capacitance $C_t$ — including the junction and package capacitance and any circuit strays — and load resistance $R_L$. The second is the transit time of carriers released in the depletion region, and the third is the diffusion time of carriers released outside the depletion layer, which as noted above move much more slowly.

Experimenting with opto-electronics

To investigate some of the above effects in a practical way, I carried out some experiments using a Semelab silicon photodiode type SMP600G-EJ. This 4-by-4mm square silicon die has an effective area of 14.74mm², a responsivity at 900nm of 0.55A/W and a capacitance at 0V reverse bias of 190pF.

The device is mounted in a two lead TO39 package with a standard glass window. I connected it in a Fig. 4b) type circuit. The actual arrangement is shown in Fig. 5a), using a TI internally-compensated TLE2061 op-amp.

In a photographic darkroom, the photodiode was illuminated by a light source modulated at about 1.2kHz, which is shown in Fig. 5b). For this purpose, the red led — a 3000mcd high brightness type — is used.

Figures 6a) and 5a), the latter has provision for a capacitor $C_f$ in parallel with the feedback resistor $R_f$ Figure 6a) shows the output of the op-amp when the photodiode is illuminated by the led, at a suitable level. Capacitance $C_f$ is not in circuit and severe ringing is evident.

One advantage of the circuit Fig. 4b) is that, as the photodiode is connected to a virtual earth, $R_L$ is zero. The first factor limiting the speed of photodiode response mentioned earlier — the time constant $C_fR_f$ — is apparently eliminated. Thus the speed of response should be limited only by the other two factors. But while the large gain at 0Hz ensures an ideal virtual earth in the steady state, as the frequency increases, the gain of the op-amp falls. As a result, a finite drive voltage is now required at its inverting input.

The op-amp’s gain typically falls at 6dB/octave beyond 10Hz, for example in an internally-compensated op-amp with a single dominant pole. This is associated with a 90° phase lag. The passive CR circuit comprising $R_L$ and $C_f$ contributes another ~6dB/octave roll-off and 90° phase lag at frequencies well beyond its ~3dB corner frequency. If this occurs well below the op-amp’s unity gain frequency — as it usually does — then at the frequency where the op-amp gain equals the attenuation through the CR feedback circuit, the loop gain is unity and the phase shift perilously close to 180°. The circuit therefore exhibits a gain peak at this frequency, and the fast edges of the square wave illumination excite this and cause the ringing observed.

Adding $C_f$ provides a phase advance, reducing the loop phase shift and avoiding the ringing, Fig. 6b). The appropriate value for the circuit of 5a) was found by experiment to be 2.2pF, the rise time being about 40µs. In this case, the response speed is limited by the characteristics of the op-amp, not by the transit time of carriers released in the depletion region. Substituting a faster one naturally improves matters.

Figures 7a) and b) show performance with the same light source and photodiode, but with a decompensated version of the op-amp, a TLE2161, substituted for the TLE2061. Faster response is illustrated by the much higher frequency ringing in Fig. 7a), where $C_f$ is 0.9pF, and by the reduced rise time of about 11µs in b), where $C_f$ is 0.9pF, i.e. two 1.8pF capacitors in series.

Figures 8a) and b) show the effect, mentioned earlier, of carriers released outside the
depletion region by long wavelength radiation, which penetrates further into the material. In a), the illumination was from chopped light from an ‘ultra-bright’ 590-345 green led, and the edges of the waveform are square.

In b), the illumination was from an infra-red emitting GaAlAs diode type TIL901. The majority of the response is due to carriers released in the depletion region, and hence is as prompt as in a). But the output then rises – or falls – further, due to the much slower diffusion of those carriers released outside the depletion region.

When using silicon photodiodes, the amplifier will often be the limiting factor as far as frequency response goes. The exception is when using a photodiode – especially a low capacitance type – in a Fig. 4a) type circuit with a low load resistance. This allows a wide-band rf amplifier to be used in place of an op-amp. However, the low value of load resistance implies a relatively low sensitivity, so when detection of very low light levels is desired, a Fig. 4b) type circuit is used.

Since designers often demand both high sensitivity and wide bandwidth, any method of extending the bandwidth of Fig. 4b) is welcome. In this circuit, as the frequency rises, the op-amp gain falls, thus requiring a larger drive voltage at its inverting input – the virtual earth fails.

Extending bandwidth
Instead of adding capacitor \( C_t \) to prevent ringing, one could in principle extend bandwidth by simply adding a negative capacitance \( -C_t \) in parallel with the photodiode. I tried this using the circuit of Fig. 9a), and it works. The snag though is that the op-amp used to provide the negative capacitance \( A_2 \) needs to have a considerably greater bandwidth than the original amplifier \( A_1 \). So if you have such an op-amp, it is simpler to use it at \( A_1 \) in the first place and forget about negative capacitance. There is however a practical way to increase bandwidth – by about a factor of 3.

This is shown Fig. 9b), applied to an integrated photodiode/op-amp encapsulated in clear plastic, Burr-Brown type OPT211. Driving the anode of the photodiode reduces the effect of its capacitance upon circuit bandwidth. With \( R_f \) at 1MO and \( C_f \) at 1pF, a bandwidth of 150kHz is achieved.

Note that \( C_t \) includes the self capacitance of resistor \( R_f \) – a separate component may not in fact be necessary. Buffer bias current is supplied via \( R_f \), and so should be negligible if a dark offset voltage is not acceptable. The P-channel buffer shown meets this requirement, while also ensuring that the anode of the diode is at ground voltage or below.

The buffer bandwidth should be at least 4MHz. The two alternative buffers shown both have disadvantages, which may not be important depending on the application. The Darlington buffer bias current will result in a dark voltage offset, while the op-amp buffer’s noise may degrade the overall noise performance slightly.

Optical links for data
Photodiodes are often used as part an optical signalling link, handling digital data such as the channel selection information of a tv remote-control handset. Here, only the variations of incident light – the data – are of interest.

Steady ambient light produces a photodiode output which must be ignored – even if its

---

Fig. 8a) Output of the the circuit of Figure 5 a) (using the TLE2061) when illuminated by light from a green led (3mm ultra-bright green, 590-345). b) As a) but receiving light from an infra red led, T.I. GaAlAs IR diode TIL901. Note the delayed contribution from carriers released in the bulk material, outside the depletion region.

Fig. 9a) Increasing the bandwidth by connecting negative capacitance in parallel with the photodiode. b) Increasing the bandwidth by bootstrapping, applied to an OPT211 integrated photodiode/op-amp type.
level should change. Simple ac coupling of the photodiode op-amp output may suffice. If need be, a sufficiently high I.f. cutoff can be added to suppress 100Hz ripple due to artificial lighting. But with a high sensitivity system, where $R_f$ is large, bright ambient light may saturated the op-amp's output.

The circuit of Fig. 10 can reject very bright ambient light, yet provide high ac gain for best signal to noise ratio. This is possible because of the very large linear range of a silicon photodiode. The auxiliary op-amp keeps the OPT211's mean output voltage at zero and thus the offset due to the photodiode. The auxiliary op-amp keeps the photodiode op-amp output may suffice. If need be, a sufficiently high I.f. cutoff can be added to suppress 100Hz ripple due to artificial lighting. But with a high sensitivity system, where $R_f$ is large, bright ambient light may saturated the op-amp's output.

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Allen Brown looks at a piece of software designed to help teach and learn engineering mathematics.

Mathplus or minus?

Mathematical software packages are an essential tool for aiding design and performing modelling or simulation processes. Since the teaching and learning of maths can be an arduous process, such packages can be of enormous benefit to students and engineers. One such package is Mathplus, from Waterloo Maple of Canada.

Based on the Maple kernel—reviewed in the May 1995 issue, p379—MathPlus is able to perform symbolic and numerical operations. Versions are available for the pc, running under Windows, and Mac.

MathPlus differs from packages such as MathCAD in that it is primarily a teaching aid. When performing an integration in MathCAD for example, the user merely expresses the integral, clicks on ‘evaluate’ and there’s the symbolic result. In MathPlus the user is expected to provide the necessary substitutions in the intervening steps, Fig. 1.

It is possible to manipulate equations, perform substitutions, expand expressions, and carry out a variety of other functions. In addition there is a wealth of graphing options including three-dimensional plotting and animation, which is very easy to set up.

User access via palettes

To help the user to access the many features of MathPlus there are two palettes. Figure 2 shows a typical palette incorporating a number of functions. One obvious icon which is absent is the derivative d/dt. Each time it is required, the user has to type it in—excluding the sets of brackets.

There is a D operator which, according to the manual, does the same task, but as far as I can see, it seems quite useless. The palette does have a partial derivative, but its use, as illustrated in the examples provided, is unconventional. Partial derivatives are not the same as whole derivatives and should not be treated as such.

One useful feature is the option for rearranging equations. Given an equation you can make any variable appearing in it the subject, provided it does not appear more than once. Figure 3 shows an example of making x the subject using the isolate option.

Once a function has been defined it is possible to generate a table or a graph of the function. This table can be stored on disk for future processing. In fact there are several algebraic manipulation operations available—typically the operations that you would use when applying algebraic operations on paper. The difference is that MathPlus tells you when you go wrong or attempt to make a mistake.

Performing an integration

\[ \int \frac{1}{x^2+1} \, dx \]

\[ \int \frac{1}{x^2+1} \, dx = \left( \frac{\sec u}{\tan u} \right)^2 + 1 \]

\[ \int \frac{1}{x^2+1} \, dx = u \]

\[ \int \frac{1}{x^2+1} \, dx = \arctan(x) \]

\[ x = \tan(u) \]

\[ u = \arctan(x) \]

\[ (\tan u)^2 + 1 = (\sec u)^2 \]

Making x the subject of the equation

\[ y = \sqrt{\frac{23.5}{x^2 - \alpha + 3 + \frac{4}{\beta}}} \]

\[ x = \left( \frac{23.5 - y^2 - \frac{4}{\beta} + \alpha}{\beta} \right)^4 \]

Plotting in three dimensions

Graphics options on MathPlus are impressive and easy to use. Once a function has been defined it is highlighted. When the graphics icon in the palette is clicked, the plot appears instantly.

Several traces can be added to the same graph. Each graph has a number of icons that allow the user to change the settings—axis, scales and zoom. MathPlus allows you to visu-
Numerical integration options are far more convincing. You have a choice of two integration algorithms — the fourth order Runge Kutta or the Euler. The Euler algorithm does not achieve the same degree of accuracy but is much faster in execution.

If you attempt to solve a system of simultaneous differential equations with cross coupling non-linear terms, they can be solved without having to convert them into difference equations. An example of this in operation is shown in Fig. 6, which illustrates the relaxation oscillations in a laser resonator.

Other features
MathPlus also has provisions for matrix manipulation, solving sets of simultaneous equations, finding Eigenvalues, dealing with Bessel functions and generating series. This includes Taylor and summation series for solving differential equations.

Wildcard variables can be used for generating certain types of polynomial series. MathPlus uses a scheme of notebooks in which the user can enter both equations and graphs. These can be customised.

To help the newcomers there is a number of preconstructed notebooks supplied with predesigned palettes for specific applications. For example there is a notebook for easing the task of performing Laplace transforms. Each notebook contains helpful notes for the application in hand. I can foresee third parties producing notebooks for a variety of teaching and learning applications.

To help new users to become acquainted with the package, two manuals are supplied — the Learning Guide and Reference Manual. The Learning Guide provides numerous examples aimed at helping new users gain confidence in using the package. The help menu is a standard Windows format — adequate for most queries.

Summary
If you are looking for a software package for teaching or learning mathematics then MathPlus will not disappoint. The learning curve needed is gentle, although to use the product efficiently you have to remember a number of quirky features and key strokes — use of the escape key for example.

MathPlus will certainly find favour among first year students, whose exposure to maths teaching has not been appropriate for an engineering degree course. It will not only be first year students that benefit from MathPlus but also candidates sitting both A level maths and physics.

The package should also appeal to engineers who — for whatever reason — need to brush up their maths with a minimum of effort.

Availability
MathPlus is available from Robinson Marshall Europe plc at a single user price of £199 exclusive of VAT and UK postage £5.99. This includes free unlimited technical support. There is a secondary school unlimited site licence at £995.

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CIRCLE NO. 143 ON REPLY CARD
Gerard Moloney outlines how he developed a C++ library for performing geometric transformations.

Within all fields of engineering, matrices are widely applied in a wide variety of settings – in particular within electronic and electrical engineering. They provide a powerful tool in areas such as network analysis, and can generally be applied to solve simultaneous equations. In addition, matrices are useful in situations requiring geometric modelling, such as image processing and cad/cam.

With the advent of computer systems, the study of numerical processing and the development of associated software has become a major topic in its own right, with extensive libraries available commercially, primarily written in Fortran.

This article outlines the development of a C++ matrix class, and specifically a hierarchy of classes for geometric transformations. Its purpose is to look at providing an intuitive design for matrix applications and to discuss issues that arise in trying to provide a generic matrix class based on the C++ template mechanism.

Eventually we decided to concentrate on a specific application, namely geometric transformations as there we had an immediate requirement for development in this area. The resulting library for two dimensional transformations is outlined below.

Geometric transformations
In the elementary study of matrices, a graphic application of their use is in the transformation of geometric objects. ‘Transformation’ generally means the movement and/or sizing of an object.

There is a set of standard transformations, which can be expressed as matrices. Likewise, as the coordinates of a point in space can be expressed as a matrix, this allows matrices and their associated algebra to be presented in a familiar and visual setting.

Rotation of a point about the origin is shown in Fig. 1. It is the set of standard transformations and their associated algebra which we wish to map intuitively onto our classes.

Specifying the library
Prior to the design phase, a number of factors emerged which were thought to be of practical importance with respect to applications to which the library was being applied. Initially, there was a requirement for the library to parallel very closely, the algebra of linear transformations. Optimisation was also required to avoid unnecessary pointer de-referencing and calls to the standard maths library.

In a number of respects, these mirror considerations must be considered generally during library development. In all cases there should be some compromise between performance and generality. Bearing this in mind, the set of classes for two dimensional transformations was developed, taking as a starting point a general matrix class that had previously been prototyped.

Library hierarchy
The hierarchy for the library, Fig. 2, forms a simple inheritance structure with all classes being derived ultimately from the matrix class. Two subsets divide the library into geometric primitives and transformations.

Homogeneous and non-homogeneous transformations.
By its very nature, a transformation may or may not map the origin onto itself. Those that do, such as rotations are termed homogeneous, whilst those that displace the origin to another point, such as a translation, are termed non-homogeneous. Intuitively it can be seen that if the origin is rotated it remains at the same point, whereas if moved by so many x and y units it obviously does not. To represent both these types of transformations for two dimensions it is necessary to employ 3 by 3 as opposed to 2 by 2 square matrices.

Whereas for homogeneous transformations we have:

\[ x' = ax + by \]
\[ y' = cx + dy \]

with non-homogeneous transformations the formula also contains a third constant value:

\[ x' = ax + by + e \]
\[ y' = cx + dy + f \]

and our matrix algebra correspondingly changes from

\[
\begin{bmatrix}
    x' \\
    y'
\end{bmatrix} = \begin{bmatrix}
    a & b & e \\
    c & d & f \\
    0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
    x \\
    y \\
    1
\end{bmatrix}
\]

The point \( p \) can be represented by the column matrix

\[
\begin{bmatrix}
    x \\
    y
\end{bmatrix}
\]

and the rotation through the angle \( A \) by the square matrix

\[
\begin{bmatrix}
    \cos A & -\sin A \\
    \sin A & \cos A
\end{bmatrix}
\]

and the point \( p' \) is the matrix product,

\[
\begin{bmatrix}
    x' \\
    y'
\end{bmatrix} = \begin{bmatrix}
    \cos A & -\sin A \\
    \sin A & \cos A
\end{bmatrix} \begin{bmatrix}
    x \\
    y
\end{bmatrix}
\]
Matrix class.

As mentioned earlier, the matrix class forms the basis from which both geometric primitives and transformations are derived. It is a class template which provides a basic matrix implementation as follows,

template < class T, int x, int y >
class matrix{
protected:
    T data [x] [y];
    int row;
    int col;
public:
    matrix(): row(x), col(y) {} 
    virtual ~matrix() {} 
};

This allows matrices of any type and size to be declared — the two integer arguments specifying the matrix row and columns.

Using this as a base, specific matrix types can be derived to represent both geometric primitives and transformations. In this instance the combination of templates and derivation provides a powerful mechanism — in effect allowing precise specialisation to be defined to a very generic concept.

Note that a minimal number of functions is provided by the base class. Support for the multiplication of matrices is provided in the derived classes. This is the organisation chosen to ensure that only valid operations are performed without the need to resort to some type of run-time type checking.

Derived geometric primitives

The fundamental geometric primitive is a point:

class point:public matrix< float,3,1 >{
public:
    point():matrix< float,3,1 >(data[0][0]=0, data[1][0]=0, data[2][0]=0);
    point(int a, int b):matrix< float,3,1 >(data[0][0]=a, data[1][0]=b, data[2][0]=1);
    ~point(){} 
};

Default arguments are provided for the template, and thus a point is defined as a 3 by 1 float matrix. Used throughout, this approach provides a solution to the perennial problem of declaring arrays of varying size. It is also equivalent to explicitly declaring an array, as follows,

float point [3][1];

As both homogeneous and non-homogeneous transformations are provided for, points are defined as 3 by 1 as opposed to 2 by 1 matrices — refer to panel.

Having defined a point, other objects are specified by their vertices. Two approaches are taken, whereby both a general polygon class and specific object classes are provided.

('//General base class for two dimensional objects.
//Polygons are specified as arrays of points.

class polygon{
    point* pt;
    int size;
public:
    polygon(){};
    polygon(point* p,int sz):pt(p), size(sz) {} 
    virtual ~polygon(){};
    point operator[](int x){return *(pt+x);} //return specified vertex.
    friend class transformation;
};

//A triangle: array of points explicitly declared.

class triangle:public polygon{
    point vertices[3];
public:
    triangle();
    triangle(point a,point b,point c){vertices[0]=a;vertices[1]=b;vertices[2]=c;}
    ~triangle(){} 
    point operator[](int x){return vertices[x];};
    friend class transformation;
};

Fig. 2. Hierarchy forms a simple inheritance structure, with all classes derived from the matrix class. Subsets divide the library into geometric primitives and transformations.

In this way it is possible to avoid the need to de-reference pointers where this is a requirement. Users may likewise derive their own classes in a similar fashion. A flexibility in approach is thus maintained, while the underlying principle — namely that all objects are defined by their vertices — is adhered to.

Transformations

Having defined all geometric primitives in terms of points it is necessary to implement transformations on the points. A base transformation class is declared as follows,

class transformation:public matrix< float,3,3 >{
public:
    transformation();
    transformation();
    virtual point operator*(point& pt)
    virtual line operator*(line& ln);
    virtual triangle operator*(triangles& tr);
    virtual polygon operator*(polygons& pol);
    virtual transformation operator*(transformations& xform);
};

Operators are provided for the multiplication of points, polygons and specifically lines and triangles. Composite transformations are also provided for. These can be combinations of any of the derived transformations. Providing these operators ensures that illegal operations are not allowed, for example the multiplication of two primitives together.

With the algebra of the library in place, we can now proceed to declare a full list of standard transformations including rotations, reflections, enlargements, shears and translations. Also, where possible, optimisations are provided for in order to avoid calls to sine and cosine functions. Examples are found in the case of rotation through 90° and reflection in the x or y axis.

The derived classes are very simple, requiring only constructors and destructors —

//The rotation class: rotation by angle theta in radians


class rotation:public transformation{
public:
    rotation();
    rotation();
    rotation(angle theta);
    rotation();
};

Constructors supply appropriate values for the matrix data and all multiplications are dealt with by the base transformation class.

It is now possible to create and manipulate our primitives in a highly intuitive manner —

//create a point and rotate it

    point pt1(100,100);
    rotation rl(pi/4);
    pt1=pt1*rl;

//create a line and move it

    _line ln1(point(0,0),point(100,100));
    translation tl(40,60);
    ln1=ln1*tl;

//do composite transformations

    triangle trl(point(100,0),point(150,50),point(150,-50));
    ttrl=trl*tl*trl;
and the results can be output to an appropriate display/device driver.

Conclusion
As stated at the outset, the library evolved from investigating templates per se. By using a combination of templates and derivation, a very intuitive solution was developed fairly quickly in this particular area — one which has been extended to three dimensional transformations.

As far as general matrices are concerned, one problem encountered was in providing arithmetic operators that could be implemented universally for matrices defined in terms of class templates. For example, how can multiplication be simulated when matrices are defined in terms of function templates, their arguments being in this instance, matrices. The concept could be extended to cater for a range of algebraic structures to which a given set of operations could be applied.

Further reading
When Performance is more important than size: two new re-programmable BASIC Stamp Computers

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ELECTRONICS WORLD+WIRELESS WORLD November 1995
Optical devices
Bright blue leds. Blue leds in a range from Sibian AG of Switzerland put out 200, 400, 600 and 1000mc at 450nm. They take 20mA from 3.6V, optional resistors being incorporated for higher voltages, and have clear or blue Fresnel lenses to give a 150° viewing angle. These leds are said by sloan to be brighter than some filament bulbs, the 1000mc type still emitting 1000mc at 2mA. Roxburgh Electronics Ltd. Tel., 01724 201770; fax, 01724 281650.

Fast silicon diodes. Prepared hands are said to get 65% faster than the competition's and up to 30% cheaper. They have densities of 64, 256 and 512bit and include programmable almost-all and almost-empty flags to output enable on an additional pin. Integrated Technology Ltd. Tel., 01372 637373, fax, 01372 378851.

Low-power flash cards. Epson announces a range of PCDMIA Type 1 flash memory cards in sizes from 4Mb to 2Kbyte. Current consumption of the ATA card is 500µA in sleep mode and 60mA/100mA for read/write, no dc input being needed to write. Start-up time for sleep-to-ready and read-to-ready is 20ms. Epson. Tel., 01442 227222; fax, 01442 227244.

Microprocessors and controllers
Temperature controller. The BTC-2220 Fuzzy Logic and PID controller from Brainchild enables a process to reach a set temperature in a short time with little overshoot or external load disturbance. A 4-digit display indicates the process value and three keys on the front panel for control and input parameters, of which those accessible by the user can be limited by, say, a supervisor. Power is 12-36V or 9-24V and output is a 3A control relay and alarm, a 4.2VmA current loop or 0-10V. The instrument is programmable for various sensors and NTC450 communication is provided. Brainchild Temperature Controllers Ltd. Tel., 01903 216514; fax, 01903 216662.

Motor control. NEC's µPD7985B is a 16-bit microcontroller, a member of the 72K family, which is designed for the pwm control of motors at frequencies up to 400kHz and for controlling dc motors and uninterruptible power supplies, being equipped with three pairs of pwm timers. Since these functions use only a small part of its processing power, the device is also able to perform other processing tasks for the other parts of the system. Minimum instruction cycle time is 125ns. Sunrise Electronics Ltd. Tel., 01908 263999; fax, 01908 263003.

Real-time multi-tasking. MultiTRAX and MegaTRAX by Aries are claimed to be "the ultimate controllers for real-time response". Using code written in Basic or C, they have five features which, we are told, are synergistic: a run-time compiler for speed; multi-tasking; hardware interrupts, commands to insert machine code into Basic programs; and extended commands for the five optional hardware modules. Development time is low, since the code development system is built in. Aries Electronics (Europe). Tel., 01908 260007; fax, 01908 260008.

Sequent PIC microcontroller. The new mid-range PIC16C621 8-bit controller by Microchip has a range of analogue features including two voltage comparators, a voltage reference and 4V brown-out protection it is an eeprom-based microcontroller and the 1K by 14 one-time programmable memory allows rapid response to code changes and quick verification. The device is supported by development aids, both by Microchip and others. Arizona Microchip Technology Ltd. Tel., 01628 851077; fax, 01628 850259.

Oscillators
"Smallest" crystal oscillator. AVX claims the new 125-355ppm oscillator, which are contained in a package of 11 by 9 by 4mm and which will handle full-sine wave applications. Frequency range is 12.8-19.2MHz at a tolerance of ±2ppm, an optional afc function allowing small adjustments by an external supply. Supply is 3V or 5V. AVX Ltd. Tel., 01252 770000; fax, 01252 770001.

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Cameras
Camera/monitor. CPDM104-C by Hitachi is a 21in, 400-line colour monitor with a built-in VX-C195 dsp camera, intended to deter rogues and vagabonds, since the camera output appears on the screen with no very obvious camera position. In addition, the picture is a good deal better than the average from this kind of equipment, the dsp camera giving automatic white balance, iris and backlight compensation. There is an RS232C socket for connection to a video recorder. Hitachi Home Electronics Ltd. Tel., 0181 849 2000; fax, 0181 569 2763.

Passive components
Power chip inductors. Surface-mounted power chip inductors in the 1210 range from Coltanics are in two series: the CTX2C carrying up to 425mAdc and the CTX32C, which handles 850mAdc. CTX2C components come in 45 inductance values at Qs between 20 and 30 from 0.1µH to 470µH and are meant for use with rss, occasionally, while there are 16 inductance values in the CTX32C type, from 1µH to 330µH, at Qs of 10-20. METL. Tel., 01844 278781; fax, 01844 278746.

SMT chip inductors. Pulse Engineering's 100BCX and 800BCX miniature chip inductors are wire-wound on an alumina substrate and
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Audio products
Digital audio processor. Philips's TDA1546T bitstream digital filter is effectively a digital audio processor and d-to-a converter that includes the functions of volume control in 0.375dB steps, balance and tone control, peak signal-level reading, overload detection and spectrum analysis. It uses 128 times oversampling, has digital de-emphasis filtering for 35kHz, 44.1kHz or 48kHz sampling rates and offers the + noise of -86dB and wide dynamic range. Philips Semiconductors (Eindhoven). Tel., 00 31 40 722091; fax, 00 31 40 724825.

Connectors and cabling
Filtered D-type connectors. A range of D-type subminiature connectors, ferrite filtered against emi/rfi, is announced by Sealevel. Filtering is pin-to-ground and pin-to-pin, preventing common-mode noise in signal or data lines in the 10-300MHz range. Current rating is 5A, dielectric strength 1000V ac and the connectors meet FCC, VDE and other emc requirements. Sealevel Insulations Ltd. Tel., 0121 6436888; fax, 0121 643 2011.

Low-deflection load cell.
Control Transducers has the Model JP semiconductor load cell which deflects by a maximum of 0.55mm for its full load of 600kg and is intended for use in applications where its presence must not affect mechanical performance. The element is a germanium strain gauge, which gives a full-scale output of 150mV for an excitation voltage of up to 24V, allowing a shorter lead time and lower cost. Voltage ranges are 6.3-100V, capacitance values 0.47F-15000pF, and temperature range -40°C to +150°C. Rubicon Corporation. Tel., 0181 8423221; fax, 0181 8417691.

Low-impedance capacitors.
Rubicon has a miniaturised XY range of capacitors made by a new process to allow a capacitance-voltage ratio to be contained within standard can sizes, allowing a shorter lead time and lower cost. Voltage ranges are 6.3-100V, capacitance values 0.47F-15000pF, and temperature range -40°C to +150°C. Rubicon Corporation. Tel., 0181 8423221; fax, 0181 8417691.
Copper gaskets. TBA ECP offers low compression-force gasket strips in beryllium copper, designed for those applications in which a low compression force is enough force to compress standard types for emi shielding. A range of gaskets is produced, in clip-on, stick-on and snap-on varieties in a number of different forms. TBA Industrial Products Ltd. Tel.: 01706 474422; fax, 01706 46170.

Instrumentation

Digitising oscilloscopes. Hitachi Denshi has renumbered the VC-7102/7104 as VC702/7024, having introduced what it calls 'giltch capture' into the instruments, with the intention of displaying and measuring 'uncommon phenomena'. The two are 150MHz types with 1000sample/s sampling on two and four channels, 25MHz single-shot and up to 8Kword/channel acquisition and storage. A 512 by 320-384 by 384 for equivalent sampling is 2ns/division to 0.2us/division (7502) and 2ns/division-0.5us/division for the 7502 and 0.5-1.0us/division for the 7540. Automatic measurement provides auto setup, and the measurement of four pulse parameters out of 17 simultaneously. A memory allows the display to be saved for up to three months and then output to a pc or colour monitor. Hitachi Denshi (UK) Ltd. Tel.: 0181 202 4311; fax, 0181 202 2451.

Four-in-one. From SJ Electronics comes the Mii Universal Electronics System, made by a Far Eastern company with input from SJ. The four instruments are a 250MHz frequency counter, a 2MHz function generator, a 4.5-digit multimeter and power supplies, all contained in one case. It has been designed with universities, schools and servicing in mind, being difficult to absent-mindedly move and only needing one mains supply. The individual instruments are completely independent and possess specifications well up to and possibly beyond those commonly found in workshop equipment at a cost far below that of four different instruments. SJ Electronics Ltd. tel.: 01376 562004; fax, 01376 562215.

Interfaces

Dual-line interface. Crystal Semiconductor announces a low-power serial interface unit (LUI) for short-haul T1 and E1 telecommunication high-volume applications that require low power and high density. The design includes digital cross connects, T1 and E1 line cards, OCN7 multiplexers and switches. It operates 160MHz per channel, with a 50% pulse density and both 3.3V and 5V versions of the CMOS 74HCT and 74ACT types. Designers can now make one board to support all T1 and E1 modes, including DSX-1, DS -1 and CCITT G.703. A 25/30/120V selecting T1 or E1 operating modes through software without changing transformers or external oscillators. Software-programmable pulse shaping makes it possible to compensate for non-standard line loads, transformers and protection circuits. Each LUI channel contains a line driver, receiver and jitter attenuator. Sequoia Technology Ltd. Tel.: 01734 258600; fax, 01734 258620.

Power supplies

Dc-to-dc converters. Vicor now offers a standard 110V dc nominal input for its V-1000 and Mega/Master dc-to-dc converter modules. With an input range of 66-160V dc, these modules are primarily for applications relying on 110V dc battery power. Component-level VI-200 converters measure 117 by 61 by 13mm and provide 50-150W. Mega/Master modules incorporate one, two or three VI-200 converters in compact, chassis-mount packages and provide 50-450W. Vicor UK, tel. 01276 68222, fax, 01276 681269.

More watts — same case. F Series power-factor-corrected power supplies by Unipower have been redesigned using more efficient devices and can now supply up to 1500W; existing types provide 550, 600 and 1000W. Power factor is 0.98 with low harmonic losses and the units meet EN6555-5, giving universal autoranging. Case sizes are 5 by 5 by 5 and 4 by 4 by 12 and there is a cooling fan. Unipower Europe Ltd. Tel., 01273 420196; fax, 01273 417140.

Remote-sensing regulator. Semitec's EZ1075 5V-echnical voltage regulator offers remote sensing of the output voltage to compensate for the resistance of wiring and connectors. Features Include full power use at 5A of load, current limiting and thermal shutdown, 1.3V dropout, stabilisation 0.15% and regulation 0.1%. Semitec Ltd. Tel., 01592 773520; fax, 01592 774781.

Radio communications products

Low-noise amplifiers. Ranatec's ACAM-7000 range of high dynamic range, low-noise amplifiers comprises ten models, covering the 2-3200MHz frequency range. Features of the amplifiers include the ability to amplify small signals without distortion in the presence of strong adjacent signals and low noise. The ACAM-7252, for example, exhibits a 1.8dB noise figure, 17dB of gain and a third-order intercept point of 40dBm over the 821-851MHz band. ACAM-7700 models cover the 5-4000MHz range in seven bands with the 7500 types and power levels of 110W are offered in the ACAM-7900 instruments in nine wide-band ranges between 0.1MHz and 2000MHz. Bandwidth of the 7500 models is 60-157MHz in a choice of five centre frequencies. Anglia Microwave Ltd. Tel., 01277 630000; fax, 01277 631111.

Power amplifiers. Wood & Douglas power amplifiers for radio modems and telemetry. They are available for hf and uhf and give outputs of up to 30W from a 0.5W input. Some have r-sensed transmitter/receive switching for semi-duplex working. All output from 12Vdc. Wood and Douglas Ltd., Tel.: 01734 811444; fax, 01734 811567.

HF security device. An Analogue Voice Security device from Harris can be used in a Harris RF-3200-E hf transmitter-receiver. It is a single board, fitting a slot in the radio and all operations is from the front panel, aided by screen prompts, selection of secure or clear working by one button. The algorithm, developed by Harris, needs no digital sync, for decoding and the system gives secure communication over the same range as clear voice, also giving tolerance to interfering signal. Coding keys are loaded into a non-volatile memory from a pc or terminal through a rear-panel RS-232 port. Harris Corporation. Tel., 011 716 244-5830.

Schottky detectors. Anglia Microwave offers the ACS Series of Schottky diode detectors in narrow

Emc emission testing. Enhancements to the emc emissions test kits made by Laplace are introduced: a broadband antenna and a Windows-based software package. The RF200 antenna is a compact, 1.6m design and covers the 10-1000MHz range as required by EN50022 with a flat response, being supplied with antenna factor information to allow its use with any analysers or receiver. Height is adjustable from 0.9m to 1.7m. EMcEngineer software is for use with the RF-KOx range of emissions test kits, is compatible with Windows and gives results related to the limits specified by emc standards. Facilities include antenna factor compensation, limit line display, correction for antenna distance, auto-correction for preamplifiers and attenuators, logfin frequency, dBm or dBm scaling and quasi-peak processing. Laplace Instruments Ltd. Tel., 01692 500777; fax, 01692 406177.
and broad-band ranges between 100kHz and 20MHz, in three different mechanical forms. Modular, coaxial and beld channel types are all internally protected against static damage and from video transients. In the coaxial and modular versions, rf impedance can be matched by an adjustment of bias level. Both coaxial and modular types have a K factor of 2300-200, the beld channel models having a K of 2000-1800. Frequency response is flat within ±0.5dB for the narrow-band types and ±1dB in the broad-band version. Anglia Microwave Ltd. Tel., 01277 630000; fax, 01277 631111.

**Protection devices**

Undervoltage monitor. ZM30364 by Zetex is an undervoltage monitor to provide the correct initialisation of microprocessors when start-up or when the power fails from 3V to 4.5V. The device output is low and reset is applied to the processor, the same occurring if the line voltage falls below 4.6V during operation, unless the built-in comparator with hysteresis prevents false reset during small line variations. Supply current is 135µA. Zetex plc. Tel., 0161-627 5105; fax, 0161-627 5467.

**Switches and relays**

Solid-state relays. From Teledyne, the C60 Series of solid-state relays are suitable for bidirectional ac or dc switching, a lower form factor, low on resistance and no off-voltage switching. Switching range of the series is up to 400V and 2A, with surge currents up to 14 times rating being handled. The relays are optically isolated. Teledyne Electronic Technologies. Tel., 0181-571 5956; fax, 0181-571 9637.

Photovoltaic relays. PV012 moisture proofing relays by International Rectifier exhibit a lower contact resistance than reed or other mechanical relays at 100mA on ac and 40mA on dc. They are normally open, single-pole relays with a 4.5A mosfet at the output and draw 5mA, being protected by the International Rectifier. Tel., 01883 713251; fax, 01883 714234.

**Television components**

Programmable synthesizers. Universal 1.3GHz frequency synthesizers in the TSA5521/2/6/7 family by Philips are for use in television receivers or video recorders containing microcontrollers, in which they are programmable via 2.5V or three-wire buses. They provide the functions for phase-locked loop control of a tuner's local oscillator. including a crystal-controlled reference frequency oscillator and dividers and a charge-pump output to give the oscillator control voltages up to 33V. Band switching is provided by giving oscillator control voltages up to 15V, including a crystal-controlled control of a tuner's local oscillator, a feature is the self-test facility, by which an electrical signal simulating the effect of an impact by an electrostatic force is applied, the output signal indicating performance. Eurosensor. Tel., 0171 405 6660; fax, 0171 405 2040.

**Computers**

Computer board-level products. Passive backplane. PCA-6105P is a part of Fairchild's new range of passive backplanes for the PCl bus. It features a mixture of PCI and ISA slots and keeping full ISA compatibility, but allowing PCI cards to avoid bottlenecks such as disk io, vga or networks. The pcu card slot conforms to the PICMG configuration, so that it can be used with Fairchild's Pentium card or those from other manufacturers. Backplanes with seven and thirteen slots are available. Fairchild Ltd. Tel., 01703 559090; fax, 01703 555910.

Transducers and sensors. Thermometer calibrator. The accuracy of thermometers and sensors can be checked on site, without the need for extra equipment, using the Hart 9100 handheld calibrator. It is simply a small bench-top instrument with a digital temperature readout and holes in the front panel into which temperature probes are inserted. Setting the instrument temperature of the mirror and reading the temperature of the user's thermometer allows a comparison to a resolution of 0.1°C at an accuracy within ±0.5°C. The units possess certificates of calibration. Electronic Temperature Instruments Ltd. Tel., 01903 202151; fax, 01903 202445.

Linear sensor. Hydrastar by Control Transducers is a developed version of an earlier model and is designed for use inside pneumatic or hydraulic systems. The new range is self-contained, with certificated displacement measurement and three-wire connection. Total length is 2.6in overall and the range covers 0-20mm to 0-610mm with an accuracy within ±0.1%. The electronics can be set to be used up to 100m away from the sensor and can be specified to give different amplification of analogue output. Control Transducers. Tel., 01234 217704; fax, 01234 217083.

Airbag accelerometer. EG&G IC Sensors has introduced a micro-machined silicon accelerometer. The Model 3255, for use in car side impact airbags, which need a greater measurement range than frontal impact types. Two chips are used for lower cost: the sensor chip and an asic in a multi-layer, hermetically sealed ceramic package for surface-mounting. A feature is the self-test facility, which by an electrical signal simulating the effect of an impact by an electrostatic force is applied, the output signal indicating performance. Eurosensor. Tel., 0171 405 6660; fax, 0171 405 2040.

Computers

Half-size 486 boards. A range of half-size single-board computers by Aculab has a processor card which performs the functions of an industrial computer with a vga display on a half card, and which is ISO 9001-certified. Processors supported include 486DX-25/33 to the 486DX-100. The electronics are standard 72-pin simms for 1-64Mbyte of dram. An on-board VL-bus vga controller for a flat panel or on and 1b禺 of display memory gives resolution up to 1524 by 769 in 16 colours or 800 by 600 in 256 colours. Loss. Tel., 0117 9703458; fax, 0117 9237255.

Data acquisition

Acquisition and control cards. IMS has a new series of pc cards for data acquisition and control, the PCL-818 series. Much of the clircling being contained in anasic, the plug-in boards are half-sized. The range of cards covers the 40kHz-330kHz sampling frequency range and features include the provision of 16 channels of 12-bit-a-d-a conversion, d-to-a conversion, 16 digital inputs and outputs and a counter/timer. At have automatic channel scan and the higher end of the range has a 1kb fifo to give high throughput for Windows application. There is also a 1000v gain card for low-sensitivity sensors. Integrated Measurement Systems Ltd. Tel., 01703 77143; fax, 01703 704301.

200kHz dataacq with 486. Modular-4 by Sorcus is a low-cost, pc-based data acquisition system having a maximum 12-bit sample rate of 200kHz and the ability to carry out multiple tasks simultaneously and independently of the pc. It comprises an 18-bit d-a converter, allowing V-to-D conversion, 120m range at either 418kHz for the UK or 433MHz in Europe. Interfacing requires a four-line interface to the host processor and another to the transceiver, the host interface being fully asynchronous and driven by an i/o port from the host. When transmitting, the host writes a 2byte packet to the RPC transmit buffer, which is then released by the interface and then read by the receiver. The interface is design to accept any of them. Philips Semiconductors (Eindhoven). Tel., 013 40 722091; fax, 013 40 724825.

Low cost programming solution. Atmel Micro Pro from Equinox Technologies can program the 40-pin 8951/992, 28-pin 8745 microcontrollers and most serial er-prom's from Atmel. Intel and Philips 87251/2 output pins are also supported. Micro-Pro is based on fpga technology rather than using a microcontroller. When programming, digital circuitry required for programming the target device is downloaded from the pc into the fpga. This allows hardware to be customised to suit each device, resulting in shorter programming times and future device support without the need for expensive adaptors. Equinox is offering an Atmel Micro Pro programming system, together with a free Atmel AT89C1051 and AT89C2051 microcontrollers for £99 + vat – which includes PSU and parallel cable. Equinox Technologies, Tel 01204 491110, fax 01204 494883.

Data communications

Packet controller. Radiometrix's RPC is a 40kbps radio packet controller chip providing processor-intensive, low-level packet formatting and data-recovery functions for high-speed, bidirectional data links and networks. It is optimised for use with the 8M radio transceiver, simplifying system design and allowing the realisation of the entire 40kbps bandwidth and 120m range at either 418kHz for the UK or 433MHz in Europe. Interfacing requires a four-line interface to the host processor and another to the transceiver, the host interface being fully asynchronous and driven by an i/o port from the host. When transmitting, the host writes a 2byte packet to the RPC transmit buffer, where a preamble is added, together with a start byte and error-check code. The whole is then encoded for security and raised and passed to the receive mode, the RPC monitors the line from...
the transceiver for a valid preamble, performs synchronisation and validation and tells the host to accept data. Low Power Radio Solutions Ltd. Tel., 01993 709418; fax, 01993 708575.

SocketModems. Rockwell's SocketModem concept enables addition of full data, fax and voice communications to a multitude of electronic designs. Packages are pin-compatible 25.4mm by 63.5mm pin dual-in-line modules, and require only an external eprom and DAA line interface. Due to their compact size and low power consumption — 45mW to 790mW — they suit anything from remote telemetry via cellular networks to motherboard integration, freeing a valuable expansion slot.

The SocketModem range extends from 2400bps data-only devices to 56Kbps data/fax modems supporting high-speed fax, voice functions, error correction, data compression and cellular protocols.

Standards supported include V.34, V.28, V.29, V.27ter and V.21. Voice capabilities include voice, business audio, ADPCM and 8-bit compression and decompression, with silence deletion and interpolation.

TCG Ltd, tel, 01256 332800, fax 01256 332810.

Development and evaluation

Can development. Hitex has a development board to ease the first stages in the development of a controller area network (can). It is fitted with two can nodes controlled by one microcontroller, network drivers being developed on the one microcontroller and all communications being looped back between controllers. By this means, a can network is developed using normal tools and with no need for bus analysers, although a simple analyser comes with the demo code to allow monitoring of the final network. The board is either on its own or part of a kit containing C compiler, assembler Hitop monitor and demo code. Hitex (UK) Ltd., Tel., 01203 692066; fax, 01203 692131.

Prototype board for re. Rapid building, evaluation and fault-finding of moderately complex analogue and digital circuits working to beyond 300MHz is facilitated by the new NFP prototyping board. RF prototyping boards already exist but they tend to use socketed components and can hence suffer from intermittent connections. The board accommodates 4 by 8 pin or 2 by 16 pin oil packages. It also features two easily decoupled power supply bus lines, large area ground plane on the top side and four BNC connectors with provisions for eight. Oxtel Ltd, tel and fax, 01865 200767.

Programming hardware

Production programmer. From Data I/O, the AutoSite production programmer for automated handling systems now has new features and supports new devices from Altera, AMD, Intel, Lattice, Microchip and Xilinx. Its memory editor and swap data operations now support 32-bit mode and the system handles use of Jedec U data and E fields. Data I/O Ltd. Tel., 01734 440011; fax, 01734 448700.

Software

Message pagers. Hexatec has extended its Windows-based SCAN1000 supervisory and data acquisition system to allow text messages to be transmitted automatically to standard commercial radio pagers. Each supervisory system equipped with SCAN1000 monitors up to 3000 channels, compares the data to defined criteria and sends the appropriate messages to field operators over the Mercury network. Software has independent data-logging facilities for large numbers of asynchronous processes, running under Windows, NT and Workgroups, also being compliant with Windows 95 standards. No programming is needed. Hexatec Ltd. Tel., 01434 605575; fax, 01434 607800.

Ups power management. From Fiskars, 32-bit power management packages for Windows NT and other operating systems. LANSafe III and FailSafe III provide uninterruptible power supply remote management, power graphics, and data-saving shut-down in Windows NT 3.5. Even when data has not been saved, the software saves it and shuts down in a graceful manner. LANSafe controls any ups from any node in a network, shutting down and rebooting any intelligent component, graphic information from every protected device being available. FailSafe is a similar facility for single pcs. Fiskars Electronics Ltd. Tel., 01734 308600; fax, 01734 305868.

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What’s the difference?

When choosing a differential amplifier, most people opt for the single op-amp configuration. Steve Winder argues that little consideration is given to how this choice copes with signals presented to it, and sets out to explain the benefits to be gained from a little more thought.

Low-amplitude signals, such as those from remote sensors, are normally carried on a twisted pair line. This is also the preferred transmission medium when the signal source and signal processing equipment do not have the same dedicated earth or common connection. In these situations, noise from earth or other circulating currents can be greater than the signal itself, so using a single wire with a common return path is not a viable option.

Where a signal is transmitted over a twisted or screened-pair line, a balanced line termination is required. This could be provided by a transformer, or by amplifiers having a differential input and a single ended output. Unwanted common mode signals may be present on the wires if signals that are in phase and present on both wires relative to earth.

If a transformer is terminating the line, common mode signals can be reduced considerably by providing an earthed metal-foil screen between the coil windings. Common-mode signals are capacitively coupled to earth by this screen.

The foil screen must be insulated so that, when wrapped around the primary winding, it does not form a short circuited turn. This occurs if the end of the foil screen is in metallic contact with its beginning.

If a differential input amplifier is terminating the line, the amplifier’s design can be critical in determining the common mode rejection. The input impedance under both differential and common-mode signal conditions must be considered.

If the amplifier has an unbalanced input impedance, the twisted-pair line becomes unbalanced and susceptible to external fields. The input impedance should also be equal to the characteristic impedance of the line.

Single op-amp differential amplifier

The simplest design uses a single op-amp, Fig. 1. Gain of this circuit is unity if all four resistors have the same value. Generally $R_1=R_3$ and $R_2=R_4$, and the gain can be found by $R_2/R_1$ or equivalently $R_4/R_3$.

This design has several shortcomings, particularly in terms of input impedance. Suppose that all four resistors are equal, at, say, 1kΩ each. A signal at input B will ‘see’ a 2kΩ impedance because an input of the op-amp presents a high impedance and the only load is the two resistors $R_3$ and $R_4$ in series. Impedance seen at input A will depend on the signal at B because feedback forces the op-amp to maintain an equal voltage at both its inverting and non-inverting inputs.

Suppose that at a certain moment a signal with an amplitude of 1V is present at input B. Potential divider action of $R_3$ and $R_4$ means that the potential at the op-amp’s non-inverting input is 0.5V. The op-amp will therefore try to keep the inverting input at this same potential.

Now, if a common-mode signal of the same amplitude is applied at input A, the potential across $R_1$ will be equal to the input voltage minus the inverting input voltage, 1V−0.5V, which is 0.5V. Thus the potential across $R_1$ is equal to the potential across $R_3$ and the two input impedances are equal. Also, since $R_2$ has the same resistance as $R_1$ it too must have a 0.5V drop. Output voltage will be zero.

Suppose now that a differential signal is applied between the two inputs A and B. At a certain moment the potential on input A is 1V and on input B it is −1V. As before, the op-amp’s non-inverting input will have a −0.5V potential on it and the op-amp will maintain a −0.5V potential on its inverting input. This time, however, the potential across $R_1$ will be −1.5V, ie −1V−0.5V. Now the potential across $R_1$ is three times that of $R_3$, so the current will also be three times as great. Voltage drop across $R_2$ must also be 1.5V, since the current flowing through it is the same as the current through $R_1$. The inverting input of the op-amp is at 0.5V, so the output must be 0.5V+1.5V, or...
2V, confirming the circuit’s unity gain.

The effective input impedance will be \( \frac{1}{2} \) of \( R_1 \) at input A and \( 2R_1 \) at B. In total, the input impedance at B is three times that of A if \( R_1 \) and \( R_3 \) have the same value. This circuit, using equal valued resistors, works well provided it is driven from a low impedance source. When used to terminate a transmission line, the source impedance is finite and impedance mismatch between the inputs makes it susceptible to noise pick-up.

### An alternative differential amplifier

An alternative circuit, presented by Geoff Pomeroy in Electronic Design 16 Dec 1995, suggested that by making the values of \( R_1 \) and \( R_3 \) different, the impedance into input A and B can be equal. Gain, \( G \), and desired input impedance, \( Z \), can be used to find the values of resistors \( R_{1,4} \).

\[
\begin{align*}
R_1 &= 0.5Z(G(G+1)+1) \\
R_2 &= G \times R_1 \\
R_3 &= Z - R_1 \\
R_4 &= R_1 - 0.5Z
\end{align*}
\]

In fact, for a unity-gain amplifier, \( R_{1,2} \) are equal and three times the value of \( R_{3,4} \). If \( R_{1,2} \) have a value of 450Ω and \( R_{3,4} \) have a value of 150Ω, the input impedance for differential signals is 600Ω, or 300Ω relative to the common rail at each input. This factor of three tallies with analysis of the previous circuit design.

Now consider a circuit with a gain of one. Suppose a differential signal is applied between inputs A and B. At a particular moment the potential at A is 1V, and at B it is -1V.

The op-amp’s non-inverting input will have a potential of -0.5V, forcing the non-inverting input to follow it. The remaining 0.5V is dropped across \( R_3 \). The voltage across \( R_1 \) will then be \( 1-(-0.5)=1.5V \), or three times that across \( R_3 \). Voltage across \( R_2 \) will also be 1.5V, because the same current flows through \( R_{1,2} \). When the voltage across \( R_2 \) is added to the inverting input potential, this gives an output of 2V. However, \( R_1 \) has a resistance of three times that of \( R_3 \), so the currents flowing through inputs A and B are equal in magnitude and are of opposite sign. The input impedances are therefore equal.

If a common-mode signal is applied to inputs A and B, having a potential of 1V at a particular moment, the voltage at the op-amp’s non-inverting input will be 0.5V, leaving 0.5V across \( R_3 \). The potential at the op-amp’s inverting input will be forced to 0.5V via feedback. At input A, the potential is also 1V, giving a potential across \( R_1 \) of 0.5V.

Voltage over \( R_2 \) will also be 0.5V, which when subtracted from the potential at the op-amp’s inverting input gives an output voltage of zero. Impedance into input A will be three times that of B. This is because the current through \( R_1 \) will be one third of the current through \( R_3 \) since its resistance is three times greater. Common-mode signals from an isolated signal source, say capacitively coupled, are generally high impedance, in which case differing input impedances’ will have some effect on circuit performance.

This circuit has the correct balanced input for differential signals, with the correct termination impedance. However, the common mode impedance is different for each input.

### Instrumentation amplifier

Figure 2 shows a triple op-amp differential amplifier. The output stage uses the same circuit as Fig. 1 with the four resistors \( R_{5,7} \) usually having the same resistance value. Because this stage is driven by two op-amps, \( A_{1,2} \), which have a low output impedance, so the impedance looking into the output stage has no effect.

The two input stages are symmetrical. Input impedance at both the op-amp non-inverting inputs is high. Inputs A and B have an impedance set by resistors \( R_{5,6} \) in Fig. 2. Resistor chain \( R_{3,4} \) is symmetrical and sets the gain of the input stages. A single variable resistor \( R_2 \) controls gain.

Consider that a common-mode signal is applied to inputs A and B with a potential at a particular moment of 1V. This voltage will be present at the op-amp non-inverting inputs, with feedback forcing the inverting inputs also to 1V. Since \( R_2 \) has an equal potential on either side, no current flows through it. There can be no current flowing through \( R_{1,2} \) either, since there is nowhere for it to go. Output voltage from \( A_{1,2} \) must be equal to the input voltage. As discussed earlier, common-mode signals are then rejected by the output stage.

Differential signals can be amplified by the input stages. Suppose the voltage at input A is 1V and voltage at input B is -1V. Also, let \( R_1 \) equal \( R_2 \) and \( R_3 \). The inverting input of \( A_1 \) will be at a potential of 1V, due to feedback. Also, the potential at the inverting input of \( A_2 \) will be at -1V, equal to the potential at the non-inverting input.

Voltage across \( R_2 \) will be 2V, since it is connected between the inverting inputs of \( A_{1,2} \). There must also be 2V across each of \( R_1 \) and \( R_3 \) since the same current is flowing through them as through \( R_2 \). The output of \( A_1 \) must be 3V and the output of \( A_2 \) must be -3V. The amplifier will produce 6V from a differential.
signal of 2V — overall gain is therefore three.

Gain of a differential amplifier can be calculated from a simple single stage gain. Resistor $R_2$ has the differential potential across it, but differential signals are symmetrical about the 0V rail, i.e., the centre of $R_2$ is always at 0V. In fact, $R_2$ can be considered as two series-connected resistors, each having half the value of $R_2$, with their common point joined to the 0V rail.

Consider amplifier $A_1$. Its feedback is $R_1$ with half of $R_2$ connected to 0V. Gain of such an amplifier is $1 + R_1/(0.5 \times R_2)$, which is 3. Performance of amplifier $A_2$ is identical.

**Dual op-amp differential amplifier**

Figure 3 shows a dual op-amp differential amplifier. Inputs $A$ and $B$ are connected to the non-inverting inputs of op-amps $A_1, A_2$, which have a high input impedance. Impedance into input $A$ and $B$ is therefore set by resistors of value $R_{id2}$.

In the dual op-amp circuit $R_1$ and $R_4$ have equal values as do $R_2$ and $R_3$. Circuit gain is calculated using $(R_1 + R_2)/R_2$. Suppose $R_1$ is three times $R_2$, then the circuit gain is four.

Let a common-mode signal be applied to inputs $A$ and $B$ with a potential at a particular moment of 1V. The voltage present at both the op-amp non-inverting inputs will be 1V.

Feedback forces both the inverting inputs to a potential of 1V. This means that 1V will appear across $R_1$, and hence one third of a volt across $R_2$. This occurs because the same current is flowing through each resistor and the value of $R_2$ is a third that of $R_1$. Output potential of $A_1$ will be 1.333V.

Potential across $R_3$ is the output of $A_1$ minus the potential at the inverting input of $A_2$. As a result, $R_3$ has 0.333V across it. Now, the current through $R_3$ is the same as $R_4$, but $R_4$ has three times the resistance, so the voltage across $R_4$ is 1V. Resistor $R_4$ is connected between the inverting input of $A_2$ and the output terminal. Since the potential at the inverting input of $A_2$ is 1V, the voltage at the output terminal must be zero in order to produce 1V across $R_4$.

Suppose at a particular moment a differential signal produces 1V at input $A$ and -1V at $B$. The output of $A_1$ will be the same as in the common-mode case, 1.333V. A -1V signal at $B$ produces a potential of -1V at the non-inverting input of $A_2$. Feedback also forces the inverting input of $A_2$ to -1V.

Resistor $R_3$ now has 2.333V across it, i.e., 1.333V present at the output of $A_1$ and -1V present at the inverting input of $A_2$. Since $R_3$ has the same current flowing through it as $R_2$, but with three times the resistance, there is 7V across $R_4$. The inverting input of $A_2$ has a potential of -1V, so the output must have a potential of -8V.

**Conclusion**

This article has shown that single op-amp differential amplifiers of either design has shortcomings that can be overcome by more sophisticated designs using two or three op-amps. The dual op-amp design, considered last, requires two resistors and one op-amp more than the simplest design. Increased cost is usually worthwhile, and by using a dual op-amp package the overall increase in board space requirement is minimal.

Where gain adjustment is essential, the instrumentation amplifier using three op-amps provides the best option.

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**INDEX ON DISK**

A computerised index of *Electronics World* + *Wireless World* magazine is now available. It covers the five years 1990 to 1994 — volumes 96 to 100 — and contains over 1400 references to feature articles, circuit ideas and applications, with a synopsis for each. The software is easy to use and very quick. It runs on any IBM or compatible PC with 512K ram and a hard disk. Each disk is scanned before shipping with the current version of Dr Solomon's Anti-Virus Toolkit.

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Power converters for LCD backlighting

Transistor requirements for backlighting purposes—the mode of operation within the backlighting circuit, important parameters, and their impact on system efficiency—are the primary focus of Zetex Application Note 14. The note also provides several CCFL power supplies for use with LCD backlighting applications.

Around 1 kV is required to strike a fluorescent tube. On striking, the tube’s gaseous contents ionise and it begins to conduct at a lower sustaining voltage. This results in a negative resistance characteristic. Other power supply constraints include an intolerance of dc current, sensitivity to waveform crest factor and radio-frequency interference criteria.

For drive waveforms at low frequencies, a fluorescent tube has time to react to the changing waveform potential, and effectively re-strikes on each reversal of the waveform polarity. This results in flicker. At high drive waveform frequencies, this effect is not apparent, and the lamp approximates to a resistive load. Usual operating frequencies range from 25-120 kHz, dictated by inaudibility requirements and converter inductor size.

Drive requirements dictated by the cold-cathode fluorescent tube’s behaviour and preferred operating conditions can be achieved by a resonant push-pull or Royer converter, Fig. 1.

Transistors TR1,TR2 are saturated by base drive provided by the feedback winding W4. Base current is defined by resistors R1 and R2. Supply inductor L1 and primary capacitance C1 force the circuit to run sinusoidally. This provides the drive waveform to the load and also results in minimised harmonic generation and rf interference.

Voltage step-up is achieved by the W1:(W2+W3) turns ratio. Secondary winding ballast capacitor C2 sets tube current.

Prior to the tube striking, or when no tube is connected, operating frequency is set by the resonant parallel circuit. This comprises primary capacitance C1 and the transformer primary windings W2 and W3. Once the tube has struck, ballast capacitor C2 plus distributed tube and parasitic capacitances are reflected back through the transformer, lowering operating frequency.

The secondary load can become dominant in circuits with a high transformer turns ratio, for example, those designed to operate from very low dc input voltages.

Each transistor’s collector is subject to a voltage 2√2xVdc or 2Vdc. Voltage Vdc is the dc input voltage to the converter. To reliably strike the tube this primary voltage is stepped up by the transformer turns ratio Ns:Np. Starting voltage is dependent on display housing, ground plane location, tube age, and ambient temperature.

Longer tube life

Incorporating the converter within a control loop can be used to regulate tube current. This helps maximise tube life, ensure a constant light output as battery pack voltage decreases and enable the adjustment of tube brightness.

The usual circuit employs a Buck or step-down converter driven directly from the battery pack to increase efficiency. It feeds either the centre tap of the transformer or the emitter current of the transistors depending on the controller’s technology and capability, Fig. 2a) and b).

The controller can monitor tube current directly in the secondary or in some recent systems by the primary...
APPLICATIONS

Fig. 3a). Linear Technology LCD backlight converter for a fluorescent lamp. Based on the Buck converter current fed Royer scheme of 2b), the circuit has a stated electrical conversion efficiency of 88%. b) Maxim LCD backlight converter.

Current. Using the primary current method allows the tube to be fully floating with low high-voltage loss. Figures 3a) and b) show circuits based on the Buck converter current fed Royer scheme of Fig 2b). Each monitors lamp current directly, averaging the positive half cycles of lamp current, and applying this signal to the controller's feedback pin. Electrical conversion efficiency using this form of circuit can be very high, the stated value for Fig. 3 being 88%. Higher efficiencies up to 92% are possible by using larger transformers to reduce copper and core losses. Additionally, the note lists detailed descriptions on transistor choices suitable for the Royer converter with regards to performance, efficiency and breakdown characteristics. Zetex, Fields New Road, Chadderton, Oldham OL9 8NP, Tel, 0161-627 5105, fax 0161-627 5467.

Active power factor correction for psus

Waveform distortion and overheating of transformers and neutral conductors in three-phase systems are just a few of the effects due to the poor power factor of electronic power conversion equipment. In its simplest form, poor power factor caused by reactive linear circuit elements results as the current either leads or lags the voltage, depending on whether the load looks capacitive or inductive, Fig. 1a). This type is easily corrected by adding a reactive component of opposite sign in parallel with the load to cancel the reactive term, Fig. 1b. Alternatively poor power factor associated with electronic power conversion equipment is caused by nonlinear circuit elements. In most off-line power supplies, the ac to dc front end consists of a bridge rectifier followed by a large filter capacitor, Fig 2a). Current is drawn from the line only when the peak voltage on the line exceeds the voltage on the filter capacitor, Fig. 2b). Since the rate of rise and fall of current is

Figure 2a). off-line power supply with a ac-dc front end consisting of a bridge rectifier and large filter capacitor. 2b) Current is drawn from the line only when peak voltage on the line exceeds voltage on the filter capacitor. c) typical input current spectrum of an electronic load. The odd harmonics are generated as a result of poor power factor occurring in electronic loads.

November 1995 ELECTRONICS WORLD + WIRELESS WORLD
APPLICATIONS

(a) Fig. 3a). Here, correction for poor power factor associated with electronic power supplies is active. A control circuit adjusts a boost voltage to maintain a sinusoidal input current. b) shows waveforms maintained by the active power factor correction circuit of 3b).

greater than that of the line voltage, and current flows discontinuously, a series of predominantly odd harmonics is generated, Fig. 2c), causing problems with the power distribution system.

Slightly improved power factor of the system of Fig. 2 can be achieved by adding series inductance with the line or decreasing the value of the holdup capacitor, which will lengthen conduction angle. Unfortunately both these solutions limit the amount of power that can be drawn from the line.

Active approach to PFC

During the operation of an active power factor correction circuit, Fig. 3a), incoming line voltage passes through a bridge rectifier producing a full wave rectified output, Fig. 3b), curve A. Since the line peak value is less than the bus voltage, no current flows into the holdup capacitor unless line voltage is boosted above the voltage present on the holdup capacitor. This allows the control circuit to adjust the boost voltage, Fig. 3b), curve B-A, maintaining a sinusoidal input current.

This is maintained by the control circuit using the input voltage waveform as a template. It measures the input current, compares it to the input voltage waveform, and adjusts the boost voltage to produce an input current waveform of the same shape, Fig. 3b), curve I.

Simultaneously, the control circuit monitors bus voltage and adjusts the boost voltage to maintain a coarsely regulated dc output, Fig. 3b), curve B. Since the primary function of the control circuit is to maintain a sinusoidal input current, a slight variation in dc bus voltage is allowed.

Because a well designed power factor correction circuit replicates the distortion present in the incoming line voltage, it is essential to use a low distortion voltage source when evaluating such circuits.

Figure 3b) illustrates the approach to power factor correction taken with the Vicor VI-HAM harmonic attenuator module, a component-level ac front end that, when used with VI-26x or VI-J6x dc-to-dc converters, provides a universal input, near-unity power factor and an off-line switching power supply meeting IEC 555.

Using an active power factor correcting circuit results in few discontinuities in input current and consequently low distortion and harmonic content of the input current drawn from the line.

This description represents most of Vicor UK's recent application note on active power factor correction.

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