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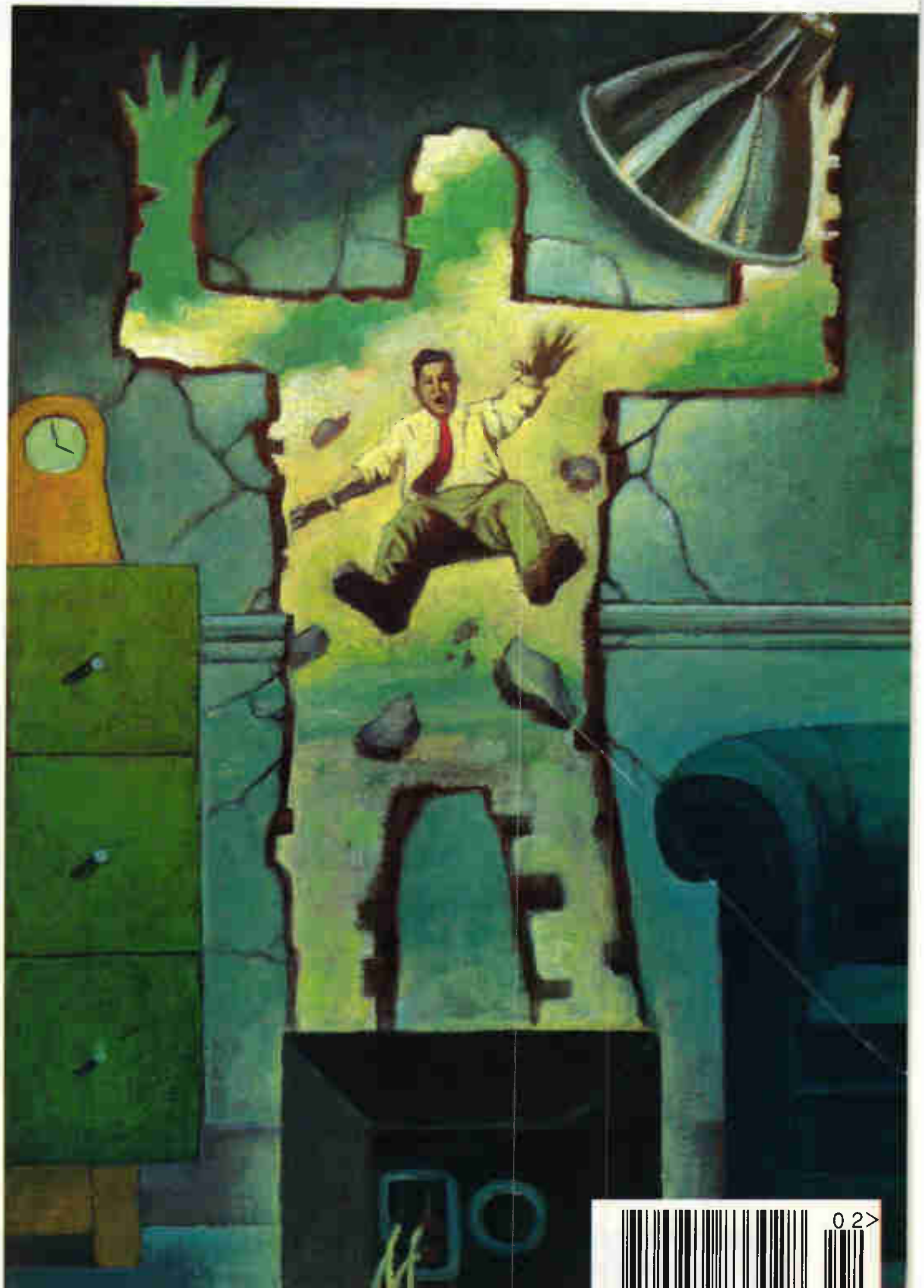

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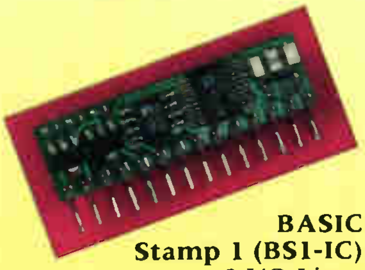

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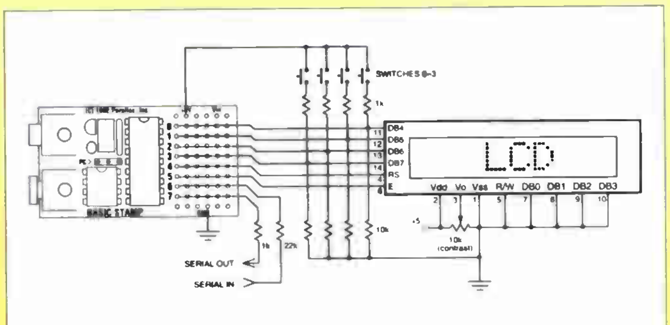


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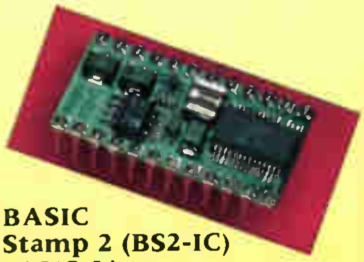

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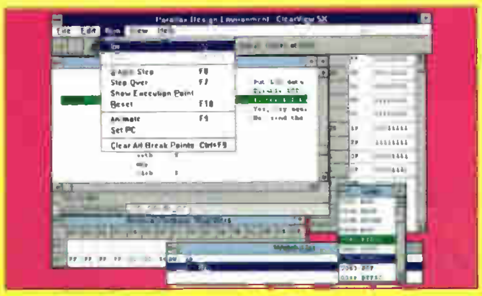

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Cover – Hashim Akib



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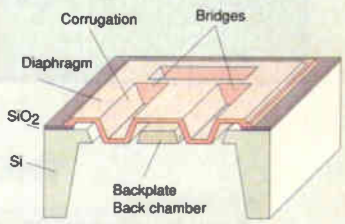


*Advances in mic-on-a-chip technology promise better fidelity and improved sensitivity – see page 98.*

*Rotary spark transmitter – believed to be sending news of Britain's declaration of war with Germany in 1914; see page 140.*

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REED BUSINESS INFORMATION

# Europhile or Europhobe?

Europhile or Europhobe? It's the political question of the day. But there's one Euro-issue on which the electronics industry should be agreed – the value of pan-European research projects.

Look at the chip business. "In the early eighties everyone was saying that the European chip industry was dead", remembers Pasquale Pistorio president of SGS-Thomson Microelectronics. Then came collaboration.

First the Siemens-Philips 'Megaproject' to get Europe up to speed on first memory technology, then JESSI added a pan-European dimension to the German-Dutch formula, now the EU is backing the JESSI successor programme MEDEA which is open to all nationalities.

"Fifteen years ago people were saying 'microelectronics is not a European kind of thing – we'll buy that in from the Americans and the Japanese'", says Horst Nasko, the chairman of JESSI and MEDEA.

Now, in the myriad disciplines which constitute a microelectronics infrastructure – from materials through to production equipment – Europe has world-class performers.

And no one could deny that our three largest microelectronics companies – Philips, Siemens and SGS – are world-class in both technology and market clout. Philips top $4bn in chip sales while Siemens and SGS have chip revenues of over $3bn.

In a decade and a half, these companies have been transformed into serious players with which major worldwide companies want to collaborate, as witness the IBM/Toshiba/ Motorola/ Siemens alliance on memory technology.

So collaboration works – as the Japanese showed in the seventies, the US Sematech programme showed in the eighties, and the Europeans showed in the nineties.

Not that we had much to do with it. Shamefully the UK's contribution to JESSI was about a tenth of the contribution of Germany or France, about a quarter that of Holland, and about the same as that of Portugal.

Now, with MEDEA coming up for funding, it looks as if the same thing is going to happen again. The provisional commitment from governments is: Germany 32 per cent; France 29 per cent; Holland 19 per cent; Italy 10 per cent; Belgium 4 per cent and the rest of Europe 6 per cent. To our shame we are in the ROE group.

Moreover the UK DTI – an organisation supposed to be helping UK industry – has decided it will only pay 25 per cent of a project's funding whereas every other country is paying 38 per cent.

As if to rub in its contempt, the DTI has also put a ceiling of £250,000 on the UK government's contribution to any one project. This effectively debars British companies from involvement in projects costing over £1m – a pitiful sum in chip research terms. Under MEDEA accounting procedures, £1m buys an eight man project lasting one year. No big deal.

So there we have it – an attitude from the UK government that is mean-spirited, petty and chauvinistic. "The attitude is more in line with people who think Europe is something the other side of the Channel", acidly comments Dr Jurgen Knorr, group president of Siemens Semiconductor and chairman of the semiconductor committee of the European Electronics Components Manufacturing Association (EECA).

***...look at Eurofighter – a project costing $40bn that has no apparent purpose...***

Our government is something else. When it takes a shine to a scheme it will shovel out the money like a drunken sailor. Look at the grants being paid to Hyundai of Korea to set up a microelectronics factory in Fife – said to amount to several hundred million pounds. Lucky Goldstar and Siemens have also been given £100m+ financial inducements to set up microelectronics companies in the UK. Or look at Eurofighter – a project costing $40bn that has no apparent purpose at all or at the really stupid 'Millenium Dome'.

Oh yes! We can dish out the lolly all right – no shortage at all when it comes to a pet government project – but when it comes to something not close to the government's heart it can be horribly mean.

Nowadays the cost of research is so great that not even regions, let alone countries, can afford to do it all alone. As Klaus Rupf from Germany's Ministry of Education, Science, Research and Technology told JESSI's last meeting, "If we really want to be world competitive we have to include partners from countries in other regions of the world."

The DTI has to wise up to the world. Otherwise the UK will be heading back to the days when we painted our backsides blue while continental Europe heads for a high-tech future. ■

***David Manners***

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# Fears surround UK digital tv

Britain 18 SET to become a backwater in digital television thanks to the regulations announced by the Department of Trade and Industry late last year, writes Svetlana Josifovska.

According to the regulations, which although preliminary are close to being finalised, broadcasters wanting access to various digital technologies will need to ask the owners/controllers of the conditional access (C.A).systems (needed for subscription) for a license. This, supposedly, will be granted "on a fair and nondiscriminatory" basis, with Oftel acting as the watchdog.

Broadcasters such as the BBC, Channel 4 and others, fear that the regulations are not tough enough to guarantee open access and common set-top box standards. The broadcasters state that any digital tv operator should provide access to other service providers' technologies to ensure audiences have a choice. They also argue that CA-system owners should be made to license the technology to ensure common specifications.

The regulations threaten to delay the launch of digital satellite television, originally scheduled for late 1997. Broadcasters, such as BSkyB, were waiting for the regulations before ordering the set-top boxes.

"At first glance, these regulations would seem to be stricter than all other countries with digital television," stated BSkyB.

"It is clearly in the interest of government and BSkyB that a workable solution is found to ensure that a digital launch is achieved during 1997," said Barry Rubbery, CEO at set-top box maker Pace.

***David Manners***
*Electronics Weekly*

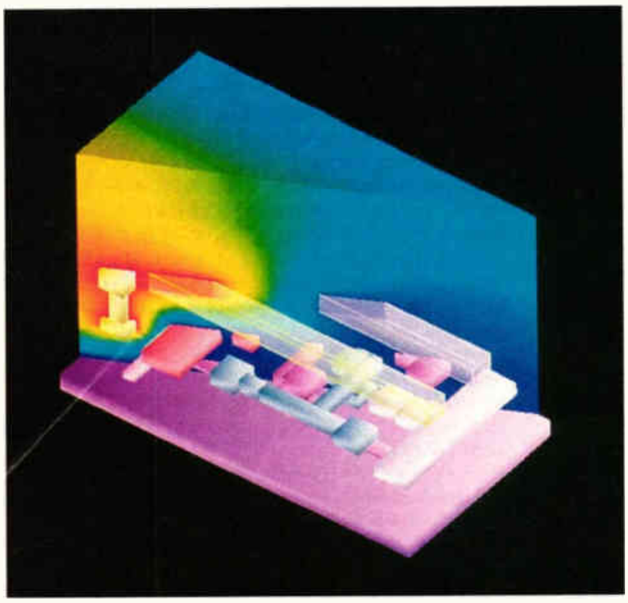
## Britain cool on Euro R&D

Fears for the UK's high technology future have escalated after the British displayed a minimal commitment to collaborative European R&D at last week's JESSI Day, which kicked off a four year microelectronics research programme.

"The UK needs to get its act together – we're so late getting involved," John Brothers, technical director of GEC-Plessey Semiconductors, told EW. "If we want to get a share of the action we've got to get involved in things that much earlier."

The programme, called MEDEA (Microelectronics Development for European Applications), proposes to send 2bn ECUs ($2.5bn) over the next four years to maintain the renaissance in Europe's high-tech fortunes following the previous Megaproject JESSI European colla~orative research programmes.

Brothers said that GPS would like to get involved in projects such in a SMIF (mini-environmenu) project. GPS is a leader in having a fully inte rated mini-environment wafer fab.



***Raphael, a tool from Technology Modelling Associates, analyses the effects of parasitic interconnect in IC designs. When used with TMA Visual, the design can see the simulation results, in this case the electrical potential distribution in an static ram when the bit line is set to a higher voltage.***

# DECT on one chip

VLSI Technology has released a single-chip baseband design for DECT, the micro-cellular in-building cordless phone system.

Called *Vega*, the chip has a dedicated DECT (digital enhanced cordless telecommunications) processor, a general purpose cpu and interfaces including those for microphone, speaker and keyboard. The only things not present are an lcd controller and the processor's rom.

Patrick Edmond, a spokesman for VLSI, said: "Once a firmware design is stable, we can add the customer's rom into a custom *Vega* chip."

Vega is designed for use in handsets and base stations. VLSI claims that the DECT processor is comprehensive enough to leave the cpu, which is an *ARM Thumb*, with nothing to do once a call has been established. Edmond said: "In a handset, the cpu can be shut down to conserve power, or it can be used for performance enhancement like echo cancellation in base stations."

Making a chip that serves base stations and handsets could leave room for a competitor to undercut VLSI in handsets which do not require the full power of the *Thumb*.

Edmund said: "The *Thumb* core takes only the same die area as a conventional eight-bit cpu core, and it is becoming a standard in handset applications, so there isn't really any scope to make a lower-cost handset chip. There is no such thing as a half *Thumb*."

Sample silicon for *Vega (VWS23101)* is available and production volumes are planned for the second quarter of 1997.

***Steve Bush***
*Electronics Weekly*

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A new concept in amplifier design to meet the needs of modern users who want the warmth and purity of sound given by valve amplifiers from the vintage years, without the problems of cost, deterioration and danger associated with trying to use valves today. It employs the newly re-discovered single-ended circuit configuration to give total freedom from crossover artifacts and to give a sound that is indistinguishable from the famous 'Williamson' design, the undisputed leader of the field, with its triode connected KT66s and all-triode drivers. Described in the September 1996 issue of EWW the new version retains the basic simplicity and purity of the original but with modern components and an increased power rating of 15W RMS per channel.

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New to the UK, VISATON offer a range of speaker kits and drive units that give the home builder access to units and designs that are unrivalled for quality, performance and value. Their designs are very well known in Germany, where they are based, and over 25 years they have built up an enviable reputation for high quality sound. All their designs come from a solid background of the best in design and research and their factory contains one of the largest anechoic chambers in the World, backed up by the very latest in computerised test equipment. This quality of research facility, added to design collaboration with major universities and high end magazines, produces products of impeccable performance and value that are the best available to the home speaker builder!. Their range of products covers the whole spectrum of sound reproduction and includes speaker kits for home cinema, hi-fi and car use. There is also a vast range of drive units from 15" woofers to ribbon tweeters. Speaker design software and database are available for the home user who wants to try his hand, or for commercial manufacture. A small selection follows, our lists will give you more!.

### ASM100 ACTIVE SUBWOOFER MODULE

This attractive module consists of a low pass filter and power amplifier ready for you to mount in a suitable sub-woofer cabinet. The combined unit can then be combined with any new or existing hi fi or home cinema speaker system to add in the real bass punch missing from most setups.
The ASM 100 module comes as a ready-to-mount unit on a solid diecast aluminium frame/heatsink. Input signal can be at line or speaker level for easy system integration. There are three separate stereo inputs at line level and the unit will use any signal presented or mix all inputs to add bass to any signal. The speaker level inputs are used by simply wiring the unit in parallel with the existing speakers to provide them with strong bass support. Crossover frequency can be selected to 50, 100 or 200Hz and the bass level can be adjusted by a front panel control. The 'Green' power supply switches the unit to standby if no signal is present. Drawings are included free for the compact 418 x 380 x 303mm cabinet.
With its powerful 125 watt output and versatile filtering the ASM 100 is the ideal universal active driver module for all subwoofer requirements.
**ASM 100** Module, complete with IEC mains lead, instructions and ASM - W20 cabinet drawings. Pt. No. V7000. **£185.29**
**W 200 S** 20cm Long Throw Drive unit for use in ASM - W20 cabinet. **£36.68**

### FIESTA 30 LOUDSPEAKER KIT

***An Ultra High Efficiency speaker, specially suitable for Valve Amplifiers.***

Specially selected as the ideal partner for the new John Linsley Hood 15W Valve Sound Amplifier, or indeed any actual valve amplifier, the FIESTA 30 features the astonishing efficiency and sensitivity needed to achieve a satisfying sound level from amplifiers of limited power output.
To complement the sound purity of such amplifiers a full three speaker system is used with a 300mm (12") woofer, 200mm (8") mid-range and high quality horn tweeter in a vented bass reflex enclosure.
All these drive units have been carefully selected for their individual virtues, and collective excellence, the tweeter for instance being a high end unit with exceptional pulse response as a result of its combination of Kapton former, aluminium diaphragm and aluminium voice coil.
Nominal Power Rating is 150W, Max. Music Power 250W, Impedance 8 ohm, Mean Sound Pressure 91dB.
Speaker kit comes with all parts to make a pair of speakers, but not the cabinet parts. Crossover units are factory assembled, ready to fit.

**Kit No.LK5963** Per Pair. **£424.93**

### HOME CINEMA SPEAKERS.

The VISATON range of speaker kits includes all you will ever need for your surround sound home cinema setup. The Hi-Tower Kit is ideal as a super luxury pair of stereo main speakers. The "Centre 80" uses special magnetically screened drivers to avoid picture disturbance and a pair of "Effect 80"s are used as rear speakers. Any of a range of sub-woofers then adds weight to the sound of the robot feet!. Centre 80 Kits include drive units, crossover, terminals and grille. (You make the box) Price each. £64.08
Effect 80, Rear Speaker Kits, per pair, £39.00

### DRIVE UNITS.

**BG30NG** 30cm. (12") Woofer. High efficiency, (95db) for sealed or vented cabinets. Peak power handling 250watts. 8 ohm. £69.61

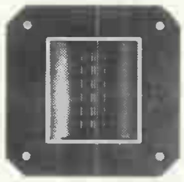
**W200S** 20cm. (8") Woofer. Long throw unit with rubber surround and extended rear pole to give no less than 20mm cone displacement. Ideal for compact sub-woofers such as ASM-W20. 8ohm. £36.68
**NG8** Protective Metal Grille. £5.66

**W100S** 10cm (4") Low/Midrange. Coated paper cone, rubber surround, high temperature voice coil. Suitable as woofer in mini enclosures or midrange in 3-way systems. 4ohm. **£18.06**
**NG4** Protective Metal Grille. £3.20

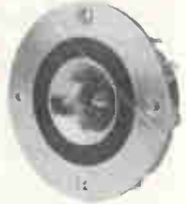
**FRS8** 8cm.(3.3") Fullrange driver. Linear frequency response between 200 and 20KHz. Large Magnet, 20mm voice coil and rubber surround. 8ohm. £8.36

**DT2.5** 10mm Polycarbonate Tweeter. High efficiency ferrofluid tweeter for use over 4,500Hz. Very good price/performance ratio. 8ohm. £8.77

**SC5** 10mm. Magnetically shielded Tweeter for use in surround sound centre speakers. 8ohm. £9.24



**RHT12S** High End Ribbon Tweeter. Superior double magnet construction gives an exceptionally low distortion and linear response from 4,000 to 30,000Hz. Cabinet cutout diameter 95mm. 8ohm. £87.77



**DHT9AW-NG** Hi-Tech, Hi-Fi, horn type tweeter. Frequency response from 3,500 to 38,000Hz and very good pulse response due to aluminium cone, Kapton voice coil and aluminium wire. Peak power handling 150W. 8ohm. £31.99

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# Taiwan d-ram is not to blame

The great tidal wave of Taiwanese d-ram, blamed for this year's catastrophic drop in prices, is a myth. The Taiwanese are at least a year away from significant volume in d-ram manufacturing.

The three new d-ram manufacturing entrants in Taiwan are Nan-Ya Technology, Vanguard Semiconductor and PowerChip Semiconductor. The previously existing d-ram manufacturers are TI-Acer and Mosel-Vitelic.

TI-Acer is a captive supplier to TI and Acer. Mosel-Vitelic has always been a speciality memory house though it is about to enter the commodity business via a joint venture with Siemens called ProMOS Technologies.

"We'll start with the 16Mbit next year," said Mosel-Vitelic's vice-president for operations, Dr Nasa Tsai. "The first phase of the fab has been equipped for 20,000 wafer starts a month."

*Mosel-Vitelic's Nasa Tsai: "16Mbit next year"*

Most advanced of the new entrants is Vanguard. "Now we have Fab 1(a) with 15,000 wafers a month and we're currently installing capacity in Fab 1(b) for another 10,000 wafers a month," said Dr F C Tseng, president of Vanguard.

Nan-Ya Technology, a subsidiary of Taiwan's largest company, Formosa Plastics, is running 16Mbit licensed from Oki Electric. "This month we will run 5000 wafers," said executive vice-president Charles Kao. "Our plan is to add another 22,000 wafers a month by the end of 1997."

The third new entrant, PowerChip Semiconductor, is a joint venture between Mitsubishi and the Umax-Elite group. "Currently, we're running 8000 wafers a month," said marketing manager K Y Tsai. "The plan is to be running 12,000 a month by March, representing three million pieces, and 15,000 a month by June."

That is the combined level of output from Taiwan this year, less than the monthly output of a Japanese or Korean fab – hardly a reason for the 1996 price collapse. "The last one in is always the scapegoat," was the wry comment from one of the island's executives.

***David Manners***
*Electronics Weekly*

## US catching up with smartcard applications

Seven top US financial services companies have endorsed the Mondex smartcard technology in what is the USA's largest vote of confidence in the sector. So far the USA has lagged behind Europe in smartcard applications.

AT&T, Chase Manhattan, Dean Witter Discover, First Chicago NBD, MasterCard, Michigan National Bank and Wells-Fargo Bank have invested in Mondex USA Services, which will use the Mondex smartcard technology in a series of pilot programmes in the USA.

"The power of this group will propel Mondex as the pre-eminent electronic cash payment system in the USA," said Janet Hartung Crane, president and CEO of Mondex USA. In spite of its heavyweight backing, Mondex will still face stiff competition from Visa and American Express, which are pursuing their own smartcard projects.

The first commercial Mondex cards will be introduced in 1998, following the results of key trials. Mondex USA says it will license its technologies to other US companies to help further establish the technology.

In a separate move, Mondex announced its agreement with Sun Microsystems for the inclusion of its format in the Java Commerce Toolkit. This toolkit will allow the development of open, secure and integrated electronic commerce applications which will link Mondex to the Internet.

## Computer learns user habits

Australian firm Formulab Neuronetics has launched a computer in the USA which it claims learns from its user and makes decisions.

The device, called the Richter Paradigm Computer, uses a parallel-processing architecture comprising 896 simple Risc processors, and costs $3000. The company says that the low cost of the system will help establish a large market for a "reasoning" computer.

In a demonstration, Formulab said that it can run neural network applications 180 times faster than an Intel Pentium 166MHz system.

Formulab also revealed plans for a supercomputer based on its computer architecture, which has taken more than 14 years to develop. The supercomputer would combine as many as 6000 microprocessors and could be used for scientific applications. It would run a special operating system that could manage the difficult task of splitting a computational problem into separate tasks and assembling the results.

The company also said that it is working on an add-on card for pcs which could assist users by learning from their work habits. It also plans to shrink its technology so that it can be embedded into products such as cameras and consumer electronics devices. Formulab said it will license the technology to other companies.

Other applications include stock buying, with the system noticing differences in stock prices and trading patterns.

***Tom Foremski***
*Electronics Weekly*

## Rockwell wins 56kbit modem support

The battle to establish the dominant 56kbit/s modem technology continues apace. Rockwell Semiconductor now says that it has won the support of Compaq, Hewlett-Packard, Toshiba, and AST Computer, while rival US Robotics has added Hitachi to its list of allies.

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HP141T+8552B IF + 8554B RF – 100KHz–1250Mc/s – £900.
HP141T+8552B IF + 8556A RF – 20Hz–300KHz – £700.
**Special Offer just in from MOD Qty 40 HP8555A RF Units 10Mc/s – 18GHzS.**
HP141T+8552B IF + 8555A 10Mc/s–18GHzS – £1200.
**HP ANZ Units Available separately – New Colours – Tested**
HP141T Mainframe – £350.
HP8552B IF – £300.
HP8553B RF 1KHz to 110Mc/s – £200.
HP8554B RF 100KHz to 1250Mc/s – £500.
HP8555A RF 10Mc/s to 18GHzS – £800.
HP8556A RF 20Hz to 300KHzS – £250.
HP8443A Tracking Generator Counter 100KHz–110Mc/s – £300.
HP8445B Tracking Preselector DC to 18GHz – £350.
HP3580A 5Hz – 50KHz ANZ – £750 – £1000.
HP3582A .02Hz to 25.6KHz – £2k.
HP8568A 100Hz–1500Mc/s ANZ – £6k.
HP8569B 10Mc/s–22GHz ANZ – £6k.
**HP Mixers are available for the above ANZ's to 40GHz**
TEK 492 – 50KHz – 18GHz Opt 1+2 – £4k–£4.2k.
TEK 492 – 50KHz – 18GHz Opt 1+2+3 – £4.5k.
TEK 492P – 50KHz – 21 GHz Opt 1+2+3 – £5k.
TEK 494AP 1KC/S – 21GHz – £7k.
TEK 496P 1KHz–1.8GHz – £4k.
TEK 5L4N 0–100KHz – £400.
TEK 7L5 + L1 – 20Hz–5Mc/s – £700.
TEK 7L5 + L3 – Opt 25 Tracking Gen – £900.
TEK 7L12 – 100KHz–1800Mc/s – £1000.
TEK 7L18 – 1.5–60GHzs – £1500.
TEK 491 10Mc/s–12.4GHzs–40GHzs – £750. 12.4Ghzs–40Ghzs with Mixers.
**Tektronix Mixers are available for above ANZ to 60GHzs**
Systron Donner 763 Spectrum ANZ + 4745B Preselector .01–18GHz + Two Mixers 18–40GHz in Transit Case – £3k.
HP8673D Signal Generator .05–26.5GHz – £20k.
Systron Donner 1618B Microwave AM FM Synthesizer 50Mc/s 2–18GHzs
R&S SWP Sweep Generator Synthesizer AM FM 4–2500Mc/s – £3.5k.
ADRET 3310A FX Synthesizer 300Hz–60Mc/s – £600.
HP8640A Signal Generators – 1024Mc/s – AM FM – £800.
HP3717A 70Mc/s Modulator – Demodulator – £500.
HP8651A RF Oscillator 22KC/S – 22Mc/s.
HP5316B Universal Counter A+B.
HP6002A Power Unit 0–5V 0–10A 200W.
HP6825A Bipolar Power Supply Amplifier.
HP461A–465A–467A Amplifiers.
HP81519A Optical Receiver DC–400Mc/s.
HP Plotters 7470A–7475A.
HP3770A Amplitude Delay Distortion ANZ.
HP3770B Telephone Line Analyser.
HP8182A Data Analyser.
HP59401A Bus System Analyser.
HP6260B Power Unit 0–10V 0–100 Amps.
HP3782A Error Detector.
HP3781A Pattern Generator.
HP3730A+3737A Down Convertor Oscillator 3.5–6.5GHz.
HP Microwave Amps 491–492–493–494–495–1GHz–12.4GHz – £250.
HP105B Quartz Oscillator – £400.
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HP6131C Digital Voltage Source + – 100V ½ Amp.
HP4275A Multi Frequency L.C.R. Meter.
HP3779A Primary Multiplex Analyser.
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HP5335A Universal Counter A+B+C.
HP59501B Isolated Power Supply Programmer.
HP8901A Modulation Meter AM – FM – also 8901B.
HP5370A Universal Time Interval Counter.
Marconi TF2370 – 30Hz–110Mc/s 75OHM Output (2 BNC Sockets+Resistor for 50OHM MOD with Marconi MOD Sheet supplied – £650.
Marconi TF2370 30Hz–110Mc/s 50 ohm Output – £750.
Marconi TF2370 as above but late type – £850.
Marconi TF2370 as above but late type Brown Case – £1000.
Marconi TF2374 Zero Loss Probe – £200.
Marconi TF2440 Microwave Counter – 20GHz – £1500.
Marconi TF2442 Microwave Counter – 26.5GHz – £2k..
Marconi TF2305 Modulation Meter – £2.3k.
Racal/Dana 2101 Microwave Counter – 10Hz–20GHz – £2k.
Racal/Dana 1250–1261 Universal Switch Controller + 200Mc/s Pl Cards.
Racal/Dana 9303 True RMS Levelmeter+Head – £450. IFFE – £500.
TEKA6902A also A6902B Isolator – £300–£400.
TEK 1240 Logic Analyser – £400.
TEK FG5010 Programmable Function Generator 20Mc/s – £600.
TEK2465A 350Mc/s Oscilloscope – £2.5k + probes – £150 each.
TEK CT-5 High Current Transformer Probe – £250.
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FLUKE 5102B AC–DC Calibrator – £4k.
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HP745A+746A AC Calibrator – £600.
HP8080A MF + 8091A 1GHz Rate Generator + 8092A Delay Generator + Two 8093A 1GHz Amps + 15400A – £800.
HP54200A Digitizing Oscilloscope.
HP11729B Carrier Noise Test Set .01–18GHz – LEF – £2000.
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Marconi TF2008 – AM-FM signal generator – also sweeper – 10Kc/s – 510Mc/s – from £250 – tested to £400 as new with manual – probe kit in wooden carrying box.
HP Frequency comb generator type 8406 – £400.
HP Vector Voltmeter type 8405A – £400 new colour.
HP Sweep Oscillators type 8690 A & B + plug-ins from 10Mc/s to 18GHz also 18-40GHz. P.O.R..
HP Network Analyzer type 8407A + 8412A + 8501A – 100Kc/s – 110Mc/s – £500 – £1000.
HP Amplifier type 8447A – 1-400Mc/s £200 – HP8447A Dual – £300.
HP Frequency Counter type 5340A – 18GHz £1000 – rear output £800.
HP 8410 – A – B – C Network Analyzer 110Mc/s to 12GHz or 18GHz – plus most other units and displays used in this set-up – 8411a – 8412 – 8413 – 8414 – 8418 – 8740 – 8741 – 8742 – 8743 – 8746 – 8650. From £1000.
Racal/Dana 9301A – 9302 RF Millivoltmeter – 1.5-2GHz – £250-£400.
Racal/Dana Modulation Meter type 9009 – 8Mc/s – 1.5GHz – £250.
Marconi RCL Bridge type TF2700 – £150.
Marconi/Saunders Signal Sources type – 6058B – 6070A – 6055A – 6059A – 6057A – 6056 – £250-£350. 400Mc/s to 18GHz.
Marconi TF1245 Circuit Magnification meter + 1246 & 1247 Oscillators – £100-£300.
Marconi microwave 6600A sweep osc., mainframe with 6650 Pl – 18-26.5GHz or 6651 Pl – 26.5-40GHz – £1000 or Pl only £600. MF only £250.
Marconi distortion meter type TF2331 – £150. TF2331A – £200.

Tektronix Plug-Ins 7A13 – 7A14 – 7A18 – 7A24 – 7A26 – 7A11 – 7M11 – 7S11 – 7D10 – 7S12 – S1 – S2 – S6 – S52 – PG506 – SC504 – SG502 – SG503 – SG504 – DC503 –DC508 – DD501 – WR501 – DM501A – FG501A – TG501 – PG502 – DC505A – FG504 – 7B80 + 85–7B92A
Gould J3B test oscillator + manual – £150.
Tektronix Mainframes – 7603 – 7623A – 7613 – 7704A – 7844 – 7904 – TM501 – TM503 – TM506 – 7904A – 7834 – 7623 – 7633.
Marconi 6155A Signal Source – 1 to 2GHz – LED readout – £400.
Barr & Stroud Variable filter EF3 0.1Hz – 100kc/s + high pass + low pass – £150.
Marconi TF2163S attenuator – 1GHz. £200.
Farnell power unit H60/50 – £400 tested. H60/25 – £250.
Racal/Dana 9300 RMS voltmeter – £250.
HP 8750A storage normalizer – £400 with lead + S.A or N,A Interface.
Marconi TF2330 – or TF2330A wave analysers – £100-£150.
Tektronix – 7S14 – 7T11 – 7S11 – 7S12 – S1 – S2 – S39 – S47 – S51 – S52 – S53 – 7M11.
Marconi mod meters type TF2304 – £250.
HP 5065A rubidrum vapour FX standard – £1.5k.
Systron Donner counter type 6054B – 20Mc/s – 24GHz – LED readout – £1k.
Racal/Dana 9083 signal source – two tone – £250.
Systron Donner – signal generator 1702 – synthesized to 1GHz – AM/FM – £600.
Tektronix TM515 mainframe + TM5006 mainframe – £450 – £850.
Farnell electronic load type RB1030-35 – £350.
Racal/Dana counters – 9904 – 9905 – 9906 – 9915 – 9916 – 9917 – 9921 – 50Mc/s – 3GHz – £100-£450 – all fitted with FX standards.
HP4815A RF vector impedance meter c/w probe – £500-£600.
Marconi TF2092 noise receiver. A, B or C plus filters – £100-£350.
Marconi TF2091 noise generator. A, B or C plus filters – £100-£350.
Marconi 2017 S/G 10Khz – 1024MHz.
HP180TR, HP182T mainframes £300-£500.
Philips panoramic receiver type PM7900 – 1 to 20GHz – £400.
Marconi 6700A sweep oscillator + 18GHz Pl's available.
HP8505A network ANZ + 8503A S parameter test set + 8501A normalizer – £4k.
HP8505 network ANZ 8505 + 8501A + 8503A.
Racal/Dana VLF frequency standard equipment. Tracer receiver type 900A + difference meter type 527E + rubidium standard type 9475 – £2750.
HP signal generators type 626 – 628 – frequency 10GHz – 21GHz.
HP 432A – 435A or B – 436A – power meters + powerheads – Mc/s – 40GHz – £200-£1000.
Bradley oscilloscope calibrator type 192 – £600.
HP8614A signal generator 800Mc/s – 2.4GHz, new colour £400.
HP8616A signal gen 1.8GHz – 4.5GHz, new colour £400.
HP 3325A syn function gen 20Mc/s – £1500.
HP 3336A or B syn level generator – £500-£600.
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HP 3575A gain phase meter 1Hz – 13Mc/s – £400.
HP 8683D S/G microwave 2.3 – 13GHz – opt 001 – 003 – £4.5k.
HP 8660 A-B-C syn S/G. AM + FM + 10Kc/s to 110Mc/s Pl – 1Mc/s to 1300Mc/s – 1Mc/s to 2600Mc/s – £500-£2000.
HP 8640B S/G AM-FM 512Mc/s or 1024Mc/s. Opt 001 or 002 or 003 – £800-£1250.
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HP 86290B Sweep Pl – 2 – 18GHz – £1250.
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HP 3580A Analyser 5Hz – 50kHz – £1k.
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Tektronix 465 – 465B – 475 – 2213A – 2215 – 2225 – 2235 – 2245 – 2246 – £250-£1000.
Kikusui 100Mc/s Oscilloscope COS6100M – £350.
Nicolet 3091 LF oscilloscope – £400.
Racal 1991 – 1992 – 1988 – 1300Mc/s counters – £500-£900.
Fluke 80K-40 High voltage probe in case – BN – £100.
Racal Recorders – Store 4 – 4D – 7 – 14 channels in stock – £250 – £500.
Racal Store Horse Recorder & control – £400-£750 Tested.
EIP 545 microwave18GHz counter – £1200.
Fluke 510A AC ref standard – 400Hz – £200.
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Wiltron 610D Sweep Generator + 6124C Pl – 4 – 8GHz – £400.
Wiltron 610D Sweep Generator + 61084D Pl – 1Mc/s – 1500Mc/s – £500.
Time Electronics 9814 Voltage calibrator – £750.
Time Electronics 9811 Programmable resistance – £600.
Time Electronics 2004 D.C. voltage standard – £1000.
HP 8699B Sweep Pl YIG oscillator .01 – 4GHz – £300. 8690B MF – £250. Both £500.
Schlumberger 1250 Frequency response ANZ – £1500.
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CIRCLE NO. 108 ON REPLY CARD

# MPEG-4: draft agreed

The main components of MPEG-4, the emerging audio visual coding standard, have achieved working draft status following a recent meeting in Brazil. The meeting also saw the Moving Pictures Expert Group kick off work on a follow-on standard, curiously called MPEG-7.

MPEG-4 aims to provide a universal mechanism for communicating audio and visual "object" data. Unlike the MPEG-1 and -2 standards, which encode frames of video, MPEG-4 reflects the emergence of myriad media content, and is capable of manipulating such content whatever its shape.

"MPEG-4 offers lots of flexibility. It will give applications developers far greater scope," said Paul Fellows, a project manager at SGS-Thomson Microelectronics involved in MPEG-4 work. "The basic techniques have been designed – experiments have identified the best techniques and these have been incorporated into the drafts."

MPEG-7, the follow-on standard, will add value to MPEG-4. According to Fellows, MPEG-7 will be concerned with "bits about the bits". It will offer ways to describe content whatever its guise, allowing identification in much the same way that search engines identify text on the World Wide Web.

# 40Gbit/s amp/filter breakthrough

A compact 35GHz amplifier suited to long-distance, high-speed optical communications has been co-developed by a group of UK and Portuguese academics. The device, which uniquely combines digital filtering and analogue amplification, is claimed to be the fastest of its type, capable of working with 40Gbit/s communication systems.

Dr Izzat Darwazeh of UMIST, and one of the academics involved in the design, said: "In today's fibre systems for long links, people use optical amplifiers which introduce some noise. Even 10ps of jitter could seriously degrade the system."

One solution is to use signal shaping filters at the receiver, traditionally an external filter after the front end. However, the filter itself introduces noise, and the physical link between the components on the board has inductance, further degrading the signal.

The circuit design, involving UMIST, University College London and the University of Aveiro in Portugal, uses a distributed amplifier. "A distributed amplifier is functionally equivalent to a finite impulse response filter," said Dr Darwazeh. By forcing the gate and drain delays to be different, the amplifier gains the filter characteristics.

The circuit, implemented as a single monolithic microwave IC (MMIC), has been built by the Fraunhofer Institute in Germany using a 40GHz HEMT process. Different lengths of the transistors define the delays and coefficients of the filter.

Dr Darwazeh says that an integrated front end would have applications in very high speed optical fibre such as transatlantic or Pacific links.

The next stage is to make an adaptive system that adjusts the filter's coefficients and the amplifier's gain depending on the signal received.

***Richard Ball,*** *Electronics Weekly*

# Film promises 70% brighter liquid crystals

A British company is developing and marketing a plastic film which promises to increase the brightness of laptop lcds by 70% for no extra power.

The film, invented by Philips in Eindhoven and now being worked on by Merck, of Poole, Dorset, acts to pre-polarise light entering the rear polariser of a standard lcd.

The rear polariser of an lcd transmits 40% of light from the backlight and absorbs the rest. The new film alters the random polarisation of the light from the backlight so that most of it is accepted by the rear polariser.

# Two new players in digital video disk arena


Hitachi and Akai are the latest companies to announce that they will sell DVD rom and DVD players. Hitachi will introduce its DVD rom player in early 1997, and has already begun shipping samples to key customers. However, a DVD player for the consumer market will not come until later in the year.

The entry of DVD has hit some snags in recent months with companies such as Toshiba and Fujitsu delaying the introduction of their products into overseas markets. A key reason has been the lack of DVD titles, since without content the DVD systems only have cd-rom based titles to play.

US media company Time-Warner has said that it will begin shipping DVD titles, which should help jump-start the market. Time-Warner said it will release four movie titles: *The Assassin*, *Blade Runner*, *Eraser* and *The Fugitive*.

Toshiba, which was the first to introduce DVD players into the Japanese market, said that the players are selling well and that it has shipped about 30,000 units. Toshiba will introduce its DVD players into the USA in early 1997, followed by a European launch. ■

***Philips set the pace in DVD roms. Now other companies are targeting the market.***

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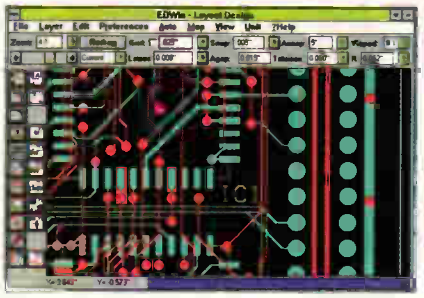

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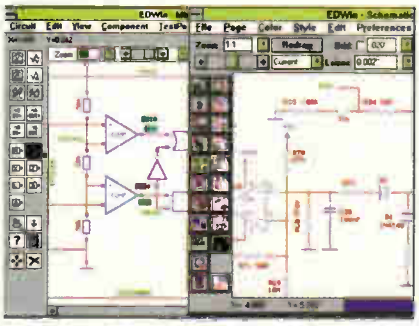

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CIRCLE NO. 109 ON REPLY CARD

# RESEARCH NOTES

Jonathan Campbell

## Single chip mic sounds the best yet

The thin, flexible diaphragm and rigid bookplate design of the condenser microphone can already be implemented on a single chip. But there have been problems in the past with residual stress in the diaphragms affecting the sensitivity of the device.

Now three Chinese researchers have manufactured a silicon condenser microphone with a a corrugated diaphragm that shows a dramatic reduction of stress.

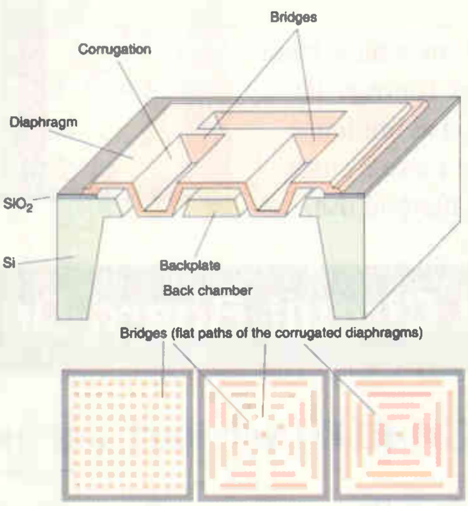
This is not the first microphone to use a corrugated diaphragm to reduce stress in this way. But the Chinese microphone has also demonstrated a flat frequency response and high sensitivity ('Design and fabrication of silicon condenser microphone using corrugated diaphragm technique,' Quanbo Zou *et al*, *J of Microelectromechanical Systems*, Vol 5, No 3, pp. 197-204).

The microphone capacitor consists of the corrugated diaphragm that acts as an active electrode, and a single crystal silicon bookplate with acoustic holes that acts as the stationary electrode. It is fabricated, using seven masks, on a single wafer by use of silicon anisotropic etching and sacrificial layer etching techniques. So no bonding techniques are required.

Up to now, the microphone has demonstrated a flat frequency response between 100Hz and 8-16kHz, and open circuit sensitivities as high as 14mV/Pa while using a low bias voltage of 10V

Further work will aim to improve the overall microphone performance, boosting sensitivity and flatness of the frequency response, by optimising the structure parameters and process conditions.

Contact Quanbo Zou, Institute of Microelectronics, Tsinghua University, Beijing, China.




***Corrugated diaphragm results enhances single-chip microphone. Diagram shows three alternative bridge configurations.***

***Sun shines again for Pathfinder:*** *The record-setting Pathfinder solar-powered research aircraft has resumed flight testing at Nasa's Dryden Flight Research Center, following its disastrous damage during a ground accident 12months ago.*

*In its last flight, the Pathfinder set an altitude record of more than 16,800m on a flight from Dryden which lasted nearly 12h. However, its latest flight was just a low-altitude check-out flight over the northern portion of Rogers Dry Lake at Edwards Air Force Base, California.*

*Low sun angle and limited hours of sunlight during the winter limit Pathfinder's altitude capability to about 6670m. This is one of the reasons why the project will be transferred to the Navy's Pacific Missile Range Facility on the island of Kauai, which lies at a lower latitude. Kauai's latitude and more favourable prevailing northerly winds will allow more opportunity for high-altitude solar-powered flying during a five-month flight test program.*

*Pathfinder is one of several remotely-piloted aircraft being evaluated under Nasa's Environmental Research Aircraft and Sensor Technology (Erast) program. The joint Nasa- industry alliance is seeking to develop technologies required to operate slow-flying unpiloted aircraft at altitudes up to 34,000m on environmental-sampling missions lasting up to a week or longer. With a span of 33m, Pathfinder is basically a flying wing.*

*Only two small pods extend below the wing's centre section to carry a variety of scientific sensors and support the craft's landing gear. The solar arrays on the wing can provide as much as 7200 watts of power at high noon on a summer day to power the craft's six electric motors and electronic systems. A backup battery provides power for up to two hours to fly the craft after the sun is down. Built primarily of lightweight composite structure, plastic foam and a thin plastic covering, Pathfinder weighs about 230kg.*

Contact: Fred Brown, Dryden Flight Research Center, Edwards, CA, USA

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CIRCLE NO. 110 ON REPLY CARD

# Robot has an office at its heart

*Working inside the robotic room as it collects information.*

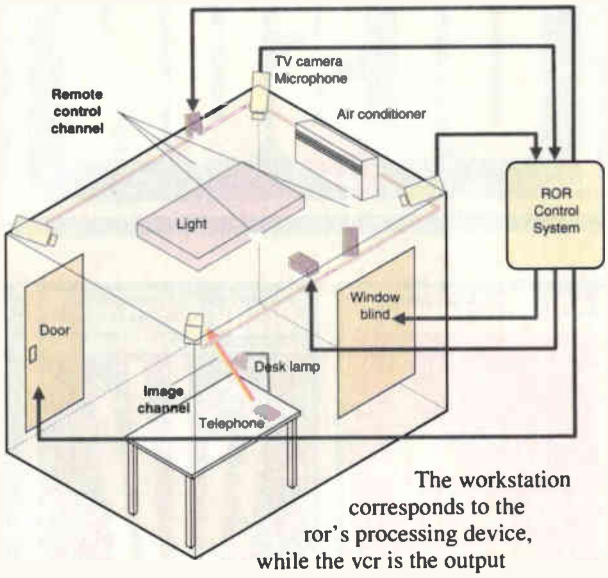
When we dream of using robots to carry out helpful tasks, we generally think about cyber-butlers precisely mixing our gin and tonics and waking us up with a newly ironed newspaper, rather than giving assistance at the office. (Though in some areas of the *EW* office, a gin-mixing, paper-ironing robot would fit in very well.)

But concentration by Hiroshi Mizoguchi and colleagues on the office environment has now given birth to the robotic office room (ror) – a robot that supports human activity within the office.

For example, when a human worker points to an object and gestures to get it, the room understands the behaviour and takes the object to them, perhaps using a long reach manipulator centrally located on the ceiling. In effect the office worker, works inside the robot.

To collect information, the ror monitors behaviour through a tv camera. When it detects pre-defined functions of the motion of an object – moved by human behaviour – the ror starts to make a response. By choosing to monitor objects that are moved by human behaviour rather than humans themselves, computing power has been considerably reduced.

An experimental prototype consists of a telephone, a pen, a tv camera vcr, a workstation and an audio set. In this case, the telephone, the pen and the tv camera are the input devices of the ror since the system can infer human behaviour by monitoring them.




The workstation corresponds to the ror's processing device, while the vcr is the output device because human memory augmentation – through recorded images – is one of the supporting functions of the ror. This is also the point of the audio device.

So far, the Japanese ror has been able to recognise when the receiver in the office has been lifted up, and can start video recording the telephone call. The volume on the audio set is also reduced automatically when a telephone call is being made.

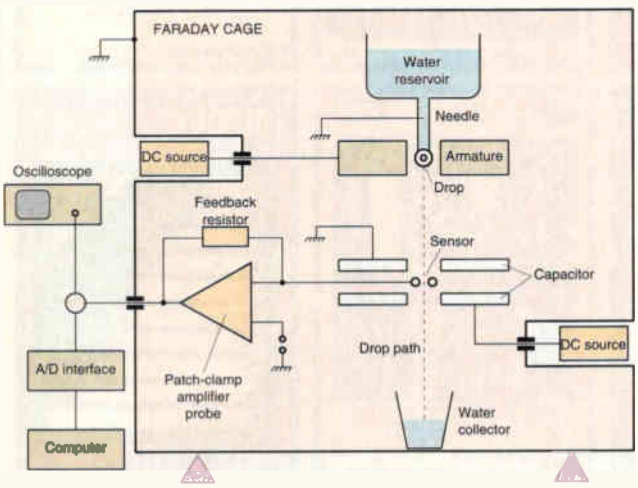
Contact: Hiroshi Mizoguchi, Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, 153, Japan email: hm@lssl.rcast.u-tokyo.ac.jp.

# Raindrops reveal their charge

*Measuring the charge on a raindrop – and no touching.*

It is not often that experimental researchers of today have cause to cite 130year old lecture papers delivered to the Royal Institute as part of their introduction. But the reference to Lord Kelvin's 1860 paper on Atmospheric Electricity by José Fornés *et al* gives an indication of how long their particular area of study has been a mystery – and how little has been achieved recently to solve it.

The question Kelvin raised, and which the Brazilian researchers have been trying to solve, is simply: "What is the pattern of charge distribution within falling or immobile rain drops?"




As the author's point out ("Evidence for multipolar charge distribution in falling water drops", *J. App. Phys*, Vol 80, No 10, pp. 6021-6027), electrical charge determination in single water drops has been undertaken since the 1920s. But despite extensive investigation, results are scarce – partly because of the difficulties in constraining a water drop without charge exchange.

A simple treatment might suggest that the result would be similar to a dielectric sphere in a uniform electric field, where a pure dipolar pattern would be observed. But this is not the case.

Formés and his colleagues have devised an apparatus that can produce drops of near zero net charge by using an aluminium ring to enclose the drop at its formation, and force it to acquire a given charge. When the drop is freed, it retains that charge.

The measuring probe consists of a copper wire loop of 2.8mm radius and a cross section of about 0.2mm, across which the drop falls. The ring is connected to a 10GΩ probe of a model 8900 Dagan patch-clamp amplifier, in the current-to-voltage configuration and set to voltage-clamp mode at voltage zero.

There is never any direct physical contact between the probe and the drop, the coupling being only capacitive. During measurement, the voltage output of the amplifier is acquired by an analogue-to-digital interface and fed to a computer.

To produce multipole charge induction, the drops (with their zero net charge) fall through a capacitor, typically maintained at 30V with 67mm plate separation. Each capacitor plate has a small hole to enable to the drop to pass through and the sensor probe is placed at mid distance between the plates.

Plotting the results show that the electrical charge on a water drop falling in the direction of an applied electric field is distributed in a multipolar pattern, possibly because of the contribution of the field-oriented water molecule multipoles.

Lord Kelvin would have been happy.

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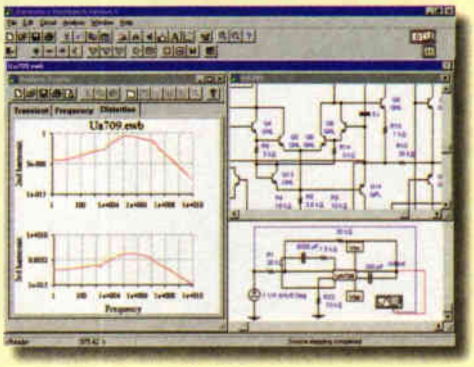

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### ANALYSES

... Operating Point: Calculates DC operating point and reports voltage at each node.

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AC Frequency Sweep: Small-signal gain and phase over range of AC frequencies at any number of nodes. Specify range, type (decade, octave or linear) and resolution (number of steps) of frequency sweep.

Fourier: Magnitude and phase of DC and Fourier spectral components of transient response. Specify fundamental frequency and an unlimited number of harmonics.

Noise: Resistor and semiconductor noise contribution reported as RMS sum. Specify device of interest, output and reference nodes, and range, type and resolution of frequency sweep.

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... external ... through time. Two digital cursors. Save data to ASCII file.

... phase ...

Word Generator: Acts as a digital stimulus editor to drive a circuit with up to 32K 16-bit words. Display and edit data as ASCII, binary or hex. Load, save, cut and paste words. Supports breakpoints and single step, burst and continuous modes. External trigger and data ready indicator for synchronization.

Logic Analyzer: Supports pre- and post-trigger. Internal or external clock, negative or positive edge. Clock qualifier to synchronize data. User-defined trigger patterns and trigger qualifier.

Logic Converter: Converts among gate, truth table and Boolean logic representations.

### COMPONENTS

Sources: DC Voltage, DC Current, AC Voltage, AC Current, Voltage-Controlled Voltage, Voltage-Controlled Current, Current-Controlled Voltage, Current-Controlled Current, AM, FM, Vcc, Clock, Pulse-Width Modulated, Frequency-Shift Keying, Polynomial, Piece-Wise Linear, Controlled, Voltage-Controlled Oscillator and Nonlinear Dependent.

Basic: Resistor, Capacitor, Inductor, Transformer, Relay, Switch, Time-Delay Switch, Voltage-Controlled Switch, Current-Controlled Switch, Pull-Up Resistor, Variable Resistor, Resistor Pack, Polarized Capacitor, Variable Capacitor, Variable Inductor, Coupled Inductor and Nonlinear Transformer.

Diodes: Diode, Zener Diode, LED, Shockley Diode, Diac, SCR, Triac and Full-Wave Bridge Rectifier.

Transistors: NPN and PNP BJTs, N- and P-Channel JFETs, 3- and 4-Terminal Enhancement and Depletion N- and P-Channel MOSFETs.

Analog ICs: 3- and 5-Terminal Opamps, Comparator and Voltage Regulator.

Mixed ICs: A-to-D Converter, D-to-A Voltage and Current Converters, 555 Timer and Monostable.

Logic Gates: AND, OR, NOT, NOR, NAND, XOR, XNOR, Tristate Buffer, Buffer and Schmitt Trigger.

Digital: RS, JK, JK, D and D Flip-Flops, Half and Full Adders, Multiplexer, Demultiplexer, Encoder and Decoder.

Indicators: Bulb, Voltmeter, Ammeter, Probe, Raw and Decoded 7 Segment Display, Buzzer and Raw and Decoded Bargraph.

Controls: Differentiator, Integrator, Gain Block, Transfer Function, Limiter, Multiplier, Divider and Summer.

Other: Fuse, Lossy and Lossless Transmission Lines, Crystal, DC motor, Vacuum Tube and Buck and Boost Converter.

74xx ICs: 7400 7402 7404 7405 7406 7407 7408 7409 7410 7411 7412 7415 7420 7421 7422 7425 7426 7427 7428 7430 7432 7433 7437 7439 7440 7442 7445 7447 7451 7454 7455 7469 7472 7473 7474 7475 7476 7477 7478 7486 7490 7491 7492 7493

74xxx ICs: 74107 74109 74112 74113 74114 74116 74125 74126 74133 74134 74138 74139 74145 74147 74148 74151 74153 74154 74155 74156 74157 74158 74159 74160 74162 74163 74164 74165 74166 74169 4173 74174 74175 74181 74190 74191 74192 74194 74195 74198 74199 74238 74240 74241 74244 74251 74253 74257 74258 74273 74280 74290 74293 74298 74350 74352 74353 74365 74367 74368 74373 74374 74375 74377 74378 74379 74393 74395 74445 74465 74466

4xxx ICs: 4000 4001 4002 4008 4011 4012 4013 4015 4023 4025 4028 4030 4040 4049 4066 4068 4069 4070 4071 4073 ... 4086 4107 4019 4024 4027 ... 4075 4077 4078 ... 40103

### MODELS

... Models for ICs: Gates and Flip-Flops in HC ... HC buffer, HC open-drain, LS totem-pole ... buffer, LS open-collector and LS open-collector buffer configurations.

Diodes: Over 1,300 models for Diodes, Zener Diodes, LEDs, Shockley Diodes and Diacs from Motorola, General Instruments, International Rectifier, Zetex and Phillips.

Transistors: Over 1,400 models for NPN and PNP BJTs, JFETs, MOSFETs, SCRs, Triacs and IGBTs from Motorola, National Semiconductor, International Rectifier, Toshiba, Harris and Phillips.

Analog ICs: Over 1,200 models for Opamps, Comparators and Voltage Regulators from Motorola, Texas Instruments, Maxim, Elantec, Analog Devices, Zetex, Burr-Brown and Linear Technology.

Other Models: a variety of Relays, Transformers, Vacuum Tubes, Transmission Lines and Crystals.

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INTERACTIVE

CIRCLE NO. 111 ON REPLY CARD

# Straightening out a pcb problem

*Charles Ume (right) examines the fringe pattern generated when a printed circuit board is heated in the new oven.*

Printed circuit boards, or pcbs, remain vulnerable to a simple, heat-induced threat: warpage. Unfortunately, warped pcb may cause a device to stop working, while boards that warp during manufacturing after expensive components are added can mean costly losses.

But a technique developed at the Georgia Institute of Technology and now licensed by Electronic Packaging Services (EPS) could provide a new weapon against warpage.

The experimental Thermoiré process provides real-time data about pcb warpage in simple and fast manner, so that manufacturers can avoid design problems.

"Electronic packaging companies can use the warpage information to make changes in their pcb design early," says Charles Ume, an associate professor in the School of Mechanical Engineering.

The heat that can warp pcbs is generated each time computers, camcorders or other pcb-run devices are turned on. Also, temperatures up to 230°C are an integral part of pcb processing.

In addition, if the pcb is small, thin and densely populated with components, as is the current industry trend, that is an invitation for warpage-related reliability problems.

For the new process, Ume developed a special oven with a glass grating top, through which the pcb placed inside is visible. A white light shines through the glass grating onto the pcb, and an inexpensive, compact, charge-coupled device camera captures warpage digitally as it occurs.

The flat glass grating is etched with equally spaced parallel lines. It is placed above and parallel to the pcb. A beam of white light is directed onto the glass at a specific angle, causing the etched lines to create a shadow on the surface of the pcb. When the surface of the pcb curves due to warpage, a moire pattern is produced by the geometric interference between the etched lines on the glass and the shadow of those lines on the pcb's surface. The more the pcb warps, the greater number of moire fringes that appear.

Ume counts the number of fringes, puts them into an equation, and a computer determines how much warpage has occurred. The warpage process is displayed in real time on a television screen and recorded on video and on computer.

The Thermoiré technique can be used to simulate the three major kinds of soldering processes – infrared reflow, convective reflow and wave – and the automated oven system can reproduce any given soldering temperature history used in producing a board. In this way, the system can pinpoint which processes or designs may cause the most warping.

Ume says that companies can use the results to make design or process changes before production, such as changing soldering temperature profiles, reducing or extending processing times, relocating key components, and changing the materials used in constructing the pcb.

The ability to measure thermally induced warpage could also enable manufacturers to validate their numerical warpage predictions, created using finite element modelling techniques.

If a certain amount of warpage is allowable, the new technique also lets manufacturers measure initial warpage, rather than assuming the board is flat before transistors and other items are added.

Manufacturers can then determine how much additional warpage develops during further processing or attachment of components. ■

Contact: Charles Ume, Georgia Institute of Technology, Atlanta, Georgia 30332-0828, USA. email: charles.ume@me.gatech.edu)

# 1997 will be the year of the blue laser

CW operation of blue laser diode devices should now be possible, with commercialisation coming in 1997-98, according to one of the leading researchers in the field.

Shuji Nakamura, of Nichia Chemical Industrie, Tokushima, Japan, made his prediction in an interview appearing in *OE Reports*, published by Spie (The International Society for Optical Engineering).

Nakamura has already been behind some of the major breakthroughs in blue leds and lasers. He has also stood against the prevailing wisdom underlaying much work in blue device research by concentrating on GaN technology, rather than using the more usual II-VI materials and then frequency doubling.

Now, when he is reported to be close to developing a commercial product, the significant degradation suffered by II-VI blue lasers is convincing scientists that GaN is the way forward.

So far Nakamura has produced a pulsed blue laser diode operating at room temperature, with wavelength variable between 390-440nm by changing the In content of the InGaN well layers.

Initially, the cost of the laser devices will be many times greater than the current $1-2 price of blue leds, though volume will naturally force this down.

The attraction of blue lasers is the impact they could have on high density storage. Current limits using a red laser diode are around 5Gbytes per side. But the shorter wavelength of blue light should allow this capability to be increased substantially, perhaps by a factor of three.


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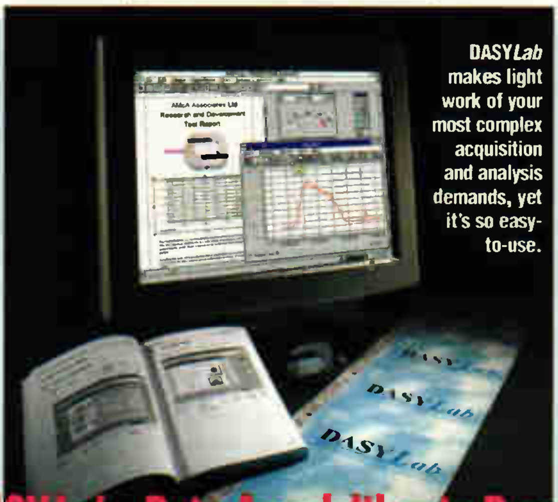


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CIRCLE NO. 158 ON REPLY CARD

# Roaring subwoofer

**Using motional feedback, Russel Breden's subwoofer produces flat response down to 15Hz – despite its relatively small enclosure. Feedback also makes feasible an infinite baffle rather than a reflex design, resulting in tighter bass.**

Inspired by Peter Baxandall's 'Low-cost, high-quality loudspeaker' series of articles in *Wireless World*, I built my first sub-woofer back in 1978. It was a 2.4ft$^3$ reflex using a KEF *B139* driver and tuned to 30Hz.

Originally, this sub-woofer was passive, but it soon became apparent that adding a dedicated power amplifier and second-order low-pass filter produced the flexibility required to interface with my existing speakers. Built in the days when home computers were a distant dream, and Thiele/Small analysis was little known, it is surprising that it worked at all. As it was, it gave me a sense of what was missing from most of the other systems around at that time.

Nearly twenty years later, things haven't changed that much. Off-the-shelf speaker systems available today rarely produce an output below 60Hz.

## Going lower

For a system to produce bass extending to at least 30Hz normally requires large boxes and expensive drivers. But by creative use of electronic circuitry, both size and expense can be cut to reasonable proportions. These techniques however require the sacrifice of hi fi's most sacred cow – flat amplifier response.

Today, we have all the tools necessary to design economical audio systems with a flat response, even though the system's component parts may be far from linear. The work of Thiele – extended by Small – provides comprehensive details about the response of a driver in an enclosure. All that is needed is to design electronic circuitry to compensate for the non-linear response of the speaker/driver combination.

## Advantages of activity

A motional feedback system operates by sensing the speaker cone's motion and feeding this back into the power amp.

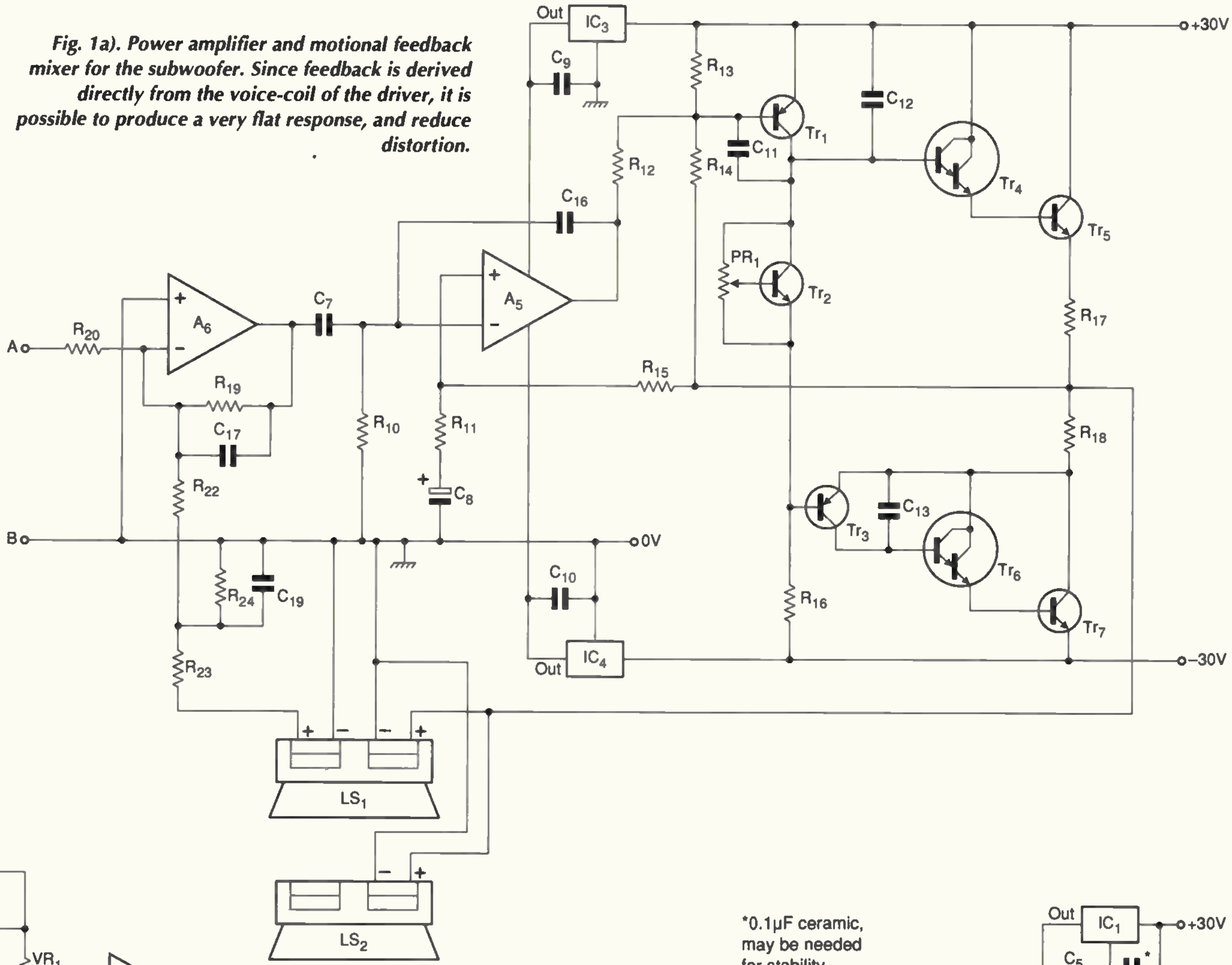
Providing negative feedback in this way forces the amplifier to produce a signal that corrects both for amplitude irregularities and the distortion generated by the speaker. The result is an acoustic output which is flat against frequency – even though both speaker and amplifier are operating in a decidedly non-linear fashion.

Motional feedback is not the only way of achieving this. You could use electrical equalisation, for example, but this would not reduce system distortion. In any event, motional feedback is an intellectually satisfying technique using well understood principles.

To produce a correcting signal, the speaker must be fitted with some form of transducer. In this design, I have used dual-coil drivers, one coil of which forms the pickup. As the cone moves, it generates a voltage signal in the coil which is proportional to cone velocity. This signal is then processed and used for correction purposes, see panel.

One major objection to motional feedback is that the feedback loop could try to force the driver beyond its limits. This

*Fig. 1a). Power amplifier and motional feedback mixer for the subwoofer. Since feedback is derived directly from the voice-coil of the driver, it is possible to produce a very flat response, and reduce distortion.*



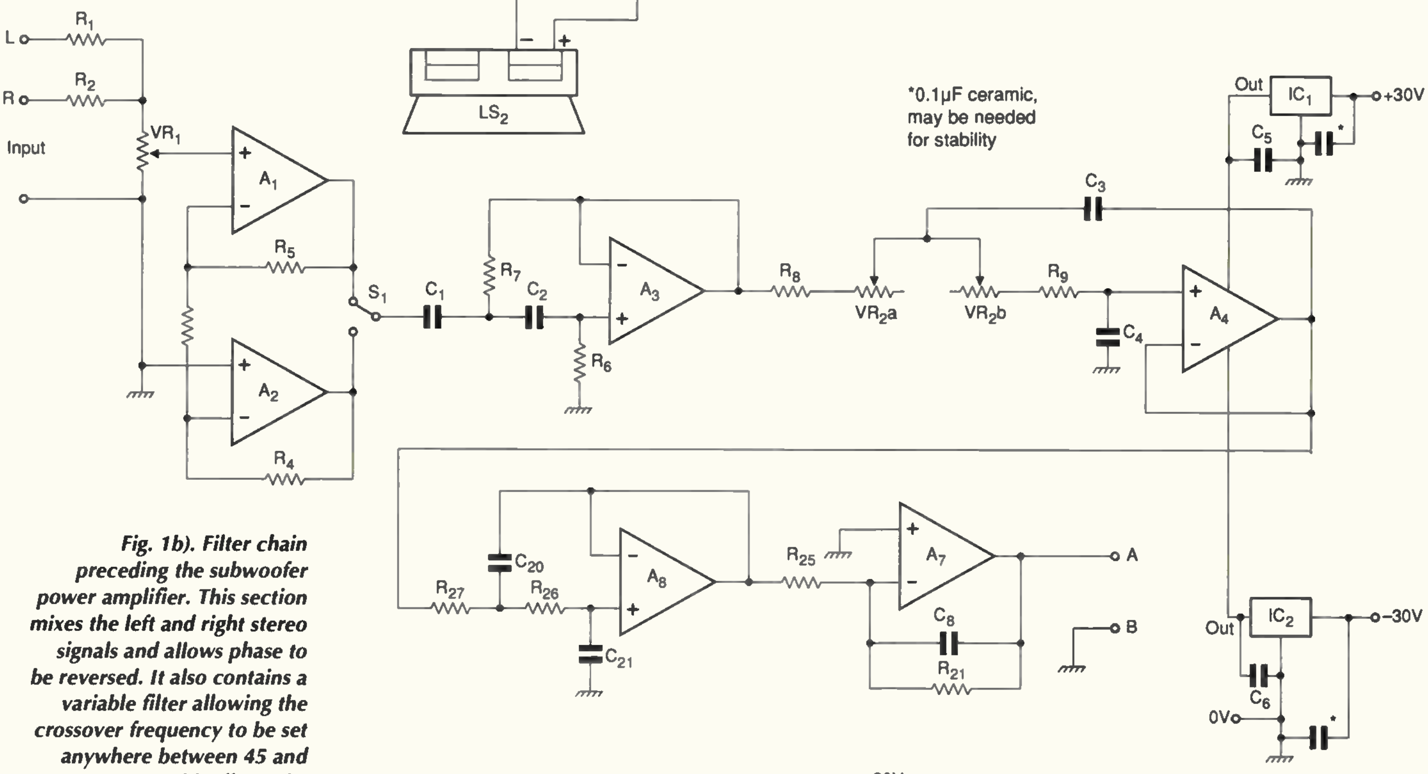




*Fig. 1b). Filter chain preceding the subwoofer power amplifier. This section mixes the left and right stereo signals and allows phase to be reversed. It also contains a variable filter allowing the crossover frequency to be set anywhere between 45 and 120Hz. This allows the subwoofer to be adapted to suit most existing hi-fi systems.*

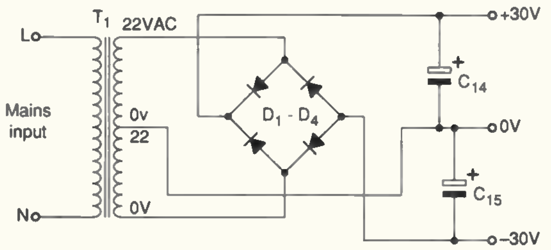



*Fig. 1b). Power supply for the subwoofer uses a dual-secondary transformer with its windings in series.*

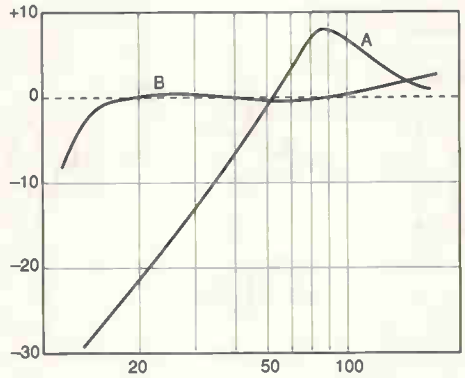



*Fig. 2. Curve A is initial system response while curve B is final system response but excluding low-pass filtering. Both curves are measured near filed, i.e. 1cm from cone.*

problem can be avoided by choosing a sealed box or infinite-baffle enclosure. Use can then be made of the natural roll-off of the driver to ensure that excursion limits cannot be exceeded (see panel).

Using an infinite-baffle enclosure means that the response is essentially that of a second-order filter. To produce a flat response down to dc – even if it were possible electrically – would require infinite cone excursion. To match such a driver, you would need an amplifier of infinite gain since the gain of a high-pass filter is zero at dc. For every octave of base extension, the power and cone excursion required increase fourfold. Obviously this cannot be carried too far. However the system described here has a flat resonance, with a –3dB point at 15Hz.

This frequency is at least an octave below the nominal cut-off of many subwoofer systems. Furthermore when I examined the output acoustically, sine wave distortion was below 2% at 15Hz.

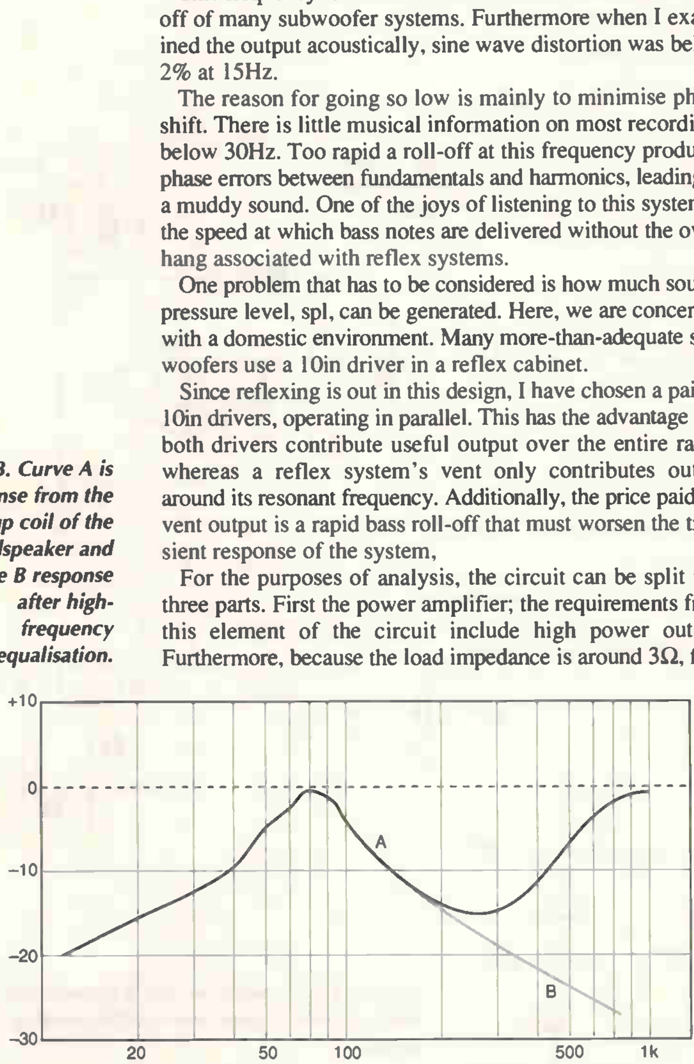
The reason for going so low is mainly to minimise phase shift. There is little musical information on most recordings below 30Hz. Too rapid a roll-off at this frequency produces phase errors between fundamentals and harmonics, leading to a muddy sound. One of the joys of listening to this system is the speed at which bass notes are delivered without the overhang associated with reflex systems.

One problem that has to be considered is how much sound-pressure level, spl, can be generated. Here, we are concerned with a domestic environment. Many more-than-adequate subwoofers use a 10in driver in a reflex cabinet.

Since reflexing is out in this design, I have chosen a pair of 10in drivers, operating in parallel. This has the advantage that both drivers contribute useful output over the entire range whereas a reflex system's vent only contributes output around its resonant frequency. Additionally, the price paid for vent output is a rapid bass roll-off that must worsen the transient response of the system,

For the purposes of analysis, the circuit can be split into three parts. First the power amplifier; the requirements from this element of the circuit include high power output. Furthermore, because the load impedance is around 3Ω, fairly large current swings are required. An extended low frequency response also implies that the power supply will tend to sag under load. Precautions must be taken to make sure that this does not affect sound quality.

*Fig. 3. Curve A is response from the pick-up coil of the loudspeaker and curve B response after high-frequency equalisation.*




Taking into account these factors I make no apology for the use of rugged TO3 output devices, namely $Tr_5$ and $Tr_7$, which are a pair of *2N3055*s. These in turn are driven by a pair of Darlingtons, $Tr_4$ and $Tr_6$. A quasi-complementary output stage is used with $Tr_3$ providing the necessary phase inversion for the lower output transistors.

## Nested feedback loops

The entire circuit is based on *TL074* quad op-amps, one of which is used in the power amplifier. However the low operating voltage and consequent low output voltage swings of this device provide insufficient power. For this reason the amplifier incorporates the idea of nested feedback loops, **Fig. 1**.

To explain further, the output stage operates from a split 60V power supply. The driver stage is built around $Tr_1$. Usually, the output stage biasing voltage is provided by the $V_{be}$ multiplier comprising $Tr_2$ and $PR_1$. Resistors $R_{17,18}$ introduce emitter degeneration in the output stage, stabilising the operating point. Local shunt feedback around both driver and output stage is taken via $R_{12,14}$.

The value of $R_{13}$ has been chosen to produce 0V output for a 0V input from $A_5$. This local feedback loop reduces distortion from the output stage to well below 1% before global feedback is applied around the circuit.

Closed-loop gain from $A_5$ output to the load is approximately five. This allows the op-amp output stage to produce the required voltage swing at the output. An incidental advantage is that the op-amp output sees a relatively high impedance and therefore operates in push-pull, Class A.

Supply voltage for the op-amp is taken from the main power supply through a pair of 15V regulators, $IC_{3,4}$. Capacitors $C_{9,10}$ provide hf decoupling. Op-amp $A_5$ is the heart of the amplifier. Note that because of the inverting action of the driver/output stage, the inputs are used in the opposite sense.

Input signals are applied to the inverting input and overall feedback to the non inverting. The voltage gain of the amplifier is set by the ratio of $R_{15}$ to $R_{11}$. Capacitor $C_8$ reduces the dc gain of the circuit to unity while appearing as a short circuit to ac signals. Resistor $R_{10}$ defines the input impedance of the amplifier.

The closed-loop gain needs to be high since most of it is used to equalise the subwoofer and reduce speaker distortion. The other components to be mentioned are mainly concerned with keeping hf stability within the amp. This is the function of $C_{12/13}$ and $C_{16}$.

It could be argued that most of the parameters of the amplifier just described are well above those required for the circuit function. For example, the slew rate of the op-amps is thousands of times faster than required. Similarly, the distortion level of the amplifier is many times lower than that generated by the speakers. This is simply a reflection on the advancement of commonly available parts. This same level of performance allows supply line voltage rejection ratio of over 100dB, and this *is* of great importance, as mentioned earlier.

The second aspect of the design, whose overall performance is shown in **Fig. 2**, involves the manipulation of the pick-up coil voltage to produce motional feedback. Referring to Fig. 1, rather than feed the speaker coil voltage directly into the amplifier's feedback loop, it is fed via the mixer stage built around $A_6$. The voice coil output feeds the network comprising $R_{22,24}$ and $C_{19}$. This is necessary because the voltage follows the impedance curve.

Below 200Hz the output is directly proportional to the velocity of the cone. Above this frequency output rises at approximately 6dB/octave. To maintain the velocity curve – not to mention amplifier stability – the output must be suppressed at high frequency. Capacitor $C_{19}$ flattens the curve to a straight line.

From here, the signal feeds the mixer amplifier $A_6$, via $R_{22}$. This is configured as a virtual earth mixer. Feedback resistor $R_{19}$ is shunted by $C_{17}$, which provides further high-frequency roll-off to the coil signal ensuring that the required response is obtained.

The net result of adding this signal to the amplifier input is that the acoustic response response from about 10Hz to 150Hz rises at 6dB/octave. In other words, amplifier output voltage is proportional to cone velocity, and acts as a power differentiator.

To obtain a flat response, the amplifier output needs to become proportional to cone acceleration, Rather than differentiate the feedback signal exactly the same result is obtained by integrating the input signal. This function is carried out by $A_7$, which, in conjunction with $R_{21}$ and $C_{18}$ forms the integrator.

At this stage we have produced a flat response speaker system – flat, at least, in the deep bass region. Plotting the response however reveals that the overall response is that of a high-Q low-pass filter. A glance at **Fig. 3** reveals that further work needs to be done. The low-pass response is due to the voice coil inductance resonating with the reflected moving mass.

Rather than complicate the circuitry further, the solution used here is to tame the response by using a low-Q low-pass filter in series with the amplifier. When this has been done the final response is flat within 1.5dB from 15 to 150Hz. The mild penalty to be paid is that the response rolls off at 24dB/octave above 150Hz. Luckily, this is of little consequence in practice since this point occurs at least half an octave – and usually more than an octave – above the roll-off point required by normal speaker systems.

## Filtering the input-stage

The main task of the input stage filtering is to extract the bass information from both incoming signals and present this to the power amplifier. In addition, the signal must be manipulated to allow 'seamless' integration of the subwoofer with the existing speakers.

For this design, I decided to drive the sub-woofer directly from the speaker outputs of the existing amplifier. This not only simplifies the design, it is the only rational place to take a signal feed. Once set up the sub-woofer will follow system volume adjustments. This is a particular advantage if, like me, you are always being told turn it down. You can also be assured plenty of drive signal.

Line outputs are rarely standard. The left and right signals

## Infinitely baffling

In order to squeeze the maximum possible bass from an infinite-baffle enclosure, the volume has to be carefully calculated. Even motional feedback systems are not immune to the laws of physics. If the enclosure is made too large, the woofer will be driven beyond its excursion limit. If it is too small, maximum power input will not allow full excursion.

In order to calculate the required enclosure volume, Thiele-Small equations are required. When a circular piston is fed with a sine wave, it can be shown that the sound-pressure level generated at 1m into half space, *A*, is,

$$A(\text{dB})=40\log_{10}(d)+20\log_{10}(app)+40\log_{10}(f)-83$$

where *d* and *app* are the diameter and peak-to-peak cone excursion respectively, both expressed in mm and *f* is the frequency of interest.

From the term $40\log_{10}(f)$, you will see that the available sound-pressure level falls with frequency at 12dB/octave. If the enclosure volume is chosen so that its response lies to the right of *A*, **Fig. 4**, then the driver will be protected from excessive excursions. If the response lies to the left of *A* then the speaker runs the risk of destruction from bass input. Ideal enclosure response coincides with *A*.

In order to calculate something useful it is essential to examine the efficiency of the driver and relate this to *A*. Maximum output that a driver can produce in the pass-band is independent of enclosure size and can be calculated from the following equations, the first of which is for driver efficiency, $\eta_o$,

$$\eta_o=\frac{k.f_o^3.V_{as}}{Q_{es}}$$

where $f_o$ is free-air resonant frequency, $V_{as}$ is equivalent compliance air volume, $Q_{es}$ is electrical *Q* and *k* is $9.64\times10^{-10}$ when $V_{as}$ is expressed in litres. Sound-pressure level in decibels at 1W and 1m distance into half space is,

$$112+10\log_{10}(\eta_o)$$

Maximum sound-pressure level in decibels at 1W and 1m distance into half space, *B*, is

$$112+10\log_{10}(\eta_o)+10\log_{10}(p)$$

where *p* is the available amplifier output in watts continuous.

All drivers mounted in an infinite-baffle enclosure exhibit second-order high-pass filter response whose amplitude, *C*, is,

$$C=(\omega^4+(d^2-2)\omega^2+1)^{-0.5}$$

where w is $f_c/f$ and *d* is $1/Q_{tc}$, $f_c$ being the resonant frequency of the driver mounted in the enclosure and $Q_{tc}$ is the *Q* of the driver in the enclosure. Unfortunately this does not help much because $Q_{tc}$ and $f_c$ are not known until the enclosure volume has been determined. But if you choose *f* at a low enough frequency, say 1Hz for convenience, then $w^4 >> (d^2-2)d^2+1$ term. This makes it possible to simplify and rewrite the equation for an approximation of *C* as, $w^{-2}$.

To avoid the excursion limit, the 1Hz response must be $-A+B$ (in dB) down with respect to maximum pass-band sound-pressure level, *B*. The corresponding amplitude is $10^{((-A+B)/20)}$, which is $w^{-2}$.

As f is 1Hz, ω must equal $f_c$ so, $f_c=w=10^{-((-A+B)/40)}$. Having obtained $f_c$, the enclosure volume can be simply calculated from,

$$V_b=V_{as}/((f_c/f_o)^2-1)$$

Calculated volume is slightly conservative, but this no bad thing considering the price of drivers.

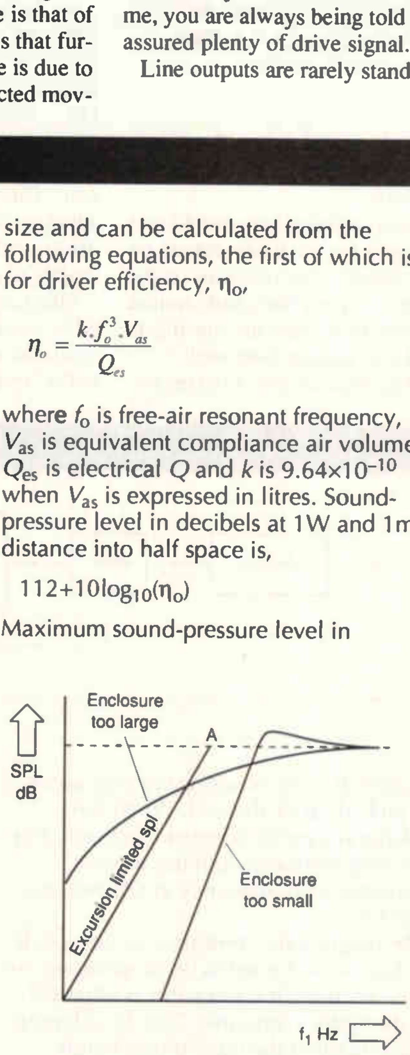



***Fig. 4. Excursion sound-pressure level limit rises at 12dB/octave. Speaker responses that intersect the left of A are limited by cone excursion. Right of A are thermally limited but cannot produce maximum sound pressure level. Ideal speaker response coincides with A.***

from the speaker sockets are passively mixed by $R_1$ and $R_2$. The resulting signal is made available across $VR_1$. From here the signal is phase split by $A_{1,2}$.

## Avoiding eigentones

Phase splitting is a useful facility for the following reason. When attempting to crossover between speakers and subwoofers, a particular obstacle is avoiding eigentones. At low frequencies, the average room acts as a gigantic speaker cabinet, with resulting resonances, caused by standing waves between parallel walls.

These resonances often occur just where you want the crossover. By judicious use of the controls, you can use phase shift to tame existing boomy speakers or room characteristics. Choice of in or out-of-phase conditions is selected by $S_1$ of Fig. 1. A small amount of voltage gain is introduced into the phase splitter circuit via $R_{4,5}$. This offsets the gain reduction produced by coil feedback in the power amplifier section. Resistor $R_3$ couples the op-amps together to provide phase inversion.

Having selected your signal with $S_1$, it is then fed it into the high-pass filter built around $A_3$. This stage defines the lower cut-off point of the system. This is set at 15Hz by the component values chosen. From here the signal is fed into the low pass filter built around $A_4$.

## Integrating the design

In order to integrate the subwoofer easily, a low-Q second-order filter is used. This stage has a Q of 0.5, critically damped for best transient response.

The –3dB point is continuously variable between 45 and 120Hz. I have yet to find a speaker system which cannot be catered for within this range. Finally, the response of the pick-up coil is modified by the low-pass filter built around $A_8$, as described earlier in the text. From here the signal gets fed into the signal integrator $A_7$, as already discussed.

I have used separate voltage regulators to power the preamplifier section. This may seem like an extravagance but it is a small price to pay for total isolation on the power lines between chips.

On the subject of power supply, Fig. 1, this is completely conventional. Mains voltage is stepped down and full-wave rectified via a bridge, before being smoothed by $C_{14,15}$. The centre tap of the secondaries is used for the 0V line,

## Points to watch out for

There are a few points to watch for when implementing the subwoofer. First the cabinet. Initially I intended to build the subwoofer in two enclosures with the intention of siting these below my existing speakers. Since there is no phase information at low frequencies, it is possible, in principle, to the site the subwoofer wherever you choose. In practice the best position is likely to be between the speakers, against the wall. This position will give you an extra 3dB of output for as the system will be driving into quarter space.

Conventional wisdom suggests that corner positions should be avoided as this will tend to emphasise room resonances. Circumstances alter cases, and the extra 3dB of output might be useful.

An advantage of small enclosures, in addition to the improved rigidity, is that they are too small for internal standing wave generation. Since I am not a carpenter and find woodwork a chore I built my cabinets from 15mm chipboard, Fig. 6, available everywhere and in a variety of finishes.

Panel fixing is easiest using Araldite rapid fairly liberally along the seams. The drivers require 230mm diameter cutouts. They should be mounted on gaskets made from self adhesive draught excluding strip. Before mounting the drivers, fill along the panel seams with filler or silicone sealant to ensure airtightness.

When assembling the electronics ensure that $PR_1$ is adjusted to short $Tr_2$'s base to collector. For obvious reasons it is desirable to set the quiescent current in the output stage before mounting the electronics.

## Inductive motional feedback

Inductive pickup is probably the simplest form of motional feedback control. In order to understand its operation, it is necessary to realise that the pickup voltage is proportional to cone velocity. **Figure 5** shows the relevant curves. Curve A is the unequalised speaker response and corresponds with the cone acceleration.

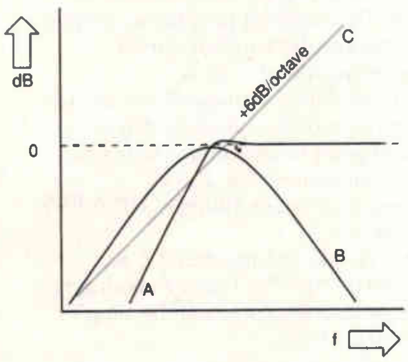



*Fig. 5a. Unequalised speaker response, A, resulting velocity curve picked up by the second voice coil, B, and resulting response curve from the speaker, C.*

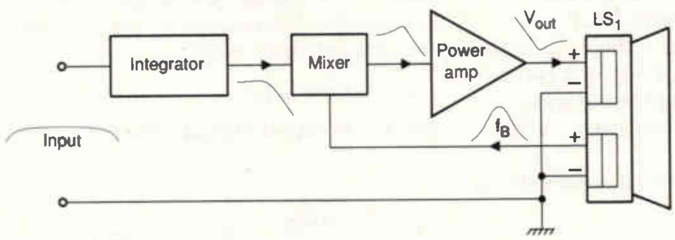



*Fig. 5b. Motional feedback using a second coil within the loudspeaker to produce the feedback signal. Error correction signal is introduced via a mixer amplifier.*

Curve B is the resulting velocity curve as picked up by the coil. When this voltage is used as negative feedback, the resulting response from the speaker increases with frequency at 6dB/octave, Curve C.

To obtain a flat response, the feedback voltage would need to be proportional to cone acceleration since this is identical to the system response. This would imply differentiating the coil voltage before feeding it back. The alternative, used in this design, is to integrate the incoming signal so that this falls at 6dB/octave. When fed from this signal the overall response of the speaker is flat. There is no difference in system performance either in amplitude or phase response between differentiating the pickup signal or integrating the input.

**Figure 5b** shows the basic circuit in block form. Rather than complicate, and possibly destabilise, the amplifier, the feedback is introduced via a mixer amplifier. This is a virtual-earth circuit which effectively adds the input and feedback signals. This is then used to drive the amplifier.

Closed loop gain of the amplifier produces the corrected signal to the speaker. The advantage of motional feedback is that errors in both the enclosure response and in the driver are considerably reduced by negative feedback.

## Motional-feedback subwoofer parts

**Resistors**

Unspecified types are 1% metal film

| | | |
|---|---|---|
| $R_{1,2}$ | 47k | 2 |
| $R_{3/24}$ | 10k | 4 |
| $R_4$ | 110k | 1 |
| $R_5$ | 100k | 1 |
| $R_6$ | 150k | 1 |
| $R_7$ | 75k | 1 |
| $R_{8,9}$ | 15k | 2 |
| $R_{10}$ | 39k | 1 |
| $R_{11}$ | 2k2 | 1 |
| $R_{12,25}$ | 22k | 2 |
| $R_{13}$ | 330 | 1 |
| $R_{14,15}$ | 82k | 2 |
| $R_{16}$ | 4k7 | 1 |
| $R_{17,18}$ | 0.47/3W | 2 |
| $R_{19,20,26,27}$ | 560k | 4 |
| $R_{21}$ | 680k | 1 |
| $R_{22}$ | 180k | 1 |
| $R_{23}$ | 43k | 1 |
| $VR_1$ | 4k7 log pot | 1 |
| $VR_2$ | 22k lin dual pot | 1 |
| $PR_1$ | 10k hor. preset | 1 |

**Capacitors**

| | | |
|---|---|---|
| $C_{1\text{-}4,18}$ | 100n Mylar | 4 |
| $C_{5,6,9,10}$ | 100n cer. disc | 4 |
| $C_7$ | 10µ/50V | 1 |
| $C_8$ | 100µF/25V | 1 |
| $C_{11/12/13/17}$ | 1nF Mylar | 4 |
| $C_{14/15}$ | 6800µF/63V | 2 |
| $C_{16}$ | 270pF cer. | 11 |
| $C_{19}$ | 47nF Mylar | 1 |
| $C_{20}$ | 2n7 Mylar | 1 |
| $C_{21}$ | 4n7 Mylar | 1 |

**Active devices**

| | | |
|---|---|---|
| $IC_{1,3}$ | 78L15 | 2 |
| $IC_{2,4}$ | 79L15 | 2 |
| $A_{1\text{-}8}$ | TL074 | 2 |
| $Tr_{1,3}$ | BC327 | 2 |
| $Tr_2$ | BC337 | 1 |
| $Tr_{4,6}$ | BDT65C | 2 |
| $Tr_{5,7}$ | 2N3055 | 2 |
| $D_{1\text{-}4}$ | 1N5408 | 4 |

**Miscellaneous**

| | |
|---|---|
| Heat sink, see text | |
| TO3 mounting kits | 4 |
| Volt DVC250/1, 8Ω drivers | 2 |
| 22-0-22V sec. 120VA transformer | |
| SPST changeover switch | 1 |
| Control knobs | 2 |

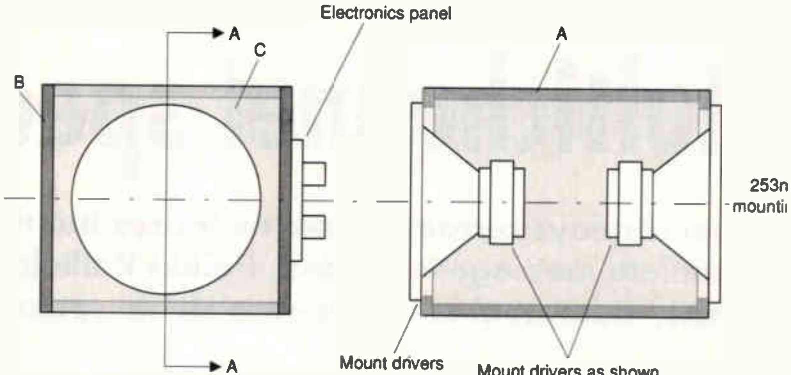



***Fig. 6. Subwoofer enclosure details. Since the enclosure is small, it is rigid and inhibits standing waves.***

With the speakers disconnected, test that the output is within 50mV or so of 0V. Quiescent current is set up by slowly adjusting $PR_1$ for a 20mV drop across $R_{17}$ and $R_{18}$. Although the heat sink gets rather warm under conditions of high drive, I have not found it necessary to use thermal feedback via $Tr_2$. But there is no reason why $Tr_2$ cannot be adhered to the sink.

I mounted the electronics within the enclosure. The output stage requires a large heat sink, of at least 1.5°/W. I used a 120 by 100mm finned sink.

Control panels are always a problem with this type of equipment. I mounted my controls and heat sink on the lid of an MB6 type ABS case which fits into a cut-out in one of the panels. This is secured by six, 30mm M3 screws. Whatever panel you use remember that an air-tight seal is needed.

The drivers are wired up as shown in the Fig. 1a, in parallel and in phase. Ensure that the pickup coil is phased as shown.

### Final adjustments

Having set the quiescent current and fastened everything into place, all that remains is to adjust the level and cut-off frequency to suit your system, The best way to start is with the cut-off frequency set high and gain set low. Next, adjust both for the best sound.

Finally, was the effort worth it? Definitely yes. I now get to hear things I have never heard before on my cds. In addition, the clarity and speed at which bass notes are generated and disappear is something of a revelation – after years of reflexed muddiness. ■

## Special offer

Any Electronics World reader mentioning page 109 of the February issue can obtain one pair of Volt drivers, as used in the subwoofer, at the special price of £234 – including VAT and UK delivery. Normally, the pair sells at over £257, excluding delivery. Send PO or cheque payable to Wilmslow Audio at 50 Main Street, Broughton Astley, Leicester LE9 6RD. Phone 01455 286603 or fax 286605 for further details.

# Multichannel speaking monitor

**Visual displays certainly have their uses but there are times when a more immediate message is needed. Heikki Kalliola's speaking monitor provides digitally-addressable and re-recordable spoken messages.**

My design for a multi-channel speaking monitor is based on an Information Storage Devices speech memory chip. With no moving parts and needing few external components, the circuit is an economical means of making many kinds of announcements, including measurements and threshold warnings.

One application of the speaking monitor is the reporting of exceptional conditions in vehicle environments. Using spoken messages, there is no need to divert your attention to the indicators on the instrument panel. This device can be mounted in an enclosure small enough to hide behind the dashboard without any rebuilding.

The *ISD1016A** speech storage chip used can record and play back 16 seconds of voice in a number of individually-addressable segments – in this case four, of four seconds each in length. Each of the four messages can be triggered according to the situation. The chip family includes members with longer recording time, but 16 seconds is enough for the purpose described here.

Inputs 1 to 4 are constantly monitored, **Fig. 1**. If one or more input is grounded, a message from the corresponding memory address is fed to the loudspeaker. The message is repeated until the grounded contacts open.

If all the inputs are used, there is time about four seconds for each message. If all inputs are not needed, the ones used can have more time allocated to them. If for example only line number 1 is used, the announcement can be a full 16 seconds.

## Recording and playing back

Recording is performed by first selecting the message to be dictated on the sensor line. Selection is done with switch $S_1$. As drawn, $S_1$ points to line 1. After line selection, button $S_3$ is pushed while you read the message in to the microphone.

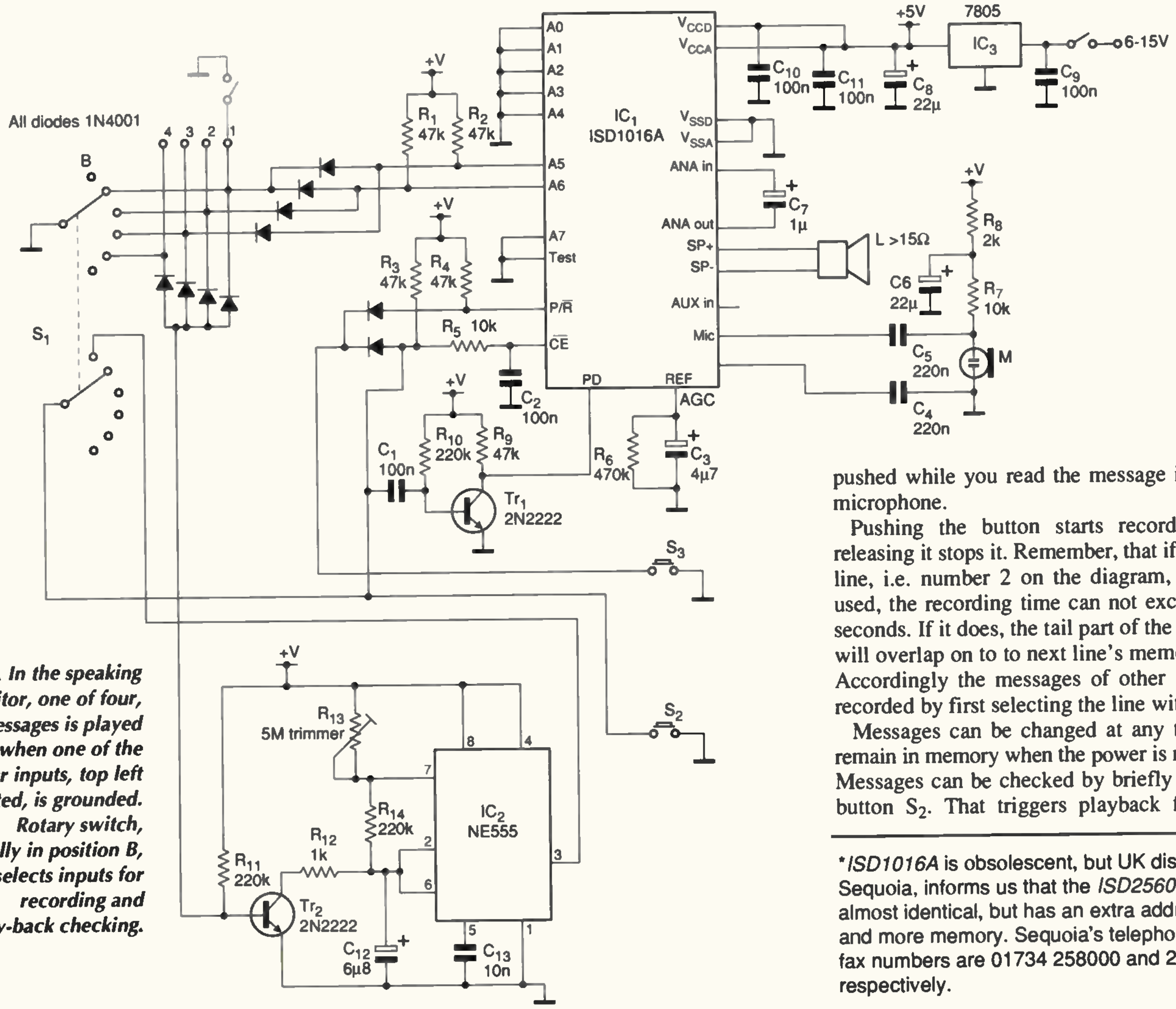



*Fig. 1. In the speaking monitor, one of four, 4s messages is played back when one of the four inputs, top left dotted, is grounded. Rotary switch, normally in position B, selects inputs for recording and play-back checking.*

Pushing the button starts recording and releasing it stops it. Remember, that if the next line, i.e. number 2 on the diagram, is to be used, the recording time can not exceed four seconds. If it does, the tail part of the message will overlap on to to next line's memory area. Accordingly the messages of other lines are recorded by first selecting the line with $S_1$.

Messages can be changed at any time and remain in memory when the power is removed. Messages can be checked by briefly pressing button $S_2$. That triggers playback from the

**ISD1016A* is obsolescent, but UK distributor Sequoia, informs us that the *ISD2560* is almost identical, but has an extra address line and more memory. Sequoia's telephone and fax numbers are 01734 258000 and 258020 respectively.

memory location pointed to by $S_1$. Thus re-recordings are easily made.

Once the messages are loaded, $S_1$ is turned to its base position, indicated as B on the diagram, and the device is ready for use. When one or more of the input lines is grounded, the message from that line's memory area is spoken from the loudspeaker and repeated until the line returns to its normal state.

## Circuit logic

When an input line is grounded, diodes set the right address with bits $A_5$ and $A_6$. At recording and check playback this grounding is performed by $S_1$.

The memory chip requires that during recording pins P/R and CE are grounded. Signal PD keeps power consumption extremely low when at +5V. To record and play back, this line must be grounded. The signal also acts as reset switch, in the event of a memory overflow. Resetting is carried out by pulling the line to +5V and back to ground again.

When recording, $S_3$ pulls pins P/R and CE down to ground via diodes. At the same time transistor $Tr_1$ stops conducting for a moment due to grounding of the base via $C_1$. A positive reset-pulse is created from the collector to pin PD. Releasing of $S_3$ generates the end-of-message mark to the memory.

To check play back, $S_2$ starts the message by pulling down the chip enable pin, CE, and creating a reset pulse to PD with $Tr_1$.Playback starts at the address pointed to by $S_1$ and continues until the end-of-memory mark.

Grounding of input line pulls also down the base of $Tr_2$. The transistor stops conducting, triggering the astable multivibrator timer chip $IC_2$. The chip puts out negative-going pulses equivalent to pushing the playback button $S_2$. If $S_1$ is at base position, B, these pulses pass through to playback triggering.

Time interval between pulses, and therefore also the rate of message repetition, is dictated by the value of $R_{13}$. If, for example, only one input is used and the maximum length message recorded in one location, the interval time must be over 16 seconds to avoid rolling over. If on the other hand, all the inputs are used, the minimum interval is about five seconds, and the message length cannot exceed four seconds.

## Anti drown-out switch for vehicles

In vehicles, there are many possible stimuli for the monitor. Examples are oil pressure warning, over-high water temperature and low fuel indication. In many cases, easily accessible switch contacts for these are already installed in the car.

When this design is used in vehicles, the usual power supply is the 12V battery, from which the voltage is dropped to 5V via regulator $IC_3$.

In automotive applications, the car radio might obscure messages. To avoid this, you can add the switching circuit of **Fig. 2**. With this modification, the radio loudspeaker replaces the monitor's loudspeaker and serves a dual purpose. Control for the output relay is taken from the speech memory's auxiliary input, which is held high during playback.

Do not forget to add a 10Ω series resistor, if the loudspeaker has very low impedance. ■

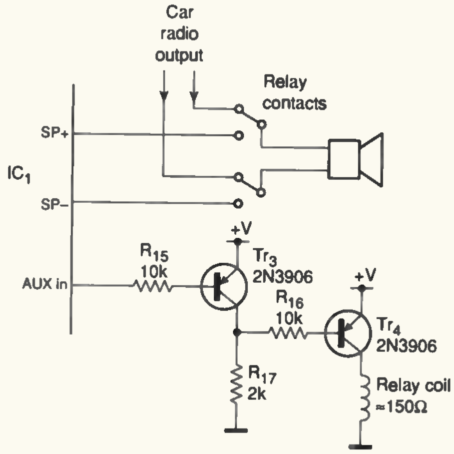
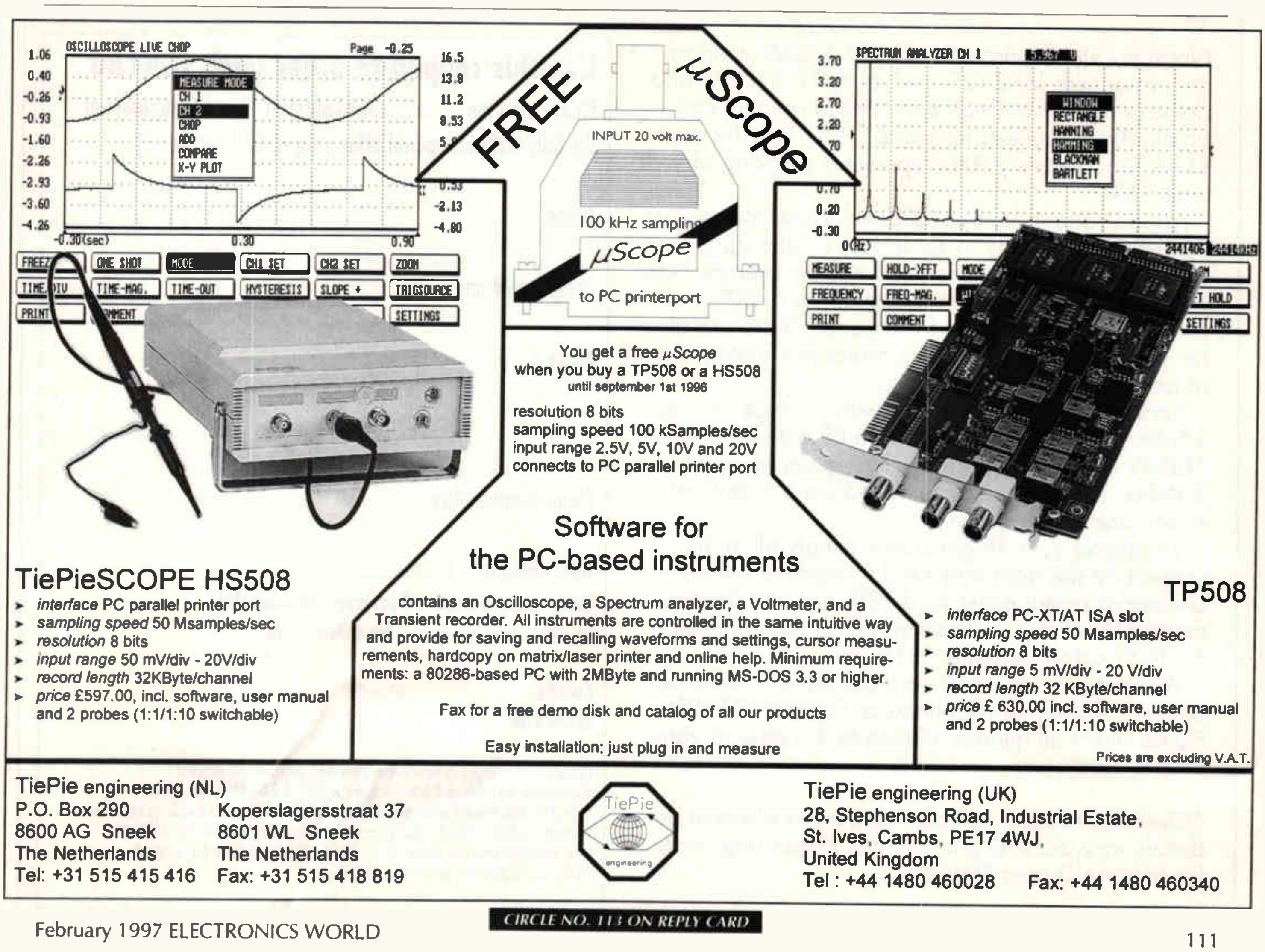



***Fig. 2. In automotive applications, this switch circumvents the problem of a loud radio obscuring the announcement by automatically switching the radio's speaker over to the speaking monitor unit when a message is triggered.***

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**Ian Hickman takes a further look at how circuit operation can be represented pictorially.**

# More in the PICTURE

An earlier article of mine[1] reviewed various ways of representing circuit action, with a view to showing how the different representations complemented each other. So the article covered vector diagrams, the circle diagram – a sort of generalised vector diagram showing what happens as the frequency varies – Bode plots – which also show what happens as the frequency varies – and pole-zero diagrams.

That was the intention, but my apologies to any readers who looked in vain for any zeros – they failed to materialise due to lack of space. This article rectifies the omission, and carries the story on another stage.

## Poles

Well, just one pole to begin with, the one to be found in the lowpass *CR* circuit of the last article, the response of which was shown there as Fig. 6, and here as **Fig. 1b)**. The equation giving the frequency response, as derived in the last article, is:

$$v_o/v_i=1/(1+j\omega CR) \qquad (1)$$

Note that, as last time, the base of the triangle (of length unity) is the vector $v_o$, then the two terms in the denominator take you from the pole at $\sigma=-1$ to the origin, and then a distance $\omega$ up the $j\omega$ axis (assuming as before that $CR=1$), where this distance represents the voltage drop across the resistor *R*.

Adding vectorially (the j indicating that these vectors are at right angles), this brings one to the tip of the sloping line, which represents the input voltage needed to give unity output voltage. Thus $v_i/v_o$ at any frequency is proportional to the distance from the pole at $\sigma=-1$ to the corresponding point on the $j\omega$ axis. So the frequency response, $v_o/v_i$, is proportional to the reciprocal of this distance.

Equation 1 also indicates the phase, as follows. First, make the denominator real, by multiplying top and bottom by $(1-j\omega CR)$, the complex conjugate of the denominator. The equation then becomes:

$$v_o/v_i=(1-j\omega CR)/(1+\omega^2C^2R^2)$$

and, since the denominator is now just a number, the phase angle is given just by the numerator. Phase angle $\phi$ is given by:

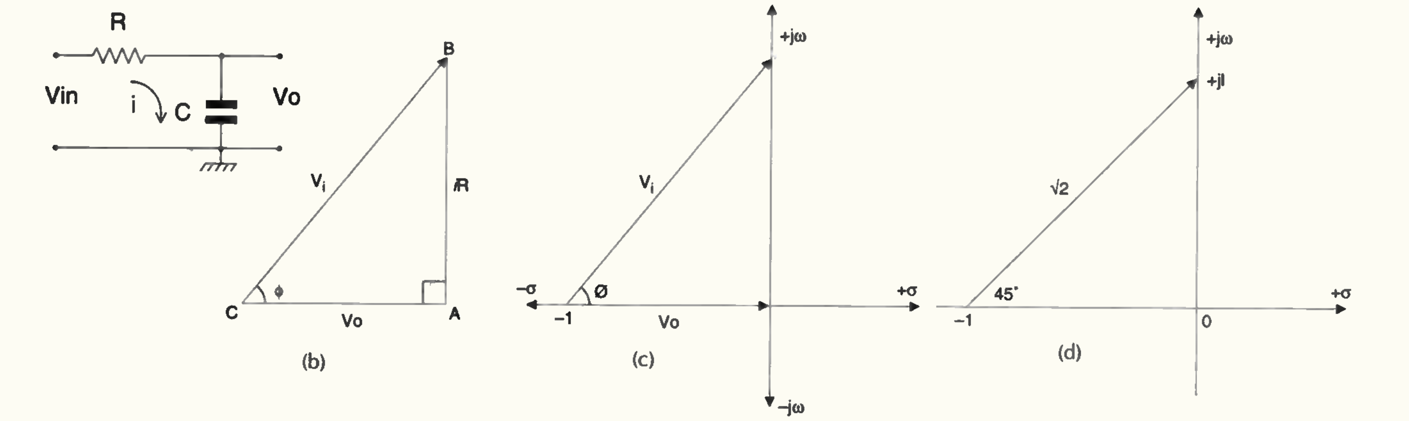
$$\phi=\tan^{-1} I/\mathcal{R}$$

where $\mathcal{R}$ and $I$ are the real and imaginary parts of the numerator. Clearly, $-\omega CR/1$ is zero at 0Hz and minus infinity at infinite frequency, so $\phi$ is 0°, at 0Hz and tends to –90° at very high frequencies.

These two results give an important rule:

*The amplitude of the response at any frequency due to a pole is inversely proportional to the length of a line from the pole to the corresponding point on the $j\omega$ axis, and the phase is given by the angle that the line makes with the positive horizontal axis, counting anticlockwise rotation round the pole as negative, indicating a lagging response.*

Figure **1c)** shows how the vector diagram ties up with the pole/zero diagram. Figure **1d)** is the same again but drawn for the –3dB frequency, the frequency where the reactance of the the capacitor equals the resistance *R*.



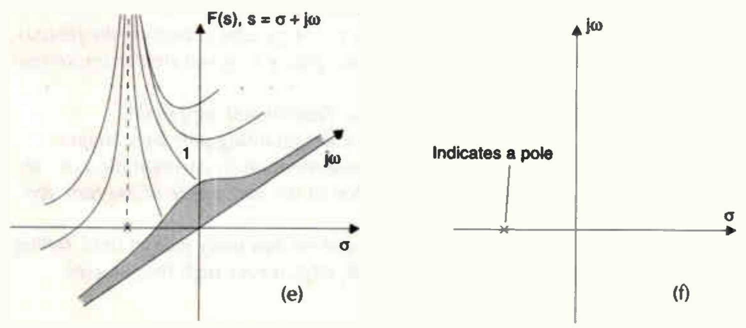
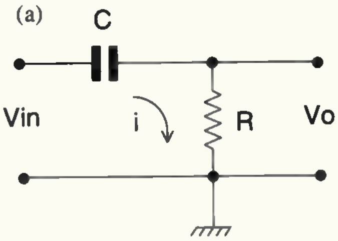
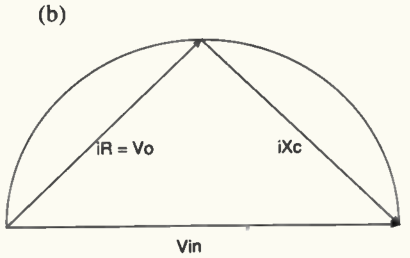




*Fig. 1a). CR lowpass circuit.*
*b) Corresponding vector diagram for one particular frequency.*
*c) is b) superimposed upon the s plane.*
*d) is c) shown for the –3dB frequency, where $V_i=\sqrt{2}V_o$.*
*e) Crude 3-dimensional representation of the magnitude of the function F(s), plotted vertically above a horizontal s plane.*
*f) Plan view of e), looking down on the s plane.*



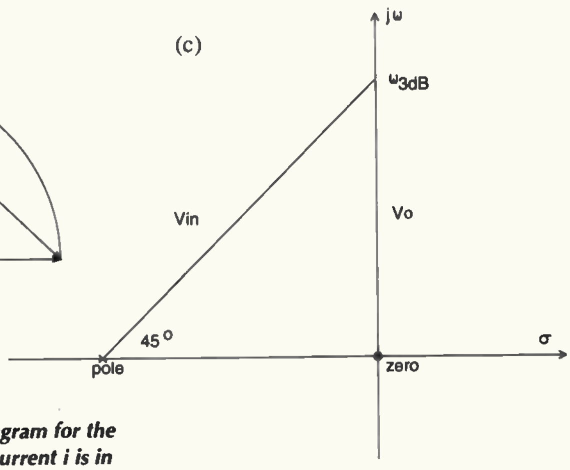




Figure **1e** is a three-dimensional representation of the magnitude of $F(s)$, plotted vertically above a horizontal s plane. Only that part of the surface to the left of the jω axis (where σ is negative) has been shown. The 'cut edge', above the positive jω axis, gives the magnitude of the frequency response, as a linear plot against frequency (also linear). In plan view, the s plane looks like Figure **1f**) – there is a pole at the point where s has the coordinates (–1, 0).

As noted in the earlier article, in terms of the complex frequency variable s, the transfer function $F(s)$ which gives $v_o/v_{in}$ becomes $F(s)=1/(s+1)$, where $s=\sigma+j\omega$.

If the pole moves further and further toward the origin, the response will rise by 6dB every time the frequency is halved, and so on indefinitely. With a pole at the origin, you have an integrator – i.e., an ideal op-amp with capacitive feedback from the output to the inverting input, and with the input applied via a resistor.

### ...and zeros

Now for a 'finite zero', that is to say a zero at a finite frequency, which will appear on the pole/zero diagram. You get one with a high-pass (bass cut or passive lead) circuit, shown in Figure **2a**), along with its circle diagram,

*Fig. 2. a) CR highpass circuit.*
*b) Circle diagram, with vector diagram for the -3dB frequency. Note: the input current i is in phase with Vo, i.e. leading Vin by 45( at this frequency.*
*c) Vector diagram of b), superimposed on the pole/zero diagram.*
*d) Crude 3-dimensional representation of the magnitude of the function F(s), plotted vertically above a horizontal s plane.*

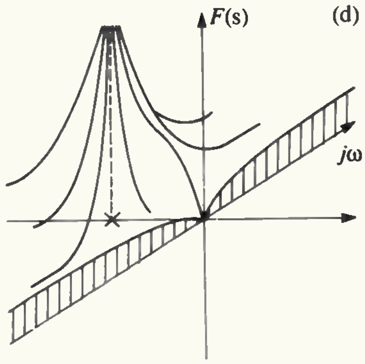



Figure **2b**). Note that, by convention, a pole on the s plane (the jω versus σ plot) is denoted by a cross, and a zero by a circle or nought.

From the vector/circle diagram of Figure 2b), for a simple highpass *CR* circuit:

$$v_o/v_i=R/(R+1/j\omega C)=j\omega CR/(1+j\omega CR) \quad (2)$$

Thus the general expression for the transfer function $F(s)$ is $F(s)=s/(1+s)$, assuming that the frequency is normalised, or (effectively the same thing) that $CR=1$.

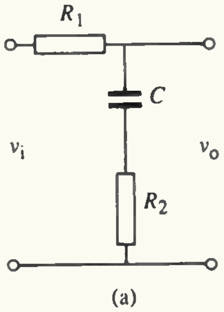
Clearly, as well as exploding to infinity when s is –1 (when ω = zero and σ = –1), $F(s)$ is 0 when s is 0 (when both ω and σ = 0), due to the s in the numerator. Figure **2c** shows the pole/zero diagram, with its zero at 0Hz, with the vector diagram superimposed, shown for the case where normalised ω=1, the –3dB point.

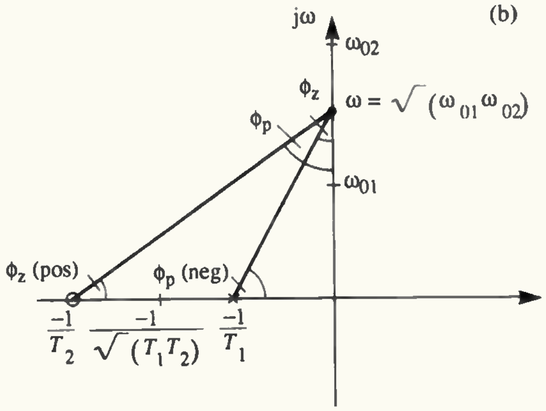
Note that in Figure 1c), $v_o$ is represented by the line from the pole to the origin. This is because, in the vector diagram, this is the voltage $iX_c$ across the capacitor. In Figure 2c), $v_o$ is represented by the line from the origin to the point on the jω axis representing the frequency of interest. This is because this line represents i*R*, across which the output voltage is developed, Fig. 2a).

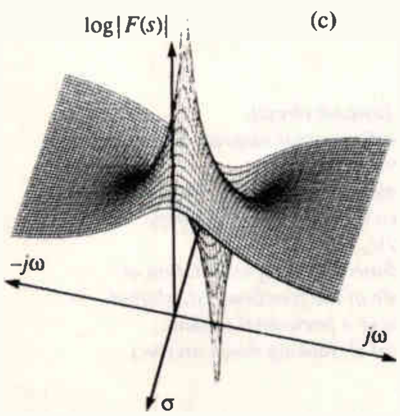
You can see from Fig. 2c) and Eqn 2 that, for very low frequencies (where $v_{in}$ is virtually horizontal and the denominator virtually equal to unity), $v_o$ is directly proportional to the distance from the origin to the point on the jω axis. Also, at very low frequencies, $v_o$ leads $v_{in}$ by 90°. This is made clear by the vector diagram, and can be checked by making the denominator of Eqn 2 real and finding tan ϕ, as was done above for the lowpass case.

These two results give another important rule:

*the amplitude of the response at any frequency due to a zero is directly proportional to the length of a line from the zero to the corresponding point on the jω axis, and the phase is given by the angle that*



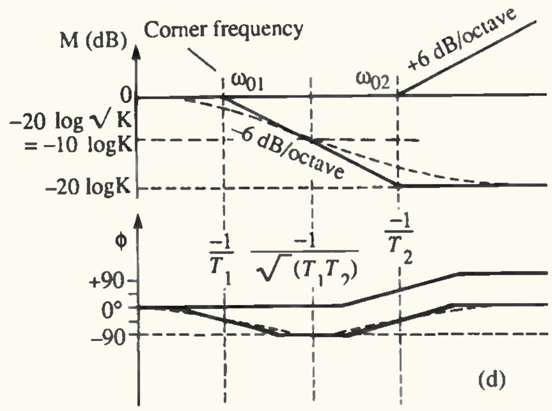




***Fig. 3. a) Transitional lag circuit.***
***b) The corresponding pole/zero diagram.***
***c) Three-dimensional representation of the logarithm of the magnitude of the function F(s)***
***d) This circuit. has unity gain at 0Hz, falling to $R_2/(R_1+R_2)$ at very high frequencies***

*the line makes with the horizontal axis, counting anticlockwise rotation as positive, indicating a leading response, clockwise a lagging response. The angle is measured with respect to the +σ axis if the zero is to the left of the jω axis, but with respect to the −σ axis if to the right of it.*

In the case of Fig. 2a), however, the effect of the zero is not the whole story. To evaluate the frequency response (the magnitude of $F(s)$ along the jω axis), you must take into account also the effect of the denominator of Eqn 2, representing the pole. So while initially, where $v_{in}$ can be considered horizontal, $v_o$ is simply directly proportional to the distance up the jω axis, remember that it is also *inversely* proportional to the distance from the pole.

At very high frequencies, these distances become more and more nearly equal. The response is thus proportional to the distance times the reciprocal of an equal distance, result unity. Likewise, the phase is everywhere equal to the sum of the angles. So for the *CR* high-pass circuit, the phase is $(90+\phi_{pole})°$ where $\phi_{pole}$ is zero at 0Hz, lagging by 45° at the −3dB point and reaching −90° at infinite frequency. Thus overall, the phase of $v_o$ starts off at 90° leading at 0Hz, dropping back to being in phase at very high frequencies.

Section (d) of Fig. 2b is a three-dimensional representation of the magnitude of $F(s)$, plotted vertically above a horizontal s plane. Only that part of the surface to the left of the jω axis (where σ is negative) has been shown. The 'cut edge', above the positive jω axis, gives the magnitude of the frequency response, as a linear plot against frequency (also linear). The zero at the origin can be seen to act as a thumbtack, pinning the surface $F(s)$ to the ground level at the origin.

If the pole is moved further and further to the left, the −3dB point, where the response is levelling out, will occur at a higher and higher frequency. If the pole moves out to infinity, the response will be rising at 6dB/octave indefinitely. With just a zero visible on the s plane, at the origin, you have a differentiator, e.g., an ideal op-amp with resistive feedback from the output to the inverting input, and with the input applied via a capacitor.

## Zeros to the left of them

Zeros can occur anywhere in the s plane – not just on the jω axis. Figure **3a** shows a circuit known as the transitional lag, which starts off behaving like the top cut circuit of Fig. 1a but, instead of the response falling indefinitely as the frequency increases, it flattens out again, the response at very high frequencies being equal to $R_2/(R_1+R_2)$. This is illustrated by the Bode diagram of Fig. **3d**), from which you can see that the response starts to fall at a "corner frequency", but stops falling at some higher corner frequency. The actual response is shown dotted, and a −6dB/octave asymptote is shown joining the low-frequency and high-frequency response levels – unity and $R_2/(R_1+R_2)$ respectively.

The −6dB/octave asymptote is a straight line

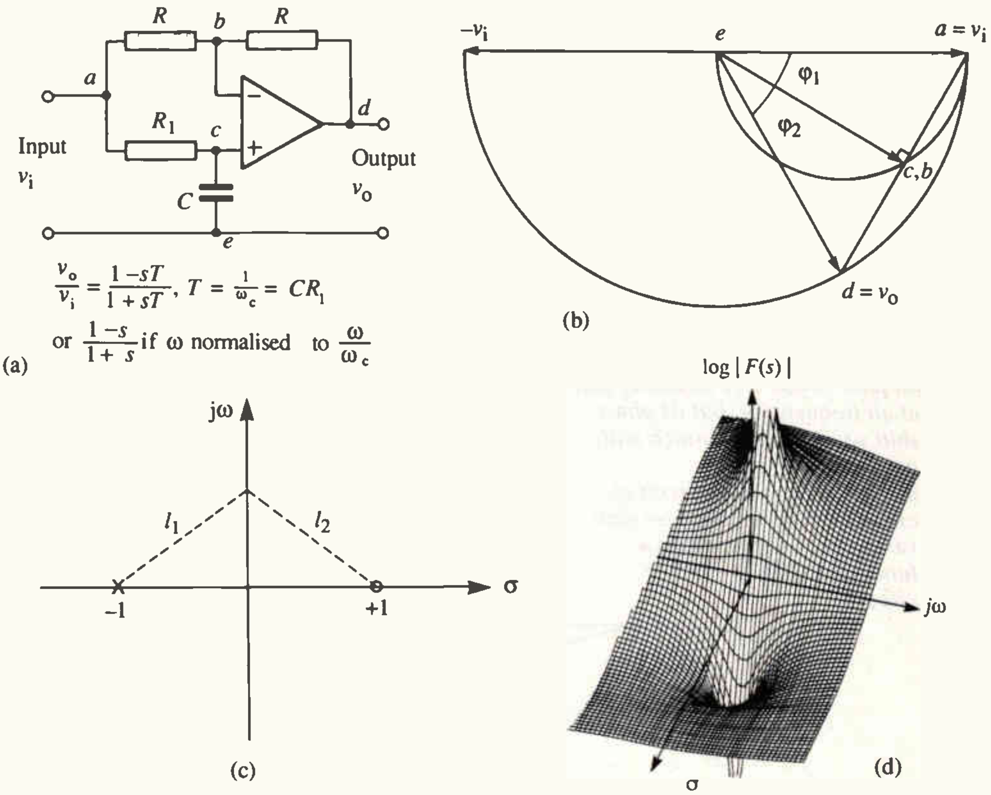



***Fig. 4. a) First-order all-pass circuit with unity gain at all frequencies has a phase shift varies with frequency. b) Vector/circle diagram for the circuit a). c) Pole/zero plot for the circuit of a). d) 3-dimensional representation of the logarithm of the magnitude of the function F(s), corresponding to c).***

because the horizontal axis, representing frequency, is logarithmic, and the vertical axis, representing the magnitude of the response *M*, is in dB – i.e., also logarithmic. The actual response will never quite reach a 6dB/octave cut-off rate unless the corner frequencies $\omega_{01}$ and $\omega_{02}$ are infinitely far apart, and of course it is curved at the corner frequencies, unlike the notional asymptote.

Up till now, it has been convenient to work with normalised frequencies since, in both the low pass and high pass circuits of Figs 1 and 2, there is just the one corner frequency, where the response changes (gradually) from flat to −6dB per octave (or *vice versa*). But with the transitional lag, there are two different frequencies to consider, and these can conveniently be defined in terms of the *CR* time constants of the circuit.

Working out the response of the transitional lag of Fig. 3a gives:

$$\frac{v_o}{v_{in}} = \frac{(1/j\omega C)+R_2}{(1/j\omega C)+R_2+R_1}$$

$$= \frac{1+j\omega CR_2}{1+j\omega C(R_1+R_2)}$$

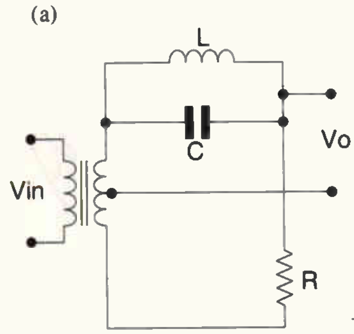
$$= \frac{1+j\omega T_2}{1+j\omega T_1} = \frac{T_2(1/T_2+j\omega)}{T_1(1/T_1+j\omega)}$$

where $T_2=CR_2$ and $T_1=C(R_1+R_2)$, or more generally: $F(s)=K(s+1/T_2)/(s+1/T_1)$ where $K=T_2/T_1=(1/\omega_{02})/(1/\omega_{01})$. Term $\omega_{01}$ is the lower corner frequency, set by $1/[C(R_1+R_2)]$ and $\omega_{02}=1/CR_2$ is the upper, which means that $K=R_2/(R_1+R_2)$.

This time, the pole zero diagram Fig. **3b**, instead of showing normalised frequencies, shows actual frequencies, defined in terms of the circuit time-constants. The point shown on the jω axis represents the frequency which is the geometric mean of $\omega_1$ and $\omega_2$, the point of inflection of the response in Fig. **3d**). Up to this frequency, $\phi_p$ is increasing faster than $\phi_z$, so that the output lags the input, but beyond this frequency, $\phi_z$ increases faster so the lag decreases again. Eventually, as $\phi_p$ and $\phi_z$ both tend to 90°, they cancel out, and the output is back in phase with the input, but reduced in amplitude to $R_2/(R_1+R_2)$.

Figure 3c shows the surface representing the magnitude of $F(s)$, drawn in three dimensions as a wire grid model. For clarity, it has been rotated so the the +σ axis is pointing toward you and, in the vertical direction, it shows the *logarithm* of the magnitude of $F(s)$. This means that a zero, instead of appearing as a thumbtack pinning the surface to the zero level, now appears like an upside-down pole, extending indefinitely downward. Only that part of the surface over the negative σ axis is shown, and the edge above the +jω axis (marked by a bold line) gives the amplitude response at any frequency ω, being unity at 0Hz and tending to *K* at very high frequencies.

If you imagine $R_2$ getting smaller and smaller, then the position of the zero at $-1/T_2$ in Fig. 3c migrates ever leftward, and *K*, the response at very high frequencies, gets ever smaller. Ultimately, as $R_2$ reaches 0Ω, the zero has disappeared leftward off the page to infinity, and you are back with the circuit and response of Fig. 1.



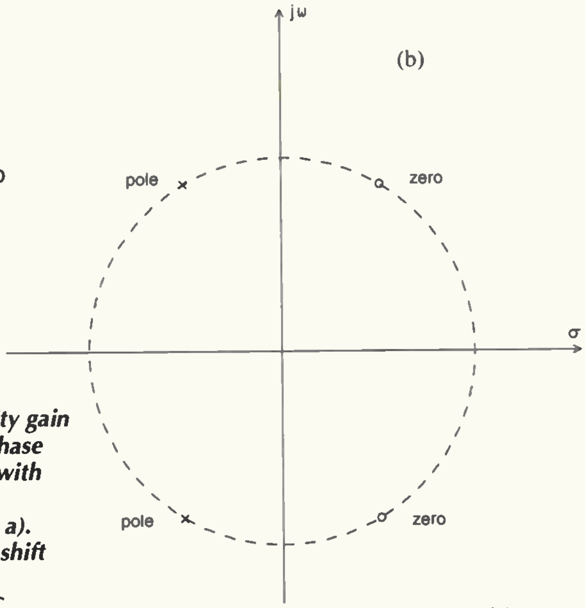
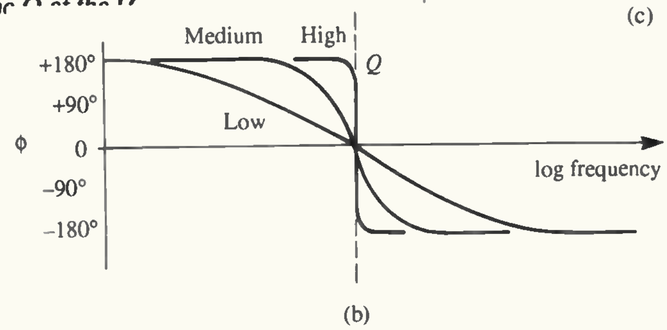




*Fig.5. a) This second-order all-pass circuit also has unity gain at all frequencies, but its phase shift varies twice as much with frequency as Fig. 4a).*
*b) Pole/zero plot of circuit a).*
*c) Showing how the phase shift varies with frequency, as a function of the Q of the LC circuit.*




If, instead of being in series with $R_2$, the capacitor in Fig. 3a had been in parallel with $R_1$, the circuit would be a transitional lead, the response rising from $K$ at 0Hz to unity at infinite frequency. In this case, the zero would be nearer the origin than the pole; the two have interchanged places. So as the frequency increases, starting from 0Hz, initially $\phi_z$ increases faster than $\phi_p$ and the phase of the output leads that of the input. Later, $\phi_p$ increases faster, and the lead disappears, as the gain gradually reaches unity.

## And zeros to the right of them

An all-pass filter is one which changes the phase of a signal by different amounts, depending on the frequency, but without affecting its amplitude. In signal transmission systems, this enables distortion due to various causes to be cancelled, and the signal restored more or less to its original condition.

The simplest all-pass circuit, also called a phase-equaliser, is the single-pole variety, **Fig. 4a**). The signal at the op-amp non-inverting terminal is applied through a *CR* low-pass circuit, exactly as considered earlier. Consequently, relative to the input $\mathbf{v}_i$ (vector e-a in circle diagram, Fig **4b**)), the voltage at the op-amp non-inverting input is the vector e-c. This coincides with $\mathbf{v}_i$ at 0Hz, falling towards 0 with a 90° phase lag at very high frequencies.

Negative feedback around the op-amp forces its output to do whatever is necessary to keep the voltage at its inverting input equal to that at the non-inverting input. So point c on the circle diagram is also point b. Since the two resistors connected to the inverting input are equal, the output $\mathbf{v}_o$ (vector e-d ) follows the larger semicircle shown, as though drawn by a pantograph set for two times magnification.

Thus the amplitude of $\mathbf{v}_o$ is independent of frequency, but its phase relative to $\mathbf{v}_i$ swings round from 0° at 0Hz, to –180° at infinite frequency. The all-pass transfer function $F(s)_{AP}$ is easily derived from that for the low-pass case, by observing that the output, in Fig 4b), is twice as big as the input, but shifted to the left by one unit – by the distance e-a. So $F(s)_{AP}=2F(s)_{LP}-1$. But the $F(s)$ for the low-pass circuit was shown earlier to be 1(s +1).

$$F(s)_{AP}=\frac{2}{s+1}-1=\frac{2}{s+1}-\frac{s+1}{s+1}=\frac{1-s}{1+s}$$

There is a zero at σ=+1, ω=0, since for s=1+j0, the numerator of $F(s)_{AP}$ is zero. This is shown on the s plane diagram of Fig. **4c**). Following the rules noted earlier, the response at any frequency is directly proportional to $\ell_2$ and inversely proportional to $\ell_1$. But since these are always equal, the magnitude of the response is always unity.

Also, as the frequency increases, $\phi_p$ increases from zero to 90°, in an anticlockwise direction indicating a lagging phase angle. And $\phi_z$ increases from 0° to 90° *clockwise*, this also according to the rule indicating a lagging response. Thus taking into account the phase contributions from both the pole and the zero, overall the phase drops steadily back from 0° at 0Hz to –180° at very high frequencies.

Figure **4d**) shows a three dimensional wire grid model of the surface representing the magnitude of $F(s)$, or rather the log of the magnitude as previously. But this time the surface along the +σ axis is shown as well, since this shows up the zero. Note that the surface is exactly skew symmetrical about the jω axis, the magnitude of log$F(s)$ along the axis being everywhere zero, or 0dB.

Like all the circuits that have been considered so far, this all-pass filter is a 'first-order' circuit, that is to say that the highest power of s in the denominator is 1. If the highest power of s in the denominator is 2, then you have a second order circuit, and if the numerator is a constant, the circuit is lowpass with a 12dB per octave roll-off.

If there is just a term in s in the numerator, the circuit shows a bandpass response with a 6dB/octave roll-off either side of the peak, while a term in $s^2$ in the numerator gives a highpass with a 12dB/octave low-frequency roll-off.

## More zeros to the right of them

The first order all-pass filter described earlier causes the output phase to drop back from 0 to –180° in a fixed and fairly gentle manner, as the frequency rises from zero to infinity. If you want the phase change to take place over a smaller frequency interval, then a second order all-pass circuit can be used. This can be an entirely passive circuit, as in **Fig. 5a**), the corresponding pole/zero plot being as in **5b**).

With this second-order all-pass circuit, the phase drops back from 0° at 0Hz, via –180° right round to –360° at infinite frequency.

If, at the resonant frequency of *L* and *C*, the reactance of each is large compared to *R*, then the phase change as the frequency changes will be very gradual. If on the other hand the reactance of each is small compared to *R*, then the phase will snap right around over a very small range of frequencies centred on the resonant frequency. This corresponds to the poles and zeros in Fig. 5b) being very close to the jω axis. In this case, over most of the frequency range, output voltage will be determined by the signal coming via the inductor (below the resonant frequency) or via the capacitor. Only at the resonant frequency, and in its immediate vicinity, where the dynamic impedance of the tuned circuit is high, will the output be due to the signal coming via *R*.

This all assumes, of course, that *L* and *C* are ideal. A more practical arrangement uses active circuitry, in particular, the state variable filter, see page 143 of Ref. 2. If you add the filter's low and high-pass outputs, plus an appropriate proportion of the bandpass output, you again get a second-order all-pass response. The transfer function is,

$F(s)=(s^2-Ds+1)/(s^2+Ds+1)$, where $D$ is the reciprocal of the filter Q. The $s^2$ term in the numerator is the highpass component, s the bandpass component, while 1 represents the lowpass component. You can see that when s=0 (so that ω=0), the transfer function is 1/1, or unity.

When s equals infinity, you can forget the other terms, so the transfer function is just ω2/ω2=1 again. When s=(σ+jω), with σ=0 and ω(the normalised frequency)=1, then $s^2$=–1, so the transfer function simply equals

–Ds/+Ds. The numerator indicates a 90° phase lag, and the denominator another, giving a total of 180° lag at the filter's normalised resonant frequency.

The pole/zero diagram makes it clear that the closer the poles and zeros are to the jω axis (the higher the circuit's Q), the more more rapidly the phase changes as you pass between the upper pole/zero pair, travelling up the +jω axis from 0Hz at the origin, towards infinite frequency.

The lower pole/zero pair has comparatively little effect on the phase in this region; it is there because both numerator and denominator are quadratic expressions, and their presence balances the upper pair, ensuring that the gain at 0Hz is unity and the phase shift 0°.

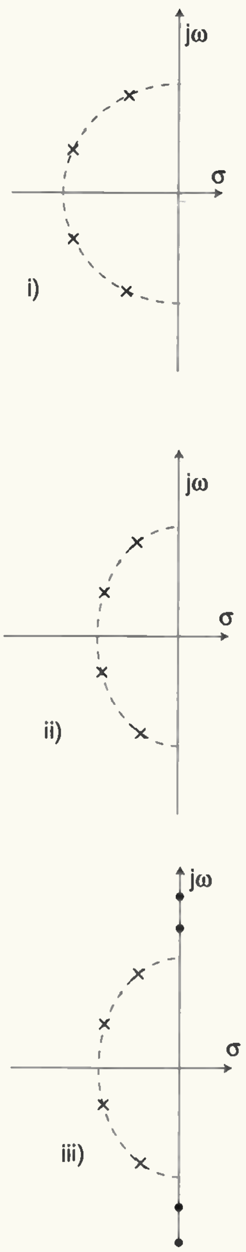
### Lots of poles – and zeros

By now, I hope you have a feel for poles (s terms in the denominator of $F$(s)) causing phase lags and gain changes, and zeros (s terms in the numerator) causing gain changes and phase lags or leads, according to where they are. So here without further ado or any detailed explanation, are some more pole zero plots, and three dimensional wire grid models of log|$F$(s)|.

**Figure 6a)**, sections i-iii shows the pole zero plots for some fourth-order lowpass filters. Those of i and ii are 'all pole' filters, i being a Butterworth maximally-flat amplitude response, and ii a Chebychev response which gives a faster initial roll-off in the stop band at the expense of ripples in the passband.

In iii is a fourth-order elliptic response, which gives an even sharper cut-off in the stop band. This is thanks to the finite zeros situated on the jω axis; but they do result in the stop-band attenuation ultimately levelling out, rather than increasing for ever like the all pole filters. Figure **6b)**, sections i- iii shows the 3D wire grid representations of log|$F$(s)| for these three filter types, in each case cut to show only the part over the –σ region.

As before, the cut edge over the jω axis – marked by a bold line – shows the frequency response, on a logarithmic or decibel scale vertically, against a linear frequency scale. The different apparent values of response at zero hertz are an artefact of the plotting program; in each case, the zero frequency response is unity or 0dB.



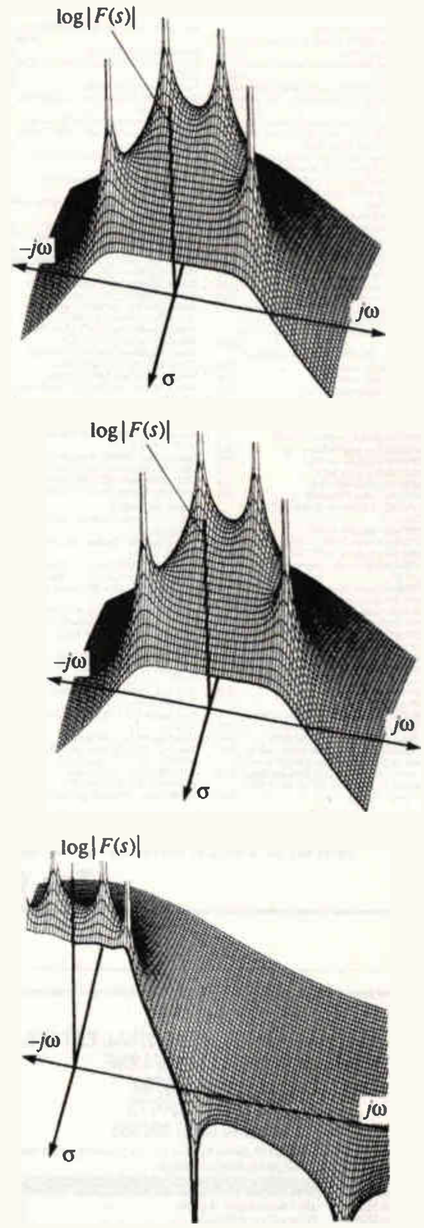




*Fig. 6a) Pole/zero plots for three popular lowpass filter types; in each case, a four pole design is shown. i) The Butterworth design gives a maximally flat amplitude response. ii) The Chebychev design gives a faster cut-off in the stopband, at the expense of ripples in the passband response.iii) The elliptic or Caur design gives an even faster stopband cut-off, but as well as passband ripples, has returns in the stopband b) Three dimensional wire grid representations of log | F(s) | for the three filter types. The frequencies of infinite attenuation in the elliptic case correspond to the positions on the j (axis of the zeros in a) iii).*

### Transforms ahoy

It may seem unnecessarily complicated to bother about the whole s plane, when all you need to find a circuit's frequency response if the value of $F$(s) for σ=0, i.e. how $F$(s) varies along the jω axis. But there is more to pole/zero diagrams than just a circuit's frequency response. The diagram can also represent an input signal to the circuit, and not just a steady-state sinewave either. A further mathematical trick – called the inverse Laplace transform – can then derive what the circuit's output waveform will look like, given its frequency response and the said non-sinusoidal input. But to cover that would take more space than is at my disposal. ■

### More on poles...

Figure 3 and 4, and parts of Figures 1,2,5, and 6 are reproduced from Analog Electronics by Ian Hickman, published by Butterworth-Heinemann, ISBN 07506 1634 2. Within the pages of this book will be found not only more on poles and zeros, but also a wealth of other information on all aspects of analog electronics, from d.c. to 1GHz. Everything analogue, in fact, except microwaves. This book is available £19.99.

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2. Hickman, I, Analog Electronics, ISBN 0 7506 1634 2, Butterworth-Heinemann 1993.

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- HP3456A 6.5 Digit Volts/Ohms Meter £600
- HP3478A 5.5 Digit LCD Display 0.02% £300
- Keithley Type: 179 True RMS Multimeter 4.5 Digit £120
- Keithley Type: 177 4.5 Digit 1 microvolt/1 milliohm/1 nanoamp sensitivity £175
- Keithley Type: 175 4.5 Digit True RMS AC Measurements £150
- Keithley Type: 2000 6.5 Digit Too many functions to list (as new) £475
- Schlumberger Type: 7055 Systems Voltmeter £250

**SIGNAL GENERATORS**
- Adret 740A 100KHz 1120MHz Synthesized Signal Generator Comprehensive Amplitude, Frequency, Phase & Pulse Modulation 50 watt Reverse Power Protection 90 Non Volatile Memories Digital Display £1650
- Adret 7100B Synthesized Signal Generator 300KHz 650MHz Comprehensive Amplitude, Frequency Phase & Pulse Modulation Rotary Control 50 watt Reverse Power Protection £700
- Adret 7100B Synthesized Signal Generator 300KHz 1300MHz (Frequency Doubler Fitted) – Details same as above £1400
- Farnell PSG520 Synthesized Signal Generator 10-520MHz CW AM FM Decade Frequency Read-Out Mains & Battery Operation £350
- Farnell SSG520 Synthesized Signal Generator 10-520MHz CW AM FM Decade Frequency Read-Out Sinad Facility Calibrated Levelled Output £450
- Marconi 2019A Synthesized Signal Generator 80KHz 1040MHz Reverse Power Protection up to 50 Watts Comprehensive Amplitude, Frequency & Phase Modulation Memory Facilities Digital Display £1800
- Marconi TF2015 + TF2171 Digital Synchronizer 10-520MHz AM FM CW Analogue Display £370
- Racal-Dana 9082H 5-520MHz Signal Generator AM FM CW Digital Display £400
- Racal-Dana 9084 Synthesized Signal Generator 01-104MHz c/w Racal 9934 GPIB Interface Digital Display £650
- Systron Donner Model 1702 Signal Generator Audio 100MHz Decade Frequency Read-Out £650
- HP8684B Solid State Microwave Signal Generator Cavity Tuned Oscillator Wide Band FM for Satellite Video, 5.4-12.4GHz £2750
- HP8656B Synthesized Signal Generator 100KHz 990MHz Output Levels of -127dBm to +13dBm CW FM or Combination £2750
- Tektronix 191 Constant Amplitude Signal Generator 350KHz 100MHz Sine Wave £75
- Tektronix PG501 5ns 50MHz Pulse Generator £325
- Tektronix PG508 0-50MHz Pulse Generator £150
- Tektronix PG504 0-50MHz Pulse Generator £250
- Tektronix FG502 0.1Hz 1MHz Function Generator £375
- Tektronix FG503 1Hz 11MHz Function Generator £180
- Tektronix PG503 1Hz 3MHz Function Generator £125
- HP8005B 3Hz 10MHz Pulse Generator Adjustable Delay Width, Rate, etc £300
- HP8004A Pulse Generator Repetition Rate Variable from 10Hz 200MHz £500
- HP8015A Pulse Generator 1Hz 50MHz 30 Volt Output £500
- HP8112A Pulse Generator 50MHz £2500

**LF & AUDIO GENERATORS**
- Farnell Synthesized Signal Generator Type: DSG-2 0.1mHz 110KHz £85
- Farnell Oscillator Type: LFM-2 LF 1000KHz Sine/Square Wave £65
- Farnell Synthesized Generator Type: DSG-1 Sine/Square Wave Output £175
- Gould Signal Generator Type: J3B 10Hz 100KHz High Output Level Low Distortion £125
- Gould AF Signal Generator Type: H1E 15-50KHz 200microV 20V £65
- Global Specialties Model 8201 20MHz Pulse/Function Generator £600
- Philips Function Generator Type: PM5132 0.1Hz 2MHz £350
- Levell Transistor Decade Oscillator Type: TG66A 0.2Hz 1.22MHz Low Distortion £95
- Marconi AF Oscillator Type: 2000 20Hz 20KHz Extremely Low Distortion 111dB Attenuator (0.1dB Steps) c/w AF Monitored Attenuator £75
- HP3200B Function Generator 10-500MHz £200
- HP3312A Function/Sweep Generator 0-13MHz £350
- HP3335A Synthesized Level Generator (High Performance) 81MHz £3475
- HP3325A Synthesized Function Generator 1microHz 21MHz 11 Digit £1500
- HP4204A Digital Oscillator 10Hz 1MHz Built-in Output Meter & Calibrated Attenuator £150
- HP651B Test Oscillator 10Hz 10MHz 50 ohm & 600 ohm Output £95
- HP203A Variable Phase Function Generator 0.005Hz 60KHz Sine/Square Wave Output Up to 30V P-P Output. Adjustable 0-360 degree Calibrated Phase Offset £200
- Wavetek Model 185 Sweep/Function Generator 0-5MHz Lin/Log £350
- Wavetek Model 1067 Sweep Generator 1-400MHz Power Range +57 to –7dBmV £400
- Wavetek Model 157 Waveform Synthesizer Programmable, 100microHz 1MHz £650
- Wavetek Model 147 Sweep Generator 0.0005Hz 10MHz 15V P-P £250
- Wavetek Model 164 Sweep Generator 0.0003Hz-30MHz 0-20V Output £250
- Wavetek Model 1728 Synthesized Function Generator 0.0001Hz 13MHz £900

**OSCILLOSCOPES**
- Gould OS300 20MHz Bandwidth, Dual Channel £125
- Gould OS3500 60MHz Bandwidth, Dual Channel, Delayed Sweep £275
- Gould OS4000 10MHz Bandwidth, Dual Channel, Digital Storage £150
- Crotech 15MHz Bandwidth, Dual Channel £125
- Hameg HM312 20MHz Bandwidth, Dual Channel £140
- Hameg HM705 60MHz Bandwidth, Dual Channel Delayed Sweep £180
- Hitachi VC6041 40MHz Bandwidth, Dual Channel, Digital Storage £550
- HP1205B 500KHz Bandwidth, Dual Channel £200
- HP1740A 100MHz Bandwidth, Dual Channel, Delayed Sweep £250
- HP1741A 100MHz Bandwidth, Dual Channel, Delayed Sweep & Storage £300
- HP1725A 275MHz Bandwidth Dual Channel, Delayed Sweep £500
- HP181A Mainframe + HP1805A Dual Channel Vertical Amplifier 100MHz + HP1823A Time Base & Delay Generator £300
- HP181A Mainframe + HP1801A Dual Channel Vertical Amplifier 50MHz + HP1820C Time Base Unit £250
- HP181A Mainframe + HP1804A 4 Channel Amplifier 50MHz + HP1825A Time Base & Delay Generator £275
- HP182C Mainframe + HP1810A 1000MHz Plug-in (Sampling) £300
- HP54111D 500MHz Digitizing (Colour Display) 1GHz Sample per second £3450
- HP54120A + HP54121A Colour Mainframe, 20GHz Digitizing, 17.5pS Rise Time, TDR System, Histogrames, HPIB £7000
- HP54501A 100MHz Digitizing £1850
- IWATSU SS5416A 40MHz Bandwidth, Dual Channel, Delayed Sweep £200
- IWATSU DMS6430 Digital Memory Scope, 8 Bit x 4096 Word Memory Length £850
- IWATSU DM2350 Digital Memory Unit 10 Bit, 20NS £400
- IWATSU SAS8130 Waveform Analyzer DC-3500MHz Dual Channel, 10 Bit x 1024 Word Memory Each Channel £1500
- Philips PM3217 50MHz Bandwidth Dual Channel, Delayed Sweep £325-£400
- Philips PM3340 2000MHz Bandwidth, Dual Channel, Digitizing, Auto Set Up 175PS Rise Time £3800
- Scopex 4010A 10MHz Bandwidth, Dual Channel £75
- Tektronix 453 50MHz Bandwidth Dual Channel, Delayed Sweep £150
- Tektronix 465B + DM44 100MHz Bandwidth, Dual Channel, Delayed Sweep £400
- Tektronix 465 100MHz Bandwidth, Dual Channel, Delayed Sweep £350
- Tektronix 475 200MHz Bandwidth, Dual Channel, Delayed Sweep £450
- Tektronix 475B 250MHz Bandwidth, Dual Channel, Delayed Sweep £500
- Tektronix 464 100MHz Bandwidth, Dual Channel Delayed Sweep Storage £400
- Tektronix 2213A 60MHz Bandwidth, Dual Channel £350
- Tektronix 2235 100MHz Bandwidth, Dual Channel, Delayed Sweep £700
- Tektronix 2245A 100MHz Bandwidth, Four Channel, Delayed Sweep, Cursors, Readout £1450
- Tektronix 2445 150MHz Bandwidth, Four Channel, Delayed Sweep Cursors, Readout £1400
- Tektronix 2445B 200MHz Bandwidth, Four Channel, Delayed Sweep Cursors, Readout £2350
- Tektronix 2336 100MHz Bandwidth, Four Channel, Delayed Sweep, Ruggerdised £850
- Tektronix 7704A Mainframe + 7A26 + 7B53A Plug-Ins 200MHz System £600
- Tektronix 7623A Mainframe + 7A26 + 7A18A + 7B92A Plug-Ins 200MHz System (Storage) £500
- Tektronix 7904 Mainframe + 7A26 + 7B87 + 7B85 Plug Ins 200MHz System £900
- Tektronix 7854 Mainframe + 7A24 + 7A26 + 7B87 + 7B85 Plug-Ins 400MHz System (Digital Storage) £1100
- Tektronix 7704A Mainframe + 7A18 + 7B85 Plug-Ins 200MHz System £300
- Tektronix 11401 Digitizing (Mainframe) £500
- Telequipment D61 10MHz Bandwidth, Dual Channel £95
- Telequipment D63 Mainframe + Differential Amplifier V3 £150
- Trio CS1566A 20MHz Bandwidth, Dual Channel £165

**TEKTRONIX PLUG-INS**
- 7A11 Internal Probe Amplifier 150MHz £100
- 7A12 Dual Trace Amplifier 120MHz £120
- 7A13 Differential Comparator £200
- 7A15A Single Channel Amplifier 80MHz £80
- 7A15N Single Channel Amplifier 75MHz £60
- 7A16A Single Channel Amplifier 225MHz £110
- 7A18 Dual Trace Amplifier 75MHz £75
- 7A18A Dual Trace Amplifier 75MHz £85
- 7A19 Single Channel Amplifier 600MHz £200
- 7A26 Dual Channel Amplifier 200MHz £125
- 7A42 Logic Triggered Vertical Amplifier 4 Channel 350MHz £500
- 7B50 Time Base £100
- 7B51 Delaying Time Base £125
- 7B53A Dual Time Base 100MHz £100
- 7B70 Time Base 200MHz £200
- 7B80 Time Base 400MHz Delayed £125
- 7B85 Time Base 400MHz Delayed £140
- 7B87 Digital Time Base 400MHz £325
- 7D01 Logic Analyzer £100
- 5D10 Waveform Digitizer £400
- 7D10 Digital Events Delay Unit £300
- 7D11 Digital Delay Unit £50
- 7D02 Personality Module PM100 Series £100
- 7D20 Programmable Digitizer £400
- DF1 Display Formatter £50
- DF2 Display Formatter £50
- 7S11 Sampling Unit £275
- S1 Sampling Head 1000MHz £150

**TEKTRONIX MAINFRAMES**
- 7403N 60MHz Mainframe £175
- 7603 100MHz Mainframe £275
- 7633 100MHz Mainframe (Fast Storage) £400
- 7704A 200MHz Mainframe £350
- 7854 400MHz Mainframe (Digital Storage) £800
- 7904 500MHz Mainframe £450

**POWER SUPPLIES**
- APlab Type: 8559 Frequency Converter 500VA Frequency Range 45 500Hz, 55-65Hz, 370-430V £350
- Farnell Type: H60-25 0-60V 0-25A Volts/Current Metered New £400
- Farnell Type: H60-50 0-60V 0-50A Volts/Current Metered £600
- Farnell Type: 830/20 0-30V 0-20A Not Metered £150
- Farnell Type: TSV70 MkII 0-35V 0-10A, 0-70V 0-5A Metered £200
- Farnell Type: TOPS3D Triple Output 4-6V, 4A & –5 to –17 & +5 to +17V 1A Bipolar Tracking £120
- Farnell Type: L12/10C 0-12V 0-10A Metered £80
- Farnell Type: E350 0-350V 0-200mA 6.3V & 5V AC Outputs £200
- Farnell Type: AP100/90 Regulated Autoranging Power Supply 3KW, 100V 90A £1100
- Farnell Type: MP30/80 Regulated Autoranging Power Supply 1KW 30V 80A £500
- HP6002A 0-50V 0-10A 200W Autoranging £500
- HP6261B 0-20V 0-50A Metered £500
- HP6111A 0-20V 0-1A £90
- Kepco Type: ATE75/8M 0-75V 0-8A Metered £120
- Kepco Type: ATE75/15M 0-75V 0-15A Metered £175
- Lambda Type: LK362 0-60V 0-25A £180
- Lambda Type: LO523 0-60V 0-0.9A £65
- Philips PE1510 0-35V 0-1A Metered £35
- Thurlby Thandar Type: RS611127 0-30V 0-1A or 0-30V 2A Isolated/Parallel/Series/Tracking £150
- Weir Type: 413 0.7.5V 0.15V 0-30V 0-4A (max) Metered £65
- Weir Type: 460 0-60V 0-1A Metered £70
- Wallis Hivolt Type: CTS87 0-30KV DC Leakage Current down to 1 Microamp Solid State £150
- Brand New & Boxed DC Power Supply Unit Type: OF173 LCD Display 0-30V 0-3A £120

**DC LOADS – ELECTRONIC**
- Farnell Type: RB1030/35 Electronic Load Maximum Rating 1KW 35A 35V £350
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- **Anritsu MG642A** – Pulse pattern generator £1500
- **Barr & Stroud** – EF3 variable filter (0.1Hz-100KHz) £150
- **Datalab DL 1080** – Programmable Transient Recorder £350
- **Datron 1061** – Precision multimeter £650
- **Dynapert TP20** – Intelliplace tape peel tester, immac. cond. £1950
- **E.I.P. 331** – 18GHz frequency counter £850
- **E.I.P. 548A** – frequency counter (26.5GHz) £2750
- **Farnell SSE520** – Signal generator (10-520MHz) £400
- **Farnell TSV70 MkII** – Power Supply (70V–5A or 35V–10A) £225
- **Fluke 5100A** – Calibrator £3500
- **Fluke 5100B** – Calibrator £4500
- **Fluke 5101B** – Calibrator £5000
- **Fluke 5200A** – A.C. calibrator £2500
- **Fluke 5205A** – Precision power amplifier £P.O.A.
- **Fluke 7105A** – Calibration system (As new) £P.O.A.
- **Helden** 1107 – 30v-10A Programmable power supply (IEEE) £650
- **Hewlett Packard 339A** – distortion measuring set £1500
- **Hewlett Packard 432A** – Power Meter (with 478A Sensor) £275
- **Hewlett Packard 435A or B** – Power Meter (with 8481A/8484A) from £750
- **Hewlett Packard 5328A** – 100MHz universal frequency counter £250
- **Hewlett Packard 3325A** – 21MHz synthesiser/function gen. £1500
- **Hewlett Packard 3437A** – System voltmeter £350
- **Hewlett Packard 3438A** – Digital multimeter £200
- **Hewlett Packard 3455A** – 6½ digit multimeter (autoscal) £750
- **Hewlett Packard 3456A** – Digital voltmeter £750
- **Hewlett Packard 3488A** – HP–IB switch/control unit (various plug-ins available) £650
- **Hewlett Packard** 3711A/3712A/3791B/3793B – Microwave link analyser £2995
- **Hewlett Packard 3776A** – PCM Terminal test set £P.O.A.
- **Hewlett Packard 3779 A/C – Primary Mux analyser** £600/£1500
- **Hewlett Packard 4271B** – LCR meter (digital) £900
- **Hewlett Packard 4275A** – Multi-frequency LCR meter £4250
- **Hewlett Packard 4342A** – Q meter £995
- **Hewlett Packard 4948A** – transmission impairment measuring set £2000
- **Hewlett Packard 4953A** – Protocol analyser £2500
- **Hewlett Packard 4954A** – Protocol analyser £2750
- **Hewlett Packard 5314A** – (new) 100MHz universal counter £250
- **Hewlett Packard 5342A** – Microwave freq. counter (18GHz) £1500
- **Hewlett Packard 5359A** – Time synthesiser £P.O.A.
- **Hewlett Packard 5385A** – Frequency counter 1GHz (HPIB) with Opts 001/003/004/005 £995
- **Hewlett Packard 6002A** – autoranging 50V-10A, PSU £650
- **Hewlett Packard 6034A** – System P.S.U. 0-60v-10a £1500
- **Hewlett Packard 6181C** – D.C. current source £150

> **Hewlett Packard 6261B** – Power supply 20V–50A £450
> *DISCOUNT FOR QUANTITIES*

- **Hewlett Packard 6652A** – System Power Supply 20V-20A £1950
- **Hewlett Packard 8005B** – Pulse generator £250
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- **Hewlett Packard 8152A** – Optical average power meter £1250
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- **Hewlett Packard 8165A** – 50MHz programmable signal source £1650
- **Hewlett Packard 8349B** – Microwave broadband Amp (as new) 2–20MHz £4250
- **Hewlett Packard 8350B** – Sweep oscillator mainframe (plug-ins avail) £2500
- **Hewlett Packard 8403A** – modulator £500
- **Hewlett Packard 8620C** – Sweep oscillator mainframe £400
- **Hewlett Packard 8660D** – Synthesised signal gen. 10KHz-2.6GHz £4500
- **Hewlett Packard 8683A** – Microwave signal gen. (2.3–6.5GHz) £2500
- **Hewlett Packard 8684A** – 5.4GHz to 12.5GHz Sig Gen £2500
- **Hewlett Packard 8750A** – Storage normaliser £375
- **Hewlett Packard 8901A** – Modulation Analyser £3400
- **Hewlett Packard 8903A** – Audio analyser (20Hz–100KHz) £1995
- **Hewlett Packard 8958A** – Cellular radio interface £4000
- **Hewlett Packard 11729B** – Carrier noise test set £2000
- **Marconi 893B** – A/F power meter £295
- **Marconi 2019A** – 80KHz–1040MHz synthesised sig. gen £1950
- **Marconi 2871** – data communications analyser £2000
- **Marconi 6500** – automatic amplitude analyser £1750
- **Marconi 6960** – Microwave power meter (+ sensor) £P.O.A.
- **Philips PM 5167** – 10MHz function gen. £400
- **Philips PM 5190** – LF synthesizer with GPIB £800
- **Philips 5518 -Tx** – TV pattern generator £1500
- **Racal Dana** 1992 – 1300MHz frequency counter opts 4B+55 £800
- **Racal Dana** 3100 40–130MHz synthesiser £750
- **Racal Dana 9084** Synth sig gen 104MHz £450
- **Racal 9301A** True RMS R/F millivoltmeter £300
- **Racal Dana 9303** True RMS/RF level meter £650
- **Racal Dana 9921** 3GHz frequency counter £450
- **Schaffner NSG 200E** – Mainframe for NSG plug-ins £1250
- **Schaffner NSG 203A** – Line voltage variation simulator £1250
- **Schaffner NSG 222A** – Interferance simulator £850
- **Schaffner NSG 223** – Interferance generator £850
- **Schlumberger 2720** – 1250MHz Freq Counter £600
- **Schlumberger 4031** – Radio Comms Test Set £6995
- **Schlumberger SI 4040** – Stabilock, high accuracy 1GHz radio test set £4995
- **Schlumberger 4923** – Radio Code Test Set £1000
- **Systron Donner 1960B** – Microwave Sweeper (12-18GHz) £2500
- **Tektronix 577** – Curve Tracer £1150
- **Tektronix** – Plug-ins – Many available such as PG508, FG504, SC504, SW503, SG 502 etc.
- **Tektronix TM5003 + AFG5101** – Arbitrary Function Gen. £1750
- **Tektronix 1240** – Logic Analyser £750
- **Textronix AM503 + TM501 + P6302** – current probe amplifier £995
- **Tektronix AA5001 + TM5006** – Mainframe programmable distortion analyser £2500
- **Textronix PG506 + TG501 + SG503 + TM503** – Oscilloscope calibrator £1995
- **Textronix CG5001** – Programmable oscilloscope cal. generator £4995
- **Time 9811** Programmable resistance £600
- **Time 9814** Voltage calibrator £750
- **Wavetek 172B** – Programmable sig. source (0.0001Hz-13MHz) £P.O.A.
- **Wayne Kerr B905** – Precision LCR meter £850
- **Wiltron 560** – Scalar Network analyser £800
- **Wiltron 6620S** – Programmable sweep gen. (3.6-6.5GHz) £650

**OSCILLOSCOPES**

- **Cossor 3102** – 60MHz dual channel £250
- **Gould OS255** – 15 MHz dual channel £150
- **Gould OS3000** – 40MHz dual channel £250
- **Gould OS3351** – 40MHz dual channel £225
- **Gould OS4000** – 10MHz Digital storage £200
- **Gould 5110** – 100MHz intelligent oscilloscope £750
- **Hewlett Packard 180D** – 100MHz 4 channel £300
- **Hewlett Packard 182C** – 100MHz 4 channel £350
- **Hewlett Packard 1740A, 1741A, 1744A,** – 100MHz dual ch. from £350
- **Hewlett Packard 54100D** – 1GHz digitizing £3995
- **Hewlett Packard 54200A** – 50MHz 2 channel digitizing £1000
- **Hewlett Packard 54201A** – 300MHz digitizing £1750
- **Hewlett Packard 54501A** – 100MHz Digitising – 4 channel £1950
- **Hitachi V212** – 20MHz dual channel £180
- **Hitachi V222** – 20MHz dual channel £200
- **Hitachi V650F** – 60MHz dual channel £350
- **Kikusui DSS 6522** – 20MHz digital storage £475
- **Kikusui COS 6100** – 100MHz 5 channel 12 trace £475
- **Kikusui COS 5100** – 100MHz dual channel £425
- **Nicolet 3091** – Low freq D.S.O. £1100
- **Philips 3217** – 50MHz dual channel £350
- **Philips 3219** – 50MHz with analogue storage, Dual CH £400
- **Philips 3263** – 100MHz dual channel with microprocessor cont. timing £400
- **Philips 3540** – logic scope (25MHz dual ch. + logic an) £350
- **Philips 3295** – 350MHz dual ch £1500
- **Philips 3315** – 60MHz D.S.O. £750
- **Philips PM3295A** – 400MHz dual channel £1750
- **Tektronix 2445** – 150MHz – 4 channel £1250
- **Tektronix 2445A** – 150MHz – 4 channel £1600
- **Tektronix 455** – 50MHz dual channel £350
- **Tektronix 2221** – 60MHz digital storage £1500
- **Tektronix 7854** – 400MHz Waveform processing oscilloscope £1500
- **Tektronix 464/466** – 100MHz, storage from £350
- **Tektronix 465/465B** – 100MHz dual ch from £350
- **Tektronix 468** – 100MHz D.S.O. £750
- **Tektronix 475/475A** – 200/250 MHz dual channel from £475
- **Tektronix 434** – 25MHz 2 channel + analogue storage £250
- **Tektronix 454** – 150MHz 2 channel £400
- **Tektronix 2213** – 60MHz dual ch. £425
- **Tektronix 2215** – 60MHz dual ch. £450
- **Tektronix 2225** – 50MHz dual trace £450
- **Tektronix 2236** – 100MHz Dual Trace with Counter/Timer/Dmm £995
- **Tektronix 2335** – 100MHz dual ch. (portable) £750
- **Tektronix 7313, 7603, 7613, 7623, 7633,** – 100MHz 4 ch. from £300
- **Tektronix 7704** – 250MHz 4 ch. from £650
- **Tektronix 7904** – 500MHz from £850
- **Tektronix 7934** – 500MHz with storage from £1000
- **Telequipment D83** – 50MHz dual channel £200
- **Telequipment DM63** – 20MHz 4 channel £150
- **Watsu SS5121** – 100MHz dual channel £425
- **Watsu SS5702** – 20MHz dual channel £175
- **Watsu SS5710** – 60MHz dual channel £375

**Other scopes available too**

**SPECTRUM ANALYSERS**

- **Advantest 4133A** – 10KHz-20GH £6995
- **Alltech 757** – 10KHz-22GHz £2750
- **Hewlett Packard 141T + 8552B + 8555A** (10MHz–18GHz) £1600
- **Hewlett Packard 182T with 8559A** (10MHz–21GHz) £3750
- **Hewlett Packard 853A with 8559A** (0.01–21GHz) £4250
- **Hewlett Packard 3562A** – dynamic signal analyser, dual channel £7500
- **Hewlett Packard 3580A** – 5Hz–50KHz £995
- **Hewlett Packard 3582A** – 25KHz analyser, dual channel £2500
- **Hewlett Packard 3709B** – Constellation Analyser with 15709A High Impedance Interface (as new) £6750
- **Hewlett Packard 8505A** – Network analyser (500KHz–1.3GHz) £4000

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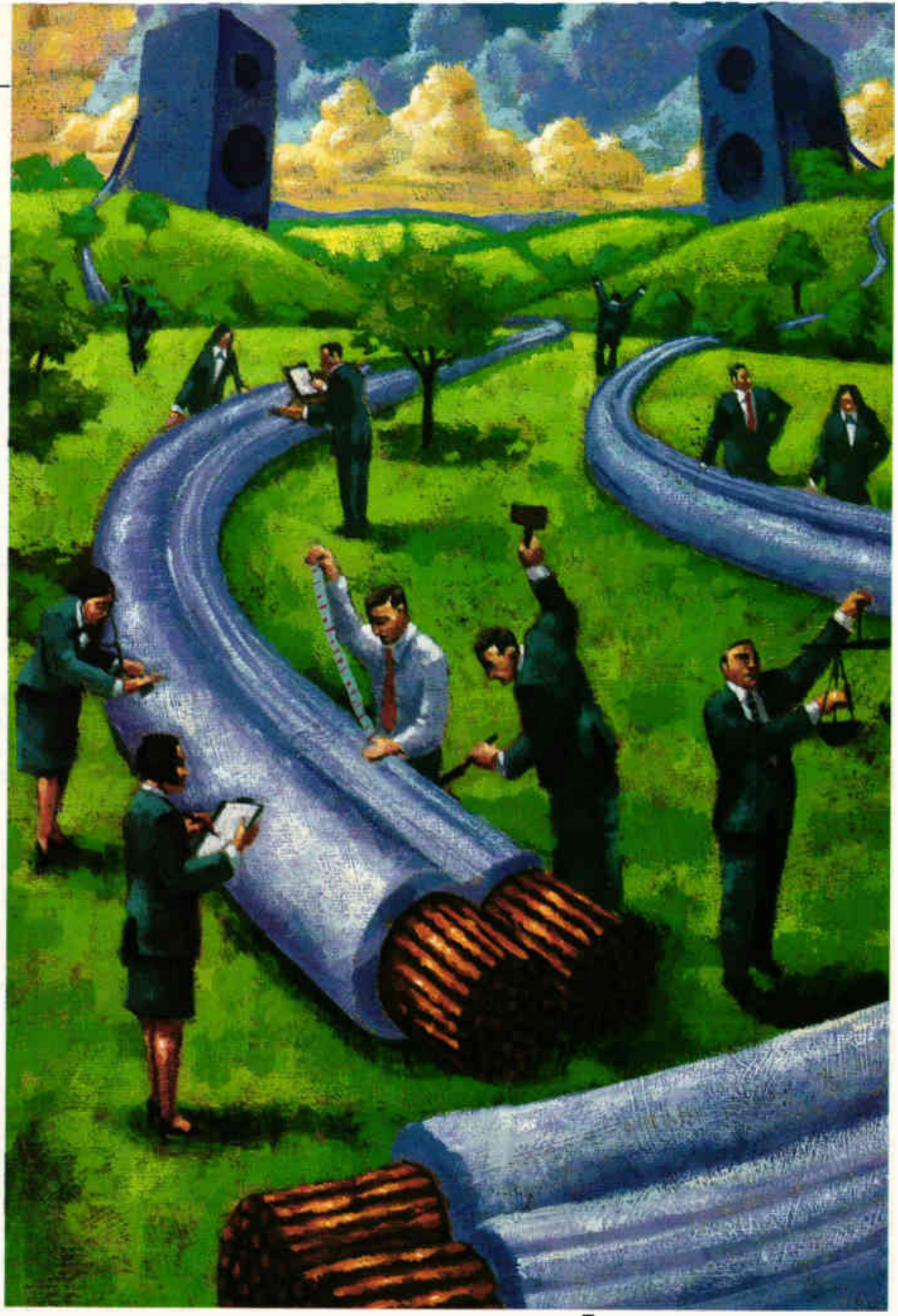


**According to Cyril Bateman's latest discoveries, the best cable for linking your power amplifier and loudspeakers is coaxial.**

# Speaker cables

### (Part three)

I started these explorations of loudspeaker cables with two main beliefs. First, that cable characteristic impedance was important at audio frequency even using relatively short cable lengths. This has been amply demonstrated by measurements[1,2] made using two quite different amplifiers and test circuits with twelve test cables. Second, that conventional sinewave distortion measurements would not identify changes of cable. Here, I put this second belief to the test.

In the first article[1], I demonstrated by use of simulations that some distortion of transients can result when an amplifier is driving a dummy high impedance but capacitive load – even with no cable. Driving similar high-impedance capacitive loads, connected using high impedance speaker cables, noticeable distortion levels are produced, **Fig. 1**.

If similar high impedance, capacitive loads exist in practical loudspeaker systems, you can expect these transient distortions to be present. But can such impedances occur in real speaker systems ?

Examination of many published test reports of loudspeaker systems indicates that load impedances higher than 20Ω are common. High impedance peaking at low frequencies is caused by bass-speaker driver resonance. In a reflex-ported cabinet, the impedance increases usually appear as a double peak, resulting from the combined cabinet and speaker driver resonances.

When more than one loudspeaker is used, a passive crossover network directs the lower and higher frequencies to the relevant driver. This network is frequently a combination of capacitors, inductors and resistances, driven from a common amplifier, and is the format assumed for this article.

For practical and economic reasons, crossover frequency is generally between 2kHz and 5kHz. As a result, a low but slightly inductive impedance at around 1kHz is produced.[3]

In any composite passive electronic circuit, change in impedance with frequency inevitably results in a change of phase. This phase is zero at the impedance peak, positive at lower frequencies and conversely a negative phase at higher frequencies. Capacitive reactance similarly exhibits negative phase, **Fig. 2**.

With a passive crossover network, which exhibits an impedance peak[4], similar phase changes occur. Frequencies below this peak have an inductive reactance. At higher frequencies, as impedance reduces, a corresponding capacitive reactance should be measurable.

The speaker systems which I have available for measurement include the workshop two-way transmission line system and an original single-speaker Daline.[5] I also have access to my son's very high power bass guitar 42Hz tuned reflex system, and a pair of elderly two-

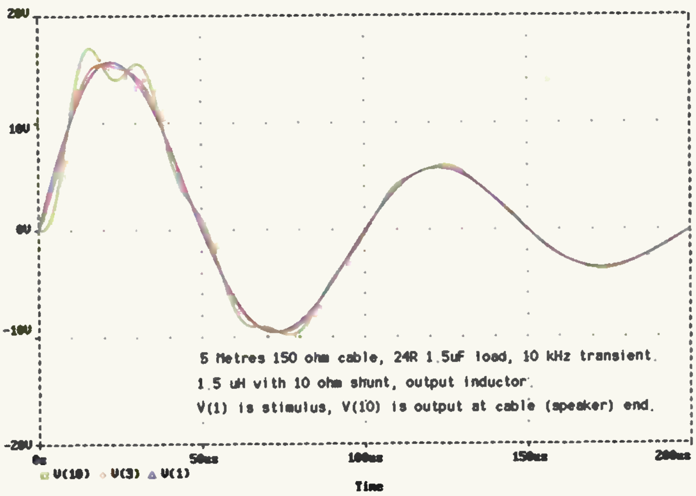



Fig. 1. *Simulation of typical amplifier output stage when driving into a capacitive load with high-value shunt impedance, via a high impedance, typical figure-of-eight-style cable. This diagram was used for the first article.*

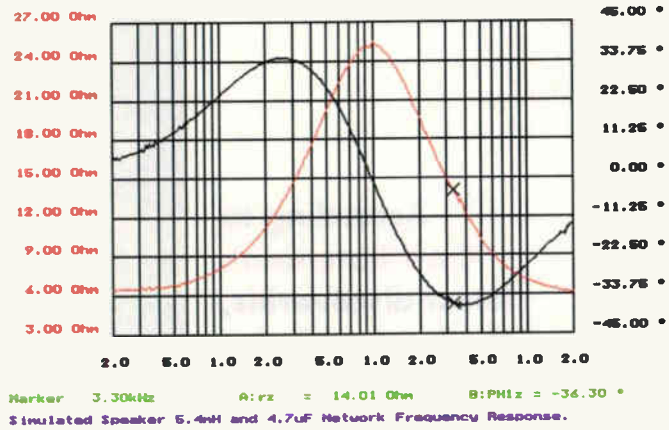



Fig. 2. *Impedance and phase plot of the 'pseudo' IHF dummy reactive load, made using a 5.6Ω resistor in series with a parallel combination of 5.4mH, 4.7μF and an 18Ω damping resistor. This shows phase change with frequency for this high-impedance resonant circuit.*

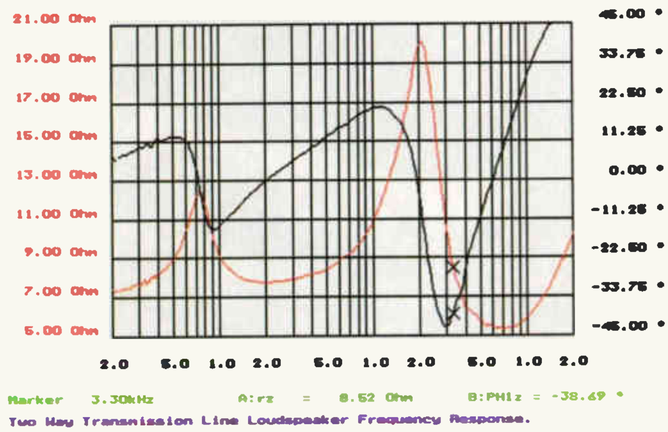



Fig. 3. *Impedance and phase plot by frequency, of rebuilt two-way transmission line test speaker. Compare with published plot in reference 3.*

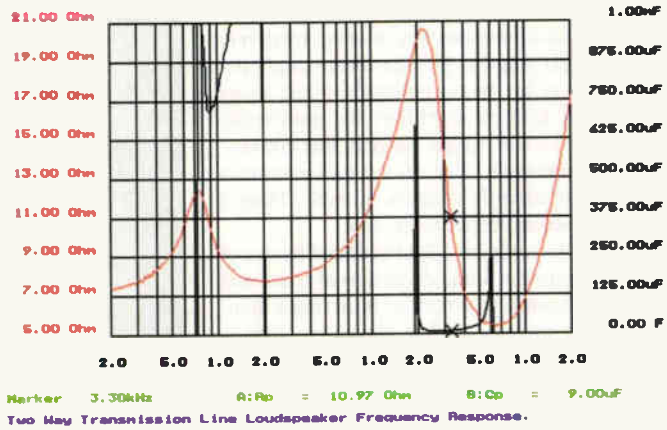



Fig. 4. *Plot Fig. 3 displayed in terms of parallel resistance and equivalent parallel capacitance values. Note relatively large equivalent capacitances near bass resonance.*

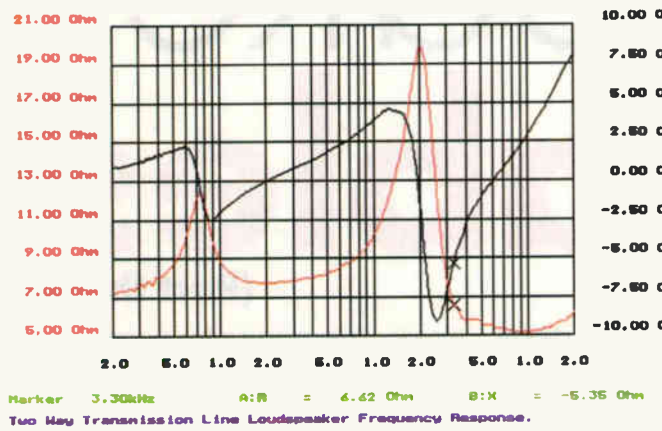



Fig. 5. *The Fig. 3 plot again but this time displayed in 'R + jX' terms, clearly showing the inductive and capacitive parts of the frequency range, with negative X values being capacitive and positive X values representing inductive reactances.*

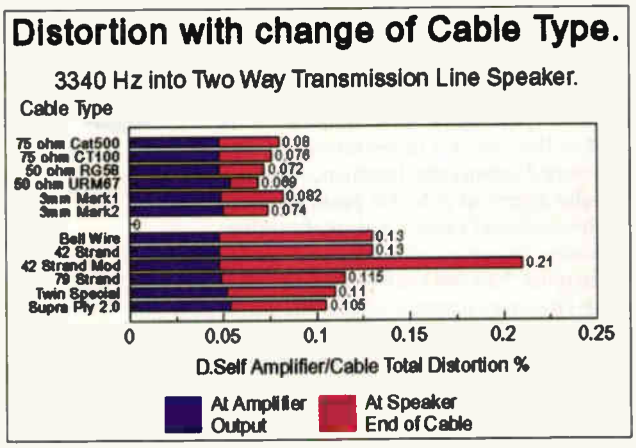



Fig. 6. *This plot of harmonic distortion measured at the test speaker terminals, with the speaker acting as a capacitive load, shows clearly how distortion changes with cable. Great care was taken to maintain all other test conditions constant, as can be judged by the small changes in distortion measured at the amplifier terminals. This test was repeated on three separate days, all giving similar results, and only small levels of non-harmonic noise were noted.*

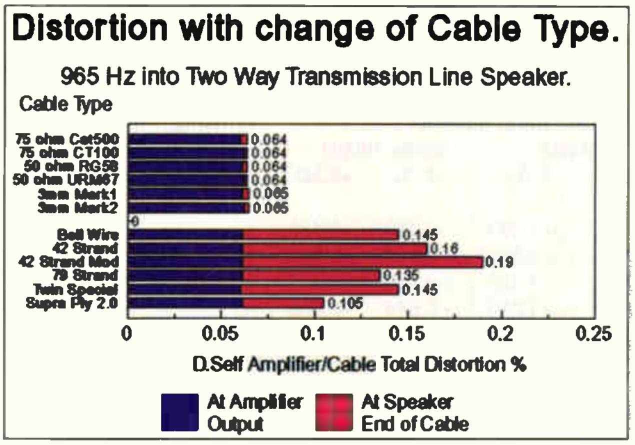



*Fig. 7. Harmonic distortion measured at the test speaker terminals, with the speaker acting as an inductive load, shows smaller distortion changes with cable. During this test, non-harmonically related noise was observed for the figure-of-eight twin-line cables, clearly showing the coaxial cable's superior isolation from transmitted noise. This pick-up partly accounts for the poor performance of the Figure 8 cables with this inductive real speaker loading.*

way corner horns in my listening room.[6] None of these is in an infinite baffle cabinet.

How can I measure the impedances and reactances of these speakers? While impedance plots can be made using nothing more than a signal generator, a known resistor and a suitable voltmeter, phase measurement is much more difficult.

Many personal computers have a 16-bit sound card. With suitable software, such a card can provide the heart of an extremely low-cost audio frequency measurement system, capable of measuring impedance and phase angle. While not state-of-the-art, this method can produce useful measurements. Two low-cost software systems for use with these sound cards are readily available (see panel on sound cards and software).

To ensure a resonant peak at crossover, I rebuilt my two-way transmission line as an 8Ω system, with a crossover based on the old Kef *DN13* design[4], built using polycarbonate and polypropylene capacitors and used with a small cone tweeter. Using the *Elektor* software with my sound card, the resulting impedance plot was similar to that published for the Tannoy *D700* system[3], **Fig. 3**.

This conventional impedance phase plot can also be viewed in terms of equivalent inductance, capacitance or as '*R*+j*X*' – whichever is preferred. Viewed as the parallel resistance and equivalent parallel capacitance, you can see that frequencies near 3kHz could provide loading similar to the simulations used for Fig. 1, with consequent distortion, **Figs 4, 5**.

Having established that the conditions needed for transient distortions

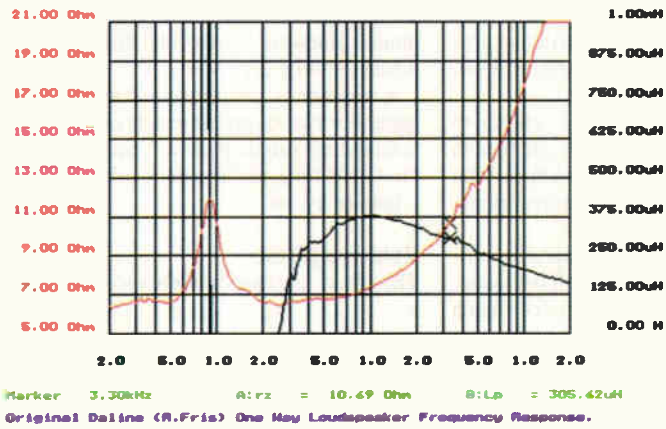



*Fig. 8. Impedance and equivalent parallel inductance plot of the R. Fris original* Daline *cabinet, clearly showing high-frequency inductive behaviour. This cabinet was chosen since it has no crossover network.*

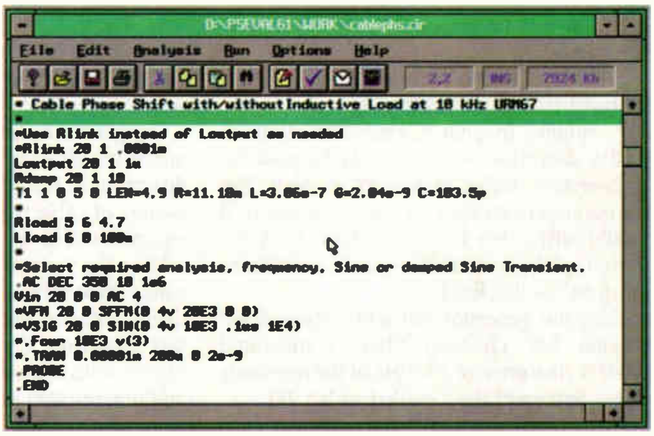



*Fig. 9. PSpice net-list used to calculate the high frequency phase deviation results, with change of cable parameters, and various loading circuits, for Table 1. Note use of Spice 'SIN' waveform.*

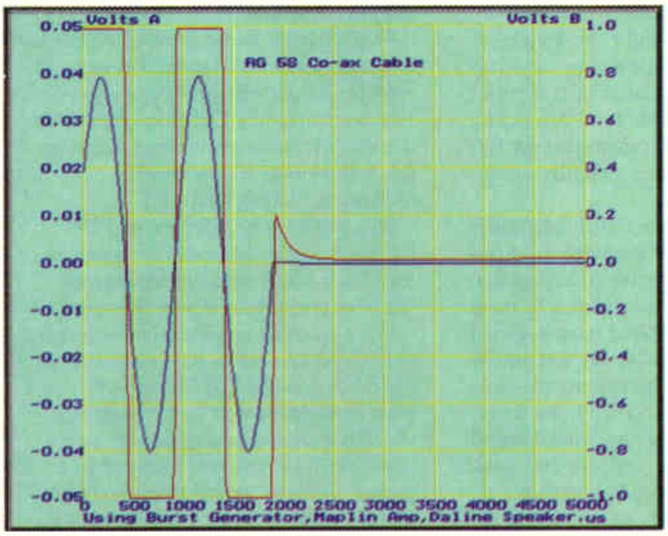



*Fig. 10. Plot of loudspeaker damping, or lack of, using RG58 cable with the* Daline *speaker cabinet. This was made using a tone-burst generator and Maplin Amplifier set to 1.6V pk/pk output, with the Pico ADC100 virtual oscilloscope. Note the close similarity to the Duncan test plots.*

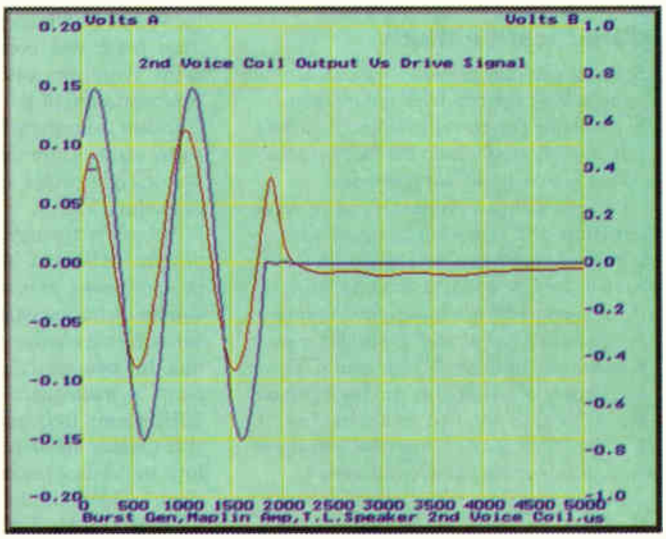



*Fig. 11. Using the Fig. 10 set-up and RG58 cable to observe speaker cone overhang using the 'spare' voice coil of the transmission line speaker as a sensor. This clearly shows cone movement at reduced amplitude, continuing far longer than the initial overshoot spike.*

*Table 1. Simulated phase shift in degrees at 10kHz for the various cables tested. Shows low/high frequency deviations by cable, with amplifier and various dummy speaker loads. Ranked for least overall change with above permutations.*

| | No output inductor | | | | With 1μH output inductor | | | | Ranking |
|---|---|---|---|---|---|---|---|---|---|
| | Resistor only | | Series 100μH | | Resistor only | | Series 100μH | | |
| | 4.7Ω | 8.2Ω | +4.7Ω | +8.2Ω | 4.7Ω | 8.2Ω | +4.7Ω | +8.2Ω | |
| Coaxial styles | | | | | | | | | |
| 75Ω Cat.500 | −1.485 | −0.859 | +0.034 | −0.211 | −2.234 | −1.293 | −0.232 | −0.480 | 5 |
| 75Ω CT100 | −1.414 | −0.815 | −0.114 | −0.284 | −2.159 | −1.245 | −0.380 | −0.553 | 6 |
| 50Ω RG58C/U | −1.219 | −0.708 | +0.386 | +0.033 | −1.961 | −1.139 | +0.118 | −0.237 | 3 |
| 50Ω URM67 | −1.149 | −0.660 | −0.249 | −0.320 | −1.903 | −1.094 | −0.515 | −0.590 | 4 |
| 3mm Mark 1 | −0.685 | −0.394 | −0.148 | −0.074 | −1.446 | −0.831 | −0.342 | −0.421 | 1 |
| 3mm Mark 2 | −0.697 | −0.401 | −0.083 | −0.155 | −1.454 | −0.836 | −0.351 | −0.427 | 2 |
| Figure-of-8 styles | | | | | | | | | |
| 2192Y 'Bell' Wire | −2.684 | −1.566 | −0.094 | −0.326 | −3.399 | −1.984 | −0.105 | −0.591 | 9 |
| 42-strand | −2.904 | −1.685 | −0.303 | −0.626 | −3.647 | −2.117 | −0.563 | −0.891 | 11 |
| 42-strand modified | −4.629 | −2.687 | −0.932 | −1.257 | −5.369 | −3.118 | −1.184 | −1.518 | 12 |
| 79-strand | −2.545 | −1.466 | −0.621 | −0.752 | −3.301 | −1.902 | −0.882 | −1.019 | 10 |
| 2mm twin special | −1.939 | −1.117 | −0.394 | −0.527 | −2.695 | −1.553 | −0.657 | −0.796 | 8 |
| Supra Ply 2.0 | −1.394 | −0.803 | −0.212 | −0.338 | −2.152 | −1.239 | −0.478 | −0.608 | 7 |

can exist, might these conditions also cause distortion with continuous sine waves? This region should be explored by practical measurements.

## Conventional distortion tests

My variable frequency generator produces 0.05% distortion, so it can only be used for comparative, rather than absolute, tests. For the purpose of comparing cables, however, it should suffice. My Hewlett Packard *331A* distortion analyser cannot measure distortions much below this level.

Using this generator with a two-stage series/parallel *L/C* clean-up filter, I measured 0.045% distortion at 3340Hz at the terminals of my Self amplifier,[7] loaded with 8.2Ω.

This amplifier, with the above instruments, was used with all twelve cables to test drive the rebuilt two-way transmission line speaker, making distortion measurements in sequence at both amplifier and loudspeaker terminals.

To help this rebuilt speaker survive prolonged testing, I used only half the drive voltage used by Duncan for his July/August article, i.e. 0.45V. Even at this reduced level, some ear protection is desirable.

Using a test frequency of 3340Hz, chosen to match my clean-up filter, notable changes in distortion at the loudspeaker terminals with change of cable were easily measured by my equipment, **Fig. 6**.

From the various simulations made investigating these cables, a similarly high but inductive impedance was expected to produce much less distortion. Change of test frequency to 965Hz, with appropriate changes to the clean-up filter, resulted in increased distortion at the amplifier terminals. However, as expected, incremental distortion was lower at the speaker end of the test cables, since the speaker was now behaving as an inductive load.

During this test, with the distortion residuals viewed by oscilloscope, non-harmonically related noise was observed for the figure-of-eight twin-line cables, providing a clear demonstration of the coaxial cable's superior isolation from transmitted noise. This pickup partly accounts for the performance of the figure-of-eight cables with this inductive speaker loading, **Fig. 7**.

At bass frequency, almost all loudspeaker designs exhibit a high-impedance resonant peak or peaks. It is reasonable to expect that similar distortion changes would also be measured with a change of cable. I have not tried this, for two reasons. Firstly, my test equipment is inadequate for measurements near 50Hz mains frequency. Secondly, the available speaker cabinets either have well damped low impedance resonance peaks or they peak close to the mains harmonic frequencies.

These 3340Hz distortions were much larger than expected, so I built a test circuit similar to the IHF (Institute of High Fidelity Inc, IHF publication A202) reactive load, using a 5.4mH inductor with a 4.7μF metallised polycarbonate capacitor to get a high impedance and similar phase to that of the speaker measured. With this test circuit, no realistic continuous sinewave incremental distortions were measured, Fig. 2.

A speaker is obviously a complex motor generator system giving results not easily represented by simple passive component models. Given time, perhaps this could be resolved – but not by me.

## Relative phase

The final parameter influenced by cable

### Other test methods

Some of you may prefer to test cables using a low-cost tone burst test more in line with the Duncan test method. I include screen shots made using the Pico adapter with a low-cost, self-built generator.

Readers with a 50Ω output square wave generator and who wish to experiment using transient waveforms similar to that used in the Spice simulations can easily make a good 10kHz replica by loading the generator output with a parallel combination of 1mH with 0.22μF and 47Ω.

A variety of test signals can be found on the *Hi-Fi News and Record Review* Test Disc III. This includes a transient waveform very similar to the Spice exponentially damped sine wave, 'SIN', used for Fig. 1. However, the tone burst included on this disc equates to the IHF tone burst in having a change in level but no distinct off periods.

### Sound cards and software

For these tests I used a Creative Labs *Soundblaster 16 Value Plug-and-Play* card with general purpose software (Elektor Electronics, part no. 966001-1). It is important to check that the dma channels and interrupts needed are not already in use in your system.

An alternative software for sound cards, targeted especially at speaker systems, is *AIRR* (Anechoic In-Room Response) by Dr J J Bunn, supplied by Old Colony Software. It is also available from Falcon Acoustics Ltd, Tabor House, Norwich Rd., Mulbarton, Norfolk NR14 8JT

Also available from Falcon and Old Colony is *Audiosuite* software, again for use with a sound card. It includes MLS functions but is much more expensive.

Those seriously interested in the design of loudspeakers rather than measurement might consider the Old Colony *IMP* (Impulse Measurement and Processing), which is a stand-alone system for a pc, available in kit form and reasonably priced. This also is available from Falcon.

Many other software and hardware systems are available, and the above list covers only some of those priced for the speaker amateur.

choice is change of high frequency phase relative to phase at lower frequencies. Every cable has a transit delay, influenced primarily by the cable's inductance and insulation material. This delay could change with frequency or test-circuit loading.

I am not well equipped to measure small phase angles but, knowing the cable's ac parameters, this could be simulated.

Most Spice-based simulators have transmission line models available but, to minimise transient simulation times, their default settings use a minimum of only two sampling points along the cable. This produces poor results with short cable lengths at audio frequencies. Also, the supplied small signal transmission line model is much simplified.

By overriding these defaults and forcing a slower simulation, acceptable results are obtainable. Many loudspeaker impedance plots show an inductively rising impedance above 10kHz. Thus, each of the twelve cables tested has been simulated using both 4.7Ω and 8.2Ω resistive loads and a series combination of these resistances with 100μH, **Fig. 8**.

Most – but not all – domestic amplifiers are protected against reactive loads by a low-value inductor in series with their output. To cover all reasonable options, the above load combinations were simulated with and without a series inductance of 1μH and 10Ω damping resistor, **Fig. 9**.

These simulations were all made at 10kHz since, with these values, it represents a worst-case frequency. Regardless of the cable, only small changes in relative phase could be observed, **Table 1**.

## In summary

The intention of these experiments was to quantify the effects of cable characteristics on amplifier speaker systems, rather than to choose a 'best buy'. This determined the cables chosen for test.

My use of coaxial cables as speaker cables is not new. Indeed, extremely low-impedance specialist *Mogami* speaker coaxial cable was reviewed by Nelson Pass[8] in his 1980 article.

However, these experiments would be incomplete without forming at least a ranking of cable performance. This ranking was unweighted, taken from simple addition of place numbers for each test. Although various test weightings could be used, regardless of this, the first four placings are unlikely to change, **Table 2**.

These rankings were supported by listening tests. However, for the reasons outlined in my first article, listening tests were performed only as the concluding test, long after completion of all published tables or figures, and with this text at the final editing stage.

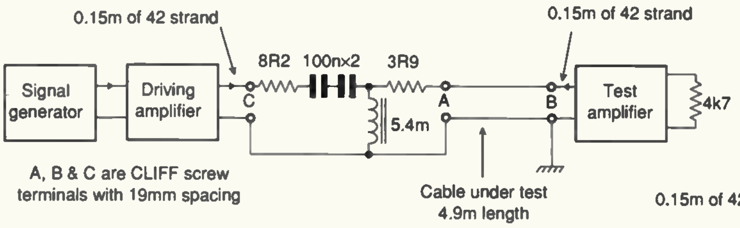
Regardless of these results, users of Naim and similar amplifiers not having an output inductor must use the maker's recommended cable and cable length, since the cable functions to replace the output inductor in protecting their amplifiers.

For all conventional inductor output amplifiers, the ideal speaker cable would have zero resistance, zero inductance and zero impedance. In other words, zero length – no cable at all[8], since all cable degradations increase with cable length.

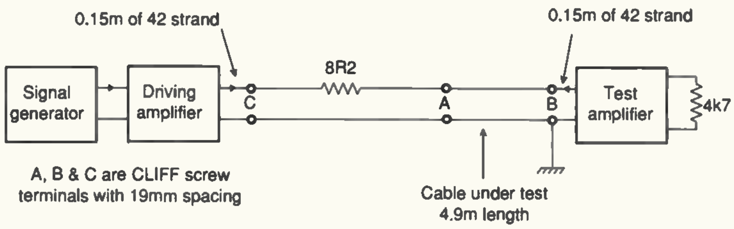
It is obvious from the results presented that a cable should have the lowest possible dc resistance, low characteristic impedance at audio frequencies, and minimal inductance.

*Table 2. Summary of cable rankings by each test performed. Final ranking derived using equal weighting for all tests. All cables 4.98m long.*

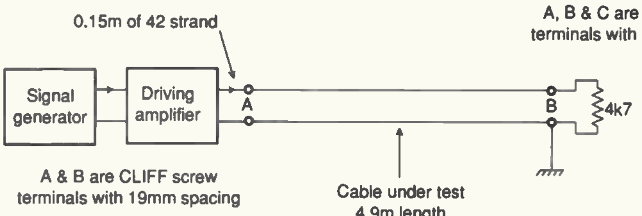
| | Circuit A | Circuit B | $Z_0$ | Inductance | DCΩ | Loss | Phase change | THD | Overall |
|---|---|---|---|---|---|---|---|---|---|
| Coaxial styles | | | | | | | | | |
| 75Ω Cat.500 | 8 | 8 | 9 | 7 | 8 | 7 | 5 | 5 | 8 |
| 75Ω CT100 | 7 | =6 | 8 | 6 | 7 | 6 | 6 | =2 | =5 |
| 50Ω RG58C/U | 10 | 10 | 6 | 4 | 11 | 2 | 3 | =2 | =5 |
| 50Ω URM67 | 3 | 3 | 4 | 3 | 1 | 1 | 4 | 1 | 3 |
| 3mm Mark 1 | 2 | 2 | 1 | 2 | 3 | =3 | 1 | 5 | 2 |
| 3mm Mark 2 | 1 | 1 | 2 | 1 | 2 | =3 | 2 | =2 | 1 |
| Figure-of-8 styles | | | | | | | | | |
| 2192Y 'Bell' Wire | 12 | 12 | 10 | 10 | 12 | 11 | 9 | 10 | 11 |
| 42-strand | 9 | 9 | 11 | 11 | =9 | 9 | 11 | 11 | 10 |
| 42-strand modified | 11 | 11 | 12 | 12 | =9 | 12 | 12 | 12 | 12 |
| 79-strand | 6 | =6 | 7 | 9 | 4 | 10 | 10 | 8 | 9 |
| 2mm twin special | 5 | 5 | 5 | 8 | 6 | 8 | 8 | 9 | 7 |
| Supra Ply 2.0 | 4 | 4 | 3 | 5 | 5 | 5 | 7 | 7 | 4 |




***Circuit A. Resonance test set-up. Input of the test amplifier is grounded via a 4.7kΩ resistor.***




***Circuit B. Resistance test set-up includes an 8.2Ω HSA25 series resistor. This resistor was chosen since it has constant impedance to 20kHz.***




***Circuit C. Loss test set-up.***

## Voice-coil driver effects

Using my tone-burst generator with a Maplin amplifier and an oscilloscope, I tested my available speaker drivers, some of which were 15Ω, and a mixture of long- and short-travel cones.

In general, smaller, lighter cones produced less cable overhang voltage. Size for size, short-travel cones produced less than long-travel cones. Similarly, 15Ω drivers produced less overhang voltage than 8Ω drivers, which produced less than 4Ω drivers, **Fig. 10**.

I was able to compare voice coil impedances quite easily. The bass driver in my two-way transmission line system is an ancient Whitely *Stentorian HF1016*. This has duplicated voice coils, and is designed to easily configure and be used as 4, 8 or 15Ω impedances.

Configured as 8Ω I can use the spare voice coil as a cone-travel sensor, giving most interesting results when viewed on an oscilloscope, **Fig. 11**.

Is it possible that cables are now considered so important due to the change to lower impedance, long-travel speaker drivers over the years?

These characteristics are almost impossible to achieve using twin-line or figure-of-eight constructions without incurring considerable cable self-capacitance. They are much more readily achieved using the coaxial construction and with acceptable capacitance.

Other frequently discussed parameters, such as sections of individual wire strands and cable insulation material, may well have some relevance, but these tests indicate that they are of secondary importance.

One obvious disadvantage of coaxial speaker cables having dense outer braids is cable end preparation and termination. It is important to avoid damaging any braid wire strands when stripping back, since this would substantially increase distortion levels. However, a dense braid is extremely effective in reducing cable pickup into the amplifier's feedback loop.

As to the test results table, with one exception, the cables segregated automatically into distinct performance groups – coaxial and non-coaxial. Five of the six coaxial cables were outstanding compared to all but one of the non-coaxial constructions tested – including the hand-made, 2mm twin-line special, **Table 2**. Of the non-coaxial styles, the Jenving *Supra Ply 2.0* was the exception, performing well and coming fourth overall,[9] Table 2.

By far the best cable of those tested is the custom made Mark II, followed closely by the Mark I. Neither of these is commercially available in cut lengths but they could be specially ordered in bulk, or further copies could be hand-made, as were my originals.

Both the Mark 1 and the Mark 2 are flexible, very low resistance and – being less than 6mm in diameter – easily installed. Mark 2 has 19 strands of 0.45mm inner wire insulated with polythene with an outside diameter of 3mm. Its outer braid is 240 strands of 0.127mm diameter. Heat shrink sleeve provided overall insulation.

Mk I is identical, except for its 37 strands of 0.32mm inner core. Designers interested in the materials used should send an sae to me via *Electronics World*'s editorial offices.

When these tests commenced, I decided to use only cables easily purchased in cut lengths so that my results could be easily replicated. However, in order to understand some early results, I needed to measure a cable having lower impedance at audio frequencies than URM67, but I was unable to buy it. I certainly didn't expect that my crude hand-made cables would perform as they did (see panel on sources of cables used for test).

Of those cables commercially available in cut lengths, the URM67 performs extremely well, coming a close third overall. It is obviously by far the best commercial cable of those tested. However, being 10.3mm in diameter with a solid polythene core and a very dense braid, it is inflexible. It could almost be used as a car tow rope.

A not-so-close fourth, the Jenving *Supra Ply 2.0*, is a specialised, relatively low-cost, high-capacitance cable, available from Jenving's UK agent[10] only in multiples of 10m. In direct contrast with URM67, it is much smaller and, being extremely flexible, drapes well. It is easily installed and hidden from sight.

Following closely on the *Supra Ply*'s heels is a tie for fifth place between the 75Ω satellite tv cable CT100 and the 50Ω instrument cable RG58, both ranking equally well overall. However, depending on your needs, you may prefer to down-rank RG58 due to its poorer performance in the resonance and resistive circuit tests and for its high dc resistance.

CT100 and Cat 500 cables are both of larger diameter than RG58. They have a secondary inner copper-foil shield which could fatigue and crack with repetitive coiling and uncoiling, so they should only be used for permanent installations.

Once more, I ask that anyone wishing to shoot these findings down in flames should first repeat the experiments.

## Cables sources

Initially, I decided that all test cables should be obtainable either from: Electrovalue or Maplin. I bought URM67, CT100, 42-strand, 79-strand, and 300Ω feeder from Maplin, while the RG58 was purchased from Electrovalue. *Supra Ply 2.0* came from Future Film Developments[10] however, and the Bell Wire and Cat 500 from local suppliers.

## Cobbler's shoes

After all these time-consuming experiments, you may wonder which brand of expensive speaker cable I use. My listening room has the the 'golden' dimensions of 6.7 by 4.6 by 2.9m, and needs cables somewhat longer than those tested.

My relatively low-cost system, based on Acoustic Research electronics with corner horn speakers[6] crossing over at 250Hz, was cabled almost 30 years ago using the old-style 7 by 0.029in twin and earth ring mains cable buried in the plaster. I used this for no better reason than that I had plenty left over. I guess its only other merit is a cross-sectional area of more than 3mm, giving reasonably low resistance at the lengths needed. Since my corner horns are 15Ω impedance, it seemed acceptable.

## Will I change this cable?

During these experiments I too, like Saul travelling to Damascus, have revised some views and intend to further develop Mark 2 for my own use. This design is now covered by Pat. No 9624876. ■

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8. Pass, N., Speaker Cables – Science or Snake Oil?, *Speaker Builder*, 2/80
9. Jenving Technology AB, Backamo 12800, S-459 91, Ljungskile, Sweden
10. Future Film Developments, 64 Oxford Road, New Denham, Uxbridge UB9 4DN


### Music used for listening tests

Test Disc 3, *Hi Fi News & Record Review*, HFN020.

*Pictures at an Exhibition*, Mussorgsky, Decca 417 299-2.

*In The Region of The Summer Stars*, The Enid, MNTLCD7.

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| Taylor Valve Tester 474 | £59 |
| Philips RF Generator PM5326 | £395 |
| HP Frequency Counter HP5340 | £595 |
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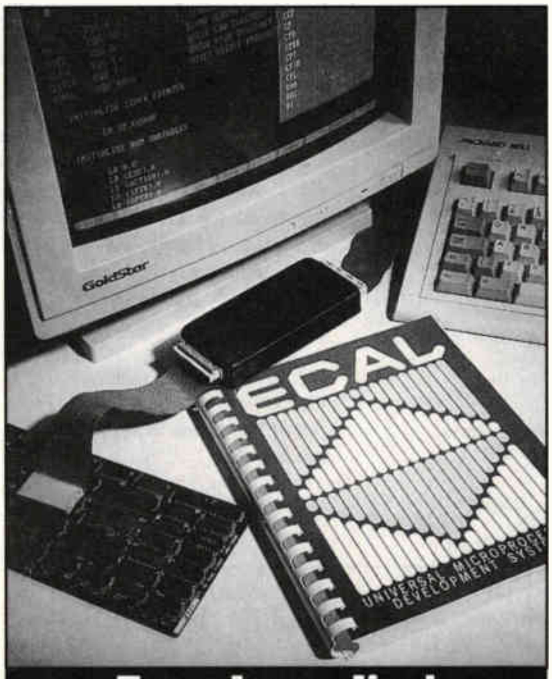


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# Gates open up

**One c-mos gate pack can form the heart of a frequency meter, a step-down switching regulator or a negative-supply generator, explains Rae Perälä.**

There are many applications for the 4011 c-mos two-input-nand gate – other than just gating. This article presents three such circuits, namely a step-down regulator, a negative-voltage switching regulator, and a frequency measuring circuit.

## Step-down regulator

Operating principle of a typical step-down regulator is shown in **Fig. 1**. Semiconductor switch $S_1$ is usually controlled by a pulse width modulator, or pwm.

While the switch is on, current flows through inductor $L$ to the output. Simultaneously, magnetic energy in the inductor increases. Diode $D$ stays in its reverse state. When the switch turns off, the inductor discharges its magnetic energy giving a current to the output. Diode D now becomes forward biased providing path for current flow.

The on-to-off time ratio of the switch is controlled by the pwm circuit. This circuit compares output voltage, $V_{out}$, to reference voltage $V_{ref}$ and changes the on-to-off ratio accordingly.

**Figure 2** is a practical step-down circuit using 4011. It makes a new regulated output voltage $V_{out}$ from a regulated +8 to +15V input voltage. Gates A and B work as an oscillator giving an asymmetrical 40kHz square wave, **Fig. 3**. Gate C controls the switching transistor, which is a BS250 p-type enhancement mode mosfet. This same gate inverts the oscillator output voltage, presenting the transistor control voltage $V_{GS}$ as in Fig. 3. The control voltage has long negative pulses interspersed with short intervals. The transistor conducts during the negative pulses.

Gate D regulates the output voltage. Its output is high when $V_{out}$ is beneath the adjusted value. The high state activates gate C, which can now control the switching transistor. When the adjusted output voltage is reached, gate D output goes low, stopping gate C, which remains in the high state. The switching transistor has no control voltage and remains off.

The regulating circuit operates using the 'missing pulse' principle. It provides pulses when the output voltage is low and ceases pulsing when the output voltage is sufficiently high.

Output voltage is adjusted via the 470kΩ potentiometer. Usable output voltage range of the circuit is 0.5 to 0.9 of $V_{in}$. The circuit can be loaded to 100mA.

## Negative voltage regulator

A negative voltage switching regulator is presented in **Fig. 4**. Gates A and B form an oscillator, giving a symmetrical square wave voltage. Gate C controls the BS250 switching transistor.

During the transistor on time, current flows through the inductor, charging the magnetic energy within it. The magnetic energy discharges while the transistor is off through the diode, producing a negative voltage at the output.

Gate C regulates the output voltage. When the output voltage is too low, the regulating input voltage of gate C is high and the oscillator voltage controls the gate C output and therefore the transistor.

When the output voltage reaches the desired negative value, the regulating input goes low and it stops the output of gate C leaving it in its high state. The transistor stays off until the output voltage goes below its adjusted value.

This circuit requires an input voltage of +8V to +15V, which can be unregulated. A regulated +5V input acts as a reference voltage.

## Frequency measurement on a dvm

A digital voltmeter can be used for frequency measurements to 1MHz using the circuit in **Fig. 5**. The frequency to be measured connects to the input of gate A. This input is biased with 330kΩ resistors to half the supply voltage. This allows low input voltages to change the output of gate A. **Figure 6** shows the gate voltages. Output voltage of gate A changes each time the input voltage passes the half supply voltage threshold.

Gate A controls gates B and C. Gate B has a delay capacitor in its output. Figure 6 shows

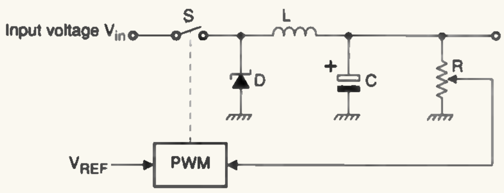


*Fig. 1. Switching converter simplified. On and off times of switch S, invariably a semiconductor switch, are controlled by a pulse-width modulator.*

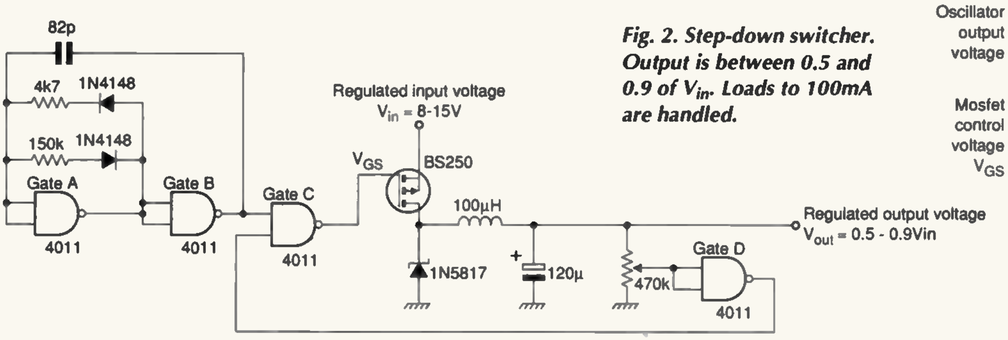


*Fig. 2. Step-down switcher. Output is between 0.5 and 0.9 of $V_{in}$. Loads to 100mA are handled.*

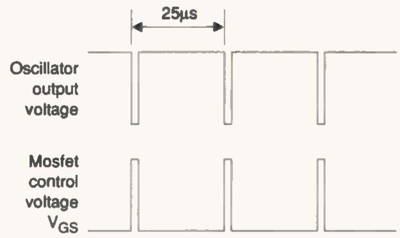


*Fig. 3. Asymmetrical oscillator gates A and B of Fig. 2 runs at about 40kHz.*

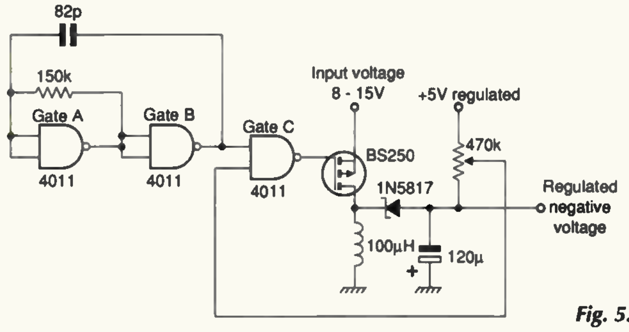


*Fig. 4. Negative supply from a positive input. Again, gates A and B are an asymmetrical oscillator. Gate C determines whether drive pulses pass to the switching transistor.*

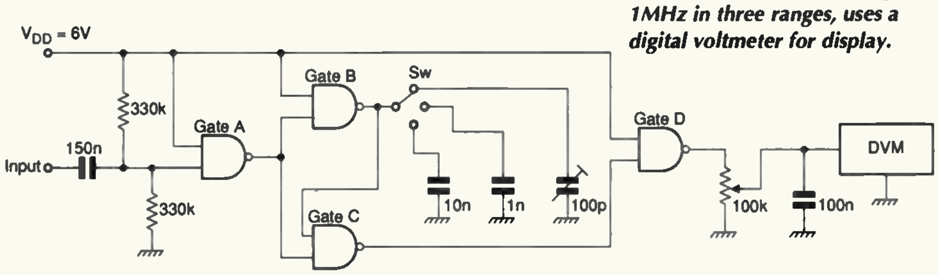


*Fig. 5. Direct reading frequency meter, capable of measuring to 1MHz in three ranges, uses a digital voltmeter for display.*

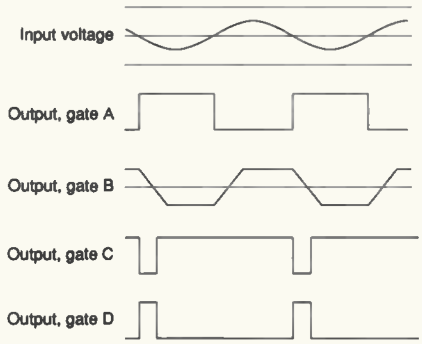


*Fig. 6. Frequency meter waveforms. Top is the ac input, which is biased toward the switching point of the logic gate. In this way, the gate switches at a significantly lower input voltage than would otherwise be needed.*

the gate B output voltage, which is reversed and delayed relative to gate A's output. One input of gate C is fed with the output voltage of gate A and in the other input the delayed voltage from gate B. Output of gate C comprises a negative pulse with a duration equal to the the time it takes for gate B to falling from its high state to its low state. Pulses from gate B are then inverted in gate D. These pulses are always similar in shape, independent of the amplitude and shape of the original input voltage.

The mean value of gate D's output voltage can then be measured by a digital voltmeter with its 200mV or 2V dc voltage range selected. The meter reading can be adjusted by the 100kΩ potentiometer so that the voltage reading directly represents the unknown capacitance.

Capacitance measuring ranges are selected by the switch, which connects a suitable capacitor to gate B's output. The 100pF capacitor should be a trimmer so that gate C's input capacitance can be compensated for. ■


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CIRCLE NO. 120 ON REPLY CARD

# OVERLOAD matters

**Doug Self takes a look at the complex subject of preamplifier overload, and how to handle it.**

There was no room in my Preamp '96 article for a proper discussion of the overload behaviour of RIAA preamp stages.[1] Like noise performance, the issue is considerably complicated by both cartridge characteristics and the RIAA equalisation.

There are some inflexible limits to the signal level possible on vinyl disc, and they impose maxima on the signal that a cartridge can reproduce. The absolute value of these limits may not be precisely defined, but they set the way in which maximum levels vary with frequency, and this is perhaps of even greater importance.

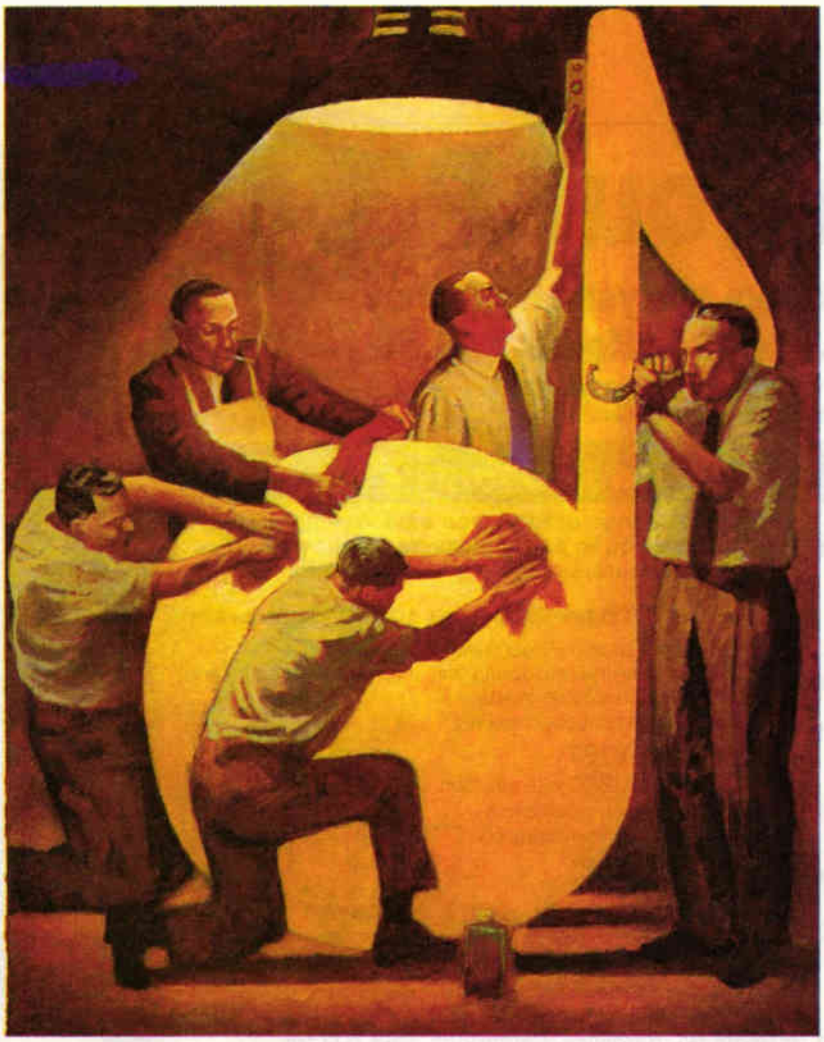


**Figure 1a** shows the physical groove amplitudes that can be put onto a disc. From subsonic up to about 1kHz, groove amplitude is the constraint. If the sideways excursion is too great, the spacing will need to be increased to prevent one groove breaking into another, and playing time will be reduced. From about 1kHz to ultrasonic, the limit is groove velocity rather than amplitude. If the cutter head tries to move sideways too quickly compared with its forward motion, the back facets of the cutter destroy the groove that has just been cut by the forward edges.

At replay time, there is a third restriction – that of stylus acceleration or, to put it another way, groove curvature. This sets a limit on how well a stylus of a given size can track the groove. Allowing for this at cutting time puts an extra limit on signal level, shown by the dotted line in Fig. 1a.

The severity of this restriction depends on the stylus shape. An old-fashioned spherical type with a tip diameter of 0.0007in requires a roll-off of maximum levels from 2kHz, while a relatively modern elliptical type with 0.0002in effective diameter postpones the problem to about 8kHz.[2]

Thus there are at least three limits on the signal level. The distribution of amplitude with frequency for the original signal is unlikely to mimic this, because there is almost always more energy at lf than hf. Therefore the hf can be boosted to overcome surface noise without overload problems, and this is done by applying the inverse of the familiar RIAA replay equalisation.

Moving-magnet and moving-coil cartridges both operate by the relative motion of conductors and magnetic field, so the voltage produced is proportional to rate of change of flux. The cartridge is sensitive to velocity rather than to amplitude (and so sensitivity is always expressed in millivolts per cm/s) and this gives a frequency response rising steadily at 6dB/octave across the whole audio band. Therefore, a maximal signal from disc (Fig. 1a) would give a cartridge output like Fig. **1b** – i.e., 1a tilted upwards.

Figure **1c** shows the RIAA replay equalisation curve. The shelf in the middle corresponds with **1a**, while an extra time constant at 50Hz limits the amount of lf boost applied to warps and rumbles. The 'IEC amendment' is an extra roll-off at 20Hz, (shown dotted) to further reduce subsonics. When RIAA equalisation 1c is applied to cartridge output 1b, the result will look like Fig. **1d**, with the maximum amplitudes occurring around 1-2kHz.

Clearly, the overload performance of an RIAA input can only be assessed by driving it with an inverse-RIAA equalised signal, rising at 6dB/octave except around the middle shelf. My Precision preamp '96 has an input overload margin referred to 5mV rms of 36dB across most of the audio band, i.e., 315mV rms at 1kHz. The margin is still 36dB at 100Hz, but due to the RIAA low-frequency boost this is only 30mV rms in absolute terms.

The final complication is that preamplifier output capability almost always varies with frequency. In Preamp '96, the effects have been kept small. The output overload margin voltage – and hence input margin – falls to +33dB at 20kHz. This is due to the heavy capacitive loading of both the main RIAA feedback path and the pole-correcting *RC* network ($R_{24,25}$ and $C_{20}$). This could be eliminated by using an op-amp with greater load-driving capabilities, if you can find one with the low noise of a *5534*.

The overload capability of Preamp 96 is also reduced to 31dB in the bottom octave 10-20Hz, because the IEC amendment is implemented in the second stage. The lf signal is fully amplified by the first stage, then attenuated by the deliberately slow initial roll-off of the subsonic filter.

Such audio impropriety always carries a penalty in headroom as the signal will clip before it is attenuated. This is the price paid for an accurate IEC amendment set by polyester caps in the second stage, as opposed to the usual method of putting a small electrolytic in the first-stage feedback path, rather than the 220µF used. Alternative input architectures that put flat amplification before an RIAA stage suffer much more severely from this kind of headroom restriction.[3]

These extra preamp limitations on output level are shown at Fig.1e, and, comparing 1d, it appears they are almost irrelevant because of the falloff in possible input levels at each end of the audio band. ■

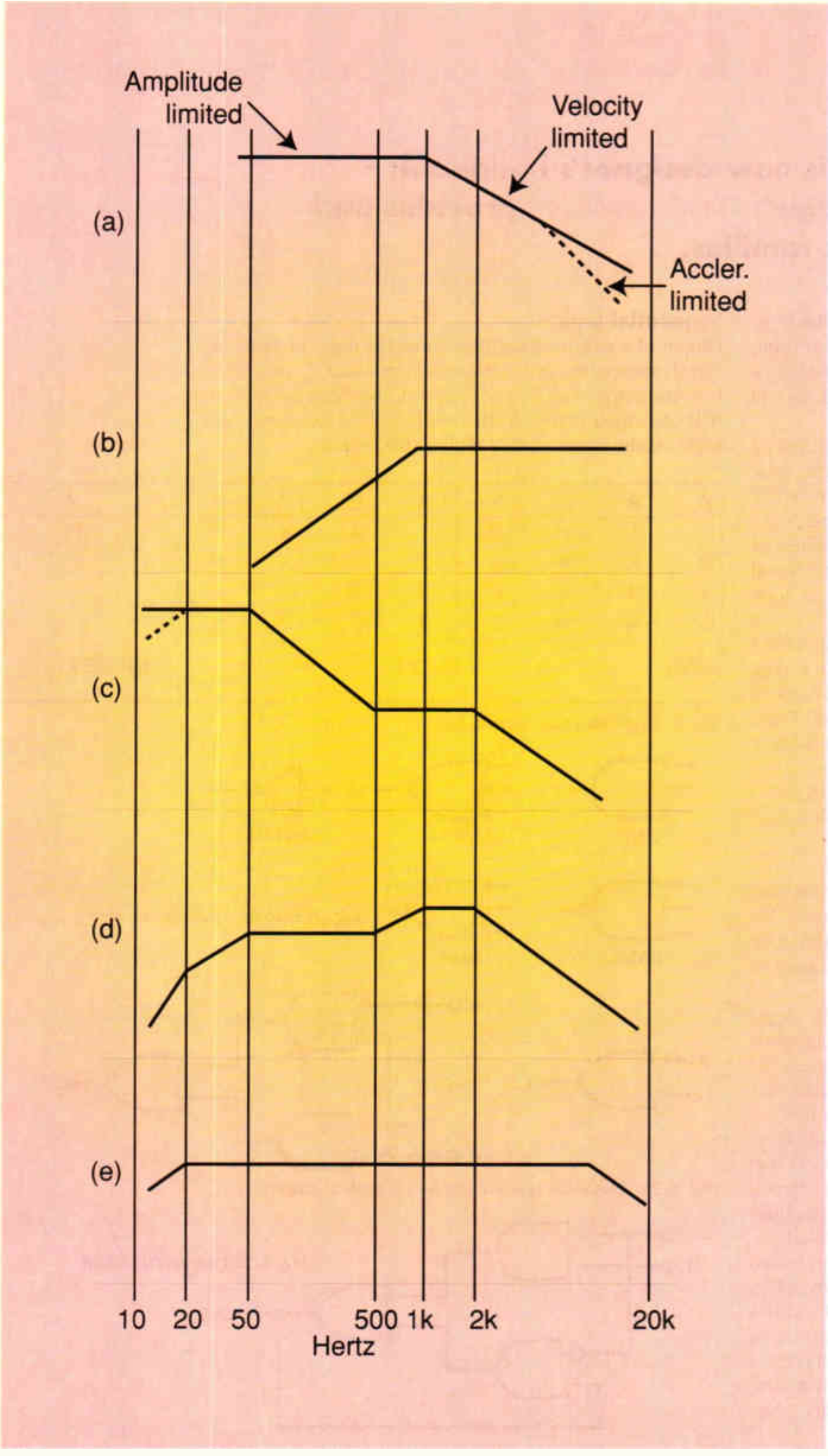



***Fig. 1a). Restrictions on the level put onto a vinyl disc. The extra limit of groove curvature – stylus acceleration – is shown dotted.***
***Fig.1b). Response of a moving-coil or moving-magnet cartridge to a signal following the maximum contour in Fig. 1a).***
***Fig. 1c). The RIAA replay curve. The IEC amendment is an extra roll-off at low frequency, shown dotted.***
***Fig. 1d). The combination of b) and c).***
***Fig. 1e). RIAA preamp output limitations. The high-frequency restriction is very common and is often much worse in discrete preamplifier stages with poor load-driving capabilities.***

## References

1. Self, D., 'Precision preamplifier '96', *Electronics World*, July/Aug and Sept 1996.
2. Holman, T., 'Dynamic range requirements of phonographic preamplifiers', *Audio*, July 1977, p74.
3. As [1], July/Aug 1996, p543.

# Programmable logic primer

**In this first article based on his new designer's handbook – 'FPGAs and programmable logic', Geoff Bostock provides and introduction to standard logic families.**

The primary building block of logic circuits is the logic gate. This is a device which operates on two or more logic signals to give an output which is defined by a logic operator. The standard logic operators are And, Or and Invert, which only acts on one signal.

There are two classical logic families – ttl, which uses a non-final 5V supply, and 4000-series c-mos, which can work from a supply of between 3V and 15V. In recent years, the 4000 series has been largely superseded by the HC high-speed c-mos family. A logic low signal is usually defined as being close to 0V, or ground, while a logic high signal normally sits close to the supply voltage, $V_{cc}$, or at least above half $V_{cc}$.

An And function is defined as only giving a high output when all the inputs are high; the Or function has a high output when any one of its inputs is high. The Invert function changes a logic signal from high to low, or *vice versa*. These functions may be written down as logic equations as follows:

| | | | |
|---|---|---|---|
| And function: | Y=A*B*C | or | Y=A&B&C |
| Or function: | Y=A+ B + C | or | Y=A#B#C |
| Invert function: | Y=/A | or | Y=!A |

Alternative notations exist because different logic compilers have adopted different conventions. Using '*', '+' and '/' for logic clashes with their more familiar use as arithmetic operators in programming languages. For the remainder of this article, I will use '&', '#' and '!'.

**Figure 1** shows an alternative way of showing logic relationships – the truth table. The symbol 'H' represents logic high, sometimes replaced by '1', while 'L' stands for logic low, with '0' as an alternative. The symbol 'X' represents don't care; the logic level can be high or low.

These three operators form the basis of all possible logic circuits. For example, the exclusive-Or gate has a low output if its two inputs are the same, but high if they are different. Its logic operator is written as Y=A$B or, sometimes Y=A:+:B. It is logically equivalent to Y=A&!B#!A&B.

These logic functions may also be represented diagrammatically. Standard gate symbols are shown in **Fig. 2**; as well as And, Or, and Invert, gates with the functions Nand and Nor are also depicted. The NAND function is an And followed by an Invert, Nor is Or followed by Invert; a small bubble on an output, or an input, signifies an inversion.

The exclusive-Or symbol, and its equivalent logic circuit, are drawn in **Fig. 3**.

## Sequential logic

Output of a gate does not depend on the order in which the signals are applied. If both inputs of a two-input And gate are low, the output will also be low; if A goes high before B, or if B goes high before A, the result will be the same – two highs on the inputs yield a high on the output.

| A | B | C | Y | A | B | C | Y | A | Y |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | H | 1 | X | X | H | 1 | H |
| 0 | X | X | L | X | 1 | X | H | 0 | L |
| X | 0 | X | L | X | X | 1 | H | | |
| X | X | 0 | L | 0 | 0 | 0 | L | | |
| AND | | | | OR | | | | INVERT | |

*Fig. 1. Logic function truth tables.*

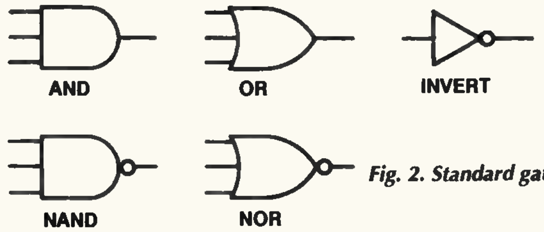



*Fig. 2. Standard gate symbols.*

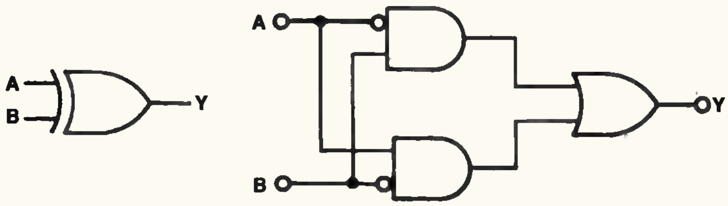



*Fig. 3. Exclusive-Or symbol and its equivalent circuit.*

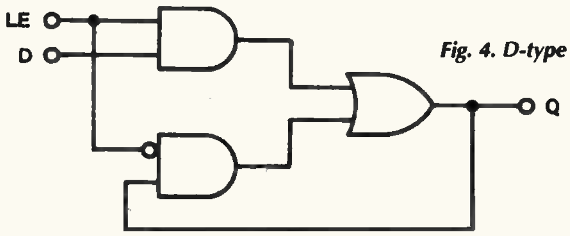



*Fig. 4. D-type latch circuit.*

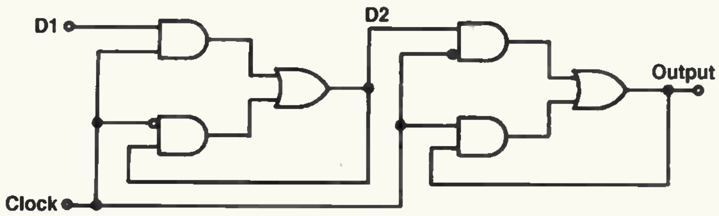



*Fig. 5. Master-slave D-type flip-flop.*

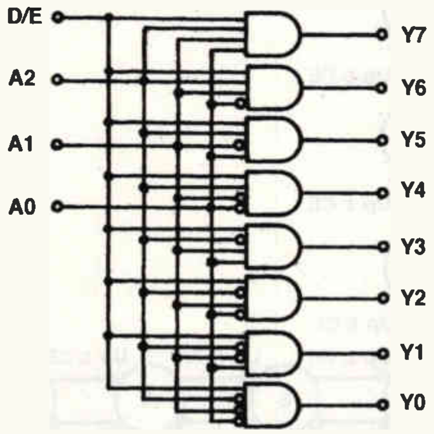



*Fig. 6. One-to-eight line decoder and demultiplexer.*

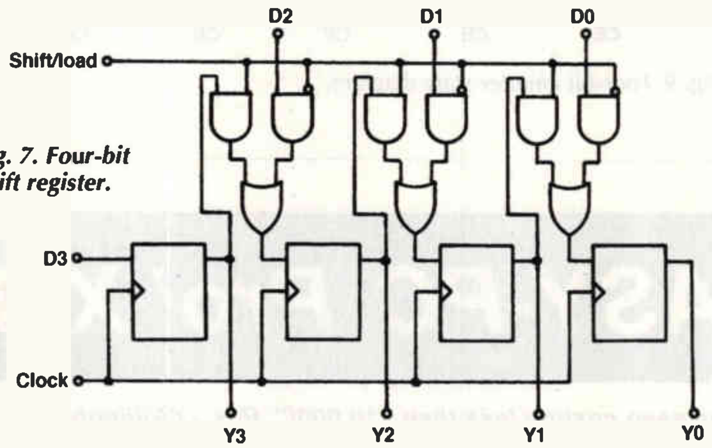



*Fig. 7. Four-bit shift register.*

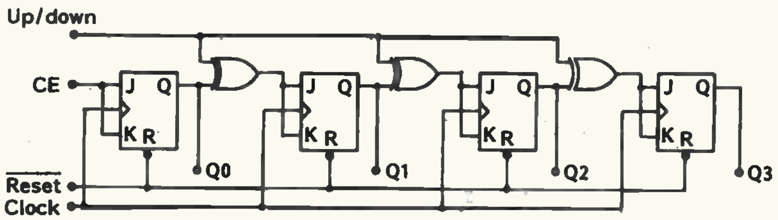



*Fig. 8. Four-bit counter.*

**Table 1. Truth table for decoder/demultiplexer, Fig 6.**

| D/E | $A_2$ | $A_1$ | $A_0$ | $O_7$ | $O_6$ | $O_5$ | $O_4$ | $O_3$ | $O_2$ | $O_1$ | $O_0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | X | X | X | L | L | L | L | L | L | L | L |
| 1 | 0 | 0 | 0 | L | L | L | L | L | L | L | H |
| 1 | 0 | 0 | 1 | L | L | L | L | L | L | H | L |
| 1 | 0 | 1 | 0 | L | L | L | L | L | H | L | L |
| 1 | 0 | 1 | 1 | L | L | L | L | H | L | L | L |
| 1 | 1 | 0 | 0 | L | L | L | H | L | L | L | L |
| 1 | 1 | 0 | 1 | L | L | H | L | L | L | L | L |
| 1 | 1 | 1 | 0 | L | H | L | L | L | L | L | L |
| 1 | 1 | 1 | 1 | H | L | L | L | L | L | L | L |

Consider **Fig. 4**. If input LE is high, the output, Q, will be the same as input D. This is because the output of the lower And gate is low – irrespective of D. Suppose that LE is now taken low; the upper gate now has a low output so Q will follow the output of the lower gate. If D was high when LE went low, Q was also high, so the lower gate was high and Q will stay high. Conversely, if D was low, Q will stay low.

This function is known as a latch. While LE is high, the latch is transparent and Q follows D; when LE is low, the level of D when LE went low is latched into Q. Output of the circuit depends on the sequence in which the signals are applied, hence the term sequential circuit.

**Figure 5** shows two latches in series, with the LE signal inverted between them. When the first latch is transparent, the second is latched, and *vice versa*. A signal applied to $D_1$ will appear at $D_2$ while $LE_1$ is high, but will not be transmitted to Q until CLK goes low, sending $LE_2$ high. At this time, LE1 goes low and locks out any changes on $D_1$. It appears that the signal on $D_1$ is sent through to Q as CLK changes from high to low. This is the principle of the master-slave flip-flop or D-type flip-flop.

## Practical logic circuits

Devices containing one or more gates, latches or flip-flops form the basis of the standard logic families. Circuit designers can use these integrated circuits to build up more complex functions by interconnecting these ssi, or small-scale integration, devices on a printed-circuit board. However, the device manufacturers anticipated these requirements by producing medium-scale integration, or msi, parts containing many of the standard circuit functions which can be built from gates and flip-flops.

A typical combinatorial msi function is a one-to-eight line decoder/demultiplexer. The circuit diagram for this function is shown in **Fig. 6**. The logic levels on the three address inputs represent a binary number in the range $000_2$ $(0_{10})$ to $111_2$ $(7_{10})$. The logic level on the data/enable input is transmitted to the output selected by the input address. The truth table for this function is shown in **Table 1**.

Similarly, msi functions can be built from sequential elements. **Figure 7** illustrates this point with the circuit of a four-bit shift register. Data on the inputs is loaded into the flip-flops when the shift/load signal is low and there is a low-to-high clock transition. When shift/load is high, the data is moved one place to the right on a clock edge. This circuit can form the basis of some arithmetic functions, or it may be used in communications to change the data format from parallel to serial or *vice versa*.

A different type of flip-flop, the J-K flip-flop, is used in the counter circuit in **Fig. 8**. A J-K flip-flop behaves like a D-type when the J and K inputs are complementary, but if both are high, the output changes from high to low, or low to high, the so-called toggle function. If both are low, no change occurs on a clock edge; the output data is unchanged, the hold condition. As long as the count enable, CE, and reset inputs are held high, the counter function will increment by one on each clock transition.

Taking the reset low makes every output low, resetting the counter to binary $0000_2$. Reset is an asynchronous function which is built into some flip-flops; it operates independently from the clock and allows the flip-flop to be put into a known condition. Some flip-flops also include an asynchronous set input which puts the output high.

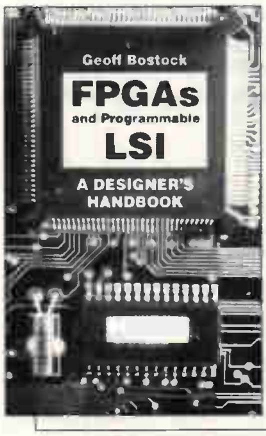
Operation of the counter may be described by a state diagram. Each combination of output levels corresponds to a binary number from $0000_2$ $(0_{10})$ to $1111_2$ $(15_{10})$, and represents a distinct state of the counter. **Figure 9** shows the counter state diagram. Each state is represented by a circle containing the output levels in that state. The arrows are labelled with the logic inputs which enable the jumps between states. A recursive arrow means that there is no jump and gives the hold condition for that state.

The CE must be true for counting to proceed: if CE is false, the counter holds its present state.

Many sequential functions are best described by a state diagram, just as combinatorial functions are often defined in a truth table. ■

In the next article, Geoff takes a more in-depth look at programmable logic elements.

This article is derived from Geoff Bostock's new book 'FPGAs and programmable LSI – a designer's handbook'. This work covers designing FPGAs, large PAL structures, RAM and antifuse-based FPGAs and FPGA selection. Comprising 215 pages, this book is available by sending a postal order or cheque with a request for the book to Electronics World, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. The fully-inclusive price is £27.50 UK, £30 Europe or £33 rest of world. Alternatively, fax your full credit card details and address on 0181 652 8956 or e-mail jackie.lowe@rbp.co.uk.



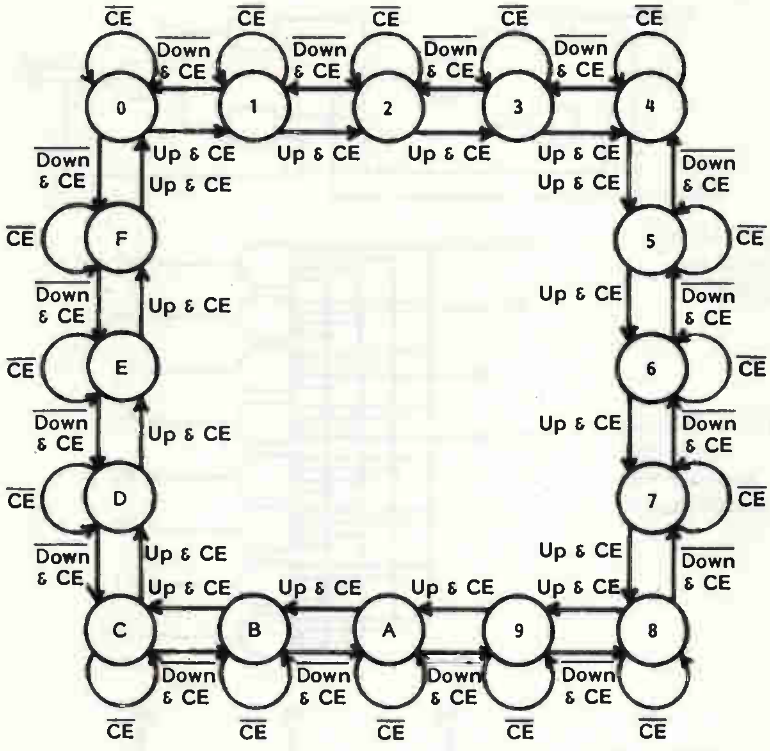




*Fig. 9. Four-bit counter state diagram.*

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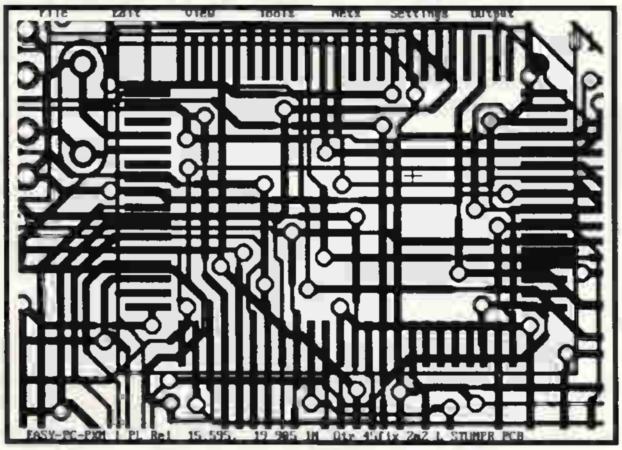

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# Designing power supplies

**Ray Fautley describes an easy-to-use procedure for designing reliable full-wave rectifiers of the centre-tapped secondary variety.**

In this version of the full-wave rectifier, the bridge rectifier is simplified to two diodes, but the transformer needs a centre tap, which becomes the ground connection.

Alternating voltage is applied to rectifier diodes $D_{1,2}$ where it is rectified and the output smoothed by reservoir capacitor $C$.

Fundamental frequency of the ripple voltage is twice that of the supply frequency. Resistance $R_s$ represents the source of the supply and $V_{sec}$ is the voltage across the whole of the secondary winding.

## Design procedure

1) Specify required dc output voltage at full load $E_{dc(load)}$ (V).
2) Specify required maximum load current $I_{dc(load)}$ (A).
3) Specify maximum voltage ripple acceptable $V_{r(rms)}$ (V).
4) Specify the ac mains supply voltage $V_{pri(rms)}$ (V).
5) Specify the frequency of the mains supply $f$ (Hz).
6) Determine the value of the equivalent load resistance $R_L$:

$$R_L = \frac{E_{dc}}{I_{dc(load)}}$$

where $E_{dc}$ is the design value of the dc output voltage. It is the required voltage across the load, $E_{dc(load)}$, added to the voltage drop across one of the diodes. As the voltage drop across the diodes occurs only while they are conducting, and they conduct alternately, the effective drop is that of just one diode.

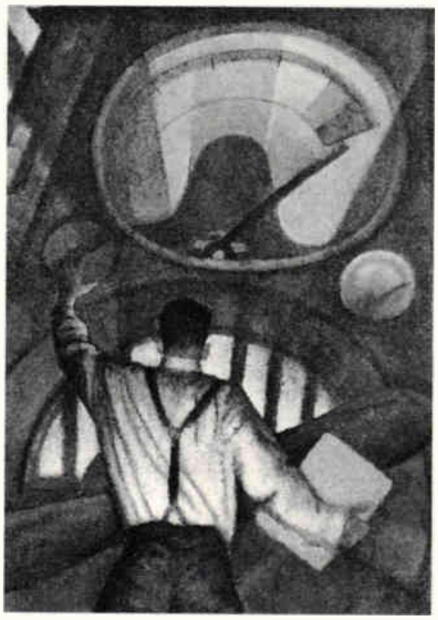
$$E_{dc}=E_{dc(load)}+V_{rec}$$

where $V_{rec}$ (the drop across the rectifier diode) is 0.9V, so:

$$R_L = \frac{E_{dc(load)}+0.9}{I_{dc(load)}}$$

7) Determine average current through each diode. Half the average current, $I_o$, will flow through each diode.

$$I_o=I_{dc(load)}/2$$



8) Determine a value for source resistance of the supply, $R_s$. If the mains transformer winding resistances are known – and it rarely is – refer to step 8 in the design preocedure the the full-wave rectifier (September 1996 issue) for the method of evaluating $R_s$. Otherwise, assume that $R_s$ is about 5% of $R_L$. Then for low resistance loads:

$$R_s = \frac{R_L \times 5}{100} + \frac{0.9}{I_o}$$

For high resistance loads, where the transformer winding resistance predominates:

$$R_s = \frac{R_L \times 5}{100}$$

9) Calculate the ratio of $R_s$ to $R_L$ as a percentage:

$$\frac{R_s}{R_L} \times 100\%$$

10) Determine percentage ripple voltage from the specified maximum ripple and the dc output voltage:

*Full-wave rectification using a transformer with centre tap needs two fewer diodes than the full-wave bridge rectifier.*

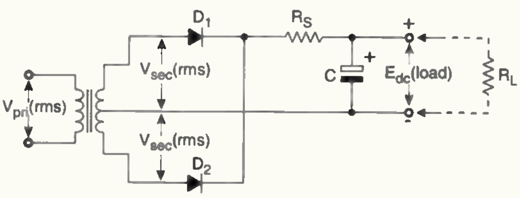


*Table 1. Finding the value for X.*

| $V_r$% | $R_S/R_L$% 0.1 | 0.3 | 1.0 | 3.0 | 5.0 | 10 | 30 |
|---|---|---|---|---|---|---|---|
| 0.1 | 771 | 740 | 709 | 646 | 614 | 583 | 463 |
| 0.2 | 381 | 368 | 354 | 324 | 309 | 294 | 233 |
| 0.3 | 257 | 247 | 237 | 218 | 208 | 199 | 158 |
| 0.4 | 195 | 188 | 177 | 162 | 154 | 147 | 120 |
| 0.5 | 154 | 148 | 141 | 129 | 122 | 116 | 95 |
| 0.6 | 128 | 123 | 117 | 108 | 103 | 98 | 81 |
| 0.7 | 110 | 106 | 102 | 94 | 89 | 85 | 69 |
| 0.8 | 97 | 93 | 88 | 81 | 77 | 74 | 61 |
| 0.9 | 86 | 82 | 78 | 72 | 68 | 65 | 54 |
| 1.0 | 78 | 75 | 71 | 65 | 62 | 59 | 49 |
| 2.0 | 38 | 37 | 36 | 33 | 31 | 30 | 25 |
| 3.0 | 26 | 25 | 24 | 22 | 21 | 20 | 16 |
| 4.0 | 19 | 19 | 18 | 17 | 16 | 15 | 12 |
| 5.0 | 15 | 15 | 14 | 13 | 12.5 | 12 | 10 |
| 6.0 | 13 | 12 | 12 | 11 | 10.5 | 10 | 8 |
| 7.0 | 10.6 | 10.3 | 9.9 | 9.2 | 8.8 | 8.5 | 7.0 |
| 8.0 | 9.1 | 8.8 | 8.5 | 8.0 | 7.7 | 7.4 | 6.0 |
| 9.0 | 8.0 | 7.7 | 7.5 | 7.0 | 6.7 | 6.5 | 5.3 |
| 10 | 7.1 | 7.0 | 6.8 | 6.4 | 6.1 | 5.9 | 4.9 |
| 20 | 2.9 | 2.8 | 2.7 | 2.6 | 2.5 | 2.4 | 2.2 |
| 30 | 1.6 | 1.6 | 1.5 | 1.5 | 1.4 | 1.4 | 1.2 |
| 40 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 |

$$V_r\% = \frac{V_{r(rms)}}{E_{dc(load)}} \times 100\%$$

11) From the figures in **Table 1**, determine the value of $X$ required to provide the percentage ripple voltage, $V_r$% in step 10) above, for $(R_s/R_L)$% calculated in 9).

12) Calculate reservoir capacitor $C$, required to provide the ripple voltage $V_{r(rms)}$ from:

$$C = \frac{X(10^6)\mu F}{2\pi f R_L}$$

The term used for frequency is $f$ and not $2f$ (the ripple frequency in a full-wave centre-tap rectifier circuit being twice the supply frequency) because the figures in Table 1 allow for the difference.

13) Find the nearest standard (or available) value for the reservoir capacitor $C$, close to (preferably just above) the value calculated in step 12). If the value of the capacitor is different from that in 12), call it $C_1$ and determine a new value for $X$ (call it $X_1$) from:

$X_1=2\pi f C_1 R_L$

with $C_1$ in μF,

$$X_1 = \frac{2\pi f C_1 R_L}{10^6}$$

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

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

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

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

*Table 2. Finding the Value of Y*

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

$$= \frac{0.707 \times E_{dc}}{Y}$$

Voltage $V_{sec(rms)}$ is only half the required secondary voltage of the transformer, which has a centre-tapped winding. So the *total* secondary winding will be:

$V_{sec(rms)}$–0–$V_{sec(rms)}$

16) Determine the peak voltage (or PIV, peak inverse voltage) that each of the rectifier diodes must withstand.

$PIV=2\times V_{sec(peak)}=2\times\sqrt{2}\times V_{sec(rms)}$
$=2.828V_{sec(rms)}$

The factor 2 occurs because each rectifier diode has both halves of the secondary winding in series applied in alternate half cycles.

17) Find the value for $Z$ from **Table 3** for $2X$ (or $2X_1$), where $X$ was found in step 11), or $X_1$ in step 13), and for $(R_s/2R_L)$%. The value for $(R_s/R_L)$% was found in step 9).

$Z=I_{(rms)}/I_o$

18) From the value of $Z$ found in step 17), determine current through each rectifier diode:

$I_{(rms)}=I_o\times Z$

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

Thus find $I_{(peak)}=I_o\times W$.

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

$$I_{on} = \frac{V_{sec(peak)}}{R_s}$$

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

21) Decide on a suitable rectifier diode type to be used. The device must have *all* its ratings equal to, or greater than, the following:

*PIV* or $2\times V_{sec(peak)}$ (sometimes $V_{RRMT}$) see step 16)

Initial switch-on current or $I_{on}$ (sometimes $I_{FSMT}$), see step 20)

Average current or $I_o$ (sometimes $I_{F(AV)}$), see step 7)

*Table 2 continued.*

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

22) Determine rms ripple current $I_{c(rms)}$, flowing through reservoir capacitor $C$ (or $C_1$):

$$I_{c(rms)} = \sqrt{2(I_{rms}^2) - (I_{dc(load)}^2)}$$

for $I_{(rms)}$, see step 18), and for $I_{dc(load)}$, see step 2).

23) Decide on the specification for the reservoir capacitor to be used. The capacitor must have ratings equal to, or greater than, the following:

Capacitance $C$ (or $C_1$) see step 12) or 13)

DC working voltage $V_{sec(peak)}$, step 16)

Ripple current $I_{c(rms)}$, step 22)

24) Total transformer secondary current $I_{t(rms)}$ is the same as the current through each diode, $I_{rms}$, i.e. $I_{t(rms)}=I_{rms}$.

25) Transformer VA (or volt-amp) rating $T_{VA}$ for each half of the secondary winding is: $V_{sec(rms)} \times I_{t(rms)}$ so total VA, $T_{VA}=2 \times V_{sec(rms)} \times I_{t(rms)}$. This determines the size of the transformer.

26) Transformer requirements are:

Volt-amp rating $T_{VA}$, see step 25)

Primary winding $V_{pri(rms)}$, step 4)

Secondary winding $V_{sec(rms)}$–0–$V_{sec(rms)}$, see step 15)

Secondary current $I_{t(rms)}$, step 24)

*Table 3. Finding the value for Z.*

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

27) When a suitable transformer has been chosen, measure resistance of *half* of the total secondary winding and the resistance of the primary winding. If the measured source resistance:

$$R_{s(m)} = \frac{R_{sec}}{2} + \frac{R_{pri}}{N^2} + R_{rec}$$

is *less* than $R_s$ calculated in step 8), then an external resistor:

$R_{ext}=R_s-R_{s(m)}$

must be added, see step 28), to limit $I_{on}$ to the value found in 20). For low resistance loads, it is unlikely that any external resistance will be necessary as the diode resistance $R_{rec}$ will tend to limit the switch-on current rather than the resistance of the transformer windings.

28) If an external resistor $R_{ext}$ was found necessary in step 20) or 27) to be fitted between the rectifiers and reservoir capacitor $C$ (or $C_1$) to limit the switch-on current to a lower level $I_{on(L)}$, its value will be:

$$R_{ext} = \frac{V_{sec(peak)}}{I_{on(L)}} - R_s$$

29) Power dissipated in $R_{ext}$ (if used) is given by:

$P_r=[I_{t(rms)}^2] \times R_{ext}$

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

30) If an external resistor $R_{ext}$ is used the regulation of the supply can be

improved by the addition of a shorting-out device as recommended for the bridge rectifier circuit in the September issue.

## Putting the procedure to work

Now for the worked example. A supply of 1200V at 0.5A is required for a valve rf power amplifier. An acceptable ripple on the supply would be 12V rms.

1) $E_{dc(load)}$=1200V
2) $I_{dc(load)}$=0.5A
3) $V_{r(rms)}$=12Vrms
4) $V_{pri(rms)}$=240Vrms
5) $f$=50Hz
6) $$R_L = \frac{E_{dc}}{I_{dc(load)}} = \frac{E_{dc(load)} + V_{rec}}{I_{dc(load)}}$$

As $V_{rec}$ is only 0.9V it can be ignored. So,

$$R_L = \frac{E_{dc}}{I_{dc(load)}} = \frac{1200}{0.5} = 2400\Omega$$

7) $$I_o = \frac{I_{dc(load)}}{2} = \frac{0.5}{2} = 0.25A$$

8) $$R_s = \frac{2400 \times 5}{100} = 120\Omega$$

9) $$\frac{R_s}{R_L} \times 100\% = \frac{120}{2400} \times 100\% = 5\%$$

10 $$V_r\% = \frac{V_{r(rms)}}{E_{dc(load)}} \times 100\%$$

$$= \frac{12}{200} \times 100\% = 1\%$$

11) Find the value of $X$ for $V_r$% and $(R_s/R_L)$%, i.e.

$$V_r\% = 1 \text{ and } \frac{R_s}{R_L} = 5$$

from Table 1 is found to be 62.

12) $$C = \frac{X(10^6)}{2\pi f R_L}\mu F = \frac{62 \times 10^6}{2\pi \times 50 \times 2400}\mu F$$

$$= 82.2\mu F$$

13) To obtain a high enough voltage rating for the reservoir capacitor, four capacitors connected in series are necessary. Four 330μF, 385V working-voltage capacitors would be suitable A resistor of about 100kΩ (2W rating) should be connected across each of the four capacitors to equalise the dc voltage across each capacitor.

14) From Table 2, the value of $Y$ for $X$ and $(R_s/R_L)$%, i.e. X=62 and $(R_s/R_L)$%=5, is found to be 0.84.

15) $$V_{sec(rms)} = \frac{0.707 \times E_{dc}}{Y} = \frac{0.707 \times 1200}{0.84}$$

$$= 1010V_{rms}$$

Total secondary winding will be: $V_{sec(rms)}$-0-$V_{sec(rms)}$ or 1010V-0-1010V.

16) $PIV$=2.828$V_{sec(rms)}$=2.828×1010=2856V

17) From step 11), $X$ = 62 and from step 9), $(R_s/2R_L)$%=5. Find the value of $Z$ for 2$X$ and for $(R_s/2R_L)$%, i.e.

$$2X = 2 \times 62 = 124 \text{ and } \frac{R_s}{2R_L} = \frac{5}{2} = 2.5,$$

which from Table 3 is found to be 2.64.

18) From step 17), $Z$=2.64 and from step 7), $I_o$=0.25A, so,

$I_{(rms)}$=$I_o$×$Z$=2.64×0.25=0.66A

19) From step11), X=62 and from step 9), $(R_s/R_L)$%=5 so the value of $W$ for 2$X$ and $(R_s/2R_L)$%, where 2X=124 and $(R_s/2R_L)$%=2.5, from Table 4 is found to be 7.92. As a result,

$I_{(peak)}$=$I_o$×$W$=0.25×7.92=1.98

20) $$I_{on} = \frac{V_{sec(peak)}}{R_s} = \frac{1.414V_{sec(rms)}}{R_s}$$

$$= \frac{1.414 \times 1010}{120} = 11.9A$$

21) Diode ratings required are,

$PIV$($V_{RRMT}$)=2856V

$I_{on}$($I_{FSMT}$)=11.9A

$I_o$($I_{F(ave)}$)=0.25A

To obtain a $PIV$ of 2856V it would be necessary to wire three BYX38-1200 diodes in series for each of the two diodes required.

22) $$I_{c(rms)} = \sqrt{2I_{rms}^2 - I_{dc(load)}^2}$$

$$= \sqrt{2 \times 0.66^2 - 0.5^2}$$

$$= \sqrt{2 \times 0.4356 - 0.25}$$

$$= \sqrt{0.6212} = 0.79A$$

23) Reservoir capacitor ratings required are,

$C$=82.2μF

$V_{sec(peak)}$=$V_{dc(wkg)}$=√2×1010=1428V

Ripple current $I_{c(rms)}$=0.79A

Four capacitors in series of 330μF, each with a working voltage of 385V dc would be suitable. To ensure that a quarter of the output voltage appears across each capacitor, a 100kΩ, 3W resistor should be wired across each of them.

24) $I_{t(rms)}$=$I_{rms}$=0.66A

25) Transformer VA
=2×$V_{sec(rms)}$×$I_{t(rms)}$
=2×1010×0.66
=1333.2VA

26) Mains transformer ratings required are,

$T_{VA}$=1333VA

Primary winding $V_{pri(rms)}$=240V rms

Secondary winding $V_{sec(rms)}$
=1010V-0-1010V

Secondary current $I_{t(rms)}$=0.66A

Previous articles in this power-supply design series covered the full-wave bridge rectifier, September 1996 issue, and the half-wave single-diode rectifier, December 1996 issue. A subsequent article will deal with the voltage doubler. ■

***Table 4. Finding the value for W.***

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

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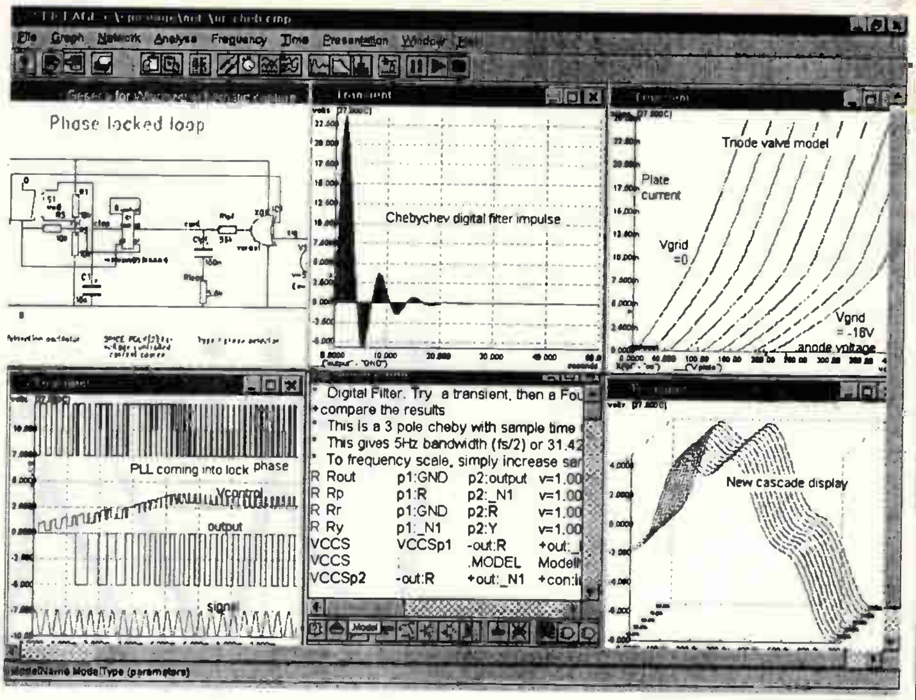


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# Making continuous WAVES

**With the competition for the first patent in wireless telegraphy won by Marconi, a new race began to emerge, to develop radio transmissions into a widely used medium of communication. Few guessed that it would result in the explosion of radio as we now know it. By Tom Ivall and Peter Willis**

Marconi may have secured the world's first patent on wireless telegraphy (*Electronics World*, June 1996) but others were already working on similar systems.

Braun in Germany, for instance, inventor of the cathode-ray oscillograph, developed a spark transmitter in 1898 and had it in service for short-range marine communication by 1900. Later, he and Marconi were to share the 1909 Nobel Prize for Physics in recognition of their radio work.

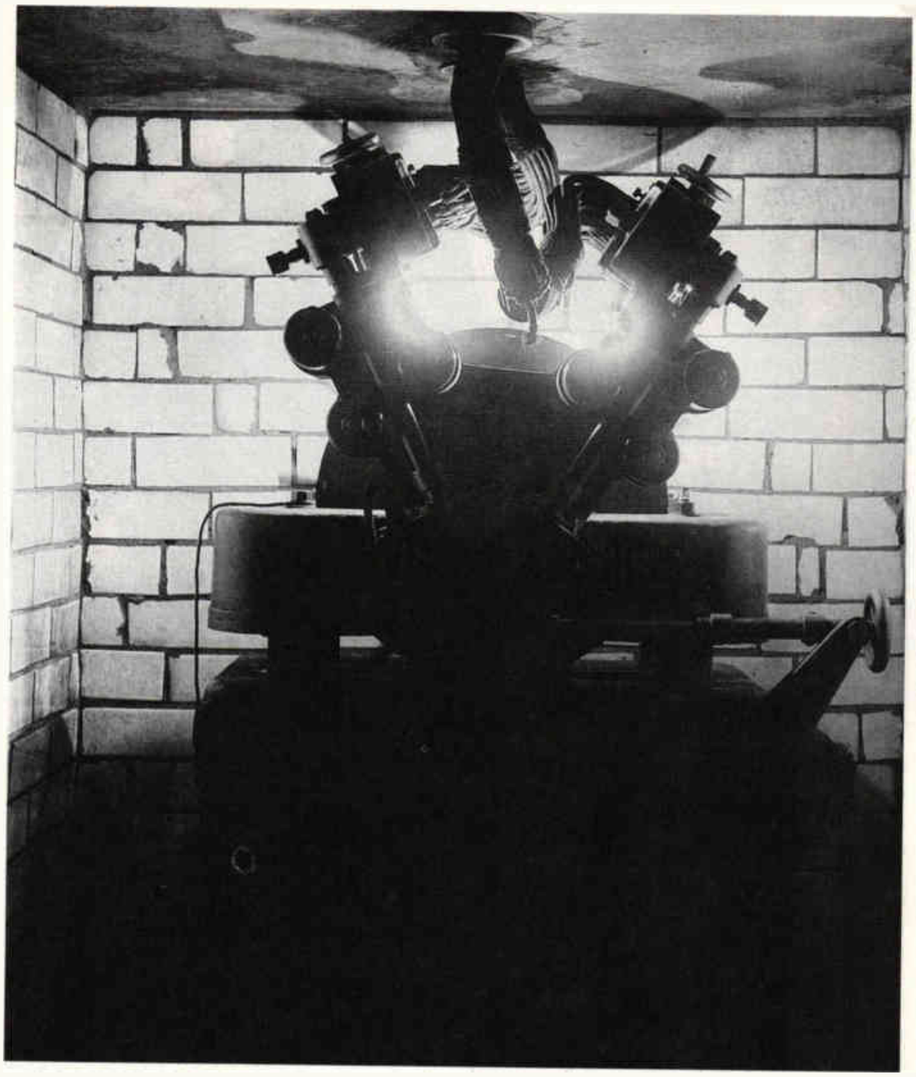
Braun and some business partners formed a wireless company called Telebraun, though this soon became a subsidiary of Siemens. At about the same time, two other German pioneers, Slaby and von Arco, supported by AEG, had set up a competing firm, Funkentelegraphie. In 1903, these two enterprises merged to form Gesellschaft für Drahtlose Telegraphie and the result was the Telefunken system, a formidable rival to that of Marconi. By 1905, it had built more than 500 stations.

Meanwhile, in the USA, Fessenden and de Forest, separately, and the partnerships of Branly-Popp in France and Lodge-Muirhead in the UK, were also developing and operating spark transmitter systems of wireless telegraphy. All were striving for greater communication ranges through more highly powered transmissions and more sensitive receivers. They also wanted much better selectivity, to allow multi-station working without mutual interference.

One way to get more radiated power from a spark transmitter was to increase the oscillatory energy in the *LCR* circuit containing the spark gap. To do this, each high-voltage pulse had to get as much charge as possible into the capacitor. But the induction coil was restrict-

Picture courtesy Barratts

*David Sarnoff, who, in 1916, elaborated on Lodge's early suggestion for broadcasting and outlined the main technical features of the domestic receiver, or "radio music box" as he called it. Then a manager at the American Marconi Company, he rose to become chairman of its successor, RCA. He is seen here on a visit to London in or about 1925.*



*Part of a rotary spark transmitter at Poldhu, Cornwall, as seen, it is claimed, while actually transmitting news of Britain's declaration of war on Germany in 1914.*

ed as a generator because it could inject only short-duration pulses of charge into a low-value capacitor.

So for higher-power transmission the induction coil was soon replaced by the engine-driven alternator, with an output of several kilovolts, plus a step-up transformer providing the necessary tens of kilovolts. This would produce as many as ten sparks, and hence damped wave-trains, per cycle of the alternator output.

As well as producing bigger charges, the alternator system could be designed to generate a relatively high spark frequency, thereby shortening the interval between wave-trains and increasing the average oscillatory energy. And this would give a musical note in receiver headphones which was more easily heard through static (atmospheric) interference than the rasping sounds produced by induction coils.

Radiated power was also increased by tighter inductive coupling between the oscillator and aerial circuits. But to achieve this, the spark had to be quenched rapidly, otherwise the interaction between the coupled circuits would cause beating and radiation on two component frequencies. This spark quenching also had the advantage of reducing arcing in fixed spark gaps. Rotary spark gaps or dischargers, driven from the alternator shafts, had the double purpose of preventing arcing and producing very regular, audible wave-train frequencies.

In the receiver, the coherer was too insensitive for long-range working and was difficult to operate. New detection techniques were invented and put into use, including anti-coherers, electrolytic and thermal principles, magnetic effects in an iron or steel medium, and rectification at contacts between crystals or between metals and crystals. Magnetic detectors proved robust in operation and were widely used.

In 1904, Fleming invented the thermionic diode, based of course on the Edison Effect, which had been known since the late 19th century. The diode, however, did not immediately supersede the earlier devices but was used as a standby detector. Two years later, de Forest put in a third electrode, the grid, and produced the thermionic triode, or Audion as he called it. It was intended as a triggering form of detector but was not particularly successful as such. Only after years of development, on the device itself and on circuit applications, did the triode become really useful – but as an amplifier and oscillator. Subsequently, the non-linear parts of the amplifier characteristic were used for detection.

Even the earliest improvements in transmitters and receivers produced good operating results. The most dramatic was Marconi signalling across the Atlantic in 1901-02. Apart from the commercial implications, this supported early ideas of a reflecting layer and Heaviside's and Kennelly's 1902 prediction of the ionosphere, though the existence of the various layers was not fully confirmed till the 1920s. Transatlantic wireless telegraphy was also achieved by Fessenden, between Brant Rock, Massachusetts, and Macrihanish, Scotland, in 1906, and the following year Marconi started a full commercial service with stations at Clifden, Ireland, and Glace Bay, Canada.

By this time, radio was already well established for marine communications. It had started in 1897 with fixed links such as those between the mainland and islands, lighthouses, lightships and moored vessels, and progressed to mobile communications with small ships such as ferries. The use of Morse code was universal.

During the first five years of the new century, large passenger vessels and warships were being equipped, and by 1911 wireless was compulsory on all ocean-going liners. In this first decade, several thousand lives were saved at sea through the use of radio.

Even before the wireless telegraph was fully established as a universal service, engineers were thinking about wireless telephony. They knew they needed continuous waves in place of damped wave-trains, and a means of modulating them with voice frequencies.

A short-lived proposal was to speed up the spark repetition rate to something above audible frequencies. But this idea was soon overtaken by two techniques which proved successful for nearly a decade, before the arrival of the triode valve oscillator made them obsolete. These were the multipole rf alternator, developed by Tesla and Alexanderson, and the Poulsen oscillatory arc, based on Duddell's 'singing arc' of 1900. The arc conduction process in hydrogen gas interacts with a series *LC*

Picture courtesy Marconi

*Music recital in 1922 from the 2LO broadcasting studio in London. Miss Olive Sturgess sings into a carbon-granule telephony hand microphone fixed in a laboratory-style clamp, raised to the required height on a decorative pot stand. Also singing is Mr John Huntingdon, while the accompanist in spats is Mr R Stanton Jefferies.*

circuit shunted across the electrodes, so that the dc flowing through the arc varies in a periodic manner at rf.

The alternator, typically working at 30kHz, was the more stable and controllable generator, while the arc was smaller and cheaper. But both had the problem that they couldn't be voice-modulated at low level – the carbon granule microphone had to be inserted in the rf power circuits, either directly in series or by inductive coupling. This, of course, limited the rf power that could be generated and hence the transmitter range.

Nevertheless, in 1902 voice transmission was achieved, by Fessenden, and in 1906 demonstrations of radiotelephony were given almost simultaneously in the USA, Germany and Denmark. The advantages of voice communications over telegraphic signals were quickly recognised, particularly by the armed forces, and warships were the first to be equipped.

Civil applications were not far behind, and these were not limited to speech communication. After music had been transmitted on an rf alternator system in 1906 and Caruso had sung over a radio-telephone in 1910, thoughtful people began to realise that the new technology could do somewhat more than convey messages from point to point. After all, music concerts and lectures had already been distributed to subscribers over wired systems, the precursors of cable radio, in the 1890s.

Under the stimulus of the 1914-18 World War, the high-vacuum triode valve was developed into a robust and reliable device, capable of being manufactured in quantity. It now had a good amplification factor and, as a result of Meissner's 1913 positive feedback circuit invention, had emerged as a new means of generating continuous oscillations, though at low frequencies.

Radio-telephone transmitters using valve oscillators began to appear. In 1913-14, speech and music were transmitted from Marconi House in London, and in 1915 the Atlantic was spanned by speech from a naval station at Arlington, USA, to the Eiffel Tower in Paris.

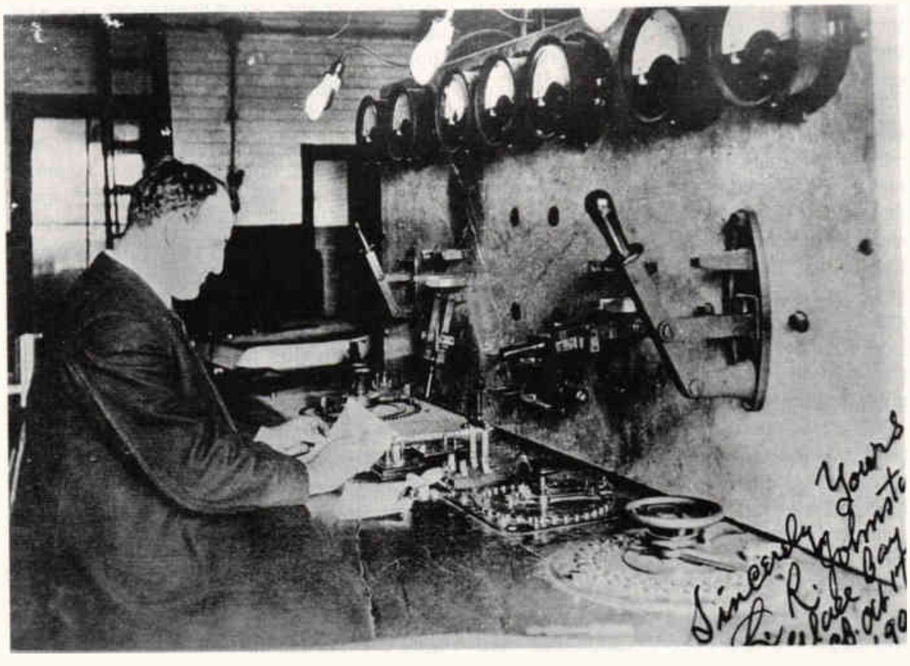
Triode valves were also coming into receivers. The idea of cascading several valve stages to give higher amplification appeared about 1912. Then Armstrong and others showed how the positive feedback principle could be used to reinforce the signal and improve selectivity – the technique of regenerative amplification, later called reaction. Fessenden had demonstrated the heterodyne principle in 1902 (already discovered acoustically as beats or 'resultant tones' by the 18th-century musician Tartini) and this eventually resulted in Armstrong's famous invention of the supersonic heterodyne or superhet receiver.

The wideband fm which Armstrong eventually developed in the 1930s was the outcome of his and others' early studies of the ever-present static interference on am radiotelephony.

So thermionic valves became the basis of radio-telephony. The extension of point-to-point radio-telephony into broadcasting, already foreshadowed by the isolated experiments mentioned above, came about almost accidentally. Oliver Lodge was the first to suggest the idea of messages being 'broadcast to receivers in all directions', in 1907. Then in 1916 an employee of the American Marconi Company, David Sarnoff, not only predicted broadcasting more firmly but suggested its main elements: transmitting stations and what he called a "radio music box" for the home.

"This device must be arranged to receive on several wavelengths with the throw of a switch or the pressing of a button," said Sarnoff. "The radio music box can be supplied with amplifying tubes and a loudspeaking telephone, all of which can be neatly mounted in a box."

The plan was still under consideration when




*The North American end of Marconi's transatlantic radio-telegraphy link was at Glace Bay, Nova Scotia. This signed memento shows operator L R Johnstone transmitting the inaugural message in October 1907, when the commercial service started.*

the USA entered the World War in 1917. After the war, American Marconi was merged with General Electric at the insistence of the US government, which required wholly US ownership. The resulting company, with a rich crop of wireless patents to exploit, was the Radio Corporation of America (RCA), and Sarnoff was eventually to become its chairman.

Regular broadcasting actually started from the US station KDKA in Pittsburg. In 1919, Westinghouse, while testing the range of a radio-telephone transmitter, decided to play some gramophone records of music as an alternative to speech. By this time, wireless enthusiasts were building crystal sets. Many of them liked what they heard and wrote to the company asking for more.

As a result, and after a well appreciated broadcast of election results, Westinghouse started regular programmes in 1920, with the idea that KDKA would create a market for radio components and receivers – which in fact it did. In the same year, regular broadcasts began in Europe from The Hague.

In the UK, the accidental birth of broadcasting came about in a similar way. At the Marconi company, the standard method of range-testing transmitters was to read out the names of railway stations from timetables. These were eagerly received by numerous amateur enthusiasts on home-built sets. To mark the introduction of a new transmitter in 1920, something less mind-numbing was devised – a concert featuring staff and local artistes, with three instrumentalists and two singers.

Despite appreciative letters from hundreds of miles away, the company persisted in its view that the future of radio lay in speech transmission, and that the purpose of broadcasts was to demonstrate the comparative ease with which messages could be exchanged. Accordingly, it substituted news transmissions for the concerts.

In June 1920, however, the firm was persuaded to transmit from Chelmsford a recital by the operatic soprano Melba. One consequence of the success of this event – gramophone recordings were made of the reception at the Eiffel Tower – was that the Post Office withdrew Marconi's experimental licence on the grounds of "interference with legitimate services".

This happened just as commercial broadcasting and the mass production of receivers were beginning to take off in the USA. It was not until 1922 that the Post Office relented and permitted Marconi's to transmit at low power, within its existing half-hour-a-week, a 15-minute programme of speech and music.

The station set up to exploit this opportunity was housed in a wooden hut at Writtle, near Chelmsford. Its call sign was 2MT and the cheerful informality of its amateur entertainments immediately endeared it to its listeners. Transmission, initially on 700m and later on 400m, was from a 250ft-long four-wire aerial at a height of 110ft.

A second permit quickly led to another station, the more famous 2LO, being established at Marconi House, London. Transmissions, still nominally demonstrations, were permitted first at 100W then later at 1.5kW for one hour daily on 360m.

Before 1922 was out, this had become the British Broadcasting Company, set up at the Post Office's instigation by a consortium of manufacturers including Marconi. Revenue came from a 10% levy on all receivers sold, plus half of the 10-shilling (50p) receiver licence.

Regional stations were set up quickly. The 2LO London station was reconstituted as purpose-built studios at 2 Savoy Hill and a 6kW transmitter on the roof of Selfridge's department store.

The BBC parted company from the set-makers in 1926 and in 1927 became a public-service organisation, established under Royal Charter as the British Broadcasting Corporation.

Throughout all this, spark transmissions continued to be allowed and were not internationally prohibited until 1940. ■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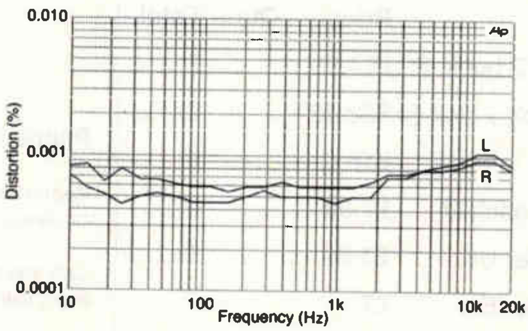


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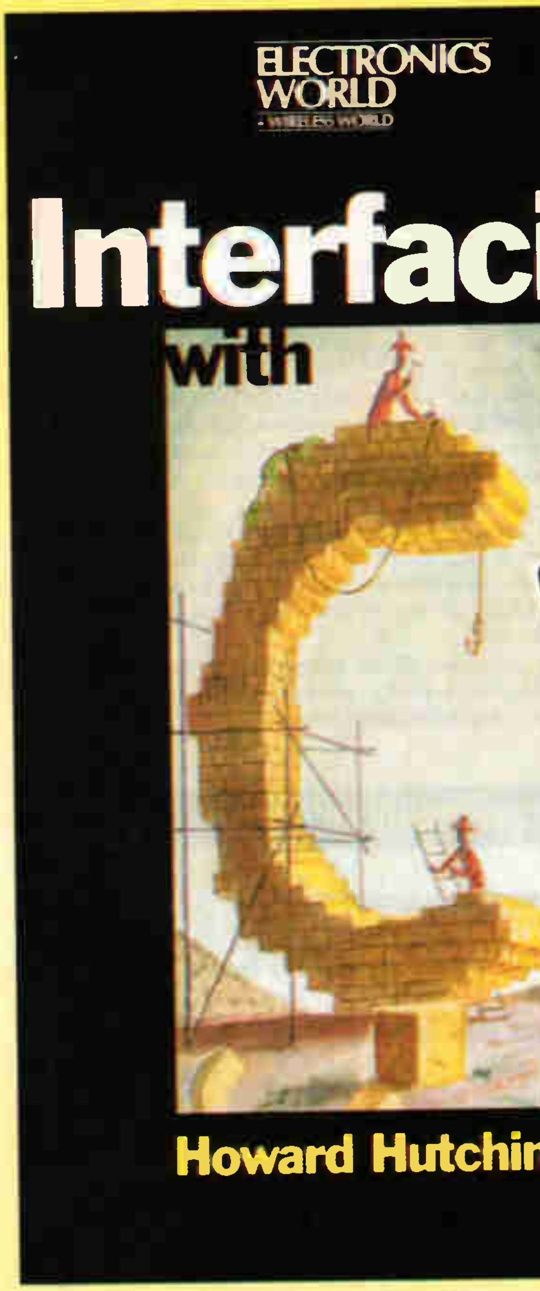


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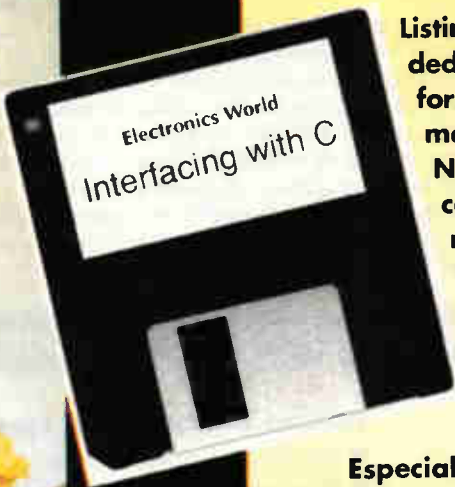


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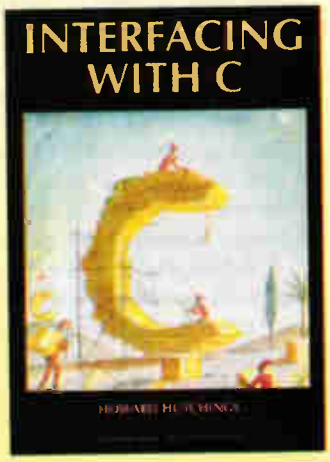


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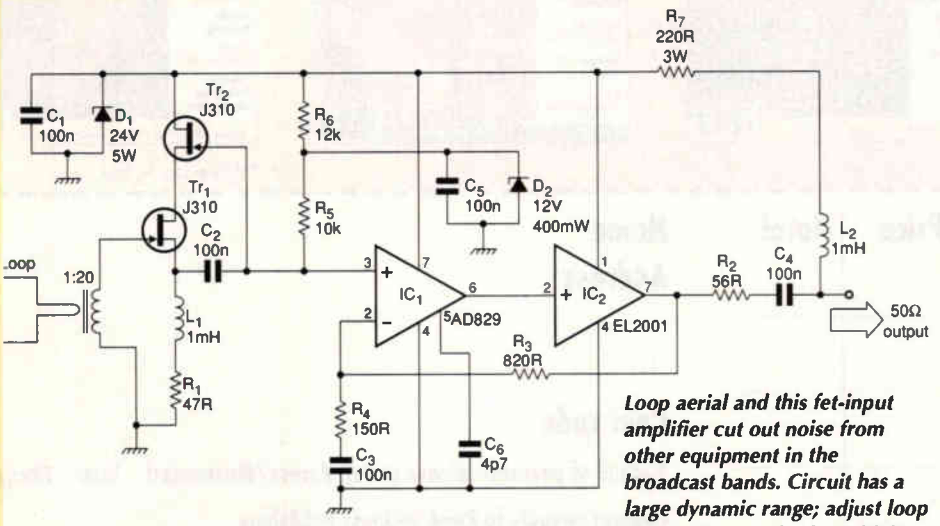
To allow the reception of long and medium waves in an environment polluted with computers and television receivers, this loop aerial and its amplifier, working with a 1m square maximum loop, reduce noise to the background level of the bands.

The business end of the circuit is formed by the input transformer and fet source follower; at long- and medium-wave frequencies, fets show low noise figures at 10kΩ source impedance. Transistor $Tr_2$ bootstraps out the gate/drain capacitance of $Tr_1$, the gate/source capacitance being low due to the follower configuration.

Maximising input transformer ratio while keeping shunt capacitance low results from the use of a toroid (*Cirkit* 55-40001 or *Fair-Rite* 26-43540001) with two primary turns of audio screened cable with the screen grounded at one end, and 40 on the secondary.

The op-amps form a low-noise amplifier driving a 50Ω cable and the other components form a phantom power supply, although a local supply could be used, in the 25-40V range.

*J A Burnill*
*Camberley, Surrey*




*Loop aerial and this fet-input amplifier cut out noise from other equipment in the broadcast bands. Circuit has a large dynamic range; adjust loop size to give required sensitivity.*

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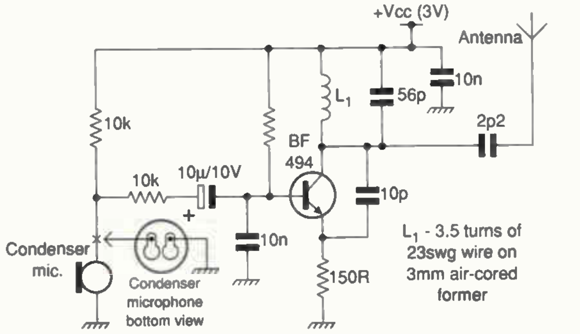
# One transistor fm microphone



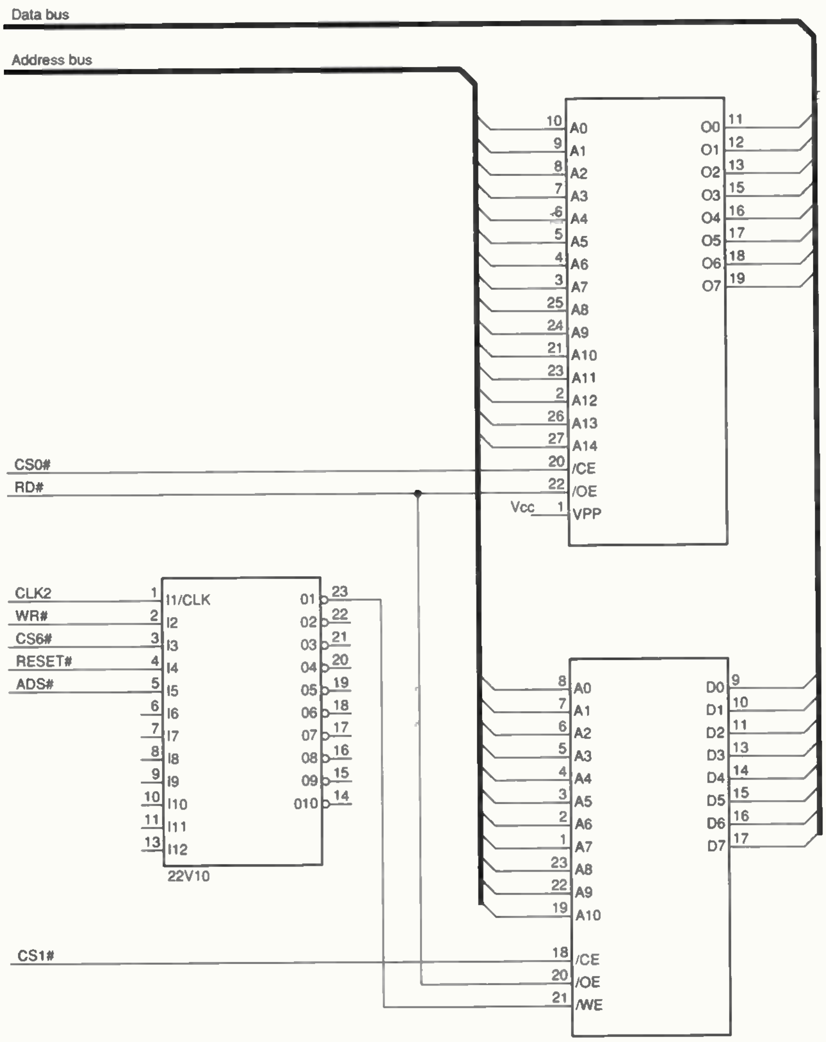

Running from two penlight cells, this sensitive fm microphone has a transmission range of around 6m. Lengthening the antenna could increase this to 30m.

Due to $L_1$, the *BF494* transistor oscillates in addition to amplifying the signal from the piezo microphone. Once the circuit is operational, tune an fm radio around100MHz until the noise quiets.

***R J Gorkhali***
*Kathmandu*
*India*

***In this fm microphone, one transistor doubles as an audio amplifier and transmitter oscillator.***

# Write protect for 386EX architectures




***In this example, part of a circuit for write protecting memory in 386 systems, /CS0 enables the eprom, /CS1 enables the ram and /CS6 defines the write-protect address range.***

In system designs using an embedded processor, it is often useful to include a 'write-protect' circuit for part of the read/write memory. This may be to safeguard configuration parameters, or simply for debug purposes.

However, it is difficult to predict exactly which areas of ram will need to be protected, and ideally the protected area should be configurable by software, so the design can be problematic.

This circuit is a mechanism for a versatile write-protect system which may be implemented in almost any design using the Intel *386EX* processor. It can often be included without adding to the component count.

Intel's *386EX* processor includes a powerful chip select unit (csu) which may be programmed to provide fully decoded address blocks for memory or i/o devices; it has seven independent outputs, so most designs will not need to use them all.

In addition, the csu allows more than one output to be active during any bus cycle, although this would normally be avoided to prevent address-decode clashes. It is therefore a simple matter to gate the processor's /WR line with a spare csu output before feeding it to the memory subsystem. This csu output is then programmed to be active only when a block of ram which is to be write protected is simultaneously addressed (in the normal way) by a different csu output.

The write protected area may then be set to cover any memory address range, subject only to the limitations of the csu itself, and it may be enabled, disabled and reprogrammed entirely by software.

The current version of the *386EX* (the 'B' step) has a number of deficiencies, one of which is an insufficient address hold time after /WR is removed. A common method of overcoming this problem is to use a PAL to foreshorten the /WR pulse, often in conjunction with a simple state machine to track the processor 'T' states. Feeding a spare csu output into this PAL is then a convenient way of implementing the write protect mechanism described above.

The diagram shows a simplified extract from a circuit which embodies this function. No doubt the scheme could be adapted to suit other processors which include a similar chip-select unit.

***Roy Bunce***
*Blandford Forum*
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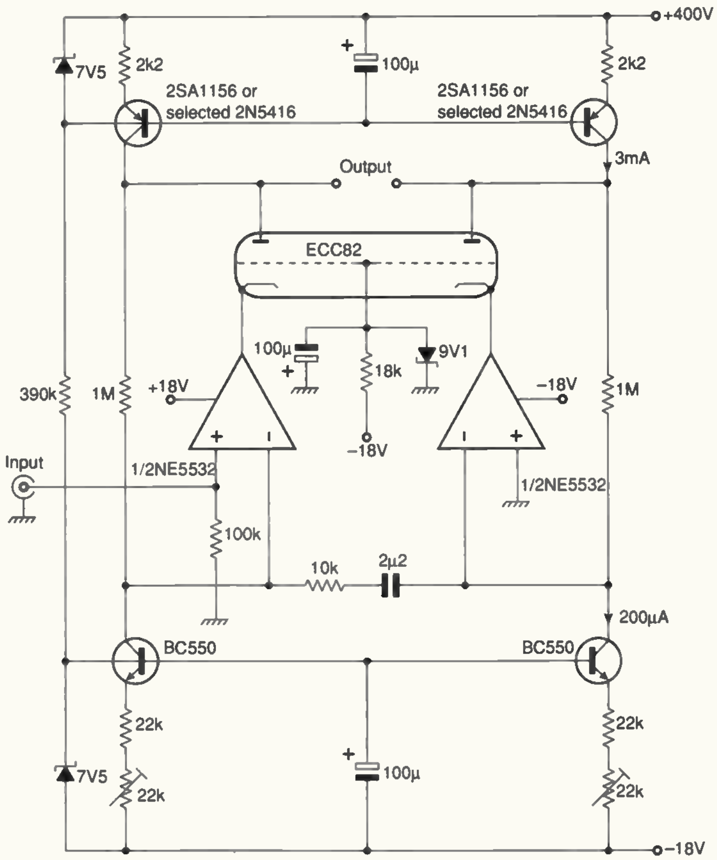


## Hybrid, high-voltage audio amplifier

A high-voltage audio output to drive an electrostatic headphone comes from a double-triode stage, itself fed by op-amps. The whole thereby combines the robustness of valves and the high gain of op-amps.

Common-grid drive to the triodes is the chief peculiarity, chosen to allow the output from the op-amps to be summed for the output and to exploit the greater stability of the configuration over the more usual common-cathode drive – all without loss of bandwidth.

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Output is 200V rms into 200kΩ – or greater from 1V rms input, although gain can be altered by varying the 10kΩ feedback resistor.

***Paolo Palazzi***
*Cervignano*
*Italy*

***High-voltage audio for headphone drive. Variations include a differential input using the non-inverting input of the right-hand op-amp and the use of bigger triodes, with an adjustment in bias voltage.***

## Simple time-out saves batteries

The circuit described here can help you avoid the problem of drained cells in a battery-powered device by breaking the current off after a certain time, determined by an *RC*-circuit.

The circuit is very simple, with only a few components. Transistor $Tr_1$, which breaks the battery current, is a *BS250* p-type enhancement-mode mosfet. When power is turned on, its gate is connected to a negative potential through $Tr_2$ – a *BS170* n-type enhancement mosfet.

Transistor $Tr_2$ turns on when voltage across its gate is positive. This voltage comes from an *RC* circuit formed by capacitor *C* and the resistor $R_2$. At turn on, the capacitor has no charge. During operation, it is charged through $R_2$. Gate voltage of $Tr_2$ goes down as the capacitor charge increases. When the gate voltage reaches the enhancement value of the transistor, it switches off and can no longer supply gate voltage to $Tr_1$. Pull-up resistor $R_1$ connects its gate to source potential and $Tr_1$ breaks the current.

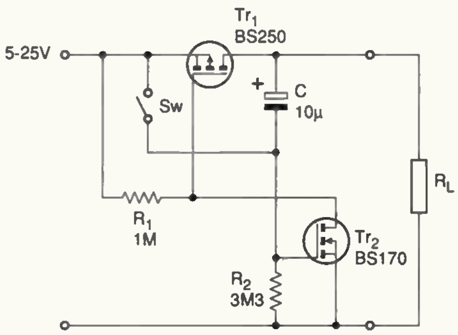
The circuit is released by momentarily closing the switch. The capacitor is discharged and $Tr_2$ has its gate voltage again. $Tr_2$ switches to on-state and gives gate $Tr_I$ a voltage, making it conductive again.

Operating voltage of the circuit ranges from 5V to 25V. The device is well suited for use with common 9V batteries. Operating time of the circuit is approximately twice the time constant $R_2C$ of the circuit, component values shown giving an on time of around a minute. Different values of the enhancement voltage of $Tr_2$ also influence on the operating time. Component values need to be selected if accurate timing is needed.

Transistor *BS250* has an $R_{DSON}$-value of approximately 4Ω, causing a voltage drop in the circuit when loaded. Loading current should not exceed 50mA. Larger loads can be handled by using a more robust transistor instead of *BS250*. For instance, *IRF9530* can easily reach loading currents up to 2A, if desired.

Operating time can be lengthened at any time by simply closing the switch. The capacitor loses its charge and the operating time is renewed to its starting value.

***Rae Perälä***
*Helsinki*
*Finland*




***Simple, time-delayed cut-out avoids the problem of inadvertently draining batteries.***

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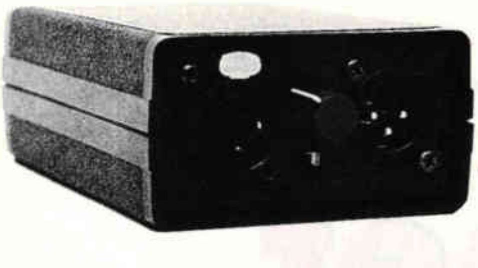

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We have taken the synthesised all mode FRG8800 communications receiver and made over 30 modifications to provide a receiver for rebroadcast purposes or checking transmitter performance as well as being suited to communications use and news gathering from international short wave stations.

The modifications include four additional circuit boards providing *Rechargeable memory and clock back-up *Balanced Audio line output *Reduced AM distortion *Buffered IF output for monitoring transmitted modulation envelope on an oscilloscope *Mains safety improvements.

The receiver is available in free standing or rack mounting form and all the original microprocessor features are retained. The new AM system achieves exceptionally low distortion: THD, 200Hz-6kHz at 90% modulation −44dB, 0.6% (originally −20dB, 10%).

***Advanced Active Aerial 4kHz-30MHz *PPM10 In-vision PPM and chart recorder *Twin Twin PPM Rack and Box Units *Stabilizer frequency shifters for howl reduction *10 Outlet Distribution Amplifier 4 *Stereo Variable Emphasis Limiter 3 *Stereo Disc Amplifiers *PPM5 hybrid, PPM9 microprocessor and PPM8 IEC/DIN −50/+6dB drives and movements *Broadcast Stereo Coders.**

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# Hands-on Internet

**Following an update on searching the net, Cyril Bateman describes his latest Spice discoveries – among them fully working free evaluation packages.**

Internet search engines described in my past columns can be used to locate many different information sources. They are also frequently used for transferring computer software programs, either by an FTP client or your Web browser.

If you know the exact file name you need, FTPSearch in Norway can almost completely automate transfer of files for you. However, if you do not know the file name, the main task becomes one of file name identification.

While Archie, discussed in the April 1996 issue, can perform searches using wildcard characters, and Wais can also help, many users who now rely almost totally on Web browser access do not have these packages. Search engines such as Alta Vista, using appropriate keywords, can be successful, but correctly identifying unknown software file names can prove difficult even for experienced Web surfers.

David Agbamu's home page on Demon[1] is dedicated to helping to solve exactly this problem. By identifying suitable search methods and providing dedicated links, the task is simplified. His page simply and effectively combines the essential information covered in the relevant FAQ documents with direct access to Internet sources – all by simply using your Web browser. David's section on using e-mail for file transfers is particularly helpful, **Fig. 1**.

If you need to identify a UK or European Business and you prefer to use the conventional Yellow Pages telephone direc-

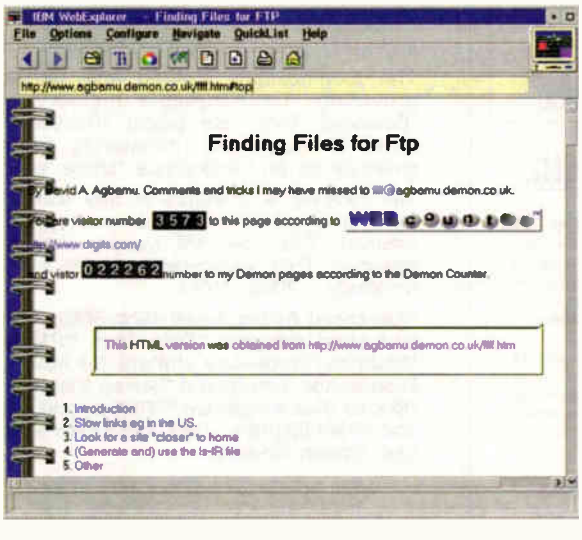


*Fig. 1. A well planned route to Ftp file name Identification.*

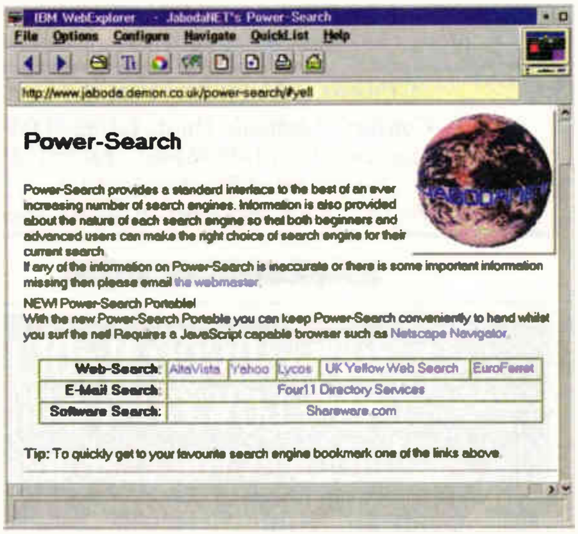


*Fig. 2. Choose the most appropriate search method – use Power-Search – a uniquely English approach to Internet searches.*

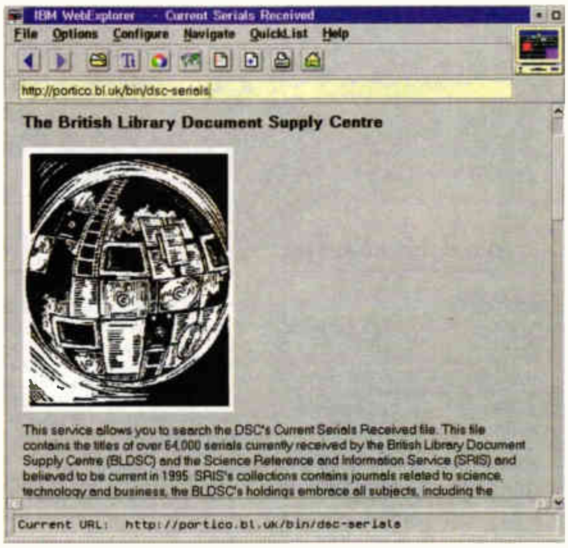


*Fig. 3. The British Library Periodicals Holding on-line service. Deeper level searches are chargeable.*

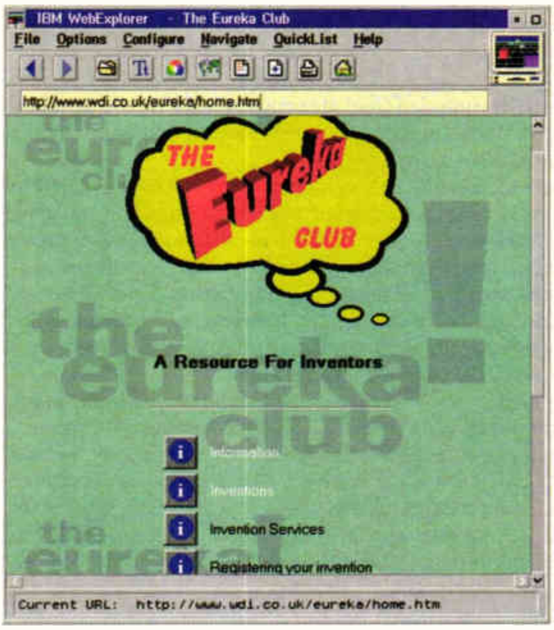


*Fig. 4. On-Line Inventors Club. Mix and Match for inventors and manufacturers.*

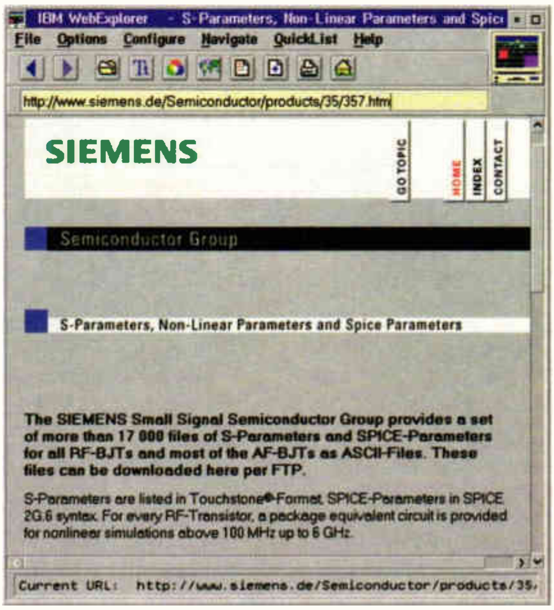


*Fig. 5. Siemens Semiconductor Group's extensive model library. Modelling from dc to 6GHz and both Spice and 'S' parameters.*

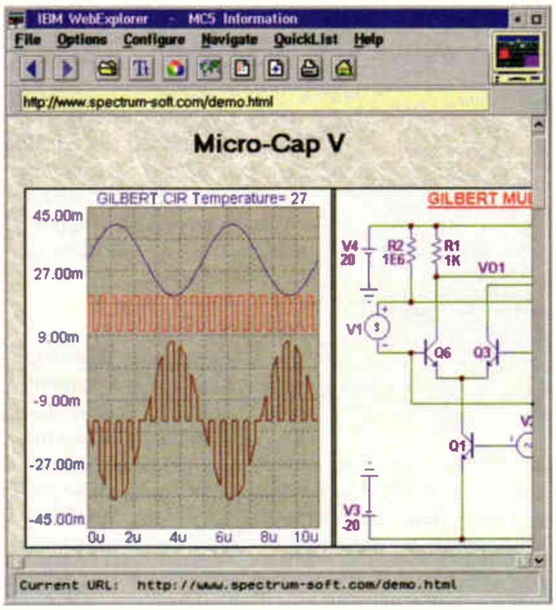


*Fig. 6. Download your free evaluation demonstration version of Micro-CapV, a well established alternative pc simulator.*


*Fig. 7. Serious simulation at an appropriate price.*

tory approach, Freepages.co.uk[2] or UK.Yellow Web[3] may provide the answer. If not, a good alternative starting point for all Web searches is Power-Search[4], also on Demon. This page gives a background description for each of the search engines listed, permitting more logical selection as well as direct access, **Fig. 2**.

Should you need to search for previously published information, the British Library Document Supply Centre[5] and the Science Reference and Information Service hold more than 64,000 serial publications. These comprise journals on science, technology, business and general interest topics, with on-line searching from the British Library Page. Having established that your required document is in these holdings, it can be obtained using the Lexicon easy-order service or, within the UK, rather more economically by request to your local branch library, **Fig. 3**.

Perhaps you have a new design or invention, but lack the resources to market your idea. The Eureka Club[6], while acting as an essential support for inventors needing assistance, also forms an on-line meeting place for designers with a new product but no production resources and manufacturers looking for their next marketable product ideas, **Fig. 4**.

## Simulation software

Symptomatic of the explosion in the use of computer simulations for electronic circuit design, the numbers and variety of simulation software packages constantly increases. While this market remains dominated by derivatives of the Berkeley *Spice 2G6* system, newer packages have emerged based on the latest Berkeley *Spice 3F5* software core.

An interesting document by Filip Gieszczykiewicz, called 'Where to get Free Spice', can be found on his page at Paranoia.Com[7]. This up-to-date but rather lengthy paper, sub-divided by operating system, gives a good overview of the low-cost Spice-based systems available.

The basic Berkeley Spice software kernel is in the public domain, and therefore inexpensive. Many commercial packages however, being enhanced versions of the basic Spice core, and having improved input and output systems, can become quite expensive.

Spice simulations are only as accurate as the the models used in the simulator. While most analogue integrated circuit


*Fig. 8. One of the new-generation simulators. It costs nothing to try so why not download this software?*


*Fig. 9. If you are curious about the different variations of the basic Spice kernel, you should read the 'Free SPICE' document and the 'SPICE 3F2' document[7] both by Filipg@paranoia.com.*

makers provide free models for their products, models for discrete devices are generally only provided by the simulator software package. Contributing significantly to their cost is the extended model library now required, since older discrete devices must still be supported while new discrete devices continue to be added.

## Spice models

One major commercial provider of Spice models is Symmetry[8], part of Interface Technologies. Its *SymLib* library contains more than 7500 analogue and mixed-signal devices of proven accuracy. Should the device you need not be otherwise available, it also offers a contract modelling service. Symmetry's models can be purchased and downloaded from its Web page.

Siemens Semiconductor Group[9] manufactures both radio and audio-frequency discrete semiconductors. For these, the company offers more than 17,000 files of S-Parameters for downloading in Touchstone format, plus Spice-parameters in Spice 2G.6 format. Details of this service, which comprises four libraries covering both low frequency and above 100MHz package equivalent data sets, are available on its Web page. My browser was allowed to access the page but not allowed to FTP any files, so a dedicated FTP program was used to download my required library, **Fig. 5**.

When I visited International Rectifier's site[10] in April last year, I only found fifth-generation MosFet models, but a recent return visit provided models also for the company's older generation products.

Comlinear, now part of National Semiconductor, offers Macromodels for its signal-conditioning product line, which can be downloaded from National's pages[11]. These Spice Macromodels are available either by individual device number or as a complete, self-extracting archive library for all types.

## Simulator engines

Spectrum Software's[12] fifth-generation *Micro-Cap* simulator, *Micro-Cap V*, unlike earlier versions, runs under Windows and is compatible with standard Spice model libraries. Note, however, that older S3 video card drivers and early Hewlett Packard printer drivers may need to be updated before running *Micro-Cap V*. A free 1.4Mbyte student/demo version can be downloaded from the company's Web page. It shows the result of simulating a Gilbert Multiplier to illustrate the use of *Micro-Cap V*, **Fig. 6**.

The Meta-Software[13] version of Spice – *HSpice* – claims to be the most accurate commercial circuit simulator available, with the MetaMOS1 (level 28) transistor model giving faster, more accurate simulations. HSpice, which is available integrated into major simulation frameworks from Cadence, Viewlogic, Zuken and Mentor, is targeted to the design of silicon integrated circuits including asics, as well as more conventional circuit design needs, **Fig. 7**.

*SIMetrix v1.1* is a Spice-based simulator with schematic editor for Windows 3.x available from Newbury Technical[14]. A free, no-time-limit version, fully working except for user definable menus, etc., called *SIMetrix intro*, can be downloaded from the company's page[14]. While some support for this free version is available by e-mail, those users downloading *SIMetrix* intro are advised to print out the Known Bugs page, **Fig. 8**.

This month's final Internet simulation offering is *AIM-Spice V2.0*[15], also available for download in a free student version. This package was developed to provide a more user-friendly interface and take advantage of newer device modelling. It is based on the Berkeley Spice 3.E1 kernel and fully described in the book 'Semiconductor Device Modelling for VLSI', published by Prentice Hall (ISBN 0-13-805656-0), **Fig. 9**.

Readers curious about the different variations of the basic Spice kernel should read the Free Spice document and the Spice 3F2 document[7], both by Filipg@paranoia.com. ■

## References


1. Finding Files for Ftp http://www.agbamu.demon.co.uk/ffff.htm
2. Freepages Group Plc http://www.freepages.co.uk
3. UK Yellow Web Search http://www.yell.co.uk
4. JabodaNET's Power-Search http://www.jaboda.demon.co.uk/power-search
5. British Library Document Supply Centre http://portico.bl.uk/bin/dsc-serials
6. The Eureka Club http://www.wdi.co.uk/eureka/home.htm
7. Where to get Free SPICE http://www.paranoia.com/~filipg/HTML/FAQ/BODY/F_Free_Spice1.html
8. Interface Technologies – Symmetry http://www.i-t.com/engsw/symm/symlib.htm
9. Siemens Semiconductor Group http://www.siemens.de/Semiconductor/products/35/357.htm
10. International Rectifier Corporation http://www.irf.com/~ir/product-info/spice
11. National Semiconductor Corporation http://www.national.com/models/spice/CL/clcspice.html
12. Spectrum Software Corporation http://www.spectrum-soft.com/demo.html
13. Meta-Software Incorporated http://www.metasw.com/products/sim/ hspice.html
14. Newbury Technolgy Ltd, http://www.newburytech.co.uk
15. AIM-Spice http://www.ecse.rpi.edu/homepages/trond/aimspice.html

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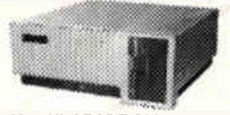

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| **TELEBOX ST** for composite video input type monitors | £36.95 |
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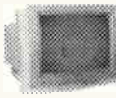

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***As New - Used on film set for 1 week only!!***
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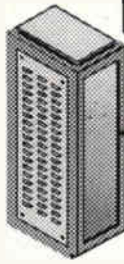

**Superb quality 6 foot 40U**
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Top quality 19" rack cabinets made in UK by **Optima Enclosures Ltd.** Units feature designer, smoked acrylic lockable front door, full height lockable half louvered back door and louvered removable side panels. Fully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

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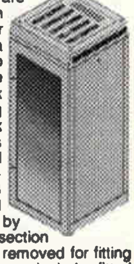

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CIRCLE NO. 128 ON REPLY CARD

# Phase comparator purity

**Continued use of the phase/frequency comparator's charge pump system looks questionable in view of the increasing demands for spectral purity, argues Edward Forster.**

The phase/frequency comparator is one of the most widely used components in phase-locked loop technology. It is applied in countless applications, increasing by the day as more radio-oriented products appear.

Although the basic logic within the phase/frequency comparator is simple and well understood, the output interface to the analogue world has several variations.

## The charge pump

The most popular output circuit is the charge pump system comprising transistors $Tr_1$ and $Tr_2$, **Fig. 1**. Disregarding the logic for the moment, it is only necessary to know that when the phases are synchronised, the output on the up/down lines consists purely of short duration pulses, normally coincident, which occur as the comparator resets in every cycle.

The duration of the reset pulses only depends on propagation delays in the logic. These can be very short compared to the reference clock period. Resulting output for these short pulses is highly dependent on the matching of the transistors.

A perfectly complementary combination would probably avoid some of the variations in comparator gain which occur near zero error. This type of output circuitry is tri-state with the third state being a high impedance state. Presumably, this fits in with the fact that the logic also has three stable states. The fourth state, in which both up and down lines are high, is inhibited by reset.

The output logic circuitry sounds more like a digital engineer's idea of analogue design. However, the main outcome is that at phase synchronism the output is essentially in the high impedance state almost continuously except for a momentary clamping of the output ideally to $V_d/2$.

**Figure 1** shows a typical error amplifier and active filter for this approach which has to be protected against the fast pulses, usually by splitting the input resistance and adding a capacitance to ground. But the extra delay due to the filter $R/2$, $C$ must not made so large as to affect loop stability.

The capacitor associated with the charge pump is the integrating capacitor in the active filter and not this $C$. The dc reference for the amplifier is $V_d/2$ so that the loop will settle at zero phase error. Reference frequency suppression is then at a maximum and the gain of the comparator is $V_d/4\pi$ volts/radian.

The source impedance seen by the op-amp is sometimes a critical factor in determining the intrinsic noise of the error amplifier and through the loop, noise on the voltage-controlled oscillator, or vco. That is, the vco may have higher close-in noise sidebands than expected or desired.

The differential output, **Fig. 2**, shows anoth-

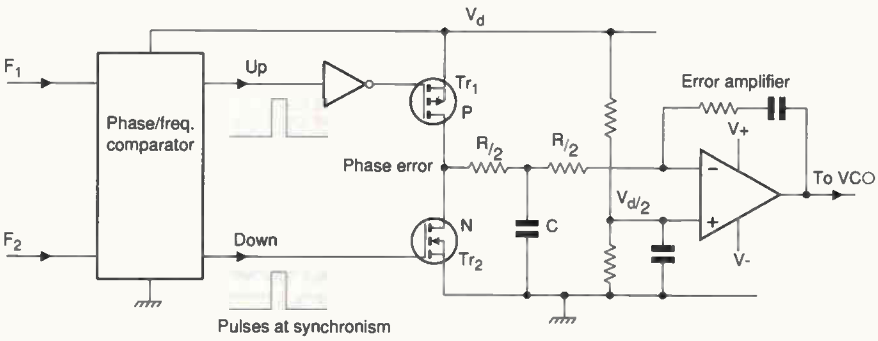


*Fig. 1. Conventional phase/frequency comparator with charge-pump output.*

er arrangement in which a differential error amplifier is driven by the up/down logic outputs directly so as to subtract them. The fast coincident pulses then become a common mode problem for the amplifier which only additional *RC* pre-filtering will satisfactorily resolve. Note that the nominal output/common mode voltage at phase synchronism is either very close to $V_d$ or ground, depending on the logic polarity. This is often inconvenient in single supply systems.

Overall noise performance tends to be improved by the higher gain, $V_d/2\pi$ V/rad, and because there is no high-impedance state.

## The resistive combiner

A better approach, which does not rely on the op-amp as a subtractor, is shown in **Fig. 3**. It is simply to take the up line in Fig. 1 and add it to the inverted down line in a 1:1 resistive network.

At phase synchronism the pulses disappear in the output which is a dc voltage of nominally $V_d/2$; the exact value depends on the high/low saturation voltages of the logic. As before, this is only true when a zero error control loop is used and adjusted correctly. The comparator gain is $V_d/4\pi$ volts/radian. Figure 3 shows that – in principle at least – infinite reference suppression is possible without filtering and that the interface is inherently suitable for wide band applications. In practice however, additional *RC* filtering is still necessary in front of the error amplifier.

Noise performance of the op-amp can be adjusted by setting the resistors *R* and the total input resistance to optimum values for the device. At phase synchronism, the output effectively shunts the supply line with a constant resistance of 2*R*. Since this resistance may at times be quite low, the extra current drain must be considered. It may be seen as a price worth paying.

## See it work

Typical discrete logic would use standard D-type bistable devices, namely positive edge-triggered 7474s with 'clear on low' inputs.

While it is possible to illustrate the waveforms, there is no better way to appreciate the circuit than to make one and test it. The simplest method is to take a signal generator, feed one input directly, and the other via a 100m of RG58, giving a delay of 500ns. By varying the frequency, all possible phase errors can be generated and the response seen.

While the comparator has a nearly –360 to +360° linear range you will find that it also has a 360° phase ambiguity, which depends on the initial conditions. As a result, it is not useful as an absolute phase comparator but it does excel in phase-locked loop applications.

## Differential resistive combiner

**Figure 4** shows a differential comparator which allows the op-amp to reject common-mode noise arising from the supply line, $V_d$. This comparator also has twice the gain ($V_d/2\pi$ volts/radian) of Fig. 3, which means that the effective op-amp noise is halved when considering its relative effect on the noise sidebands of the voltage-controlled oscillator.

Lock detection is also shown and a complete comparator can be made with just two standard ics. Extended frequency range comparators for special applications are thus very simple indeed. ■

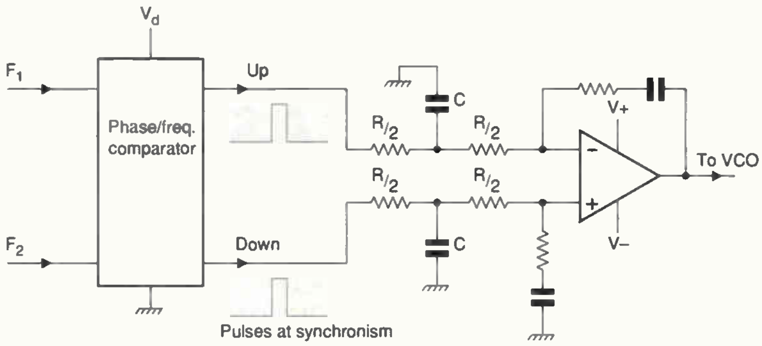


***Fig. 2. Using a differential output with the conventional phase/frequency comparator improves noise performance.***

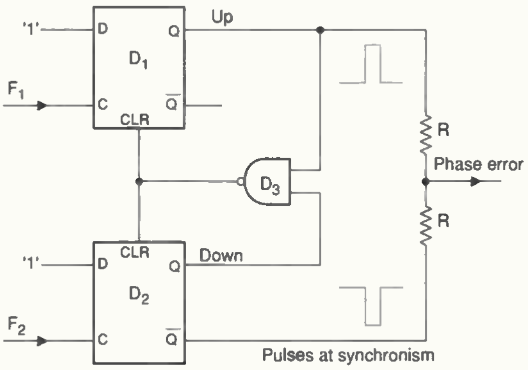


***Fig. 3. Phase/frequency comparator with resistive combiner is an improvement over Fig. 2's differential output. In theory, infinite reference suppression is possible.***

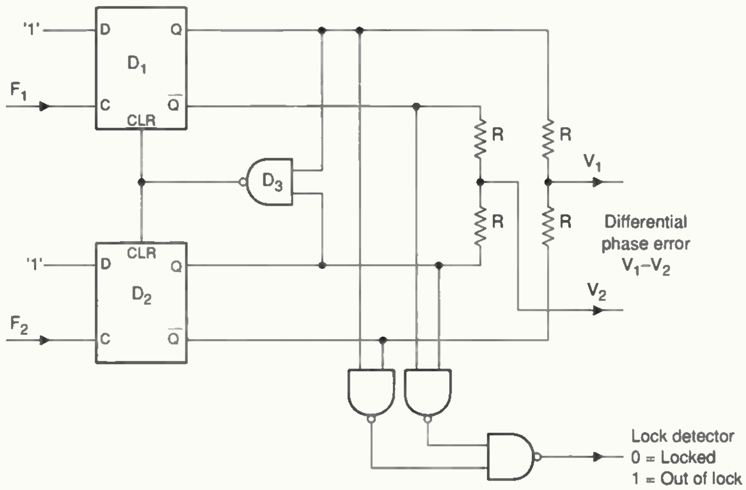


***Fig. 4. Differential phase/frequency comparator allows common-mode supply noise rejection and reduces noise due to its higher gain.***

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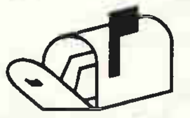

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# ACTIVE

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

**100Msample/s a-to-d converter.** From Strategic Test and Measurement comes *CompuScope 8012*, said to be the world's fastest analogue-to-digital conversion system. It is an IBM-compatible ISA bus card carrying out 12-bit a-to-d conversion in real time at sampling rates up to 100Msample/s in single-channel mode (50Msample/s in dual-channel mode), while maintaining a 60dB s:n ratio. On-board memory stores up to four million samples for later reading by the computer, since the conversion is faster than the bus, and a special 'stacking' feature enables high-prf pulses to be handled. Software supplied with the card allows it to be used as an oscilloscope, complete with storage, analysis, printing and export for spreadsheets, etc. Strategic Test and Measurement Systems Ltd. Tel., 01189 795950; fax, 01189 795951.

## Discrete active devices

**Surface-mount tunnel diodes.** Advanced Control Components' *ACTM Series* of s-m tunnel diode detector modules are meant for use in low-noise video work. Although measuring 4.6mm square and 2mm high, these devices contain full detector circuits with dc return, rf bypass capacitors and the option of input pads for range alteration or protection. In six bands, the series covers 10MHz-4GHz; sensitivity is 800-1000mV/mW with no bias supply needed, at a flatness of 0.2-0.4dB. Thermal stability is 0.015dB from –55°C to 100°C. Anglia Microwaves Ltd. Tel., 01277 630000; fax, 01277 631111.

**Voltage references.** Zetex introduces the *ZRC400/500* voltage references, which are micropower devices for 4V and 5V respectively, operating with extremely low knee currents: *ZRC400* takes a minimum 23μA and the *ZRC500* 25μA, nominal maximum being 5mA, although they will handle much more. The devices attain stable operation in microseconds, need no external stabilising capacitor and will drive capacitive loads. Power dissipation depends on package type, between 330mW and 625mW. Zetex plc. Tel., 0161-627 5105; fax, 0161-627 5467.

## Linear integrated circuits

**Cheap instrumentation amplifier.** *AD622* from Analog Devices is the first in a series of amplifiers at a price to make one think twice about rolling one's own two or three op-amp circuits – particularly as they are said to offer better cmrr (>86dB at a gain of 10), linearity and temperature stability, not to mention taking up less space; voltage noise is 12nV/√Hz at 1kHz. No external passives are needed for a unity-gain amplifier and a single resistor for gains between 2 and 1000. Analog Devices Ltd. Tel., 01932 266000; fax, 01932 247401.

**Jfet op-amps.** Linear introduces the *LT1462/3* (slew rate 0.13V/μs) and *LT1464/5* (slew rate 0.9V/μs) jfet op-amps characterised by input bias currents of 1pA and 0.5pA respectively, together with unity gain, 10nF capacitive load stability. Supply current for the 175kHz *1462/3* versions is 45μA; for the 1MHz 1464/5 types, 200μA. Linear Technology (UK) Ltd. Tel., 01276 677676; fax, 01276 64851.

## Microprocessors and controllers

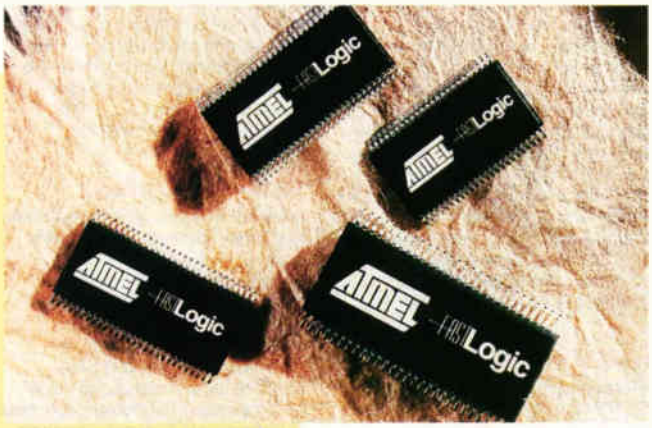
**"Most powerful" 16-bit controller.** Mitsubishi says its *M16C* family of 16-bit microcontrollers is the most powerful yet. The mcu is a compact design, optimised for high-speed, 16-bit operation, its 18mW power consumption and number of on-chip peripherals allowing its use in previously unsuitable designs. Features include efficient C programming, good noise suppression and advanced debugging. On-chip peripherals comprise 126Kbyte of rom, 10Kbyte ram, with dmac, crc, usart, fast a-to-d, d-to-a, eight 16-bit timers and multifunction input/output. Program bugs discovered after masking can be corrected by an interrupt in software. Clock speed is 10MHz, although single-cycle instructions confer a performance that belies the clock speed, being equivalent to 40-60MHz in other mcus. Mitsubishi Electric UK Ltd. Tel., 01707 276100; fax, 01707 278692.

**200MHz embedded VXI controller.** *VXIpc-850/200* is an improved version of National's 133MHz and 166MHz Pentium embedded controllers, this one using the 200MHz Pentium. Simple upgrades are available. All controllers in the series are VXI plug and play types and compatible with software tools such as the company's *LabWindows/CVI* and *LabVIEW*. Prices on all Pentium-based embedded VXI controllers have been reduced by 25%. National Instruments UK. Tel., 01635 523545; fax, 01635 523154.

**Control starter kit.** *EasyStart Kit* by Z-World offers a rapid and simple method of programming embedded microcontrollers in C for beginners, as well as making life easier for experienced programmers. The kit consists of the Windows-based *EasyStart C* software-development suite, including editor, compiler and debugger for a simplified version of standard C, and the *Little Star* controller, which has 16 ttl inputs and 14 high-current digital outputs. It is complete with 9MHz *Z180*, 126Kbyte of eprom and 32Kbyte of static ram. Also in the kit are lcd and keypad, manual, demo board, power supply and cabling. Z-World. Tel., 001 916 7573737; fax, 001 916 7535141. E-mail http://www.zworld.com

## Mixed-signal ICs

**RS232 transceivers.** Analog's *ADM2xxE* 5V RS232 and V28 transceivers, which meet EU emc requirements, protect against ±15kV of discharge and ±2kV of fast transients. They are meant for modems, laptop and notebook computers and generate electromagnetic emissions to EN55022 and are immune enough to satisfy IEC-1000-4-x. These devices are protected against latch-up, are immune to high rf fields and will work in unshielded enclosures in "electrically harsh environments". There is a number of driver/receiver combinations, in SOIC, SSOP and TSSOP packages. Advanced Micro Devices (UK) Ltd. Tel., 01483 740440; fax, 01483 756196.




## Logic

**"World's fastest" logic family.** Already in production by Atmel Corporation are the first members of what is claimed to be the fastest industry-standard fast cmos logic devices, the *Atmel Fast Logic (AFL)* series. Speed is down to 2ns and the first circuits in the series are 16-bit devices for 5V: a bidirectional transceiver (*AT16245*), a buffered line driver (*AT16244*), a transparent latch (*AT16373*) and a tri-state register (*AT16646*); 16-bit, 3V units are to come next. Atmel UK. Tel., 01276 686677; fax, 01276 686697.

**Optical isolators.** *PVI5013R* dual-channel opto-isolated mosfet gate drivers by IR are new members of the *Gen2* range and are the first to offer fast turn-off circuitry. The two channels will drive two devices or can be connected in parallel or series to give higher-current drive for power mosfets or higher voltage for igbts. Input/output isolation is to 3.75kV rms and input-output isolation 1.2kV dc. International Rectifier. Tel., 01883 732020; fax, 01883 733410

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**Communications mmic**. NEC has a silicon microwave ic up-converter and quadrature modulator, the *µPC8104GR*, which has a frequency range of 900MHz-1.9GHz and is intended for digital communications work in lans and telephones. It operates from 2.7-5.5V, taking 28mA at 2V and 0.1µA when power-saving. There is a digital phase meter on chip, with a self-phase compensation facility, and an internal 90° phase shifter, which has a phase error of 0.86°and modulation accuracy of 2.1%. NEC Electronics (UK) Ltd. Tel., 01908 691133; fax, 01908 670290.

## Motors and drivers

**Microstepping driver**. Allegro's *SLA7042* multi-chip module controls two-phase stepper motors and provides microstepping operation, containing two independent pwm current-control ics with four nmos fets in an 18-lead Powertab sil package. It is rated for motor voltages to 46V, peak outputs to 5A and 1.2A continuous. By means of digitally selected motor-current ratios and linear input reference control, the device may be used as a half-step, full-step and microstep driver, all modes providing smooth drive. No heat sinks are needed. Allegro MicroSystems Inc. Tel., 01932 253355; fax, 01932 246622.

**150MHz, 4Mword dso.** Yokogawa's *DL1540L* – a four-channel, 150MHz, 200Msample/s digital storage oscilloscope – has a 4Mword memory, or 1Mword on each of four channels. As an example of performance, the signal from one track of a magneto-optical disk or a whole composite tv field can be captured, low and high frequencies included, and the standard waveform measurement function also benefits. The instrument has a built-in floppy drive and a printer. Martron Instruments Ltd. Tel., 01494 459200; fax, 01494 535002.

## Optical devices

**Infrared receiver**. New Japan Radio has a new infrared remote-control receiver. In the one three-pin package, there are a photodiode, bandpass filters, a limiter and a preamplifier, so few external components are required. Low pulse-length distortion of 50µs provides a clean signal and noise becomes less of a problem, the metal case helping to increase screening and affording some physical protection. The device will operate at all the common frequencies from 32.75kHz to 56.8kHz and is effective at a range of up to 18m. Young-ECC Electronics. Tel., 01628 810727; fax, 01628 810807.

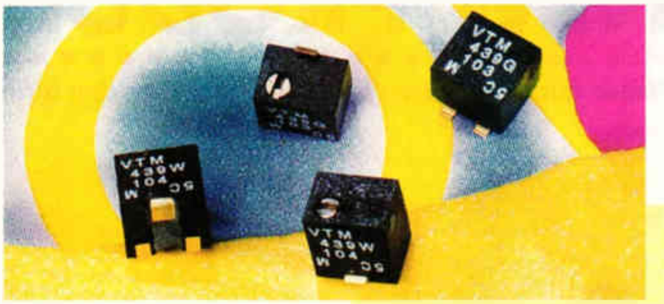
# PASSIVE

**Chip inductors**. Toko's *LL Series* of multi-layer chip inductors now come in the 0402 size, as well as in 0805 and 0603 sizes. This new type is suitable for frequencies up to 6GHz, inductance being 1-27nH and *Q* 50 at 1GHz. The 0805 1.5-470nH size copes with frequencies to 2.5GHz, with a *Q* of 30 at 800MHz and the 0603 operates to 3GHz, its inductance being 1.2-100nH and *Q* 30 at 800MHz. Cirkit Distribution Ltd. Tel., 01992 444111; fax, 01992 464457.

## Connectors and cabling

**Backplane connector**. GTK has a new range of backplane connectors to give up to 192 pins for signal or power circuits at 1A or 3A. *Metrix* connectors are available in 12, 24, 48 and 96mm modules with contacts on a 2 by 2mm grid, the basic 12mm module providing 24 signal contacts or eight power contacts. All can be made as press-fit or through-hole types. GTK (UK) Ltd. Tel., 01344 304123; fax, 01344 301414.

**Pga sockets with preforms**. Robinson Nugent's through-hole pga sockets eliminate the time and expense of a separate soldering operation by the provision of solder rings on the socket's pin tails, the solder preform reflowing into the pcb hole by capillary action. Matching the preform to the board ensures that there is the right amount of solder and that there is no residue and no need for screening or solder paste. Robinson Nugent (Europe) Ltd. Tel., 01256 842626; fax, 01256 842673.



## Displays

**Loop-powered displays.** Trolex has a range of loop-powered displays with IS certified versions for hazardous areas. Displays can be in panel-mounting, DIN-rail or 19in rack-mounting form, as well as in a field-mount type. They are usable with all standard sensors, process instruments and plcs, all having a loop test facility and direct connection to two-wire process signal loops. Signal processing is to 12-bit accuracy and the four-digit display is an lcd. Trolex Ltd. Tel., 0161 483 1435; fax, 0161 483 5556.

## Hardware

**Emergency stops.** EAO-Highland now provides bright yellow shrouds for its range of emergency stop switches, which meet the requirements of the EU Machinery Directive with regard to inadvertent operation. This new shroud sticks up above the top of the E-stop actuator so that the switch cannot be accidentally operated and it has cut-outs in the side to allow it to be twisted to release it after a genuine fault. EAO-Highland Electronics Ltd. Tel., 01444 236000; fax, 01444 236641.

**Zif bga sockets**. Adding only 2.2mm to the height of a device, *Methode*'s zero-insertion-force ball-grid array socket needs no external hold down and its 25 by 25 array of pins are inspectable. It incorporates heatsink capability and the metal-to-metal connections have a self-inductance of 5nH. A sliding carrier has actuator slots to mate with the bga device, horizontal movement locking and unlocking the device to and from the socket. Methode Electronics Europe Ltd. Tel., 01389 732123; fax, 01389 732777.

**Bobbins, bases.** Coil bobbins and mounting bases for inductors used in switched-mode power supplies and in power conversion can be had from BFI Ibexsa. They are all UL approved, are particularly suitable for development but are also offered in a low "skyline" range for EPC and EFD use. BFI IBEXSA Electronics Ltd. Tel., 01622 882467; fax, 01622 882469.

## Test and measurement

**20MHz oscilloscope.** Goldstar's *OS-5020P* is a 20MHz, dual-channel, general-purpose oscilloscope for use in education or servicing. Vertical sensitivity is 5mV/div, plus a x5 position, and sweep speed 0.2µs/div with a x10 switch. Combined Precision Components plc. Tel., 01772 654455; fax, 01772 654466.

**Multi-turn s-m pots**. VTM *439 Series* of multi-turn, surface-mounted trimmers will handle all soldering processes and meet the requirements of MIL-R-22097, characteristic F. Although the pots have eleven turns, dimensions are the same as those of single-turn devices. Resistance range is 10Ω to 2MΩ at 0.25W and 300V. Surtech Interconnection Ltd. Tel., 01256 51221; fax, 01256 471180.

**Power-off board testing.** *Prober II* by Huntron automatically tests boards up to 35.6cm square with power switched off, combining analogue signature analysis with a probe, which needs no additional fixture and will cope with pin or test-point spacing of 0.01in, moving in 0.001in increments. Parameters such as *v*, *i* and *f* are programmable and the *Star* feature (safe tracker active range) prevents damage to components. There is a ccd camera vision system, which runs under Workstation for Windows, and an output for other test instruments. Martron Instruments, Tel., 01494 459200, fax 01494 535002.

**Multimeters**. *MX52B/54B/55B/56B* handheld multimeters by Metrix are provided with an RS232 interface with a view to data transmission to a pc or printer. All versions have a 50,000 count display, 0.025% accuracy, true-rms reading and test functions. *MX56B* is the top version, with its 100kHz bandwidth, timer-counter, audio power measurement (in decibels), indication of mains disturbance and pulse width measurement down to 20µs. Metrix Electronics plc. Tel., 01384 402731; fax, 01384 402732.

**Logic analyser**. Thurlby Thandar's *TA4000-80* logic analyser provides synchronous data capture at up to 400MHz on 16 channels with a memory depth of 8Kword. At this speed, timing resolution is 2.5ns, which is usable with 50MHz logic; at 50MHz and below, the number of channels may be increased to 80. Sixteen channels can be displayed simultaneously, with a marker scale, and a group of channels can be defined as a bus and shown on one line of the screen. Triggering may be performed by up to four trigger words ORed together (NOTed, if required). GPIB and RS-232 interfaces are provided for control and data transfer and there is a Centronics interface for screen dumps to a printer. Thurlby Thandar Instruments Ltd. Tel., 01480 412451; fax, 01480 450409.

## Literature

**Ac/dc power.** *Coutant Lambda* offers a new guide to the company's range of ac/dc power supplies. The guide is free of charge. Coutant Lambda Ltd. Tel., 01271 865656; fax, 01271 864894.

**Power mosfets.** *Toshiba* mosfets, which handle 16-1000V and 1A-60A, are described in a new short catalogue, including types for direct drive from 3.3V logic. Toshiba Electronics UK Ltd. Tel., 01276 694600; fax, 01276 694800.

**Surtech.** Surtech Distribution has a new catalogue of *hardware* such as *Cs*, *Rs*, *Ls*, suppression components, piezo and magnetic products, connectors and switches from people like Murata and Methode. Surtech Interconnection Ltd. Tel., 01256 51221; fax, 01256 471180.

## Navigation systems

**GPS starter pack.** Rockwell offers the *Jupiter Starter Pack*, which is an easier way to have a GPS application up and running. The unit is based on a Rockwell Jupiter-12 GPS engine to give rapid signal acquisition even in town centres and foliage. It allows the connection of power, antenna, serial cable for a pc port and differential input, with option setting. Software includes Rockwell's *Labmon* monitor program, the Psion *NMEA* GPS monitor and other utilities. Telecom Design Communications Ltd. Tel., 01256 332800; fax, 01256 332810.

## Power supplies

**Efficient dc-to-dc converter.** Philips has the *TEA1204t* 8W dc-to-dc converter ic which is 95% efficient. It is intended for the telephone market, to extend talk and standby time. It will convert the output of a two or three-cell NiCd/NiMH battery or a single-cell Li-ion pack to 3.3V or 5V or the output of a four-cell pack down to 3.3V or 3.6V, configurations that cover virtually all mobile telephones. A combination of pwm and pulse frequency modulation not only confers high efficiency, but allows rapid response to changing loads, so that the device is particularly suited to GSM telephones using burst-mode transmissions. Philips Semiconductors (Eindhoven). Tel., 00 31 40 2722091; fax, 00 31 40 2724825.

**Auto-pfc, ac/dc supply.** Computer Products introduces the *NLP65* 65W, ac/dc input, open-frame supply, said to be the smallest of its type to have automatic power-factor correction by an active low-frequency method. The unit complies with European harmonics and flicker standards and is CE marked. Package size is 5 by 3 by 1.26in, this being achieved by means of a new 100kHz switched-mode technique, the high frequency helping to reduce emi. It also uses a patented flyback boost technique to improve efficiency under full load, giving a power sensitivity of 4W/in$^3$. Input is universal at 85-264V ac or 120-370V dc and outputs are 5, 12, 15 or 24V dc from the single units, 5/12V or 5/24V from dual types and 5/±12V, 5/±15V from the triple versions. Computer Products, Power Conversion Ltd. Tel., 01494 883113; fax, 01494 883419.

**600W dc-to-dc supplies.** Single-output dc-to-dc power modules in Coutant Lambda's *PH600S* range provide 330-600W of output at fixed voltages between 3.3V and 48V. Input voltage is 200-400V dc, switching frequency 300kHz and efficiency at 280V dc and maximum output current is 86%. Facilities include remote sensing, overcurrent and overvoltage protection and there is provision for a remote on/off control. Coutant Lambda Ltd. Tel., 01271 865656; fax, 01271 864894.

**Ups.** *PowerWorks A30* is a new uninterruptible power supply by Fiskars, designed to replace *PowerServer* 20 and 30 ranges. This one uses "double conversion on-line technology" to provide reliable protection for computers and workstations, etc. In the 600VA-6kVA range. These units are modular in form for simple installation and offer "plug-and-play" expansion, with four hours backup. An automatic switch takes power directly to the load to handle temporary overload – a feature that removes the need for excessively large ups – and the units use new Lansafe III power management software. Widened input voltage ranges help to conserve battery power. Fiskars Electronics Ltd. Tel., 01734 306600; fax, 01734 305868.

**Lead battery charger.** Mascot's *9319* lead battery charger is over 80% efficient and delivers a current up to 2.4A. Output voltage is adjustable between 11.5V and 15V, with others to special order, and there is a current limiter to prevent overcurrent at the start of the charge cycle. This CE-marked unit is provided with a UK or European mains plug built into the case and a choice of output plug leads. Relec Electronics Ltd. Tel., 01962 863141; fax, 01962 855987.

## Radio communications products

**Telemetry transceivers.** A new range of radio telemetry transceivers by Wood & Douglas enables the company to offer equipment covering the 130MHz to 500MHz range of frequencies. The *T100/200/400* range is meant for use outside Europe, being designed to meet the FCC specification; more stringent demands of European use call for the *E100/200/400* alternative range, which meets ETS 300 200, MPT1328 at vhf and MPT1329 at uhf. The T series radios put out 2W at vhf and 1W at uhf, while the European ones emit 0.5W. There are 100 fixed frequencies or 16 reprogrammable ones. Wood and Douglas Ltd. Tel., 01734 811444; fax, 01734 811567.

## Switches and relays

**Audio connectors.** *Deltron's* range of professional audio connectors, now available from Electrospeed, covers all audio requirements, including phono connectors, loudspeaker types, and a range of circular DIN connectors of the non-latching, latching, insulated, chassis or board mounting versions. *Silent Jacks* are two-pole jack plugs which eliminate the buzz on insertion, a spring-loaded sleeve switch connecting tip and sleeve connected until the movement of the sleeve on connection reinstates the signal; a two-position collet allows the use of a number of cable diameters. Electrospeed. Tel., 01703 644555; fax, 01703 610282.

**Piezo switches.** Schurter's range of single-key piezo switches are rated to IP40 or IP67 and are proof against water, dust, heat and cold and the brain-dead. Piezo-ceramic discs generate small voltages when touched, the voltages being processed internally to control the normally open switching action. They come in a range of colours and materials including chrome-plated brass, steel or aluminium. Options include special finishes and normally closed versions. Actuating force is 1-3N, contact travel 0.0002mm, switching voltage and current 100V dc, 100mA and breaking capacity 10W. Radiatron Components Ltd. Tel., 01784 439393; fax, 01784 477333.

## Video

**Remote, digital camera.** Active Imaging announces the *Mv-NET*, a networked digital camera for remote inspection and monitoring. Images are sent to the monitoring station, which is simply a pc running the relevant software, in compressed digital form over telephone lines, lans or GSM/wireless lan. Inside the camera are colour Pal sensor, frame-grabber, processor, disk storage and a network module, all mounted in an enclosure with climate control and/or tilt and pan control; settings are controlled from the monitoring station. The presence of the processor means that the camera can notify the monitor if an alarm is activated and can then be made to record whatever nefarious deed is being perpetrated. Active Imaging plc. Tel., 01628 415444; fax, 01628 415481.


**Loop tester.** A digital loop tester, the *Avo Megger LT7*, is a hand-held instrument giving a direct reading of prospective short-circuit current and earth fault current, other tests including phase, earth and phase and neutral supply loops, performed at both 110V and 230V socket outlets and distribution boards. For circuits using rcds that would normally be tripped by high current, a low-current test is available. The instrument meets Low-Voltage and EMC directives. PIDA. Tel. and fax., 0756 799737.

**Pc to tv.** *TMC2360* by Raytheon is a single-chip VGA-to-Pal/NTSC video processor, converting analogue rgb+sync. from a pc to broadcast quality NTSC or Pal video; no external memory is needed. The device includes three a-to-d converters, an interlace filter, clock processors, reference and three d-to-a converters and a three-line adaptive flicker filter with selectable operating modes. 2001-METL. Tel., 01438 742001; fax, 01438 742002.

**3-D camera.** A three-dimensional portrait camera, the *C3D model 2020* by the Turing Institute, consists of a pod with a stereo camera pair and lighting, connected to a pc. In under 0.5s, high-resolution polygon models can be produced in VRML or DXF formats in monochrome or 24-bit colour. Simple operation allows non-technical users to operate the camera. The Turing Institute. Tel., 0141 337 6410; fax, 0141 339 0976.

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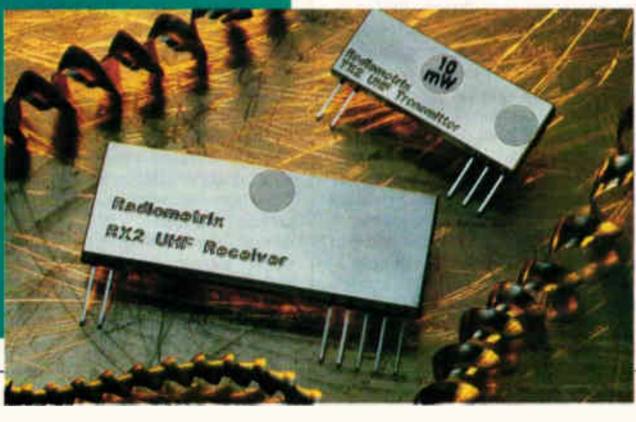
## Transducers and sensors

**Touch pad.** A semiconductive touch-pad element by Interlink Electronics Inc. is based on the company's force-sensing resistor, instead of the more often seen capacitive technique. The device requires a slight touch from a finger or stylus and will operate in wet or dry surroundings; it uses only 15% of the power needed by capacitive pads and is more flexible in its use. It is mainly intended for use in notebook computers, where its power saving, enhanced by the inclusion of a sleep mode, and its lower cost compared with that of capacitive devices, makes it an attractive choice. A complete touch-pad using the technique, the *VersaPad oem module*, is now available. Interlink Electronics Inc. Tel., 001 805 484-8855; fax, 001 805 484-8380.

**Current sensors.** Vacuumschmelze GmbH has some new compensation current sensors for current detection in motor control systems or power supplies; they are based on existing designs, but provide greater current ranges in the same shape cases, those now available being for 50A, 100A and 400A. The compensation principle allows the detection of dc as well as ac up to about 100kHz, and enables better linearity than in other methods. Use of a metallic detector instead of a Hall device reduces offset and drift by an order of magnitude. Vacuumschmelze GmbH. Tel., 0049 61 81/38-26 29; fax, 0049 61 81/38-28 60.

**Fm wireless datacomms.** Radiometrix has a transmitter/receiver pair for 40kbit/s data communication over distances of 300m over open ground (75m inside). They are made for 433.92MHz, the transmitter providing +10dBm to ETS 300-220 in Europe and 418MHz, 0dBm to MPT1340 in the UK; the receiver is a double-conversion superhet, which powers up in under 1ms and detects carrier rapidly for power saving. The pcb-mounting modules can be used in analogue or digital communication and will work with helical, loop or whip antennas. Radiometrix Ltd. Tel., 0181 810 8647; fax, 0181 810 8648.




**Pressure sensors.** Lucas's *NPP Series* of piezoresistive, board-mounted pressure sensors are meant for use where small size and resistance to mild corrosive fluids are important. It is the first to appear in a standard SOIC-8 package for automatic handling and insertion, the lead frame design reducing the stress found in surface-mounted ceramic types. Ranges are 0-15, 0-30 and 0-100lb/in$^2$(absolute), producing a 60±20mV output on 3V dc. Error due to all causes is less than 0.3% of full scale. Lucas Control Systems Products. Tel., 01535 661144; fax, 01535 661174.

**Humidity sensors.** Self-cleaning, heat refresh humidity sensors in the *HS30* from Steatite are for use in industrial positions where conventional types become clogged and stop working properly. Measurement range is 10% to 95% RH, without condensation, and accuracy ±5% RH at up to 80°C. Power consumption is 1.35W, rated working voltage 1V ac and heat refresh temperature 600°C. Steatite Insulations Ltd. Tel., 0121 643 6888; fax, 0121 643 2011.

**Chip thermistor.** *NTH5G* is an ntc thermistor on an 0805-size chip made by Murata and intended for use in temperature compensation in ics, transistors and oscillators. Its construction provides resistance to humidity; resistance tolerance is ±5%; maximum power 20mW; and B tolerance ±3%. Resistance values in the range 220Ω-100kΩ are available. Murata Electronics (UK) Ltd. Tel., 01252 811666; fax, 01252 811777.

# COMPUTER

## Computer board-level products

**PCI-bus logic analyser.** From RAM Technology comes the half-card *TA200* logic analyser that is simply plugged into the bus, no probes being needed. It allows users to debug and characterise hardware and software using Windows-based software, which, it is said, gives a good balance between simplicity and analysis capability. An enhanced parallel interface to the host enables very fast data transfer and the board is compatible with all PCI systems including short-form designs. Future developments are taken care of by on-board sram and fpga technology; updates will be available on disk and from a Web site. RAM Technology Ltd. Tel., 01825 761456; fax, 01825 761543.


**Enhanced ICEPIC.** RF Solutions has extended the coverage of its PIC emulator by the introduction of a new daughter board. *ICEPIC* is a non-intrusive emulator for PICs working at up to 10MHz, for source-level debugging in assembler or C. This new 74A board allows ICEPIC to cover *16C62/63/64/65/72* and *74* processors, and comes with all new emulators, being available as an upgrade for older ones. RF Solutions Ltd. Tel., 01273 488880; fax, 01273 480661.

## Computers

**Fault-tolerant computer.** Blue Chip's *Icon* series of rack-mounted pcs are available with dual redundant power supplies. Both operate normally but, in the event of a fault, each is capable of handling the full 250W load, an alarm sounds and a led illuminates; this signal can also generate a pop-up alarm, using a watchdog card. Further alarms may be generated by the use of Blue Chip's Pentium cpu card, which monitors the power supply and temperatures. Blue Chip Technology. Tel., 01829 772000; fax, 01829 772001.

## Data communications

**"World's smallest" transmitter.** An am transmitter by RF Solutions looks like a small ceramic capacitor in that it is encapsulated in epoxy and has two wires; you can have it in a key fob, if you ask properly. It is for short-range telemetry and data comms and things in cars and works over a 30m range. Licence-exempt in the UK, it is approved to MPT1340 and is available for European operation at 433MHz. Power is 5-12V at 2.5mA and the two aforementioned wires are for cmos/ttl data input and output to a whip aerial. RF Solutions Ltd. Tel., 01273 488880; fax, 01273 480661.

## Development and evaluation

**USB controller emulator.** An emulator for Intel's *82930* universal serial bus controller, which is an Intel 251 micro with an interface to the 12Mb/s bus, is now available. iSYSTEMS *82930* power emulator probe allows real-time execution without wait states, the trace option recording every instruction cycle and breakpoints being set at any location without slowing execution. C compilers are supported and dos or any of the Windows variants will support the emulator. Clock speed is up to 100MHz and the optional trace buffer is 96bit wide. Changing pods on the emulator adapts it to over 200 8-bit and 16-bit devices. Computer Solutions Ltd. Tel. and fax, 01932 829460.

**32-bit 68020 emulator.** Noral Micrologics's *FlexTools* family of real-time development tools mow includes the *Flex-ICE020*, a hand-held, non-intrusive, zero-wait-state emulator for all 68020 derivatives up to 33MHz. It is compatible with the company's Windows-based debugger, *Flex*, and has an expandable 32K by 128 real-time, time-stamped buffer for analysis without breaking execution. Dual porting provides emulator ram access for ICE and target to give real-time read and write of system memory. The unit accommodates over 500,000 breakpoints. Noral Micrologics Ltd. Tel., 01254 682092; fax, 01254 680847.

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# MEASURE wow and flutter

**With so much digital audio equipment around, it is easy to overlook the fact that a meter for checking fluctuations in the speed of analogue replay systems is still a useful tool. Christopher Kuni explains how to design such a meter.**

Measurement of wow and flutter may seem anachronistic in this age of digitised, locked-in, rock-stable audio reproduction. However, a glance at the display window of any commercial electronics shop will reveal that analogue equipment, with its susceptibility to speed variation, is still very much with us in the form of cassette and even reel-to-reel tape machines, and video recorders. And there are still millions of phonograph disks in existence.

Every turntable and analogue tape transport has measurable speed variations that worsens with age. Checking wow and flutter requires a measuring instrument with reasonable sensitivity and precision; such instruments have become rare and expensive.

The meter described here has proved more than adequate. Its most sensitive range is 0.1% full scale, peak or rms-indicating average. The –3dB points of its frequency response are 0.4Hz and 180Hz. Alternatively, the frequency response weighting curve recommended by the major standards associations can be selected[1].

Output level of the typical moving-magnet cartridge provides adequate drive without preamplification. Only one simple calibration adjustment is required, or, if rudimentary accuracy can be tolerated, high precision (i.e., repeatability and internal consistency) can still be enjoyed with no calibration at all.

**Figure 1** shows the overall system design. A 3 or 3.15kHz signal of a few millivolts to a few volts rms is amplified, if necessary, to an adequate level before bandpass filtering to remove noise. A zero-crossing detector then squares the signal to further reduce noise effects and to condition the signal for a phase-locked loop, or pll, frequency discriminator.

Demodulated signal passes through a wideband bandpass filter that sets the overall wow-and-flutter frequency response. A weighting filter can be switched in if desired. Peak or average rectifiers can be chosen to drive the storage capacitor, the potential of which is measured by a dc voltmeter.

## Circuit details

**Figures 2-6** show circuit details. All op-amps in the prototype are *TL071*, *-72*, or *-74* types. Similar types will function equally well. Each nor gate is one section of a c-mos 4001.

The input carrier signal sees the high input impedance of $IC_1$, Fig. 2. Together with its associated components, $IC_2$ provides up to 20dB gain. This gain control circuit, described by R. Williamson[2], has an approximately exponential characteristic that I find convenient when the expected level of the input signal may cover several orders of magnitude; a circuit with a linear characteristic may, of course, be substituted.

Noise transmission to the pll is reduced by the filter formed by $IC_{3,4,5}$. A biquad circuit was chosen because of the flexibility it affords in the choice of Q and gain, and because of its easy tuning. The main trade-off in the design of this filter is between wow-and-flutter bandwidth and noise rejection. A high-Q filter will limit the upper frequency components of the wow-and-flutter signal but will also reduce the undesirable effect of noise in the input carrier signal.

This consideration is more critical than you may first think. Although the pll demodulator is inherently noise-insensitive, the modulation levels that we are dealing with are extremely low – down to less than 0.01%. Even a pll will show significant relative noise sensitivity at these levels, so line transients, clicks on the test record, rumble in the turntable and other noise signals can spoil measurements.

The bandwidth of a frequency-modulated signal is approximately equal to twice the sum of the frequency deviation and the modulating frequency[3]. For a 3kHz carrier modulated at 1% peak deviation at 200Hz, the bandwidth is thus about 2×(30+200)=460Hz.

For a 200Hz, 1% flutter signal, the system will suffer about a 3dB loss in sensitivity if filter Q is 3000/460=6.5. The values shown in the biquad filter give a Q of about 5.5; this filter, in conjunction with the bandpass filter following the pll, gives an overall system bandwidth of about 180Hz, a reasonable figure. Rejection of the noise in my environment is sufficient to allow measurements near the bottom of the 0.1% range.

Filter Q can be changed, if desired, by changing $R_a$; $Q=R_a/33{,}000$. With the values shown, gain of the biquad filter is 50 – a value that can be maintained if Q is changed by altering $R_b$; $gain=Q(33{,}000/R_b)$.

## Further noise rejection

A zero-crossing detector with hysteresis $IC_6$ further rejects noise. Transistor $Tr_1$ still further squares the 3 or 3.15kHz signal from $IC_6$ and shifts the negative-most level of the square wave to near zero. The diode and associated voltage divider give a dc signal that allows for gain adjustment; gain should be adequate to give a clean square wave at $Tr_1$'s collector but

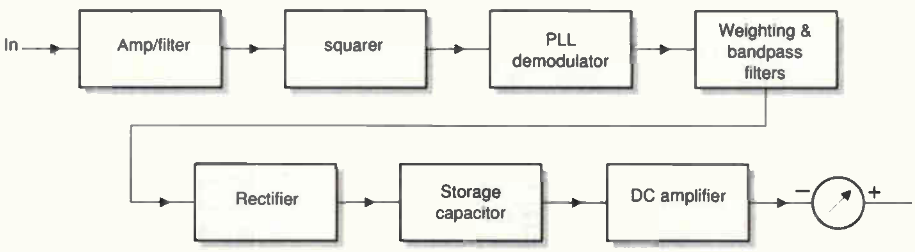


*Fig. 1. In this simple sensitive wow-and-flutter, weighting is switch selectable.*

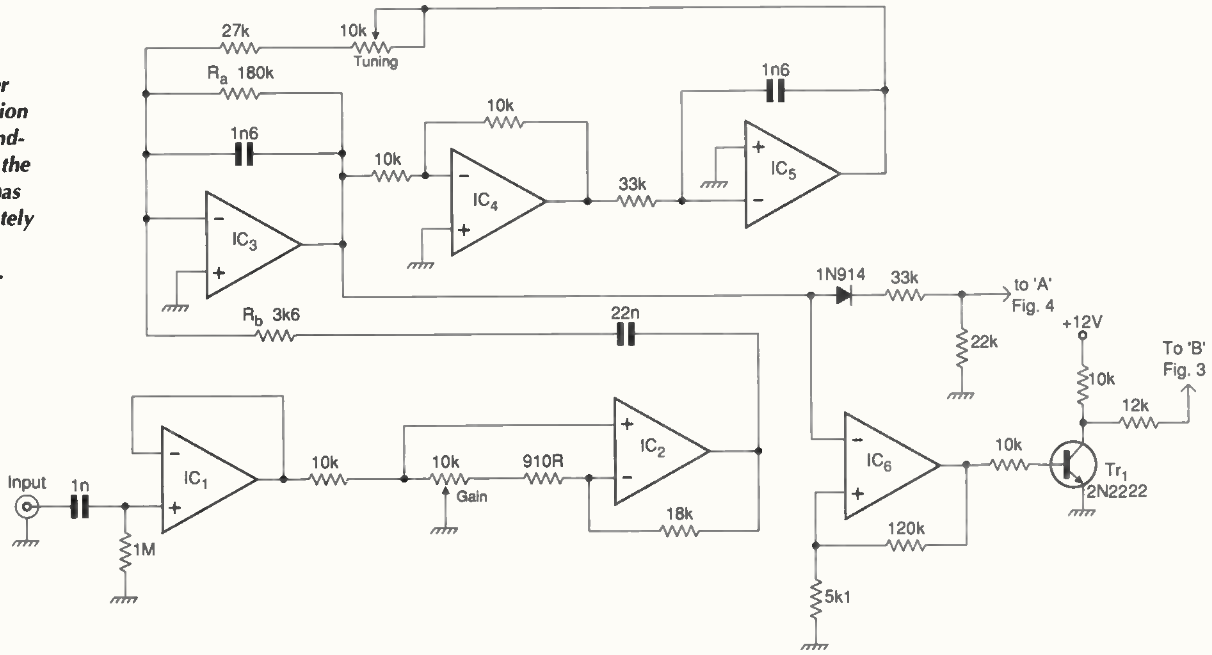


*Fig. 2. In the input amplifier and filter section of the wow-and-flutter meter, the gain control has an approximately exponential characteristic.*

not so high that the biquad filter is overloaded. After $S_1$ in Figs 3, 4 & 5 is switched to the 'set' position, the biquad is tuned for maximum meter reading and the gain is adjusted for a reading anywhere in the top two-thirds of the meter scale.

The squared carrier signal is sent to the 4046 pll, $IC_7$, Fig. 3. Demodulated output from the pll goes to two filter chains, selected by $S_2$, to give either a flat or a weighted bandpass ($IC_{8,9}$ or $IC_{8,10,11}$.

Op-amp $IC_{12}$ provides appropriate gain for 0.1%, 0.3%, or 1.0% full-scale meter deflection; range is selected by $S_3$. The 180kΩ resistor at $S_{1A}$ causes the gain of the $IC_{12}$ circuit to yield rms-reading average measurement when $S_1$ is set to 'average'.

The feedback resistors around $IC_{12}$ are calculated for a meter movement on which the full-scale values are 10dB apart – i.e., 1.0 on one scale and 3.16 on the other. Use of the less common movement, on which the full-scale values are 1.0 and 3.0, would require recalculation of the resistors. Output is provided for monitoring the detected, filtered signal with an oscilloscope or a spectrum analyser.

The detected signal is sent to a full-wave rectifier consisting of $IC_{13,14}$, and associated parts, Fig. 4. When $S_1$ is set for average readings, the low impedance output of $IC_{14}$ charges and discharges $C_a$ through $R_c$ so that the voltage across $C_a$ is the average value of the rectified signal.

Two series diodes at $IC_{15}$ limit the voltage to which $C_a$ can be charged in off-scale conditions such as switching transients. This minimises the settling time once normal conditions have returned. When $S_1$ is set for peak readings, $IC_{15}$ and its feedback diode form a low impedance charging source for $C_a$ through $R_d$ but no discharge path; the sole discharge path is then through $R_e$.

## Time constants

Charge and discharge time constants for average readings and the discharge time constant for peak readings are 7.3 seconds; this somewhat long time constant gives stable readings even for the 1.8s period of 33rev/min wow. The charge time constant for peak readings is 36ms, which is short enough for a significant response to only a few cycles of a 180Hz flutter signal.

Reduce $R_d$ to decrease the peak-reading time

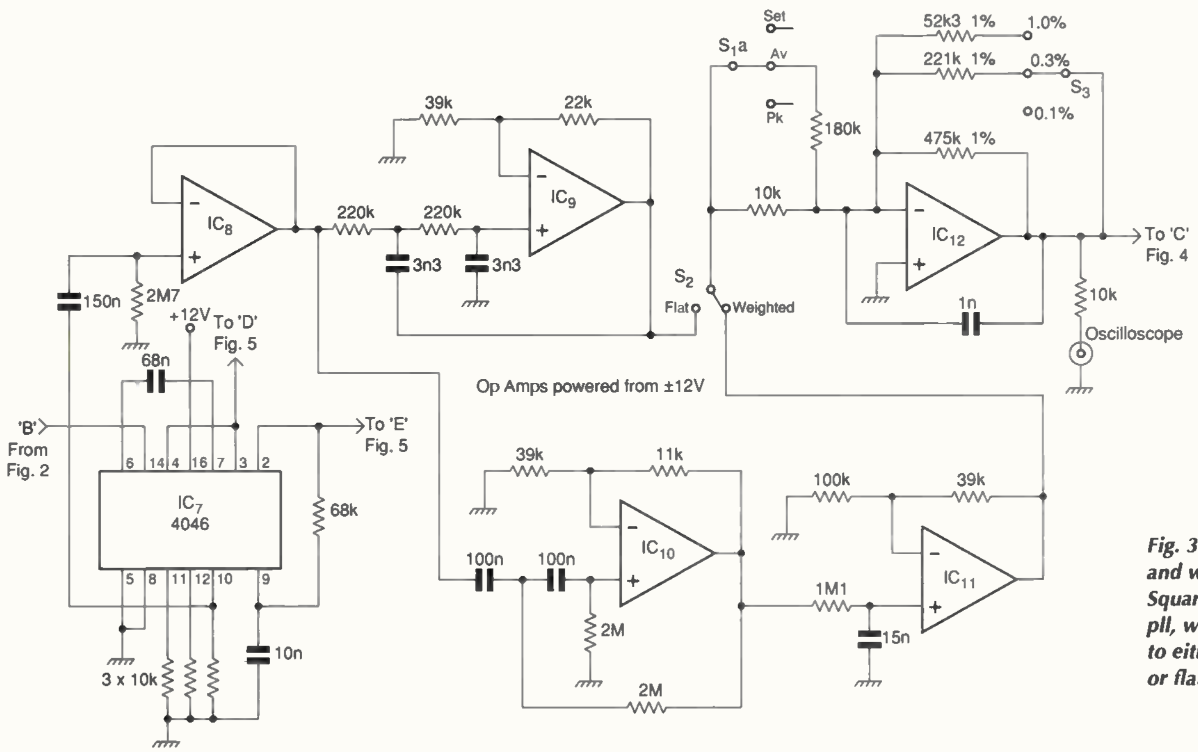


*Fig. 3. Phase-locked loop and weighting filter. Squared input feeds the pll, whose output passes to either the weighted or flat filter.*

constant at your own risk. Doing so will drastically increase sensitivity to impulse noise.

Charge voltage of Ca is sensed by $IC_{16}$, which drives the meter movement. The movement, one that happened to be on hand, has a 200µA full-scale sensitivity and a resistance of 1k3Ω. Standards associations specify meter ballistics, but I chose not to attempt to duplicate these specifications electronically. Instead, I subjectively determined a driving impedance for the movement such that the resulting ballistics appeared close to those of a borrowed professional wow-and-flutter meter.

The movement's open-circuit ballistics are on the sluggish side, so a rather high driving impedance proved satisfactory. The resistors associated with $IC_{16}$ could be changed to accommodate virtually any reasonable meter movement.

Circuit Fig. 5 serves two purposes. First, the logic circuitry detects the lock condition of the pll unambiguously. I wanted the led at $Tr_2$ to be completely extinguished when the pll is not perfectly locked and to be lighted without flicker when the pll is locked. I also wanted it to to follow the state of lock virtually instantaneously. If this situation can be accomplished directly from the 4046 without external logic, I haven't discovered how.

Secondly, $Tr_3$ discharges $C_a$ summarily when the pll falls out of lock, preventing wild swings of the meter pointer when the carrier is switched in or out or when the instrument is switched on. This function, plus the series diodes at $IC_{15}$ in Fig. 4, keeps the meter tamed.

The power supply in Fig. 6 is straightforward. A separate +12V supply for the pll is necessary to prevent 3kHz spikes originating in the pll from leaking into the rest of the circuit.

## Calibration options

Several options exist for calibration. When a 200µA, 1.3kΩ meter movement is used, the simplest is merely to set the calibration potentiometer, Fig. 4, to the centre of its range and forget it. Although absolute accuracy will suffer, the instrument will be perfectly satisfactory for almost all uses. Should you find this approach unacceptable, you have at least three alternatives for accurate calibration.

In the first method, the demodulator-filter sensitivity is measured, and a signal generator is used to inject a simulated flutter signal of amplitude corresponding to 1% into the amplifier preceding the meter rectifiers. Temporarily short the 150nF capacitor at $IC_8$ of Fig. 3. Connect a stable audio generator set to 3kHz to the system input. With $S_1$ switched to 'set', peak the tuning control and adjust the gain control for a reading in the top two-thirds of the meter scale.

Monitor the generator frequency with a counter and the voltage at the output of $IC_9$ with a digital voltmeter. Vary the generator frequency around 3kHz and tabulate frequency versus the $IC_9$ output voltage. The change in voltage divided by the corresponding percentage change in frequency is the sensitivity of the demodulator and the $IC_9$ lowpass filter. In my case this was 0.18V per 1.0% frequency deviation.

Remove the short from the 150nF capacitor. Temporarily ground $Tr_3$'s base, Fig. 5, and disconnect the pole of $S_2$ from the pole of $S_{1A}$ in Fig. 3. Inject a 100Hz or so signal with an amplitude corresponding to 1.0% peak deviation, for example 0.18V peak, into the pole of $S_{1A}$. Set $S_1$ to 'peak' and $S_3$ to '1.0%. Adjust the calibration pot for a 1.0 reading. If 3kHz and 3.15kHz are not well within the capture range of the pll, trim the 68nF capacitor at $IC_7$.

If you have a good ear for music, a own a generator, but no counter, then zero-beat the generator to a piano or other fixed-pitch musical instrument. The frequency of each note is 1.059463 times that of its semitone-lower neighbour. On the International music scale, defined by $A_4$=435Hz, $G_7$ is 3100Hz. On the American Standard scale, where $A_4$=440Hz, $G_7$ is 3136Hz.

For the second method, lash up an fm generator with an 8038 function generator chip oscillating at 3kHz and swept to 1.0% peak deviation by a low-frequency second oscillator. Initially, connect a variable dc voltage source and a dvm to the modulation terminal of the 8038, and monitor the 8038's oscillation frequency with a counter. Once the 8038's modulation sensitivity is known, its modulation terminal can be driven by a sine wave of appropriate amplitude for 1.0% peak deviation. The output of the 8038 is then used as a test signal for the wow and flutter meter.

The third method uses a desk-top computer with a sound card. A few lines of code can generate a sound file that represents a digitised 3kHz carrier modulated at any level and frequency and that can be played through the sound card. Or, to avoid the programming, use one of the several available inexpensive digital audio editors that feature flexible generators.

I have tried all three methods of calibration. The most accurate and flexible is the third, but not everyone has the necessary computer hardware and either the software or the desire

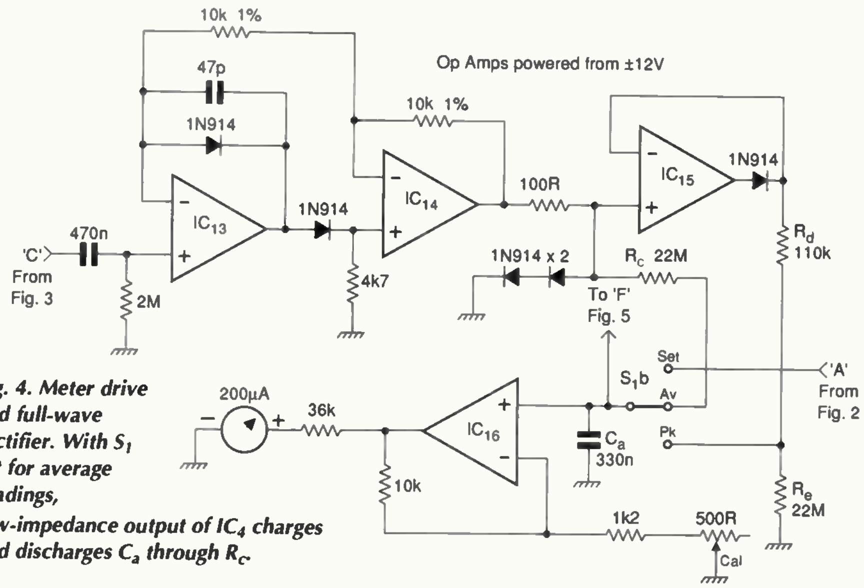


*Fig. 4. Meter drive and full-wave rectifier. With $S_1$ set for average readings, low-impedance output of $IC_4$ charges and discharges $C_a$ through $R_c$.*

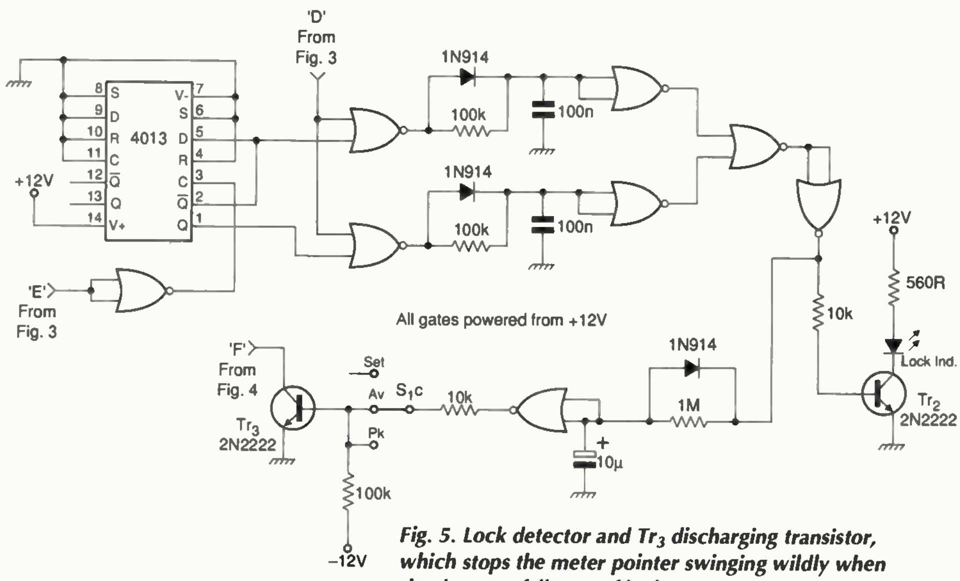


*Fig. 5. Lock detector and $Tr_3$ discharging transistor, which stops the meter pointer swinging wildly when the detector falls out of lock.*

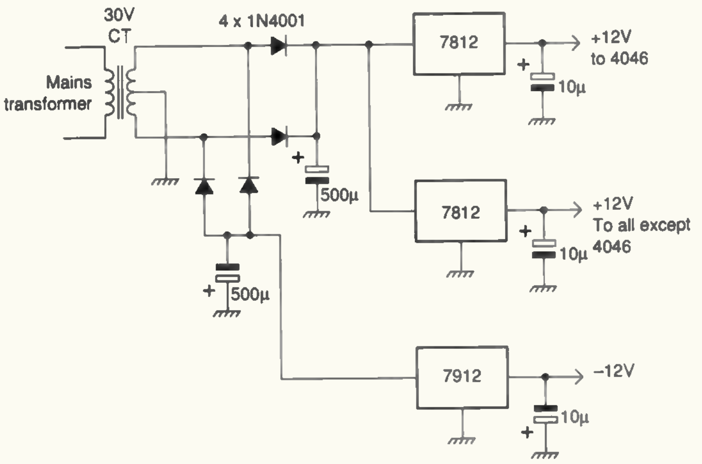


*Fig. 5. Power supply. Mains-rated filtering at the transformer primary may be needed to prevent mains borne interference affecting readings.*

to write software. Methods two and three have the theoretical advantage of allowing for testing or calibration of the whole system at once. The first method is fast, almost as accurate as the third, and can be done in a pinch with only an audio generator and a voltmeter.

## Summary

This simple meter has been in use for years with no problems. The effects of flywheel or platter weight and balance, bearing wear, and drive-belt quality are easy to measure objectively.

Readings are within a few percentage points of those obtained on a calibrated, professional wow and flutter meter when both meters are set up similarly and driven with a sine-modulated test carrier. Congruence is sometimes rather less for non-sinusoidal impulsive functions, and this difference may be due in part to the differences in meter movement ballistics.

Drift measurement was not included in the design, because drift is easily tracked with a frequency counter. This feature could be included with the addition of a dc amplifier and a second meter movement having a centre-scale zero. Provision would be required to tune the pll exactly to the carrier frequency.

One last word: if you've never measured wow and flutter, you'll be surprised at the apparent discrepancy between manufacturers' specifications and reality. The peak-reading, non-weighted settings are the most useful for trouble-shooting and for testing design changes, but new equipment is usually specified with a weighted rms-calibrated average reading. The difference between these measurements can be nearly an order of magnitude. On the other hand, a superb turntable may have less speed variation than the residual of even a good test record, especially given the difficulty of centring the record precisely on the platter. ■

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2. Williamson, R., 'Volume control attenuates to zero', *Electronics World*, 97:29, 1991.
3. Terman, F.E., Radio Engineering, McGraw-Hill, New York, 1947, pp485-489.

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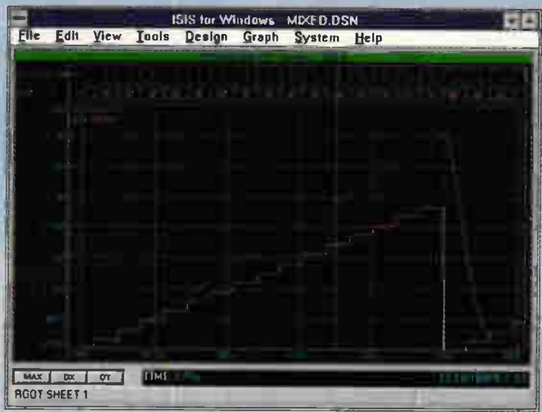


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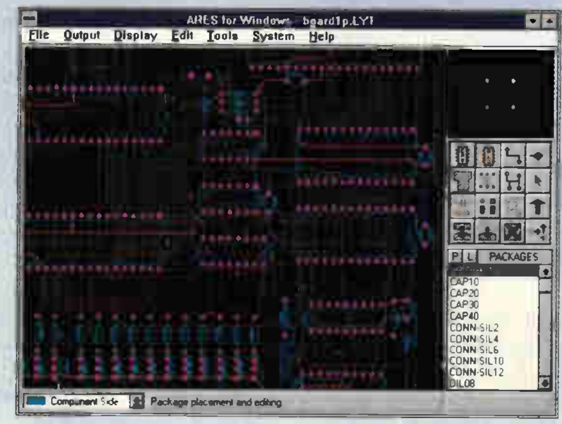


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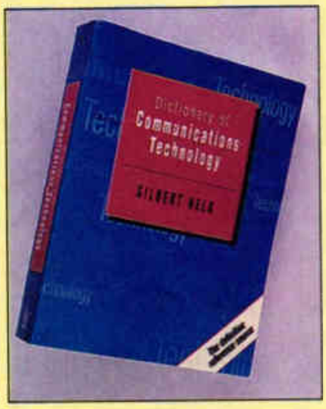


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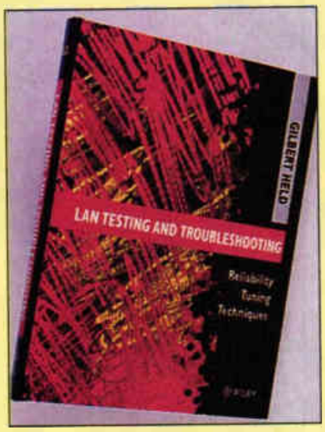


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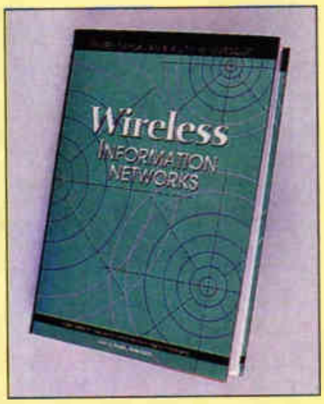


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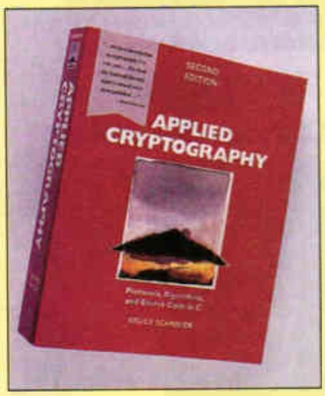


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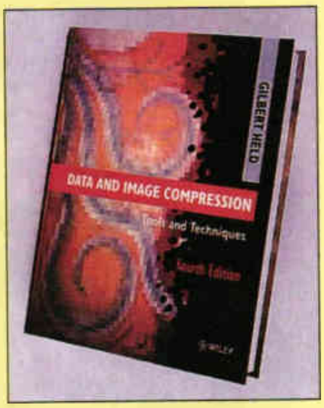


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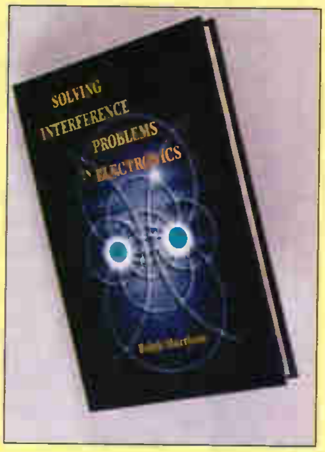


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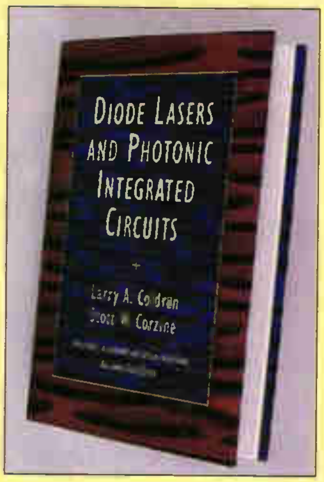


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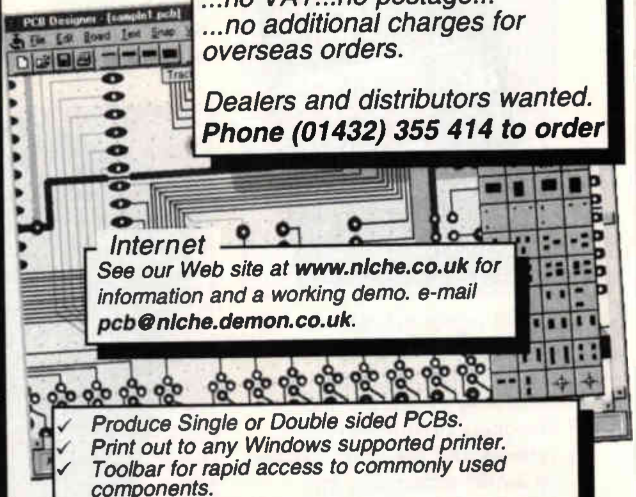

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# LETTERS

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

## LVD is not new

In his editorial, *EW* Oct '96, Rod Cooper paints a more gloomy picture than is justified – and one statement is quite wrong. The Low Voltage Directive came into force in 1976 – yes, 20 years ago. What happened on 1 January 1997 was that you had to use CE mark. But you have had to do that, for safety as well, since 1 January 1996, for anything that falls within the EMC Directive.

It is very important for the health and welfare of the electronics industry in the UK not to encourage people to close down projects or even companies through fear of the Directives. More stringent regulations have been in force in Germany and Austria for more than a decade, and their small electronics businesses have learned how to cope: so it is possible.

The chance of any large company trying to use a Directive against a very small competitor is minimal. It is certainly impossible to forecast that there will be no chief executive who suffers a fit of paranoia and goes down that route, but most would see that the game is not worth the candle – particularly if there are actually no grounds for the complaint.

It is true that the engineering profession is disunited, but it is not to be expected that they could unite in opposition to requirements introduced under the EMC Directive. For example, the requirements of EN 61000-3 (all four Sections) are bound to be looked on with favour by the power industry, which would like to preserve their 50Hz sine-waves undistorted. But the regulations are a bane to equipment designers.

The idea of eliminating immunity tests has been raised before, and seems attractive at first sight. But lack of immunity can result in quite dangerous situations, which are almost entirely unpredictable because the manufacturer often has no idea what his equipment may be used for. Of course, these are the events that captured the imaginations of the politicians in the first place, and helped to 'sell' the Directives to them.

Furthermore, complaints of lack of immunity in the field receive virtually no publicity, but the broadcasters, BT and the electricity suppliers receive thousands of complaints every year – usually directed to quite the wrong body. The cost of following these up, and solving them where possible, is quite large.

On the subject of EMC in Australia (page 724 of the same issue), without the 'benefit' of Brussels, the SMA seems to have produced requirements which are more severe than apply in Europe at present, although they have backed off on some points.

***John Woodgate***
*Rayleigh*
*Essex*

## Fooling stereo

In his article 'Music in mind' in the Oct. '96 issue, Ian Hickman wondered why his gyroscopically-controlled headphones refuse to work in stereo.

I wasn't totally convinced by explanations from the experts in the letters pages of subsequent issues, so here's my guess. While processing time or volume differences, the brain needs the signal from both ears to be approximately equal, as in a mono-signal. It is impossible to determine phase difference from two completely different signals.

If you mixed, say, a third of the right-hand channel's signal to the left channel and a third of the left channel's signal to the right, the brain would maybe have enough information to fool it.

***Hannu Multanen***
*Joensuu*
*Finland*

## Preamp defence

I would like to comment on Mr Allen Wright's letter (*Electronics World*, Nov. 1996) concerning Douglas Self's pre-amp.

My comments come from two viewpoints – as a collaborator with Douglas in the design of the pcb for the pre-amp, and as a self-employed designer in the professional audio industry.

Over the past 15 years, my work has taken me into a number of UK companies specialising in the design and manufacture of top-of-the-range mixing consoles that end up in radio, television and recording studios throughout the world. All the companies use *5532* and *5534* devices; they also all use large-value electrolytics for signal coupling.

It is a fact that Douglas's preamplifier has been designed with the same criteria used to design professional mixing consoles.

Mr Wright states that budget mixing console manufacturers stopped using the *5532* years ago. I will not contest the budget manufacturers' lack of use of the *5532*, as my experience is not at the budget end of the market. But may I be so bold as to suggest that the term 'budget' is significant? The *5532* is expensive. Is it financial constraints rather than sonic performance that preclude its use?

As for the existence of an "unpleasant sonic signature" from the *5532*, I am surprised. I would like Mr Wright to tell us more about it.

The ultimate conclusion to his statement of the existence of a "signature" is that virtually all live and recorded sound will be afflicted with the "signature" by virtue of the recording and/or broadcast equipment used to get the sound to the listener.

No matter what devices are used in a preamplifier, if it is well designed, it will faithfully reproduce at its output what is offered to its input. The output will include Mr Wright's alleged, "unpleasant sonic signature", which will have been introduced earlier in the signal chain, and is therefore beyond the control of the pre-amp designer or the listener.

***Gareth Connor***
*GJC Designs*
*London*

## CAD inadequacies?

The reviews on pcb cad failed to answer the one question I wanted answered. All the packages seem to work on the same basis: having designed your circuit, you use the schematic drawing package to produce a professional printable schematic and the computer does the rest – i.e. it produces for you a parts list, it captures the circuit for the layout and even simulates the circuit performance.

The problem comes in the phrase 'having designed the circuit'. A word processor package doesn't assume that you had produced hand written draft before you start typing and pcb cad shouldn't assume you have done a paper circuit first. I design the circuit on-screen. I may import bits from earlier circuits. When I draw a bias chain I don't know what the values are going to be, that is left until I'm happy that I have got the configuration right. The design process may include several changes of mind, adding components, taking the out, etc.

## Q&A

### Shifting phases?

I am looking for a circuit to phase shift by 90° the components of a signal with frequencies in the range 10Hz to about 350Hz. Although simple integration or differentiation can achieve this, they do so at the expense of a frequency dependent change in the signal amplitude which I cannot use.

In *Electronics World* April 1993, Terrance Finegan mentions that such 'a useful analogue function may be realised differentially with all-pass filters', but this hint has proven insufficient. Text books even mentioning all-pass filters seem to be the exception – at my level of mathematical sophistication anyhow.

Are there any readers with a solution to this problem? It would help me, and being an unusual function may inspire other interesting designs.

***Alan Scrimgeour***
*London*

*(This question is repeated from p 790, Oct '96 issue – ed)*

In answer to Alan Scrimgeour's query, it is only possible to produce an approximation to a wide-band 90º phase-shift. The complexity of the solution depends very much on the tolerable errors. To handle 10Hz signals, only active all-pass filters are really practicable. The design procedure is too lengthy to reproduce here but is not difficult, and a good source of the information is the 'Electronic filter design handbook' by A B Williams (McGraw Hill). The ISBN of the first edition is 0 07 070430 9, and this deals with the subject fully, but there is a later edition.

***John Woodgate***
*Rayleigh*
*Essex*

In answer to the question from Alan Scrimgeour: The need to phase shift audio frequencies by 90º is also required in the phasing method of ssb generation. The article on this subject in *Electronics World* March 1994, pp202-206 covers this subject along with the merits of polyphase networks versus 'all-pass' filters.

***John Crabtree***
*Connecticut*
*USA*

When I am happy with the configuration I renumber the components, take a print, get the calculator out and work out the values and decide on whether a capacitor needs to be a 1% polystyrene, or a ceramic, or whatever. In other words when I am drawing the circuit I do not know either the value or the package of the components and the chances of the circuit reference remaining unchanged is negligible.

To simply re-number one component in *Easy PC Professional XM* requires switching from keyboard to mouse to keyboard to mouse to keyboard to keyboard and finally to mouse.

What I want is a cad package which at the schematic stage does not worry about value or package size.

***John Kennaugh***
*Callington*
*Cornwall*

*Rod replies:*
It think that John Kennaugh has not read the first issue, i.e. Sept. '96, in which I said, "The review is not intended to enable the reader to choose one program to suit his or her particular requirements.." and this letter is about just that.

I don't think John can have read the October issue either, in which I said "I think relative to having the circuit drawn before you on real paper, all methods of representing the circuit on screen are inferior if planning a circuit from scratch rather than just drafting... neither is the mouse a good drawing tool."

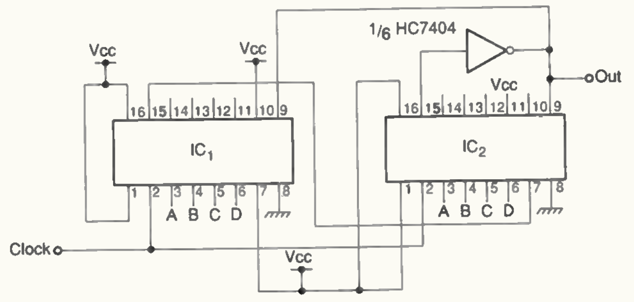
The comparison between a word processor and cad is not satisfactory. It would be valid if you had to give a value and specify a package for the letter "A", letter "B" and so on, then position it as you do with the parts in a schematic program. Then a word processor would be just as clumsy as today's schematic drawing programs!

Schematic drawing programs are only there as an entry into those things you just cannot do well with pen and paper – simulating a circuit, routeing a pcb – and are regarded as a necessary evil. The difficulties are minimised in *CircuitMaker* and *Electronics Workbench*, and I make this clear in the review, but they are still there. Moreover, in the more expensive up-market products, schematic drawing does not get any easier: you just get more features.

My review was about producing pcbs, and not about using the monitor screen as an improvised circuit design tool. So it is not surprising the review did not answer John Kennaugh's question. The very title should have told him that.

Is there a need for a 'scribble-pad' type of schematic drawing program for designing rather than drafting? I'm not sure there is. If there were a need, I think that one of the current generation of software writers would have produced it by now. ■

***Rod Cooper***
*Sutton Coldfield*
*West Midlands*




## Divide by integers to 256

This circuit appeared as part of Nick Wheeler's article on page 893 of the November 1996 issue. Apologies. The original circuit redraw contained an error in the connections around the output.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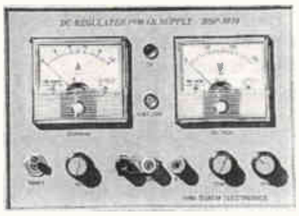

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| R.A. SMITH ANTENNA TEST SET type 12-402-4 | £2000 |
| URADIUM EP501 Audio Analyser | £250 |
| FERROGRAPH RTS2 Recorder Test Set | £250 |
| KEMO Dual Variable Filter VBF/3 0.1Hz-100KHz | £200 |
| LEADER LSG216 Signal Generator | £450 |
| TEKTRONIX 1421 Vectorscope with 528A Waveform Monitor | £1500 |
| PHILIPS 5567 Vectorscope with 5565 Waveform Monitor | £1000 |
| BRADLEY 192 Scope Calibrated from | £500 |
| RACAL 9104 R.F. Power Meter 100Hz-1GHz 140W-300W | £325 |
| MARCONI TF2700 Universal Bridge. Battery Operated | from £150 |
| WAYNE KERR 8424 Digital Component Meter LCR | £200 |
| FARNELL AP100/30 0-100V; 0-30A; Autoranging | £1000 |
| FARNELL H30/100 0-30V; 0-100A | £800 |
| SORENSEN DCR600-4.5B 0-600 Volts 0-4.5 Amps | £700 |
| H.P. 6268 0-40 Volts, 0-30 Amps | £800 |
| FARNELL H60/50 0-60 Volts; 0-50 Amps | £800 |
| FARNELL H60/25 0-60 Volts; 0-25 Amps | £400 |
| FARNELL B30/10 30 Volts; 10 Amps. Variable | £150 |
| FARNELL L30-5 0-30 Volts; 0-5 Amps. 2 Meters | £150 |
| FARNELL L30E 0-30 Volts, 0-5 Amps. Metered | £100 |
| FARNELL L30-2 0-30 Volts; 0-2 Amps. Metered | £80 |
| FARNELL LT30-1 0-30 Volts, 0-1 Amp Twice | £130 |
| FARNELL L30-1 0-30 Volts; 0-1 Amp. Metered | £65 |
| THURLBY-THANDAR TSP3222 Programmable 32V; 2 Amp Twice GPIB | £300 |
| THURLBY PL320QMD 0-30V; 0-2A Twice Digital | £225 |
| BRANDENBURG Model 472R +/– 2KV Metered | £200 |

MANY OTHER POWER SUPPLIES AVAILABLE

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| H.P. 8565A 0.01-22GHz | £3000 |
| ALTECH 727 0.001-20GHz | £2000 |
| H.P. 853A with 8558B 100KHz-1500MHz | £2750 |
| H.P. 182 with 8558B 100KHz-1500MHz | from £1500 |
| MARCONI TF2370 30Hz-110MHz | £700 |
| MARCONI 2370 with TK2373 30KHz-1.25GHz | £1750 |
| MARCONI 2382 100Hz-400MHz | £4000 |
| H.P. 3582A Dual Channel 25KHz | from £2000 |
| Some H.P. 141T Systems Available – Please enquire | |

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DRS153 input 20-40vdc output 15v 3A £20
DRS243 input 29-40vdc output 24v 3A £15

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SMT20000/4 3-24vdc operation, 28-280vac 4A £5.00
ZRA6025F 28-280vd/ac operation, 28-280vac 25A £7.00

**200 WATT INVERTERS** Nicely cased units 12v input 240v output 150watt continuous, 200 max. £49 ref LOT62.

**6.8MW HELIUM NEON LASERS** New units, £65 ref LOT33

**COINSLOT TOKENS** You may have a use for these? mixed bag of 100 tokens £10 ref LOT20.

**PORTABLE X RAY MACHINE PLANS** Easy to construct plans on a simple and cheap way to build a home X-ray machine! Effective device, X-ray sealed assemblies, can be used for expermental purposes. Not a toy or for minors! £6/set. Ref F/XP1.

**TELEKINETIC ENHANCER PLANS** Mystify and amaze your friends by creating motion with no known apparent means or cause. Uses no electrical or mechanical connections, no special gimmicks yet produces positive motion and effect. Excellent for science projects, magic shows, party demonstrations or serious research & development of this strange and amazing phychic phenomenon. £4/set Ref F/TKE1.

**ELECTRONIC HYPNOSIS PLANS & DATA** This data shows several ways to put subjects under your control. Included is a full volume reference text and several construction plans that when assembled can produce highly effective stimuli. This material must be used cautiously. It is for use as entertainment at parties etc only, by those experienced in its use. £15/set. Ref F/EH2.

**GRAVITY GENERATOR PLANS** This unique plan demonstrates a simple electrical phenomena that produces an anti-gravity effect. You can actually build a small mock spaceship out of simple materials and without any visible means- cause it to levitate. £10/set Ref F/GRA1.

**WORLDS SMALLEST TESLA COIL/LIGHTENING DISPLAY GLOBE PLANS** Produces up to 750,000 volts of discharge, experiment with extraordinary HV effects, 'Plasma in a jar', St Elmo's fire, Corona, excellent science project or conversation piece. £5/set Ref F/BTC1/LG5.

**COPPER VAPOUR LASER PLANS** Produces 100mw of visible green light. High coherency and spectral quality similar to Argon laser but easier and less costly to build yet far more efficient. This particular design was developed at the Atomic Energy Commision of NEGEV in Israel. £10/set Ref F/CVL1.

**VOICE SCRAMBLER PLANS** Miniature solid state system turns speech sound into indecipherable noise that cannot be understood without a second matching unit. Use on telephone to prevent third party listening and bugging. £6/set Ref F/VS9.

**PULSED TV JOKER PLANS** Little hand held device utilises pulse techniques that will completely disrupt TV picture and sound! works on FM too! DISCRETION ADVISED. £8/set Ref F/TJ5.

**BODYHEAT TELESCOPE PLANS** Highly directional long range device uses recent technology to detect the presence of living bodies, warm and hot spots, heat leaks etc. Intended for security, law enforcement, research and development, etc. Excellent security device or very interesting science project. £8/set Ref F/BHT1.

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**ULTRASONIC BLASTER PLANS** Laboratory source of sonic shock waves. Blow holes in metal, produce 'cold' steam, atomize liquides. Many cleaning uses for PC boards, jewllery, coins, small parts etc. £6/set Ref F/ULB1.

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**ANTI DOG FORCE FIELD PLANS** Highly effective circuit produces time variable pulses of accoustical energy that dogs cannot tolerate £6/set Ref F/DOG2

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**LASER LIGHT SHOW PLANS** Do it yourself plans show three methods. £6 Ref F/LLS1

**PHASOR BLAST WAVE PISTOL SERIES PLANS** Handheld, has large transducer and battery capacity with external controls. £6/set Ref F/PSP4

**INFINITY TRANSMITTER PLANS** Telephone line grabber/ room monitor. The ultimate in home/office security and safety! simple to use! Call your home or office phone, push a secret tone on your telephone to access either. A) On premises sound and voices or B) Existing conversation with break-in capability for emergency messages. £7 Ref F/TELEGRAB.

**BUG DETECTOR PLANS** Is that someone getting the goods on you? Easy to construct device locates any hidden source of radio energy! Sniffs out and finds bugs and other sources of bothersome interference. Detects low, high and UHF frequencies. £5/set Ref F/BD1.

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**ELECTROMAGNETIC GUN PLANS** Projects a metal object a considerable distance-requires adult supervision £5 ref F/EML2.

**ELECTRIC MAN PLANS, SHOCK PEOPLE WITH THE TOUCH OF YOUR HAND!** £5/set Ref F/EMA1.

**PARABOLIC DISH MICROPHONE PLANS** Listen to distant sounds and voices, open windows, sound sources in 'hard to get' or hostile premises. Uses satellite technology to gather distant sounds and focus them to our ultra sensitive electronics. Plans also show an optional wireless link system. £8/set ref F/PM5

**2 FOR 1 MULTIFUNCTIONAL HIGH FREQUENCY AND HIGH DC VOLTAGE, SOLID STATE TESLA COIL AND VARIABLE 100,000 VDC OUTPUT GENERATOR PLANS** Operates on 9-12vdc, many possible experiments. £10 Ref F/HVM7/TCL4.

**INFINITY TRANSMITTERS** The ultimate 'bug' fits to any phone or line, undetectable, listen to the conversations in the room from anywhere in the world! 24 hours a day 7 days a week! just call the number and press a button on the mini controller (supplied) and you can hear everything! Monitor conversations for as long as you choose £249 each, complete with leads and mini controller! Ref LOT9. Undetectable with normal RF detectors, fitted in seconds, no batteries required, lasts forever!

**SWITCHED MODE PSU'S** 244 watt, +5 32A, +12 6A, -5 0.2A, -12 0.2A. There is also an optional 3.3v 25A rail available. 120/240v I/P. Cased, 175x90x145mm. IEC inlet Suitable for PC use (6 d/drive connectors 1 m/board). £10 ref PSU1.

**VIDEO PROCESSOR UNITS?/6v 10AH BATTS/12V 8A TX** Not too sure what the function of these units is but they certainly make good strippers! Measures 390X320X120mm, on the front are controls for scan speed, scan delay, scan mode, loads of connections on the rear. Inside 2 x 6v 10AH sealed lead acid batts, pcb's and a 8A? 12v torroidal transformer (mains in). Condition not known, may have one or two broken knobs due to poor storage. £17.50 ref VP2

**RETRON NIGHT SIGHT** Recognition of a standing man at 300m in 1/4 moonlight, hermatically sealed, runs on 2 AA batteries, 80mm F1.5 lens, 20mw Infrared laser included. £325 ref RETRON.

**MINI FM TRANSMITTER KIT** Very high gain preamp, supplied complete with FET electret microphone. Designed to cover 88-108 Mhz but easily changed to cover 63-130 Mhz. Works with a common 9v (PP3) battery. 0.2W RF. £7 Ref 1001.

**3-30V POWER SUPPLY KIT** Variable, stabilized power supply for lab use. Short circuit protected. suitable for profesional or amateur use 24v 3A transformer is needed to complete the kit. £14 Ref 1007.

**1 WATT FM TRANSMITTER KIT** Supplied with piezo electric mic. 8-30vdc. At 25-30v you will get nearly 2 watts! £12 ref 1009.

**FM/AM SCANNER KIT** Well not quite, you have to turn the knob your self but you will hear things on this radio that you would not hear on an ordinary radio (even TV). Covers 50-160mhz on both AM and FM. Built in 5 watt amplifier, inc speaker. £15 ref 1013.

**3 CHANNEL SOUND TO LIGHT KIT** Wireless system, mains operated, separate sensitivity adjustment for each channel, 1,200 w power handling, microphone included. £14 Ref 1014.

**4 WATT FM TRANSMITTER KIT** Small but powerful FM transmitter, 3 RF stages, microphone and audio preamp included. £20 Ref 1028.

**STROBE LIGHT KIT** Adjustable from 1-60 hz (a lot faster than conventional strobes). Mains operated. £16 Ref 1037.

**COMBINATION LOCK KIT** 9key, programmable, complete with keypad, will switch 2A mains. 9v dc operation. £10 ref 1114.

**PHONE BUG DETECTOR KIT** This device will warn you if somebody is eavesdropping on your line. £6 ref 1130.

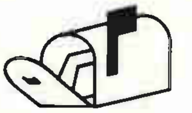
**ROBOT VOICE KIT** Interesting circuit that distorts your voice! adjustable, answer the phone with a different voice! 12vdc £9 ref 1131

**TELEPHONE BUG KIT** Small bug powered by the 'phone line, starts transmitting as soon as the phone is picked up! £8 Ref 1135.

**3 CHANNEL LIGHT CHASER KIT** 800 watts per channel, speed and direction controls supplied with 12 LEDS (you can fit triacs instead to make kit mains, not supplied) 9-12vdc £17 ref 1026.

**12V FLOURESCENT LAMP DRIVER KIT** Light up 4 foot tubes from your car battery! 9v 2a transformer also required. £8 ref 1069.

**VOX SWITCH KIT** Sound activated switch ideal for making bugging tape recorders etc, adjustable sensitivity. £8 ref 1073.



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**PREAMP MIXER KIT** 3 input mono mixer, sep bass and treble controls plus individual level controls, 18vdc, input sens 100mA. £15 ref 1052.

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**15 WATT FM TRANSMITTER (BUILT)** 4 stage high power, preamp required 12-18vdc, can use ground plane, yagi or open dipole. £69 ref 1021.

**HUMIDITY METER KIT** Builds into a precision LCD humidity meter, 9 ic design, pcb, lcd display and all components included. £29

**PC TIMER KIT** Four channel output controlled by your PC, will switch high current mains with relays (supplied). Software supplied so you can program the channels to do what you want whenever you want. Minimum system configeration is 286, VGA, 4.1,640k, serial port, hard drive with min 100k free. £24.99

**FM CORDLESS MICROPHONE** This unit is an FM broadcasting station in miniature, 3 transistor transmitter with electret condenser mic+fet amp design result in maximum sensitivity and broad frequency response. 90-105mhz, 50-1500hz, 500 foot range in open country! PP3 battery required. £15.00 ref 15P42A

**MAGNETIC MARBLES** They have been around for a number of years but still give rise to curiosity and amazement. A pack of 12 is just £3.99 ref GI/R20

**NICKEL PLATING KIT** Proffesional electroplating kit that will transform rusting parts into showpieces in 3 hours! Will plate onto steel, iron, bronze, gunmetal, copper, welded, silver soldered or brazed joints. Kit includes enough to plate 1,000 sq inches. You will also need a 12v supply, a container and 2 12v light bulbs. £39.99 ref NIK39.

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**BUGGING TAPE RECORDER** Small voice activated recorder, uses micro cassette complete with headphones. £28.99 ref MAR29P1.

**POWER SUPPLY** fully cased with mains and o/p leads 17v DC 900mA output. Bargain price £5.99 ref MAG6P9

**9v DC POWER SUPPLY** Standard plug in type 150ma 9v DC with lead and DC power plug. price for two is £2.99 ref AUG3P4.

**COMPOSITE VIDEO KIT.** Converts composite video into separate H sync, V sync, and video. 12v DC. £8.00 REF: MAG8P2.

**FUTURE PC POWER SUPPLIES** These are 295x135x60mm, 4 drive connectors 1 mother board connector. 150watt, 12v fan, iec inlet and on/off switch. £12 Ref EF6.

**VENUS FLYTRAP KIT** Grow your own carnivorous plant with this simple kit £3 ref EF34.

**6"X12" AMORPHOUS SOLAR PANEL** 12v 155x310mm 130mA. Bargain price just £5.99 ea REF MAG6P12.

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

**ROCK LIGHTS** Unusual things these, two pieces of rock that glow when rubbed together! belived to cause rain! £3 a pair Ref EF29.

**3' by 1' AMORPHOUS SOLAR PANELS** 14.5v, 700mA 10 watts, aluminium frame, screw terminals, £44.95 ref MAG45.

**ELECTRONIC ACCUPUNCTURE KIT** Builds into an electronic version instead of needles! good to experiment with. £7 ref 7P30

**SHOCKING COIL KIT** Build this little battery operated device into all sorts of things, also gets worms out of the ground! £7 ref 7P36.

**FLYING PARROTS** Easily assembled kit that builds a parrot that actually flaps its wings and flies! 50 m range £6 ref EF2.

**HIGH POWER CATAPULTS** Hinged arm brace for stability, tempered steel yoke, super strength latex power bands. Departure speed of ammunition is in excess of 200 miles per hour! Range of over 200 metres! £7.99 ref R/9.

**BALLON MANUFACTURING KIT** British made, small blob blows into a large, longlasting balloon, hours of fun! £3.99 ref GI/E99R

**9-0-9V 4A TRANSFORMERS**, chassis mount. £7 ref LOT19A

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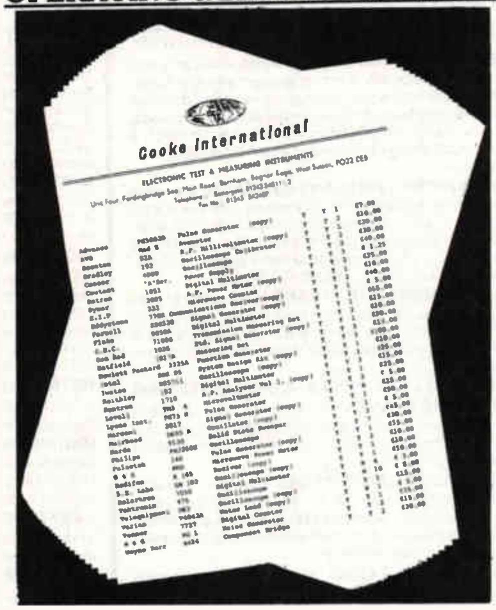

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## ADVERTISERS' INDEX

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The British Antarctic Survey, a Government-funded body, organises and carries out a balanced and optimal programme of research in Antarctica of global significance in the Earth, Atmospheric and Life Sciences. As well as its headquarters building on the outskirts of Cambridge, three permanently manned stations and one summer only station are maintained in the Antarctic.

We are looking to recruit an Instrumentation Scientist/Technician to work with the atmospheric boundary layer group. Duties will include calibration and maintenance of micrometeorological equipment for eventual deployment in Antarctica. Responsible for the upkeep of hardware documentation, other duties will also include the repair and possible modification of returning field instruments and some upgrading of 'realtime' logger software.

As you will spend up to six months in the Antarctic each austral summer and assist in the deployment of new equipment, you must be physically fit.

The post is for three years.

You will have a degree in Electronic Engineering, Physics or equivalent. Post-graduate experience in instrumentation would be highly desirable. However, no experience of low temperature or extreme environment equipment design is expected and training in these areas will be provided at the BAS Headquarters in Cambridge.

Starting salary will be from £13,698 per annum depending on qualifications and experience.

**For further details and an application form please contact the Personnel Section, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET. Tel: 01223 251508/507. Please quote ref: BAS 55/96. The closing date for completed application forms is 23 January 1997.**

British Antarctic Survey
Natural Environment Research Council

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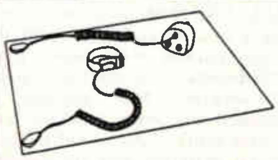

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ANRITSU MS420J 10Hz-30MHz network/spectrum analyser £5000
AVCOM – portable, battery operated, to 1000MHz £2000
TEKTRONIX 492 21GHz portable spectrum analyser, with options 1, 2 and 3 £6500 or £7500 with multiplexor and mixers to 40GHz
HP8711A 300kHz-1.3GHz network analyser £4000
HP8753A vector network analyser, 3GHz £7500
HP8702B lightwave component analyser (options 006 011) 6GHz £10000
HP8559A/182T 21GHz £4500
HP8557A/182T 350MHz £1500
HP8590A 1.8GHz portable, RS232 option £4250

## MARCONI INSTRUMENTS

2018 synthesized AM/FM signal generator 80kHz-520MHz £1250
2019 synthesized AM/FM signal gen 80kHz-1040MHz £2000
2305 modulation meter £2500
2828A/2829 digital simulator/analyser £500
2955 radio communications test set £3250
6460/6421 power meter & sensor 10MHz-12.4GHz £350
65xx waveguide detector for use with 6501//2-scalar analysers £350
TF2910 TV interval timer £250

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## TEST EQUIPMENT

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ANRITSU MS420J network/spectrum analyser 10Hz-30MHz £500
BRUEL & KJAER 2307 level recorder £1000
BRUEL & KJAER 2308 analogue X-Y pen recorder £750
CHASE LFR1000 interference measuring receiver 9kHz-150kHz £1000
DATRON 1061 & 1061A – various, digital multimeter & 1065 – call from £500
DATRON 1065 digital multimeter all ranges plus IEEE £500
FARNELL SSG2000 synthesized signal generator 10Hz-2000MHz £2500

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*ISO9002 ACCREDITED STOCKIST MEASUREMENT & TEST EQUIPMENT*

PHILIPS PM5167 1mHz-10MHz function generator £275
RACAL-DANA 9300 milli-voltmeter £400
RACAL-DANA 9301A true RMS RF milli-voltmeter £350
SCHLUMBERGER 7081 precision voltmeter 8.5 digits £2750
TEKTRONIX P6201 FET PROBE £350
WANDEL & GOLTERMANN WM30 level tracer £500
WANDEL & GOLTERMANN PJM-4S jitter meter for SONET & SDH £5500
WAVETEK 23 synthesized function generator 0.01Hz-12MHz £1250
WAVETEK 1067 opt 522 1-500MHz sweep generator £500
WAYNE KERR 3220 20A bias unit (for 3245 inductance analyser) £1250
TEKTRONIX AM503/P6303 current probe £1500

## HEWLETT PACKARD

1640B serial data generator £500
3764A digital transmission analyser £1500
3335A synthesizer/level generator £2000
3235A switch/test unit £1000
3324A synthesized function generator £2000
33320G/33322G programmable attenuators 4GHz, with driver 11713A £1000
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37900D signalling test set with 2 x 37915A interface cards £5500
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435B microwave power meter, analogue £400
5386A 3GHz frequency counter £1500
54100A 1GHz digitizing oscilloscope, now inc 2 x 1GHz active probes £2000
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8018A serial data generator £1000
8082A pulse generator 250MHz £2000
8111A pulse generator 20MHz £1250
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816A slotted line 1.8-18GHz with 809C & 447B probe £500
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87510A gain-phase analyser 100kHz-300MHz £6500
8753A 3GHz vector network analyser £7500
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J2219A 486-based, colour option main-frame £1000
J2219A/J2171A 486-based colour screne option network advisor £3000

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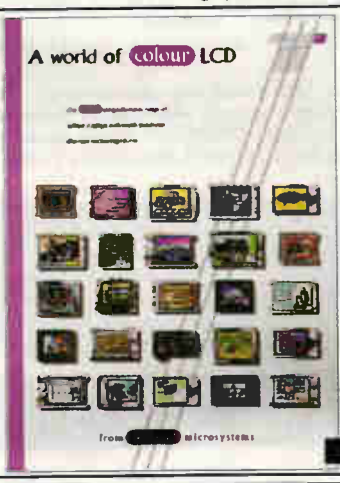


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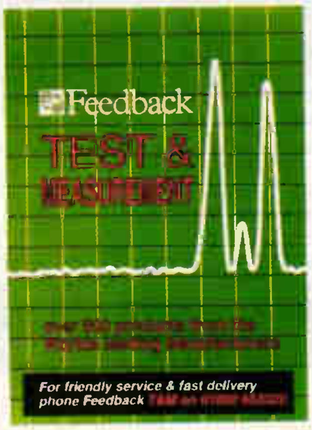


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| Atmel Part Code | 89C51 | 89LV51 | 89C52 | 89LV52 | 89C55 | 89S8252 | 89C2051 | 89C1051 |
|---|---|---|---|---|---|---|---|---|
| Flash Code ROM (bytes) | 4K | 4K | 8K | 8K | 20K | 8K | 2K | 1K |
| RAM (bytes) | 128 | 128 | 256 | 256 | 256 | 256 | 128 | 64 |
| EEPROM | - | - | - | - | - | 2K | - | - |
| [illegible] | [illegible] | [illegible] | - | - | - | [illegible] | [illegible] | [illegible] |
| I/O Pins | 32 | 32 | 32 | 32 | 32 | 32 | 15 | 15 |
| [illegible] | 2 | 2 | 3 | [illegible] | [illegible] | [illegible] | 2 | [illegible] |
| Watchdog timer | - | - | - | | - | YES | - | - |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Serial UART (full duplex) | YES | YES | YES | YES | YES | YES | YES | - |
| [illegible] | [illegible] | [illegible] | [illegible] | - | - | YES | [illegible] | [illegible] |
| Analogue comparator | - | - | - | - | - | - | YES | YES |
| [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Package Pins (DIL) | 40 | 40 | 40 | 40 | 40 | 40 | 20 | 20 |

- Atmel microcontrollers feature on-chip re-programmable FLASH code memory
- FLASH is electrically erasable in under 15ms (no need for UV eraser)
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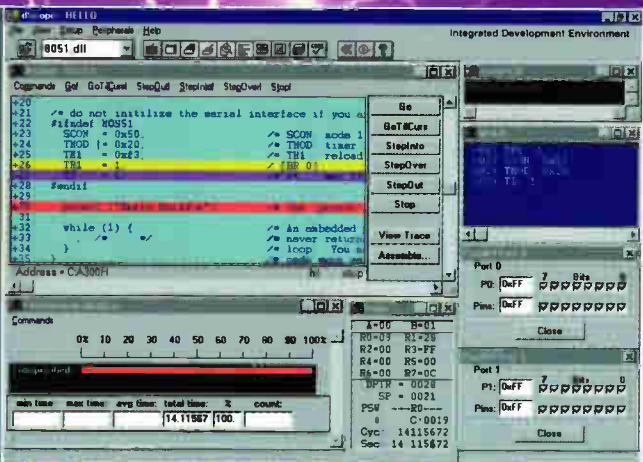
- 89C2051 is a single-chip 8051 in a 20 pin package...even retaining the serial port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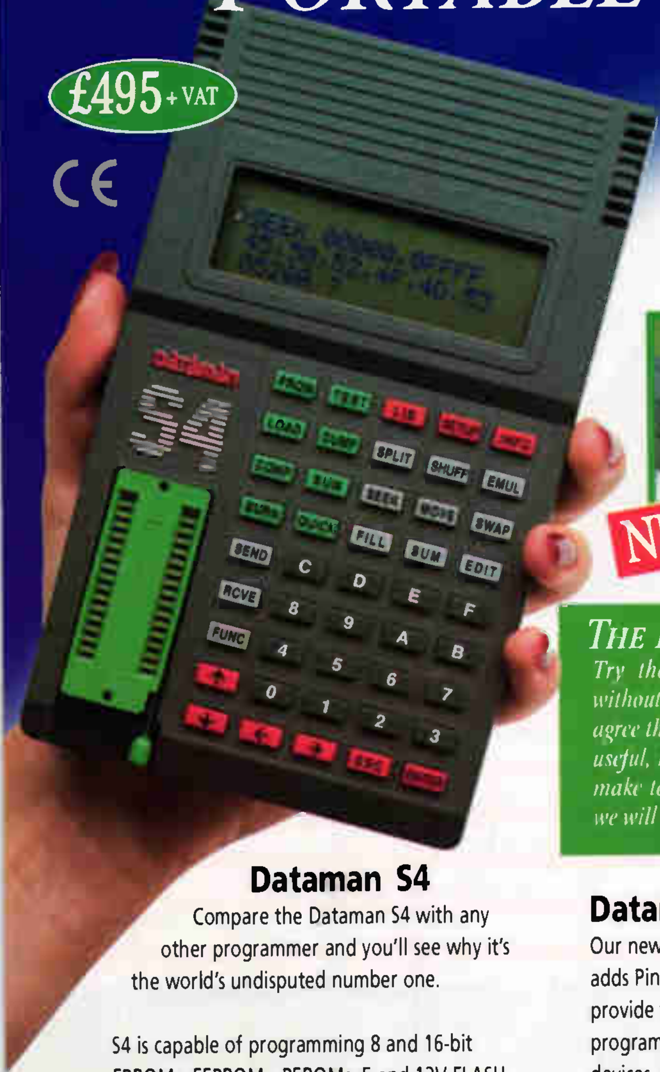


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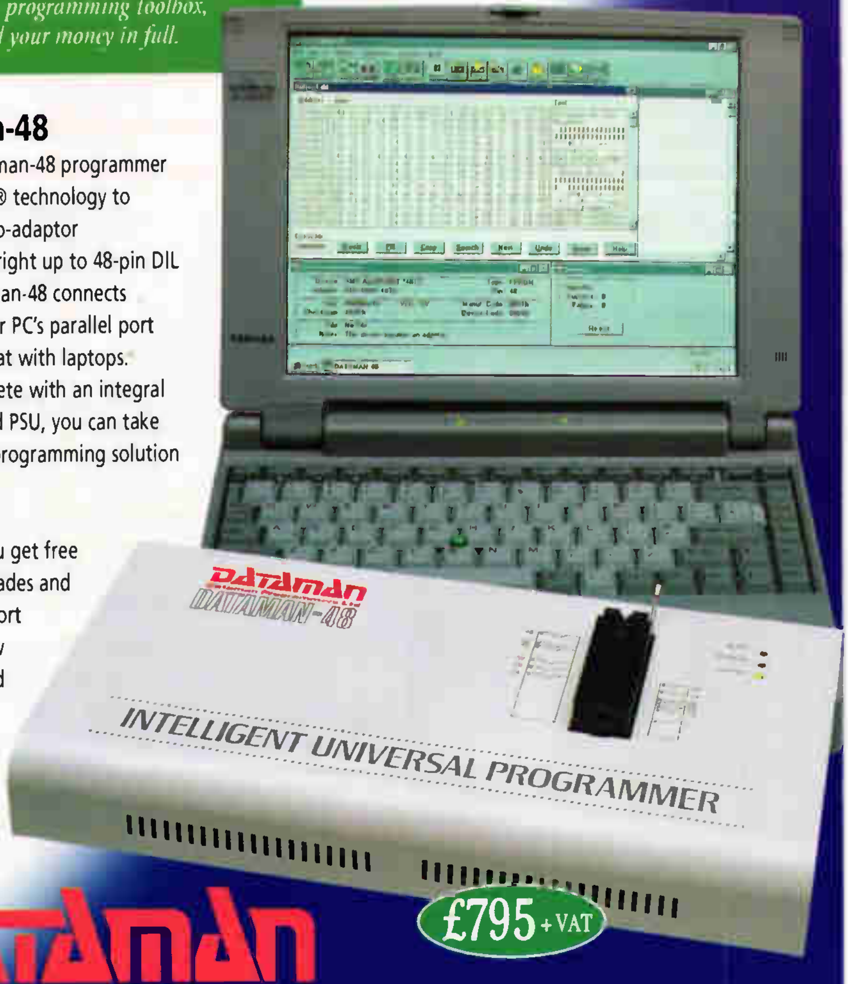


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