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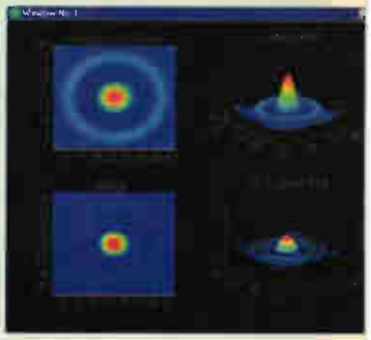

A new language for helping scientists and engineers to visualise data is available to Electronics World readers exclusively at discounts to 44% – see page 464.

This Kenwood 20MHz dual-trace oscilloscope is on offer to EW readers at just £319 – turn to page 471.

Cars with surround-sound systems based on flat-panel loudspeakers could appear this year – see page 444.

JULY ISSUE
ON SALE 5 JUNE

Pre-election blues

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NEWSTRADE ENQUIRIES
0171 261 7704

The election campaign had its moments. Forget Neil Hamilton and Martin Bell. Our vote for the most intriguing comment of the campaign came from Ian Taylor MP, Minister for Science and Technology in pre-election days.

"We now have a semiconductor industry in this country second to none," said the minister.

This remark may be surprising to many readers, familiar with the long list of failures in the UK semiconductor industry from GEC's closure of Elliott Automation and Marconi-Elliott Microelectronics in the seventies and its pull out from the GEC/Philips chip-making joint venture Associated Semiconductor Manufacturers, to the demise of Ferranti Semiconductors and the takeovers of Plessey Semiconductors and Inmos in the 1980s.

Taylor's next words gave the clue to his apparently curious remark: "LG, Samsung, Siemens ..." – he was talking about the inward investors.

Inwardly investing chip companies have done a lot for the UK, from Motorola, National Semiconductor and General Instrument Microelectronics in the seventies, to NEC and Fujitsu in the eighties, to Siemens, Hyundai and LG in the nineties.

They have, as have the inwardly investing Asian tv set manufacturers, helped redress the import deficit for electronics, they have employed a lot of people, they have initiated generations of young engineers into chip manufacturing, and they have acted as a forcing ground for aspiring managers.

Many a high-flying career in the semiconductor industry started at the offices of the inward investors.

So noone's knocking the inward investors, but it would be a pity if the attitude to microelectronics in official circles in the UK is that it is something done by foreigners and all our money and effort in the area should be directed at encouraging foreigners to do it here.

That would be a pity because we have a flourishing and technologically advanced microelectronics industry in the UK from the fully integrated GPS – a world-class (top ten) player in areas such as analog and mixed signal arrays – and to fabless design-based companies like Wolfson Microelectronics which sell worldwide. In the universities the expertise is still world-leading – as witness Cambridge University's single electron memory project.

So an aware and astute government could do much to achieve the synergies and environment in which our design strengths can be encouraged both to develop new products and compete on the world stage.

It has to be said that microelectronics does need government involvement. Even in America the contribution of government-funded laboratories to the chip industry is immense and the government-backed Sematech consortium maintained the US industry's world-class abilities in basic process technology when it looked, in the mid-80s, as if the companies could not afford to develop it themselves.

In Japan the collaborative programmes such as the VLSI programme of the 1980s are well-documented and led directly to Japanese domination of the memory business.

In Taiwan the government bought basic CMOS technology (seven micron) from RCA and refined it in the same government funded laboratory for twenty years – now down to quarter micron – every so often transferring the latest process to a commercial company and spinning it off as a start-up.

In Korea, the government funded the original acquisition of chip technology through the Korean Institute for Electronics Technology (set up in 1979) and followed that with the Semiconductor Industry Promotion Plan in 1982. Now the Korean Big Three – Samsung, Hyundai and LG – are all in the world top fifteen companies.

"We now have a semiconductor industry in this country second to none,"

In Europe collaboration such as the 1980s Megaproject, and the 1990s Jessi programme, helped Philips and SGS-Thomson to top ten status, and Siemens to become No.12 in the semiconductor firmament.

So we need government involvement and funding in microelectronics. We need the government to help our companies to participate in MEDEA - the new European joint R&D project, we need government to help to facilitate transfer of technology from defence establishments to our companies, we need it to enable our relatively small chip companies to engage in world markets, and we need it to lubricate university/industry co-operation.

But will the politicians look behind the glamour of the headlines that accompany billion pound investments from foreigners to see and support the indigenous UK companies surviving, without much help, in a bitterly competitive world? ■

David Manners

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EMC law proving difficult to enforce

European EMC legislation may not be enforceable in its present form due to the cost of investigation, claims a trading standards chief.

"It's becoming questionable whether the legislation is going to be properly enforced," said David Holland, head of Cardiff County Council's trading standards unit.

Holland's team is halfway through what could turn out to be the UK's first EMC related prosecution. The unit bought four pcs and found three failed EMC tests. Trading standards officers have interviewed the companies in question.

Holland said: "In two instances all components were CE-marked. We now have to examine all the components to determine why the pcs failed."

This burden means Holland is now doing far more work than originally envisaged. He may need to draw manpower from other investigations, placing a heavy drain on the unit's resources. If Holland discovers components were improperly CE-marked, further investigation of suppliers will be needed.

Whether or not the pc manufacturers sold faulty equipment is not in question. "The people we've interviewed have committed offences," said Holland, "that is clear cut."

But the real question that must be determined before prosecution is whether they showed due diligence when designing their products. "If they have done nothing, we will prosecute," Holland confirmed. But proving this could turn out to be far too expensive for many trading standards units to justify.

The Europe-wide EMC legislation came into force on 1 January, 1996. The first year of its existence was dubbed the 'year of grace'. EMC clubs and trading standards units worked with companies to ensure conformance with the directives.

Since the start of this year, trading standards units responsible for policing the legislation have taken a tougher line. Any company at the wrong end of a successful prosecution can expect a fine of up to £5000.

Wireless data services to increase fourfold

The wireless data services market is expected to increase four-fold over the next few years despite confusion on the part of users over what services are available. A report by FTMedia & Telecoms predicts a $10bn mobile data market by the year 2000.

Engineers lack lateral thinking

The engineering profession needs to attract a different type of person if its to produce more top flight executives. So argues a book published by Warwick University's Institute for Employment Research.

Engineers in Top Management, based on a three-year study of over 250 companies, shows that companies run by accountants tend to outperform all others, while those headed by qualified scientists and engineers do least well.

The reason for this, argues Rob Wilson, one of the book's authors, is due to the personalities attracted to engineering and science in the first place. They do not have the lateral thinking required for top management. "Someone who goes for engineering tends to be more focused," he said.

Measures to improve the situation include the training of qualified scientists and engineers in management practice, as well as the development of a cadre of outstanding managers to be 'corporate mentors'.

The long term solution, described by the institute as 'brutal', is to attract what the book calls 'divergers' – bright students who currently opt for humanities subjects. "It is important that we attract our best and brightest into the profession," said Wilson.

Car makers give flat panel speaker a hearing

This year's car models are likely to have high-tech surround sound systems built-in thanks to an agreement between Noise Cancellation Technology (NCTI) and the developer of flat panel speakers NXT – a subsidiary of UK company Verity Group.

The two companies signed a cross-licensing agreement last week which allows them to use each others technologies and customise them for specific markets as well as commercialise them there. NCTI will focus intensely on the automotive market through new and existing tie-ups with car system makers and vehicle manufacturers.

"We believe that they (Verity) will utilise their expertise in licensing, manufacturing and distribution to deliver flat panel speaker products that will revolutionise the industry," said Michael Parrella, NCTI's president.

NCTI is already in a joint venture with the US-based Johnson Controls, which makes car headlining that will ideally incorporate the flat panel speakers to create a truly surround-sound environment in the passenger cabin.

Currently NCTI and Johnson Control are in discussion with various car makers that will integrate the technology into new car models.

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World standard DAB setback

The worldwide adoption of the European Eureka 147 standard for DAB, or digital audio broadcasting, has taken a blow after a US decision to favour a satellite-based system.

To this aim, the US Federal Communications Commission (FCC) has auctioned frequencies in the S-band spectrum (2310 to 2360MHz). However, satellite-based DAB systems, unlike Eureka 147, cannot deliver cd-clarity audio to stationary and mobile users in open and urban areas, countering the whole purpose of adopting DAB.

The US government's decision has been described by the Consumer Electronics Manufacturers Association (CEMA) as "disastrous for digital audio radio in the US".

CEMA now hopes to sway the US government towards giving up the L-band frequencies (1452 to 1492MHz), currently reserved for Pentagon use. The L-Band is suited to the improved quality terrestrial delivery of DAB, and CEMA is lobbying to get the Eureka 147 system implemented in the spectrum, even though it believes the license fees demanded for Eureka 147 are too steep for US broadcasters.

Frans Westra, DAB project leader at Philips, countered the claim by saying: "It's not quite clear what is going on, but I have never seen a technically superior system fail because of high licence fees."

Moreover, certain Eureka 147 DAB receiver makers are not unduly concerned about developments in the US. "Currently we are looking at Europe although we are keeping a close eye on the situation in the States," said Tony Starling, sales director at Kenwood, which is launching the first commercial car-DAB receiver in a couple of week's time.

Eureka 147 has been selected by 20 countries worldwide. Japan has still to choose and is watching developments in the US.

End of 56kbit modem war in sight

Peace talks next month could end the 56kbit/s high speed modem standard war.

Lucent Technologies and Rockwell, who are promoting their joint K56Flex protocol, invited their rival, US Robotics, which is marketing its x2 modem, to the inaugural meeting of the Open 56K Forum held in New York.

Although US Robotics could not make the conference in time – "Unfortunately, they only asked us to join half-an-hour before the first meeting," said a US Robotics spokesperson – the company is considering taking part in the next one, scheduled for later this month.

It raises the possibility that all three companies contribute to a common standard which would be put before the International Telecommunications Union (ITU) for approval, so users can be confident the modem they buy will be compatible with those used by all Internet service providers.

UMIST researches self drive cars

Cars which drive themselves is the goal of research being carried out at University of Manchester Institute of Science and Technology (UMIST).

Follow on from the EC-funded Prometheus project aimed at preventing accidents through corrected steering, UMIST is developing vision systems which enable cars to operate on all road types.

Panos Liatsis, of UMIST's Control Systems Centre, explained that a system for motorway use, where the road is well defined, is relatively straightforward, but "driving within the city is far more adventurous."

According to Liatsis, the intelligent sensing system for obstacle detection currently being developing relies on image analysis and neural network techniques. It consists of two modules: one for obstacle detection, the other for classification.

The first module examines an image for edges, to determine regions of interest (ROIs). The second module uses higher order neural networks (HONNs) to identify obstacles within the ROIs. They decompose ROIs into coarse fields, which are matched with known vehicle shapes.

The system has been tested with 400 images containing objects with different scaling and positions, and achieved a detection accuracy of 96 per cent.

Marconi archive to stay in UK

Guglielmo Marconi's archive of scientific equipment and documents relating to his years developing the first practical radio transmitters at the beginning of the century is to be given to the nation by GEC-Marconi, the present owner.

Original plans to auction the archive – valued at between £1m and £3m – were scrapped earlier this year in response to criticism, including a letter to *The Times* from Marconi's daughter, that the archive was too important to the history of scientific discovery to be broken up.

GEC-Marconi has agreed to give the archive of over 1000 items, which includes Marconi's first patent for improvements to wireless telegraphy, a letter from Queen Victoria and radio message transmitted from the sinking Titanic, to the Science Museum in London.

Part of the archive will be displayed in a Marconi centre to be set up at the Chelmsford site where Marconi built the world's first radio factory.

Intel to lose ground

Intel is the undisputed king of the x86 microprocessor market. But it will lose a big chunk of its market over the next three years, predicts US market research firm Dataquest, which is impressed with the performance of Advanced Micro Devices' new K6 microprocessor.

Advanced Micro Devices (AMD), Cyrix and others, could snag 25 percent of the market by the year 2000, reducing Intel's share from 95 percent to 75 percent. The x86 microprocessor market was worth about $15.4bn in 1996.

A key beneficiary of Intel's lower market share will be AMD which has managed to match the performance of Intel's microprocessors with its K6 microprocessor.

"Unlike prior incursions, when AMD arrived with too little fab capacity or too late with competitive performance, this time, bolstered by the technology boost it received via its NexGen acquisition, AMD's gun may shoot real bullets," said Nathan Brookwood senior analyst at Dataquest.

Philips back in the top ten

Philips has returned to the top ten of the world's semiconductor manufacturers, according to industry analyst Dataquest (see table below).

Dataquest's final 1996 worldwide market rankings shows that Philips, after increasing revenues by 8.2 per cent on 1995, is at number nine, just ahead of SGS-Thomson Microelectronics. Mitsubishi dropped out of the top 10 to number 11 with revenues of $4.1bn.

Provisional figures, released in January have been largely confirmed with Philips and Mitsubishi being the only companies to swap positions.

World wide semiconductor ranking for 1996

1	Intel	17.781
2	NEC	10.428
3	Motorola	8.076
4	Hitachi	8.071
5	Toshiba	8.065
6	TI	7.064
7	Samsung	6.464
8	Fujitsu	4.427
9	Philips	4.219
10	SGS-Thomson	4.112

Hand-held records MPEG

In 1995, Hitachi developed a prototype camera that recorded digital video on a 400MB multi-layered flash memory. Now the company has demonstrated a camera that can record JPEG compressed still images and MPEG-1 compressed full motion video on a slot-in PCMCIA hard disk. And it's small enough to be held in the hand. The breakthrough has come through Hitachi's development of a single chip integrating the 300,000 components necessary to handle all camera functions, including real-time MPEG-1 and high speed JPEG encoding/decoding and playback. This CODEC LSI chip uses a 3-layer 0.5 micrometre c-mos process, and has a power consumption of 500mW (the camera consumes 6.5W in total). Image resolution is said to be greater than 352x240 dots. The 260MB disk can store up to 2880 JPEG images – or 1000 with 10 seconds of MPEG audio each – 20 minutes of MPEG-1 video and audio, or four hours of audio alone.

NEWS IN BRIEF

BT has received a veiled warning from industry regulator Oftel over its plans to become a global telecommunications group. Oftel is to investigate whether **BT's expansionist plans**, which includes the proposed merger with US operator MCI, will have a detrimental impact on the telephone operator's services domestically.

After a consultation period Oftel will decide whether any safeguards should be added to BT's license. "It is possible that BT's moves towards globalisation may have an impact on the company's ability and willingness to meet its UK license obligations," said Oftel director general Don Cruickshank.

DVD-ram, the rewritable version of digital versatile discs, or DVDs, has moved a step closer to its commercialisation. Last week ten major consumer electronics firms agreed on a single **DVD ram format**. Its specification will be published later in April.

Toshiba demonstrated its version of DVD ram hardware in Tokyo last month.

Other equipment makers are expected to produce DVD ram systems sometime before the spring of 1998.

USA Global Link has introduced what it says is the first **worldwide Internet telephony** system.

The Global Internetwork service will be offered in 35 countries with rates varying between 25 cents and 50 cents per minute. The company claims that voice quality will be comparable with satellite-routed phone calls which often have a voice delay, but will be better than using Internet-connected PCs to call other PC users.

Global Link is not the first company to offer such services but it is the first to plan a worldwide one. The company is a leading 'call back' firm, offering overseas clients cheap phone rates by offering access to a US dial tone and cheap US phone rates.

The company plans to install gateways in various countries that will connect local phone users to the Internet. However, there are concerns that such services will further congest the already overburdened Internet.

M/A COM, the US microwave and rf specialist has produced a range of very **low cost 14GHz Schottky** diodes in plastic packaging. Charles Howell, a company spokesman, said: "Consumer applications like DBS and VSAT can't afford $5 for a ceramic part. Plastic packaged diodes cost 25 to 30¢ and we got the capacitance on ours down to allow them to work at 14GHz." Schottky diodes are used as mixers for frequency converters in receivers. Howell said: "The highest frequency diodes, in hand assembled and tuned beam-lead packages, will work at 100GHz."

ICER, the Industry Council for Electronic Equipment Recycling, has launched its design **guidelines for the recycling** of electrical and electronic equipment. "The guidelines include information on the principles of designing for recycling and cover developing an appropriate design strategy," said Claire Snow, the director of ICER. The launch is to be followed by an industry-wide consultation process, promoted by ICER, beginning in April.

• The 30 page ICER Guidelines: Design for Recycling Electronic and Electrical Equipment document is available at £20 from ICER. Tel: 0171 729 9121. ■

RESEARCH NOTES

Jonathan Campbell

Computer can respond to thought

Research at Imperial College could open up the world for severely disabled people by allowing them to communicate through computer – simply by thinking.

Will Penny and colleagues, researching into biosignals as part of the Brian Computer Interface project, are attempting to use information from the motor cortex region of the brain, recorded using electrodes attached to the scalp, to interface directly with a computer.

The basis for the work is that movements of limbs, for example, are preceded by desynchronisations and synchronisations within the electroencephalogram (EEG). But these event-related desynchronisations and sychronisations (ERD and ERS), appear to be present when volition to move a limb occurs, even when actual movement of the limb does not in fact take place.

Clearly, the accurate real-time determination and classification of the ERD/S offers many exciting possibilities for the control of peripheral devices via computer analysis.

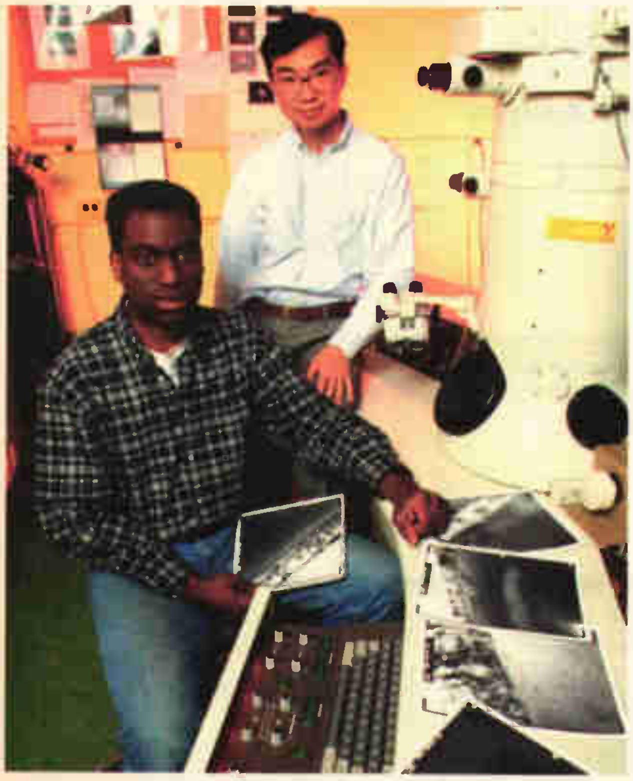
This project aims to research this protocol. The primary application is expected to be computer interfacing and control by severely disabled people.But the methodology is general and has numerous other application areas.

Key areas of technical research to be solved include better preprocessing techniques for the spontaneous (non-averaged) EEG and development of suitable pattern recognition algorithms. This will also include investigation of dynamic 'neural' network architectures.

Research effort will also be directed at the issues of multi-channel sensor fusion and the development and use of methods for assessing 'confidence' measures (or error estimates) for the output of neural' classifiers.

Will Penny, Department of Electrical Engineering, Imperial College, London SW7 2BT,UK. Email: w.penny@ic.ac.uk.

Revolutionary twist for silicon manufacturing



Yu-Hwa Lo, Cornell University associate professor of electrical engineering, right, and Felix Ejeckam, doctoral candidate, examine transmission electron microscope photographs that demonstrate the success of a technique they developed for a universal substrate for compound semiconductors. Photo by Charles Harrington, Cornell University.

Scientists at Cornell university have announced creation of a "universal substrate" for semiconductors, promising to eliminate many of the obstacles in conventional semiconductor manufacturing. The technique allows pure, single crystal growth of any film on a semiconductor substrate.

Results are still in their preliminary stages, but if the idea truly works – and the researchers are confident it will – the technique could revolutionise the microelectronics industry.

The potential is "unimaginable", according to Yu-Hwa Lo, Cornell associate professor of electrical engineering who is leading the work opening the door for manufacturing whole new classes of devices in optoelectronics and microelectronics, for such items as new lasers, detectors, sensors, imaging systems, signal processing and computer chips, compact discs, data storage and dozens of other examples.

Conventionally, a major obstacle to the manufacture of semiconductors is that the single-crystal semiconductor thin films must be deposited on a crystal of the same structure. For example, a light-emitting gallium arsenide thin film must be deposited on a gallium arsenide bulk substrate, or else defects will result and the semiconductor cannot be used.

Each single crystal is characterised by its lattice structure and lattice constant. When a crystal layer is grown on a bulk crystal substrate, even a mismatch of 1% in lattice constants causes problems. But the Cornell technique, for which Cornell has applied for a patent, shows that a mismatch of 15% can be overcome – a feat previously unachievable.

The Cornell team solved that problem by what might be called a simple twist. By rotating a thin film slightly and bonding it to a substrate, the surface of this new substrate becomes flexible, or compliant, and a crystal of any material can grow on its surface. The researchers call it a twist boundary, in which the crystal materials are bonded by angular misalignment; and the result is a new compliant substrate.

The Cornell team has demonstrated the technique with thick, pure crystal layers of indium gallium phosphide, gallium antimonide and indium antimonide, with mismatches as high as 15%. Crystals of these compounds have successfully been grown on a gallium arsenide wafer that had a flexible layer thin film. With traditional methods, it would not have been possible.

The Cornell team, in collaboration with researchers from the Wright Patterson Laboratory and the Sandia Laboratory, has demonstrated that the defect density in an indium antimonide layer has been reduced by at least 100,000 times with the new method, compared to the conventional method. This means

NOW THE BATTLE IS REALLY OVER

After 10 years and with more than 20.000 users, ULTImate Technology now introduces the ULTIboard Wizard. This system is highly praised for its very powerful placement and routing algorithms by both the less experienced users and by the experts. The technology applied in the ULTIboard Wizard used to be available only as options on the more powerful and expensive Workstations.The PCB design depicted below illustrates the capability of the Wizard, its 4-layer version was employed in the ULTIboard Professional Design Contest at the Electronics'95 Exhibition. The same design was now executed in a 2-layer version with the ULTIboard Wizard in less than 2 hours.

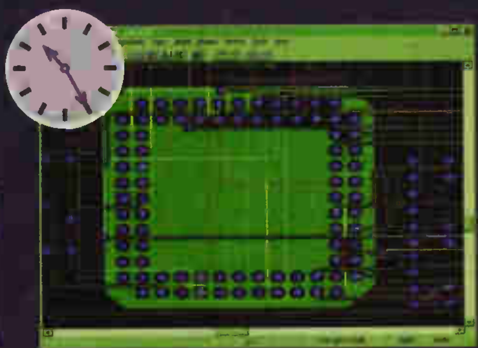
ULTIBOARD WIZARD

The schematic is ready, the board outline established and all components are imported. The components with a fixed location are placed interactively. (10 min.)

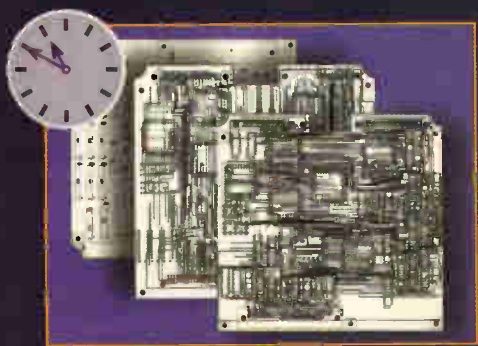
AutoPlace rapidly and conveniently places the remaining components with algorithms that approach the interactive method of expert designers. On-line changes are possible. (5 min.)

Power and Ground are routed semi automatically (under the management of the designer). The (EMC) critical connections are also layed interactively. (15 min.)

Now the SPECCTRA Autorouter is employed to finish the routing of the design at high speed and with high-grade quality. All design rules



All adjustments are done quickly and efficiently with the interactive autorouter. All the corners of the traces are chamfered and polygons are placed. (10 min.)



Following the connectivity- and design rule checks, the output on matrix or laser printers, pen or photo plotters can be run. Back-Annotation automatically updates the schematic. (25 min.)

ULTImate Technology now makes the best PCB Design tools available at very competitive prices from UK £ 2.675,- (Excl. VAT, 1400 pins version with 4 signal layers). We imagine you will want to see for yourself whether you too can achieve such fantastic results with the ULTIboard Wizard. Please come to our stand J135 at ICAT 97 at NEC (Birmingham) and convince yourself. A demo-CD is available.

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that indium antimonide crystals can be grown on gallium arsenide, to form the basis for infrared detection and a Hall sensor – a sensor that has been used in airplanes and soon will be used in cars.

If this can be done for another compound semiconductor, gallium nitride, which has a lattice mismatch of about 20%, then high-quality blue and ultraviolet lasers as well as high-temperature, high-power electronic circuits can be fabricated.

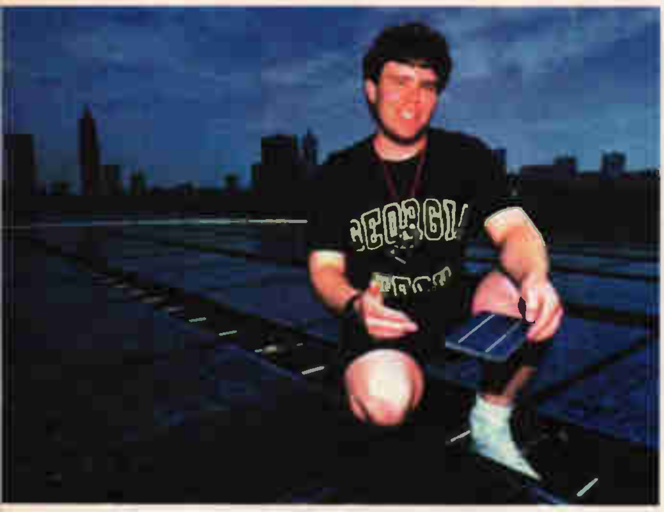
Blue lasers, rather than red, will be used in the next generation of compact discs, for example, because the shorter wavelength stores more data. High-powered electronic circuits that can also withstand high temperatures are used in automobile, aerospace, communication and power industries.

The Cornell team expects it can be achieved with this technique, and is currently in the process of trying it. The researchers also believe that the crystals can be grown on silicon wafers, opening the door for computers that, for example, could have different types of semiconductors operating at the same time on the same motherboard.

Contact: Yu-Hwa Lo, Electrical Engineering, Cornell University,

Sun power put into practice . . .

Data being collected from a 0.75acre 342kW photovoltaic system at Georgia Tech is providing a valuable insight into how commercial solar electricity generation might work in real world applications.



Doctoral student Mike Ropp with the 342-kilowatt photovoltaic system on top of the Georgia Tech Aquatic Center. Photograph Stanley Leary, Georgia Tech Communications Division.

So far, the system, installed at Georgia Tech's Aquatic Center, has operated close to its expected efficiency, although actual energy production has been lower than predicted. For the seven-month period from July 1996 through to January 1997, it produced 162.2MWh of electricity, against a predicted 409MWh, which is enough to power about 35 average homes.

Factors that affected energy output, included fuses blown when lightning struck the Center roof in July and a water main break that flooded the electrical control room and forced a 10-day shutdown in October. Also, sunlight levels were lower than expected and extremely high temperatures in August decreased the efficiency of the system, which operates better in cooler temperatures.

Continuing experiments to compare performance-model equations to the real operating data brought further shutdowns, but will help take the guesswork out of solar energy production.

In the future, researchers plan to study "islanding," where the main power source shuts down but the photovoltaic system continues to function. This creates a safety hazard for workers doing maintenance or repairs, especially if they're not aware of the secondary power source.

The Georgia Tech system is made up of 2856 photovoltaic modules, each with 72 multicrystalline silicon solar cells connected in series. A power conditioning system, or inverter, converts the array's dc power to utility-compatible ac power, which then feeds into the Aquatic Center's main power system. The inverter also controls and monitors the overall photovoltaic system.

A data acquisition system samples all vital signs every 10s, then averages and stores them every 10min. Incoming data includes meteorological parameters such as ambient air temperature, wind velocity and array temperature, and performance parameters such as ac power, dc voltage and dc current.

Although the photovoltaic system is operating as expected, researchers continue to seek ways to improve solar energy production. At 10-15% efficiency, photovoltaic systems are below traditional ones like coal, natural gas or nuclear power, which have efficiency ratings that fall somewhere between 30-60%. But their fuel source – the sun – is free and unlimited, and its operation is silent and non- polluting.

"There's money to be made in solar technology for those far-sighted enough to make the investment," said Christine Ervin, assistant secretary of the DOE's Office of Energy Efficiency and Renewable Energy. "The work we're supporting at Georgia Tech is at the cutting edge of this technology. What we learn from projects like the Aquatic Center increases the confidence of those potential investors in photovoltaics products and sets the foundation for our industry's growth and profitability."

. . . And put into space

Aeronautical engineers in Southern California are developing an aircraft – called Centurion – that they believe will push solar-powered aircraft concepts to new heights, and provide a vehicle for scientific experiments.

Engineers for AeroVironment are designing the aircraft to fly at over 30,000m altitude as part of Nasa's Environmental Research Aircraft and Sensor Technology (Erast) program. Like its predecessor, the AeroVironment-developed Pathfinder, the Centurion will be an ultralight flying wing with multiple electric motors along its wingspan, powered by solar cells spread across the wing's upper surface. But Centurion's wingspan, will be more than twice that of Pathfinder.

According to Dryden reports, recent flight tests of a quarter-scale battery-powered model of the craft at El Mirage Dry Lake in Southern California's high desert have answered questions about the Centurion's aerodynamics and stability. Next step is to scale up the aircraft, designing new airfoils that are more efficient for high altitudes and optimising the systems.

The final solar-powered Centurion will be designed to reach the ultra-high 30,000m altitude for a relatively short duration – about 2h – while carrying a small 90kg payload of scientific sensors. The full-scale

Centurion will span between 70 and 80m.

The Centurion is one of several unpiloted aircraft being developed by an alliance between Nasa and several small aeronautical development companies and universities under the Erast program. The goal of the program is to develop aeronautical technologies that will lead to development of a new family of high-flying remotely piloted aircraft for scientific missions.

Test results of the quarter scale model have made scientists optimistic about developing a pilotless solar aircraft that will fly at 30,000m.

Millimetre-sized machines could provide jet thrust

Could an array of hundreds of tiny jet turbines, each a fraction of a cm wide, one day replace a single jet engine to power an aircraft? That is what researchers at Stanford University's Rapid Prototyping Laboratory hope, and is among the blue-sky possibilities suggested by a new approach to mechanical design called massively parallel mechanical systems.

Although replacing a jet engine is well beyond the current state of the art, the scientists propose demonstrating the value of this approach by building several simpler but still useful devices.

One such device is a system to keep aircraft wings from stalling, a condition that causes the wing to lose the upward force that keeps it in the air: another is a tactile interface for virtual reality and tele-operation systems.

The aircraft device would work by covering critical parts of a wing with thousands of tiny holes each about 1mm in diameter and separated by 5mm. In front of each hole would be a small pressure sensor. When a sensor detects the conditions that precede a stall, it instructs a tiny valve to open, allowing a jet of pressurised air to blow out through the hole behind it. If properly triggered, such jets could prevent a stall from developing.

The tactile interface for virtual reality systems would be next step on from force feed-back mechanisms that are currently used and give tele-operators a better feel for what they are manipulating. The new device would be something like a flat pin cushion, consisting of a dense array of millimetre-square pins attached to actuators that would position and push them up and down with a controllable amount of force. The millimetre spacing between individual pins would make the interface feel almost like a solid surface when all the pins are positioned at the same level. Under computer control, however, the surface could be programmed to imitate the shape and hardness of different surfaces.

The difficulty with such engineering is that it falls between normal manufacturing methods that can create objects a cm or larger, and micro-mechanical devices that measure a few microns made using semiconductor manufacturing techniques.

The Stanford team is currently developing methods to make large numbers of mesoscale-sized mechanical devices, by combining two different types of techniques – miniaturising traditional manufacturing methods while scaling up techniques used in the semiconductor industry.

So far the researchers have fabricated an array of nine nickel wheels, each one 0.3mm thick and 5mm in diameter, mounted on nickel axles to demonstrate they can make entire mechanical devices in place, without any assembly. Similarly, they have made a four-bladed propeller, 5mm in diameter.

Physics sets engineering challenge

Two of the World's largest superconducting magnets, for use in an international particle physics experiment, are to be designed and built by a team under the guidance of a scientist from the UK. Elwyn Baynham, the project leader from the CLRC Rutherford Appleton Laboratory and one of the World's experts on superconducting magnets, is to lead a team of engineers and scientists to design, construct and test a pair of massive toroidal magnets. These magnets will form a key part of the end cap detectors of the Atlas experiment on the large Hadron collider (LHC) currently being constructed at the European particle accelerator laboratory at Cern in Geneva.

Over 30km of Rutherford cable will be used to form the coils of the magnet. The coils will operate at 4.5K – just above absolute zero – and the conductors will carry a current of 20,000A with zero power loss. The magnets will have a stored magnetic energy of over 400Mj – equivalent to the kinetic energy of an inter-city train at 125mile/h.

The huge scale and complexity of the finished product means that it will not be possible to build a prototype of the end caps, so special modelling techniques involving finite element analysis and virtual reality simulations are being used to ensure that the design is feasible. When the design stage has been completed the components will be fabricated in industry to the defined specifications of the design team and finally assembled, integrated and commissioned into the detector at Cern.

When the Atlas detector has been completed it will be used by particle physicists worldwide to search for evidence of the Higgs Boson. The LHC is due to be switched on in July 2005. ■

Loudspeakers exposed

With all the remaining components of an audio chain being increasingly refined, John Watkinson argues that the loudspeaker has become the limiting factor in audio quality. Here, he looks at the problems and presents solutions.

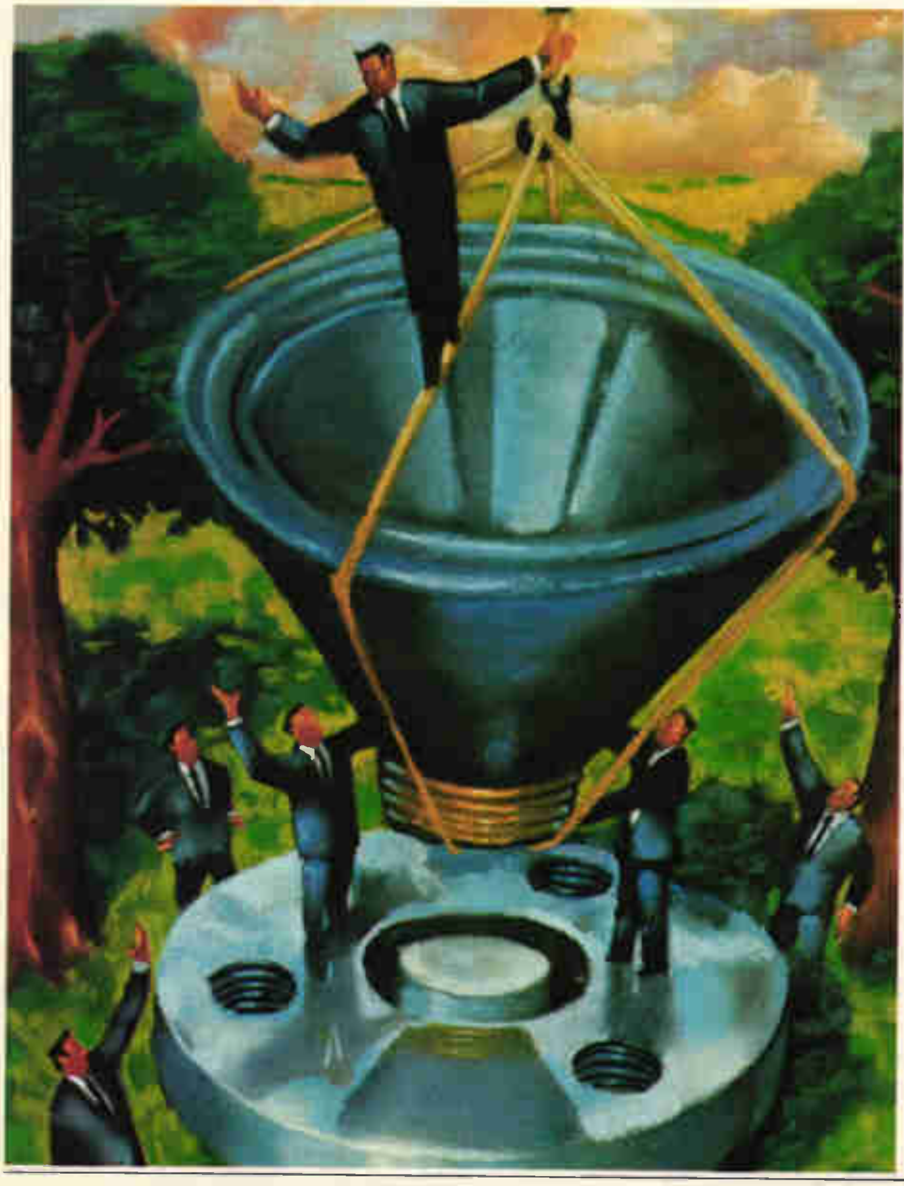


ILLUSTRATION JAMEL AKIB

Until recently, virtually every component in the audio chain was capable of causing audible impairment. If high quality was the goal a degree of determination and plenty of time was needed to adjust equipment to a finely balanced point faster than it drifted. Because things were never good enough there was a consistent research effort and this has given tangible results.

In a typical modern audio system, a microphone feeds an a-to-d converter, connected to a digital recorder, driving a d-to-a converter, a power amplifier and a loudspeaker. At some point a mixing console may be found. The weakest link determines the overall quality.

Modem microphones have an extremely flat frequency response, and adequate dynamic range and linearity. Modern converters using noise shaping and oversampling with 18 and 20-bit resolution are outperforming our ears, – provided some attention is given to clock jitter.

If a digital audio recorder uses digital i/o, then provided it doesn't use compression, it doesn't have a sound quality. Numbers coming in are the same as numbers going out. High quality modern mixing consoles have reached a stage where they are virtually transparent. Power amplifiers have reached a state where further developments will be in the area of efficiency and the friendliness of the load presented to the ac supply.

Most of the quality loss in a modern sound reproduction system is due to the loudspeakers, which for some reason have not seen the development of other components. In my opinion loudspeakers are now causing a quality bottleneck. Such an area is ripe for research because for a given effort the rewards will be more significant in comparison with more mature technologies where the returns diminish as the ideal is approached.

I should stress that I am interested in precise sound reproduction rather than in hi-fi. There was a time when the two were synonymous, but nowadays in many respects hi-fi has become a religion in which beliefs are more important than truths and enthusiasm replaces knowledge. The temples of hi-fi are the phenomenally expensive hardware installations and the high priests are journalists who find pseudo-scientific reasons to make the believers feel comfortable with the vast sums they have spent.

The laws of physics involved in audio reproduction are established beyond any shadow of a doubt yet they are regularly called into question by hi-fi journalists whose ejaculations usually serve only to raise the noise floor for the genuine researcher.

It is impossible to make other than accidental or empirical progress without a clear picture of the processes involved and an understanding of the key criteria. To determine what part of one's knowledge base can be trusted it is necessary to remove from it all of the myths and pseudo science and to establish what is and is not the case. It is surprising how long this takes if one is to be impartial and scientific about every spurious theory.

> ***"The laws of physics involved in audio reproduction are established beyond any shadow of a doubt yet they are regularly called into question"***

Without a knowledge of psycho-acoustics it is impossible to assess the relative merits of differing approaches. The human hearing system is complex and highly sensitive in some areas, yet surprisingly casual in other areas. If this is understood, precision will be placed in areas of sensitivity, whilst shortcomings can be mitigated by placing them in other areas.

As audio systems are designed for human listeners, the criteria for audio quality can only be subjective. Audio systems form a window between the listener and the original sound. All that is necessary is to make that window larger than the sound passing through it in all respects. If human listeners are unable to detect an impairment, then the quality is sufficient and the window is big enough. Making it even bigger simply drives up the cost.

Listening tests are vital once all objective tests have been passed, but in order to be significant, such tests have to be properly conducted to avoid bias. I can listen to a loudspeaker as well as anyone, but unlike many, I do not consider myself competent to do so alone. This is simply because the spread of human hearing performance is so great that I cannot be truly representative. I will naturally listen to my own designs more favourably than those of others.

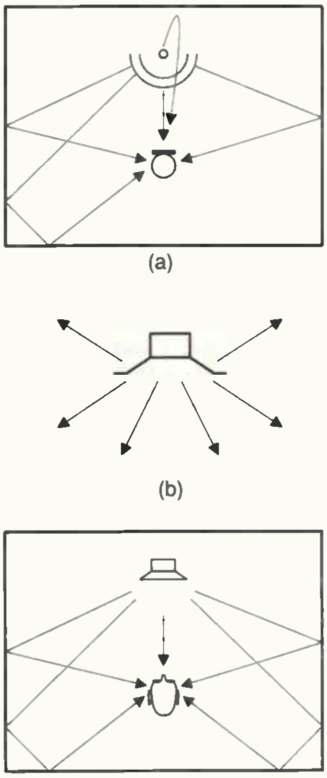


Fig. 1a) Sound approaches microphone from many directions due to ambience and reverberation. b) In anechoic conditions a single loudspeaker produces exactly the opposite of a). c) Loudspeaker in reverberant conditions simulates situation of a) at listener's ears.

In a significant listening test, neither the operator nor the subjects must be aware of the reason for the tests, and the design of the tests must be approved by a statistician who can determine how likely it is that identical results could have been obtained by chance. I can only listen to a loudspeaker of my own design to ensure that it has no obvious warts, but to compare it meaningfully with another speaker of similar performance is beyond any individual.

The ideal

An ideal speaker might be one which was a sphere whose volume changed according to the input waveform. Such a device would behave as an ideal point source, having frequency independent dispersion and a frequency response like a ruler. What is more it would be perfectly linear and would not exhibit energy storage, which would also make it perfectly phase linear.

Some of these consequences bear explanation. A pulsating sphere acts as a point source because wherever one stands, the part of the surface nearest is moving directly towards and away from one. All points on the surface move in the same phase, therefore there can be no vibrations propagating across the surface of the sphere. Consequently there is no requirement to suppress such vibrations. Radiation cannot occur after the input ceases. If the output stops when the input stops, the system is phase linear.

A good microphone produces an accurate version of sounds approaching it from many directions. Even if a loudspeaker reproduced the microphone waveform exactly, the resulting sound is leaving in many directions. Spatially, a single loudspeaker is producing sound travelling in exactly the opposite direction to the original. Consequently reproduction of the original sound field is simply not possible.

Figure 1 shows the problem. Sound approaching a microphone at **a)** does so from a multiplicity of sources whereas sound leaving a single loudspeaker superimposes all of these sources into one. Consequently a monophonic or single loudspeaker is doomed to condense every sound source and its reverberation to a single point.

When listening in anechoic conditions **b)** this is exactly what happens. While the waveform might be reproduced with great precision, the spatial characteristics of such a sound are quite wrong.

However, when listening in a room having a degree of reverberation, a better result is achieved irrespective of the reverberation content of the signal. The reverberation in the mono signal has only time delay and no spatial characteristics whatsoever whereas the reverberation in the listening room has true spatial characteristics. The human listener is accustomed to ambient sound approaching from all directions in real life and when this does not happen in a reproduction system the result is unsatisfactory.

Thus in all real listening environments a considerable amount of reverberant sound is required in addition to the direct sound from the loudspeakers. Figure **1c)** shows that the reverberation of the listening room results in sound approaching the listener from all sides giving a closer approximation to the situation in a). Clearly better reverberation will be obtained when the loudspeaker is out in clear space in the room. So-called bookcase loudspeakers mounted on walls or shelves can never give good results.

Better spatial accuracy requires more channels and more loudspeakers. While the ideal requires an infinite number of loudspeakers, with care, as few as two speakers can give a convincing spatial illusion. The improvement in spatial performance using two speakers is enormous. Tests have shown that most people prefer stereo with poor bandwidth and significant distortion to pristine mono.

Two speakers can only give spatial accuracy for sound sources located between them. Reverberation in the listening room then provides ambient sound from all remaining directions. Clearly the resultant reverberant sound field can never be a replica of that at the microphone, but a plausible substitute is essential for realism and its absence results in an unsatisfactory result. This renders the traditional use of heavily damped rooms for monitoring suspect.

If realism is to be achieved, the polar diagram of the loudspeaker and its stability with frequency are extremely important. A common shortcoming with most drive units is that output becomes more directional with increasing frequency. **Fig. 2a)** shows that although the frequency response on-axis may be ruler flat giving a good quality direct sound, the frequency response off-axis may be quite badly impaired as at **b)**. In the case of a multiple drive unit speaker, if the crossover frequency is too high, the low-frequency unit will have started beaming before it crosses over to the tweeter which widens the directivity again.

The figure shows that the off-axis response is then highly irregular. As the off-axis output excites the essential reverberant field the tonal balance of the reverberation will not match that of the direct sound. The skilled listener

"If realism is to be achieved, the polar diagram of the loudspeaker and its stability with frequency are extremely important."

can determine the crossover frequency, which by definition ought not to be possible in a good loudspeaker.

The resultant conflict between on- and off-axis tonality may only be perceived subconsciously and cause 'listening fatigue', where the initial impression of the loudspeaker is quite good but after a while one starts looking for excuses to stop listening.

The hallmark of a good loudspeaker installation is that one can listen to it indefinitely. Unfortunately such instances are rare. More often loudspeakers are used having such poor off-axis frequency response that the only remedy is to make the room highly absorbent so that the off-axis sound never reaches the listener. This has led to the well-established myth that reflections are bad and that extensive treatment to make a room dead is necessary for good monitoring. This approach has no psychoacoustic basis and has simply evolved as a practical way of using loudspeakers having poor directivity.

The problem is compounded by the fact that an absorbent room requires more sound power to obtain a given sound-pressure level. Consequently heavily treated rooms require high-power loudspeakers which have high distortion and often further sacrifice polar response in order to achieve that high power.

A conventional box shaped loudspeaker with drive units in the front will suffer extensive shading of the radiation to the rear and thus will create a coloured reverberant field. Clearly a much more effective way of exciting reverberation with an accurate tonal balance is for the loudspeaker to emit sound to the rear as well as to the front. This is the advantage of the dipole loudspeaker which has a figure-of-eight polar diagram.

Loudspeakers have also been seen with additional drive units facing upwards in order to improve the balance between direct and reverberant sound. These techniques work well but obviously in a dead room are a waste of time as the additional radiation will never reach the listener. The fault is in the room, not the speaker.

Air is not very dense. As a result it is not possible to influence very much mass at once. Thus it is difficult to radiate energy into air with a mechanical device because the mass of the moving part of that device will eclipse the mass of air influenced. In engineering terms a diaphragm has a high mechanical impedance but the air has a low impedance, resulting in a mismatch, meaning that loudspeakers will always be inefficient. With the almost limitless power from modern amplifiers this is a minor problem.

As an alternative the horn loudspeaker is a kind of acoustic transformer which raises the impedance of the air adjacent to the diaphragm in order to improve the power transfer. Unfortunately, acoustic transformers are difficult to make linear and the resulting distortion is difficult to eliminate.

A great problem with loudspeaker design is the span of wavelengths involved. These range

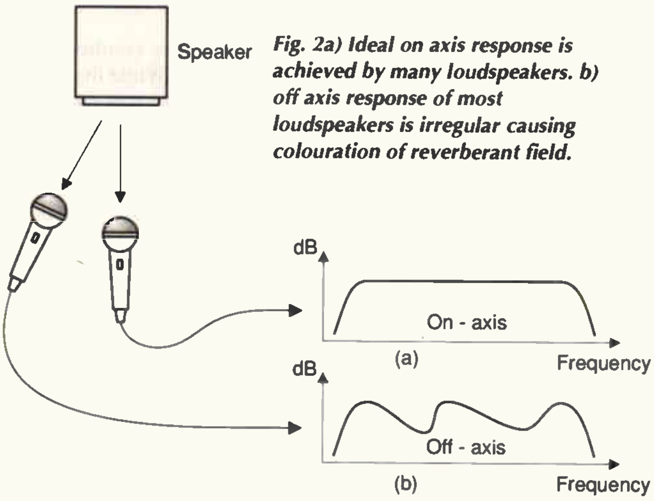


Fig. 2a) Ideal on axis response is achieved by many loudspeakers. b) off axis response of most loudspeakers is irregular causing colouration of reverberant field.

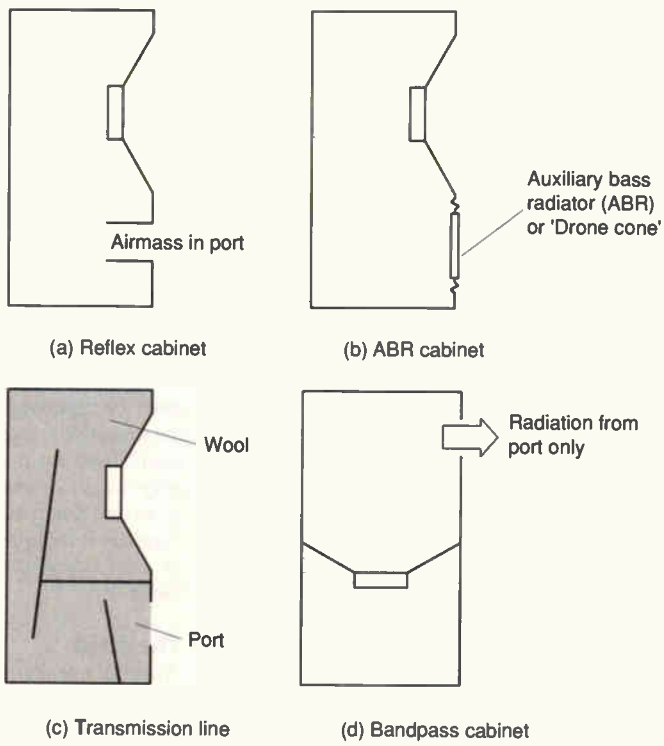


Fig. 3. Various attempts to reproduce low frequencies. a) mass of air in reflex duct resonates with air spring in box. b) air mass replaced by undriven diaphragm or auxiliary bass radiator. c) rear wave is phase shifted 180° in transmission line to augment front radiation. d) bandpass enclosure puts drive unit between two resonating chambers. None of these techniques can properly reproduce transients and active techniques have rendered them obsolete.

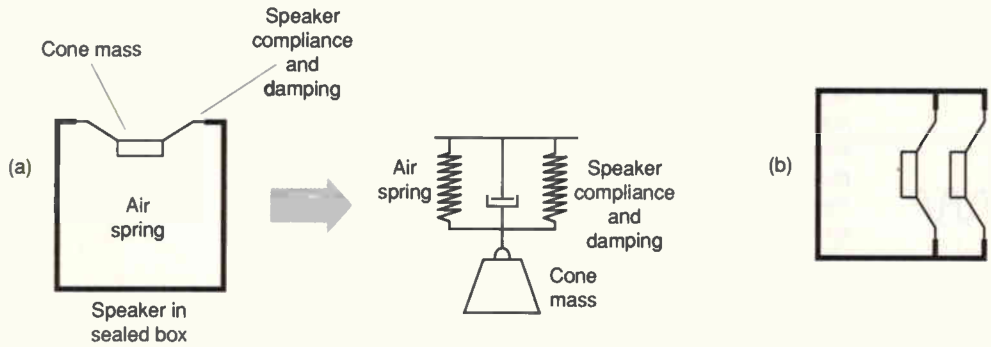


Fig. 4a) Sealed enclosure forms a non-linear air spring in parallel with driver compliance. This stiffens the compliance and raises the fundamental resonance. b) isobaric or compound woofer has tandem diaphragms.

from a few millimetres at the highest audible frequency to several metres at the lowest. There cannot be many disciplines in which mechanical motion is required over such an octave range.

Wave theory is dominated by the relative sizes of the source and the wavelength. Thus in a loudspeaker at the highest frequencies the transducer is much larger than the wavelength, whereas at the lowest frequencies it is much smaller. As a practical matter it is necessary to use more than one drive unit with a crossover network.

Reproducing low frequencies

In order to allow a diaphragm to generate low frequencies, it must be provided with an enclosure which prevents an acoustic short circuit. Provided the wavelength is larger than the enclosure, the resulting radiation will be omnidirectional and the result will be exactly the same as if a pulsating sphere had been used.

The lowest frequency to be reproduced is debatable and depends upon the material to be reproduced. If we want to be able to reproduce all musical instruments, we have to include the organ. Organ pedal notes don't start to be realistic unless a response is maintained to around 20Hz. At this frequency you do some of your listening with your chest – even at moderate sound-pressure levels. Low-frequency roll-off is unavoidable, but it must be monotonic and preferably have a slope of no more than 12dB/octave.

Most loudspeakers cannot faithfully reproduce the input waveform at low frequencies, but unless this is done, a loudspeaker is simply not accurate enough. An obvious example is the transient when an organ pipe begins to speak or stops speaking. The sound is distinctive and a good loudspeaker should reproduce it – but most don't. Further examples include marimbas and other bass percussion instruments like hollow logs.

Many loudspeakers employ resonances to obtain an extended frequency response in the mistaken belief that only steady state frequency response is important, **Fig. 3**. By definition, resonance works by storing energy. This energy is taken from the leading edge of a bass transient and added to the trailing edge. Again by definition a tuned loudspeaker cannot be phase linear. Consequently transient edges are blurred and unrealistic and arrive out of time with the treble energy. The correct term is linear distortion.

Therefore reflex loading, the auxiliary bass radiator and its more recent relative the bandpass enclosure, are unacceptable on fidelity grounds. These all achieve a lower frequency steady state response by destroying the waveform of bass transients. They have a steeper roll-off below resonance which is unnatural. The transmission line loudspeaker fails because there is an assumption that a phase shift in the line is as good as an inversion. Again this is unfortunately only true on continuous sinewave.

Reflex, auxiliary bass radiator, transmission line and bandpass enclosures are all traditional approaches which were the best that could be done with the simple electronics of the day. The active loudspeaker, which can easily be made phase linear, renders all of these approaches obsolete except for economy or to get high sound-pressure with old fashioned magnet technology. The only published techniques which do not violate the ideal are the sealed enclosure and its relative the isobaric. Untuned loudspeakers which do not store energy are essential for high fidelity because they can be made phase linear.

With a traditional approach to the sealed enclosure, the optimal reproduction of low frequencies requires a physically large loudspeaker. The mass of the diaphragm and the stiffness of the air in the enclosure behind it form a resonant system, as **Fig. 4** shows. Below resonance there is little output and so the lower the resonant frequency the better.

The smaller the cabinet, the higher the stiffness of the air within, and the higher the fundamental resonance. Also the internal pressures generated rise with small cabinets, resulting in a large force on the diaphragm and an increased likelihood of breakup. This is where the isobaric configuration scores by isolating the outer driver from the enclosure pressure.

"While it is well known in engineering that pressure containment vessels should be cylindrical or spherical, loudspeaker designers cling to the rectangular box."

The resonant frequency can be lowered by raising the diaphragm mass, but that reduces the efficiency too, causing a coil dissipation problem. The force on the diaphragm can be reduced by using a smaller diameter, but then the throw has to be increased, increasing distortion. Thus if a good low-frequency response and low distortion is required at reasonable sound-pressure levels, the traditional loudspeaker has to be large.

In strictly theoretical terms, a low-frequency loudspeaker only needs to be able to displace a sufficient volume of air to achieve the required sound-pressure level, and this has nothing to do with its enclosure volume. Thus in principle at least, a small low-frequency loudspeaker is possible, but this will not be based on the conventional approach and it will not be passive. With active techniques the motion of the diaphragm and its apparent resonant frequency are under the control of the amplifier designer.

Clearly a loudspeaker cabinet must be totally inert. As the interior of the cabinet is driven by a secondhand signal from the back of the drive units, there is no way that this can be allowed to radiate. As the area of the enclosure walls eclipses the area of the diaphragm, even small enclosure vibrations can have a serious effect on clarity.

While it is well known in engineering that pressure containment vessels should be cylindrical or spherical, loudspeaker designers cling to the rectangular box. The flat panels of a box are easy for carpenters to assemble, and eliminate the need for spending money on industrial design. But from any acoustic standpoint, they are inadequate. Has anyone ever seen a square submarine or a rectangular aerosol can?

Reproduction at higher frequencies

When a plane diaphragm transducer is much larger than the wavelength, it tends to produce plane waves which are directional. In the case of an unenclosed diaphragm, a bipolar response is achieved in which the front and rear radiations are identical but anti-phase.

Directionality rises with frequency and the result is that the highest frequencies can only be discerned directly on axis. As has been seen, this result is unacceptable and in a well engineered tweeter steps must be taken to avoid it.

At high frequencies, the cone acts as a mechanical transmission line for vibrations which start at the coil former and work out-

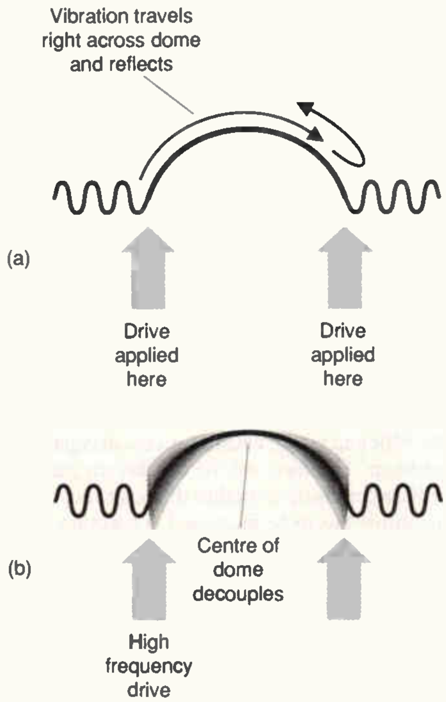


Fig. 5a) In a rigid dome there is nothing to stop vibrations travelling right across the apex and being reflected. b) At high frequencies, the centre of the dome decouples giving exactly the wrong characteristic for good directivity.

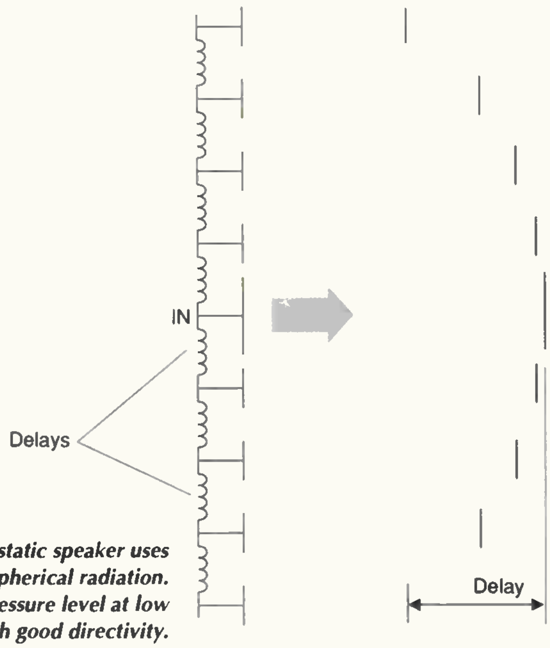


Fig. 6. Phased array electrostatic speaker uses delay lines to simulate spherical radiation. Can achieve high sound-pressure level at low distortion with good directivity.

wards. It is possible to introduce frequency dependent loss into the transmission line so that the higher the frequency the smaller is the area of the cone which radiates. Done correctly this yields a constant dispersion drive unit which simulates a sector of our ideal pulsating sphere.

The main concern is that there are vibrations travelling out across the surface and there must be a cone surround which acts as a matched terminator so that there can be no reflections.

If you consider the popular dome driver, to the casual observer it looks like a section of a

> **"The passive loudspeaker has so many flaws that it is difficult to know where to begin."**

sphere and should therefore be close to the ideal. Unfortunately, as has been pointed out many times in the literature, this is a myth. The dome moves on a single axis, and this is not the same thing at all as a pulsating sphere. Domes cannot be rigid, and so the vibrations from the coil must propagate inwards from the circumference to the apex. This causes two problems as shown in **Fig. 5**.

First, when the vibrations arrive at the apex, there is nothing to terminate them, so they must continue on until they arrive back at the coil. Consequently rigid domes must suffer from energy storage and hangover.

The alternative is to use a 'soft dome' which is lossy. In this approach, losses in the dome mean that the amplitude of vibration falls towards the centre. This is the exact opposite of what is wanted for good dispersion. Consequently domes can only work over a narrow frequency range and need to cross over to smaller units at frequencies where a transparent crossover cannot be achieved. As I showed earlier, this causes the directivity index to resemble a dog's hind leg. While the on-axis response may be flat at the sweet spot, the reverberant field will be extremely non-uniform.

From the theoretical standpoint, the dome has no acoustic merit. The practical advantage of the dome is that it can be fitted with an immense coil which can dissipate a lot of power without cremating itself.

In the electrostatic loudspeaker, the diaphragm does not need to be rigid because it is driven uniformly. As a result it can be lighter with corresponding benefits in efficiency, phase linearity, transient response and freedom from intermodulation distortion.

The electrostatic diaphragm is supported between two driving plates and the spacing is a compromise between the amplitude of motion possible and the drive voltage needed. They are invariably used in bipolar mode without a cabinet. While this is advantageous for exciting the reverberant field, it means that they suffer an acoustic low-frequency roll-off and are best used in conjunction with a linear phase woofer.

A large, flat, uniformly moving diaphragm beams dreadfully at high frequencies. The elegant solution of the *Quad 63* was to make the mechanically flat diaphragm behave like a sphere by splitting the electrode structure into concentric rings fed by lossy delay lines, as shown in **Fig. 6**. The outward propagation of vibrations across the diaphragm again allow a close simulation of a sector of the ideal pulsating sphere.

Again matched termination at the perimeter prevents reflections. Unfortunately when the Quad was designed, it was simply not possible to produce a woofer of matching quality and a full range electrostatic design having restricted sound-pressure levels was inevitable. With modern active woofer technology these restrictions no longer apply.

With a phase array electrostatic transducer used from the low midrange upwards it is possible to get staggering sound-pressure levels because of the sheer volume velocity available, but without sacrificing the low distortion and near ideal dispersion. Moving coil designs simply cannot reach these low distortion figures.

Loudspeaker electronics

One approach to improving loudspeakers is to treat the amplification, crossover and transducer stages as part of a single system having an overall transfer function. When this is done, a great many new avenues open. The tradition of building general purpose amplifiers which are remotely sited from passive loudspeakers built by someone else has nothing to recommend it.

The passive loudspeaker has so many flaws that it is difficult to know where to begin. The low-frequency response of a passive speaker is determined by the mechanical parameters and not by the control system and will be inferior for a given enclosure size.

It is intuitively obvious that the two outputs from a crossover network should sum to produce the original signal. Unfortunately in a passive crossover this requirement simply cannot be met. Having heavy woofer currents and their distortion products flowing in the same wiring as the tweeter drive, as a passive speaker does, is asking for trouble. One engineering tenet which is seldom broken with impunity is to put the power source near the load.

The only accurate solution is to use one power amplifier per transducer with the crossover function performed at signal level prior to the amplifiers. Power amplifiers are so cheap today that there is little excuse for any other approach.

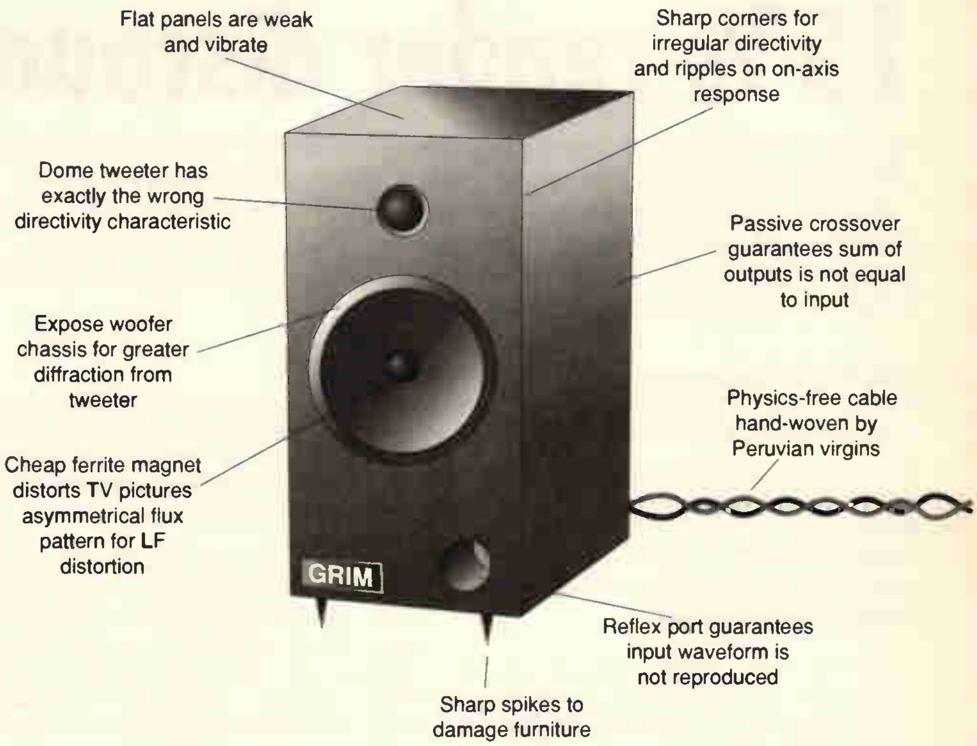
Another advantage of integrating the amplifiers into the loudspeaker is that the endless and boring mythology of loudspeaker cable audibility is neatly sidestepped.

The future?

The traditional loudspeaker is so flawed that for high quality applications, the end of the road has been reached. Although countless learned papers have appeared pointing out the flaws of traditional speaker design, which are encapsulated in **Fig. 7**, there has been little reaction from traditional manufacturers who either lack the vision to see the future or who lack the wide range of skills needed to put the vision into practice.

In the future, the highground of precision sound reproduction will be captured by active loudspeakers whose design is based on a deep understanding of engineering, acoustics and psychoacoustics.

At a technological disjuncture of this kind, where an old technology is being replaced by new, the opportunity arises for entirely new companies to emerge and capture the market while the traditional suppliers do ostrich impersonations. ■



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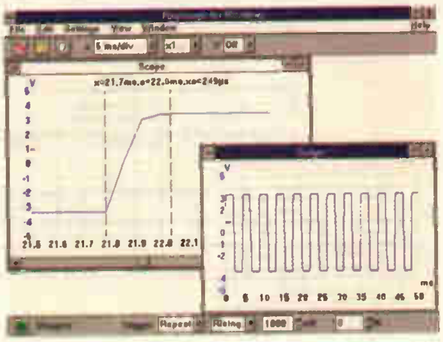

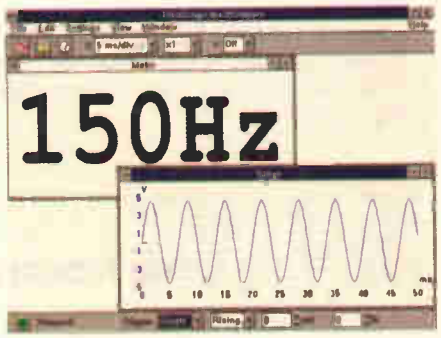

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A look at LIGHT

ILLUSTRATION JAMEL AKIB

With the aid of his new light meter design, Ian Hickman has been investigating the properties of some of the more recent opto devices around.

Light emitting diodes have improved enormously, in both efficiency and brightness, over the years. I recall obtaining a sample of one of the first leds – red, of course – to become available, around 1970. This Texas Instruments device came in a single lead can, with glass window, smaller than TO18, the can itself being the other lead.

It was a great novelty to see a wee red light coming out of a solid. But as a replacement for a conventional panel indicator lamp, it was far too dim.

Since then, TI has continued to be a major force in opto products, several of these having been featured in articles in this magazine.[1,2,3] But many other manufacturers are active in the field, which covers not only leds, photodiodes and phototransistors, but optocouplers, laser diodes, fibre-optic data products and other devices.

Light-emitting diodes in particular have seen major advances recently. Being fortunate enough to obtain samples of a number of the latest types, I was interested in finding out just what they will do, and exploring ways of applying them.

Applications a-plenty

Light-emitting diodes are available covering the whole spectrum, from infra red to blue, and have a variety of uses. Infra-red types are used – commonly in conjunction with a photodiode fitted with a filter blocking visible light – in tv remote controls, and in infra-red beam intruder detectors, etc.

High-intensity red leds are now commonly employed as cycle rear lights, in place of small incandescent filament lamps. They are also suitable as rear lights for vehicles. Amber high-intensity leds are used as turn indicators or flashers.

Blue leds were for a long time unavailable. When they did appear they were much less bright than devices of other colours. But now, really bright blue leds are in production. A typical application is as one of the primary colours in large colour advertising displays. A good example is the Panasonic *LNG992CF9* blue led in a T1$^3/_4$ package. Surface-mount types are also available. It provides a typical brightness of 1400mcd over a ±7.5° angle, at a modest forward current of 20mA.

While most leds produce incoherent light, covering a range of wavelengths around the predominant frequency, special types operate as lasers, producing essentially monochromatic light. The result is a beam with very low dispersion. Uses include laser pointers as aids to visual presentations, and as read and write sources in optical disk products.

Panasonic produces laser diodes, but these are not at present marketed in the UK. They are intended for use in consumer products and hence available only in production quantities. Alas, there seems to be no manufacturer of cd players in this country.

Measurements are a must

In any branch of engineering – or science in general – little if any progress can be made without suitable measuring instruments.

For my experiments with opto, I needed a light meter with the widest bandwidth possible. But high sensitivity was equally desirable. These two parameters result in an inevitable trade-off.

In the event, a medium-area silicon photocell was chosen. It was operated with zero reverse bias to achieve a low dark current and good noise figure, at the expense of sensitivity.

The final circuit, **Fig. 1**, offers a wide range of sensitivities, sensitivity on range 1 being a hundred thousand times that on range 6. The photocell used was an 'unfiltered' example of the *SMP600G-EJ*, i.e. one fitted with a clear window.[4] This is a silicon diode with an area of 4 by 4mm overall, an effective active area of $14.74mm^2$ and a capacitance at zero volts reverse bias of 190pF. A similar alternative is RS 194-076.

Responsivity as a function of wavelength is as shown by the unfiltered curve in **Fig. 2**. The diode connects to the virtual earth of an op-amp. This op-amp is used as a transimpedance amplifier; that is to say, the photodiode output current is balanced by the current through the feedback resistor, giving a volts-out per microamp-in determined by the value of R_f.

The op-amp selected might seem an unusual choice, but it offers very wideband operation. It has a very low value of input bias current of 2pA typical, although at $20nV/\sqrt{Hz}$, its input noise is not as low as some other op-amps. Especially bearing in mind that the noise is specified at 1MHz; the $1/f$ voltage noise corner frequency and the current noise are not specified on the data

The *TSH31* has a slew rate of 300V/µs and a gain bandwidth product of 280MHz. In addition, it has a modest gain of typically 800 under open-loop conditions. This means that for the higher values of feedback resistor in Fig. 1, all of the loop gain is safely rolled off by the *CR* consisting of R_f and the capacitance of the diode, before the loop phase shift reaches 180°.

Even on range 6, where R_f is 100Ω, the circuit is stable – at least with the diode connected. With it removed, the circuit oscillated gently at 160MHz, so there might be problems if one elected to use this op-amp with a small area diode, having a much lower capacitance.

On the other hand, where sensitivity to extremely low light levels is needed – the proverbial black cat in a cellar – the value of R_f can be raised to 100MΩ, 1000MΩ or whatever, as desired. But note that using a tee attenuator in the feedback path, to simulate the effect of a very high resistance with more modest values, will incur a severe noise penalty. It does this by raising the 'noise gain' of the circuit. Raising R_f provides more gain with no penalty of increased noise.

Careful construction is needed, with short leads around the op-amp and especially for the decoupling components. But for possible further experimentation with different photodiodes, the diode was connected via a 180° five way DIN plug and socket. The board carrying the op-amp circuitry was mounted as close as possible to S_1 and the DIN socket.

The photodiode was mounted in the backshell of the DIN plug which, being of the better variety with a retaining latch, had a shell of solid metal construction. I removed the rubber cable support sleeve, and reamed the hole out to accept the metal can (a two-lead, half-height TO39 style) of the photodiode.

One lead is connected to the diode cathode and also to the can, so naturally this lead was earthed. When the diode is illuminated, the anode tries to go positive, and thus sources current which is sunk by the short circuit provided by the op-amp virtual earth. Thus, due to the inverting configuration, the output signal is negative-going.

A small mains transformer with a single 7.5V secondary winding was used to power the instrument, the op-amp being supplied via *78L05* and *79L05* ±5V regulators. In addition to providing a sample of the op-amp output voltage for monitoring on a oscilloscope, a 1mA full-scale meter was provided. This reads the average value of the photodiode output at frequencies where the inertia of the movement provides sufficient smoothing – i.e. from a few hertz upwards.

Prototype testing having been satisfactory, I constructed the final version in a small sloping panel instrument case, RS style 508-201. The

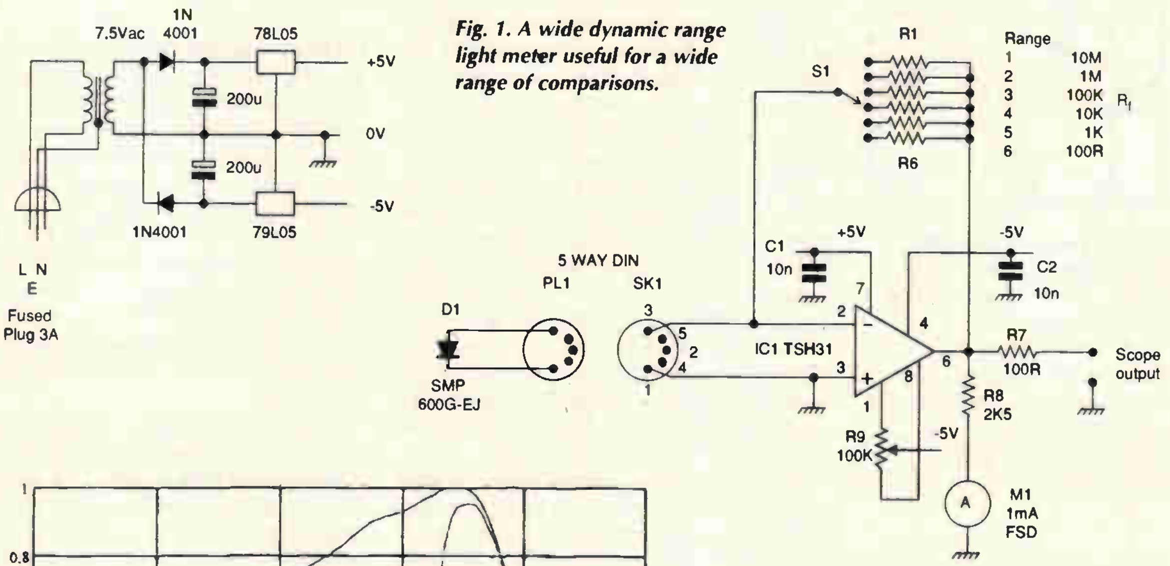

Fig. 1. A wide dynamic range light meter useful for a wide range of comparisons.

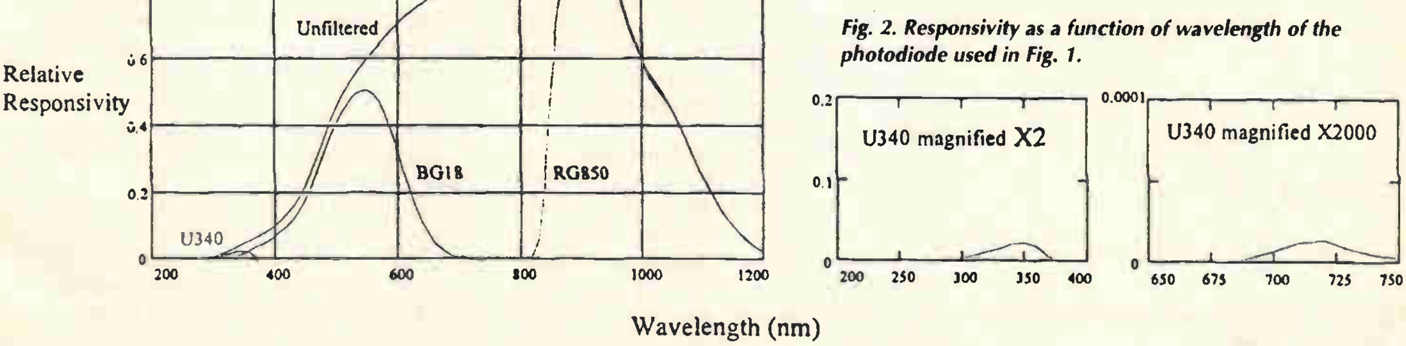

Fig. 2. Responsivity as a function of wavelength of the photodiode used in Fig. 1.

DIN socket was mounted at the centre back, S_1 top rear, the meter on the sloping panel and the mains transformer as far forward as possible.

Provision was made for fitting a screen between the transformer plus power supplies board at the front, and the op-amp circuitry at the rear, but in the event this proved unnecessary. Even on the most sensitive range there was no visible hum pickup amongst the general background noise, which amounted to some 20mV peak to peak on range 1, the most sensitive range.

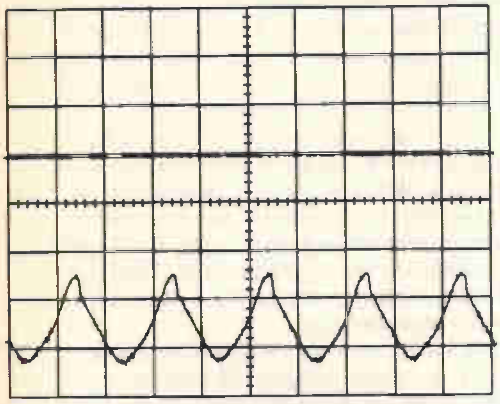

Fig. 3. Variation of light output from a 'white' fluorescent lamp. Photodiode at 50cm from the tube, lightmeter set to range 3. Oscilloscope settings 5ms/div. horizontal, 0.2V/div. vertical, 0V at centre line.

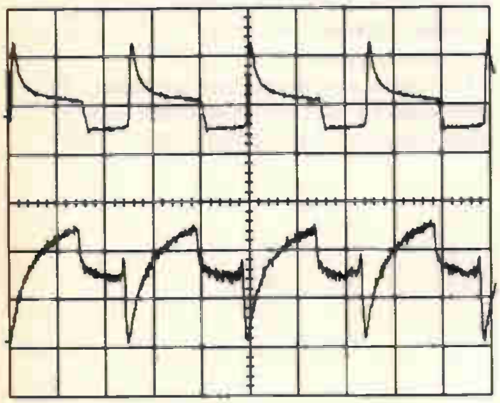

Fig. 4. Variation of light output from an uncoated fluorescent lamp. Photodiode at 30cm from the tube, lightmeter set to range 3. Lower trace: light output as measured by circuit of Fig. 1, 5ms/div. horizontal, 0.2V/div. vertical, 0V at centre line. Upper trace: waveform of the voltage applied across the tube, via capacitive pick-up, 5ms/div. horizontal, 2V/div. vertical, 0V at two divisions above centreline.

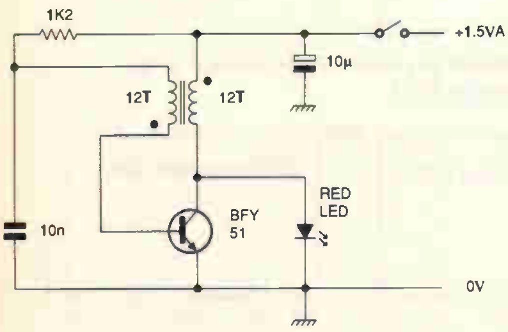

Fig. 5. Circuit diagram of a pocket torch using a 3000mcd red led.

Measures leds, but what-else?

Before measuring any leds, I used the instrument to check two other sources of light, one of them the fluorescent light over my bench.

I believe that high-frequency ballasts are more efficient than conventional ballast chokes because the gas plasma does not have a chance to recombine between successive pulses of current in a high-frequency choke.

In a fluorescent fitting with a conventional ballast inductor, part of the energy in the 100Hz current pulses is spent re-establishing the plasma on each cycle. But recombination is not entirely complete between pulses; if it were, then the starter would need to produce a high-voltage kick every half cycle.

It was interesting to see the actual variation of light output over a mains cycle, shown in **Fig. 3**. This waveform was recorded on range 3 of the lightmeter, with the photodiode head at 50cm from the tube, a Thorn 2ft 40W '*white 3500*' type – presumably with a colour temperature of 3500°. Given the 5ms/division timebase setting, the intensity variations are seen to be, as expected, at 100/s.

Characteristics of a silicon photodiode, used in voltage, i.e. open-circuit, mode are non linear and independent of the diode area. But in current, or short-circuit, mode, the sensitivity is proportional to the effective area of the diode, and extremely linear versus incident light intensity. It remains linear over eight or more orders of magnitude, from a lower limit set by the noise-equivalent power upwards.

The zero current line in **Fig. 3**, corresponding to complete darkness, is indicated by the trace at one division above the centre line. So Fig. 3 shows that between peaks at 4.25 divisions below the zero line, the light output falls to just under 60% at 2.5 divisions below.

There certainly seems to be evidence of a sudden increase of light just after the start of each half cycle of voltage, following the dip. And of course, being ac, the tube current must go through zero twice every cycle.

How brightly the plasma glows at that instant is a moot point, since the light output is mainly due to the tube phosphors of assorted colours, to give a whitish light. If the phosphors used have different afterglow times, there will be variations in 'colour temperature', as well as light output, over the course of each half cycle – just to make things even more complicated.

So I next looked at the radiation from a fluorescent tube without any phosphor, which therefore produced a bluish light. Being entirely without any safety filter, it also produced both soft and hard ultraviolet radiation. It was a 12in tube type *G8T5*, used in an electronic ballast powered from 12V dc. This started life as a camping light, but the original tube was removed and the ultraviolet tube fitted when it was converted into a homemade eprom eraser.

The unit was fitted into a long box, the front being closed by a removable, long, L shaped eprom carrier. This was to avoid external radiation when in use, as hard ultraviolet light is bad for the eyes.

With the carrier removed and the photodiode at a distance of 30cm from the tube, the light output measured on range 3 is indicated by the lower trace in **Fig. 4**. The 30cm separation was more than sufficient to ensure that there was no capacitive coupling between the high voltage waveform applied to the tube, and the photodiode element via the window. This is an important precaution, because the photodiode was not fitted with a mesh screen, available on other models.

The upper trace shows the waveform of the voltage applied across the tube. As measuring this voltage directly was inconvenient, it was recorded simply by placing the tip of an oscilloscope probe close to the end of the tube. The waveform at the other end was identical, but of course, the other way up.

The zero-voltage reference for the lower waveform is the graticule centre-line. It is clear that the light intensity closely follows the modulus of the voltage waveform, with just a little rounding. This rounding is not due to any limitations of the frequency response of the lightmeter. Presumably this means that the degree of ionisation in the plasma does not vary appreciably over the course of each cycle.

LEDs across the spectrum

It is clear from Fig. 4 that the electronic ballast ran at a frequency of about 20kHz – not so very different from a small pocket torch I made a few years back, when the first really bright leds appeared. It used a 3000mcd red led, powered from a single cell.

The circuit is as shown in **Fig. 5**. My records show that the circuit was built and tested as long ago as the end of 1990. It was constructed in one of those small transparent boxes used by semiconductor manufacturers to send out samples – very useful for all sorts of purposes.

Typical forward voltage of an led is between 1.5V and 3V, so some kind of inverter is necessary to run it from a single 1.5V cell. Figure 5 uses a blocking oscillator: the resistor provides base current to turn on the transistor and positive feedback causes it to bottom hard.

When the collector current reaches a value the base current can no longer support, the collector voltage starts to rise, and positive feedback causes the transistor to cut off abruptly. The collector voltage flies up above the supply rail, being clamped by the forward voltage of the led.

Energy stored in the inductor gives a pulse of current through the led, which was monitored by temporarily inserting a 1Ω resistor in its cathode ground return. The current peaked at 150mA and had fallen to a third or less of this value before the transistor turns on again.

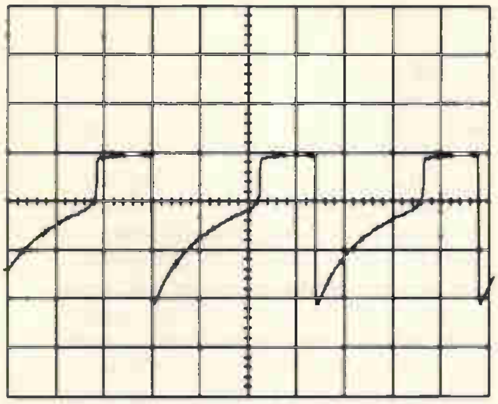

Fig. 6. Light output of the circuit of Fig. 5, measured using range 4 of the light meter, at a range of 1cm. 500mV/div. vertical, 0V reference line at one division above centreline, 10µs/div. horizontal.

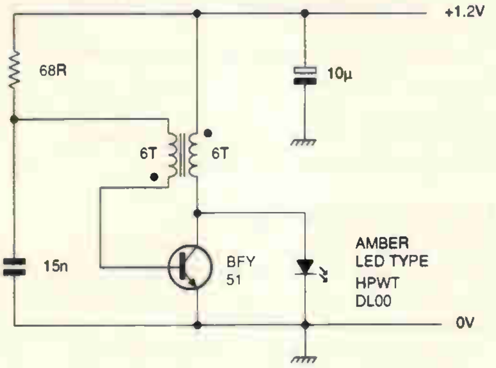

Fig. 7. Circuit of a pocket torch using an HPWT-DL00 amber led, designed to run from a single 1.2V NiCd cell.

The transformer consisted of a twelve turn collector winding of 0.34mm enamelled copper wire and a twelve-turn feedback winding of 40SWG enamelled copper, on an *FX2754* two-hole balun core, which has an AL of 3500nH/turns squared.

You would not normally expect a 1:1 ratio for a blocking oscillator transformer, but special considerations prevail when designing for such a low supply voltage. Light output is shown in **Fig. 6**, measured using range 4 of the light meter, at a range of 1cm.

Operating frequency – given the 10µs/division timebase setting – can be seen to be a shade under 30kHz. Although of course of a totally different colour, the red led torch seemed about as bright as one using a 1.2V 0.25A lens-end bulb, while drawing, by contrast, only 50mA. The circuit worked well also with the Panasonic blue led mentioned earlier.

I recently obtained some samples of very bright leds from Hewlett Packard Components Group, exemplifying the latest technology. The *HLMP-D/Gxxx Sunpower* series are T-1 3/4 (5mm) precision optical AlInGaP lamps in a choice of red, shades of orange, and amber.

These lamps are designed for traffic management, outdoor advertising and automotive applications, and provide a typical on axis brightness of 9300mcd. The *HPWx-xx00 Super Flux* leds are designed for car exterior lights, large-area displays and moving message panels, and backlighting.

An *HLMP-DL08*, with its half power viewing angle of ±4°, was compared with an *HPWT-DL00* with a half power viewing angle of ±20°. At a spacing from the photodiode of 1cm on range 4, with 30mA in each diode, they gave similar readings, but at greater ranges, the reading from the *HLMP-DL08* exceeded that from the *HPWT-DL00*, on account of its narrower beam.

However, the total light output from the *HPWT-DL00* is greater, so it was chosen for an updated version of the led pocket torch of Fig. 5.

And brighter still...

The resulting circuit was as shown in **Fig. 7**, again using an FX2754 core. Due to its broad beam, the *HPWT-DL00* produced a less bright spot on the opposite wall of the room than a two-cell torch with a 2.5V 300mA bulb. But this is only because the latter had the benefit of an extremely effective reflector, giving a very small spot size.

With the aid of a small deep curve 'bulls eye' lens from an old torch of the sort that used a No 8 battery, the torch of Fig. 7 more than held its own. It drew only 150 mA from

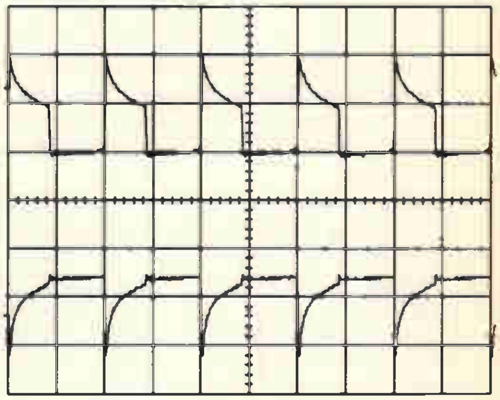

Fig. 8. Performance of the circuit of Fig. 7: a) collector waveform (upper trace), 2V/div. vertical, 0V line at one division above centreline, 10µs/div horizontal. b) base waveform (lower trace), 2V/div. vertical, 0V line at two divisions below centreline, 10µs/div. horizontal.

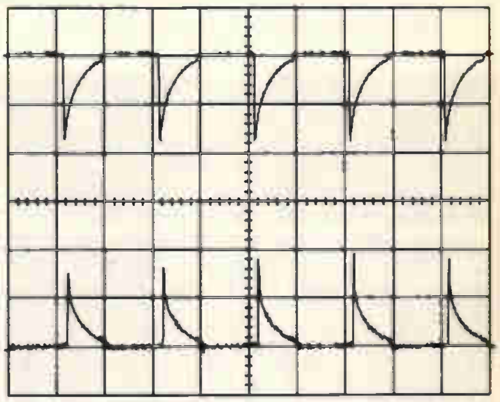

Fig. 9. Performance of the circuit of Fig. 7: a) light meter output (upper trace), 1V/div. vertical, 0V line at three divisions above centreline, 10µs/div. horizontal. b) diode current waveform monitored across a 0.18Ω resistor, lower trace), 50mV/div. vertical, 0V line at three divisions below centreline, 10µs/div horizontal.

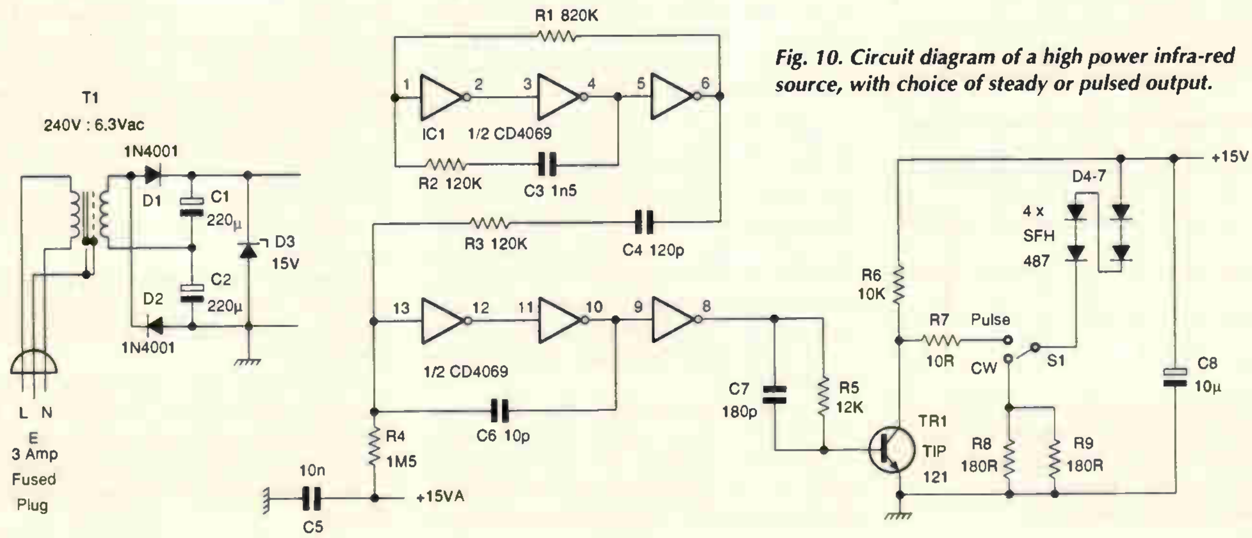

Fig. 10. Circuit diagram of a high power infra-red source, with choice of steady or pulsed output.

from a single cell. This makes it about four times as efficient as the torch bulb, with a colour rendering that is not so very different. It is certainly much more acceptable that the red led torch.

Figure 8 shows the performance of Fig. 7. The upper trace shows the collector voltage waveform at 2V/div. vertical, the 0V line being at one division above the centreline, and 10μs/div horizontal. On the lower trace is the base waveform at 2V/division vertical, 0V line at two divisions below centreline, 10μs/div horizontal, the operating frequency being about 50kHz.

Figure 9 shows the output of the light meter on range 4 at 1V/div. vertical, 0V line at three divisions above centreline, 10μs/div. horizontal. It is clear that the light pulse has almost completely extinguished by the time that the transistor turns on again to store more energy in the transformer primary. This is also seen in the diode current waveform, monitored across a 0.18Ω resistor. The lower trace is at 50mV/div. vertical, 0V line at three divisions below centreline and 10μs/div. horizontal.

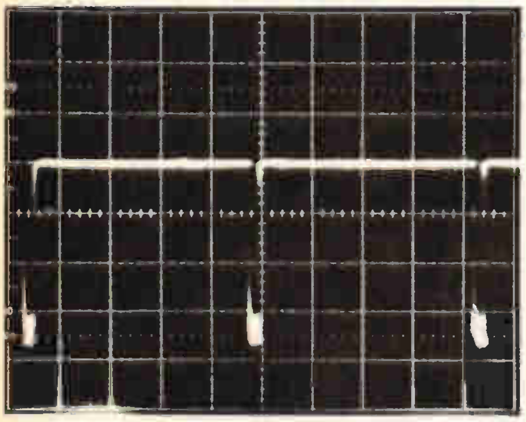

Fig. 11. Lightmeter output at a range of 2cm from the four diodes, on range 5. 1V/div. vertical, 0V reference at centre line, 10μs/div horizontal.

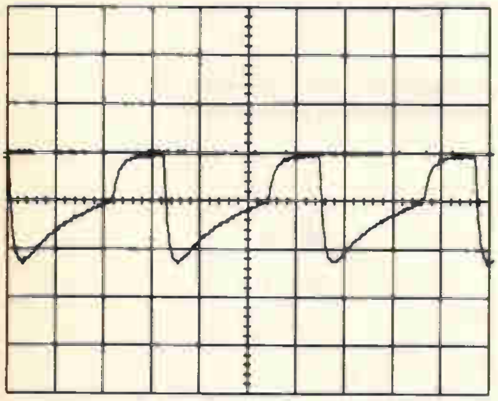

Fig. 12. Light output of the circuit of Fig. 5, measured using range 2 of the light meter, at an increased range. 500mV/div. vertical, 0V reference line at one division above centreline, 10μs/div. horizontal.

Peak diode current is just on 400mA. Although peak current for the *HPWT-DL00* is not quoted on the data sheet, the average current is safely within the 70mA maximum allowable at 25°C.

The circuit again used a *BFY50* transistor. It also worked with a *BC108*, although that device actually needed a lower value of base resistor. This was despite its small signal h_{FE} of 500, against the 130 of the *BFY50* – which only goes shows that in a switching circuit, a switching transistor beats one designed for linear applications.

Very bright – but invisible

Figure 10 shows the circuit diagram of a little instrument I made up recently for a specific purpose, of which more later. It uses four Siemens infra-red leds, type *SFH487*.

The unit offers a choice between constant and pulsed illumination. The three-inverter oscillator runs at about 450Hz, and its output is differentiated by C_4 and R_4. This 180μs time constant, allowing for the effect of R_3 and the internal protection diodes of the inverter input at pin 13 of the *CD4069*, results in a positive-going pulse of about 100μs duration at pin 8.

Having a string of three inverters speeds up the trailing positive edge of the pulse at pin 13. But with three inverters on their own, a glitch on the trailing edge of the pulse is inevitable, due to internal coupling between the six inverters in the package. So C_6 is added to provide a little positive feedback to make the trailing edge of the pulse snap off cleanly.

Figure 11 shows the output of the lightmeter when illuminated by the diodes, at a range of 2cm on range 5. Despite the presence of D_3, there is still some 100Hz ripple on the supply line. This results in some 100Hz modulation of the the pulse amplitude, and also of the pulse repetition frequency, or prf, both visible in Fig. 11.

To show this, I used a Polaroid photograph of the display on a real time analogue oscilloscope. My simple digital storage oscilloscope stores only a single trace per channel at a time; its facilities do not run to a variable persistence mode such as is found on the more expensive models.

Fortunately, for the intended purpose, the 100Hz modulation was unimportant. The predominant wavelength of the infra-red radiation from the diodes is 880nm, this being in the range favoured for physiotherapy purposes. Incidentally, although the spectral bandwidth is quoted as 80nm, the tail of the spectral distribution evidently extends some way – even just into the visible part of the spectrum – as in operation the diodes exhibit a very faint red glow.

Switch S_1 allows the four infra-red diodes to be powered by dc, or via Tr_1, with the pulses. Given their aggregate forward voltage of about 5V, the current through the diodes on cw, determined by $R_{8,9}$ and supply voltage, is the rated maximum for the devices of 100mA.

In pulse mode, the peak current reaches the rated peak maximum of 1A. But the duty cycle of around 5% keeps the average current to just half of the steady state dc maximum.

The circuit is supplied from an old 6.3V transformer which was probably intended originally as a tv spare. It would have been used to power the heater of a crt which had developed a heater/cathode short, thus extending its life and avoiding a costly replacement. This would explain the inclusion of an interwinding screen in such a small, cheap transformer.

In the cw position of S_1, the supply voltage is a shade under 15V, but tended to rise to nearer 17V with the lower average current drain in the pulse mode. So I added D_3 to give the designed nominal supply voltage value of 15V on pulses also.

Resistor R_6 serves to pull the collector of Tr_1 up to +15V between pulses. Without it, the voltage lingers at about +10.5V, since with much less than 5V across the string of diodes, they become effectively open circuit.

Limitations of the lightmeter

Useful as the lightmeter has proved, it is necessary to bear in mind its limitations. One of these is the sensitivity/bandwidth trade-off mentioned earlier.

To illustrate this, **Fig. 12** shows the same waveform as Fig. 6, the output of the red led torch of Fig. 5. But whereas Fig. 6 was recorded with the lightmeter set to range 4, for Fig. 12, the light reaching the photodiode was greatly reduced. In addition, range 2 – which is a hundred times more sensitive – was used.

The reduced bandwidth is clearly evidenced by the rounding of the edges of the waveform. With the incident light lowered yet further and range 1 selected, the waveform was reduced almost to a triangular wave. But while waveform high frequency detail was lost, note that the average value of the incident light is still accurately recorded.

The other great limitation of the lightmeter is, of course, that it provides no absolute measurements. To do so, it would have had to be calibrated with a standard light source, and none was available. Even then, absolute measurements would be difficult, as they always are in photometry. This especially true when comparing 'white' light sources of different colour temperatures, and even more so with leds where about 90% of the output radiation is within ±5% or less of the predominant wavelength.

Nevertheless, the instrument is exceedingly useful for comparisons, and for studying the variations of light output of a source as a function of time.

It can be made even more useful by incorporating a filtered diode. Using a diode with the *U340* filter, see Fig. 2, the blue led tested earlier even produced zero response on range 1. Its predominant wavelength lambda is 450nm.

The spread delta lambda is quoted as 70nm, although the data sheet does not say whether this represents the 50%, 10% or 1% power bandwidth. But evidently there is no significant tail to the distribution extending as far into the ultra-violet at 375nm, where the *U340* filter cuts off. The ultra-violet filtered diode did show a small output when held close to a 60W bulb. This was due to the very small filter response shown in Fig. 2, in the region of 720nm.

Medical applications

Clearly, one should be very wary of experimenting in this area*. Some medical applications of optoelectronics are spectacular and hence deservedly well known, such as the use of laser radiation to stitch a detached retina back in place. Other uses are less well known, but one, the use of infra-red radiation in physiotherapy I have personal experience of.

It was used, with great success some years ago, to treat supraspinatus tendonitis, alias a painful right shoulder. At the time, an infra-red laser with just 5mW output was used, although since then equipments with 50mW output have become available.

The low dispersion offered by a laser source, means that the energy can be applied with pinpoint accuracy to the affected spot, which is very useful when the power available is low. But I was advised by a physiotherapist (with a degree in physics and an interest in electronics) that apart from this, there is no reason to suppose that an infra-red laser has any specific advantage over any other source of infra-red.

Having recently experienced a return of the tendonitis, I designed the unit of Fig. 10 to treat it. Despite my earlier warning about experimenting, this seemed a safe enough procedure, given that both the condition, and the treatment had been previously properly diagnosed.

At 100mA forward current, the four diodes provide a total radiant flux of 25mW each. They were mounted as close together as possible on a scrap of 0.1in pitch copper-strip board, each angled slightly in so that their beam axes crossed at about 1cm out. It is thus possible to flood the affected area with infra-red radiation, where, the theory goes, it 'energises the mitochrondria', the chemical power house of each cell, promoting healing.

I am happy to report a marked improvement, following a few five minute sessions on alternate days. The pulse mode was incorporated to allow for the possibility that the effect is nonlinear with respect to intensity.

Instead of half the radiation producing half the effect, and a quarter just a quarter, it might be that half the radiation intensity produced only a tenth of the effect, and a quarter none at all. But the interim conclusion of my limited experience suggests that there is little difference between the efficacy of the pulse and cw modes. ■

*Ian's medical experiments have been reported purely for interest. We do not advocate that you try such experiments yourself. Medical experiments should be carried out only with medical supervision – Ed.

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Hands-on Internet

Cyril Bateman looks at new search options, a directory for finding UK electronics companies and filter design tools.

The continuing escalation of Web pages available on Internet has resulted in very heavy loading and consequent delayed responses, for the most popular all-purpose search engines. This has resulted in two major improvements – the location of mirror sites outside North America for these all-purpose search engines, and the development of search engines targeted only to specific tasks.

In the March issue I highlighted the version of 'YahooUK', dedicated to searching Internet for UK and Irish surfers. This month's 'bookmark' site, Altavista.telia.com[1] has introduced local search engines available for most countries and languages, which truly complements the parent site. While the full address is quite long, bookmarking it makes for extremely easy access.

Previously, telephone and fax numbers for North America were easily accessed using Internet, but not so for other countries. Applegate Media[2] has now released its Web site which specifically aims to supply the telephone and fax numbers of the UK electronics industry. Since this is a lengthy listing it is best accessed during a quiet period, and downloaded to your hard disk for easy future reference.

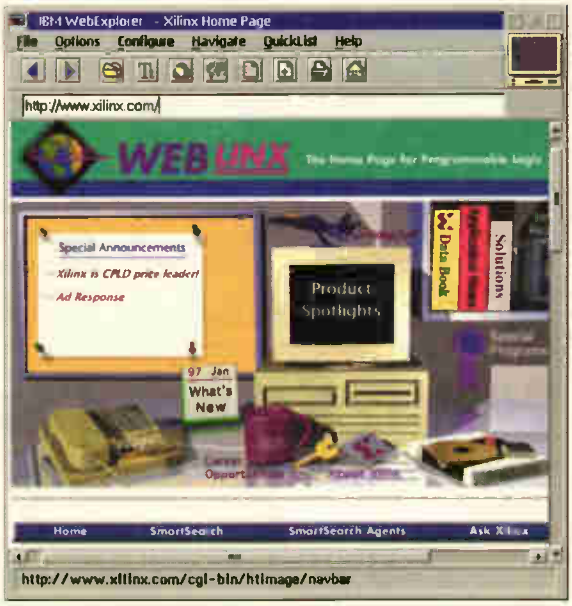

Fig. 2. In my view, the best selection of programmable logic data information available on the Net. Register here to set up your desired smartsearch agent.

Fig. 3. Home of the surface-mount technology reference centre contains directories of surface-mount equipment and component suppliers.

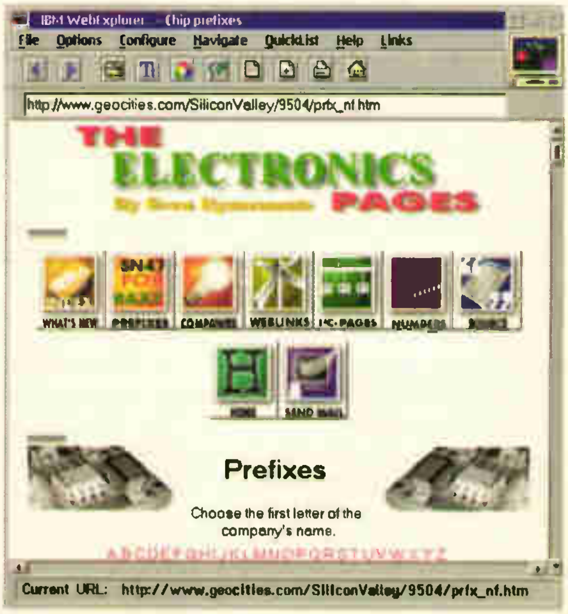

Fig. 1. Easy identification of Internet addresses for Semiconductor Companies. Find direct links to home or data-sheet pages.

You can often guess the Internet address of a company by simply using its name, plus '.com'. When this fails, in the past I have found a search on Altavista able to supply the needed address. However for Web addresses of semiconductor makers, the best method now is to use Electronics Pages[3]. This not only supplies the addresses, it also provides direct web links to either the required home or data sheet pages. While the initial download is lengthy, once retained in your browser's temporary disk files, repeat access is extremely quick, beating all other methods, **Fig. 1**.

Still in development, EDAMall[4] a new site, is based on an electronic shopping 'mall' which allows you to try, using real-time demonstrations, or buy, using a credit card, several electronic design automation systems. With its large reference library of technical articles and industry news, surfing this site can dramatically reduce the time needed to find essential pre-purchase information.

This site requires use of 'Java', 'Javascript' and a 'Java' enabled Netscape browser for full access. Three subsidiary malls cater for mechanical cad, scientific cad and software development.

When looking for programmable logic data, try Xilinx.com[5] This site has its own specialised Weblinx smartsearch method which looks for information within the fifty best PLD sites as well as Xilinx itself. Regular users can define their own smartsearch 'agent' which automatically informs them via e-mail of any updates or new documents within the parameters they specified, **Fig. 2**.

Almost all new electronic designs use surface mounted parts, so SMTnet[6] is an essential stopping off place to browse for a few minutes. Particularly useful are the industry directories of surface mount equipment makers and surface mount component suppliers. This last is searchable either by product or manufacturers name. Alternatively an alphabetical list of all component suppliers can be generated, **Fig. 3**.

Many established technical libraries of data, or software models, are located at sites which can only be accessed using Telnet. While a web browser can link you to a Telnet site, once connected one cannot access the site using a browser and must continue by using a Telnet client, its protocols and typewritten commands.

While having a dedicated Telnet client in my computer, I must confess to using it with some reluctance for one-off site visits. For regular access to a particular site, having learned that site's command set, Telnet is a very good access method indeed, but unlike Web pages, Telnet certainly is not a point and click method.

Perhaps this is about to change. TechOnline,[7] formerly known as DSPnet, has been updated by Aliphas to become a truly interactive engineering forum. It is based on use of a Java applet which allows your browser to emulate a Telnet terminal within a Web page. This applet loads and executes dsp and other demonstrations automatically, using the site's so-called virtual laboratory. In this way, data searching is neatly combined with dsp simulations, **Fig. 4**.

Software simulated and Fairchild reborn

A return visit to National[8] to download up to date details of state variable filter chips together with listings of relevant application notes, revealed a late news item. Fairchild Semiconductor, comprising the old logic, memory and discrete lines of National, was relaunched in January as a separately funded subsidiary. For further details see the new Fairchild[9] home page, **Fig. 5**.

Effective active filter circuits can be built using either switched-capacitor or time-continuous techniques. For many low-noise, wide dynamic range or high-frequency design needs, the time-continuous filter is essential. Given the appropriate macromodels, the circuits can be simulated using a version of Spice. However, this design task is especially suited to the use of simple but dedicated filter design software.

Burr-Brown[10] offers similar time-continuous filter products and design software. This company too had a news announcement. The Burr-Brown home page has been given a new look and extra functions by way of celebrating the first anniversary of their publishing a Web page. While Spice

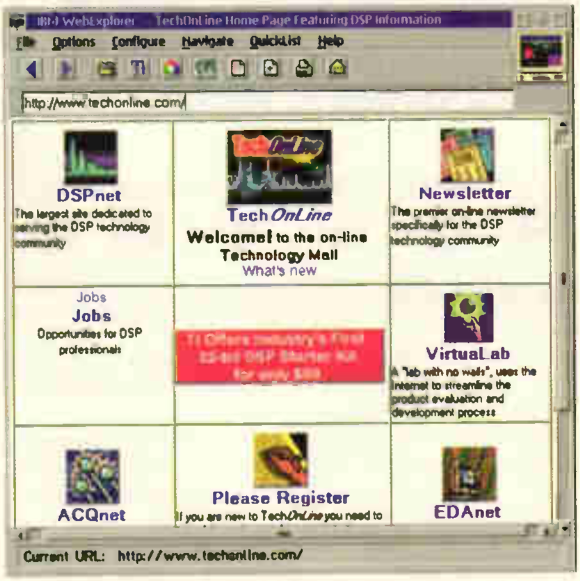

Fig. 4. Virtual dsp test laboratories on-line are provided by the home of dsp. Using a unique Java applet it links the Web browser with Telnet.

Fig. 5. National announces Fairchild spin-off. Visit to download your filter application notes in PDF format.

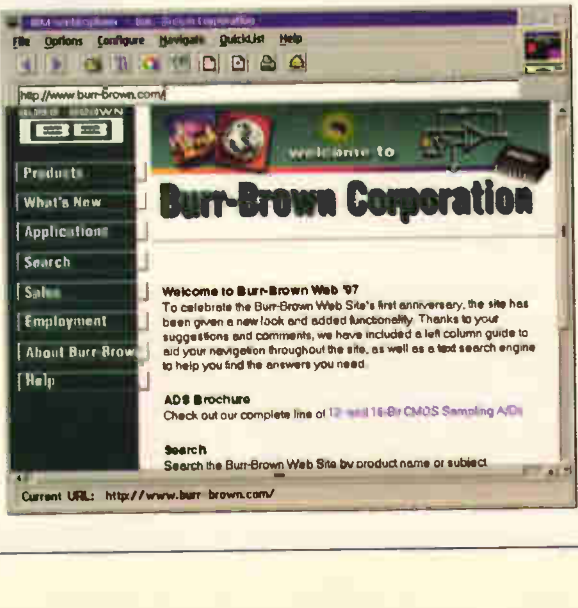

Fig. 6. Burr-Brown's Web anniversary celebration homepage. Download Filterpro software and application notes on-line.

Fig. 7. New look and name for Motorola Semiconductors' page. View Motorola manufacturing locations worldwide.

models for individual parts can be down-loaded, completing their literature request form will arrange a disk containing all their Spice macromodels, sent by post.

The company's software, *FilterPro*, which can be down-loaded, unpacks to give two dos packages; *Filter2* caters for mfb, or multi-feedback, style as well as Sallen-Key designs, while *Filter42* is dedicated to the *UAF42* state-variable chip, **Fig. 6**.

Design-net.com[11] is a new service from Motorola Semiconductor Products Division, dedicated to the design engineer's needs, giving easy access to data and applications sheets. The Semiconductor Division has more than twenty design and manufacturing locations world wide which can be viewed on the facilities page map, **Fig. 7**.

In November, I mentioned the new Windows evaluation version of PSpice 7.1 was available on cd rom as part of Motorola's *DesignLab* evaluation software. This has now been joined by the Intusoft *Spice and So Much More* demonstration cd.

While both evaluation software packages are fully usable, perhaps of even more benefit to the simulation novice and experienced user, is the wealth of application notes and on-line manuals these disks contain. While any of this software or data could be downloaded from Internet, the sheer volume of data contained on either cd, is only practical when supplied on cd rom. ■

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Error feedback in audio power

In response to a plea for help on a feedback problem, William de Bruyn has unearthed three alternative methods of error feedback for power amplifiers that *do* work.

Following K H Ellis's plea for help in 'Feedback on Feedback' in the December 1996 issue, it seems to me that his amplifier (outlined later) was always bound to be unstable. Little or no attention seems to have been given to issues of loop stability.

Addition of the 22pF capacitor simply inserts a dominant pole at a suitable frequency; it does not 'filter' noise. The operational amplifier chosen for this implementation of Hawksford's error-cancelling idea is not particularly suitable as the inherent slew rate limitations of the device restrict the potential bandwidth.

There has been a number of practical amplifier designs which have used the idea of an error feedback loop around the output stage of an amplifier.

First is a design by E. M. Cherry, which deals with a number of issues rather elegantly. Quiescent current is sensed and controlled without any need for complex schemes of thermal feedback. Such schemes bring with them the difficulties of dealing with all of the thermal/electrical time constants.

Prof. Cherry's approach to this problem – the feedback loop around the back-to-back differential pairs – also permits accurate setting of the gain of the output stage to some desired level.

His concept of nested differentiating feedback loops achieves unconditional stability with high levels of feedback and very low distortion within the audio band.

A further amplifier of note is designed by Robert Cordell. It was published in 1983 and reprinted in the *Journal of the Audio Engineering Society*, Vol. 32, No 1/2, 1984, Jan/Feb.

This amplifier employs a simple method of feed-forward error correction based on Hawksford's scheme. The error-correction loop uses only two fast small signal transistors and the resulting improvement in transfer linearity is quite remarkable. Most of the crossover and transfer artefacts, that so much recent correspondence has concerned itself with, become relatively minor issues.

This design is capable of extremely low distortion over a very wide frequency band – less than 0.001% from 20Hz-20kHz. It also exhibits extraordinarily good high-frequency and transient performance and achieves a slew rate of more than 300V/μs.

The third amplifier is a commercially produced design, namely the Tandberg *3009A*. This also uses a variant of Hawksford's scheme. In this case no overall feedback is applied, each stage relying on local feedback for setting of overall gain. In this instance , the output stage used Hitachi mosfets. These fets are distinguished from *Hexfet* structures by their substantially lower transconductance and threshold voltages. This Amplifier is capable of good high-frequency performance.

All in all, I feel that much of the rather heated debate regarding the linearity of igbt devices as opposed to mosfets, 'batwing' transfer curves, etc. is rather absurd and has more to do with what people grasp with their hands

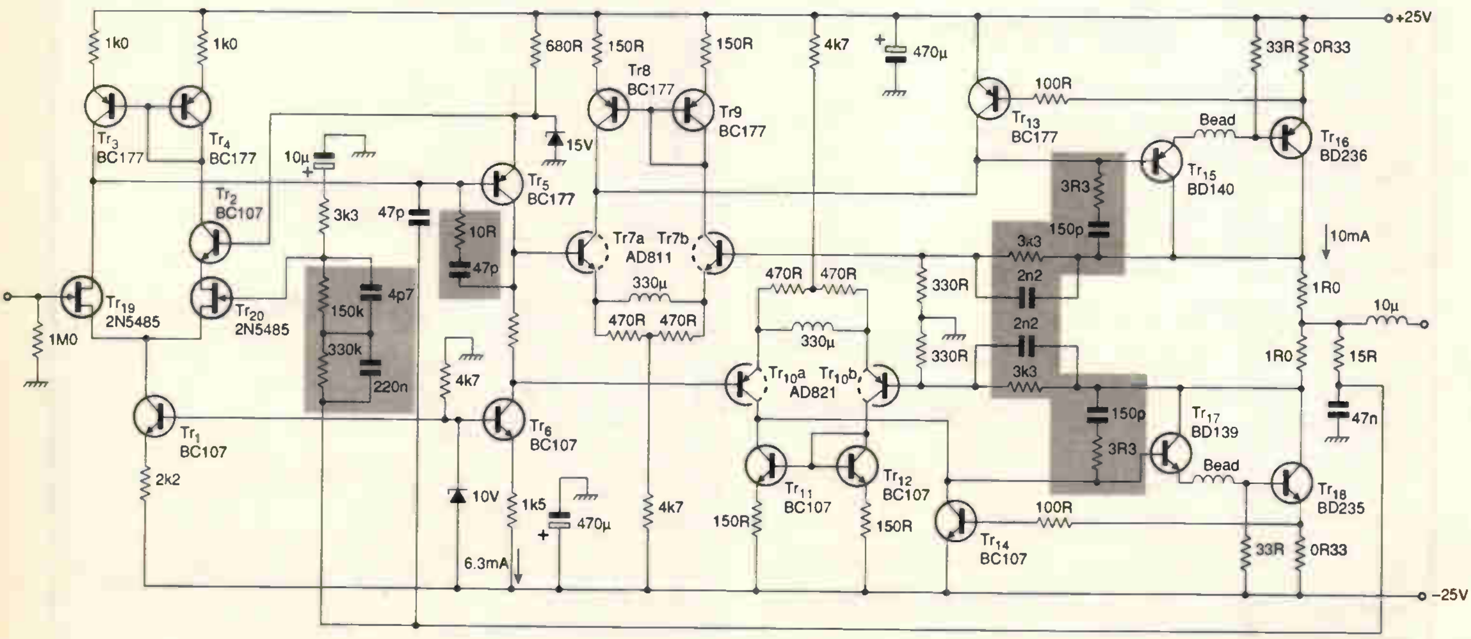
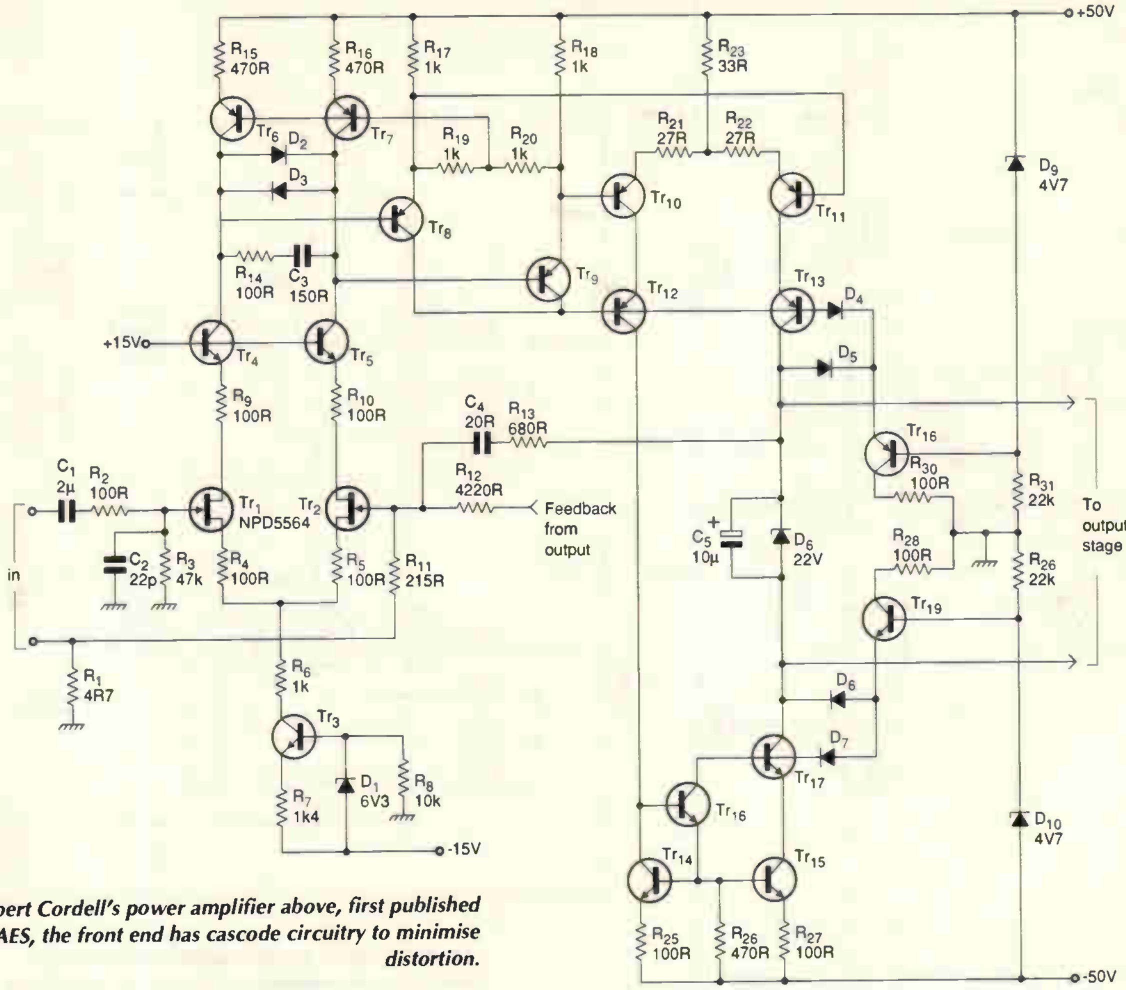
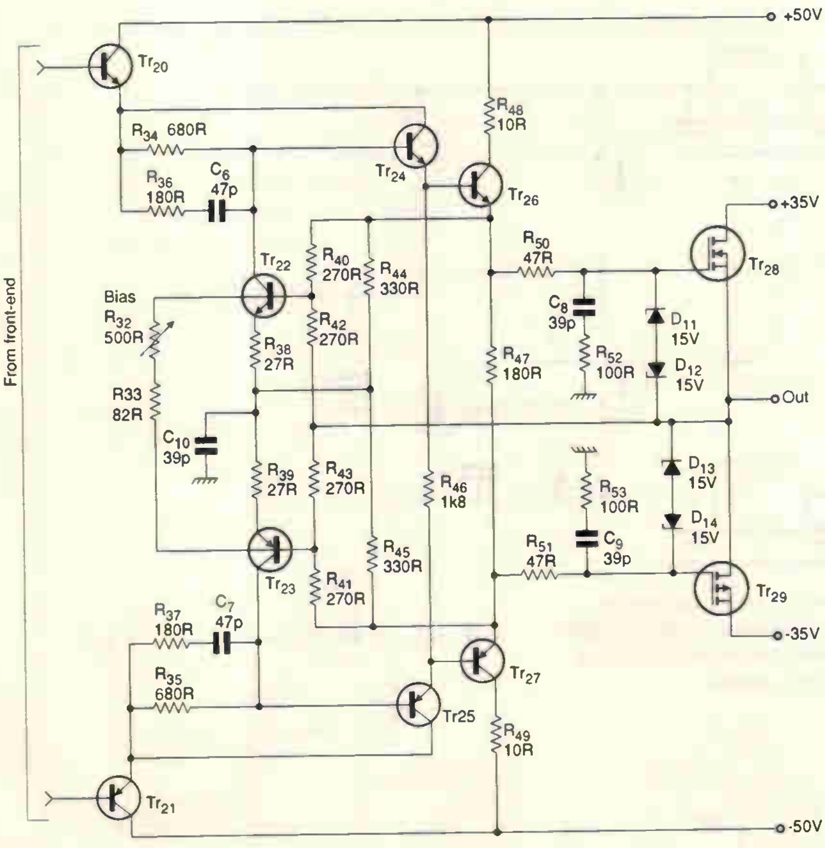
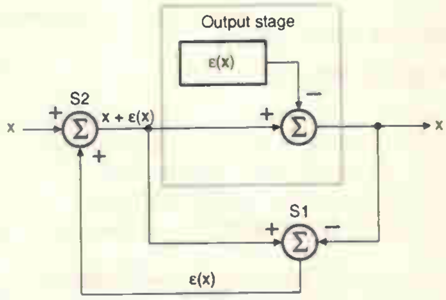


Fig. 1. Ed Cherry's 15W, 15Ω power amplifier, first published in IREE transactions, nested differentiating feedback loops are used. Note the driver circuit with inherent quiescent current regulation and substantial local feedback around the output stage.



In Robert Cordell's power amplifier above, first published in JAES, the front end has cascode circuitry to minimise distortion.





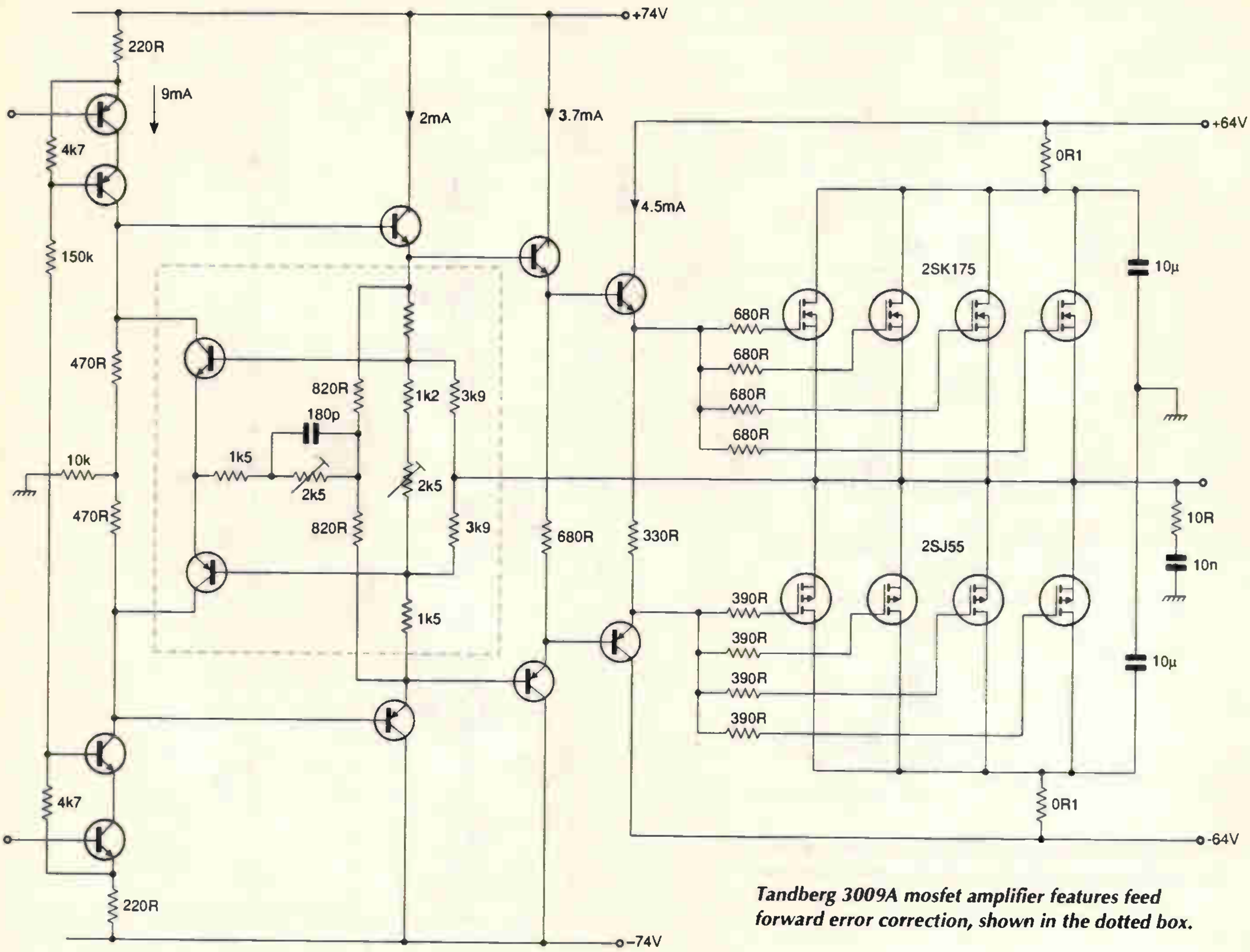
Error correction concept, above, for Cordell's power amplifier output stage, left, in which Tr_{22} and Tr_{23} provide the error correction.

rather than with their minds.

As many of the problems associated with amplifier design seem to centre on achieving ever greater bandwidth, it seems – to me at least – that the fastest available devices are the preferred option.

Poor transfer linearity can be readily dealt with by applying some sort of error correction around the output stage, without the problems of dealing with all of the poles that the application of overall feedback has to contend with.

I would be pleased to see someone apply some form of error cancelling feedback loop around, say, a valve amplifier output stage. Such devices are inherently less linear than mosfets and have much lower transconductance than any solid state device.



Tandberg 3009A mosfet amplifier features feed forward error correction, shown in the dotted box.

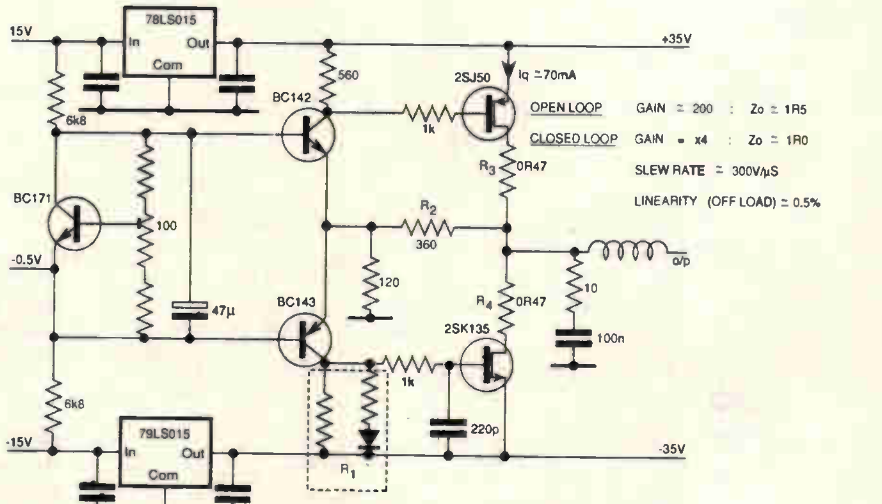
Extract from Ellis's original query

...applying negative feedback to give a gain of four, the stage shown gives reasonable performance, except that output impedance is about 1Ω. Also, when loaded, the stage distorts because there is nothing to increase the drive.

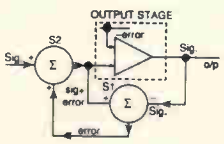
I was about to give in when I came across a reference to an error cancelling technique by Hawksford. The small diagram below gives the theory. Having got the gains right, the results were astounding.

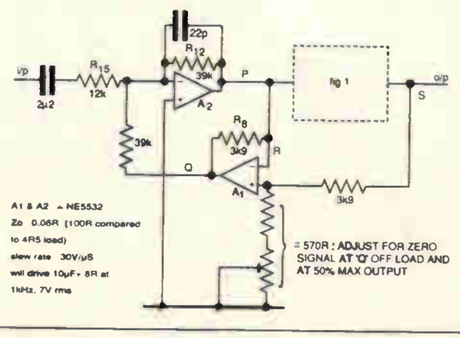
During testing, I found that a capacitive load of more than 22nF caused a high output at high frequency. This was a surprise as the output stage itself would happily drive a 10µF at 1kHz. More experimenting gave the feeling that this was not parasitic oscillation, but rather amplified and filtered noise. While loading the output with increasing values of capacitor, the output of A_1 became increasingly noisy until it burst into oscillation at about 2MHz. Putting a small capacitor across R_8 (A_1) stopped the oscillation but was not the best place as only the error signal was being filtered. The best solution was a 22pF across R_{12} (A_2) to filter signal and error. The amplifier now drives 10µF with no problem.

I would welcome your comments.



TI Texan output stage, top, before a practical implementation (below right) of Hawksford's error-cancelling idea, below left, was added.





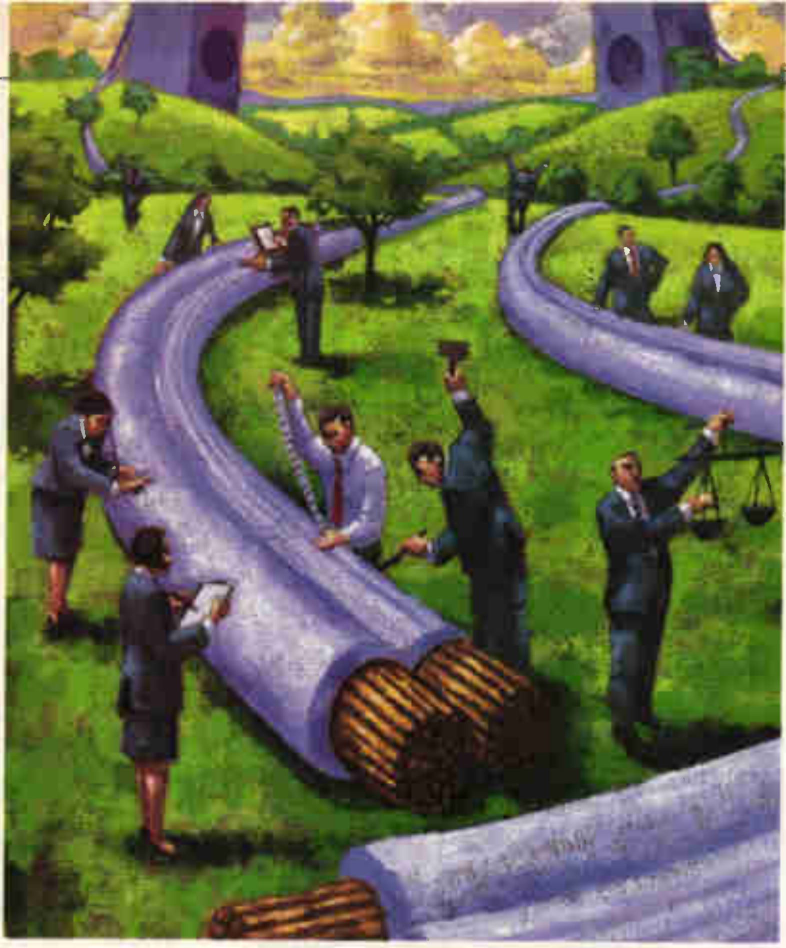


ILLUSTRATION JAMEL AKIB

RF effects on AF

Could mysterious audio power amplifier distortions be explained by rf noise from broadcast stations? Cyril Bateman investigates.

Performing distortion measurements on various speaker cables[1], I noticed and remarked on a level of non-harmonic residue, especially with the figure-of-eight cable styles. This residue was clearly visible on the oscilloscope output of my Hewlett-Packard *331A* distortion meter.

The on-screen appearance of this residue supported by its notable absence when testing co-axial cables, led me then to believe it resulted from wideband noise radiated from the 50Hz domestic mains supply.

Recent measurements, using a 3MHz wideband rf millivoltmeter of 1MΩ/20pF input impedance, at the loud speaker terminals in my listening room using my old speaker cables, indicated some 6mV of noise, with my AR amplifier powered but not driven. Subsequent oscilloscope measurements show an amplitude modulated signal around 1MHz in frequency, which could be 'synched' to the trace at 1μs/cm, as well as a multitude of lower and higher frequency noise.

Identification of this rf noise

Further experiments used this double-beam oscilloscope with traces synchronised to an rf signal generator, displaying noise on channel 1 and generator signal on channel 2.

Slow variation of the rf signal generator frequency, resulted in both traces being stationary at several frequencies. The largest of these stationary traces at 1.05MHz. was visibly amplitude modulated.

Observing this trace while tuning a portable radio with my amplifier switched off, suggested the signal I was watching was 'Talk Radio' on 1053kHz, having some 20mV peak to peak amplitude. Talk radio commenced broadcasting two years ago and since I never listen to medium-wave broadcasts, I was previously unaware of its existence.

Using the scan tuning mode of my AR receiver, I identified seven broadcast transmissions with very high signal strengths in the medium-wave band. Judged by the tuning indicator deflection, the strongest was indeed Talk Radio on 1053kHz, with Radio 5 on 909kHz from Brookmans Park some 170km distant, the weakest noted, **Table 1**.

The medium-wave broadcasting band, extending from 526.5kHz to 1606.5kHz, is covered by a large number of transmitters, many being of very high power, so it was no surprise that many other weaker signals were obtained using manual tuning.

The long-wave broadcasting band extends from

148.5kHz to 283.5kHz, it also has a number of powerful transmitters giving coverage throughout UK.

Powerful non-broadcast transmissions at frequencies very much lower than the long-wave band are used for long distance data or time code transmissions. The National Physical Laboratory at Teddington transmits the MSF time signal from the 50kW Rugby transmitter, a far reaching signal, at 60kHz.

Advice from the BBC[2] and Radio Authority[3] engineering departments stated the service limit for medium-wave broadcasts is a minimum signal level of 2mV/m, with 5mV/m required for long wave. Any clearly received broadcast will thus much exceed this field strength at your location.

The engineer's field strength contours for my location, suggested for 'Talk Radio' a field strength of 100mV/m. This level is by no means unique. Examination of the various broadcast transmitter locations and powers suggests much greater levels are common.

With the most powerful transmitters being located close to densely populated regions,. locations in the Home Counties, West Country, Midlands, Yorkshire, North East, Scotland and Northern Ireland, situated close to these transmitters could experience field strengths exceeding 500mV/m (see the panel on propagation). However the frequencies of highest strength may differ from those I found, **Table** 2.

These medium and long-wave transmissions are not unique to the UK, but are controlled under internationally agreed standards and used in many countries. Transmissions from Europe are frequently received in the eastern counties of the UK, as demonstrated by my unidentified foreign station on 1395kHz, **Table 1**.

Could these signals affect audio power amplifiers? In order to find out, the complete circuit involved in the closed feedback loop within the amplifier and the amplifier components outside this feedback loop has to be considered. This includes the loudspeaker cable parameters, loudspeaker crossover network and the speaker drivers in their cabinet.

Depending on the amplifier's design, a varying level of audible distortion, or significant increase of noise levels, resulting from 20mV rf signals, has previously been reported[4]. Subsequently, many amplifiers now have in-built protection against rf energy presented to their input terminals but not similar dedicated protection for their output terminals.

The possibility that "audible intermodulation products can arise from spurious signals with frequencies above human hearing" was also touched on by Ivor Brown[5] in a letter to Douglas Self.

Most amplifiers have a low value output inductor and Zobel capacitor resistor network between their feedback loop and their output

Low and medium-frequency rf propagation

This discussion involves frequencies between 30 and 3000kHz. Since it is almost impossible to build a quarter-wave vertical antenna for this frequency band, transmission invariably results from short vertical antennas at low heights above ground. At these frequencies the main reception mechanism results from ground-wave propagation. This is attenuated both by increased distance and frequency, also the ground and sub-surface conditions the wave travels over.

Given a near perfect ground surface – e.g. sea water – the theoretical figure for propagation will be approached,[8]

$$E=300P^{1/2}$$

at 1km, where P is radiated power in kW and E is rms mV/m. Over land this figure[3] is commonly reduced to,

$$E=221.8P^{1/2}.$$

When directional aerials are used, the above figures must be suitably modified.

Low-frequency ground-wave propagation initially reduces almost inversely with distance, but rather more rapidly as distance or frequency increase, to some 110dB loss at 160km compared to 64dB loss at 16km, both assuming a frequency of 1MHz[8].

Note that the above description has been greatly simplified; refer to the references for more details.

Table 1. Locally received high signal strength medium and long wave transmissions, strongest listed first. Data based on BBC and Radio Authority engineering information, confirmed by measurements using a 1m vertical whip antenna and wavemeter.

Program name	Frequency (kHz)	Transmitter location	Radiated erp (kW max)	Distance to test site (km)	Field strength mV/m est.
Medium Wave					
Talk Radio	1053	Postwick	18	10	100
Radio 5	693	Postwick	10	10	40
Foreign	1395	Unknown			30
Radio Broadland	1152	Brundall	0.83	8	25
Radio Norfolk	855	Postwick	2	10	18
Virgin Radio	1215	Postwick	1.2	10	14
Radio 5	909	Brookmans Park	150	170	12
Long Wave					
Radio 4	198	Droitwich	500	250	20

Table 2. Listing of major long and medium-wave transmitters of 50kW and above, based on BBC and Radio Authority engineering information. Some sixteen other transmitters have power outputs between 5kW and 50kW, with a further two hundred and eight below 5kW.

National LW/MW transmitter sites	Frequency (kHz)	Radiated erp (kW max)	Frequency (kHz)	Radiated erp (kW max)	Frequency (kHz)	Radiated erp (kW max)	Map reference
Brookmans Park	909	150	1,089	400	1,215	125	TL259050
" "	1458	125					" "
Burghead	198	50	810	100			NJ125685
Clevedon	909	50					ST400697
Droitwich	198	500	693	150	1053	500	SO929663
" "	1215	105					" "
Lisnagarvey	1341	100					I258619
Moorside Edge	909	200	1,089	400	1,215	200	SE070154
Stagshaw	693	50					NY986709
Start Point	693	50					SX814378
Washford	882	100	1089	80	1215	100	ST058410
Westerglen	198	50	810	100	909	50	NS868773
" "	1089	125	1215	100			" "
Saffron Green	1548	97.5					TQ216977

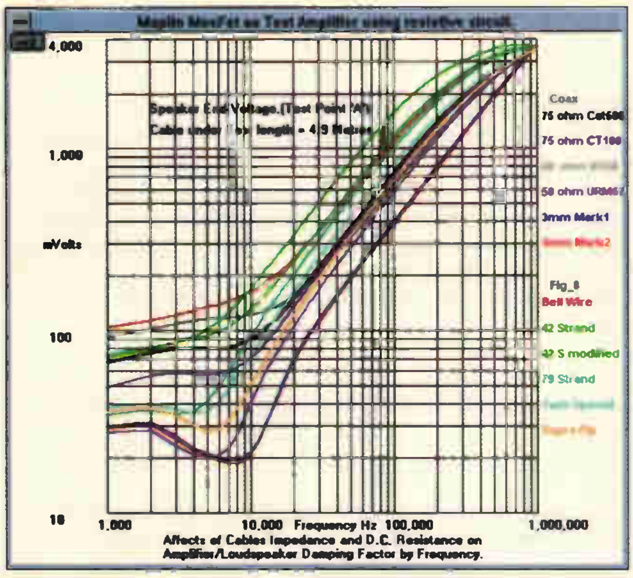


Fig. 1. Speaker end damping voltage by test cable and frequency using Maplin mosfet amplifier.

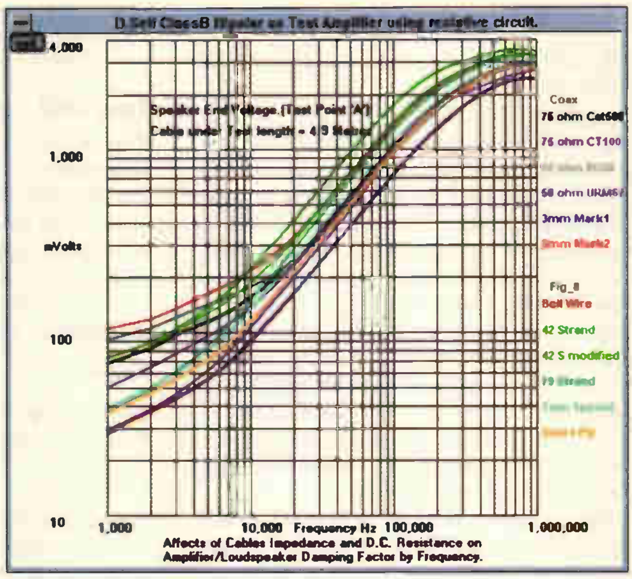


Fig. 2. Speaker end damping voltage by test cable and frequency using D. Self's bipolar amplifier.

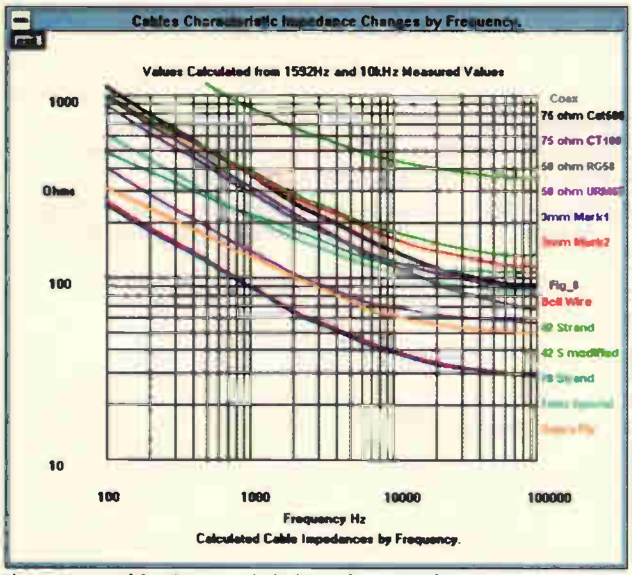


Fig. 3. Test cable characteristic impedance by frequency.

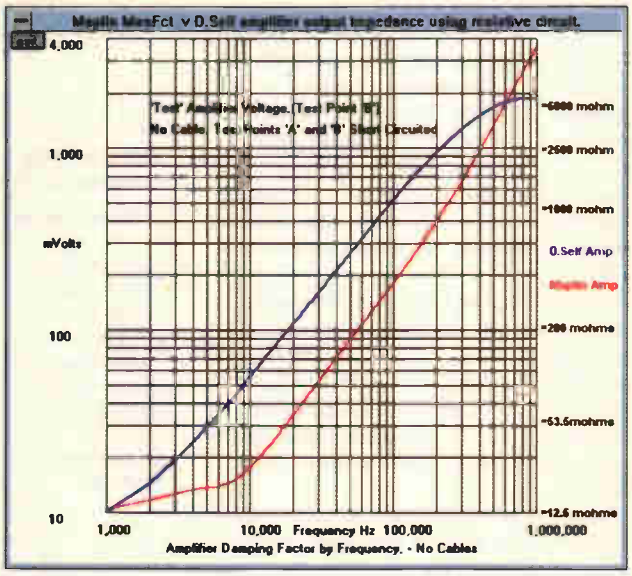


Fig. 4. Comparison of Maplin mosfet and D. Self bipolar amplifier output impedances by frequency. Notice the diverging behaviour of these amplifiers at the higher frequencies.

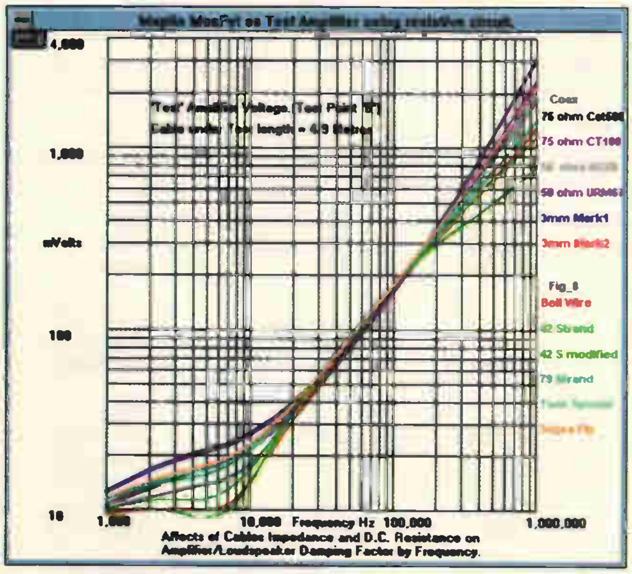


Fig. 5. Amplifier-end damping voltage by test cable and frequency using Maplin mosfet amplifier. Notice the diverging behaviour of this amplifier compared with Fig. 6, at the higher frequencies.

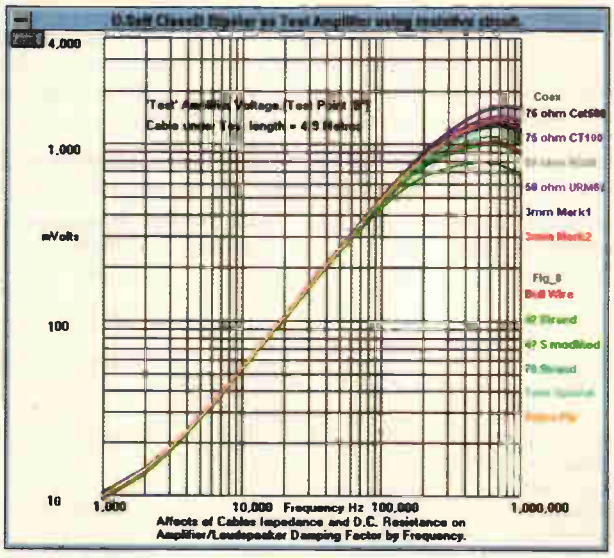


Fig. 6 . Amplifier-end damping voltage by test cable and frequency using D. Self's bipolar amplifier. Notice the diverging behaviour of this amplifier, compared with Fig. 5, at the higher frequencies.

terminals. This is added to improve stability with reactive loads.

All inductors have an inevitable level of distributed self capacitance – several picofarads in value – effectively in parallel with the inductor. The capacitance of printed board tracks from the inductor's terminals, also appears effectively in parallel with the inductor. Depending on these inductance and capacitance values, the combination will 'parallel' resonate at some high frequency. At frequencies above this resonance the inductor will act as a capacitor and its effective series impedance reduce with frequency increase.

At frequencies below this resonance, the output inductor and Zobel Network should reduce the level of rf signal measured in the feedback loop, compared to that injected at the amplifier output terminals.

The level of rf measured at the amplifier output terminals depends on the amplifier's effective output impedance combined with the characteristics of the cables and speaker used, at these rf frequencies.

My previous articles measured cable characteristics and amplifier output impedance for two representative amplifiers[6] but only to 100kHz. These measurements were repeated with frequencies extending from 1kHz to 1MHz, to clarify the working impedances that need be considered, **Fig. 1-6**.

The rf millivoltmeter measurements show the average of the signal levels involved. Since these also include amplifier and other audio frequency noise sources, a means to identify signal levels by frequency is needed. Obviously an rf spectrum analyser is ideal, however a wavemeter will suffice.

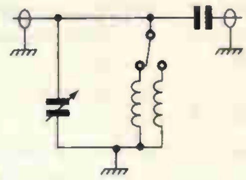
As a minimum, a wavemeter requires only an air-variable capacitor and suitable low loss inductor, housed in a fully screened enclosure, used as a pre-selector for the rf millivoltmeter. The variable capacitor must of course be fitted with a suitable reduction drive and dial to facilitate retuning to known frequencies. (see box 'What is a wavemeter?').

Having a Muirhead precision 50-1250pF air variable capacitor, with precision reduction drive fitted with a four-digit readout dial, already housed in an extremely substantial diecast case, I needed only to add the inductor, coupling capacitor and two BNC connectors. A frequency calibration chart, using my rf generator together with off air signals picked up by a 1m square-loop aerial, was quickly plotted.

My Self amplifier was already housed in a

What is a wavemeter?

Essentially, a wavemeter consists only of a tuneable parallel circuit of a low loss variable capacitor with a low loss inductor. One common connection is grounded to earth and the circuit is loosely coupled to the antenna system. This loose coupling can comprise a tapping on the coil winding, a coupling coil winding or a low value capacitor between the 'hot' common connection and the aerial.



Wavemeter, comprising tunable parallel circuit, is loosely coupled to the antenna system.

When used with higher impedance antennas, very high Q can be attained with tight frequency discrimination. Small single-turn loop antennas – especially when connected to the low impedance of an audio amplifier/speaker system – will achieve low 'Q', with consequently broader tuning. This is regardless of coupling method used.

The wavemeter circuit used here incorporated a 50-1250pF air variable capacitor and a 47pF coupling capacitor. Since they were to hand at the time, for frequencies below 1100kHz I used a 55μH air core, switching to a 25μH air core for the higher frequencies.

Due to its high input impedance, I was able to connect my rf millivoltmeter directly to the hot end of the tuning capacitor.

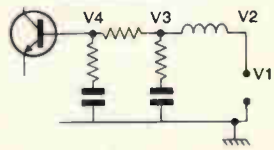
Table 3. Wavemeter measurement of rf pick-up at output terminals of D. Self amplifier, with wavemeter used to select individual transmission frequencies. Workroom location as used for distortion measurements, also listening room amplifier location for comparison. Field strength measured using a 1m square single-turn loop aerial connected directly to wavemeter. All cables were 4.9m long.

Cable under test	693kHz (μv)	909kHz (μv)	1053kHz (μv)	1152kHz (μv)	1395kHz (μv)
Coaxial styles					
75Ω Cat. 500	41	51	110	42	45
75Ω CT100	40	52	106	40	44
50Ω RG58C/U	42	52	115	40	40
50Ω URM67	41	52	105	44	46
3mm Mk I	42	53	113	44	46
3mm Mk II	41	54	113	46	46
Fig. of 8 styles					
2192Y bell wire	56	60	520	91	157
42 strand	56	62	540	96	170
42 strand modified	56	63	560	112	180
79 strand	59	63	570	100	173
2mm twin special	56	62	520	91	163
Supra-Ply 2.0	58	63	560	86	152
With 8.2Ω termination only	32	35	52	34	33
Loop-antenna field strength	2200	2500	20 000	7600	8200
Using D.Self amplifier with old listening-room cables	320	520	5600	1050	1300

Detailed on page 124 of the February issue, the MkI and II cables are custom fabricated, very flexible and less than 6mm in diameter. The MkII has a 19-strand, 0.45mm inner wire insulated with polythene with a 3mm outside diameter. Its outer braid is 240 strands of 0.127mm wire. Heat-shrink tube provides overall insulation. MkI is identical, except for its 37 strands of 0.32mm inner core.

Table 4. RF voltage levels, in millivolts, within the two power amplifiers tested, measured using oscilloscope probe. Signal generator output was applied to the amplifier output terminals with level set to 10mV, measured at pc board output pads (V2).

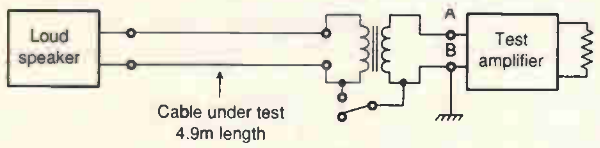
Measuring point	D. Self amplifier 900kHz	1000kHz	1100kHz	Maplin amplifier 900kHz	1000kHz	1100kHz
Amplifier terms. V1	11.2	11.4	11.3	10.8	10.5	10.6
At pc board out. V2	10.0	10.0	10.0	10.0	10.0	10.0
At Zobel network V3	1.26	1.4	1.55	7.1	7.8	7.2
Self Tr_3 base V4	0.41	0.52	0.66			
Maplin Tr_2 base V4				0.48	0.44	0.17



Measurement points, simplified. Node V1 is the amplifier output terminals while V2 is the same output point at the pcb.

Table 5. Wavemeter measurement at 1053kHz of rf pick-up at D. Self amplifier output terminals. Using figure-of-eight cables in balanced and un-balanced configuration to connect to loudspeaker system alternately to 8.2Ω dummy loudspeaker load. Balun transformer made with 30 twisted bifilar turns of 0.5mm wire, wound on TMC107523 toroidal core, which was un-balanced using removable link from earthy output to one wire of figure-of-eight cable. Cables 4.9m long.

Cables under test	Balanced w. balun (µV)	Unbalanced w. balun (µV)	Unbalanced with cable direct wired (µV)
With speaker load			
42 strand	440	720	740
42 strand modified	460	820	800
With 8.2Ω load			
42 strand	330	460	560



Test set-up for making the cable measurements, showing the balanced/unbalanced switch.

Table 6. RF millivoltmeter measurements, in microvolts, of pick-up with amplifier replaced by dummy amplifier loading network of output inductor with 10Ω shunt resistor, a Zobel network and 0.033Ω termination resistor. Measured at this dummy load, with crossover or cable screened in turn, to determine proportion of noise pick-up due to crossover/speaker and cable under test. Shows excessive rf pickup with figure-of-eight cable. Cables 4.9m long.

Cable under test screened	In normal use	W. Xover screen	Cable screened	Both
Coax styles				
75Ω Cat. 500	54	47	26	19
75Ω CT100	52	46	30	20
50Ω RG58C/U	45	40	20	16
50Ω URM67	45	40	22	20
3mm MkI	40	33	20	15
3mm MkII	40	36	20	15
Fig. of 8 styles				
2192Y bell wire	440	420	30	22
42 strand	460	430	35	20
42 strand modified	710	660	40	25
79 strand	420	410	26	20
2mm twin special	265	255	29	21
Supra Ply 2.0	280	260	20	16
Termination only	16			

substantial aluminium screened case. I measured the wavemeter output, for five of the locally strong medium-wave frequencies, at the amplifier output terminals with the amplifier powered but not driven. The rf pick-up from the twelve test cables and speaker system, was measured using the same cable locations and orientation as for the distortion measurements, **Table 3**.

This wavemeter/amplifier measurement system was also used to measure the signal levels picked up by the old cables in my listening room. These were significantly higher due to increased cable lengths, the cable's direction and proximity to the ring mains.

Having established the frequency and voltage levels at the amplifier terminals when used with the various test cables, attempts were made to measure similar signals within the amplifier. Obviously should its output inductor sufficiently block these signal levels from entering the amplifier. In this way, the rf signals could not cause any audible intermodulation distortion.

With my rf signal generator set to a test frequency of 1MHz, I used *HP9100* oscilloscope probes to connect the test points to my rf millivoltmeter. With the signal generator output applied to the amplifier output terminals and signal level set to 10mV measured at the amplifiers pcb output pads (V2), I measured 1.4mV at the 'Zobel' network and 0.52mV at Tr_3 base, of the Self amplifier. Having established that for this design a measurable rf level can be found within the feedback loop, the measurements were repeated for 900kHz and 1.1MHz, then with the Maplin amplifier. **Table 4**.

Having now confirmed that rf signals picked up on speaker cables can intrude within the amplifier, and that this rf level differs substantially between figure-of-eight and co-axial cable styles, how are these signals picked up ? Just what is the pickup mechanism ?

RF pick-up mechanisms

A single-turn loop antenna can be formed by winding coaxial cable around a wooden frame and connecting the outer braid free end to the inner feeder conductor at the completion of the loop. Its termination at the receiver is unbalanced, i.e. the braid is connected to earth.

Alternatively an antenna can comprise a figure-of-eight cable partially unzipped, with each unzipped wire wrapped around one half of the frame, the free ends then being joined to complete the loop. Using balanced termination at the receiver minimises any stray pickup on the cable connecting the loop antenna to the receiver. This balanced termination is important, since any unbalanced figure-of-eight or twin feeder cable will both transmit[7] and receive signals.

Signal pickup depends on the area enclosed by the loop, and while pickup of higher frequencies is quite good it discriminates heavily against much lower frequencies. The cable/amplifier rf pickup measurements of Table 3 also show similar frequency discrimination

When a figure-of-eight cable is used with a conventional amplifier as a loudspeaker cable, one line of the cable is earthed by the amplifier's 'low' output terminal, the cable is clearly unbalanced. The speaker ends of the cable are terminated by the speaker's rf impedance. Hence the figure-of-eight test cable and speaker system could form a very shallow single-turn loop aerial.

To put this to the test, I wound a simple 1:1 balun transformer, of some 50µH primary inductance, and re-measured the rf picked up by the 42-strand figure-of-eight cables. If the above analogy was correct, I expected a notable reduction in rf when measured with the figure-of-eight cable balanced to earth, versus the same cable deliberately unbalanced.

Using my wavemeter set to 1053kHz, approximately half the level of rf signal was measured with cables balanced compared to the same system unbalanced. To eliminate the balun transformer losses from clouding these results, the balun and its connections with the test cable were retained for both measurements. A temporary earth link, connecting amplifier 'low' output to one line of the figure-of-eight cable, was used to establish the unbalanced state, it was removed for the balanced configuration, **Table 5**.

Regardless of loudspeaker cable used, the speaker cabinet wiring and the inductors used in any crossover network, will also function as antennas with some degree of rf signal pickup. Since speaker and crossover systems vary widely in their construction and thus potential for rf pickup, this has not been investigated other than to clarify the relative pickup levels with my test speaker system.

The methods used were both simple and effective. I decided to measure rf levels with the speaker and cables arranged exactly as for the distortion measurements. Next they were measured with the crossover network screened by a Faraday shield, and finally with the speaker cable similarly shielded. Not having a suitable metal container easily able to contain my test speaker cabinet, or my amplifier complete with the test cables, I needed to simplify the task.

The crossover had previously been moved outside the speaker cabinet for the distortion measurements. Connection to both drivers involved short lengths of 42-strand figure-of-eight cable. Replacing the amplifier with a dummy load allowed the test cable leads to be easily coiled up and screened. Grounding one dummy load terminal ensured the figure-of-eight test cables remained unbalanced at one end, exactly as in normal use.

This dummy amplifier load was made up using a typical output inductor, Zobel network and 0.033Ω resistor to replace the amplifier. A few experiments confirmed my metal waste-bin, suitably earthed, served as an excellent Faraday shield.

Using the rf millivoltmeter, I measured the voltage levels at this dummy amplifier load for each of the 12 test cables. First, I measured with nothing shielded, next with the crossover only shielded, then with the cables coiled up and placed in the shield, and finally with both cable and crossover shielded.

In every case, the greatest reduction of measured rf resulted from simply screening the cable, thus clarifying the cable's pickup is the major contributor to rf pickup with my test speaker. While measurable changes were found for all cables, the unbalanced figure-of-eight cables were found to be particularly prone to rf pickup, **Table 6**.

Coaxial cable definitely is best

Due to the considerable variations in amplifier design and thus potential sensitivity to rf, no attempt has been made to confirm whether these rf signals caused measurable or audible distortions with either test amplifier. However the work published by Paul Miller[4] suggests this is more than likely with most amplifier designs, given sufficient rf levels.

However, these signals cannot be beneficial and are thus best avoided. Using coaxial cables with a conventional inductor output amplifier minimises this rf pickup. When combined with the other benefits already established in my previous articles, there remains no good reason for not changing to coaxial speaker cables.

One final *proviso*, the output terminals of two amplifiers arranged in a bridge output configuration may be truly balanced with respect to earth. The output terminals of a valve amplifier could also be balanced if neither terminal of the output transformer secondary winding were tied to earth.

When amplifier output terminals are balanced to earth at rf, to be effective in reducing rf pickup, coaxial cables must be wired correctly. The inner cores should only be used to convey signal power, with the inner of a second coaxial cable used to return the signal. The amplifier end of each braid should be connected to earth, providing a Faraday shield for each signal conductor.

With a conventional amplifier system, the coaxial cable inner wire is connected to the 'hot' terminals at the amplifier and speaker system, with the outer braid connected to both the amplifier and speaker 'cold' terminals. This completes the return path while shielding the amplifier's hot output terminal from rf pickup.

In summary

Having brought this anomaly of noise signals to a conclusion, work is now proceeding rapidly to refine the MkII coaxial cable design to give even more improved performance, reduce materials cost and improve ease of manufacture. ■

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Applying double-balanced mixers

Darren Conway illustrates how to get the best from double-balanced diode mixers.

Double-balanced diode mixers are widely used in communications equipment. Their wide dynamic range and relatively low noise has made them a popular choice.

When properly applied, very good results can be obtained with diode mixers, but designing circuits that include them is not a trivial task. The main difficulty with applying the double balanced diode mixer is that mismatch at any of the three ports degrades performance.

These mixers are particularly sensitive to mismatch at the IF port, which results in greater conversion loss and the generation of unwanted mixer products. Ideally, the IF port should be terminated into a post mixer filter with a constant input impedance and a low pass frequency response.

This article uses simulation to compare various designs for post mixer IF filters with the purpose of identifying an optimum design.

Applying diode mixers

The following research was completed as part of the design of a satellite receiver capable of detecting low earth orbital satellites transmitting on about 137.6MHz. The design is an entirely conventional double superheterodyne. Its first intermediate frequency is 37.5MHz selected largely because of the ready availability of cheap and effective SAW filters commonly found in televisions.

Surface acoustic wave filters are physically small, require no tuning, and are easy to interface. The type used features a 3MHz band width. This means that it is also suitable for the front end of a receiver designed for high data rates available from many satellites.

For the first mixer, a double balanced diode type was selected because of the wide dynamic range and a relatively good noise figure. The wide dynamic range is necessary so that the weak satellite signals can be received in the presence of strong interference from any nearby transmitters. A low noise figure improves the ability to detect and demodulate very weak signals.

Matching problems

The effect of termination mismatch on a double balanced diode mixer is not the same for each port. Mismatch at the rf port is the least problematical, which is fortunate because in many applications it is not practical to match to this port. Mismatch between the local oscillator and the mixer degrades third-order performance but can be improved simply by adding a –3dB 50Ω pad. The output level of the local oscillator needs to be adjusted to overcome the loss. The effects of having each port reactively terminated are shown in **Table 1**. Performance is degraded even further if more than one port is mismatched.

To achieve minimum conversion loss through the diode mixer and prevent harmonics reflecting back into the mixer, it is particularly important that the IF output is correctly matched to a 50+j0Ω resistance.

If the term $F_{LO}+F_{RF}$ is reactively terminated, then it will reflect back into the mixer and combine in anti-phase with the local oscillator to produce the terms $F_{LO}+F_{RF}-F_{LO}$, and $2.F_{LO}+F_{RF}$. This causes conversion loss and produces spurious responses.

It is not sufficient to properly match the IF port to the low order harmonics. In order to achieve the best performance from a mixer, it is necessary for the IF port to be terminated with a 50+j0Ω resistance over an extensive frequency range.

Table 1. Effects of terminating the double-balanced diode mixer's ports reactively.

Termination condition	Conversion loss	RF compression level	RF desensitisation level	Harmonic modulation products	Third-order IM products
IF=reactive	can vary ±3dB	can vary ±3dB	can vary ±3dB	can vary ±20dB	can vary ±20dB
LO=reactive	No effect if LO drive adequate	No effect if LO drive adequate	No effect if LO drive adequate	can vary ±10dB	can vary ±10dB
RF=reactive	Typically ±0.5dB for 2:1 vswr	±0.5dB	±0.5dB	No first-order effect	No third-order effect

*source, reference 3

In this application, it means that the post mixer IF filter should be matched to at least 200MHz. Proper matching at higher frequencies is highly desirable.

It is possible to achieve good matching by terminating the IF output with a 50Ω resistor followed by a post mixer IF amplifier. The problem with this method is that the amplifier applies equal gain to all harmonics in addition to the wanted IF. This increases the risk of over driving the post mixer amplifier and generating additional harmonics.

The diode mixer should therefore be followed by a low pass filter with a constant input impedance of 50+j0Ω. Output of the filter should then be matched to the IF amplifier.

Specifying the IF filter

The intention in this application was to find an efficient IF filter circuit that gave the best performance from the least number of components. The desired specifications of the IF filter are as follows:

- A return loss of no less than –20dB across the frequency spectrum as specified by the diode mixer manufacturer.
- Insertion loss of no more than –0.25dB. The insertion loss adds directly to the noise figure of the mixer and should be as low as possible.
- No more than three inductors. Limiting the number of inductors in a filter automatically limits the filter order and complexity.
- A low-pass filter function with a roll off of at least –18dB/octave. Good frequency roll off is required because the low-order, high-amplitude mixer products are relatively close to the IF.
- Easy to design, build and set up.

Analysing performance

Analysis of the circuits described below was completed using the MicroSim version 6.2 Spice simulator. The quality of the circuits was evaluated using four parameters.

Return loss was calculated using the network of resistors $R_{1\text{-}4}$ and a 2× voltage gain block[7] to provide a voltage across R_{rl} which is plotted as VdB(Rrl).

Ideally, the return loss should be very large across the frequency spectrum, indicating that energy has been efficiently transferred from the mixer output to the filter circuit. A small return loss approaching 0dB indicates that all energy is being reflected back to the source.

Resistor R_c which has a value of 1μΩ is used as a sense resistor to measure current and voltage applied to the test circuit. Input impedance is calculated using the voltage and current passing through R_c and is plotted as V(Rc:1)/I(Rc).

The variable $-I_p(R_c)$ measures the angular phase of the input current. Input current phase indicates the reactance of the test circuit. A purely resistive circuit will have zero phase shift. A capacitive or inductive component will cause the current phase to rotate. In this application, the IF filter should ideally be purely resistive at all frequencies.

The frequency response is measured across the load resistor R_l. All IF filters analysed here have been designed for an IF of 37.5MHz, but the values can easily be modified for other frequencies. Plots of these four parameters are combined on single graphs and fully define the important characteristics of the IF filters under test.

LC tuned tank

The *LC* tuned tank circuit, **Fig. 1** represents a simplistic solution to the IF filter problem that has been used in early receiver designs. It consists of an *LC* pair tuned to the IF at which point it appears to have a 50+j0Ω input impedance. This is shown in the Spice analysis in **Fig. 2**, where at

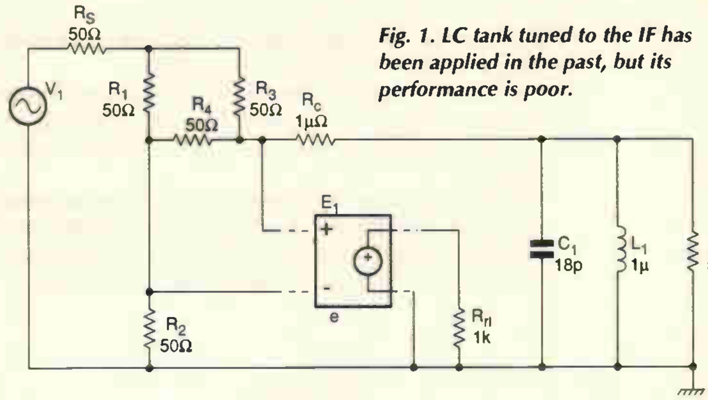


Fig. 1. LC tank tuned to the IF has been applied in the past, but its performance is poor.

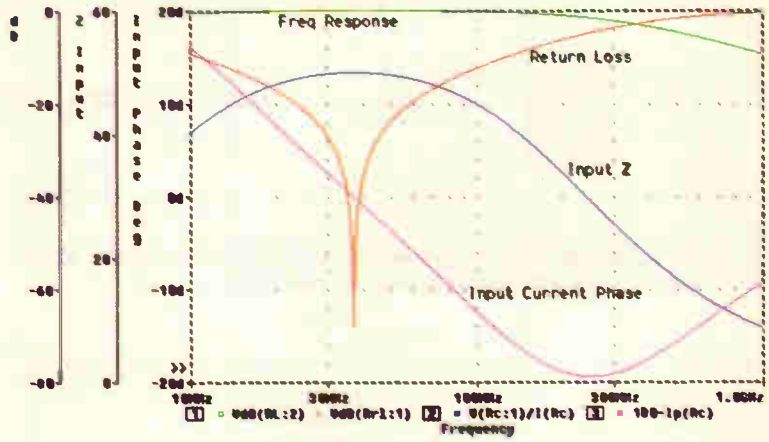


Fig. 2. Analysis of the LC tuned tank, Fig. 1.

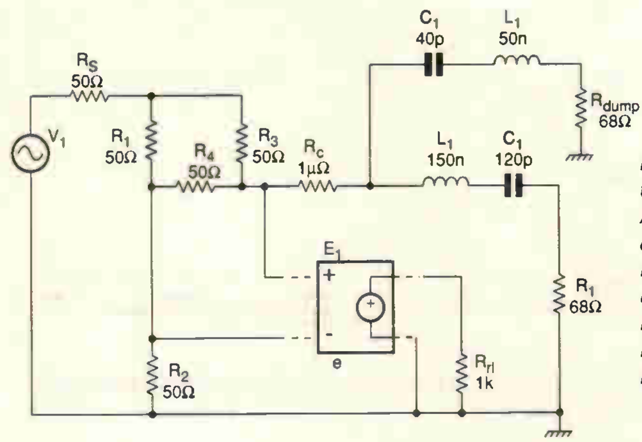


Fig. 3. Series tuned diplexer. Although this circuit is an improvement on the LC tank, its performance is far from ideal.

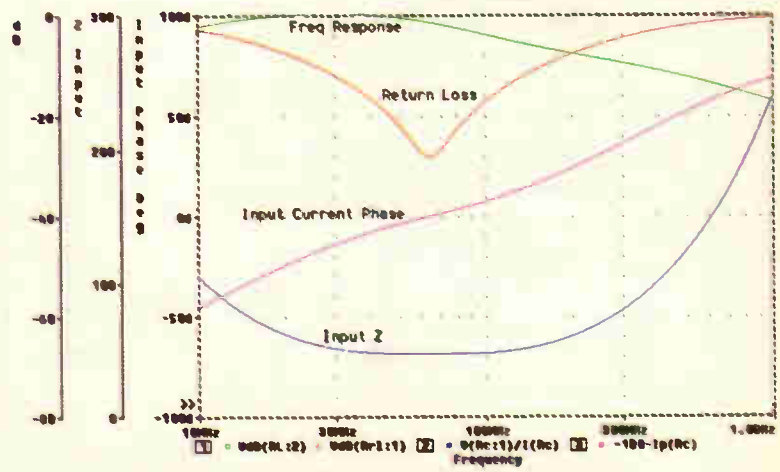


Fig. 4. Analysis of the series tuned diplexer, Fig. 3.

37.5MHz the input impedance is 50Ω, the input current phase is 0° and the return loss is very high.

At all other frequencies the circuit is reactive and reflects significant harmonics back into the mixer. The frequency response is particularly poor giving only –1dB attenuation at 200MHz.

The *LC* tuned tank circuit demonstrates all the undesirable features of a bad IF filter. Any receiver that uses this circuit would probably give better performance if the capacitor and inductor were removed, leaving only the 50Ω resistor.

Series-tuned diplexer

The series-tuned diplexer design is intended to terminate both the IF and the third-harmonic (3.IF) into 50+j0Ω loads. This circuit is designed to provide a resistive termination to the most troublesome low-order mixer products.

Values of the inductors and capacitors shown in **Fig. 3** were selected simply to resonate at the correct frequencies. You can see from **Fig. 4** that the input impedance is reasonably well matched between about 25MHz and 150MHz. Normally the signals are terminated into 50Ω resistors but analysis showed that 68Ω resistors are required to achieve a 50Ω input impedance.

The plot of input current phase shows that this filter is reactive at all frequencies except one. This characteristic combined with the increasing impedance at higher frequencies means that harmonics will be reflected back into the mixer.

Frequency response is also poor providing only –7dB attenuation at 200MHz. Although this circuit is an improvement on the *LC* tank circuit, the performance is far from ideal.

Butterworth band pass

An IF filter based on a band-pass Butterworth filter appeared to offer some hope. One of the useful properties of Butterworth filters is that they ideally display a constant impedance through the pass band.

Outside the pass band, the impedance increases or decreases depending on the filter topography. In addition, they can be designed to have different input and output impedances.

The filter shown in **Fig. 5** is designed with a pass band centred at 37.5MHz and a 10MHz band width. The input is matched to a source impedance of 25Ω defined by the impedance of the mixer and the 50Ω resistor.

Output impedance of the filter is 250Ω, intended to provide some degree of matching to the IF amplifier. The analysis results in **Fig. 6** show an improvement in overall performance compared to the previous filters but there are still major flaws with this circuit. The insertion loss of –0.8dB in the pass band is higher than desired but attenuation at 200MHz is a healthy –52dB. The return loss and input impedance vary significantly over the pass band, which is likely to create unwanted reflections from received signals close to the rf input. From a practical constructive view, the 21nH inductor is a very small value and would be difficult to implement. The sharp dip in the return loss at 37.5MHz makes this filter sensitive to component drift and tuning errors.

Although this circuit offers reasonable performance in theory, it would be very difficult to construct and tune. It is therefore not recommended.

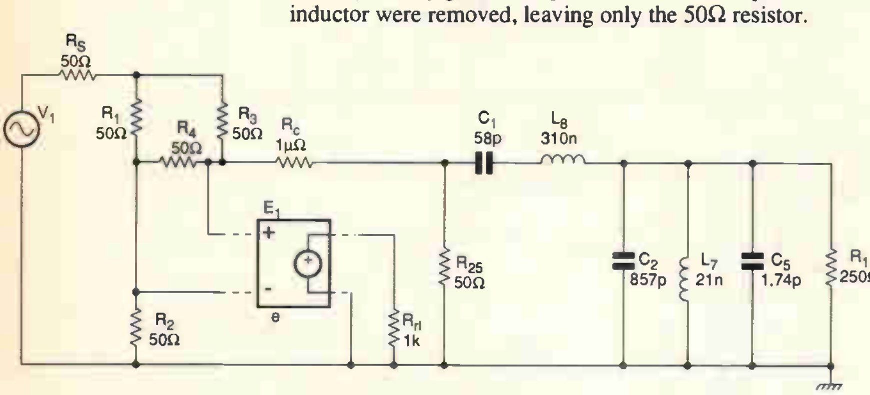


Fig. 5. IF filter comprising a Butterworth band-pass circuit. One of its useful features is that it displays constant impedance through the pass band.

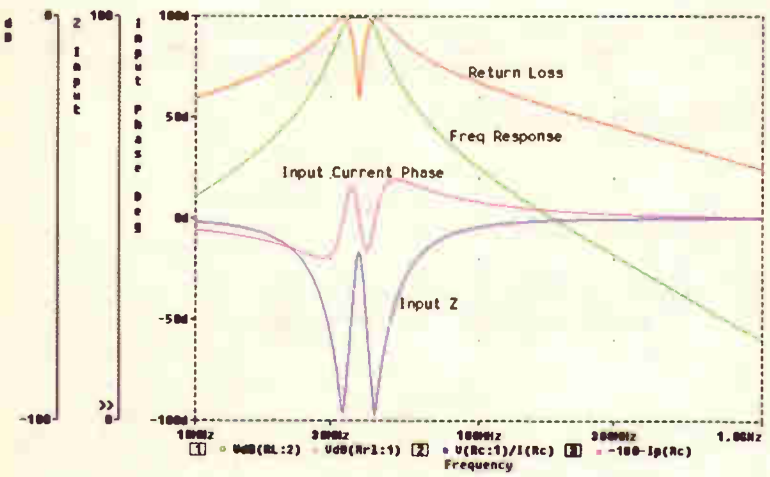
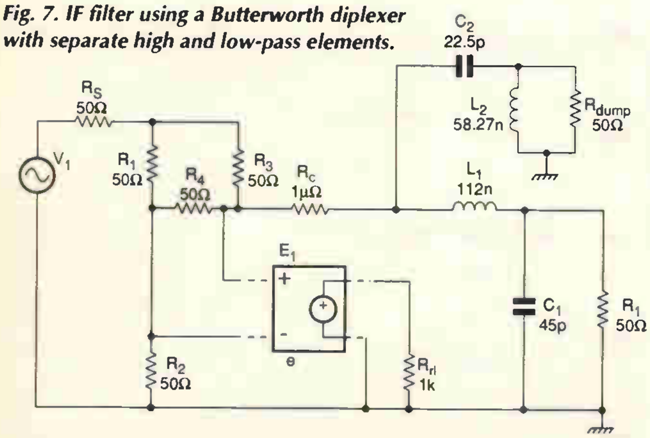


Fig. 6. Analysis of the Butterworth band-pass IF filter, Fig. 5, with 37.5MHz centre frequency and 10MHz band width.

Fig. 7. IF filter using a Butterworth diplexer with separate high and low-pass elements.



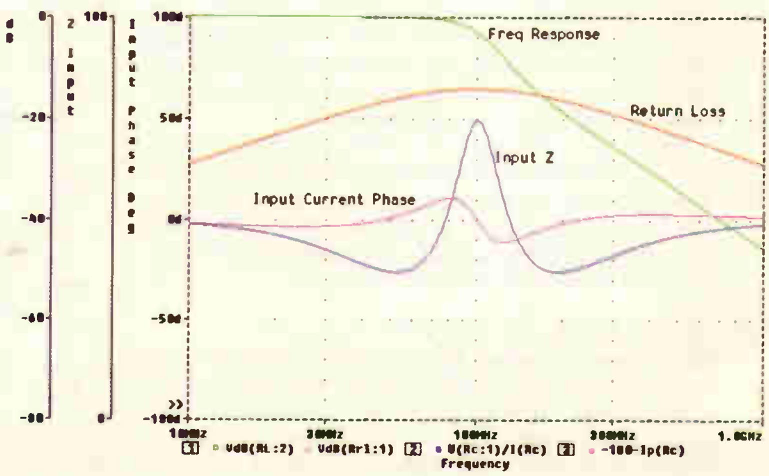


Fig. 8. Analysis of the 100MHz centre-frequency Butterworth diplexer, Fig. 7, shows that attenuation at 200MHz is a modest –18dB.

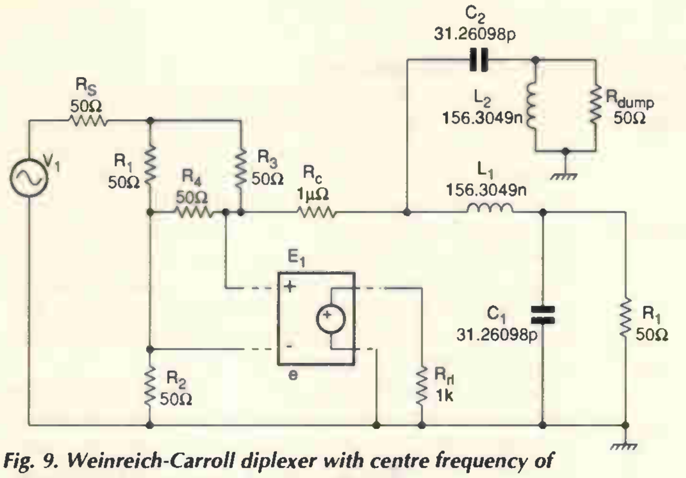


Fig. 9. Weinreich-Carroll diplexer with centre frequency of 72MHz exhibits insertion loss of –3dB at IF.

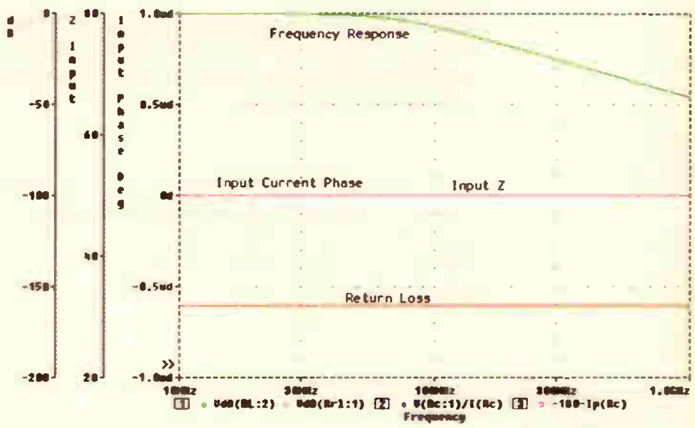


Fig. 10. Weinreich-Carroll diplexer analysis. Although simple, this circuit achieves perfect matching across the entire rf spectrum.

Butterworth diplexer

As a variation to the Butterworth filter theme, separate high-pass and low-pass filters were configured as a diplexer centred on 100MHz as shown in **Fig. 7**.

The results show that this circuit has better characteristics than the Butterworth band-pass filter above. At worst the return loss is –14dB which is 6dB less than the required value of –20dB. Both the input impedance and the input current phase remain reasonably close to ideal across the frequency spectrum.

Upward deflection of the frequency response plot at 150MHz is due to interaction between the high and low pass sections at their inputs. Insertion loss at 37.5MHz is only –0.084dB while attenuation at 200MHz is a modest –18dB.

None of the plots exhibits any excessively sharp peaks or dips which in this case means that the circuit is tolerant to component errors and drift. The values of the inductors are not too widely spread and are large enough to allow a practical filter to be constructed.

This circuit has the same number of components as the diplexer shown in Fig. 3 and yet displays superior performance. In spite of this, the Butterworth diplexer does not conform to the required specifications and a better solution was sought.

Weinreich-Carroll diplexer

The Weinreich-Carroll diplexer[1] is a second-order filter designed so that all capacitors and inductors have an impedance of $\sqrt{2}\times 50=70.7$ at the centre frequency. A centre frequency of 72MHz was selected for this circuit, being the geometric centre between the IF and the image, $\sqrt{(F_{IF}.F_{LO+IF})}$. This results in an insertion loss at the IF of –0.3dB.

Attenuation at 200MHz is a modest –17.9dB. The analysis plots in **Fig. 10** show that this very simple circuit achieves perfect impedance matching across the entire rf spectrum. These ideal results will not be achieved in practice because of the effects of component errors, drift and parasitics. High quality components should however provide results close to those shown in Fig. 10. The only disadvantages with this circuit are the slow frequency roll off and the mediocre attenuation of harmonics.

Weinburg diplexer

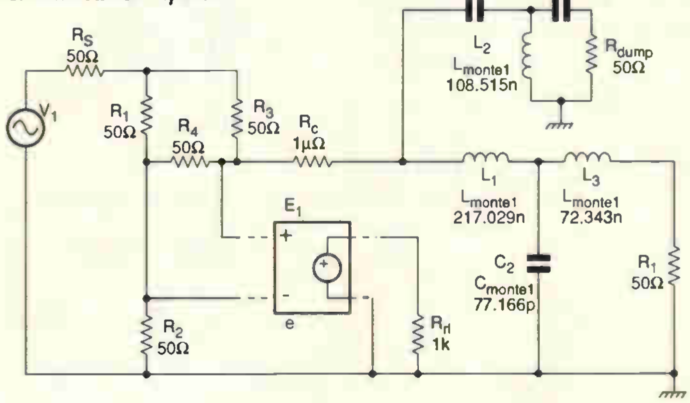
A better frequency response can be obtained using a third order diplexer shown in **Fig. 11**. Like the Weinreich-Carroll diplexer, the Weinburg diplexer has the ideal constant input impedance of 50+j0Ω at all frequencies, resulting in a very high return loss, **Fig. 12**. It also has a much better frequency response providing 33.8dB attenuation at 200MHz.

This circuit has been designed using the values[10] in **Table 2**, with a centre frequency of 55MHz. The sharper roll off means that a lower centre frequency can be used without an excessive insertion loss. At 37.5MHz, the insertion loss is 0.418dB.

Additional simulations were run to further define the performance of this diplexer. The graphs in **Fig. 13** show a Monte-Carlo analysis based on a 10% component variation to determine how sensitive the circuit is to component errors. The upper graph plots variations in input impedance. The lower graph plots variations in return loss and frequency response.

These plots show that the return loss is very sensitive to

Fig. 11. Weinburg diplexer has improved frequency response relative to the Weinrich-Carroll diplexer.



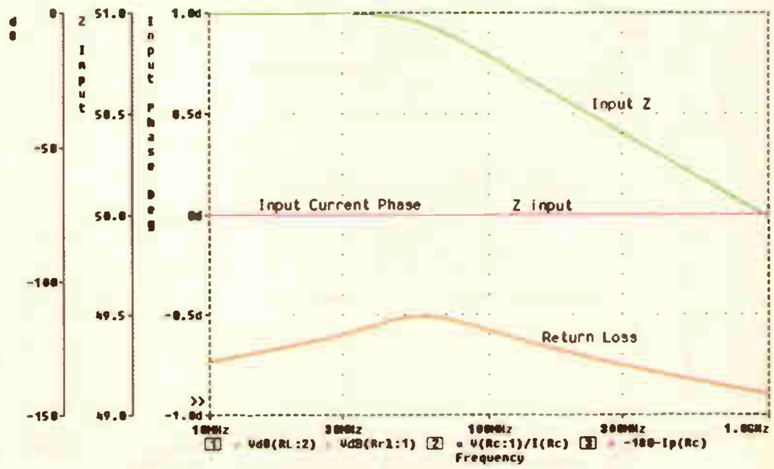


Fig. 12. Weinburg diplexer analysis. Sharper roll-off means that a lower centre frequency can be used without excessive insertion loss.

component errors varying over a range of about 90dB. At worst, the return loss is –24dB which remains within the required specification. Perfect results can only be achieved with perfect components.

Table 2. Weinburg diplexer normalised values.			
Low pass	L_1	C_2	L_3
Third	3/2	4/3	1/2
High pass	$1/C_1$	$1/L_2$	$1/C_3$

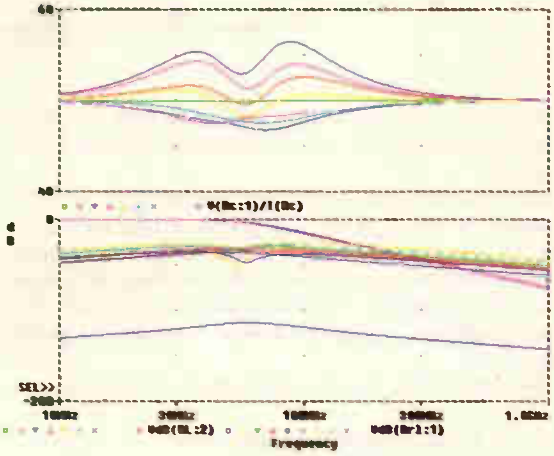


Fig. 13. Weinburg Monte-Carlo analysis based on 10% component variation demonstrates the circuit's sensitivity to component errors. Upper plots are input impedance while lower are return loss and frequency response.

Veltrop-Wilds diplexer

Diplexers based on modified Chebyshev filter tables offer good frequency response with near ideal input impedance. The diplexer shown in **Fig. 14** is based on formula by Veltrop-Wilds[2]. The circuit was calculated for a 3dB point of 55MHz which was selected to achieve an insertion loss of less than 0.25dB at the IF. This circuit yields the results shown in **Fig. 15**. Input impedance varies between 46Ω and 54.8Ω, which is not ideal, but entirely adequate. Return loss is at worst –25.3dB and improves at higher frequencies. The insertion loss at 37.5MHz is only –0.238dB while the attenuation at 200MHz is a respectable –39.7dB.

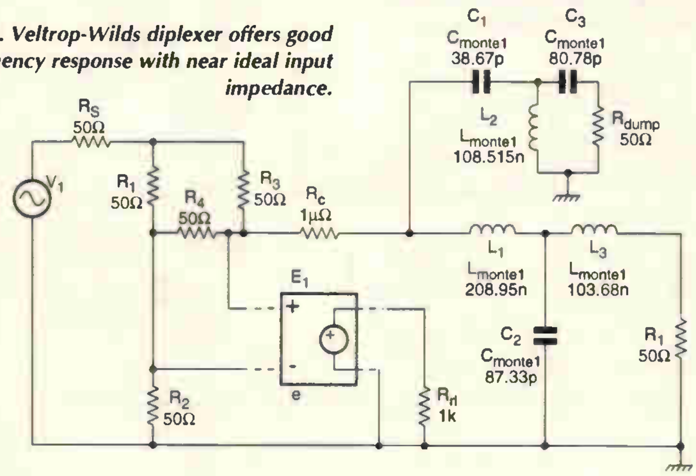
For applications requiring a steeper frequency roll off, the values for normalised 3rd, 5th and 7th order filters are shown in **Table 3**. Band-pass/stop diplexers may also be implemented with the values in Table 3 using the same techniques used to calculate component values with standard filter tables.

As before, a Monte-Carlo simulation based on a 10% component variation was run for the Veltrop-Wilds diplexer. The results of this analysis in **Fig. 16** show the return loss is at worst –23.3dB which remains within the specifications and is only slightly lower than for the Monte-Carlo analysis of Weinburg diplexer.

Likewise, the input impedances for the two filters look similar. In real circuits with parasitics and component errors, there is unlikely to be any significant difference in measured return loss between a Weinburg or a Veltrop-Wilds diplexer.

Having determined that the input characteristics of the Veltrop-Wilds and the Weinburg in a real circuit are likely to be almost identical, a closer analysis of the output charac-

Fig. 14. Veltrop-Wilds diplexer offers good frequency response with near ideal input impedance.



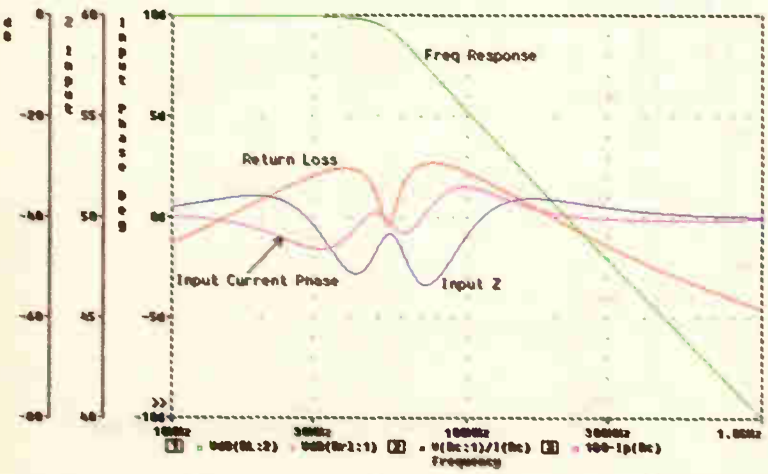


Fig. 15. Analysis of the Veltrop-Wilds diplexer reveals that input impedance varies between 46 and 54.8Ω.

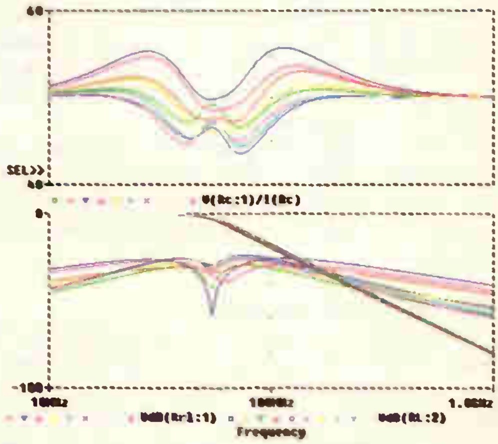


Fig. 16. Veltrop-Wilds Monte-Carlo analysis with 10% component variation show that return loss is at worst –23.3dB.

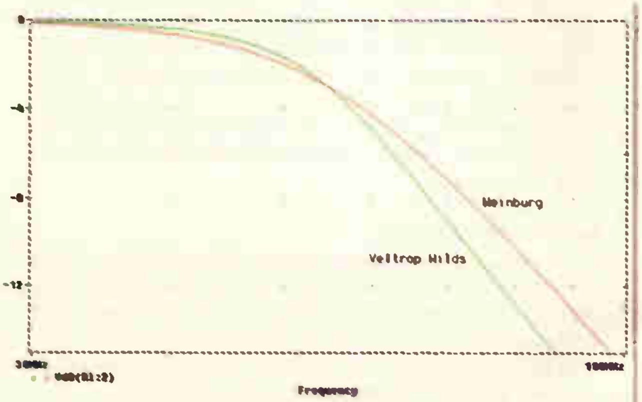


Fig. 17. Frequency-response comparison between the Veltrop-Wilds and Weinburg diplexers.

teristics was conducted. The results are plotted in **Fig. 17** which shows a close in view of the frequency responses of both the Veltrop-Wilds and Weinburg diplexers.

You can see that the –3dB point for both diplexers occurs at 55MHz as expected. The Veltrop-Wilds diplexer has the advantage of a sharper roll off resulting in an additional –4.25dB attenuation at higher frequencies compared to the Weinburg diplexer. In addition, at the IF of 37.5MHz, the insertion loss differs by 40% in favour of the Veltrop-Wilds diplexer.

Analysis of the filter output characteristics shows that the Veltrop-Wilds diplexer has a small but significant advantage over the Weinburg diplexer.

Final selection

The Veltrop-Wilds diplexer circuit shown in Fig. 14 and selected for this application exceeds all specifications and comes close to the 'ideal' IF filter. It does not provide a perfect 50+j0Ω input impedance seen in the Weinreich-Carroll or the Weinburg diplexers, but it is close enough for practical purposes.

Compared with the Weinreich-Carroll or Weinburg diplexers, the Veltrop-Wilds diplexer has a better frequency response and there is the potential for further improvement by increasing the order of the filter. For this application, the Veltrop Wilds diplexer is considered to display the best overall characteristics.

Designing the Veltrop-Wilds diplexer

The design principle of the Veltrop-Wilds diplexer is to modify the values of standard Chebyshev low-pass filters in order to produce a diplexer with a constant input impedance. This is accomplished using the following general equations:

$\varepsilon=[(\text{antilog}(A_m/10))-1]$

$\omega'_{3dB}=\cosh(1/n.\cosh^{-1}\sqrt{[(1+2\varepsilon)/\varepsilon]})$

when n is even and,

$\omega'_{3dB}=\cosh(1/n.\cosh^{-1}\sqrt{[(1/\varepsilon])})$

when n is odd, where A_m is the ripple value in dB and ω'_{3dB} is the modification factor. Full mathematical derivation can be found in reference 2.

The result is a modification factor ω'_{3dB} that is multiplied with each capacitor and inductor to obtain the modified low-pass table values. To obtain the modified element values for the high pass filter, each modified inductor is replaced with a capacitor equal to $1/C$ farads, and each modified capacitor is replaced with an inductor equal to $1/L$ henries. The 0.5 normalised conductance values for the high pass and low pass filters are now placed at the crossover frequency of ω=1.

Tuning the filter

The results of the Monte-Carlo analysis indicate which variable should be used to 'tune' the filter. Frequency response does not vary greatly with component errors and is therefore unsuitable for tuning the filter.

Return loss is the most sensitive to component errors and varies by up to about 30dB in the analysis of both the Veltrop-Wilds and Weinburg diplexers. For optimum performance, a network analyser used to measure return loss will provide the most effective means of tuning the filter.

The next best alternative is use a grid-dip meter and capacitance meter. First, accurately measure and set the values of each capacitor allowing about 3pF for in circuit parasitics, then selectively fit inductors to form LC pairs. Using the grid-dip meter, each inductor is adjusted until the LC pair resonates at the correct frequency.

By fitting and removing components to create LC tuned circuits, the correct values can be set in circuit and the final filter response should closely match the simulated results. When constructing these filters, every effort should be made to minimise both parasitics and component errors in order to obtain results like those shown in the simulations.

Table 3. Veltrop-Wilds diplexer normalised values for 0.1dB ripple.

Low pass	L_1	C_2	L_3	C_4	L_5	C_6	L_7
3rd	1.5133	1.509	0.7164				
5th	1.561	1.8069	1.7659	1.4173	0.6507		
7th	1.5748	1.8577	1.921	1.827	1.734	1.3786	0.6307
High pass	$1/C_1$	$1/L_2$	$1/C_3$	$1/L_4$	$1/C_5$	$1/L_6$	$1/C_7$
Input end							Output end

In summary

One of the important results of these simulations is that good performance does not necessarily require complex designs and high component counts.

The most complicated circuit analysed has six reactive components, while the simplest has just two. A wide range of results from the positively bad to nearly ideal were obtained from circuits that at a glance look remarkably similar.

The results graphically display the importance of selecting the right circuit for the right job. Design efficiency can be measured in terms of performance *versus* complexity. Complex designs are usually difficult to build and maintain. There are significant downstream advantages in ensuring that the most efficient design is used.

The above simulations show that some commonly used post diode mixer IF filters perform very poorly compared to the ideal IF filter. Performance can be improved using constant-impedance filters based on the Butterworth function but they are not recommended.

At all frequencies, the Weinreich-Carroll diplexer has a perfectly matched 50+j0Ω impedance, but its frequency response is only mediocre . The Weinburg diplexer also has a perfectly matched input impedance combined with a good frequency response. The best results are obtained using the Veltrop-Wilds diplexer which combines near ideal input matching with a superior frequency response.

Unlike the Weinreich-Carroll diplexer, the frequency response of the Veltrop-Wilds diplexer can be improved by using higher order variants.

The Veltrop-Wilds diplexer is recommended above all others for use with double balanced diode mixers. ■

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LETTERS

Letters to "Electronics World"
Quadrant House, The Quadrant,
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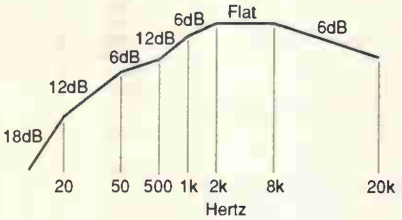
Overloaded

In Self's 'Overload matters' in the February '97 issue, Figs 1b and 1d omit the final downward break in the maximum level curve due to acceleration limits. This is significant because it shows the severe restriction in the possible high



frequency level for the LP record. As an engineer I am proud that my preamp can handle 1V at 20kHz with 0.0008% thd, but I know it is meaningless in the real world. If a preamp can handle 100mV at 1kHz then it need handle only 80mV at 20kHz to have a uniform overload characteristic. (See figure above).

In the seventies, Tom Holman proposed the 'Holman test' for phono preamps – which now I'm sure he would rather us forget. It used a 1kHz square wave, band limited by a 6dB per octave rolloff at 30 or 100kHz, passed through an inverse RIAA. The output of the preamplifier was examined for even harmonics which are not present in a square wave.

A considerable furore ensued when many respected preamps failed the test. As we can see from Self's graph the rolloff should have been at 2kHz not 30 or 100, with an additional rolloff at 8kHz. A totally unrealistic test.

Back in the sixties, an engineer friend suggested to me that the RIAA curve should really level off at 10kHz instead of continuing downward. This is trivial to implement with the common topologies and would have reduced the number of burnt-out cutter heads with little noise penalty. That would have been a real world benefit unlike the misguided IEC 'amendment' – if you need a subsonic filter then use a steep one.

David Hadaway
Rindge
USA

Douglas replies:
This is essentially a matter of definition. The input impedances for a floating voltage source are the same in the sense that a given voltage must cause the same current in each input. The voltages on them are far from equal, being indeed zero for the cold input – as described in detail in my article.

On mature reflection, it seems more sensible to say that a floating source can only have one meaningful input impedance, in this case between the hot and cold inputs. This is 20kΩ.

A measure of resistance

I was reading through the article 'Resistors in C' in the April edition, and was getting on fine until I came across "...it is advisable to use at least a 486DX... because of 57600 calculations ... a lesser pc will take several minutes". Continuing the extrapolation, an old eight bit 2MHz processor running interpreted Basic would have taken around an hour – it didn't. So I thought something's wrong here and I started to look at the code listing.

It appears that each of the E24 values over ten decades is paired with every other value, to see if a match occurs within the required tolerance, using 57600 (24×10×24×10) comparisons. The code tests each pair twice, the result for 1k and 12k will be the same as 12k and 1k so straight away the number of calculations could be halved to 28800.

Further, it is rare to combine resistors where their ratio is greater than 1/(tolerance) so that for 1% components the limit would be 100:1. In the example given in the article 0.1% would equate to 1000:1, thus the search could be limited to a range of three decades instead of ten.

More fundamentally, all these calculations are repeated on each run generating exactly the same data; all that changes is that a different set of tests are applied. Therefore this data could be in a look up table, but it is still quite a large amount of data.

However, as resistor values are based on a decade structure once you have found the combinations to give 11.11R=12R//150R, the values for 111.1R follow simply as 120R//1500R. So the look up table only needs to cover 1728 (24*1*24*3) entries.

If this table was arranged in numerical order only 12 comparisons would be needed to find the entry closest to any particular value – a reduction in run time calculations of 4800:1.

So I would recommend readers to resist the special offer on this program, and have a go at coding it themselves in whatever language they choose.

David Markie
Ascot
Berkshire

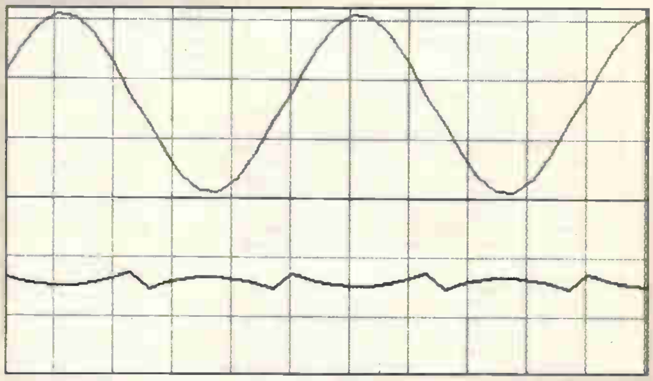
Q & A

Simulating crossover distortion

A In answer to your query from Ian Hegglun, any good CAD package such as *Electronics Workbench*, can be used to simulate crossover distortion. The tricks are to use a low frequency to avoid masking with transit time effects, a low signal level and of course no negative feedback.

To isolate and display the transfer hiatus characteristic on its own, sum the input signal to the output – suitably attenuated, of course – in a difference amplifier. This technique, which may be used to show most forms of distortion, was outlined by me in Circuit Ideas on page 608 of the July/August 1996 issue.

Reg Williamson
Whitehill
Staffordshire



Instability problem

Q Cyril Bateman's letter about amplifiers going unstable with a piece of screened lead attached to their inputs brought back memories of this happening to amplifiers built or modified by me over the years.

I too cured this by means of a series resistor between the screened cable and the amp input terminals. My amplifiers used to oscillate at either rf, around 100kHz, or in the audio-frequency range. Efforts to discover the cause of this led nowhere.

Have any other readers experienced this? I'd love to know why it happens and how to fix it.

Charles Coultas
Wokingham

Bio-galvanic batteries?

Q Within some information supplied with a product called the 'Experimental printed circuit kit' – which is at least thirty years old – a 'Bacteria-powered radio' driven by a bio-galvanic battery appeared. The battery produced 2.5 to 3V, delivered around 5mA, and were said to be capable of running for a year or more on a few spoonfuls of sugar or a stale loaf of bread. Does this mean anything to anyone?

David Heaton
Wakefield
West Yorkshire

Before you ask, yes I have seen photocopies of the originals, and they do mention such cells – Ed.

Q & A

Outputs in phase quadrature?

Q 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* of April 1993, Terrence 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 anyway.

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 query was originally published in the October 1996 issue.)

A In response to Alan Scrimgeour's question in entitled 'Shifting phases?' on p. 790 of the Oct. 1996 issue, the design of two all-pass filters whose outputs are in phase quadrature can be obtained by suitable transformation applied to a prototype low-pass filter. This can be either a Butterworth type, or an elliptic type – provided that the pass and stop-band ripples are chosen to be power complementary. A fairly complete treatment of this design problem may be found in reference 1.

I have worked out a particular design featuring a phase quadrature accurate to within 1.10 over a range extending from about 5Hz to above 700Hz; this would meet Mr Scrimgeour's specifications of 10Hz to 350Hz with an octave to spare at either end.

Each all-pass function is the cascade of first-order all-pass sections having a transfer function of the form,

$$A(s)=\frac{s+p}{s-p}$$

where s is the complex frequency variable and p is the pole of the filter. The design uses one third-order all-pass filter and one fourth-order all-pass filter, whose transfer functions are, respectively,

$$A_1(s)=\frac{s+p_1}{s-p_1}\,\frac{s+p_3}{s-p_3}\,\frac{s+p_5}{s-p_5}\,\frac{s+p_7}{s-p7}$$

$$A_2(s)=\frac{s+p_2}{s-p_2}\,\frac{s+p_4}{s-p_4}\,\frac{s+p_6}{s-p6}$$

in which the pole locations are, p_1=–13.922, p_3=–145.749, p_5=–948.030 and p_7=–9925.083 for the first all-pass function, and p_2=–54.627, p_4=–371.718, p_6=–2529.390 for the second.

The diagram plots the phase difference between the two all-pass functions, i.e., $\angle A1(2\pi jf)-\angle A_2(2\pi jf)$, where $\angle$ designates phasor angle, f is frequency and $j=\sqrt{-1}$; note the equiripple approximation to a 90° phase difference.

A design procedure which may be adapted to other specifications requires first finding a prototype low-pass filter, whose pole locations may then be transformed to yield the poles of the two all-pass functions. It may be summarised as follows:

1. Let f_1 and f_2 be the frequency extremes over which phase quadrature is desired. In Mr Scrimgeour's problem, we have f_1=10Hz and f_2=350Hz. Convert these frequencies to radians-per-second, for which the conversion factor is 2π; this gives $\omega_1=2\pi f_1$=62.8319rad/s and $\omega_2=2\pi f_2$=2199.11rad/s.

2. Let ϕ denote the maximum deviation from phase quadrature over the desired frequency range, and set, $\delta=\sin-1(\phi/2)$. This constant determines the necessary pass and stop-band attenuations required of a low-pass filter prototype. For the design above, I used ϕb=1.1°, giving δ=0.0096.

3. Let C denote the geometric mean of ω_1 and ω_2: $C=\sqrt{(\omega_1\omega_2}$. In Mr Scrimgeour's problem, this becomes $C=\sqrt{(62.8319\times2199.11)}$=371.718rad/s.

4. Now define two prototype frequencies according to,

$$\Omega_s=\frac{\omega_2+C}{\omega_2-C},\ \Omega_p=1/\Omega_s$$

For this design, Ω_s=1.4068rad/s and ω_p= 0.7108rad/.

5. Next, find a low-pass filter $H(s)$ whose magnitude response $|H(j\omega)|$ satisfies the following specifications:

$$1\geq|H(j\omega)|\geq(1-\sqrt{1-\delta^2})\ \text{ for } 0\leq\omega\leq\Omega_p \text{ (passband)}$$

$$|H(j\omega)|\leq\delta \text{ for } \omega\geq\Omega_s \text{ (stopband)}$$

For reasons explained in '1', it is preferable to use either a Butterworth low-pass filter, or an elliptic low-pass filter for which the passband and stopband ripples are power complementary. This ensures that the poles of the low-pass filter so designed will all lie at a common radius from the origin in the complex s-plane. Scale this common radius to unity. I used a seventh-order elliptic low-pass filter, whose pole locations q_1 through q_7 are,

q_1=–1; $q_{2,3}$=–0.6797±j0.7735;
$q_{4,5}$=–0.2877±j0.9577; $q_{6,7}$=–0.0748±j0.9972.

(The notation '$q_{2,3}$' means that poles q_2 and q_3 occur in complex conjugate pairs, and similarly for $q_{4,5}$ and $q_{6,7}$). More detail on designing low-pass filters may be found in references 2 and 3, among many other sources.

6. From the poles q_i, define transformed poles p_i according to,

$$p_i=C\frac{1+jq_i}{j+q_i}$$

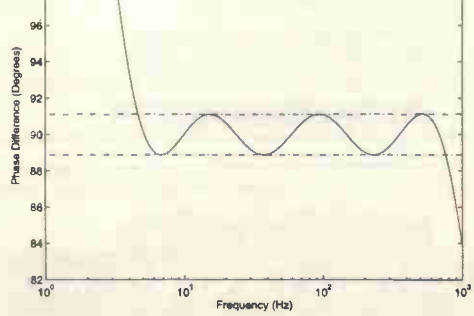
recalling the constant C from step 3. Provided each pole q_i has unit radius, each transformed pole p_i will now lie on the negative real axis of the complex s-plane. Renumber these transformed poles, if necessary, into increasingly negative values: $0>p_1>p_2>p_3>$... Then distribute these poles alternately between two all-pass functions according to,

$$A_1(s)=\frac{s+p_1}{s-p_1}\,\frac{s+p_3}{s-p_3}\cdots$$

$$A_2(s)=\frac{s+p_2}{s-p_2}\,\frac{s+p_4}{s-p_4}\cdots$$

The two all-pass functions A_1(s) and A_2(s) now exhibit the desired phase quadrature over the desired frequency range. Using numerical values for q_1 through q_7 from step 5 above, the pole locations p_1 through P_7 listed above are obtained.

Prof. Phillip Regalia
Institut National des Telecommunications
Evry, France



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One-component oscillator

Using two components to make an oscillator[1] is, perhaps, a little over the top; you can use an op-amp and reduce the number of components by fifty percent. A *CA3130* connected as shown in **Fig. 1** with 7.5V oscillates at about 1.3MHz.

To complicate matters slightly, **Fig. 2** is a voltage-controlled version, which varies in frequency from 140kHz to 27MHz at the rate of 2MHz per volt when control voltage changes from 2V to 14V. Peak-to-peak output is roughly sinusoidal, amplitude being about 75% of the control voltage; the filter will improve the waveform and give a more constant level of about 1V pk-pk. If you use the other Schmitt inverters in the hex package to reduce output impedance, the control voltage might need to be limited to avoid excessive dissipation.

P Gascoyne
Wantage
Oxfordshire

Reference

1. M F Abuelma'atti and S S Buhalim. *Electronics World*, July/August, p.615, 1996.

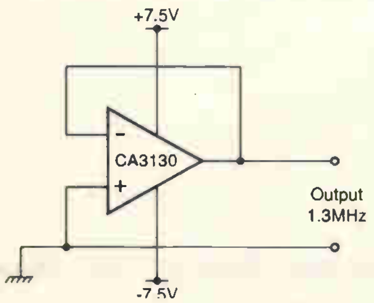
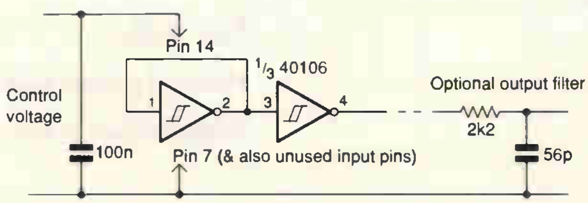


Fig. 1. They do not come simpler than this oscillator, if you ignore the components inside the op-amp.

Fig. 2. A hex Schmitt inverter used as a voltage-controlled version of the skeletal oscillator shown in Fig.1. This one covers 140kHz-27MHz.



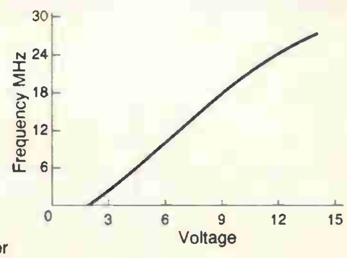


Fig. 2. Curve of frequency/control voltage for oscillator of Fig. 2.

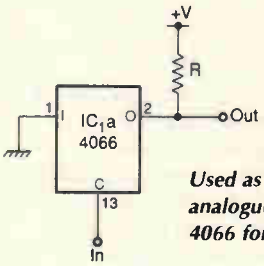
Switch/latch/trigger

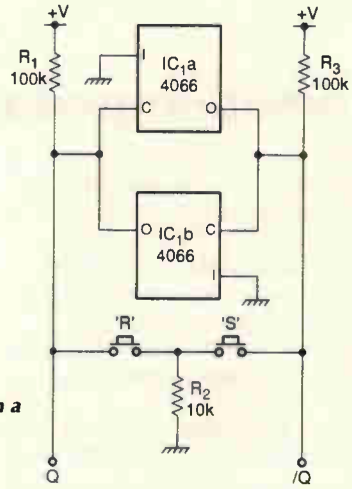
Switches from a *4066* cmos quad analogue switch are usable as inverters. When input to pin 13 in **Fig. 1** is high, the switch is open and the output on pin 2 is low. In the reverse state, the channel is closed and the pull-up resistor holds the output high.

Two such switches form the latch trigger shown in **Fig. 2**. When the Q output is high, the channel of $IC_{1(b)}$ is off, which causes the input of $IC_{1(a)}$ to be high and its channel turned on, /Q being low.

Activating the reset switch brings the Q output low by means of $R_{1,2}$ and $IC_{1(a)}$ switches off; the input of $IC_{1(b)}$ goes high, pulled up by R_3, and its channel turns on. The /Q output is now high and Q is low. Pushing the set switch reverses the situation.

V B Oleinik
Kaliningrad
Moscow





Used as inverters, analogue switches from a 4066 form a S-R latch.

Interference-resistant infrared proximity detector

This retro-reflective, pulsed detector was intended as an obstacle detector for a small robotic vehicle. Its advantages over commercial types are its low power consumption, its resistance to interference from other ir sources and the fact that no optics are needed.

In the transmitter, a *555* timer generates current pulses of about 1μs duration at a frequency of 3kHz. The p-n-p *BFY64* discharges the capacitor through the *TIL38* infrared led at a peak current of 0.7A, which can be increased by either increasing Vcc or using a lower on-resistance transistor. To achieve a well-shaped current pulse, the type of capacitor used was a Siemens *B32650* pulse-resistant polypropylene 1000V type. A pulse with the same duration as the ir pulse is emitted from pin 3 and used as reference by the integrator.

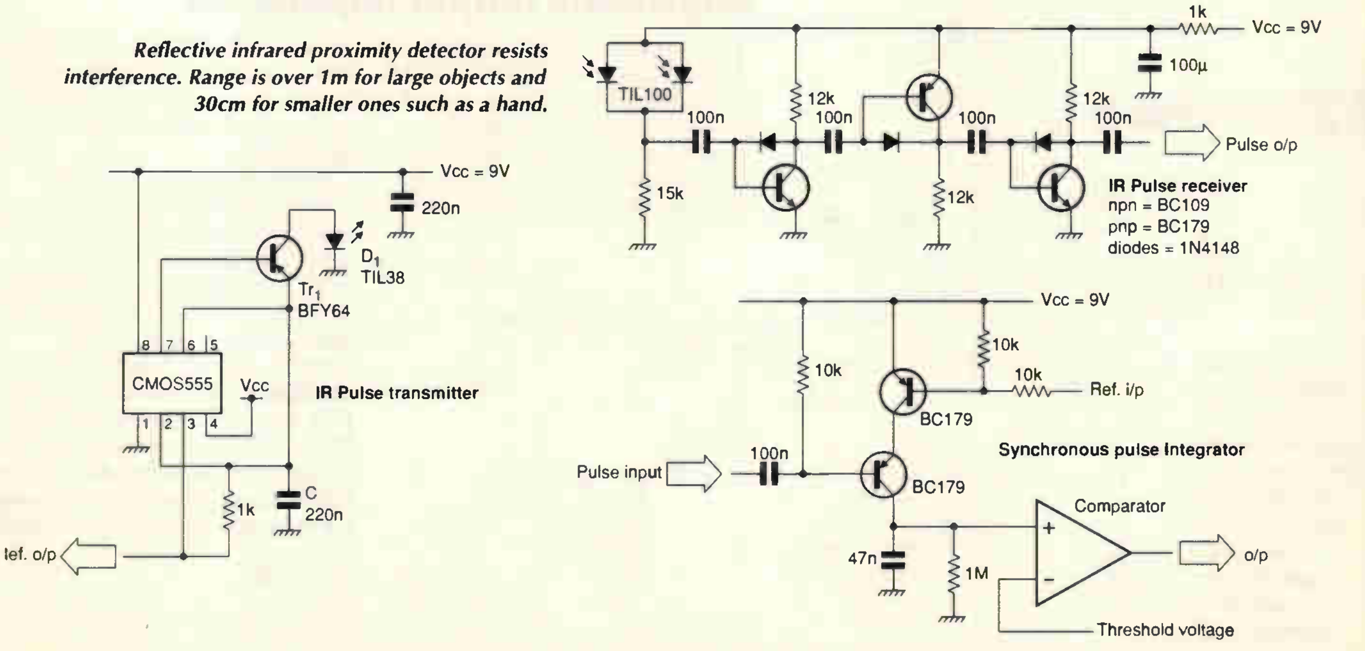
The receiver is unusually simple. Diode bias enforces stage gain dependent on signal amplitude and polarity, the stages using alternate *BC179* p-n-p and *BC109* n-p-n types to allow for signal inversion; pulse shape is unimportant here, only its arrival time being of interest. Output pulse is of 1-2μs duration. No instability showed itself, but good layout and screening are needed to prevent feedback; in particular, the photodiodes must be screened from the led. Improved performance is gained by the use of multiple photodiodes and by the use of a stop to confer the same field of view seen by the led.

In the integrator, pulses are converted to a dc level, the integrator being synchronised with the transmitter by the two-transistor gate and the reference signal from the transmitter. Improved resistance to interference is gained by applying a pseudo-random modulation to the transmitter by controlling the 555 reference at pin 5.

W Gray
Farnborough
Hampshire

£100 WINNER

Reflective infrared proximity detector resists interference. Range is over 1m for large objects and 30cm for smaller ones such as a hand.



Infinite-impedance detector

Infinite-impedance rf detectors have been with us for almost 60 years[1], the first consisting simply of a cathode-follower with a high-value cathode resistor and a cathode capacitor, the charge on the capacitor tending to cut the triode off on negative-going excursions of the rf input. But it was in 1959 that Telefunken patented the transistor version[2].

Figure 1 is a useful example of the circuit. Transistor Tr_1 is the detector, taking the rf input from a 50Ω line. Capacitor C_1 charges up to nearly the positive peak of the input, C_1 discharging between the peaks at I_{E1}/C_1 volts/s, which is made sufficiently slow to maintain most of the charge between rf peaks but speedy enough to follow the modulation. The effect is to produce a dc offset to the base-band output, which is compensated by Tr_2 at the input to the op-amp buffer, the amount of offset being adjusted by the 20kΩ pot to give zero output level when rf input is at zero.

T H O'Dell
London W2

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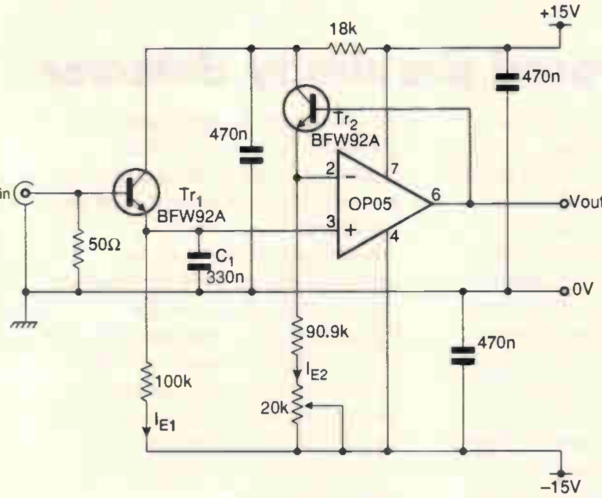
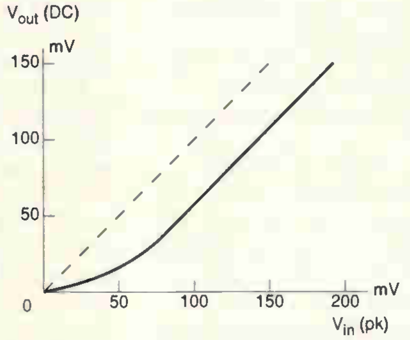


Fig.1. The infinite-impedance detector resurrected – in this case with an adjustment to eliminate output offset.

Fig.2. Performance of the circuit between 100kHz and 50MHz. Offset from the ideal, shown dotted, is about one-tenth of that from a good Schottky detector and the input impedance is much higher at 20kΩ.



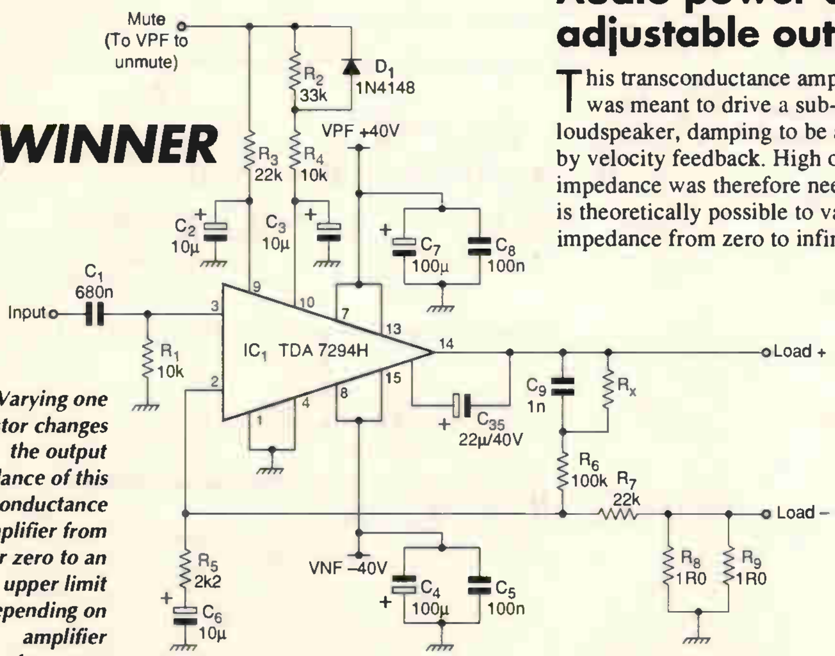
£75 WINNER

Audio power amplifier with widely adjustable output impedance

This transconductance amplifier was meant to drive a sub-woofer loudspeaker, damping to be applied by velocity feedback. High output impedance was therefore needed. It is theoretically possible to vary the impedance from zero to infinity by so varying R_x, although amplifier loop gain imposes restraints. Apart from audio use, the circuit should find application in industrial applications.

Resistor $R_{8,9}$ in parallel define transconductance, these resistors being specified to avoid gain variation with temperature. The *TDA7294* typically gives 70W into 4Ω or 8Ω if heat-sinked adequately, although any available power amplifier should serve. These amplifiers need a minimum closed-loop gain for stability; in this case, 24dB. This figure cannot always be guaranteed with current drive and at high frequencies, which is the reason for the inclusion of C_9 to provide hf feedback.

Paul Mills
Airdrie
Lanarkshire



Varying one resistor changes the output impedance of this transconductance amplifier from near zero to an upper limit depending on amplifier performance.

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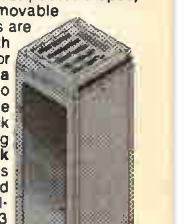

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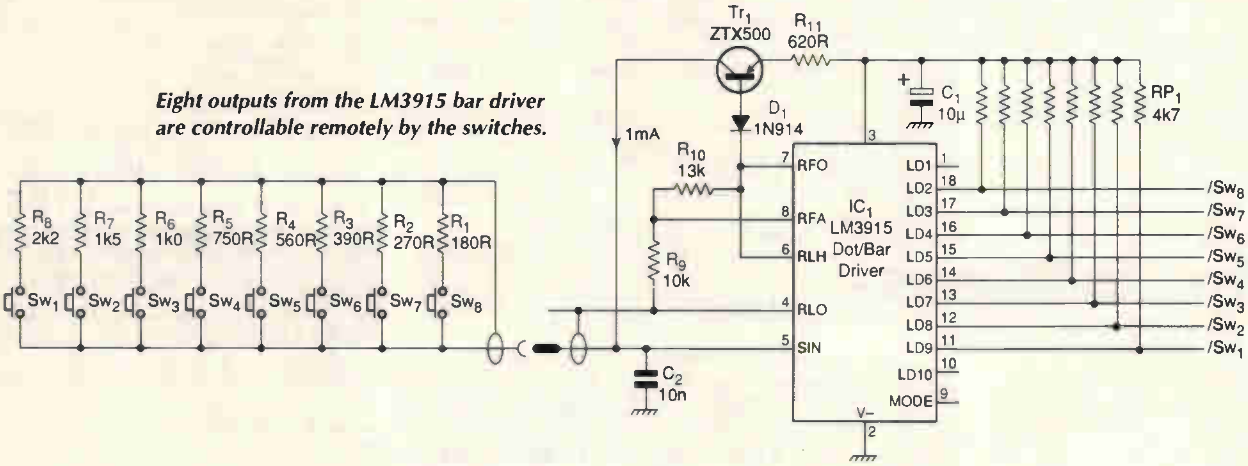
Two wires control eight outputs, in this case to a dot/bar driver.

The *LM3915* supplies constant current to the switch/resistor chain at the remote end of the wires. Selecting one of the resistors by means of a switch applies the voltage dropped across it to one of the driver outputs, the log. scale of the driver allowing fairly wide resistor tolerance. Since, according to the data sheet, LM3915s may be cascaded, the number of remote resistors can be increased to suit other purposes.

Alex Birkett
London
SE22

Eight outputs from the LM3915 bar driver are controllable remotely by the switches.



Offset source for op-amps

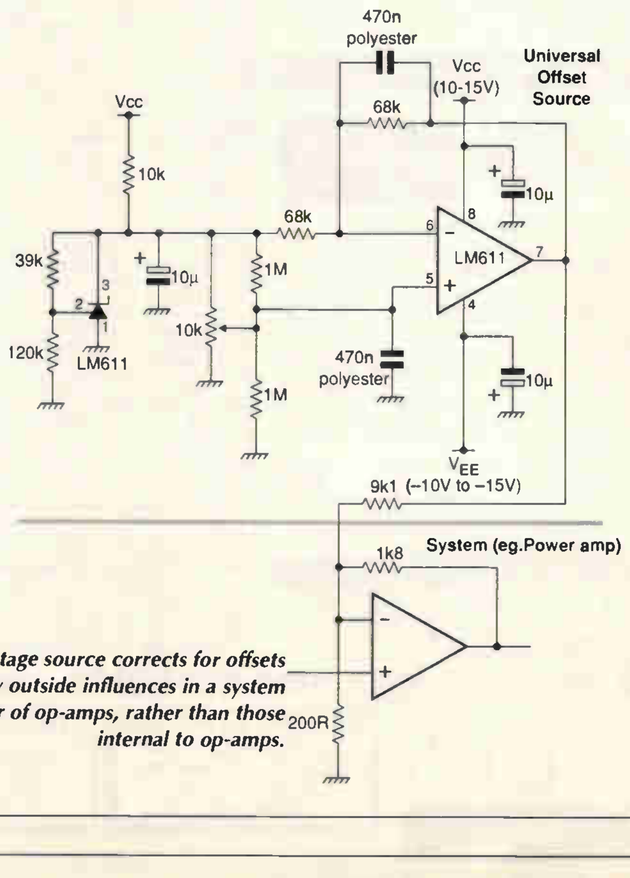
A separate source of offset voltage for a number of op-amps avoids the need to use the offset adjustment on some op-amps, which is intended for the op-amp's internal offset, not that from other parts of a system. Further, such procedures can adversely affect other characteristics such as offset drift and, in some cases where the gain from the offset terminals is high, cause trouble with noise pickup from inevitably longish connections to the adjustment pot. This one provides a stable source of offset voltage, independent of the power supply.

A band-gap reference, well decoupled, provides up to 5V. which is divided to reduce the effect of the *LM611* offset and allow the 611 output to be only loosely coupled to the rest of the system by a largish resistor.

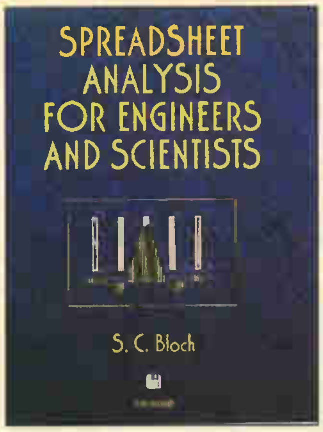
Since gain from the 611 non-inverting input is +2 and that from the inverting input –1, varying the potentiometer end to end varies the output between –5V and +5V. The two 1MΩ resistors ensure that, in the event of the wiper being open-circuit, the 611 output becomes zero rather than swinging to a supply rail.

Care with wiring is needed, particularly for ground connections.

Phil Denniss
University of Sydney
NSW
Australia



Offset-voltage source corrects for offsets caused by outside influences in a system using a number of op-amps, rather than those internal to op-amps.



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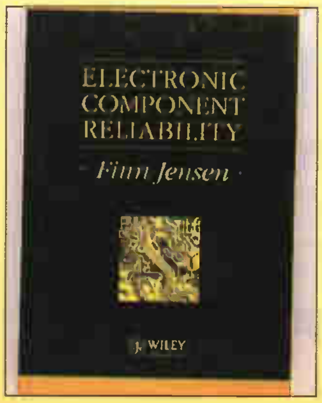

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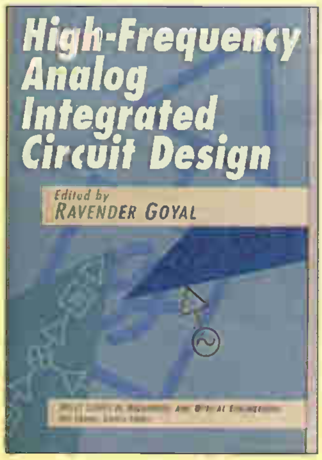

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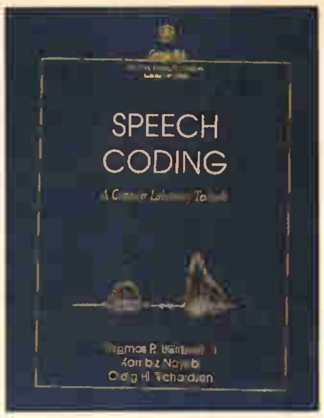

perform a wide variety of speech coding and speech processing experiments. The text presents and explains a set of basic speech coders analytically and in terms of the specific parameters controlling each coder. The manual leads the student through the experimental process of understanding how speech coders work and sound via over 70 exercises and projects. The class-tested menu-driven, Dos-based software can be operated by students with little or no training.

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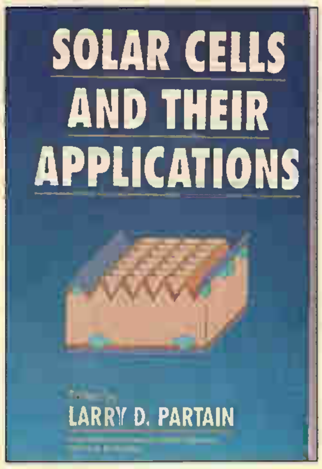

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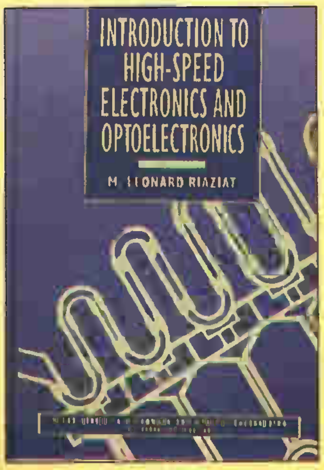

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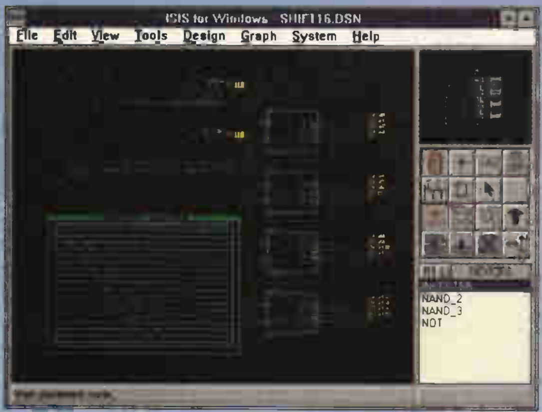

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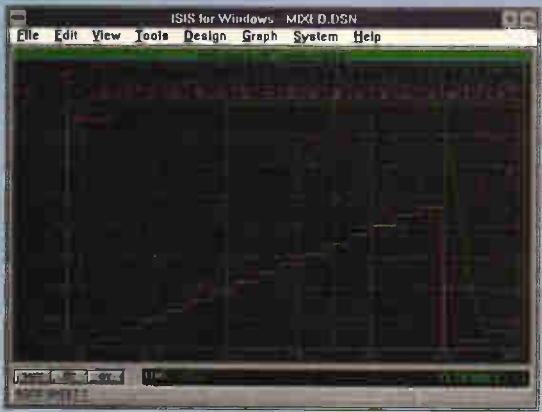

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CIRCLE NO. 135 ON REPLY CARD

Ray Fautley shows how to design reliable voltage doubling power supply circuits with the aid of look-up tables.

Voltage doubling

The symmetrical voltage doubler, shown in the diagram, is useful for providing high voltages at low currents.

The term 'symmetrical' is used as the diodes and capacitors are connected in a symmetrical fashion, looking rather like the bridge-rectifier circuit. There is no direct connection between the alternating input and the dc output. (Another type of voltage doubler circuit is the common-terminal circuit where the ac supply and dc output have a common terminal, and so is not 'symmetrical'.)

Alternating voltage is applied to the two rectifier diodes D_1 and D_2. When point x is positive, diode D_1 conducts but D_2 is cut off. Current through D_1 charges capacitor C_A to approximately the peak of the transformer secondary voltage. During the next half cycle point x will be negative with diode D_2 conducting and D_1 cut off.

Current through D_2 charges capacitor C_B, again to approximately the secondary peak voltage.

As the two capacitors C_A and C_B are connected in series, so are the voltages across each of them. The two voltages – being of suitable polarity – add, providing nearly twice the output voltage of a single diode half wave rectifier. This is logical because the voltage doubler is really just two half wave rectifiers in series.

Source resistance is shown as resistor R_s.

Voltage doubler design procedure

The procedure for designing the symmetrical voltage doubler is similar to that used for the rectifier circuits described in my previous articles.

1) Specify required dc output voltage at full load $E_{dc(load)}$ in volts.

2) Specify required maximum load current $I_{dc(load)}$ in amps.

3) Specify maximum ripple voltage acceptable, $V_{r(rms)}$ in volts.

4) Specify the ac mains supply voltage $V_{pri(rms)}$ in volts.

5) Specify frequency of the mains supply f in hertz.

6) Determine the value of 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 any voltage drop across the diodes.
As this type of rectifier is mostly used for obtaining a high voltage at low current the diode voltage drop can be ignored, so,

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

7) Determine the average current I_o through each diode:

$I_o = I_{dc(load)}$

8) Determine a value for the source resistance of the supply R_s. As only high resistance loads – i.e. high voltage and low current – are to be considered, the predominant resistance will be that of the transformer windings. So,

$$R_s = R_{sec} + \frac{R_{pri}}{N^2}$$

However, as it's likely that the transformer winding resistance are not known, assume R_s is about 2% of R_L. So,

$$R_s = R_L \times \frac{2}{100}$$

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

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

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

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

11) From the **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 step (9).

12) Calculate the value of capacitors C_A and C_B in the circuit diagram.

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

13) Find the nearest standard, or available, value for C_A and C_B, close to, or just above, the value calculated in step (12). If the practical value of C is different from that in step (12), call it C_1 and determine a new value for X (call it X_1) from, $X_1 = 2\pi f C_1 R_L$, or with C in microfarads,

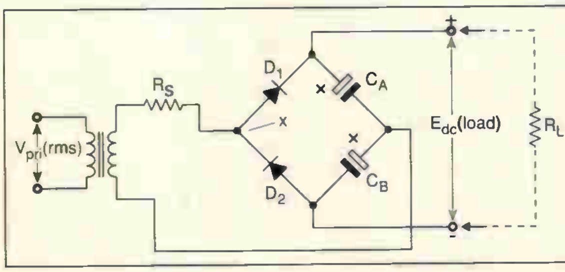
$$X_1 = \frac{2\pi f C_1 R_L}{10^6}$$

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),

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

$$= \frac{0.707 \times E_{dc(load)}}{Y}$$



Used for providing high voltages at low current, this circuit produces nearly twice the voltage of a single-diode half-wave rectifier.

16) Determine the peak voltage, or PIV, that each of the rectifiers must withstand,

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

17) Find the value for Z from **Table 3** for $0.5X$ (or $0.5X_1$) where X was found in step (11) or X_1 in step (13), and for $(R_s/0.5R_L)\%$, where $(R_s/R_L)\%$ was found in step (9),

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

18) From the value of Z found in step (17), determine the current through each rectifier diode from $I_{(rms)}=I_o\times Z$.

19) Determine recurrent peak current I(peak) through each rectifier diode. From **Table 4**, for $0.5X$ (or $0.5X_1$) and $(R_s/0.5R_L)\%$ find W, which is $I_{(peak)}/I_o$. Next find $I_{(peak)}$ from $I_o\times W$.

20) Determine initial switch-on current I_{on}. As capacitors C_A and C_B are 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. As a result,

$I_{on}=V_{sec(peak)}/R_s$.

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, the source resistance R_s must be increased by adding an external resistor R_{ext} where R_s is shown in the circuit diagram. 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. The device must have *all* its ratings equal to, or greater than, the following,

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

Initial switch-on current or I_{on}
(sometimes I_{FSM}), see (20)

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

22) Determine rms ripple current $I_{c(rms)}$, flowing through capacitors C_A and C_B,

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

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

23) Decide on the specification for capacitors C_A and C_B. Each capacitor must have ratings equal to, or greater than, the following,

Capacitance C_A and C_B see (12) or (13)

Working dc voltage $\sqrt{2}\times V_{sec(rms)}$, see (15)

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

24) Total transformer secondary current $I_{t(rms)}$ comprises two currents, one in each rectifier, which must be summed by,

$I_{t(rms)}=\sqrt{[(I_{(rms)}{}^2)+(I_{(rms)}{}^2)]}$
$=\sqrt{2}\times I_{(rms)}=1.414\times I_{(rms)}$

Table 1. Finding the value of X for the voltage doubler design.

V_r%	(R_s/R_L)% 0.1	0.3	1.0	3.0	5.0	10
0.1	1780	1594	1428	1279	1210	1145
0.2	863	772	691	618	585	553
0.3	561	506	456	411	390	370
0.4	418	375	337	302	286	271
0.5	332	299	270	243	231	219
0.6	280	250	224	200	189	179
0.7	238	214	193	174	165	157
0.8	203	183	165	149	141	134
0.9	183	165	148	133	126	120
1.0	163	147	131	120	114	109
2.0	80	72	64	58	55	52
3.0	52	47	42	38	36	34
4.0	39	37	35	33	32	32
5.0	30	27	24	22	21	20
6.0	24	22	20	18	17	16
7.0	20	18	17	15	14	14
8.0	18	16	15	13	12	12
9.0	14	13	12	11	10.7	10.5
10	13	12	11	10	9.6	9.2
20	4.8	4.5	4.3	4.0	3.9	3.8
30	2.3	2.2	2.1	2.0	2.0	2.0
40	1.1	1.07	1.04	1.02	1.01	1.0

For $I_{(rms)}$ see step 18.

25) Transformer volt-amp, or VA rating T_{VA} is,

$T_{VA}=V_{sec(rms)}\times I_{t(rms)}$

This determines the size of the transformer.

26) Transformer requirements:

Volt-amp rating T_{VA}, see step (25)
Primary winding $V_{pri(rms)}$, see (4)
Secondary winding $V_{sec(rms)}$ see (15)
Secondary current $I_{t(rms)}$, see (24)

Table 2. Finding the value of Y.

X	(R_s/R_L)% 0.1	0.25	0.5	1	1.5	2	3	4	5	6	7	8	10	13	20
1.3	0.60	0.59	0.59	0.58	0.58	0.58	0.57	0.57	0.56	0.55	0.55	0.54	0.53	0.51	0.49
1.5	0.66	0.65	0.64	0.64	0.63	0.63	0.63	0.63	0.62	0.62	0.61	0.60	0.59	0.56	0.54
2	0.77	0.76	0.75	0.74	0.74	0.73	0.73	0.72	0.71	0.70	0.69	0.69	0.68	0.66	0.62
3	0.93	0.92	0.92	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.85	0.85	0.83	0.77	0.71
4	1.04	1.03	1.03	1.02	1.01	1.00	0.98	0.97	0.96	0.95	0.94	0.93	0.89	0.81	0.74
5	1.13	1.12	1.12	1.10	1.09	1.08	1.06	1.03	1.03	1.02	1.00	0.98	0.94	0.93	0.75
6	1.19	1.18	1.17	1.16	1.15	1.14	1.12	1.06	1.08	1.07	1.03	1.01	0.97	0.84	0.75
7	1.25	1.24	1.24	1.22	1.20	1.19	1.16	1.14	1.12	1.09	1.06	1.02	0.98	0.85	0.75
8	1.31	1.30	1.29	1.27	1.25	1.24	1.21	1.18	1.15	1.12	1.08	1.04	0.99	0.85	0.75
9	1.35	1.34	1.32	1.30	1.29	1.27	1.24	1.21	1.17	1.13	1.09	1.05	1.00	0.85	0.75
10	1.39	1.38	1.36	1.34	1.32	1.31	1.27	1.23	1.19	1.15	1.10	1.06	1.01	0.86	0.75
15	1.51	1.50	1.48	1.44	1.42	1.39	1.33	1.27	1.22	1.17	1.13	1.08	1.02	0.86	0.75
20	1.62	1.61	1.59	1.54	1.52	1.47	1.39	1.31	1.25	1.19	1.15	1.10	1.03	0.87	0.75
30	1.77	1.72	1.68	1.62	1.57	1.51	1.42	1.34	1.27	1.21	1.16	1.11	1.03	0.87	0.75
40	1.79	1.77	1.73	1.65	1.60	1.53	1.43	1.35	1.28	1.21	1.17	1.11	1.03	0.87	0.75
50	1.82	1.79	1.75	1.67	1.61	1.54	1.44	1.35	1.28	1.22	1.17	1.12	1.03	0.87	0.75
60	1.84	1.81	1.76	1.68	1.61	1.55	1.45	1.35	1.28	1.22	1.17	1.12	1.03	0.88	0.76
70	1.85	1.82	1.77	1.68	1.62	1.55	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
80	1.86	1.83	1.78	1.69	1.62	1.55	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
90	1.87	1.83	1.78	1.69	1.62	1.56	1.45	1.36	1.29	1.22	1.17	1.12	1.03	0.88	0.76
100	1.88	1.84	1.78	1.69	1.62	1.56	1.45	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
200	1.91	1.85	1.78	1.70	1.63	1.56	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
300	1.92	1.86	1.79	1.70	1.63	1.56	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76
400	1.93	1.86	1.79	1.71	1.63	1.57	1.46	1.36	1.29	1.22	1.17	1.12	1.04	0.88	0.76

27) When a suitable transformer has been chosen, measure the resistance of both windings. If the *measured* source resistance,

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

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

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

must be added, see (28), to limit I_{on} to the value found in (20).

28) If an external resistor R_{ext} was found necessary in (20) or (27) to be fitted where R_s is shown to limit 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 R_{ext} is used, the regulation of the supply can be improved by adding a shorting-out device, as recommended for the bridge rectifier circuit described my article in the September 1996 issue.

Voltage doubler design example

Finally, here is a worked example for the voltage-doubler circuit. Assume that a supply of 1000V at 100mA is required, having an acceptable ripple level of 10V rms.

1) $E_{dc(load)}=1000V$

2) $I_{dc(load)}=100mA$ or 0.1A

3) $V_{r(rms)}=10V$ rms

4) $V_{pri(rms)}=240V$ rms

5) $f=50Hz$

6)

$$R_L = \frac{E_{dc(load)}}{I_{dc(load)}} = \frac{1000}{0.1} = 10k\Omega$$

7) $I_o=I_{dc(load)}=100mA$

8) Let R_s=2% of R_L, i.e.,

$$R_s = R_L \times \frac{2}{100} = \frac{10^4 \times 2}{100} = 200\Omega$$

9)

$$\frac{R_s}{R_L}\% = \frac{200}{10^4} \times 100\% = 2\%$$

10)

$$V_r\% = \frac{V_{r(rms)}}{E_{dc(load)}} \times 100\%$$
$$= \frac{10}{1000} \times 100\% = 1\%$$

11) The value of X for V_r% and (R_s/R_L)%, i.e. V_r%=1 and (R_s/R_L)%=2 from **Table 1** is found to be 125.

12)

$$C = \frac{X(10^6)}{2\pi f \times R_L}\mu F = \frac{125 \times 10^6}{2\pi \times 50 \times 10^4}\mu F$$
$$= \frac{125}{\pi}\mu F = 39.8\mu F$$

13) The nearest standard value above 39.8μF is 47μF, so,

$X_1=2\pi f \times C_1 \times R_L$
$=2\pi \times 50 \times 47 \times 10^{-6} \times 10^4=148$

14) From **Table 2**, the value of Y for X_1 and (R_s/R_L)%, i.e. X_1=148 and (R_s/R_L)%=2, is found to be 1.56

15)

$$V_{\sec(rms)} = \frac{0.707 \times E_{dc(load)}}{Y}$$
$$= \frac{0.707 \times 1000}{1.56}$$
$$= 453\text{V rms}$$

16) PIV=$2.828V_{\sec(rms)}$=2.828×453=1281V

17) From **Table 3**, the value of Z for $0.5X_1$ and $(R_s/0.5R_L)$%, i.e. $0.5X_1$=0.5×148=74 and $(R_s/0.5R_L)$%=2/0.5=4, is found to be 2.46.

18) $I_{(rms)}=I_o \times Z$=0.1×2.46=0.246A or 246mA

19) From **Table 4**, the value of W for $0.5X_1$ and $(R_s/0.5R_L)$%, i.e. $0.5X_1$=74 and $(R_s/0.5R_L)$%=4, is found to be 7.02. As a result, $I_{(peak)}=I_o \times W$=0.1×7.02=0.702A, or 702mA.

20)

$$I_{on} = \frac{V_{\sec(peak)}}{R_s} = \frac{1.414 \times V_{\sec(rms)}}{R_s}$$
$$= \frac{1.414 \times 453}{200} = 3.2A$$

21) Diode ratings required:

PIV (V_{RRM})=1281V
I_{on} (I_{FSM})=3.2A
I_o ($I_{F(AV)}$)=0.1A

For safe operation, two *BYX38-1200* type diodes should be used in series for each of the two diodes in the voltage doubler circuit.

22)

$$I_{c(rms)} = \sqrt{[I_{rms}^2] - [I_{dc(load)}^2]}$$
$$= \sqrt{0.246^2 - 0.1^2}$$
$$= \sqrt{0.0605 - 0.01}$$
$$= \sqrt{0.0505} = 0.225A$$

23) Capacitor ratings required. $C_A=C_B=C$
C=capacitance=47μF
$V_{\sec(peak)}=V_{DC(wkg)}=\sqrt{2}\times453=641V$
$I_{c(rms)}$=ripple current=0.225A

Table 3. To Find the value for Z.

0.5X	**(R_s/0.5R_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	4.03	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

24) $I_{t(rms)}=\sqrt{2}\times I_{rms}=\sqrt{2}\times 0.246=0.348$A, or 348mA

25) $T_{VA}=V_{sec(rms)}\times I_{t(rms)}=453\times 0.348$ =158VA

26) Mains transformer ratings required,

T_{VA}	volt/ampere rating	158VA
$V_{pri(rms)}$	primary winding	240V
$V_{sec(rms)}$	secondary winding	453V
$I_{t(rms)}$	secondary current	348mA

I hope that the four simple procedures for designing the four key types of rectifier circuits that I have described over the past few months will prove as useful to you as they have to me over the years. ■

Designing reliable rectifiers

Ray Fautley has produced three earlier articles along similar lines to this one, covering:

Full-wave bridge rectifier
September 1996 issue, p. 691
Half-wave rectifiers
December 1996 issue, p. 980
Full-wave rectifier with centre tap
February 1997 issue, p. 133

Table 4. To Find the value for W.

0.5X	(R_s/0.5R_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

NEW PRODUCTS CLASSIFIED

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ACTIVE

Arrays

High-*I/V* darlingtons. Arrays of seven and eight darlington driver transistors by FET Electronics interface between logic-level circuitry and power loads such as relays, print hammers and displays. *FE ULN2001-24* (seven drivers) and *FE ULN2801-2824* (eight) take up to 500mA through each driver, outputs being paralleled for more, and all have open-collector output and clamp diodes. Voltage rating is 50V or 95V, depending on type. Various input characteristics cope with pmos, comos and cmos input. FET Electronics Ltd. Tel., 01635 524490; fax, 01635 552244.

A-to-d and d-to-a converters

Fast a-to-d converters. Philips intends its *TDA8762A* and *TDA8763A* high-speed, high-accuracy and low-power converters for use in broadcast quality cameras, communications and medical imaging. Both provide 10-bit resolution at 80Msample/s and 50Msample/s respectively, the 8762 giving a ttl output and the 8763 cmos output from 2.7V to 5.25V. When sampling at 40Msample/s, the *8763* achieves an effective bit length of 9.4bit, s:n of 58dB and thd of –68dB, the *8762* at 80Msample/s being similar but with an effective bit length of 9.3bit. Sample-and-hold circuitry is not needed and low input capacitance avoids the need for buffering. Gothic Crellon Ltd. Tel., 01734 788878; fax, 01734 776095.

Transmission d-to-as. Analog Devices' *AD976x* family of cmos d-to-a converters is meant for use in the transmission path of communications and signal-generation equipment, all members providing differential 20mA output current and sharing a common 28-pin SOIC package. The 125Msample/s family consists of the 8-bit *9708*, 10-bit *9760*, 12-bit *9762* and 14-bit *9764*, plus the 50Msample/s, 10-bit *9760-50*. All run from a 2.7-5,5V single supply on 45mW (3V) with a power-down mode on 25mW. Performance features include a spurious-free dynamic range over the Nyquist band from 53dB when clocked at 100Msample/s to 79dB at 50Msample/s. Total harmonic distortion of the 9752 clocked at 25Msample/s with a 1MHz output is –78dB. Analog Devices Ltd. Tel., 01932 266000; fax, 01932 247401.

Logic

Electronic tagging. *Holtek HT6P20* electronic serial number chips offer 2^{24} combinations and are intended for use in wireless key fobs, access control and burglar alarms. They are available programmed or blank and in five styles: the *HT6P20* outputs its code on power-up; *6P20B* allows the last two digits to be set by the user to identify the type of sensor or area from which the code was transmitted; and *HT6P20D/E* allow the last four and eight bits to be set. Supplies down to 2V will power the devices. With a Holtek *48000* 8-bit microcontroller, a low-power tagging system can be made for under £1. Flint Distribution. Tel., 01530 510333; fax, 01530 510275.

Optical devices

Multiple leds. Dialight's range of led arrays now includes the *553 Series*, a dual, six-position type previously to special order and now standard. It replaces six bi-level devices or 12 separate ones, removing the need to bend 24 leads and giving accurate alignment. The leds have integral resistors for 5V, draw 2mA and are available in two-colour types. Viewing angle is 30°. Dialight. Tel., 01223 424313; fax, 01223 423493.

PASSIVE

Passive components

Miniature coils. Three new miniature wire-wound coils in the 1008 package from Toko, the *FSLU2520 Series* offer inductances from 0.01μH to 220μH in E12 values, low resistance, typical *Q* of 45 and 750ppm/°C temperature coefficient. Coils are in a sealed, heat-resistant case for flow or reflow soldering. Cirkit Distribution Ltd. Tel., 01992 444111; fax, 01992 464457.

Thick-film resistors. Virtually non-inductive thick-film power resistors from RS Components are made by two suppliers: Vishay-Sfernice make the 5-50W types, while the 100W and 250W resistors come from Meggitt CGS. Cermet thick-film techniques are used, the housing being hard epoxy, and the components are meant to be mounted on a heat sink. The V-S resistors are to ±5% tolerance and work in temperatures from –55°C to 125°C, the Meggitt CGS ones having a ±10% tolerance and –55°C to 70°C temperature range. All types will withstand a short-term overload. RS Components Ltd. Tel., 01536 201234; fax, 01536 405678.

Wirewound, switched pots. BFI Ibexsa offers a range of 24mm diameter, single-turn wirewound potentiometers with a 4W rating and values in the 10Ω-22kΩ band. Switches are two-pole changeover types rated at 240V ac, 4A and 12V dc, 10A. Spindles are supplied to customers' specification, in either metric or imperial sizes. BFI Ibexsa Electronics Ltd. Tel., 01622 882467; fax, 01622 882469.

Audio products

Comprehensive sound processor. Mitsubishi announces the *M62460FP* sound processor which forms a single-chip providing Dolby Pro Logic surround sound including centre and surround sound channel trimming for five speaker systems. It is an analogue processor with Pro Logic decoder, on-board memory and the I^2C bus for closed-circuit television. A microprocessor interface renders the device simple to use, facilities including disco, hall, live mode and five delay time positions for digital space surround effects and 147.5ms or 196.6ms echoes. The use of BiCMOS is said to provide improved performance over cmos devices, as does the analogue design over combined analogue-digital types. Mitsubishi Electric UK Ltd. Tel., 01707 276100; fax, 01707 278837.

Communications equipment

Comms boards. *C320* from Amplicon Liveline is an intelligent communications system providing between eight and 32 RS232 or RS422 serial comms ports for any pc having a free ISA slot. Each contains a plug-in controller board for the pc, a cpu module which is mountable up to 100m from the pc and a uart to plug into the cpu module to give eight serial channels, each cpu taking up to four uarts for 32 channels and each pc holding four controller boards to give a total of 128 ports. Controller and cpu both have 46MHz risc processors and RS422 interfaces which, with the 512K of dual-ported ram in the controller, relieves the host of processing overhead. Software supplied is configuration and driver software for Windows3.x, NT, 95, dos, SCO Unix, SCO Xenix, Unix SVR3.x, Unix SVR4.2, UnixWare and Solaris x86. Amplicon Liveline Ltd. Tel., 0800 525 335 (free); fax, 01273 570215.

Microwave components

L-band GaAs fets. Over the 1.6GHz to 2GHz, Toshiba's *TPM1919-40* GaAs fets deliver an output power of 42.7W or 46.33dBm, with a gain of 13.3dB and 42% power added efficiency; saturated power output is 51.3W. This is said to be the highest power at 1.8GHz ever achieved by a GaAs fet. gain flatness is ±0.5dB. Steatite Microelectronics Ltd. Tel., 0121 643 6333; fax, 0121 643 2011

Connectors and cabling

D-type connector hoods. Hoods for 9-37 way D-type connectors made by *ODU UK* are quick to assemble, need no fixing screws and come in a choice of ten colours. They are made in one piece and snap to lock together, incorporating a quickly-assembled reversible cable clamp with self-tapping screws to enable the use of cables of varying diameters up to 15mm thick for the 37-way hood. All have a captive steel thumb screw.The connectors themselves are of the mixed variety, in which data, power, coaxial and high-voltage contacts can be used in the one shell. ODU UK Ltd. Tel., 01653 600489; fax, 01653 600493.

Bga socket. Methode's 1.27mm pitch ball-grid-array socket provides a simple means of removing the bga device from the board, effectively turning the bga device into a pin grid

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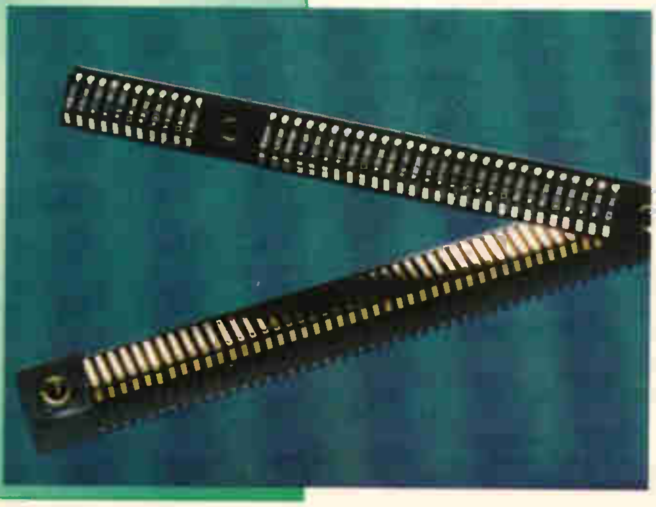
array type for socket or through-hole mounting. It is compatible with all popular bga packages and heat sinks; it needs no hold-down device and the footprint is standard bga size. Insertion force is 2oz/position and withdrawal 0.35oz/position, with several choices of ejector. Contact rating is 0.5A dc at 20-40mΩ. Methode Electronics Europe Ltd. Tel., 01389 732123; fax, 01389 732777.

Crimps and housings. AMP *CST-100* crimp contacts and housings are available with 2-28 positions pitched at 0.1in and are compatible with the Molex KK series. This is a low-cost wire-to-board connection with a 250V ac, 4A rating and contact resistance of 2mΩ. Both tin and gold-plated contacts are supplied and there is an overstress feature to prevent damage to the contact. Locking tabs and polarising tabs are standard. Gothic Crellon Ltd. Tel., 01734 788878; fax, 01734 776095.

Solderless connector. *Surface Stack* board-to-board connectors from Selwyn are fixed to the board by through-hole or threaded inserts, electrical connection to pads on the board being made by gas-tight beryllium-copper springs. There are models with from 22 to 78 contacts on a 1.27mm pitch. Selwyn suggests that the connectors are suitable for hand-held data collection devices, in which the pcb pads would be exposed for mating with the connector, avoiding the use of cables. Selwyn Electronics Ltd. Tel., 01732 763436; fax, 01732 763395.



Crystals

Wide-pull oscillator. *Model 937* from Oak Frequency Control Group is a high-frequency voltage-controlled crystal oscillator covering the 100-155.52 range of frequencies and is contained in a 16-pin dip. Output is ecl complementary in a variety of pin arrangements and standard frequency units are available from stock. Wyle Ginsbury Electronics Ltd. Tel., 01634 290903; fax, 01634 290903.

Test and measurement

Digital wattmeter. The *Yokogawa Wt1000* is a versatile digital power meter with a maximum bandwidth of 300kHz and working to an accuracy within 0.1%. It is available in single-phase or three-phase versions and there is a version for testing the performance of motors. Input range is 15V-1kV rms and a filter with a selectable cut-off frequency isolates fundamental frequencies in inverters to allow harmonic analysis on fundamentals from 440Hz to the 50th harmonic. On three phases, the instrument simultaneously measures the phase difference between phases and active, reactive and apparent power of the fundamental., simultaneously showing voltage, current and a choice of other quantities on four front-panel displays. Martron Instruments Ltd. Tel., 01494 459200; fax, 01494 535002.

Jitter tester for comms. *JitterGEN* from NoiseCom tests communications systems, PSTN, cellular and PCS base stations, for behaviour in the presence of digital noise to the specifications of AT&T, Accunet, TR62411 and international specs such as G.823 and G.702. The instrument provides controlled fm and pm jitter and wander in the 0.009Hz-400kHz range and unit interval-controlled jitter from 0 to 200ui, either under the control of an external controller or stand-alone. Jitter is applied to a self-generated clock or to a data stream from another source and re-output to the system under test. Jittergen is contained in a portable unit with a fold-away keyboard, having a pc architecture and Windows gui. Sematron UK Ltd. Tel., 01256 812222; fax, 01256 812666.

Rf absorbing clamp. For the measurement of radiated emissions from the cables of electrical equipment, the EMC standard EN55014 specifies the use of an rf absorbing clamp, contrary to the impression many engineers have that a broadband antenna is needed. Laplace has such a clamp, the *RF400*, which consists of ferrite rings which open up to admit the cable and are then closed and held with no gap by springs. Insertion loss is ±1dB, maximum cable diameter is 18mm, load current is unlimited and there are wheels underneath the instrument so that it can be run along the cable. Instruments are supplied with a six-metre mains test cable and antenna factor data to load into a receiver or spectrum analyser. Laplace Instruments Ltd. Tel., 01692 500777; fax, 01692 406177.

CE-compliance tester. CE marking under the Low Voltage Directive now being in force, Seaward's new *Premier LVD tester* will help with the design of products to enable self-certification. It is microprocessor-controlled and contains all necessary data for testing to seven harmonised standards, accommodating ten programmable safety tests, manually or automatically. After selection of the standard, the instrument will carry out the sequence of tests and display the results on an lcd with pass or fail indication. Results are recorded and may be downloaded for printing. An optional Windows package is available to allow remote control from a pc. Accessories such as various probes and a remote-control earth bond can be supplied. Seaward Electronic Ltd. Tel., 0191 586 3511; fax, 0191 586 0227.

Lab. in a box. Several instruments from Feedback fit into one bench-top case, the *604 Mini-Lab.* There is a 20MHz function generator with am/fm modulation producing sine, triangle, square, ramp and pulse waveforms, a 4-digit led readout being accurate to within ±1 count, and usable as a log/lin sweep generator; a 30MHz counter; a power operational amplifier; ±15V, 1A, adjustable dual or 5V, 3A power supplies; and a 3.5-digit multimeter measuring *V*, *I*, *R* and true rms. Feedback Test and Measurement. Tel., 01892 653322; fax, 01892 663719.

Fm/am signal generators. Kenwood announces the *SG Series* of programmable fm/am signal generators to cover the 100kHz-2GHz range of frequencies. SG-7200/7130 models go up to 2GHz and 1.3GHz respectively, being provided with a GPIB interface and modulation consisting of fm, am, am-fm and fm-fm simultaneously. Output levels increase in 0.1dB steps from −133dBm to 13dBm. SG-5150/5155 cover 100kHz-150MHz, the 5150 having fm stereo modulation and both having the GPIB interface. All have both rotary knobs and a keypad for control. Kenwood UK Ltd. Tel., 01923 218794; fax, 01923 212905.

Literature

Racks. Vero has published the *KM6-II Selector* to help engineers find their way through the maze of options available in sub-racking systems, explaining the choices of style and the sizes of Eurocard to fit, considerations discussed being screening, ease of assembly, cost and number of configurations. The same process is then carried out for front panels and plug-in units. Vero Electronics Ltd. Tel., 01703 266300; fax, 01703 265126.

Power supplies. In 216 pages, *Chloride Powerline's* new catalogue, The Power Guide, describes a range of linear and switched-mode supplies, dc-to-dc converters and inverters from many of the leading makers. It also contains applications information and data on safety standards and the EMC Directive. Chloride Powerline. Tel., 0118 9868567; fax, 0118 9755172.

Electromechanicals. Roxburgh can supply a catalogue of *Grayhill* components, featuring series encoders, push-buttons and keylock switches, a new section describing the full range of optical and mechanical decoders. Roxburgh Electronics Ltd. Tel., 01724 281770; fax, 01724 281650.

Frequency control. *Fordahl GB* (used to be McKnight Crystals) has a new catalogue of components and assemblies for a range of products for frequency control, such as quartz clock oscillators, voltage-controlled oscillators and crystal filters. Fordahl GB. Tel., 01703 877200; fax, 01703 846532.

Power supplies

High-reliability dc-to-dc converters. Interpoint has four new models in its *MFL Series* of converters, delivering 2V, 3.3V, 8V and 28V at up to 65W and intended for applications in which reliability is essential. All have a 16-40V dc input

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range, nominal being 28V, they are isolated to 100MΩ at 500V dc and are synchronised for system work. Conversion frequency is 550-650kHz. Protection includes short-circuit, input transients and low-voltage lockout. All have the facility for parallel working for up to three units. Interpoint UK Ltd. Tel., 01252 815511; fax, 01252 815577.

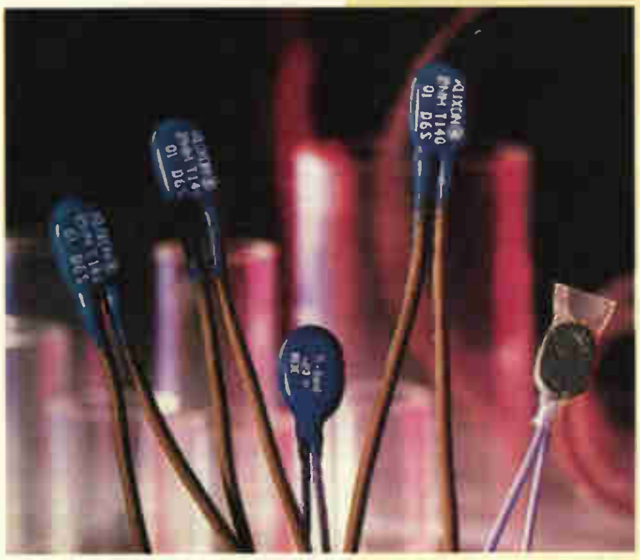
3.3V/5V smps. New to Power-One's *MAP110* range of universal-input, switched-mode supplies is the *MAP110-4300*, which provides, in addition to the 5V, 8A and ±12V,1A, a 3.3V,15A main channel, overvoltage protection being a feature of both 3.3V and 5V outputs. Others include zero minimum turn-on load, and optional power failure and thermal shutdown. Relevant standards requirements are met, an emi filter helping with FCC and CISPR 22 level B. The units come in three styles: open-board, with L brackets or totally enclosed. With forced air cooling, output is 110W or, with conventional cooling, 80W. Power-One Europe. Tel., 01769 540744; fax, 01769 540756.

100W pluggable supply. Vero's *EC100* range of low-cost, pluggable switched-mode supplies provide 5V and 24V rails for both logic circuitry and peripheral components such as relays and contactors. The supplies are in 3U by 12HP modules taking up three slot positions in a 19in rack and the rear heat sink is so designed to allow interfacing with both backplane and free-standing interconnection systems by way of a standard DIN41612 H15 connector. Versions are available to give 24V at 4A and 5V at 3A with power sharing, or 5V at 12A, 12V at 2A and –12V at 0.2A. Units are CE marked. Vero Electronics Ltd. Tel., 01489 780078; fax, 01489 780978.

Three channels, eight traces. Kenwood has two new oscilloscopes, the *CS-5270/75*, 100MHz bandwidth, three-channel, eight-trace instruments that offer ±3% measurement accuracy. Features include delayed sweep for expanded waveforms, single sweep and variable hold-off. There is automatic trigger and 1mV/div vertical sensitivity. The display is a 150mm rectangular tube with an internal graticule and illuminated scales, the *5270* also being provided with a digital readout and a cursor. Kenwood UK Ltd. Tel., 01923 218794; fax, 01923 212905.

Low-current voltage regulators. FET Electronics has a range of positive and negative regulators, *FE 78LXXA* and *FE 8LXXA* which, in a number of versions, provide fixed outputs from ±5V to ±18V at up to 100mA on inputs of ±25-35V. They are seen as replacements for resistor/zener combinations with much better performance and lower current. There is thermal shutdown and short-circuit current limiting. FET Electronics Ltd. Tel., 01635 524490; fax, 01635 552244.

Brighter ups. Five new accessory modules increase the intellect of Vero's *SmartSlot* range of intelligent, uninterruptible power supplies. The *Interface Expander* module enables one ups to handle three different servers, which may be running different operating systems. On power failure, the *Expander* signals each server to shut down gently, tells the ups to start battery conservation and then manages each system's reboot when mains power is restored. *Measure-UPS* monitors ambient temperature and humidity within set limits and uses other sensors to detect fire, unauthorised access, etc. The *Remote UPS Management Device* uses a modem to control the ups remotely and to initiate tests, dialling two pagers if anything is amiss. *Relay I/O Module* allow control and monitoring via a dry contact interface, the format used by pbx and alarm makers. Vero Electronics Ltd. Tel., 01703 266300; fax, 01703 265126.



Thermal cut-outs. Texas Instruments' range of *Klixon* bi-metallic thermal trips now includes 2mm and 8mm versions with very reliable snap-action silver contacts. The smaller one can be installed in cavities in transformers and motors and has a layer of epoxy resin to protect it against transformer and motor impregnations. Rated at 3A and 7A, the larger type works over the 70-160°C temperature range in 5°C increments at a tolerance of ±5°C. Steatite Power Ltd. Tel., 0181 778 6611; fax, 0181 778 7722.

Protection devices

Low-*C* transient suppressors. Semtech offers the *LC03-6* transient voltage suppressor, which has a peak pulse power of 360W for a pulse width of 10ms and is designed to protect devices connected to ISDN interfaces and high-speed data comms lines from voltage surges caused by discharges, fast transients and lightning-induced spikes. Operating and clamping voltages are 6V and 12V and the design, consisting of a tvs diode and bridge rectifier, affords transient protection in both common and differential mode in the one device. Peak pulse current is 30A, leakage current 5μA and operating temperature –55°C to 150°C. Capacitance is 30pF. Semtech Ltd. Tel., 01592 773520; fax, 01592 774781.

Switches and relays

Separate membrane switches. From EAO-Highland comes the *Series 70* range of pcb-mounted pushbuttons and spacers in the form of discrete membrane units, from which can be assembled a complete membrane switch panel, coloured caps and multi-chip or T1 led backlighting being available. EAO-Highland Electronics Ltd. Tel., 01444 236000; fax, 01444 236641.

Photo-interrupter. Isocom's *ISTS802* optical interrupter has a 5mm wide slot for the opaque object to pass through and a light aperture of 0.5mm. Switching time is typically 3μs. There is a number of case styles with either pins or flying leads, special designs being made to order. Isocom Components Ltd. Tel., 01429 863609; fax, 01429 863581.

Television components

Wireless cctv. Radio Data Technology announces its *VideoWave* hand-portable viewer/receiver for surveillance work and for setting-up procedures with the *VideoWave* wireless transmission system. It needs no licence for use in the UK and works indoors or outside with no need for line-of-sight transmission paths. Features include signal scrambling and low power, a battery pack or lighter socket providing sufficient. The detachable viewer screen is a 2.9in lcd with a removable light shield. Radio Data Technology Ltd. Tel., 01376 501255; fax, 01376 501312.

Transducers and sensors

Sensor interface. Industrial sensor interface *MCA7707* provides programmable analogue signal conditioning for silicon piezoresistive

Please quote *"Electronics World"* when seeking further information

sensors. It will calibrate and compensate transducers, several at a time if required, to better than ±0.1% total error over the industrial temperature range and, in conjunction with an eeprom, store the calibration data and link to a pc via a parallel port. Both analogue and digital outputs are provided for pressure and temperature, a frequency output being obtained by using an external custom gate array. FET Electronics Ltd. Tel., 01635 524490; fax, 01635 552244.

Signal-conditioned accelerometer. Possibly the smallest conditioned dc-response accelerometer available, the *Model 3255* from AG&G IC Sensors contains a micro-machined accelerometer die and an asic for signal conditioning, all in a 16-pin surface-mounted ic. In three versions handling ±50g, ±250g and ±500g, typical sensitivity is 40, 8 and 4mV/g respectively at bandwidths of 2kHz, 3kHz and 3kHz. A self-test pin is provided, an electrostatic force moving the mass to simulate an acceleration. Over-range stops are built in. Eurosensor. Tel., 0171 405 6060; fax, 0171 405 2040.

Optical encoders. Control Transducers offers the *MD Series*, a series of modular optical shaft encoders to detect position, speed and direction of movement, which are intended to supply feedback for position control in mechanical positioning equipment such as hydraulic presses or antenna positioning. Line counts are 96-2048 pulses per revolution, dual-channel, with or without index pulse and a line driver for long cable runs is available. The encoders, which have internal signal conditioning, are 25mm or 50mm in diameter and will take up an axial shaft play of ±0.25mm without damage. There is a variety of mounting accessories. Control Transducers. Tel., 01234 217704; fax, 01234 217083.

Hall sensor gives direction. Allegro has a family of Hall-effect sensors that provide contactless speed and direction sensing. *A3420/1/2* contain two latches, the Hall elements being spaced 1.5mm apart. Each latch independently detects the ambient magnetic field to give high or low outputs, a subsequent logic circuit providing the direction signal. Latching means that the action requires a field reversal to operate, giving clean and positive switching. The chips contain internal voltage regulators for both analogue and digital circuitry. Allegro MicroSystems Inc. Tel., 01932 253355; fax, 01932 246622.

Dual thermostat chip. Two thermostats sharing one sensor in National's *LM56* operate from a 2.7V supply and need 230μA of quiescent current. The device contains a temperature sensor, two comparators and a reference in the one 8-pin ic, three external resistors serving to set up trip points from –40°C to 125°C. An additional analogue output provides 6.25mV/°C with good linearity. Hysteresis over the whole range is 5°. Applications will include the control of system fans. National Semiconductor GmbH. Tel., 0049 1805 32 7832; fax, 0049 814103515.

Small speakers. *Kingstate* miniature waterproof speakers have Mylar cones, a rated input of 0.5W and come in impedances in the 8-500Ω range. In a number of frame styles, sizes are from 20mm to 50mm diameter, frames being in metal or ABS, 5mm in depth, some cased for pcb mounting. There are units for voice to 4kHz or for full-range working up to 9kHz. Roxburgh Electronics Ltd. Tel., 01724 281770; fax, 01724 281650.

Vision systems

Conference camera. *eaZy* is a colour ccd camera for video conferencing (conferring?) that gives video and audio output to interface to MPEG or similar computer cards. Resolution is 320 000 pixels from a 0.25in ccd sensor through a 4mm, f3.8 lens with a built-in colour filter. It works in light levels from 10lux, 500lux being recommended, and there is an auto-white balance and electronic shutter with speeds from 1/50s to 1/120s. Voltage requirement of 5V can be obtained from the host in most cases. Premier Electronics Ltd. Tel., 01922 634652; fax, 01922 634616.

COMPUTER

Computers

Reconfigurable hardware. Embedded Solutions announces its first product, the *Accelerator*, which can be used to increase integer performance of processors, to provide customised interfaces to external devices, for prototyping and evaluation or for building scalable computing systems. Its main feature is the use of two field-programmable gate arrays instead of a conventional processor, an approach that offers the possibility of reorganising the hardware in a different configuration. Two Xilinx field-programmable gate arrays are connected to each other and to a daughter board, the connector to which may be used to interface the board to input/output devices or to make network interfaces between Accelerators and other devices. A companion communications board allows connection to transputer networks, converting an OS serial link to two parallel buses, linked to as many Accelerators as necessary. Embedded Solutions Ltd. Tel. and fax; 0118 9771682.

Data acquisition

Anti-alias cards. From Laplace Instruments, the *AAF-16* 16-channel anti-alias filter card for data acquisition using a pc. Filters can be specified as Bessel, Butterworth, Cauer or linear phase types, depending on the application, roll-off being up to 120dB/octave for the Cauer. Cut-off frequency is programmed from the pc from 2Hz to 50kHz or 100kHz, depending on filter type. Single-ended inputs are at 2MΩ impedance and the input range is ±10V, with protection to 120V rms and 250V for 5s. An optional daughter board provides protection against clock aliasing. Software supplied includes Windows in its various incarnations and Dos programs for setting key parameters and drivers compatible with Visual Basic, Visual C++, C and Pascal; drivers for LabView are also available. Laplace Instruments Ltd. Tel., 01692 500777; fax, 01692 406177.

Data communications

Data/fax modems. *ClipperCom World* by Apex Data is a PC Card data and fax modem providing 33.6kb/s V.34 performance with MNP2-4 and V.42 error correction, and MNP-5 and V.42.bis data compression. Software included allows faxes to be sent directly from applications and to be scheduled for later transmission, faxes being sent and received in the background. The card is compatible with many notebook computers and with Windows 3.X, 95, NT Workstation, OS/2 and Dos. DIP Systems. Tel., 01483 202070; fax, 01483 202023.

Data logging

Black box for vehicles. *RoadRecorder* is a video logging system for buses, trains, police cars, etc., that collects relevant data in much the same way as does the flight recorder found in aircraft. Video and other types of data are logged and saved to hard disk to provide information on accidents or crime. On buses or trains, it is envisaged that there may be several video cameras inside and around the outside to provide internal security and to deter vandals. There could also be one pointed forward to record what happens in accidents. A GPS navigation and location device might be integrated with the system. Visimetrics UK Ltd. Tel., 01436 677557; fax, 01436 672131.

Multimedia

Web guide to CE marking. If, after reading leaflets, books and posters, watching videos and using computer programs, you are still baffled by CE marking, you can now catch it all on the Worldwide Web site of the Assessment Services. It shows which Directives apply to common products, although "...obviously the list is not exhaustive.". Highlighting a product brings up the Directives for that product and what you have to do to make sure it conforms to Holy Writ. If you already know which Directives are relevant, you can see more information on any of six specific Directives applicable to most electrotechnical products. You can also ask questions by e-mail. To see all this try http://www.neag.co.uk/cgi-bin/ce-mark.cgi "and get in the fast lane to compliance". Assessment Services' Tel., 01329 443350; fax, 01329 443421.

Computer security

Computer safe. If a technically inclined tealeaf is intent upon stealing a computer's memory, nothing will stop him, but the *Armagard* family of computer safes will at least give him pause for thought; the Crown Jewels spring to mind. Latest in the range is the one for Mini Tower pcs; the computer cowers inside a 2mm thick steel box that has a seven-lever mortice lock. The whole thing bolts to the desk, has an inset door with concealed hinges, is of welded construction and is fitted with dog-bolts so that the door cannot be removed without unlocking it. There is a brush strip for cables at the rear, ventilation is taken care of and a fan can be fitted. Computers up to 350mm high, 220mm wide and 500mm deep fit inside and stay there while working. Intek Electronics Ltd. Tel., 01352 810603; fax, 01352 810403.

Software

Efficient C compiler. Version 4 of Cosmic Software's C cross compiler for 68HC11 microcontrollers is source-code-compatible with earlier versions but has a new C driver structure for multipass processes, new unified compiler options and a 32-bit internal data structure for unrestricted development of new code optimisation. There is also a new C parser for optimisation before compiling. The company says that Version 4 is a virtually new package, methods used in earlier ones having reached a limiting point. This one is said to produce the most efficient code for the 68HC11. Included in this full ANSI C package are a macro assembler, linker, librarian, object inspector, hex file generator, object format converters, debugging support, a royalty-free run-time library source code and a multipass compiler command driver. Cosmic Software. Tel., 0118 9880241; fax 0118 9880360.

Software verification for VME. In its latest version, CodeTEST from AMC is applied to VMEbus system software for test and analysis. *CodeTEST-VME* will trace the code execution of a cpu or follow the workings of several cpus via VME system trace. The package consists of a single-slot 6U board, plugging into the VMEbus backplane, and application software modules for in-circuit verification of software performance, memory allocation analysis and deep trace capability; it runs on H-P and Sun workstations and pcs running Windows 95 or NT. Applied Microsystems Corporation Ltd. Tel., 01296 625462; fax, 01296 623460.

Waveform analysis. For use with its dsos, data acquisition systems and recorders, Gould has introduced *ProView*, an analysis and report generating package. Its features include display and manipulation facilities, a search function for points of interest in waveforms and a document composition tool to assist in making reports. The package is to be used with the company's *Transition 2, View II or View-to-ASCII* linking software to connect ProView with digital storage oscilloscopes or to signals on disk and memory cards in recorders and data systems. Analysis includes a variety of statistical and mathematical functions and those in the frequency domain. Gould Instrument Systems Ltd. Tel., 0181 500 1000; fax, 0181 501 0116. ■

DIFFERENTIAL THERMOSTAT KIT Perfect for heat recovery, solar systems, boiler efficiency etc. Two sensors will operate a relay when a temp difference (adjustable) is detected. All components and pcb. £29 ref LOT93

MAGNETIC RUBBER TAPE Selfadhesive 10 metre reel, 8mm wide perfect for all sorts of applications! £15 ref LOT87

MAINS POWER SAVER UK made plug in unit, fitted inseconds, can reduce your energy consumption by 15%. Works with fridges, soldering irons, conventional bulbs etc. Max 2A rating. £9 each ref LOT71, pack of 10 £69 ref LOT72

YUASHA SEALED LEAD ACID Batteries, ex equipment but ok bargain price just £5.99 each ref YA1. 100 or more £3.50 each.

DC TO DC CONVERTERS
DRM58 input 10-40vdc output 5v 8A £15 DRM128 input 17-40vdc output 12v 8A £18 DRM158 input 20-40vdc output 15v 8A £18 DRM248 input 29-40vdc output 24v 8A £12 DRS123 input 17-40vdc output 12v 3A £10 DRS153 input 20-40vdc output 15v 3A £20 DRS243 input 29-40vdc output 24v 3A £8

HITACHI LM225X LCD SCREENS 270x150mm, standard 12 way connector, 640x200 dots, tec spec sheet, £15 each ref LM2

VARIABLE CAPACITORS Dual gang, 60x33x45mm, reduction gearing, unknown capacity but probably good quality (military spec) general purpose radio tuner. £9 ref VC1

ELECTRONIC FLASH PCB Small pcb fitted with components including a flash tube, Just connect 12vdc and it flashes, variable speed potentiometer. £6 ref FLS1

THIEF PROOF PEN! Amazing new ball point pen fitted with a combination lock on the end that only you know! £2.49 ref TP2

JUMBO BI COLOUR LEDS PCB with 15 fitted also 5 giant seven segment displays (55mm) £8 ref JUM1

HOME DECK CLEARANCE These units must be cleared! leads, a n infra red remote qwerty keyboard and receiver, a standard UHF modulator, a standard 1200/75 BT approved modem and loads of chips, capacitors, diodes, resistors etc all for just £10 ref BAR33.

6.8MW HELIUM NEON LASERS New units, £65 ref LOT33

COINSLOT TOKENS You may have a use for these? mixed bag of 100 tokens £5 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 experimental 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 Minature solid state system turns speech sound into indecipherable noise that cannot be understood without a second matching unit. Use on telephone to preventthird 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.

BURNING, CUTTING CO2 LASER PLANS Projects an invisible beam of heat capable of burning and melting materials over a considerable distance. This laser is one of the most efficient, converting 10% input power into useful output. Not only is this device a workhorse in welding, cutting and heat processing materials but it is also a likely candidate as an effective directed energy beam weapon against missiles, aircraft, ground-to-ground, etc. Particle beams may very well utilize a laser of this type to blast a channel in the atmosphere for a high energy stream of neutrons or other particles. The device is easily applicable to burning and etching wood, cutting, plastics, textiles etc £12/set Ref F/LC7.

MYSTERY ANTI GRAVITY DEVICE PLANS Uses simple concept. Objects float in air and move to the touch. Defies gravity, amazing gift, conversation piece, magic trick or science project. £6/set Ref F/ANT1K.

FRUIT POWERED CLOCK Just add a fresh orange, tomato, banana or any other fruit plug in the probes and the clock works! £9.95 ref SC154

DYNAMO FLASHLIGHT Interesting concept, no batteries needed just squeeze the trigger for instant light apparently even works under water in an emergency although we haven't tried it yet! £6.99 ref SC152

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.

ULTRA HIGH GAIN AMP/STETHOSCOPIC MIKE/SOUND AND VIBRATION DETECTOR PLANS Ultrasensitive device enables one to hear a whole new world of sounds. Listen through walls, windows, floors etc. Many applications shown, from law enforcement, nature listening, medical heartbeat, to mechanical devices. £6/set Ref F/HGA7

WOLVERHAMPTON ELECTRONICS STORE NOW OPEN IN WORCESTER ST TEL 01902 22039

ANTI DOG FORCE FIELD PLANS Highly effective circuit produces time variable pulses of accoustical energy that dogs cannot tolerate £6/set Ref F/DOG2

LASER BOUNCE LISTENER SYSTEM PLANS Allows you to hear sounds from a premises without gaining access. £12/set Ref F/LLIST1

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.

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.

MEGA LED DISPLAYS PCB fitted with 5 seven segment displays each measuring 55 x 38mm. £5 ref LED5.

MOD TRANSMITTING VALVES 5J180E £80 ref LOT112

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). £15 ref LOT135

HYDROGEN FUEL CELL PLANS There is a lot of interest in using Hyrogen as the fuel of the future, Hydrogen is easy to produce using chemicals and surplus solar generated electricity. It is also easy to store with little or no loss. Hyrogen fuel cells are designed to store hydrogen and weight for weight will hold twice as much energy as a full petrol tank. Our plans give you loads of information on Hyrogen production, storage and practical plans to build your own Hydrogen fuel cell! you will need access to a well equiped workshop for this but full construction details and drawings are included. Ful cell plans £9 ref HY1

VIDEO PROCESSOR UNITS?/6v 10AH BATTS/24V 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? 24v torroidlal transformer (mains in). sold as seen, may have one or two broken knobs etc due to poor storage. £15.99 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.

MAKE YOUR OWN CHEWING GUM KIT Everything you need to make real chewing gum, even the bowl and tree sap from the Sapodilla tree £7.99 ref SC190

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. £9 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! £15 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. £18 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. £17 Ref 1014.

4 WATT FM TRANSMITTER KIT Small but powerful FM transmitter, 3 RF stages, microphone and audio preamp included. £24 Ref 1028.

STROBE LIGHT KIT Adjustable from 1-60 hz (a lot faster than conventional strobes). Mains operated. £17 Ref 1037.

COMBINATION LOCK KIT 9 key, programmable, complete with keypad, will switch 2A mains. 9v dc operation. £13 ref 1114.

PHONE BUG DETECTOR KIT This device will warn you if somebody is eavesdropping on your line. £9 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! £12 Ref 1135.

3 CHANNEL LIGHT CHASER KIT 800 watts per channel, speed and direction controlssupplied 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.

HELPING HANDS Perfect for those fiddly jobs that need six hands, 6 ball and socket joints, magnifier. £7.99 ref YO57A

VOX SWITCH KIT Sound activated switch ideal for making bugging tape recorders etc, adjustable sensitivity. £10 ref 1073.

PREAMP MIXER KIT 3 input mono mixer, sep bass and treble controls plus individual level controls, 18vdc, input sens 100mA. £15 ref 1052.

SOUND EFFECTS GENERATOR KIT Produces sounds ranging from bird chips to sirens. Complete with speaker, add sound effects to your projects for just £9 ref 1045

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

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. £45 ref NIK39.

Minature adjustable timers, 4 pole c/o output 3A 240v,
HY1230S, 12VDC adjustable from 0-30 secs. £4.99
HY1260M, 12VDC adjustable from 0-60 mins. £4.99
HY2405S, 240v adjustable from 0-5 secs. £4.99
HY24060m, 240v adjustable from 0-60 mins. £6.99

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

COMPOSITE VIDEO KIT. Converts composite video into separate H sync, V sync, and video. 12v DC. £12.00 **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 FLY TRAP 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, £55 ref MAG45.

ELECTRONIC ACCUPUNCTURE KIT Builds into an electronic version instead of needles! good to experiment with. £9 ref 7P30

SHOCKING COIL KIT Build this little battery operated device into all sorts of things, also gets worms out of the ground! £9 ref 7P36

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! £8.99 ref R/9.

COMPAQ POWER SUPPLIES WITH 12V DC FANS Ex equipment psu's, some ok some not but worth it for the fan alone! probably about 300 watt PC unit with IEC Input. £3.50 each ref CQ1

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

MEGA LED DISPLAYS Build your self a clock or something with these mega 7 seg displays 55mm high, 38mm wide. 5 on a pcb for just £4.99 ref LOT16 or a bumper pack of 50 displays for just £29 ref LOT17.

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SMT20000/3 3-24vdc operation, 28-280vac 3A £4.50

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CIRCLE NO. 108 ON REPLY CARD

CD Jitter bug

Chris Daly believes that his enhancement to the interface between a cd player's transport and its d-to-a converter improves sonic performance by reducing problems associated with signal jitter.

All compact-disc player transports incorporate a processing ic that reads the eight-to-fourteen modulation, or efm, signal. This chip provides the Sony/Philips digital-interface format, of SPDIF, signal as one of its many outputs. It also interfaces with either a combined oversampling d-to-a converter or to a separate oversampler and converter.

Jitter in the interface data stream produces clock jitter at the d-to-a converter, degrading the audio quality[1]. The way that the processor interfaces with the oversampler and converter is the topic of this discussion. I will outline a new method of conveying the digital information providing improved integrity relative to the accepted SPDIF standard.

Individual signals involved are data, bit-clock and left/right clock. Manufacturers name these signals with some uniformity. The Burr-Brown *DF1700* application data is useful in this regard.

The advantage of my new method is that the identity of each clock signal can at last be properly recognised. I am not the first to provide an alternative method. One of the earliest references I can recall is Stan Curtis of Cambridge, who provided such an enhancement in the *CD1* player.

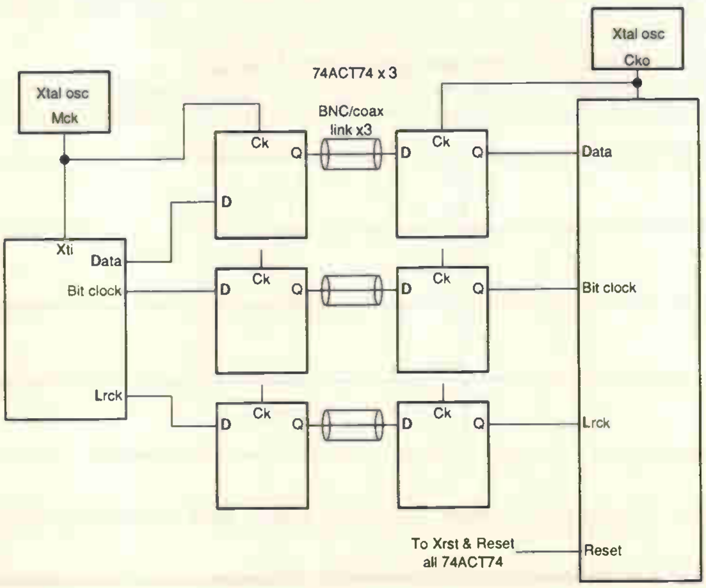
The above-mentioned signals feed from the processor ic of the cd player/transport to the oversampling ic. In the case of the main bit clock signal, this travels back from the oversampling ic to the processor. All the signals travel over circuit-board tracks with a length of between 20 and 50mm and can become corrupted.

Using interpolation improves signal integrity. D-type bistable ics can be seen as single-sample interpolators. The method is to use the existing clock in the player/transport to clock the processor. Each of the three *74AC74* bistable devices is arranged to interpolate the bit clock, the data signal, and the left/right clock relative to the existing clock. Output Q of the aforementioned bistable ics then exits the player using rf terminations. It is advisable to use Van den Hul *D300 MKIII* coaxial cable with good BNC or TNC plugs and sockets.

On arrival at the digital-to-analogue convertor, these same signals need terminating again. The data signal, bit clock and left/right clock signals enter the data inputs of 74AC74 bistables which have a clock reference from the Xti/Xto pin of the oversampling ic. This is usually available via a buffer, for example at pin 9 of the Burr Brown *DF1700*.

Finally, the signals exits at the Q output of each bistable device to interface with the oversampling ic inputs, called bit-clock input, data input and left/right clock input.

Reset of all bistable devices and reset of oversampling ic are returned to the XRST line of player. The 'set' inputs of the bistables are held high and the ground of the player and d-to-a converter are linked.



Linking the modification

Some 70% of cd player transports are Sony types and hence similar. Within these, 330 to 470Ω resistors usually interface each signal to the player's digital filter. These provide easy access to the signals. It is advisable branch the signals to the input of the bistable devices with a similar value resistor.

Usually, the clock signal feeds the cd-player transport's digital filter, which then outputs to the decoder's XTAI input. Once again, this signal is usually resistor coupled and similar branching can be used to couple the signal to the bistable ic clock inputs.

Connection into the d-to-a converter requires either removal of the digital receiver or breaking of the bit clock, data and left/right clock connections feeding the digital filter. Often, the receiver is a *CS8412*.

The prescribed modification no longer involves decoding of a clock signal. As a result, it is necessary to provide a *74AC04* clock driver to drive XTI of the digital filter. Alternatively, the digital filter's XTI/XTO and clock output (CKO on the Burr Brown *DF1700*) facilities could be used to drive the bistable ic clock inputs.

Both of the above methods require a crystal for the digital filter operating at $256f_s$, i.e. 11.2896MHz, of $384f_s$, or 16.9344MHz.

In my experience the enhancement works exceptionally well. My cd player is a Pioneer *701, Audio Synthesis DSM UA.* ■

Reference

1. Fourre, R., What is jitter, *Stereophile*, October 1993.

Programmable logic

Geoff Bostock looks at the most popular language used to describe logic systems – VHDL – and discusses how schematics are turned into code for programmable devices.

Hardware description languages, or HDLs, are a more generalised method of describing the behaviour of logic systems than logic equations. However, they do embody some of the characteristics of logic and state equations. In this next section, I concentrate on one particular language – VHDL.

This language is becoming an industry standard, spurred on by MIL STD 454L, which requires all ASIC designs for the USA Defense Department to be documented in this language. It was devised as part of the VHSIC, or very high-speed integrated circuit, project to allow complex ASICs to be specified and simulated without reference to any specific technology. Having specified a circuit in this way, it should be transferable to any process or manufacturer with guaranteed reproducibility.

VHDL, an abbreviation derived from VHSIC HDL, describes logic systems from a top-down architectural standpoint. A system is visualised as a set of 'black boxes', called entities, with a set of interfaces. Top level entities may be broken into successively less complex functions until the bottom level is reached; this may be a gate-level description of the function.

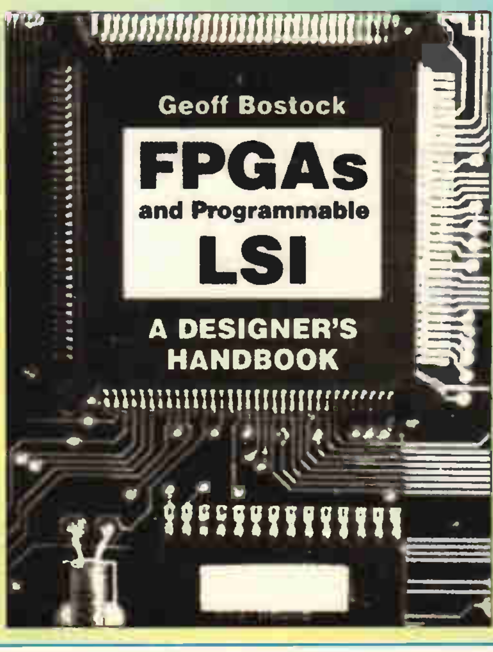
Because each level of the logic hierarchy is specified uniquely, each may be simulated to check both syntax and logic function. The lowest level may be validated first so that a completely tested system is built from the bottom up. This is followed by a synthesis step which translates the whole design to the logic cell level after which it is simulated at gate level with built-in timing parameters.

This hierarchical design allows whole systems to be defined without specifying technology, or even partitioning into devices. The whole process is akin to designing software in a high-level language, with the low-level entities playing the same role as subroutines. A complete system may be defined and then tested without specifying a target device. The modules are designed separately and may be stored and used over again in future designs; in effect a library of functions is generated for re-use in new designs.

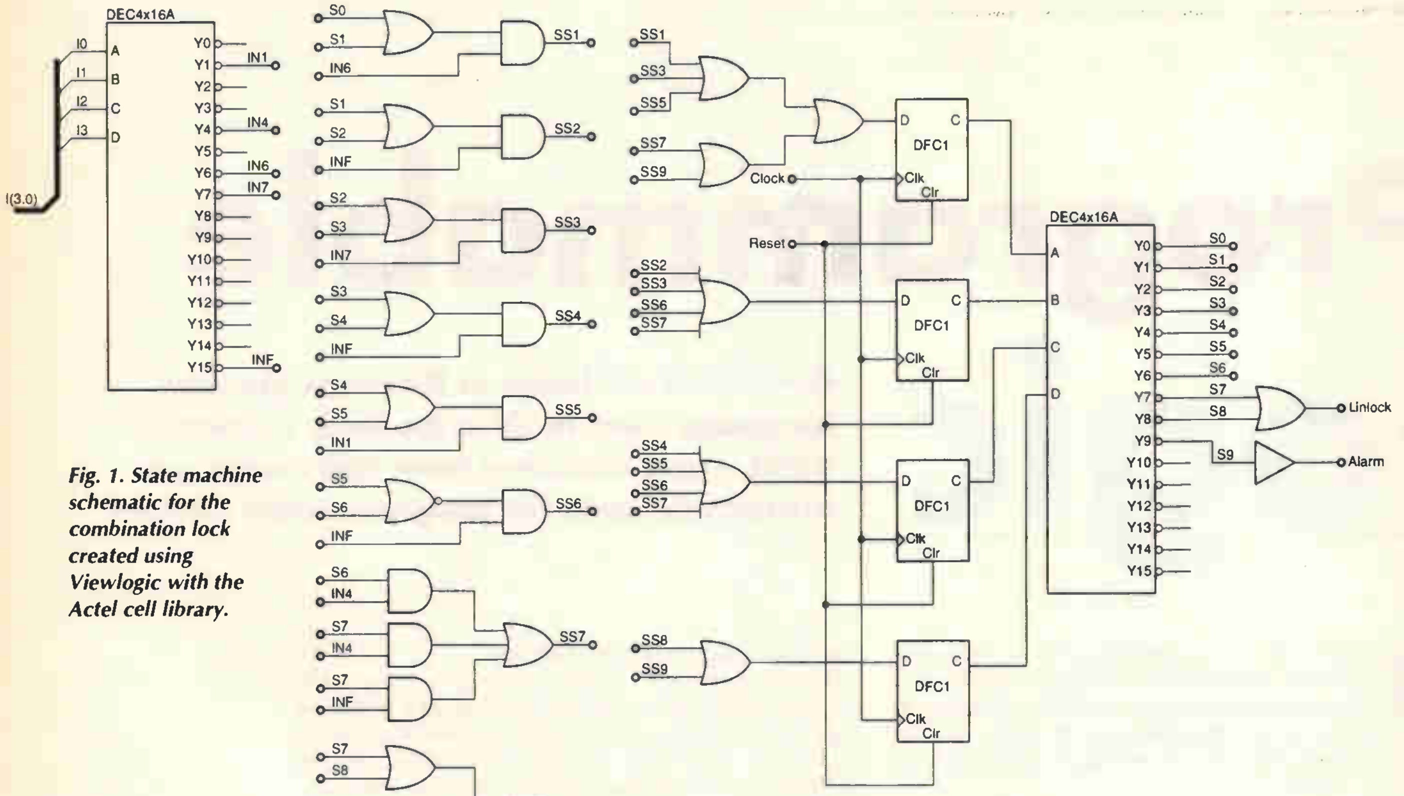
VHDL logic specification

Examples of VHDL definitions can show the difference between basic equations and HDL constructs. A four-bit

This article is derived from Geoff Bostock's new book 'FPGAs and programmable LSI – a designer's handbook'. The 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.



Geoff Bostock runs his own FPGA/PLD Design Consultancy, and may be contacted on 01380 828241, or by e-mail at geoff.bostock@zetnet.co.uk



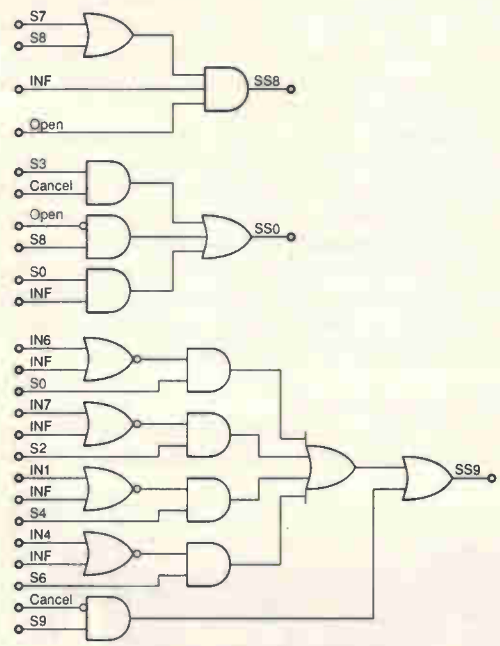


Fig. 1. State machine schematic for the combination lock created using Viewlogic with the Actel cell library.

adder may be defined as follows,

```
entity ADDER4 is
   port( A,B: in INTEGER range 0 to 15;
      C: out INTEGER range 0 to 15 );
end ADDER4;
```

The entity section defines the signal interfaces and sizes. Defining a range of 0 to 15 implies that each signal has four bits. It must be followed by an architecture section to define the logic relationship between the signals. This may be written as:

```
architecture BEHAVIORAL of ADDER4 is
begin
   C<=A+B;
end BEHAVIORAL;
```

The type of architecture, in this case BEHAVIORAL, is arbitrary as it is ignored in the compilation process; it is good practice to make it relevant to the way in which the architecture is being defined. Here, we are using a high-level description which will be understood during simulation but might need synthesising at a lower level to achieve a good performance.

Lower level definition is generally specified as rtl, or register transfer level, which does not need to involve registers. The '<=' symbol represents the function 'signal assignment'; in the adder, the value of A+B is transferred to C.

In a multi-transfer definition all assignments are made concurrently. VHDL differs from software programming languages in this respect; in a programming language, the order in which commands are written defines the order in which they happen, in VHDL the simulator assumes that all signal transfers are simultaneous, except where sequential processes are defined.

A multiplexer specified to operate as a discrete logic '157 type illustrates the structure of an rtl function definition,

```
entity MUX157 is
   port( A, B: in BIT_VECTOR( 0 to 3);
      G, SEL: in BIT;
      Y: out BIT_VECTOR( 0 to 3));
end MUX157;
architecture RTL of MUX157 is
begin
   Y<= '0' when (G= '1') else
   B when (G= '0' and SEL = '1') else
   A
end ;
```

In order to specify state machines it is necessary to invoke sequential statements which occur within a process. The process itself is concurrent because it may be called at any time, when one of its signals changes. Essentially, a state machine consists of two parts – a sequential part which defines the ability of bistable devices to change state, and a combinatorial part which defines the signals offered to the bistable device as a function of present state and inputs.

List 1. Code for combination lock logic.

```
entity DOOR_LOCK is
    port ( OPEN, CANCEL in bit;
        CLOCK, RESET in bit;
        I in BIT_VECTOR (3 down to 0);
        UNLOCK, ALARM out bit) [
end DOOR_LOCK
    architecture RTL of DOOR_LOCK is
    --double hyphen is VHDL comment syntax
    --now define internal signals which are not signal ports
    --by first defining types for the state signals
type StateType is (S0, S1, S2, S3, S4, S5, S6, S7, S8, S9);
    --then we define the signals we are going to use
    signal State, NextState: StateType;
    begin
        SEQUENCE: process ( CLOCK, RESET)
        --this defines a process called SEQUENCE which is
        --invoked whenever there is a change in the value
        --of CLOCK or RESET
        begin
            if (RESET = '0') then
                State <= S0;
            --then we define a rising clock edge by
        elsif (CLOCK'event and CLOCK = '1') then
            State <= NextState;
        end if;
    end process;
    --we can now define the state jumps as a
    --combinatorial process
        COMBINATORIAL: process (I, OPEN, CANCEL, State)
        begin
            --assign default output levels
            UNLOCK <= '0';
            ALARM <= '0';
            case State is =>
                when S0=>
                    if (I = 6) then
                        NextState <= S1;
                    elsif (I/= 6 and I/= 15) then
                        NextState <= S9;
                    end if
                when S1=>
                    if (I = 15) then
                        NextState <=S2;
                    end if
.
.
.
                when S9=>
                    ALARM <= '1';
                    if (CANCEL = '1') then
                        NextState <= S0;
                    end if;
            end case;
        end process         ;
end RTL;
```

The door lock described in the May issue may be specified as in **List 1**. This listing is the complete specification for the door lock function. A function of this size would normally form only part of a complete fpga so the above would be just one entity of a total design listing.

Having defined a logic entity it may be used as often as desired within the whole design. Each use of the function is given a unique name and referred to this specification. This process is called instantiation because each time the logic module is called up it forms an instance of that logic.

It is usual to verify each entity individually before connecting them together in the top level design. This requires a simulation routine to be devised and written, as described in the next section.

Simulation with VHDL

In order to simulate an entity – or a complete design – a test bench must be created. The syntax for this is similar to the syntax for specifying logic entities. For example, the entity declaration will be:

```
entity TEST_DOOR_LOCK is
end TEST_DOOR_LOCK;
```

This defines the test bench because it has no ports, only signal drivers. The architecture must define the signals, components and stimuli. It does this in the same way as in a logic architecture, **List 2**.

Finally, the results must be written to a file so that they can be examined to assess whether the simulation has achieved the desired result. VHDL includes a standard package – TEXTIO – to manage this function.

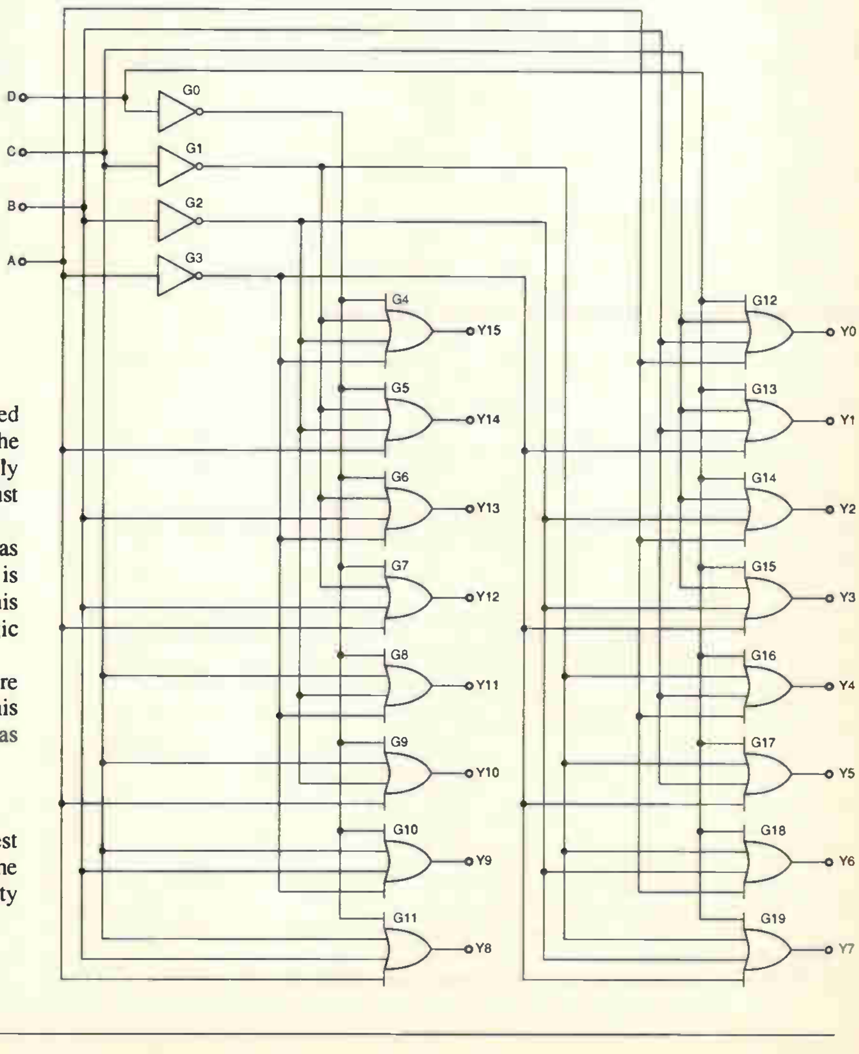
Capturing circuit schematics

Schematic capture is probably still the most popular method of defining logic for field-programmable gate arrays, and many ASICs. It is a computer-aided design system dedicated to logic design.

Logic functions of complexity ranging from an inverter to multi-bit counters are stored in a library which describes both their functions and a graphical symbol. The designer calls up the symbols from the library, places them on the screen of a pc or workstation, and connects them with wires and busses.

The design is taking place on two levels. At the visual level the designer is creating a visual

Fig. 2. This is the schematic of the decoder at the top left corner of Fig. 1. Showing this much detail on the main diagram would make the whole difficult to interpret.



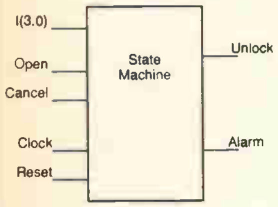


Fig. 3. State machine symbol providing an overview of the combination lock function.

representation of the logic which he requires, in terms of familiar symbols for the components. At a level below this is a net list which defines the location of each component on the screen, and the way it is connected to the other components in the design.

Hierarchical design is still possible, indeed necessary, for all but the simplest of circuits. This can be illustrated via the door lock function used previously.

Figure 1 shows how the state machine may be drawn up. This schematic was created using *Viewlogic* with the Actel cell library, but a similar result would be obtained with other capture packages and manufacturer's libraries.

The schematic may be broken into four parts which just fit on to a single sheet of the capture display. On the left is a decoder. This is a standard Actel macro and generates the individual number inputs from the four-bit input line. The decoder schematic can be seen at a lower level of hierarchy; there is no need to draw the gate-level function on this sheet as the function of the block is clear. Replacing the symbol with the gate schematic, as in **Fig. 2**, would make the picture less clear.

Note that the outputs from the decoder have been labelled INl, IN4, etc., to indicate the number being input; note also that they are active low.

A second decoder on the right-hand side generates signals to indicate the present state of the state machine. These are labelled S0, S1, S2, etc., to correspond to the state numbering already used.

These signals are also active-low. Although the decoder function was pre-defined, by using it twice it only needs defining once. As a general point, any block of circuitry which is used in more than one location need only be defined once, but used in as many locations as desired.

Outputs from the state machine are generated from the state signals on the right-hand side of the drawing. The block of gates in the middle of the schematic form the combinatorial section, defining the jump conditions from each state. They have been arranged to generate a 'next state' signal for each state. The jump to S0 is, in fact, superfluous since the state register is fabricated from D-types which set low in the absence of an input when clocked. It is included in our schematic for completeness although it would be automatically excluded at the place and route stage when components with 'dangling outputs' are eliminated.

Because the input and state signals are active-low, most of the gate inputs are 'bubbled'. Although a NOR gate with inverting inputs is logically equivalent to an AND gate, the bubbled input gates are used for clarity. For example, the top function says that state S1 is entered when a '6' is input in either state S0 or S1 – the hold condition.

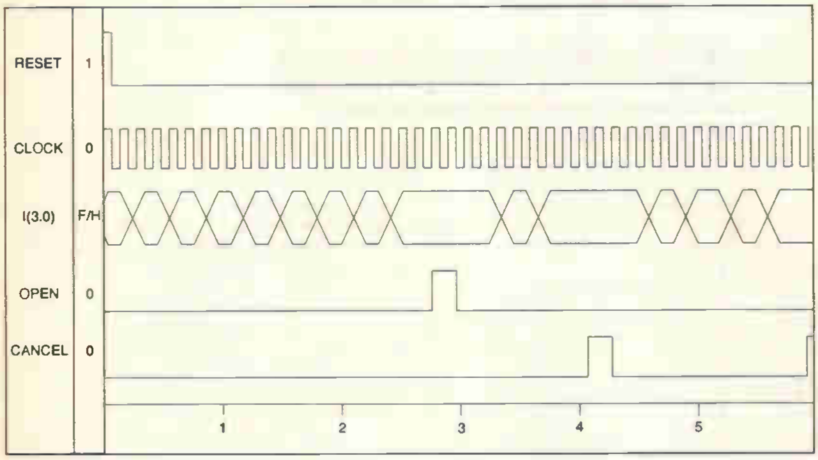


Fig. 4. Waveforms involved in the combination lock system.

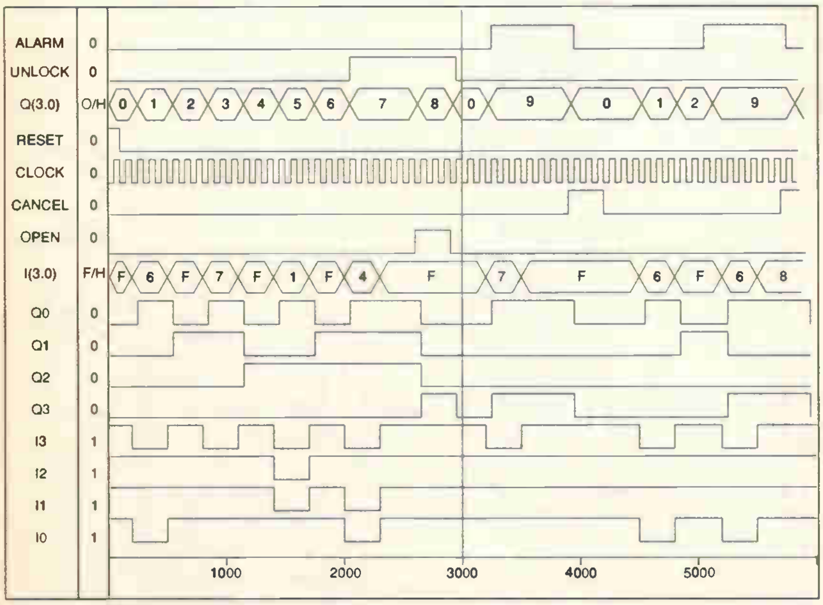


Fig. 5. Display of simulation results for the combination lock detection system.

List 2. With VHDL, in order to simulate a design, a test bench needs to be created. This example is for a combination lock.

```
architecture TEST_BENCH of TEST DOOR_LOCK is
    signal CLOCK: Std_Ulogic := '1'; -- defines '1' as
    --the initial level
    signal RESET: Std_ulogic := '0';
    signal OPEN: Std_Ulogic := '0';
    signal CANCEL: Std_Ulogic := '0';
    signal I: Std_Ulogic_Vector (3 down to 0) := '1111';
    signal DOOR: Std_Ulogic;
    signal ALARM: Std_Ulogic;
    constant CLK_PD: Time := 100ns;
    constant RST_PD: Time := 50ns;
    --Std_Ulogic type of signal allows bit definitions
    --such as 'undefined'
    --'don't care', and 'tri-state' as well as '0'
    --and '1', and give more information
    --in a simulation result.
    component DOOR_LOCK
        port (
            CLOCK: in Std_Ulogic;
            RESET: in Std_Ulogic;
            OPEN: in Std_Ulogic;
            CANCEL: in Std_Ulogic;
            I: in Std_Ulogic_Vector (3 downto 0);
            DOOR: out Std_Ulogic;
            ALARM: out Std_Ulogic
            );
    end component;
        begin
    DOOR_LOCK
        port map (
            CLOCK→CLOCK, --explicitly maps a
            --signal to a port
            .
            .
            );
    TB: BLOCK
    begin
        CLOCK <= not (CLOCK) after CLK_PD/2; --defines
        --10MHz clock
        RESET <= '1' after RST_PD;
        I <= 6 after 1µs, 15 after 2µs,
        7 after 3µs, 15 after 4µs, 1 after 5µs -- etc.
        .
        .
    end BLOCK TB;
```

List 3. Part of the net list for the combination lock illustrates the structure used to store the design information.

```
DEF DOORLOCK; IN3, CANCEL, OPEN, IN0,
        CLOCK, RESET, IN2, IN1,
UNLOCK, ALARM.
USE ADLIB: INBUF; $1I6.
USE ADLIB: INBUF; $1I5.
USE ADLIB: OUTBUF; $1I11.
USE ADLIB: INBUF; $1I9
USE ADLIB: INBUF; $1I8.
USE ADLIB: INBUF: $1I7.
USE ADLIB: INBUF; $1I3.
USE ADLIB: CLKBUF; $1I10.
USE ADLIB: INBUF; $1I4.
USE ST_MACH; $1I2.
USE ADLIB: OUTBUF; $1I12.
NET $1N13; $1I11:D, $1I2 :UNLOCK.
NET $1NI5; $1I2:ALARM, $1I12:D.
NET $1N22; $1I2:OPEN, $1I7:Y.
NET $1N24; $1I2:CANCEL, $1I8:Y.
NET $1N26; $1I2:RESET, $1I9:Y.
NET $1N28; $1I2:CLOCK, $1I10:Y.
NET ALARM; ALARM, $1I12:PAD.
NET CANCEL; CANCEL, $1I8:PAD.
NET CLOCK; CLOCK, $1I10:PAD.
NET IO; $1I2:IO, $1I6:Y.
NET I1; $1I2:11, $1I5:Y.
NET 12; $1I2:I2, $1I4:Y.
NET 13; $1I2:13, $1I3:Y.
NET INO; INO, $1I16:PAD.
NET IN1; IN1, $1I5:PAD.
NET IN2; IN2, $1I4:PAD.
NET IN3; IN3, $1I3:PAD.
NET OPEN; OPEN, $1I7:PAD.
NET RESET; RESET, $1I9:PAD
NET UNLOCK; UNLOCK, $1I11:PAD.
END.
```

The gate inputs are all labelled with the appropriate signal names. Connections do not have to be made with actual wires on the screen; if two nets are labelled with the same name they will automatically be connected in the net list. The converse is also true; wires which must not be connected must have different names. Thus 'S1' has been used for a present state output but 'SS1' for a next state input.

The final section of the state machine is the state register and encoder. A full priority encoder is not needed to drive the state register because, if the logic is designed correctly, only one next state signal is active at any one time. Thus Q3 of the register must be set high by SS8 or SS9, Q2 by SS4, SS5, SS6 or SS7 and so on.

The schematic was generated in the order in which it was described, except that a symbol was created first. This is shown in **Fig. 3**, and could be used to define the state machine in a higher level of hierarchy; possibly, it could be incorporated into a single fpga with a keyboard encoder, to form a complete system.

Part of the net list is shown in **List 3**: this is not intended to convey any information, except as an example of the structure used in saving the design information, and to show that while the drawing serves as a primary human interface, the net list is in a form easily read by a computer.

Generating and simulating waveforms

Having constructed a logic circuit on paper, it is necessary to show that it fulfils the desired function.

Just as the circuit was drawn on the screen, at the same time generating an underlying net list, so a set of test waveforms in 'oscilloscope format' can be constructed. Simultaneously, a command file to drive the simulator can be produced. **Figure 4** shows the door combination lock.

First, a 10MHz clock is generated, together with the power-on reset to initialise the circuit to state S0. Input starts at 'F'; changing it to '6' should change it to S1, and stay in S1 until

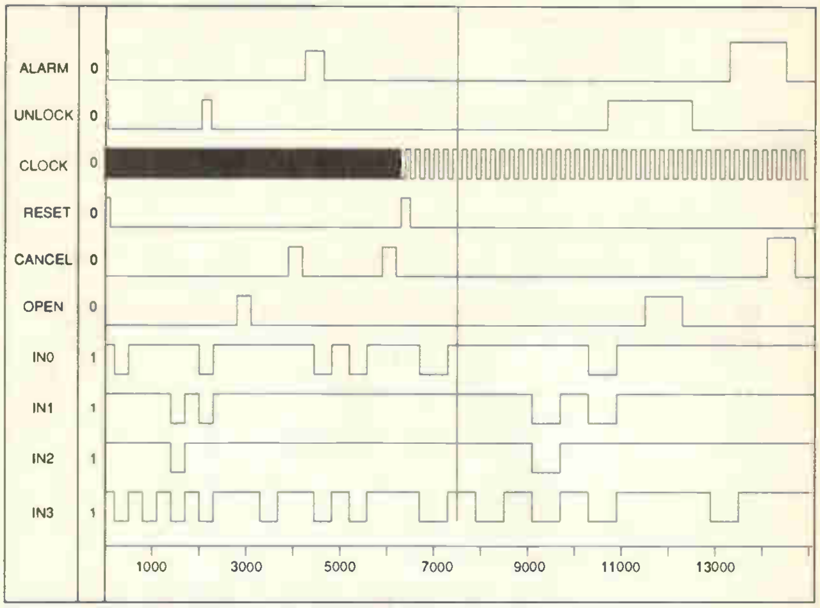


Fig. 6. Post-layout simulation of the combination lock detector. Until the clock is slowed to 5MHz, just to the left of the centre line, the circuit does not function properly.

the input changes back to 'F'. The sequence should run through the states until the door is unlocked, then simulate the door opening and closing, and finally return to S0.

Changing the input to '7' should set the alarm, in state S9, returning to state S0 on activating CANCEL. You can then go on and simulate any number of wrong entries – only one more is illustrated – to prove the complete functionality of the circuit.

The waveform may also be defined in a command file and checks included to ensure that the circuit operates as intended. The format for this is:

```
vector INPUT I[3:0]
| this defines the signals forming the input
vector
vector STATES Q[3:0]
| this defines the state outputs
vector SIGNALSIN RESET OPEN CANCEL INPUT
vector SIGNALSOUT UNLOCK ALARM STATES
| initialize the system
restart
wave DOORLOCK.WFM clock input states
        signalsin signalsout
| this defines the signals for display
wfm CLOCK 0=0 (500=1 500=0) *60
| this defines 60 cycles of 10MHz clock
        (500x0.1ns LOW, 500x0.1ns HIGH)
break CLOCK 0 do (assign SIGNALSIN<APPLIED;
        +check SIGNALSOUT < TESTPATT)
sim 60000
```

We then have to set up the applied vector pattern in file 'APPLIED' and the test pattern in file 'TESTPATT'. These will be as follows for APPLIED:

```
4F\h
0F\h
06\h
06\h
0F\h, etc.
```

and for TESTPATT:

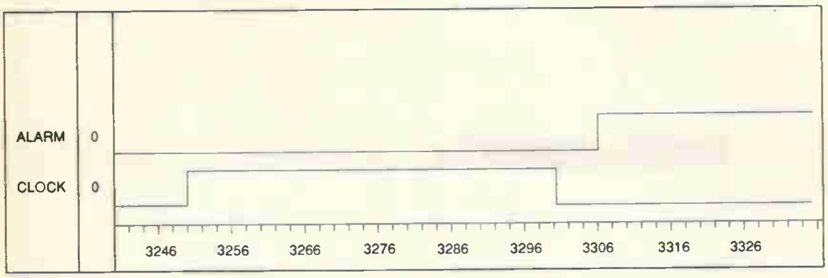


Fig. 7. Exploded section of the simulation Fig. 6 allows detailed examination of timings and delays.

```
>00\h
00\h
00\h
01\h
01\h
02\h...
```

Figure 5 shows the result of the simulation. The next step is to assemble the logic net list into a real device, using the place-and-route program. Estimated timings may now be inserted into the net list and the circuit resimulated to gauge its probable performance. In our case the circuit does not behave properly, however, if we slow the clock to 5MHz as in the right-hand part of **Fig. 6**, correct operation is restored. It appears that the circuit delays prove too great for the 100ns clock period.

By zooming into part of the waveform we can obtain a good estimate of real circuit delays. **Figure 7** shows the delay between the active clock edge and the alarm output; you can see that this is about 56ns, for four logic levels plus input and output buffer. As the loop round the state machine is between six and nine levels deep, it is possible for problems to arise with a 100ns clock period.

In summary

Various methods exist for defining the logic for fpgas. Schematic capture is probably the most popular because this has been promoted by both device manufacturers and software providers. It also produces an output which looks most like a designer's mental picture of a logic system.

VHDL is derived from logic equation/state equation entry, which was the standard method of defining logic for 20/24-pin plds. However, it has a syntax which is closer to a software programming language so it should be easy to migrate from software to hardware design. It also has the benefit of being a universal language which is not targeted at any particular device manufacturer or product.

Both approaches have the capability of fitting a top-down design hierarchy. Both also allow for individual testing of the component modules before they are connected into a final structure. Most design systems cater for a mixed design approach, where some parts of the system may be defined in VHDL, the entities then being represented by symbols which can be connected together in a top-level schematic.

Whichever approach is used, the basic pattern is the same – logic entry, then logic simulation, followed by device definition and logic synthesis. Once the chip is laid out and routed, the estimated delays can be back annotated to the simulation and real performance forecast. Proper use of the design tools leads to a solution which meets the original design specification. ■

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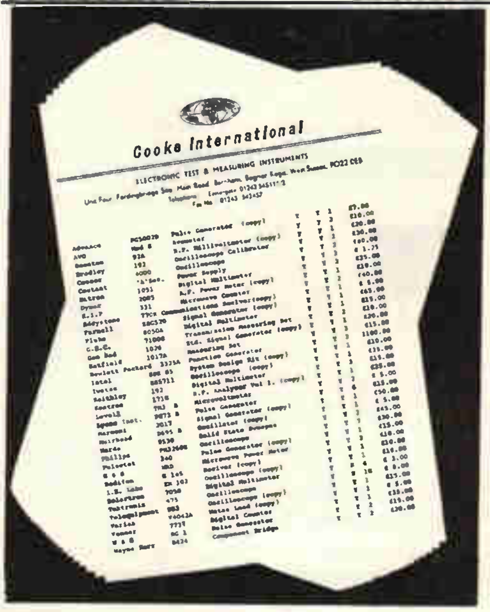

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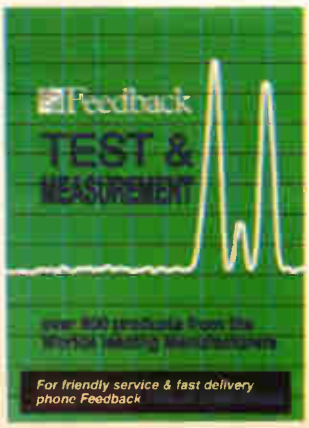

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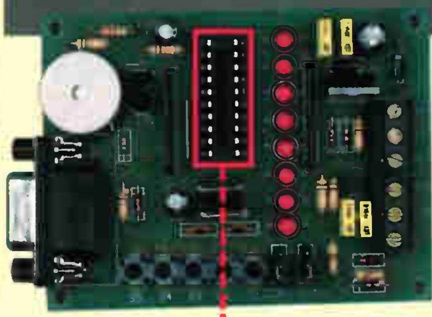
RAM (bytes)	128	256	256	256	256	64	128
EEPROM	-	-	-	2K	-	-	-
In-system re-programmable	-	-	-	YES	YES	-	-
I/O Pins	32	32	32	32	32	15	15
16-bit Timer/Counters	2	3	3	3	3	1	2
Watchdog timer	-	-	-	YES	YES	-	-
Interrupt sources	6	8	8	9	9	3	6
Serial UART (full duplex)	YES	YES	YES	YES	YES	-	YES
SPI Interface	-	-	-	YES	YES	-	-
Analogue comparator	-	-	-	-	-	YES	YES
Data pointers	1	1	1	2	2	1	1
Package Pins (DIL)	40	40	40	40	40	20	20

C51 Microcontroller Starter System



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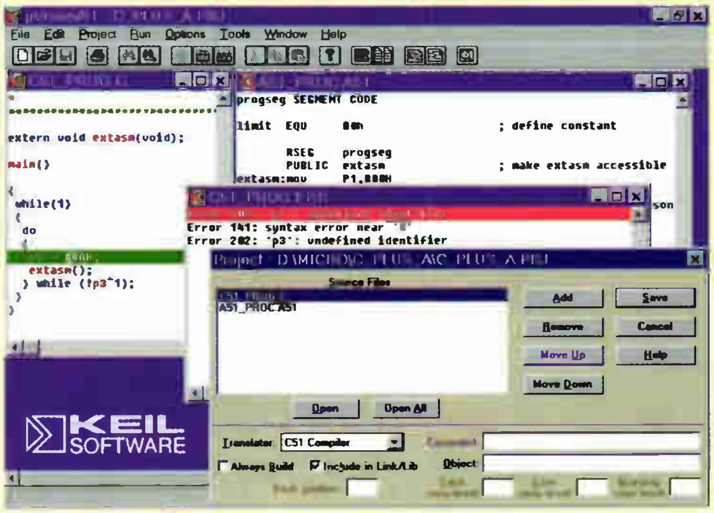

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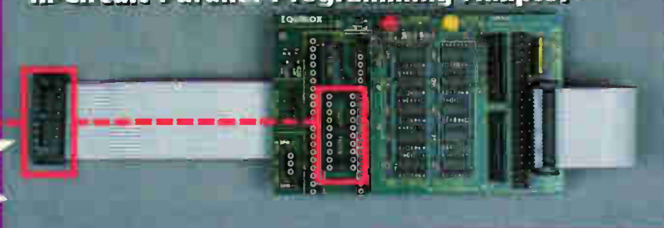

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