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COVER: THE DESIGN REVOLUTION

Ten years ago technologists predicting the information explosion realised that communication would be impossible without innovative RF technology, operating in untapped parts of the spectrum. In a new series, Tim Stanley looks inside the latest generation of semiconductor devices to find the RF revolution.

ALL POWERFUL – OR ALL TOO MUCH

For PCB cad, P-Cad does everything. But John Anderson wonders if you can have too much of a good thing.

BEHAVIOURAL MODELLING WRAPPED UP IN A BLACK BOX

Basim Al-Hashimi shows how behavioural models of analogue circuits are developed and uses an AM mod/demod system to illustrate some of the models available.

GENUINE SOLUTIONS TO SPURIOUS ARGUMENTS

In the third part of his series of articles on DDS, Ian Hickman puts spurious signals under the microscope.

WHY CAVENDISH KEPT “COULOMB’S” LAW A SECRET

Henry Cavendish experimentally proved "Coulomb's" law before Coulomb. Leonid Kryzhanovsky suggests why he kept the work to himself.

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Filtering can cut out the input components which cause A-to-D aliasing errors. David Mawdeswy demonstrates why choice is a matter of compromise.

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Pat Hawker reports on the eye hazards of handhelds and the RF exposure puzzles that still remain.

In next month's issue: Field programmable gate arrays will become as important to design engineers as TTL logic did 20 years before. FPGA provides a flexible and reprogrammable alternative to TTL. Learn about it here.

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Did you watch the science documentary series *Life on Earth*? Of course you did. Make the most of it because no science based documentaries are likely to be made on this scale again. Not my warning but that of Sir David Attenborough, delivering the presidential address at this year’s meeting of the British Association for the Advancement of Science. Sir David warned that ITV early evening schedules are to be regraded for mass audience with a single bottom line of viewing figures: “No programme will be shown in the evening before 10.30 pm unless it can command a minimum guaranteed audience of at least 8 million.” That means that from next year onwards, no serious science programmes will be shown on independent television at times that most people are able to see them” said Sir David.

While I would be the first to agree that television (anc electronic magazines) should, in general, be entertaining rather than overtly educational, the demotion of science from peak viewing times will do nothing to help the cultural role that science and technology should fulfill in an advanced society.

And it is not just ITV which denies science a place in the living room. BBC current affairs output is highly regarded. But does it deserve this regard? If the Pound loses half a Pfennig against the Deutschemark, does it deserve this regard? If the Pound loses half a Pfennig against the Deutschemark, programme producers will wheel in an industrial editor to comment on the effects of a possible interest rate rise on ‘industry’, a financial editor to comment on stock market reaction, a political editor to comment on the (usually) predictable mutterings from government and opposition benches, a foreign affairs editor to comment on the EC perspective and, finally, a home affairs editor interviewing the chairman of a building society.

Compare this with media coverage of IBM’s announcement that it had developed a scanning, tunnelling electron microscope, at its Zurich research facility. Consider the manner in which the BBC reported news of an instrument that gives us direct 3-D sight of atoms in a lattice, a development so important that it will permanently change our view of materials for solid-state physics and biochemistry. I don’t think that there was any.

We now live in a country built from, and surrounded by, science and with little culture of its understanding. Indeed, there is almost an anti-culture. How many times have you heard the Great and the Good publicly boasting of their incompetence with household technology?

But there are worse things than being governed by terminally stupid people. Ask sixth form pupils about their career ambitions. Top of the list will be law, medicine, media, public relations and accountancy. Middle ranking interests include business and financial services. Chemistry, physics and maths are seldom the preferred choice.

There is a real possibility that physics will disappear from the UK entirely. University science places, particularly those in physics, are available with bargain basement A-level grades; funding rules are now strictly tied to capital which means that university science departments are having to maintain their facilities on a shrinking budget while arts departments prosper.

The importance of science to society must be recognised. It seems unlikely that we shall be able to maintain our living standards based on an education system which produces only lawyers and hairdressers.

Frank Ogden.
Engineers shift their footing

A fundamental restructuring of the engineering profession has been proposed. It represents the latest thinking of the Steering Group set up at the beginning of this year under the chairmanship of Sir John Fairclough, Chairman of the Engineering Council. Its thoughts were circulated this week to the engineering institutions, The Engineering Council and the Royal Academy of Engineering in a consultation paper.

The document considers the formation, role and organisation of a new single body to act as a focal point for the engineering profession, including Chartered Engineers, Incorporated Engineers and Engineering Technicians. The steering group has considered the relationship between a new single body and the institutions, selection of members for the new body, the registration of engineers and the relative merits of a statutory or non-statutory system.

The new single body will subsume The Engineering Council either by reforming it or replacing it, so forming a new relationship with the engineering institutions.

An alternative to one single body would be formation of a collegiate structure in which groups of institutions form intermediate bodies between the individual institutions and the central organisation. While this would support effective decision-making by focusing responsibility for sectoral issues directly onto the appropriate organisations it would introduce an extra layer of bureaucracy into the current two-tier system of Council and institutions.

Responses to the consultation document are now being sought and must be submitted by November 10, 1992. They will help the Steering Group prepare an interim report due to be submitted to the Council of Presidents of the Institutions early next year.

Shades of Dan Dare and the Mekon.

A talking head that appears out of a desk is just one of the futuristic ideas in telecommunications being researched at BT Laboratories, Martlesham near Ipswich, for business life in the 21st century.

The head is part of the Future Desk which may replace the familiar constructions of wood and metal with screens and surfaces capable of achieving 3D videoconferencing through holographic projections of a human being.

The Future Desk is just one of the concepts being pioneered by a group of technical and scientific experts in the systems research division who are working as a think tank for combinations of telecommunications technology that can be applied to the future.

Transistors to replace magnetrons?

Philips Semiconductors has developed a microwave power transistor capable of producing a 750W output pulse for radar transmitters. Designed for class-C operation, the MX1011BY700Y runs from a 50V collector rail and is characterised for a duty cycle of one per cent. It should reduce the output transistor count in airborne and vehicle radar systems operating between 1030 and 1090MHz. The associated gain is 6.3dB.

IBM to end PC manufacture?

US computer giant IBM is expected to announce plans to turn its $7bn PC and workstation systems manufacturing business into a separate subsidiary. Industry analysts say this will allow the computer maker to cut costs in its PC operation dramatically.
US opens up for space telephones

US plans for satellite-based mobile telephone systems cleared a regulatory hurdle last month but there is still a lot of work to be done to demonstrate the technical feasibility of the low earth orbit satellite systems.

The US regulatory authority, the FCC, has granted licences to three companies for trials using the 1610-1626.5MHz and 2483.5-2500MHz bands agreed at WARC this year.

But one of the licence holders Motorola-backed Iridium, which plans to launch its systems.

First five satellites in 1996, has modified its backed Iridium, which plans to launch its systems.

null

Single chip GPS?

Single chip microwave receivers are about to slash the cost of high accuracy satellite based global positioning system technology.

Motorola has plans for a single chip GPS receiver next year.

According to a spokesman in the company’s RF group the design of the downconverter chip will need at least two more iterations before it can be combined with an LNA into a single device.

The chip will take unidirectional or bidirectional signals from the GPS antenna and deliver a demodulated signal at baseband which can be processed to extract the positioning information. The accuracy of the system is defined by the signal generated by the GPS satellites. This is better than 100m for civil applications.

GEC Plessey Semiconductors is also expected to announce a GPS chipset two or three ICs before end of the year. Engineering samples of a two-chip GPS design are already being evaluated by UK companies. The two chips are a 1.575GHz low noise amplifier (LNA) and a dedicated GPS downconverter.

Current GPS receivers use discrete components and custom hybrids. They are about the size of a personal stereo and cost around $500. Single chip designs could drive prices below $100 which opens up mass market applications in car navigation and electronic security systems. More than one European cellular telephone maker is investigating the incorporation of a GPS receiver in its handsets.

BiCMOS boost

IBM is developing a bicmos process which it hopes will double the performance of its current bicmos lines. The bipolar transistors in IBM’s current lines have a cut-off frequency of less than 20GHz whereas the new process will allow frequencies up to 60GHz. Furthermore, the cmos section will be built on a 0.25μm process, instead of the current 0.5μm geometry.

An IBM spokesman said that this should double the switching speed of the cmos. He claimed that the new technology would be superior to gallium arsenide in all aspects including speed and density. First production will appear by 1995.

Richard Wilson, Electronics Weekly

Optical radar provides night picture

A laser radar that can spot power lines in the way of low-flying military helicopters is being developed as part of an Anglo-French research project.

British radar maker GEC-Ferranti Defence Systems and French firm Dassault Electronique are believed to be collaborating on the project, reportedly called Clara, to demonstrate a helicopter based optical-wavelength scanning radar.

Optical lasers have several advantages over infra red and millimetric systems. The most important is that laser light is easier to steer using conventional mirror optics which are also highly compact. A rapidly scanning pencil-beam laser radar system can provide television quality night vision systems for helicopter pilots; computerised image processing highlights hazards.

Laser radars use little power and allow fine beam, precision measurement at short ranges. Atmospheric absorption -- basically clouds and fog -- makes them of little use for long range air-to-air detection. But radar makers can exploit this to provide stealthy protection and prevent the enemy detecting the laser beam from afar.

The project will build on technology previously test flown by GEC Avionics.

A question of image: Rock Band Genesis on its latest US tour using three Sony Jumbotron screens, each measuring 5.6m high by 3m wide and weighing six tonnes, to ensure fans can both see and hear.
Dianagate raises questions of technology and law

The widely publicised telephone conversation alleged to have taken place between Princess Diana and an admirer has alerted the general public to the risks of saying anything private, personal or secret on any phone which relies on a radio link. It may also prompt the police and government to use existing laws to protect privacy.

Cellular phones are inherently insecure, as are most cordless phones that are used around the home and garden. For less than £200, anyone can buy scanners which allow them to listen to and record conversations. Eavesdropping on radio phone calls has now become a hobby.

None of the companies or government bodies involved – British Telecom (owner of Cellnet), Vodafone, Oftel, Scotland Yard, the Department of Trade and Industry, and Home Office – has taken responsibility for the problem. They argue that users of radio phones should always be aware of the inherent lack of security.

Both Cellnet and Vodafone now acknowledge that it is possible to eavesdrop on calls. “It is not illegal to buy or sell the equipment,” says Cellnet, “and the law on use is unclear.”

Under the Telecommunications Act, the Wireless Telegraphy Act and the Interception of Communications Act, electronic eavesdroppers can be jailed for up to two years. But the acts have seldom been used to curb such eavesdropping. The papers which have published transcripts of the “Diana” tapes, and made them available by telephone to inquisitive readers, have now pushed the law to new limits.

Britain’s two cellular phone networks currently work with analogue frequency modulated speech signals at frequencies of around 900MHz. The inherently more secure digital GSM standard systems are not yet available, and neither are they likely to be for a couple of years.

The cellular phone networks have played down the risk of eavesdropping with scanners, arguing that the two halves of a cellphone conversation, to and from the mobile phone, are carried on different radio frequencies. Also, these frequencies change as the caller moves between cells served by different transmitters.

In 1989 there was a spate of newspaper articles on eavesdropping, revealing what equipment is needed and how much it costs. An eavesdropper with a single-frequency receiver can hear both halves of a conversation because the cellphone call passes through the public telephone network, which provides a sidetone so that both callers, on a conventional or a cellular phone, can hear in their earpiece what they say into their mouthpiece.

The radio cells in an urban area may be only a few kilometres wide, so the frequency of a moving cellphone will switch every few minutes. Cells in rural areas are much larger because they need to cater for fewer simultaneous calls. So when a scanner locks onto a conversation it will hold it for much longer.

Barry Fox, New Scientist.

Intel processor gets speed boost

Intel is now delivering a 66 MHz 486 DX2 processor chip. Systems using it with a 33 MHz system clock can execute their applications, on average up to 70 percent faster than systems using a 33 MHz 486 DX CPU.

The 486 DX2 family operate at an internal frequency that is double the rest of the system. The company has already shipped some 300,000 50MHz DX2 chips.

The technology operates by doubling the external system clock signal it receives through the system bus and providing the internal 2x clock signal to on-chip sub units. As a result, blocks such as the CPU and cache can run at a 2x internal clock rate to execute instructions.

The CPU operates at maximum efficiency when incorporated with fast design elements such as second-level cache, burst memory controllers and write buffers. For example, second-level cache helps eliminate wait states by providing the CPU’s on-chip cache with a high-speed pool of data. If an application or operating system causes the microprocessor to access off-chip data, the second-level cache can supply the data immediately rather than forcing the chip to wait for slower system memory to provide the data.

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- Set break points
- PC drivers available
- On-screen disassembly of code
- PC host software communicates via serial port

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Physicists at Stanford University in California claim to have measured the gravitational constant with unprecedented accuracy using "fountains" of atoms chilled to within a few millionths of a degree absolute. The procedure is complex, but the principle is simple: if you cool an atom, then by definition you reduce its random motion. That in turn allows more time to observe its critical parameters and make accurate measurements of its behaviour. Since almost all fundamental physical quantities, such as frequency and time, are based on atomic measurements, a cool atom is an accurate atom.

Most of us, when we want to cool something down, immediately think in terms of extracting energy using a freezer or some other sort of heat pump. But when physicists want to cool something to within a fraction of a degree above absolute zero, different techniques are called for. They mostly now make use of intersecting laser beams to create what is irreverently called "optical molasses" or "optical goo" – a state where

Continued over page
OSCILOSCOPES

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RESEARCH NOTES

photons can absorb energy from atoms and trap them in what amounts to suspended animation.

Optical goo takes advantage of the fact that atoms absorb certain frequencies of light much better than other frequencies. A laser beam tuned to a frequency either side of those critical frequencies will not disturb the majority of atoms. But if an atom happens to be moving towards the laser source the Doppler shift raises the laser frequency slightly, making the atom more likely to absorb a photon of energy, which then slows down the atom. By directing six lasers into a small space, the Stanford group can slow down the random movement of atoms in any direction, thus cooling all the atoms present.

Stephen Chu, one of the team, says that if you drop an atom into the optical goo, within a few milliseconds it comes into thermal equilibrium and for all practical purposes stands still. When he first did that in 1985, the effective temperature of the atoms was a few hundred milliKelvin. Later experiments showed that it is possible to cool atoms to within a few microKelvin, that is as near to absolute zero as makes no difference.

The Stanford group have not only trapped sodium atoms at almost zero K, they have also manipulated them in space by adjusting the frequency of some of the laser beams. In one experiment Mark Kasevich lifted the atoms upward and was able to observe them in free fall, a sort of atomic fountain that lasted a whole second. Atoms at room temperature normally move at supersonic speeds, so to be able to watch them drifting around at about 2m/s is what Kasevich describes as a "new regime in atomic physics".

An atom chilled to near absolute zero accelerates under the influence of gravity and so the frequency of its energy levels gradually changes. By measuring this change for a whole second, Kasevich has been able to measure the force of gravity to within three parts in $10^9$. He and Chu expect to improve that precision to around one part in $10^{10}$ in the near future.

A portable gravity meter with the latter accuracy could measure changes in distance from the centre of the Earth to within a third of a millimetre; it could also detect underground anomalies such as water or mineral deposits with unprecedented ease.

Stable photo-conductive polymers

Materials developed at the University of Rochester, NY, and by a team at the Xerox Corporation could have implications for imaging technology. The new materials have formed the basis of the first patent application filed by the US National Science Foundation’s Center for Photoinduced Charge Transfer at the university.

Scientist Martin Abkowitz at Xerox has evaluated thin films of polymer, only a fraction of the thickness of a human hair, fabricated by Samson Jenekhe, associate professor of chemical engineering at the University of Rochester. The materials were found to be sensitive to the red light emitted by the solid-state lasers widely used in printers and in some electronic copiers. Any material that responds efficiently to light from such lasers is of particular interest for these imaging applications.

Experiments have shown that the polymers are robust and remain intact and stable up to hundreds of degrees, much higher than most photosensitive materials used in copiers and printers. Previously fabricated high-temperature materials have been very difficult to process into useful devices or thick films, but the latest ones are much easier to work with while still retaining their robustness.

The new polymers are example of photocconductors, materials that act as electrical insulators when kept in darkness, but which become conductors when they are exposed to light. Photocopiers, laser printers, solar cells and even the human eye are based on such photosensitive materials. In the field of imaging, photocconductors are used to create latent images in the form of electrical charge patterns.

Such a latent image is made by applying an electrical charge across the surface of a photoconductive material and then selectively discharging it with light focused by a lens or from a laser. The latent image is made visible when particles of toner – dry ink – are applied to the surface of the photoconductive material and then adhere to the charge pattern. This now-developed image is then transferred to paper and fused into the paper to make a permanent copy.

The polymers the University of Rochester and Xerox scientists are working on are double-stranded with molecular links between the strands. They are known as ladder polymers and include polybenzimidazoles, polybenzophenanthrolines and polyquinolines.

Xerox (Martin Abkowitz, left) and University of Rochester (Samson Jenekhe, right) laying the ground-work for new imaging technology.
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October 1992  ELECTRONICS WORLD+WIRELESS WORLD  803
Soldering techniques all in a flux

Scientists at Sandia National Laboratories in Albuquerque, NM are developing environmentally-friendly soldering techniques for producing electronic products without using ozone-destroying chemicals, principally CFC (chlorofluorocarbon) solvents. One of the main uses of CFCs at present is the cleaning of fluxes from printed circuit boards.

Today’s fluxes, usually rosin-based, are necessary to promote wetting of the base metal by the solder alloy. For solder to be drawn into the gap of the soldered joint and to make an effective bond, the metal surface and the solder must be free from oxide or other obstructing films. But fluxes have to be removed after they have done their job; otherwise there is a risk of corrosion or other obstructing films. But fluxes have to be removed after they have done their job; otherwise there is a risk of corrosion or other obstructing films.

Figures from 1989, the most recently available, indicate that globally more than 100,000t of the chlorofluorocarbon CFC-113 were used to clean fluxes from soldered printed circuit boards. That figure was approximately half the world’s annual consumption of CFC-113.

Researchers at Sandia’s Center for Solder Science and Technology are developing CFC-free, fluxless soldering methods that do not require the use of any CFC solvents. These methods involve the development of a number of different techniques including the use of controlled atmospheres, thermo-mechanical surface activation and protective coatings.

Controlled atmosphere soldering makes use of various “clean” or chemically-reducing atmospheres to maintain solderable surfaces. As well as the use of a vacuum these atmospheres include inert or reducing gases, reactive plasmas or dilute acid vapor/inert gas mixtures. In controlled atmosphere soldering, researchers have demonstrated that hydrogen plasma cleaning of heavily oxidized copper can produce oxide-free, solderable surfaces at temperatures below 250°C.

Thermo-mechanical surface activation soldering uses different forms of energy to break up the surface oxide and to facilitate wetting of the underlying metal. The use of lasers, solid-state diffusion and ultrasonics are typical ways in which this can be achieved. These thermo-mechanical processes can be done either in air or in a controlled atmosphere.

Using a laser, for example, Sandia researchers have developed a soldering process for making closure joints on radar modules. This fluxless soldering involves the melting of a pre-placed solder preform with a directed laser beam under a protective gas cover. Rapid heating and cooling of the soldered joint produces a very fine microstructure with improved mechanical properties.

The Center for Solder Science is also working with the University of California at Berkeley and the State University of New York at Stony Brook to develop protective coatings that enhance fluxless solder wettability. This involves studying the microstructure and fluxless wettability of nickel-gold platings and also the bonding behaviour of organic inhibitors on metallic surfaces and their effect on subsequent solder wetting.

A Sandia scientist inspects a printed circuit board produced through fluxless laser soldering. A laser soldering station is in the background.

Staring winkers open windows?

Scientists at Leicester University and De Montford University (formerly Leicester Poly) have developed a way of enabling severely disabled people to operate Windows programmes without the need for a mouse or a keyboard.

Ergonomist Howell Istance has made use of existing technologies that make a cursor move wherever the operator’s eyes are pointing.

Together with optometrist Peter Howarth, Istance has developed the art far beyond that of existing systems. These are mostly limited to distinguishing into which of four screen quadrants the eyes are looking. Such systems, as well as being relatively crude, also require specialised software. This has excluded a lot of disabled users from using much available computer software.

The Leicester equipment uses a Micromeasurements system 7000 binocular eye tracker, employing a pair of infra-red cameras that sample eye positions 60 times a second. As the eyes move up, down, right or left, the system records each eye position and sends the appropriate commands to the computer. The eye tracker can thus emulate a mouse and the cursor or pointer moves around the screen as the operator’s eyes move.

Emulating the movement of a mouse is one thing; the more difficult task has been to provide an eye-driven equivalent of the operate button. Peter Howarth says that he is currently working on two different approaches, one based on staring at the required icon for an unnaturally long time and the other based on winking at it. Normally when selecting items on screen, the eyes flick about continuously, and rarely settle anywhere for long. Howarth says that it is easy to simulate a command by winking, but recognising an unnatural stare (it also sounds a wonderful way of prompting operators who daydream).

The second approach is even more interesting. Since the eye tracker is a binocular system, it can be programmed to recognize differences between the movement of one eye and the other. Howarth says that, normally, we do not move our eyes independently. The system can therefore ignore a blinking (or sleeping) operator, but instantly recognises some unnatural eye movement such as a wink. (The mind boggles at what complications this could lead to in the average office.)

The accuracy of the system at present is such that a person can play a game called “Windows Solitaire” with little difficulty. For screen targets of 20 pixels high by 50 pixels wide, the system performance is comparable to that of a mouse. For larger targets it can be superior. The only snag, says Howarth, is that you have to keep your head reasonably still. That may be enough of a restriction to prevent the system coming into widespread use among able-bodied operators, but for those who are currently unable to operate any sort of machine, it could prove a godsend. The researchers are keen to hear from anyone interested in discussing potential applications.
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October 1992 ELECTRONICS WORLD+WIRELESS WORLD
Ten years ago, technologists were predicting an information explosion – not only an increase in information, but, equally, the means to communicate it. They envisaged that user freedom would require radio frequency technology operating in untried parts of the spectrum. But they needed a new generation of semiconductors to drive an RF revolution. A new design series by Tim Stanley.

**Modfets, GaAsfets, tegfets, beam lead diodes, planar doped diodes, mmics and asics are keywords in the revolution’s lexicon.** Some of these device types are effective at hundreds of GHz; millimetre-wave devices return noise figures measured as fractions of a dB. Multiple functions on a single chip have, in many applications, obviated much circuit design effort. For example, a complete, digital paging receiver will soon be offered using only two ICs.

This series will consider devices from the application viewpoint. It will include low-noise discrete radio devices; radio systems ICs and building blocks including digital signal processing; RF power devices; passive devices; asics, and other devices for special applications, such as animal tagging and some non-communication RF applications in medicine.

We start at the front end, with discrete devices for low-noise receiver applications.

**Modulation-doped field-effect transistors – modfets**

The modfet is the fastest three-terminal semiconductor device in the world. Also known as the high electron mobility transistor (hemt),
This Harris microwave gallium arsenide fet is the first in a series of standard fets optimised for Ku to Ka performance. At 18GHz, the n-channel HMF03400 offers 8.5dB typical maximum available gain (mag), 11dBm typical output power at mag tuning, 15dBm typical output power at 1dB gain compression and a typical 1dB compressed gain of 5.0dB. At 26GHz, a typical mag of 5.0dB is obtained selectively-doped heterostructure transistor (SDHT) or the two-dimensional gas field-effect transistor (tegfet) the modfet currently leads technology for lowest-noise microwave applications. Present-day performance delivers noise of 0.6dB at 60GHz; transition frequencies exceed 250GHz with 400GHz devices under development. But how is it done?

Gallium Arsenide fets have been with us for many years, a variant being the metal-on-semiconductor fet (mesfet) shown in Fig 1. This has been refined by reducing the gate length, using photo-lithography, to a practical limit of about 0.35µm. A noise figure of about 1.2dB at 12GHz is about the limit with this device. Electron beam lithography can further reduce gate geometry, but requires serially exposing each gate rather than a complete wafer, and therefore is not suitable for cost-effective mass production.

The modfet is a mesfet but with a very thin layer of electron gas between the AlGaAs and GaAs layers. This is achieved by constraining i.e. “modulating” the electrons in the gas by applying an external voltage across the heterojunction interface to constitute a “two-dimensional” electron gas, Fig 2. Hence the term modfet. This technique is more appropriate for high volume, low-cost production.

Figure 3 shows noise performances for two variants of modfet compared with the mesfet demonstrating the former’s superiority, particularly at millimetre-wave frequencies.

Beam epitaxy allows single crystals to be produced one layer at a time. This results in a barrier that is a single, high quality crystal rather than a relatively crude metal-semiconductor interface, eliminating many undesirable properties of Schottky diodes. This beam lead diode from GEC Plessey Semiconductors. requires just 280µW of LO power for maximum conversion efficiency.
Modfets as used in a front end radar system amplifiers for use on the proposed Polar Platform satellite POEM 1. Produced by Matra Marconi Space, it achieves a noise figure of 0.7 dB with 21 dB gain at 5GHz. The modfet is described by them as having demonstrated “excellent reliability for space-borne, low-orbit applications.”

Applications
DBS manufacturers have used the resultant improvement in receiver sensitivity to shrink dish size. The additional cost is about $2 to $5 for a packaged, 0.25μm gate length device. A low-noise down-converter by Matsushita, comprising a modfet followed by three GaAs L.C.s, achieves a system noise figure of less than 1.3 dB with an associated gain of at least 60 dB from 11.7 to 12.2 GHz.

Mitsubishi’s recommended line-up of its discrete devices for the same application is shown in Fig. 4, giving overall converter block noise figures from 0.8 to 1dB depending on the choice of the first-stage device.

The modfet is also a unique device for operation at low temperatures, where high electron mobility is achieved. During the Neptune flypast by Voyager II, workers at the National Radio Astronomy Observatory (NRAO) replaced the first stage of a three-stage 8.4GHz GaAs mesfet low-noise amplifier, operating at 15°K, with an AlGaAs/GaAs modfet, thus reducing the noise temperature of the LNA by a factor of two from 22°K to 11°K. This improvement allowed NRAO to accomplish the mission without the conventional helium-cooled maser technology.

Low-noise mixers – exit the Schottky?
The Schottky diode has a chequered history in two respects – the behaviour of practical devices has often been too variable for sustained agreement to be reached in understanding between theory and experimentation, and on the technological side, the sensitivity of the current voltage characteristics to the detailed fabrication conditions has been a persistent problem. A technique known as molecular beam epitaxy (MBE) can now produce single crystals an atomic layer at a time. This means that the active barrier is a single, high-quality crystal, rather than a relatively crude metal-semiconductor interface, with the result that many of the undesirable properties of Schottky diodes can be eliminated. Immediate advantages to the front end designer are lower noise and much lower oscillator drive level requirements.

An MBE structure of particular interest here is the planar-doped barrier diode (PDB), comprising a doping sequence of n-i-p-i-n layers. The p-layer is highly doped, but typically only about 30 layers thick. It attracts electrons to its acceptor sites, setting up a barrier to the motion of other electrons. An important char-

An engineer from Continental Microwave tests LNBs used in broadcast satellites. The popularity of the application has resulted in a mass market for GaAsfets, which has been instrumental in radically reducing production costs.
characteristic of a mixer diode is the tightness of the knee of the I-V characteristic around forward turn-on, which determines the mixing (and detecting) ability of the device.

Marconi Electronic Devices claims to be a world leader in this field, and a comparison of one of its PDB diodes with conventional Schottky is shown in Fig. 5. Of particular note is the low level of oscillator drive requirement – as low as 2nW for the minimum noise figure of 6dB as compared with about 1.3mW for a GaAs Schottky device. This reduction in LO drive has obvious advantages, not only in simplified oscillator stages but in reducing LO radiation. It appears that these PDB devices maintain the advantages over the more conventional types to about 100GHz.

Lowering the noise floor

Noise figure is usually the most critical parameter of a microwave receiver front end. It may be described as the ratio, in dB, of the degradation of signal/noise caused by the device:

\[ \text{Noise figure (dB)} = \frac{\text{signal at output}}{\text{signal at input}} - \frac{\text{noise at output}}{\text{noise at input}} \]

All units measured in dB

Looking at Fig. 3, we see that for, say, 20GHz, the noise figure of a GaAs mesfet is about 1.5dB, and for a modfet is about 0.5 dB. Hence, we might expect that the modfet device would give an advantage over the mesfet of about 1dB in noise figure, and hence of 1dB in signal/noise ratio at the receiver output (assuming the devices are similar in other respects).

However, this assumes that the input noise reference is that generated by a resistor at room temperature, i.e. 21°C which is 294°K. In practice, the actual source in a working system comes from the aerial and whatever noise it is picking up. The source noise from the sky is much less than 294°K at 20GHz for an aerial pointing skywards but not at the sun. It probably averages about 3°K. However, the aerial system itself is a noise generator, owing to the thermal movement of electrons in the aerial and feeder, etc. Some noise may also be picked up by side-lobes of the aerial (which is typically a dish at these wavelengths) from relatively warm objects such as the earth and buildings. It is difficult to predict what the equivalent noise temperature of an aerial system might be, but 100°K is a reasonable assumption.

We may recalculate the noise performance of the devices with reference to 100°K which gives new “noise figures” of 3.3dB and 1.3dB for the mesfet and modfet respectively. Hence, the advantage in this system would be 2dB (i.e. 58% as a power ratio) not 1dB (26%) as might have been assumed by simple comparison of conventional noise figures. The striving of the device designer for fractions of a dB in noise performance is more significant than initially meets the eye.

Even so, an advantage of 2dB may seem trifling. Perhaps so, if the circuit or system designer is concerned with a “one-off” radio link or small network. Consider, though, the cost savings in a large communications network such as a cellular telephone system, where a 2dB advantage in receiver sensitivity means that the transmitter output power rating can be 60% less (assuming no extraneous off-air interference) giving capital and running costs savings. Multiply these by the hundreds of transmitters required for national coverage, and the cost effectiveness of these modern receiver devices can be appreciated.

Consider, also, a radar system, where the high, and expensive, transmitter power requirement can be reduced by improved receiver sensitivity. Again, the cost advantage is obvious, particularly where supply power and aerial size may significantly be limited, such as in a satellite, or an airborne radar system. As Fig. 3 shows, the advantage of the modfet increases significantly with frequency.

Next month ICs at the front end.
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Improved preamps put dat back on the road

The new dat recording machines combine portability with high quality recording. But microphones used may be degrading the result. Adrian Pickering and Max Hadley investigate.

Digital audio personal-stereo-type machines can now offer high recording quality while on the move, with performances hitherto only achievable with professional quarter-inch recorders such as a Uher or Nagra. The dat recording format is stereo, 16-bit linear sampling at 48kHz, of comparable quality to CD. But, since almost all recordings made with a portable dat machine are likely to be from a microphone, the performance of the microphone preamplifiers becomes critical. Unfortunately, manufacturers have not paid as much attention to this as perhaps they should — the result is often a dat machine with recording quality degraded by microphone preamplifiers more suited to a good cassette recorder!

The solution is to substitute a better-quality microphone preamplifier. This is relatively straightforward if there are no constraints on power consumption or size. Clearly, the whole purpose of using a portable dat machine is its convenience, so any ancillary equipment must not cause compromises here. The requirement is for a compact dat-quality microphone preamplifier with a low power consumption.

Preamp requirements
The low-noise preamplifiers traditionally employed in microphone input transformers have many advantages, and provide a balanced input and excellent common-mode rejection. But they can be very susceptible to stray magnetic fields which are often encountered in "out-and-about" recording locations.

Compact transformers with a good AF response and immunity to external fields are expensive and so a transformerless design is to be preferred. A balanced input would be desirable, though not absolutely essential since the microphone lead is likely only 1-2m long. Microphone type does affect preamplifier design. Professional moving-coil microphones have low output levels. Commonly-available electrets give a higher output, but this is accompanied by their internal preamplifier noise.

Studio-quality capacitor microphones have high output levels and low noise, but are expensive and usually phantom-powered.

For portable use, powered microphones of any type are a nuisance as they need constant feeding with fresh batteries to assure an uninterrupted "take". So the moving-coil microphone still has much to commend it and the basic performance specification for the preamplifier thus emerges:

Low noise. The preamplifier should have the best noise and distortion performance attainable with the available power supply (see below). Resulting recordings should be at least as good as those made on portable quarter-inch recorders (typically, 60dB signal to noise ratio).

Gain. A typical professional 2002 moving-coil microphone in face-to-face interviews generates a signal level of about -65dBu. 0dBu (0.775Vrms, 1mW in 600Ω) is the standard line level for professional equipment. Taking into account the extra gain available from the dat line inputs, the preamplifier gain needs to be about 45dB. Any higher gain would reduce headroom and generate excess noise.

Output. The dat with its unbalanced line inputs is used right next to the preamplifier so
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that the output from the preamplifier can be unbalanced too.

**Power supply.** Difficult access to the dat power supply makes batteries necessary. There should be a single battery of a type commonly available from local shops and it should be replaced as rarely as possible. Equipment performance should gently degrade as the battery reaches the end of its life.

Users – radio journalists or electronic engineers – must have confidence in the equipment; conducting an interview can be stressful enough without having to worry about the equipment. Any doubts over reliability will lead to the machine rapidly being rejected in favour of equipment that worked before. Equipment must be robust and idiot-proof – and useable. However good the electronics, if equipment is difficult to use it will surely be discarded.

**Rotary switches.** Rotary switch types – least likely to be misoperated by something rubbing against the equipment – should show a clear indication of the position of the switch. If switches of any other type are used they should be guarded or stiff to operate.

**Minimise the number of connectors.** As the enclosure must be compact, small connectors and fragile, thin, cables are undesirable. Instead, robust leads should be wired direct from the enclosure and be long enough so that, during normal use, they plug straight into the microphone(s) via a locking XLR.

**Positive on/off indication.** A constantly-illuminated light should indicate that equipment is on and functional, and also helps to remind the user to switch the equipment off after use. The light should serve as a battery health indicator.

**Mono mode.** Most radio journalism is still in mono; it is a classic differential amplifier with the input resistors omitted and their function performed by the microphone source resistance, \( R_s \).

The LT1028 will operate at ±4.5V, which means it is possible to power it from a 9V battery. The specialised Analogue Devices SSM2017 microphone preamplifier performs no better but has significantly higher power consumption (10mA) and requires split supplies of ±2.5V – difficult to use with a single 9V battery.

In the circuit (Fig. 1), the LT1028 is used as a classic differential amplifier with the input resistors omitted and their function performed by the microphone source resistance, \( R_s \). Gain is inversely proportional to \( R_s \). Any resistances in the input generate their own thermal noise and should be avoided; any \( R_s \) is clearly unavoidable. The topology requires that the microphone be able to work into an (active) short-circuit.

It is a popular myth that all microphones must drive into a 1kΩ load. Although most manufacturers characterise their microphones with such a load, their actual behaviour changes little – and possibly even for the better – if they drive a lower impedance. So using an LT1028 in the circuit, the largest single noise source is the resistance of the microphone itself (1.8nV/41–1z for 200Ω).
Modifying the configuration

On its own, the configuration is not wholly satisfactory, as both inputs are driven, via the feedback resistors, at half output voltage. There is a considerable risk that the LT1028 input could be driven outside its common mode input voltage range when powered from the 9V battery. Also, the operation of some single-point stereo microphones may be affected if both channels share a common earth. Hence the circuitry around IC1 (Fig. 2) is added to force the inputs to lie symmetrically about ground by making their sum zero.

A low power operational amplifier, the Maxim MAX403, is used to minimize the overall power consumption. Up to the frequency at which the MAX403 runs out of gain (10kHz), $IC_2$ sees almost no CM signal so its CMRR is unimportant and its distortion is minimized.

Note that although $R_2$ plays no part in controlling differential mode gain up to this frequency since $IC_1$ provides the microphone current (see box), the common mode rejection ratio (CMRR) at higher frequencies is still dependent on $R_2$ and $C_2$ matching $R_3$ and $C_3$.

The MAX403 output drives each input of the LT1028 via a pair of closely matched resistors, $R_3$ and $R_{10}$. Its output drive current is split precisely between them. When the MAX403 counters a CM signal, any mismatch between $R_3$ and $R_{10}$ generates a differential mode signal which will degrade the total CMRR.

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For a high gain configuration together with its equivalent noise voltage source, high gain means that $R_{2}>>R_{1}$. The equivalent noise current sources of each input have been omitted as their contribution is negligible with bipolar operational amplifiers and low source impedances.

Calculations show the addition of the amplifier and resistor input noise densities to find the total equivalent input noise voltage density $e_{eq}$ for a number of circuit choices. As the noise sources are uncorrelated, the noise powers add, therefore noise voltages are given by an RMS sum:

$$e_{eq} = \sqrt{e_1^2 + 4kT (R_1 + R_2)} \quad \text{V/} \sqrt{\text{Hz}}$$

Case 1. $R_1 = 200\Omega$, $R_2 = 470\Omega$ and a RC560 with $e_1 = 7nV/\sqrt{Hz}$:

$$e_{eq} = \sqrt{0.01 + 4 \times 290 \times 10^{-3} \times (200 + 470)} \quad \text{V/} \sqrt{\text{Hz}}$$

Case 2. $R_1 = 200\Omega$, $R_2 = 470\Omega$ and an NE5534 with $e_1 = 4nV/\sqrt{Hz}$:

$$e_{eq} = \sqrt{0.01 + 4 \times 290 \times 10^{-3} \times (200 + 470)} \quad \text{V/} \sqrt{\text{Hz}}$$

Case 3. The inverting configuration can generate the same noise. Choosing an operational amplifier with a low $e_1$ means higher equivalent current noise, $i_n$. Fortunately, this is still insignificant in this configuration. This is the basis of the microphone preamplifier circuit presented here.

### Interview technique

Following a stint as a "Media Fellow" in 1990, an academic working in the mass media to promote science, I have been a freelance radio journalist for local FM radio, reporting on science and technology.

Shortly after I started, it became obvious that every radio journalist needs his or her own tape recorder. The quarter-inch tape machine is still the standard in radio programme production, its format allowing manual editing to the highest broadcast standards with the simplest of tools: chinagraph pencil and razor blade. But the low recording density that permits this is also a fundamental weakness. Portable quarter-inch tape recorders have to be physically large and are tape and power hungry. Nevertheless the StevaVoX, Uher and Nagra portables are in wide use, the resultant material being immediately editable.

All other options involve dubbing to quarter-inch for subsequent editing. If this overhead is acceptable then the possibilities extend to high-quality, professional compact cassette or proprietary miniature formats, such as mini-Nagra, and DAT.

DAT has become an accepted studio format. To a limited extent, professional portable DATs are in use in radio journalism. But the newer consumer portable tablet-style models promise the same quality for significantly less money.

The Aiwa HD-51 and Sony TCD-D3 have been tried and both were found to be noisy microphone preamplifiers. I currently use the Sony with a Beyer M58 moving-coil omnidirectional microphone making mono recordings via the preamplifier described here. The result is dubbed to quarter-inch on a Studer A807 for editing and subsequent broadcast.

Adrian Pickering

### Operational amplifiers and noise

The contribution from the operational amplifier is comparable to the noise from $R_2$ and $R_1$ and this is about the best that can be done without changing component values significantly.

Case 3. The inverting configuration can reduce the value of $R_1$ or even omit it, making a lower noise amplifier worthwhile. With $R_2 = 200\Omega$, no $R_1$ and a LT1028 with $e_1 = 0.9nV/\sqrt{Hz}$:

$$e_{eq} = \sqrt{0.01 + 2 \times 290 \times 10^{-3} \times 0.9 \times 10^{-3}} \quad \text{V/} \sqrt{\text{Hz}}$$

The noise from $R_2$ is dominant but irreducible. Choosing an operational amplifier with a low $e_1$ means higher equivalent current noise, $i_n$. Fortunately, this is still insignificant in this configuration. This is the basis of the microphone preamplifier circuit presented here.
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What The Press Said About RANGER1

For most small users, Seetra’s RANGER1 provides a sophisticated system at an affordable price. It is better than EasyPC or Tsien’s Boardmaker since it provides a lot more automation and takes the design all the way from schematic to PCB. Other packages separate designs for both. That is, no schematic capture. It is more expensive but the ability to draw in the circuit diagram and quickly turn it into a board design easily makes up for this.

Source JUNE 1991 Practical Electronics

Pay by Visa or Access
Differential mode gain

A signal source being “shorted” means there is no input voltage to define a voltage gain. But for the purposes of comparison with other designs the voltage gain here is defined as the output signal divided by the unloaded input voltage. The voltage gain here is defined as the output the purposes of comparison with other designs

The feedback around /C7 ensures that there are no voltages across R8 either. The only remaining route for the microphone current is from the output of IC2 via R10. IC1's output voltage will be \( V_{out} \), giving a 23dB CMRR.

Noise measurements with \( R_{S} = 2k{\Omega} \), using a 20kHz brick-wall filter and precision multimeter show that the equivalent input noise (EIN) in this bandwidth is -129.6dBu (2.1nV/Hz equivalent input noise voltage density). The figure compares well with the calculated value using the typical \( e_{n} \) and \( i_{n} \) figures for the LT1028.

The thermal noise of a 200Ω resistor at 25°C in a 20kHz bandwidth bandwidth is -129.6dBu, the noise figure is 1.4dB at this input impedance. Power consumption is about 8mA per channel.

Common mode gain

Input current into the positive input to IC1 is \( 2V_{cm}/R_{s} \). Once again, the only source for this current is via \( R_{10} \) and the same current will flow through \( R_{8} \). Now, instead of adding, this current cancels the input current into the inverting input. No current flows through \( R_{1} \) and so the output, and hence the gain, is zero. This is only true if \( R_{8} = R_{10} \). If \( R_{8} = R - \delta R \) and \( R_{10} = R + \delta R \), then the common mode gain is:

\[
A_{cm} = \frac{R_{5}}{R_{10}} \left( \frac{R + \delta R}{R - \delta R} - 1 \right)
\]

For \( R = 2k{\Omega}, \delta R = 2{\Omega} \) (0.1%) this gives \( A_{cm} = -10dB \), giving about 54dB CMRR. Using a 3½ digit DVM it is feasible to match \( R_{8} \) and \( R_{10} \) to within 20Ω giving \( A_{cm} = 23dB \) (better than 67dB CMRR).

References


Acknowledgement

Thanks to Richard Dudley for making the Audio Precision analyser measurements.
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October 1992  ELECTRONICS WORLD+WIRELESS WORLD
PSU regulation boosts audio performance

Power rails in most electronics are assumed to be stiff enough to hang any amount of circuitry off them without worrying — provided current capability is observed. In reality, stiffness is finite, with finite impedance causing spurious signal-related voltages to be developed along supply buses, commensurate with any change in signal current and/or voltage.

Most signal processing topologies exhibit power supply rejection (PSR), indicating that a change in rail voltage is only partially reflected at the output port. But the PSR ratio (PSRR) of any individual stage is finite too. The upshot is that communal supply rails always induce some interactions between stages. Power rail feed-through makes no distinction between logical sequence, so later stages can interfere with earlier ones, and vice-versa.

In general, with the predisposition to couple wholly unrelated stages and sections, the feed-through may be regarded as complex, even chaotic.

Devolving small signals

How big is this feed-through? Sensible, economically justifiable PCB conductor cross-sections and lengths realise baseline source impedances ($Z_s$) in the realms of low mΩ. This, combined with typical current fluctuations of tens of milliamps in moderately complex small signal circuits, produces power rail voltage fluctuations in the order of 1-300µV, or -120 to -70dBV.

The PSRR of any half-way-decent signal processing block will be at least -10dB at 20kHz and below, ranging up to -100dB with good circuits at 100Hz. So error voltages entering the signal path will be in the region of -80 to a hypothetical -200dBV.

For the bulk of electronics, pollution on this scale is of no concern. But if greater than -120dB (ie -146 to -160dBV; see terminology explanation box), it can be a problem in music reproduction — arguably the most critical class of processing. Here an error-to-noise ratio (ENR) better than -120dB is needed.

Real requirements of regulation

To be positively inaudible, the output stage's supply should be suppressed so its contribution at the output results in SPLs below the hearing threshold. Assuming a maximum capability of 125dB SPL, then supply artefacts must be at a level that creates < -125dB SPL, or -125dB relative to the system's electrical output.

If the PSR in the audio band can fall to 25dB worst case, but no lower, we need < -100dB on the rails. To achieve this, with a modest maximum peak current of 20A, a PSU impedance below 25µΩ is required. If attained by capacitative decoupling alone, a hypothetical 250 pure Farads would be required to

---

**Fig. 1. Audio power regulation scheme.** $V_{ref}$ is external and independent. The active device's inductive $Z_d$ is compensated for, and heavily damped up to RF, with an ultra-low impedance reservoir array, tightly noded. Audio output current is drawn directly from across the array.

**TERMINOLOGY**

*High sonic resolution:* A subjective description indicating relative absence of intermodulation, adverse harmonic and other error signals occurring simultaneously with music program.

$dB$: dB referred to a given reference voltage, in this case a power amplifier's maximum rms output, typically ranging 20V to 100V, or +26 to +40dBV.

$dBV$: dB referred to 1 volt rms, any impedance.

PSRR: Power Supply Rejection Ratio, normally expressed in decibels.

*Time-population space:* The sum of the operating hours of all the population of a given artefact.
maintain this specification down to 20Hz. Clearly, some kind of active regulation is needed.

Beyond a very low and preferably invariant flat $Z_{i}$ vs frequency, and low noise, regulator requirements specific to audio have not been widely documented. Stability needs to be verified over a wide range of supply currents and waveforms. Loudspeaker peak current demand (in worst case conditions up to 60A with some studio monitors) must be sourceable for musically significant periods, up to hundreds of milliseconds. With music and speech, the long term RMS draw from a class A-B amplifier will be around 1-10% of peak capability. But the regulator will need to be able to source 10-25% of peak current demand on a near continuous basis to pass steady-state sine-wave tests performed (solely) by makers, repairers and reviewers.

High-power audio regulator demands the best possible load regulation, though line regulation is no more important than usual. Output voltage stability is not an issue, so long as any change is below audio frequencies and stochastic, i.e. true drift.

Short-circuit protection is also not so essential as in a bare lab or industrial supply. With abusive output loading, the amplifier’s output devices will likely expire before the regulator’s. To some extent, it was the misguided use of foldback current limiting to hide inadequate current/power capability that sealed the fate of audio power regulators in the early 70s. With modern, high SOA devices and supplies below ±50V, thermal protection on the pass device’s heat-sink can be

![Fig. 1. Capacitative divider schemes overcome the need to have two regulators when split rails became the norm circa 1972. But, the capacitors need to be rated at rail-to-rail voltage, in the case of a DC fault (shown dashed). They must also be capable of passing above 60 peak amperes of output current. Single, large reservoir electrolytics do not meet modern audio quality requirements.](image)

**History**

The error voltage problem has been considered obliquely by many in reference to capacitative supply decoupling. But the role of active regulators in increasing supply stiffness is sparsely documented. In 1980, Sulzer published a "super regulator" for small signal audio (e.g preamplifiers), aimed at markedly reducing supply impedance through liberal use of NFB. While developing a commendably low $Z_{i}$ at the output node of well below 1mΩ at 1kHz, $Z_{i}$ is non-flat throughout the audio band, and increases to around 12mΩ at 10kHz. The obvious drawback is that beyond powering a single, abruptly adjacent stage, the regulator’s low $Z_{i}$ will be swamped by the power rail’s resistance and inductance, unless supply lines to all additional stages are extremely short and stout.

Since 1983, I have pioneered the principle of powering every stage in my reference standard audio designs from individual regulators. The regulator acts to increase PSR while inter-stage isolation means $Z_{i}$ is less critical than it might otherwise be. Subsequently, many critical listeners have reported that this scheme makes a lasting improvement to sonic quality. Objective evidence is available in the form of spectral measurements. It sounds extravagant, but this localised application is precisely what the originators of the monolithic regulator foresaw. The question then arises, why not regulate a power output stage?

**Two decades of unregulated power**

The first transistor amplifiers ran from single supplies. They had mostly local feedback and poor PSR. For today’s more critical and better-equipped listeners, regulated supplies would be needed, if only to reduce 100Hz (+ harmonics) ripple feed-through to acceptable bounds. By the late 60s, use of the long-tailed input pair and high NFB provided enough 100Hz rejection.

But a few quality amplifiers, (eg Quad’s 203 and later models by Radford and Naim) employed a stabilised supply, ostensibly because it offers a tightly defined power output, irrespective of loading or mains voltage. This is valuable to avoid unexpected clipping if the system is sufficiently underpowered to need to be routinely used within 3dB of maximum output voltage swing. Another advantage is improved isolation between stereo channels if they must share a single supply.

In the early 70s, Robert Carver argued that "saggy" unregulated supplies gave better music performance. They could satisfy the high transient excursions, without the cost penalties of a transformer and heat-sink rated to sustain full power continuously. The argument was relevant to steady-state testing, lab and industrial use, but not the majority of music. At the same time, amplifier power began to spiral above 100W, and split rail designs became the norm, requiring either two suitably high current regulators, or else a single regulator combined with rather dubious capacitative divider schemes (Fig. 1). Designers were meanwhile becoming increasingly aware, not just of speakers’ tendency to dip to a fraction of their nominal impedance at spot frequencies, but also the ability of more adventurous passive cross-overs to phase shift the drive units’ back-EMFs, increasing dynamic current demand by 200% or more.

Altogether, these factors indicated that an amplifier’s ability to source high peak currents – around ten times but up to twenty times the maximum steady state – is important if sound quality is not to be compromised in some passages, when driving difficult speaker models. It followed that a regulator would need current capabilities and transient response commensurate with the amplifier itself. The conclusion is a doubling in complexity of amplifier circuitry and cost. Even in an up-market design, it appeared an inelegant route. Benefits were seen at the time solely in terms of steady state specifications at spot frequencies – and these could have been obtained simply by increasing NFB.

The regulator’s disadvantage, other than budgetary, was to reduce the amplifier’s short-term power or IHF rating, the “big number” beloved of unscrupulous makers. From the mid 70s, unregulated supplies based on increasingly large reservoir capacitors became the norm, and regulated supplies for output stages became a dim memory for most.

The easy way to build a good-sound power amplifier is in class A. Commercial examples above 50W are ecological disasters, both through their electricity consumption, and through employing hugely over-rated PSUs. Overrating is partly to deal with almost any loudspeaker’s worst case demand, and partly to yield higher sonic resolution. But class A’s sonic benefits have little to do with the guaranteed absence of cross-over artefacts, and much more to do with the lack of thermal and power rail intermodulation.

Greg Ball’s recent article Distorting Power Supplies brings the picture up to date and explains with vigour why this should be so, with a cogent survey of the mechanisms at work in the unregulated supplies of today’s class A-B audio power amplifiers.

The outcome is that energy saving class A-B can approach or meet class A standards, provided either the supply’s or the amplifiers’ PSR is vastly improved. To tackle the problem at its heart, we must deal with the former, alias PSU regulation.
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enough to protect both the regulator and mains transformer from prolonged over-dissipation.

**Design features and results**

A design employing series pass devices, controlled by a drive circuit, which uses NFB to sample the output voltage (Fig. 1) differs from previous designs in subtle but crucial ways. Feedback ratio in this circuit is exceedingly high, on the order of $10^7$ at 10Hz – and still 1000 at 100kHz – and a moderately large but extremely low impedance output decoupling array is part of the regulator and intimately coupled to it. A large capacitance is needed to source transient currents up to 60A or more (short of paying for added pass devices, larger heat-sinks and a mains transformer) – all for a requirement, albeit vital, that persists for just a few moments in any percentage of music played flat out. Also the $Z_o$ of any regulator employing NFB looks inductive, as $Z_o$ rises with increasing frequency, commensurate with reducing open-loop gain. Using an output capacitor to compensate, flattening the $Z_o$ curve risks resonance. But a very low impedance array intimately connected through heavy bus bars with micro-ohms of series resistance damps the resonance, yielding an almost flat $Z_o$ across several decades of frequency. The method counters the trend for high order harmonics to be emphasised, as in conventional NFB regulators.

Critically, output current is drawn directly across the array, and all grounds are nodded to it. Ultra-low inductance needed for RF stability is achieved by paralleling a large number of modern low-inductance units. These are connected in the prototype by multiple braids with resistances under 2µΩ/m; by their proximity (within 100mm) to the pass devices, and by connecting the NFB sensing wire nodally. Array parasitics should be diminished as far as is practical by analysing the micro-impedance of interconnection geometry. Then conventional compensation capacitors in the order of a few pF can be connected around and within the control loop to tidy up any residue in the 10s and 100s of MHz. The compensation will degrade output impedance and rejection, but at frequencies where it will not bother audio.

No attempt is made to derive the reference voltage $(+V_{ref})$ from the input or output of the supply, as in conventional regulators. Instead, it is taken from the driver circuit’s separate supply, as in conventional regulators. Instead, it is taken from the driver circuit’s separate supply which is already provided by a conventional, small signal regulator. The key benefit is that regulator output is governed by a low-noise voltage that is inherently isolated from the main supply’s large and highly complex ripple and signal-dependent voltage perturbations. Using only three modestly priced bipolar power transistors as pass devices gives a potential 45A capability. So the regulator is easily able to sustain any prolonged (but essentially short-term) audio demand that exhausts the output reservoir: current availability is then limited by the raw reservoir and mains transformer.

Turning to results, Fig. 2 and 4 show the rejection and $Z_o$ of the unregulated and regulated conditions when used to power a class A-B amplifier, driven at maximum with and without a resistive load. $Z_o$ is estimated by dividing the residue voltage by the output current. The simulation model’s predictions (Fig. 3) make an interesting comparison. Overall,
the improvement in listening, static THD and driven SNR numbers, and the implied spectra is real and vast (Tables 1 and 2). Most of all, the regulator is not expensive — especially taking into account the savings made by being able to reduce the primary supply’s component ratings by up to ten-fold.

Table 1. PSR in dB with full drive into 4Ω at 10Hz, 1kHz and 20kHz.

<table>
<thead>
<tr>
<th>Condition</th>
<th>10Hz</th>
<th>1kHz</th>
<th>20kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unregulated supply of 15,000µF</td>
<td>-24</td>
<td>-57</td>
<td>-57</td>
</tr>
<tr>
<td>+ regulated supply with 15,000µF output array</td>
<td>-92</td>
<td>-92</td>
<td>-92</td>
</tr>
<tr>
<td>PSR improvement</td>
<td>+92dB</td>
<td>+66dB</td>
<td>+35dB</td>
</tr>
</tbody>
</table>

Table 2. %THD+N reduction.

A given amplifier driven at 0.5dB < clip into 4Ω resistive

<table>
<thead>
<tr>
<th>Condition</th>
<th>10Hz</th>
<th>1kHz</th>
<th>20kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without regulator</td>
<td>0.002%</td>
<td>0.04%</td>
<td>0.04%</td>
</tr>
<tr>
<td>With regulator</td>
<td>&lt;0.006%, 20Hz - 20kHz (flat)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References
4. Ben Duncan, AMP-01, May to Nov ‘84; CDU Dec, Jan 87/88, AMP-02/DSM Sept 89 to Sept 90; Hi-Fi News.
5. Robert Widlar, a versatile monolithic voltage regulator, National Semiconductor AN-1 (USA), Nov ’67.

Fig. 4. PSRR of the completed regulator, driving 8.75A peak into 4Ω (upper plots) and open circuit (lower). Damped resonance centred at 4kHz shows effect of imperfect nodding and layout in prototype. Rise below 30Hz shows dropout due to inadequate Vmin, fixed by increasing transformer voltage. All plots include stochastic noise, explaining in part how they differ from simulations in Fig. 3.

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All-Powerful — or all too much?

P-Cad does everything you will ever need from PCB cad. But John Anderson wonders if you can have too much of a good thing.

Few PCB design packages can claim to have all aspects of the process covered. But compared with the rest, P-Cad has everything, taking the design from a hierarchical schematic capture to the control programs for manufacture pick and place. Complexity is one of the penalties that has to be paid for this level of functionality. So a little formal software training could prove a worthwhile investment to get the most out of the package.

P-Cad itself is a mature PCB layout product, with a somewhat chequered commercial history. P-Cad Inc was acquired by Cadcam specialists Cadam in 1989, and Cadam was in turn acquired by IBM. So the software is actually the de facto IBM PCB cad program, with over 19,000 systems installed worldwide.

The user interface is based around a series of two-pane text screens, with options in the left hand pane selected using the cursor keys. As each option is selected, the right hand pane changes to show either the structure of the program and database at that level, or details of the operational syntax. So the somewhat archaic text interface is actually quite a good route map for using the system.

An alternative is that each program in the system can be executed from the dos command line.

Schematic entry

The schematic entry graphics screen is well organised with all controls normally mouse operated. There is a menu of commands on the right of the screen, with some commands being two layer, bringing up a different selection menu. Drawing, redrawing and utility of the schematic entry is generally very good.

But one area which can cause confusion is in informing P-Cad about the directory structure of the data and library files — even though P-Cad installation put the files there in the first place.

The reason is that entering schematic capture from the command line results in a small menu from which default set-ups, including directories, can be set. Inside the schematic editor there is no way to access information about the current directory or move to another, and to edit a file in a directory that is not configured requires typing in the whole path — tedious. One way to solve this problem is through the dos shell facility, the only way to view a file directory.

Placement

Placement is achieved by its own program, run either from the P-Cad shell or from the dos command line. The system works in the graphics editor environment, and with component footprints loaded, the user can move and fix the position of specific (or all) components. A grid is defined for the devices, the intersection of the grid lines being referred to as lattice points. Placement barriers can be defined to stop components being placed in particular areas.

During placement, horizontal vertical histograms can be displayed indicating the degree of congestion of tracks with that particular placement. Placement is aided through a complete series of commands, such as component alignment, gate swap to reduce track length and a suite of component move and rotate commands.
Track editing
The schematic editor for PCB layout has the same user interface as the schematic and placement editors and operates with similar layered menus.

Full forward and back annotating transcribes schematic data to the PCB and PCB data back to the schematic so that consistency is ensured between circuit diagram and PCB.

Autoroute
P-Cad autorouter provides the usual memory and maze routing strategies, and includes a rip-up router suitable for more difficult routing tasks. Related facilities include via minimization, and blind and buried vias (in multi-layer PCBs). Everything takes place on all layers on a 0.001in grid.

To neaten the final result and to help ensure that design rules are not broken, the router can work with a separate grid for the vias.

Libraries
Comprehensive libraries cover most common components. For going beyond these, other libraries span the dominant technologies (TTL, cmos, ECL, linear etc) and major suppliers (National, Intel, Motorola etc). The package also reveals its insular US roots here, as libraries cover only the products of US corporations – an annoying weakness with more and more of the leading-edge electronic components coming from Japan.

But a nice touch is the library of standard PCB outlines that includes PC, Pcat, Apple, Multibus and several others.

Schematic library items can be added to the library, using the same graphics editor as for normal schematics.

Installation and documentation
Installing P-Cad is not a good introduction to the package. The software uses a novel serial dongle system comprising a 250 x 80 x 40 box containing small plug-in keys for each section of the program. The box itself – which buzzes annoyingly – plugs into a separate mains outlet.

But the problem is that the dongle uses a 25-way D-shell for the serial interface without adapters for the 5-way serial connectors (introduced with the IBM AT). So two adapters are required.

Installation itself is fast and slick, the distribution discs being accepted in any order, and in about 15 minutes all was completed – all 20Mbytes of it! The promotional material suggests a 30Mbyte disc is required. But with this amount of software I would suggest 100Mbytes to avoid having dos struggle with fragmented clusters.

Installation includes a fiddle with AUTOEXEC and CONFG files, but the software tells you exactly what it is doing.

Documentation makes War and Peace look like a short story. No less than eleven 18 x 9in paperback books, with probably over 5000 pages, stack up to make a thickness of nearly 8in – more than a little daunting. But the software turns out to be surprisingly easy to use, and the great stack of books is actually very useful for learning and reference (and filling up your book shelves impressively).

The manuals are professionally published and well organised so that even with so much data, references can be found without too much difficulty.

SUPPLIER DETAILS
P-Cad Associate designer AD-4 £2000 is written by Cadam Inc, Burbank, California. It is available in the UK from KGB Micros Ltd, 162 Bestobell Road, Slough, Berks SL1 4SZ. Tel: (0753) 696069

Other products in the range:
AD-1 entry level similar to the AD-4 but excluding auto-place and route £1100.
Master Designer MD-1 similar to AD-4, but with more features and larger databases £6500.
Professional PCB for Unix on Sun Spark or IBM 6500 £9980.
Little bits extra

Several export facilities are available – indeed one of the manuals is dedicated to export. Amongst the formats are DFX and IGS as well as the usual plotters, photoplotter and NC drill. But P-Cad always seems to offer that much more, and included in the exports are panelisation (grouping PCBs into panelled sets), and control output for pick and place and auto insertion manufacturing machines.

At first it looked as though the package was going to be especially interesting, with menu features detailing data capture and compilation for programmable logic devices (PLDs). But on closer inspection, this part of the menu system was inoperative, and the package needed to be upgraded for those functions.

There is also a simulation menu option – again this proved to be inoperative on my review software – and the sales literature indicates there is a logic simulator and a file export to Spice analogue simulation.

Importance of training

As expected, the product from an IBM company is good – though the price compared with the competition is certainly a premium.

In terms of facilities P-Cad seems to have the lot. Not surprisingly, the wide range of basic commands, option settings and configurations can make this one of the most daunting software products to learn and use; the 11 reference manuals are evidence of the enormous volume of material.

No one can be expected to memorise this amount of data and put it together in a structured way to make the system work first time. As a result, to obtain full value from the product software training has to be a serious consideration.

KGB, the UK distributors, offer training for schematic capture (two days), interactive layout (two days) and auto-placement and routing (three days); each day costs £350 and should be costed into the price of the final product.

So P-Cad is undeniably a powerful product, taking the design from a hierarchical schematic capture to the control programs for manufacture pick and place. But potential users should think very carefully about whether they are up to using a package having this level of complexity and no on-line help.

SPECIFICATIONS

Schematic and PCB editors:

- 100 layers
- Cut and paste editor
- On-line connectivity checking
- User defined macros
- 600C standard symbol and footprint library
- 130C component, 2500 net and 32000 pin capability
- Up to 300 schematic sheets in one design

Schematic capture:

- Back annotation
- Real time component drag with orthogonal rubber-banding

PCB layout:

- 0.001 in or 10µm resolution
- PCBs to 60 x 60 in
- SMD support includes both sides of PCB

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- Audio Mixing Desk transformers (all types).
- Miniature transformers.
- Microminiature transformers for PCB mounting.
- Experimental transformers.
- Ultralow frequency transformers.
- Ultra linear and other transformers for Valve Amplifiers up to 500 watts.
- Inductive Loop transformers.
- Smoothing Chokes.
- Filter Inductors.
- Amplifiers to 100 volt line transformers (from a few watts up to 1,000 watts).
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One of the advantages of analogue behavioural modelling (ABM) is the ability to model analogue circuit functions using equations, tables and transfer functions. Designers can use the technique to simulate complex systems as a combination of “black-boxes” each of which performs a specific function.

In this way performance can be predicted before circuits are built, a detailed component design of a system being described to the simulator using a basic set of components such as resistors, transistors and various voltage and current sources. Component connections are then expressed in terms of nodes—a type of simulation often called the structure or primitive level simulation.

In a simple example, take as a system under simulation a 2nd-order lowpass filter. To optimise performance, the effect of changing the filter type (Butterworth, Bessel, etc.) on system response needs to be examined.

Until recently, this meant a number of different type filters would have to be designed and simulated—a time consuming task. A more effective way to tackle the problem is to simulate the filter as a “black-box”, where the input/output relationship can be expressed in terms of an equation. As a result filter component design is unnecessary at this stage, since the filter function has been modelled using a mathematical expression. At a later stage the model can be replaced by actual circuitry.

In this “behavioural level” simulation, a functional block can be described by its behaviour without worrying about its physical structure. The description can be an equation or data table, and a user has the ability to check and optimise a system without needing to perform circuit design. Complex systems can also be simulated quickly and more efficiently than at the primitive simulation level. Several simulators offer analogue behavioural modelling (ABM) but here we will look in detail at Pspice. (For a good introduction to Pspice see “Adding Spice To Technology”.)

Pspice ABM
ABM comes as an extra option to the basic Pspice simulator, allowing the user to describe analogue component or circuit operations using equations and tables. Descriptions are implemented using four functions: Laplace, frequency, table and value.

Laplace is usually used to describe the frequency response of circuits in terms of a transfer function in the Laplace transform variable. Frequency response of a circuit can also be written as a table using the frequency function, where each entry in the table consists of a frequency and the magnitude and phase of the response at that frequency. The table function allows circuit operation to be described by a function of the form:

$$ V_{out}(s) = \frac{V_{in}(s)}{s} $$

where $V_{out}(s)$ is the output voltage in the Laplace domain, $V_{in}(s)$ is the input voltage in the Laplace domain, and $s$ is the complex frequency variable.

Frequency response of a circuit can also be written as a table using the frequency function, where each entry in the table consists of a frequency and the magnitude and phase of the response at that frequency. The table function allows circuit operation to be described by a function of the form:

$$ V_{out}(f) = \frac{V_{in}(f)}{f} $$

where $V_{out}(f)$ is the output voltage at frequency $f$, $V_{in}(f)$ is the input voltage at frequency $f$, and $f$ is the frequency variable.

Table functions are used to describe circuit operation in terms of a table of values. Each entry in the table consists of a frequency and a value, where the value represents the response of the circuit at that frequency. Table functions are used to describe circuit operation in terms of a table of values. Each entry in the table consists of a frequency and a value, where the value represents the response of the circuit at that frequency.
look-up table, with the table consisting of input-output data pairs.

Value handles voltage or current sources whose output is any arithmetic function of voltages and currents elsewhere in the circuit.

**Pspice** performs ABM using two controlled sources: VCVS (voltage controlled voltage source) and VCCS (voltage controlled current source), identified by **Pspice** as a component starting with the letter E or G respectively. The E component will be used when an output voltage is required, the G component when output current is needed.

**Circuit modelling**

In this section, a number of commonly used analogue circuits will be modelled as "blackboxes". These include filters, amplifiers and rectifiers. As indicated earlier, a 2nd-order lowpass filter provides a simple example to illustrate the development of a behavioural model. The voltage transfer function of this filter is:

\[
(V_{out}/V_{in}) = A_1/(s^2 + sA_2 + A_1)
\]  

where \(s\) is the Laplace transform variable, \(A_1\) and \(A_2\) are expressing the filter characteristics and are given by:

\[
A_1 = 4\pi^2\omega_0^2\omega\pi^2
\]

\[
A_2 = (2\pi\omega_0 F_c)\pi
\]

\(\omega_0\) is the normalised frequency (rad/s), \(Q\) is the quality factor and \(F_c\) is the denormalised cut-off frequency of the filter (see box, "Laplace transform and s domain"). The filter transfer function has been written in terms of \(s\), therefore, the Laplace function, the E component will be used to model the filter. Also, since the output of the filter is a voltage, the E component will be used.

So Eq(1) is described in **Pspice** as:

\[
E20\text{Laplace}[V(1)] = [A_1/(s^2 + sA_2 + A_1)]\]

where the input to the filter is a voltage at node 1, and the output is a voltage at node 2. Nodes have been chosen arbitrarily to show how the "black-box" filter model would be connected within a system.

The 2nd-order lowpass behavioural filter **Pspice** model is (black-box notation, shown in Fig. 1):

The simple nature of the transfer function allows changes in the model to be made easily. For example, changing the filter type simply involves entering the appropriate values of the parameters \(a_1\) and \(Q\) selected from Table 1 into Eq (3). **Pspice** allows parameters to be declared and used in expressions within an input file, giving a great deal of flexibility when developing and modifying circuit models. In the model, note how the filter parameters are defined using the .PARAM command. This illustration demonstrates how only the transfer function is used, allowing a model to be developed for a lowpass filter. Generalised models for filters are possible such as lowpass, highpass or bandpass, further simplifying the operation. The technique can be extended to other circuit functions where only the Laplace transfer function needs to be specified. Frequency response of our lowpass filter could also have been modelled using the "frequency" function (see box, "Examples of ABM circuit models", which also considers the modelling of amplifiers and rectifiers).

**Laplace transform and s domain**

The relationship between the input and output of linear systems can be expressed by a series of differential equations. Obtaining the system response usually means solving the differential equations, which can be tedious. A mathematical method, the Laplace transform provides an easier way of solving these equations.

For example, the Laplace transfer function of the RLC circuit shown in the figure is derived as follows. Input and output voltages of this circuit are related by the differential equation,

\[
V_{out} = R I + \frac{dV}{dt} + V_{out}
\]

using Kirchoff's voltage law. Using the Laplace transform method, \(d/dt = s\), where \(s\) is the Laplace transform variable. The equation can then be expressed as

\[
V_{out} = R R + s I + V_{out}
\]

Substituting Eq (ii) into Eq (i) and simplifying yields

\[
(V_{out}/V_{in}) = (1/LC)/(s^2 + s(R/L)+ 1/LC)
\]

Table 1. \(Q\) of the various filter responses.

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterworth</td>
<td>0.707</td>
</tr>
<tr>
<td>Chebyshev</td>
<td>0.864</td>
</tr>
<tr>
<td>Bessel</td>
<td>0.577</td>
</tr>
</tbody>
</table>

**Behavioural level**

Some of the behavioural circuit models developed earlier (and shown in "Examples of ABM Circuit Models") can be used to simulate an AM modulator and demodulator. These circuits have been selected because **Pspice** does not provide AM modulation directly — they also strike a reasonable balance of simplicity and modularity. The AM system (Fig. 2) consists of a sum-
SIMULATION

ming amplifier and analogue multiplier — describing the modulator — and a rectifier and lowpass filter which represents the demodulator.

An AM modulated signal is described by:

\[ V_{um} = A \sin(\omega t) (1 + m \cos(\omega t)) \]  

(4)

where \( \omega_m \) and \( \omega_c \) are the angular frequency of the modulating and carrier signals respectively, \( A \) is the amplitude of the modulating and carrier signals respectively, and \( m \) is the modulation index. Examination of the equation suggests that an AM signal can be modelled in two stages using ABM. In stage one, the modulating signal \( (m \cos(\omega t)) \) is added to a fixed DC voltage of 1V to obtain \( (1 + m \cos(\omega t)) \). In the 2nd stage, the result of this addition will be multiplied by the carrier \( (A\sin(\omega t)) \). Both of these operations are easily achieved using the value function of the ABM. The Pspice input file of the AM system is:

```
* This file simulates an AM system
Vnd 1 0 sin (0.5v 1K 0 0 0 90) ;modulating signal
Vdc 2 0 1v ; dc input
R1 1 0 1G
R2 2 0 1G
R3 3 0 1G
R4 4 0 1G
R5 5 0 1G
R6 6 0 1G
R7 7 0 1G
Vmod 1 0 sin (0 0.5v 1K 0 0 90) ;modulating signal
Vcar 4 0 sin (0 Iv 100K) ; carrier signal
Erect 6 0 Table (V(5))= (-1.5,0) (0,0) (1.5,1.5) ; rectified signal
Emult 5 0 Value= (V(3)*V(4)) ; summing ampl
Erect 7 0 Table (V(6))= (-1.5,0) (0,0) (1.5,1.5) ; rectified signal
Femult 8 0 Value= (V(5)*V(6)) ; rectified signal
```

*2nd-order filter parameters
*param omega= {1} ; Butterworth filter
*param Q= {0.707} ; Butterworth filter
*param Fc= {1K} ; F3dB point
*param pi= {3.142} ; Constant
*param pi_square= {-pi*pi} ; Constant
*param A1- (4*pi_square*omegeomega*Fc*Fc) ; see Eq (2)
*param A2= {2*pi*Fc`omega/Q} ; see Eq (2)
E 2 0 Frequency {v(1)}=(0.1,0,-16)(0.5,0,-68)(1,0,-128)(1.5,0,-232)(2,0,-362) ; filter model
E 3 0 Table {v(1)}= (-1,0) (0,0) (1,1) ; filter model
E 4 0 Frequency {v(1)}=(0.1,0,-16)(0.5,0,-68)(1,0,-128)(1.5,0,-232)(2,0,-362) ; filter model
E 5 0 Table {v(1)}= (-1,0) (0,0) (1,1) ; filter model
```

These resistors all needed to satisfy Pspice requirement for a minimum of 2 nodes to every component.

The modulating signal, DC voltage and carrier signal have been defined using various independent voltage sources as shown at the start of the above Pspice input file.

Simulating the demodulator involves modelling the operations of the rectifier and the lowpass filter. Both of these circuits have already been modelled.

In the case of the lowpass filter, the Laplace transfer function model will be chosen in preference to the frequency response table model (see box, “Examples of ABM circuit models”), because it offers greater flexibility. The filter has been assumed to be of the Butterworth type with -3dB frequency point at 1kHz. In the Pspice simulation of the AM signal and its frequency spectrum (Figs. 4 and 5), Pspice correctly models the carrier at 100kHz and the two sidebands at 99kHz and 101kHz respectively. Figure 6 shows the demodulated signal at the filter output which corresponds to the input signal.

**ABM circuit models**

This box includes the modelling of filters, amplifiers and rectifiers, which form the basis of an AM modulator/demodulator system shown in Fig. 2. Here the 2nd-order lowpass filter will be modelled using an alternative function to the “Laplace” function illustrated in the main text. Frequency response of the circuit is written as a table using the “Frequency” function. Each entry in the table consists of a frequency, magnitude (dB), and phase (°). For example, a normalised 2nd-order Butterworth filter is modelled as:

\[ E 2 0 \text{ Frequency } \{v(1)\}=(0.1,0,-16)(0.5,0,-44)(0.75,0,-5.5,66) \]
\[ (1,3,-90) (1.25,-5,-108)(2,12,-137) \]
\[ (3,-19,-151)(4,-24,-160) \]

To scale this filter to a specific cut-off frequency, all the frequencies in this table must be multiplied by the required cut-off frequency.

Also, if a different filter type is required, all the magnitude values need to be changed according to the chosen filter type. So the functions “Laplace” and “Frequency” can both be used to model frequency response, but clearly as can been seen from the filter example, the “Laplace” function offers more flexibility with respect to circuit modifications through at the expense of developing a transfer function.

In many applications, circuit operations must be modelled by arithmetic equations, for example a summing amplifier. Using the value function, the amplifier is simply modelled as:

\[ E 3 0 \text{ Value } = |V(1)| + V(2) \]

This describes a summing amplifier with an output voltage at node three. The value of this voltage is equal to the summation of the voltages at nodes one and two. Some analogue circuit operations are best described by a look-up table. In this case, the function table offers the best option for modelling, because it allows unrestricted pairings of parameters (unlike frequency which is always frequency, magnitude, and phase). An example is the half-wave rectifier modelled as:

\[ E 2 0 \text{ Table } \{v(1)\} = (-1,0) (0,0) (1,1) \]

The table has three entries, describing the full operation of the rectifier. The first value of each bracket is the input; the second value is the corresponding output. So in this example, the amplitude of the input signal at node one varies from -1V to +1V. Output at node two is 0V for inputs ≤0V, 1V for inputs ≥1V and input=0V in between.
Fig. 5. Simulated AM frequency spectrum. Pspice correctly models the carrier at 100kHz and the two sidebands at 99kHz and 101kHz respectively.

Fig. 6. Simulated demodulated signal, corresponding to the input signal.

Fig. 7. Primitive level circuit of the AM system shown in Fig. 2.

Table 2. Comparison of the two simulation approaches.

<table>
<thead>
<tr>
<th>Behavioural Primitive</th>
<th>Development</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5 day</td>
<td>1 day</td>
</tr>
<tr>
<td></td>
<td>175s</td>
<td>220s</td>
</tr>
</tbody>
</table>

Simulation times were measured on PC 386SX.

Behavioural vs primitive

As a comparison, the same AM system was simulated using primitive level components, Fig. 7. The amplifier was simulated using a VCVS, in other words modelled using an equivalent circuit. There is no equivalent circuit available for an analogue multiplier. An ideal analogue multiplier could be modelled by a discrete transistor circuit or by using polynomial sources. Polynomial sources are an accepted technique for use in the basic Pspice without ABM and offer a more convenient method for simulation of ideal circuits than actual circuit design (see Pspice manual for more information).

The rectifier was simulated using a combination of a diode, a resistor and a capacitor, and the filter was modelled using a VCVS, four resistors and two capacitors. The filter was assumed to be implemented using an active Sallen-Key circuit.

Both behavioural and primitive approaches have been shown to yield similar and satisfactory results. But there is a saving in development and simulation time associated with the behavioural approach (Table 2). Clearly optimisation of system performance is most effectively achieved by the use of ABM.

Finally, though this article has mainly dealt with modelling ideal circuits, ABM can be used to model practical components and circuits. Examples of these are given in the Pspice manual and MicroSim newsletter magazines; for instance, April 1991 issue dealt with modelling of a lossy transmission line.

Acknowledgment

Thanks to Alan Holden for his help in preparation of this article.

References

2. Pspice, Microsim Corporation, 20 Fairbanks, Irvine, California 92718.
Understand capacitor soakage to optimise analogue systems

Veteran circuit designers often had a shocking introduction to dielectric absorption when supposedly-discharged high-voltage oil-filled paper capacitors reached out and bit them. Indeed, the old oil-filled paper capacitors were notorious for what was once called soakage — a capacitor’s propensity to regain some charge after removal of a momentary short. Today, few of these capacitors are still in use, but soakage is still a problem. How do you deal with it?

Nowadays, effects of dielectric absorption are likely to be noticed in more subtle ways: perhaps in the performance of an integrator that can not be reset to zero; or a sample/hold that refuses to work correctly. But whether effects are (literally) felt or merely observed in a circuit’s behavior, dielectric absorption is a characteristic that every capacitor possesses. It is inherent in the dielectric material itself — though poor manufacturing or inferior foil electrodes can contribute to the problem.

Apt description
Soakage seems an apt term for dielectric absorption — considering what the capacitor seems to be doing. In a typical example a capacitor charges to 10V for a long time \( T \) and then discharges through a small-value resistor for a short time \( \tau \). If the short circuit is removed and the capacitor terminals monitored with a high-impedance voltmeter, the capacitor will be seen to charge back to 0.1%, 1% or as much as 10% of the original voltage. For example, a 1\( \mu \)F Mylar capacitor charged to 10V for 60s \( (T_{\text{CHARGE}}) \) and discharged for 6s \( (T_{\text{DISCHARGE}}) \) charges to 20 or 30mV after 1 min \( (T_{\text{HOLD}}) \). **Figure 1** shows a simple evaluation circuit for measuring the characteristic.

A capacitor exhibiting dielectric absorption acts as if during its long precharge time the dielectric material has soaked up some charge that remains in the dielectric during the brief discharge period. Charge then bleeds back out of the dielectric during the relaxation period and causes a voltage to appear at the capacitor terminals.

**Figure 1.** A simple test fixture allows evaluation of dielectric absorption at low speeds. To use, start with all switches off and throw \( S_1 \) and \( S_2 \) on for 1min; then throw \( S_1 \) and \( S_2 \) off and wait 6s, throwing \( S_3 \) on during the wait period. Next turn \( S_2 \) on and watch \( V_{\text{OUT}} \) for 1min. To compensate for leakage, leave all switches off for 1min and then throw \( S_2 \) and \( S_3 \) on. Monitor \( V_{\text{OUT}} \) for 1min and subtract this value from the \( V_{\text{OUT}} \) value obtained earlier.
Figure 2 depicts a simple model of this capacitor. When 10V is applied for 1min, the 0.006µF capacitor charges almost completely. But during a 6s discharge period it only partially discharges. Then, over the next minute, the charge flows back out of the 0.006µF and charges the 1µF capacitor to a couple of dozen millivolts.

The example indicates that a longer discharging time reduces soakage error but that discharging for only a small fraction of that time results in a larger error. Illustrating the point, Fig. 3 shows the results of conducting the basic Fig. 1 test sequence for 1s, 6s and 12s discharge times. Note that the capacitor tries to remember its old voltage, but the longer it is held at its new voltage, the more effectively it forgets – in the Fig. 3 case, soakage errors equal 31mV at tDISCHARGE=1s, 20mV at tDISCHARGE=6s and 14mV at tDISCHARGE=12s.

Do these low-speed tests have any bearing on a capacitor’s suitability in fast millisecond or microsecond sample/hold applications? If the Fig. 1 experiment is repeated for TCHARGE=THOLD=1000µs and tDISCHARGE=10µs, very similar capacitor-voltage waveforms are seen but with about ten times smaller amplitudes. In fact, for a constant T/T ratio, the resulting soakage error decreases only slightly in tests ranging in length from minutes to microseconds.

Figure 4 circuit approximates the capacitor characteristic, which can be observed on actual capacitors by using test setup shown in Fig. 5. Here, a sample/hold IC exercises the capacitor under test at various speeds and duty cycles, and a limiter amplifier facilitates close study of the small residual waveforms, without overdriving the oscilloscope when the capacitor is charged to full voltage.

Such experiments illustrate that if a certain amount of charge is put into a less-than-ideal capacitor, a different amount of charge will result, depending on the wait time. Thus, using low-soakage capacitors proves important in applications such as those involving high-resolution dual-slope integrating A-to-Ds. Sure enough, many top-of-the-line digital voltmeters do use polypropylene (a low-soakage dielectric) devices for their main integrating capacitors.
But dielectric-absorption characteristics are most obviously detrimental in applications involving sample/holds. Manufacturers guarantee how fast these devices can charge a capacitor in SAMPLE mode and how much their circuits' leakages causes capacitor-voltage droop during the HOLD mode. But they do not give any warning about how much the capacitor voltage changes because of soakage — a factor especially important in a data-acquisition system, where some channels might handle small voltages while others operate near full scale. Even with a good dielectric, a sample/hold can hurt accuracy, especially if the sample time is a small fraction of $T_{\text{HOLD}}$.

For example, although a good polypropylene device can have only 1mV hysteresis per 10V step if $T = 10$ms/10ms, this figure increases to 20mV if the $T$/$T_{\text{HOLD}}$ ratio equals 100ms/0.6ms. Because most sample/hold data sheets do not warn of such factors, capacitors should be evaluated in an application.

Other applications in which soakage can degrade performance are those involving fast-settling AC active filters or AC-coupled amplifiers. In the circuit shown in Fig. 6, $C_1$ can be a Mylar or tantalum unit because it always has 0V DC on it. But making $C_2$ polypropylene instead of Mylar noticeably improves settling. For example, settling to within ±0.2mV for a 10V step improves from 10 to 1.6s with the elimination of Mylar's dielectric absorption. Similarly, voltage-to-frequency converters benefit from low-soakage timing capacitors, which improve V/F linearity.

**Dielectrics good at all speeds**

Fortunately, good capacitors such as those employing polystyrene, polypropylene, NPO ceramic and Teflon dielectrics perform well at all speeds. Figure 7 shows the characteristics of capacitors using these dielectrics and others such as silver mica and Mylar. In general, polystyrene, polypropylene or NPO ceramic capacitors furnish good performance, although polystyrene can not be used at temperatures greater than 80°C. Although NPO ceramic capacitors are expensive and hard to find in values much larger than 0.01µF, they do achieve a low temperature coefficient (a spec not usually significant for a S/H but one that might prove advantageous for precision integrators or voltage-to-frequency converters). Teflon is rather expensive but definitely the best material to use when high performance is important. Furthermore, only Teflon and NPO ceramic capacitors suit use at 125°C.

If dielectric-absorption values in Fig 7 are studied, wide differences in performance for a given dielectric material can be seen.

For example, polypropylene sample A is about as good as B at = 6s, but B is four times better at high speeds. Similarly, NPO-ceramic sample A is slightly worse than NPO-ceramic sample B at low speeds, but A is definitely better at high speeds.

Some Mylar capacitors (sample A) get better as speed increases from 1000 to 100µs, but others (sample B) get
worse. So if consistently good performance from capacitors is required, they should be evaluated and specified for the speed at which they will be used in a particular application.

Keep in mind that because most sample/holds are used at much faster speeds than those corresponding to the 1min or 5min ratings usually given in data sheets, a published specification for dielectric absorption has limited value.

In addition, other dielectrics furnish various levels of performance. The following questions and answers reveal the differences.

- Any long word that starts with poly seems to have good dielectric properties. So how about polycarbonate or polysulfone?
  - No -- they are about as bad as Mylar.
- Does an air or vacuum capacitor have low soakage?
  - It might, but many standard capacitors of this type are old designs with ceramic spacers, and they might give poor results because of the ceramic's hysteresis.
- If a ceramic capacitor is not an NPO device, is it any good?
  - Most of the conventional high-K ceramics are just terrible—20 to 1000 times worse than NPO—and even worse than tantalum.
- Is silicon dioxide suitable for small capacitances?
  - Although Fig. 5 test setup, used in preparing Fig. 7 chart, only measures moderate capacitances (500 to 200,000 pF), silicon dioxide appears suitable for the small capacitors needed for fast S/Hs or deglitches.

Cancellation improves accuracy

A practical method of getting good performance with less-than-perfect capacitors is to use a soakage cancellation circuit such as one of the form shown in Fig. 8, in which a capacitor of the type modelled in Fig. 4 serves as an integrator. (Only the first two soakage elements are shown.) The integrator's output is inverted with a scale factor of -0.1, and this voltage is then fed through one or more experimentally chosen RC networks to cancel the equivalent network inherent in the capacitor's dielectric material.

Figure 9 shows a practical sample/hold circuit with an easily trimmed compensator. The network provides about a ten-fold improvement for sample times in the 50 to 20000ps range (Fig. 10). Although the compensation is subject to limitations at very fast or slow speeds, the number of RC sections and trimming pots employed can be extended.

Simple circuits similar to Fig. 9 or Fig. 8 have been used in production to let inexpensive polypropylene capacitors provide better-than-Teflon performance. In turn, using these compensator circuits with a good Teflon capacitor furnishes a dynamic range of 16 to 17 bits.

Robert A Pease, National Semiconductor Corp.
ELECTRONICS WORLD+WIRELESS WORLD October 1992

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CIRCLE NO. 131 ON REPLY CARD

ELECTRONICS WORLD+WIRELESS WORLD October 1992
Mic lines
Tim McCormick’s article “Putting Mic Amplifiers on the Line”, (EW + WW, May 1992), targets lack of operating point stability in discrete input transistor pair at high gain settings in convetional mic preamps (his Fig. 3), as a starting point for development of his incredibly complex – and hence impractical – final design. But existence of excellent low noise PNP transistors such as the Rohm 2SB747 (quoted rgs of 2Q and typ Eo of 0.4 nV/Hz), permits allowable emitter degeneration of typically 2Q per transistor to balance currents, linearise the stage and set maximum gain, without resorting to unbiased capacitors. The following IC differential amplifier can then be capacitor coupled, as is indeed his second stage, to provide remaining required gain: done, with a minimum of low cost components and few matched resistors, to achieve adequate CMRR.

But the whole argument fades into insignificance with advent of the Bowers topology SSM2017, an eight pin miniop 750 pV/Hz device. This requires only one external gain setting resistor, for dB to 60dB at low cost, permitting reduced assembly time, PCB real estate and well defined performance. A manufacturer would be hard pressed to ignore such a device in favour of a complex “roll your own” approach, unless some definite sonic virtues could be demonstrated.

Greg Ball
Coolangatta
Australia

Engineers of the world unite!
Congratulations on a splendid analysis of current industrial problems (EW + WW, Comment, August 1992). Unfortunately, such views hardly ever reach those in charge of events or general public.

UK electronic related industries, have had little rational planning of development (as evidenced by the Breema book “The Seimakers”, a sorry tale indeed).

UK engineers are themselves much to blame, for quietly enjoying their work so much they allow, without effective comment, really important decisions to be taken by those in charge who sometimes have no up to date understanding of technology – or even no understanding at all.

Now the engineering community needs to inform the general public, government and especially their own employers of useful developments which could be provided if appropriate decisions were to be taken. If those who make or approve investments are unaware of skills and ideas being wasted, they can hardly be blamed for ignoring them.

Financial matters are discussed at interminable length in several media but engineering related matters almost never.

R H Pearson
Lines

Visually challenging
I am writing on behalf of the Joint Working Group of the Institute of Food Science & Technology, Royal National Institute for the Blind, Guide Dogs for the Blind Association and British Computer Society for the Blind.

We aim to seek a viable method enabling blind and partially-sighted people to read information on food labels. Our major objective has been print on food packages, but now we are seeking a system which would benefit visually-impaired people, far beyond reading food labels, assisting shopping independence and providing them with greater access to information of all kinds.

Such a system needs to be operated by an individual, involving scanning text on any food package and converting it to a synthesised speech output. Ideally it should be light, portable and compact and needs to recognise as many character fonts and sizes as possible while being as inexpensive as possible (many potential users are elderly and on low incomes).

There are at least 1,000,000 visually-impaired people in the UK alone, and an even larger number throughout the English-speaking world. There are also those who need software appropriate to other languages. There must be someone among your readers who would see a threefold opportunity: a substantial new market waiting for a product, an exciting technical challenge and a chance to help blind people. What a wonderful combination!

J R Blanchfield
5 Cambridge Court
210 Shepherd’s Bush Road
London W6 7NL

Misguided CFA
Textbook writers on electromagnetic radiation, who carry out proper retarded-function mathematics, seem to concentrate on the distant magnetic effect of current flowing in transmitting aerial wire1, or on effects of current in wire plus distant electric effect of charges collecting at wire ends2,3. Moullin2, for example, considers a vertical wire, supposed to carry a uniform current, joining two conducting spheres. He shows, at distances sufficiently great, that induction fields become negligible; the radiation magnetic field vector due to current, and electric field vector due to charges on spheres, are in phase and in the fixed ratio (μE/V)6,9, 9 – the generally accepted result.

There seems to be a whiff of sleight-of-hand in these analyses. In low-frequency electromagnetic problems, magnetic effects of all parts of the circuit carrying current are considered. Yet in dealing with electromagnetic radiation, the contribution to radiation of current in the aerial wire is taken into account. But, mysteriously, the contribution to radiation of the return, displacement current flowing back outside the aerial wire is not considered. Why not? Displacement current certainly gets considered, but as an effect (of the inductive electric field), not as a cause. But it seems to have to as much right to be considered as contributing to radiation as does current in the wire.

Could there be a lacuna here, in

RC modification
I would like to suggest a simple circuit modification to the RC oscillator in Dan Stiurca’s article “Staying in control in an all-pass filter RC oscillator”, (EW + WW, July 1992).

It produces constant control pulse widths regardless of VREF and solves low amplitude harmonic distortion problems.

Offset nulling of A5,7,8 is just one way of eliminating phase-shifting effects of op-amp/comparator offsets.

A R Pleasance
Bradford

Circuit modification where A5,7,8 must have offset nulling capabilities.
standard treatment of electromagnetic radiation, accounting for continued rumblings, in these columns, on a crossed-field aerial?

Here, inventors do the opposite of other writers by considering the magnetic effect of displacement current between their $D$-plates, but ignoring magnetic effects of current in the short piece of conductor exciting the upper $D$-plate. Whatever the knee jerk response to the CFA it is difficult to criticise inventor accounts of it as incomplete, when standard texts invent the CFA it is difficult to criticise.


Crude science - bad science

I find it increasingly incredible that the scientific world still uses, let alone places any value on, experiments conducted on live animals in an attempt to extrapolate the results to humans. Messrs Silvio De Flora and Francesca D'Agostini (EW + WW, Research Notes, July 1992) themselves admit difficulty doing exactly that.

Effects of UV radiation on human skin are already well known. Spectra produced by quartz-halogen lamps is not only well established, but is easily and painlessly measured. As your report pointed out, Colin Driscoll of the Radiological Protection Board made public three years ago the risks of UV over-exposure from these lamps, so what is the point of such research? Are lives of poor creatures expended merely to enable De Flora and D'Agostini to write a career-enhancing paper? It is precisely such blatant disregard for non-human life which makes animal-based research a controversial issue.

I am involved with audio electronic field research, and would not dream of measuring distortion produced in an op-amp circuit in an attempt to determine distortion exhibited by a power amplifier, even though the two might be related. It would simply be bad science. Bad science surrounds and permeates animal based research.

degradation and delining science in general. It should be shunned by those remotely connected with science or who care about creatures who share our precious planet. Surely it is time the scientific community stood up against the relic of barbaric times which has nothing to do with science.

P Williams
Hertfordshire

PSR PS

A M Wilkes, (EW + WW, Letter, August 1992), may wish to know amplifiers using his proposals concerning power supply and PSR - including a 20kHz pulse width regulating power supply in an internal diecast box - were produced some twelve years ago by Masaru Naganti of Sony. A pair of these 200W monoblocks, TAN60 Espirit, have done daily duty in my home without fail. At a mere 10.5kg each, they have shrugged off challenges from quite a few goliaths with "vastly over-built power supplies" of a "naive, resource-wasteful band-aid" variety to quote Greg Ball (EW + WW, May 1992). Nothing sampled so far has persuaded me to change and a number of revered four man lift, room heater, models have proved, long term, to be not nearly less involving.

Recently I read that a design by John Franks, Chord Electronics’ SPM 1200, has taken up the SMPS cause at 80kHz. Praise be, it has achieved at least one rave review - tempered by sheer incredulity at something so small and light which could deliver the goods. I have not tested it myself, but am prepared to accept its authenticity.

Why are audibly superior and technologically advanced designs never commonplace? Several competent designers tell me they would love to use SMPS but their marketing people forbid it. In many countries weight and size are major consumer criteria. Hence 4mm steel chassis, 1cm thick panels, OTT toroids and generally wasteful specifying of major components. If he can think of some way to tilt the see-saw back from macho to music there might be some room for Mr Wilkes and others to advance the cause.

Geoffrey Horn
Oxford

America’s Marconi

Echoing the title of KA Ioffe’s article, “Popov: Russia’s Marconi” (EW + WW, July 1992), Telsa could be considered as America’s Marconi. Indeed, there were a few innovations in early radio Telsa had not pioneered. Telsa tolerated Marconi using devices which he patented until 1915 when he applied for an injunction against Marconi. But the injunction was denied because very few people understood the significance of Telsa’s work. In 1943, a review board decided Marconi’s patents were invalid because very few people understood the significance of Telsa’s work. In 1943, a review board decided Marconi’s patents were invalid because very few people understood the significance of Telsa’s work.

Telsa employed a Branly type coherer modified to electromagnetic pulses generated by lightning. But, while well suited to coherer type receivers, waves are too few to be tuneable. At close range, pulses are too weak. Continuously for some hours, the signals finally ceased when it was estimated that the storm was more than 200miles away. Telsa believed this phenomenon was caused by “earth standing waves”. Unfortunately, I have been unable to repeat Telsa’s observations, but, with a replica of his rotating coherer, in conjunction with an earth probe antenna, I have detected pulses. Presumably these are the same mysterious pulses which shocked my original LC very long wave tuner into oscillation (EW + WW, Letters, February 1991).

George Pickworth
Kettering

Wavetrains produced by replica of a typical 1901 spark transmitter.

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References


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Valve advice...

How can I read valve markings (eg. 6L6, 35Z5) that have been rubbed off?

I have already tried breathing on the glass, hoping condensation formed will show up the markings - it works sometimes. It does not work with metal-bodied valves.

I do not know whether putting valves under a UV lamp will show up marking remains and do not want to try in case I damage the valve.

Stephen Shaw
South Africa

...interface information

Does anyone know of any software/interface available for use with an IBM compatible PC which can decode audible Morse code or digital transmission and can tune into my SW radio on dozens of different frequencies?

Michael Lec
Gt Yarmouth

Sudden infant death

Effects of electromagnetic pollution on various aspects of the human condition have been reviewed in Roger Coghills's article "Killing fields-biophysical evidence" (EW + WW, February 1990). Increase in incidence of sudden infant death, reported by Coghills, among babies living near high voltage power lines and electric railways can be explained in terms of effects caused by electrical discharges on levels of condensation nuclei and oxides of nitrogen in the atmosphere.

Condensation nuclei are small particles of matter, which may or may not be charged, that are present in the air. They are of relevance in cloud formation, fog, smog and other atmospheric processes.

If the baby is sleeping in an environment with a significant level of condensation nuclei, then the exhaled air on cooling may not remain supersaturated but may condense on the nuclei.

Sudden infant death can now be explained in terms of pooling of excess exhaled air, high in carbon dioxide, at the infant's face.

I A Corbyn
Fremantle
Western Australia

The alternative killing fields

I read with interest Alasdair Philips' article "Power Politics: Playing with Lives" (EW + WW, April 1992). I have read similar articles before and I remain unconvinced because, in any study concerning people's health, there is always one factor which researchers fail to consider; the physical position of the subject upon the earth.

The earth is not neutral in its effect upon us as dowsers have repeatedly shown. Serious illnesses frequently occur where noxious earth energies exist.

Michael J Cooney
London

Distorted Logic

We are often told it takes a very good engineer to design a bad amplifier these days. Now with Doug Self's very apt article (EW + WW, Letters, August 1992), I have had my confidence shaken.

I was turning over some old papers and came across a photo taken for a commissioned article on Audio Amplifier design, published in Wireless World as long ago as June 1969. It is a screen shot of a "scope, showing clear hiatus in transfer characteristics at 1 watt", "crossover distortion", also appeared in full colour on your front cover. It was, of course, taken from output of a DF meter, after sampling voltage across a dummy resistive load connected across speaker output terminals of a much favoured hi-fi amplifier. If my faded notes can be relied upon, it was a little less than 8mV p-p but because of meter inertia, would not read on a waveform analyser. Yet, it was clearly audible and uncomfortably so. And what, I hear you say, did it sound like? I can use a comparison I could not have used then - rather like quantization distortion!

Ironically I recall commenting we had a new, younger generation of audio engineers who appeared to be unaware of this type of distortion.

Oh, dear. Plus ça change.....

Reg Williamson
University of Keele

Michelson-Morley type experiments are real, not apparent; the earth really is located at the centre of the universe. Geocentric scientists, including the Tychonian Society, bring much recently discovered evidence from astronomy and quantum physics to support their cosmology. In addition, if Relativity is wrong, then weight has to be lent to claims of top anti-relativists such as Stefan Marinov, Howard Hayden, Peter Beckmann and Carl Zapfe, who state the electromagnetic doctrines of Maxwell and Hertz, as well as Newton's Third Law and the First Law of Thermodynamics are all suspect. This could put all of physics on to a new track, and lead to development of some new and revolutionary electrical devices, see


André Goldberg
London

OOOOO0ps!

I don't suppose I will be first to point this out, but in my article "Squeezing into the Picture" (EW + WW, August 1992), superscripts seem to have gone astray under the sub-heading "Improving on 1000 years", 1,023 should read 10^{12}; Improving on; 100,000,000,000,000,000,000,000,000 years!!

Andy Wright
Buckinghamshire
Analog Electronics
Ian Hickman
Good all-round electronics designers are hard to find, according to the recruitment specialists. There are either bad all-rounders or good specialist (for example, microwave, power supply, microprocessors specialists). Many young designers have been lured away from the fundamentals of electronic design to more 'glamorous' digital work yet there are many simple pieces of electronic equipment for which a purely analogue realisation is still cheaper, more reliable and more appropriate than a microprocessor-based solution. Analogue staff are in desperately short supply, and in many fields - telecommunications for example - analogue skills are very much in demand. Ian Hickman's latest book includes many examples from his large collection of circuits (built up over thirty years in commercial, professional and defence electronics), selected for their usefulness in a wide range of applications. Hardback 300 pages. Price £32.40

Circuit Designers Companion
Tim Williams
This compendium of practical wisdom concerning the real-world aspects of electronic circuit design will be invaluable for linear and digital designers alike. The subjects covered include grounding, printed circuit design and layout, linear ICs, logic circuits and their interfaces, power supplies, electromagnetic compatibility, safety and thermal management. How to design to production and to cost restraints is stressed throughout. The style is direct, lucid and non-academic, aimed at the practical designer who needs straightforward, easy-to-follow advice. Hardback 300 pages. Price £26.50

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Keith Brindley
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Michael Tooley
This book sets out the principles and practice of personal computer servicing in a handy reference manual. It contains a wealth of information, including a large number of circuit and block diagrams. Various software diagnostic routines have been included together with listings and, where appropriate, actual screen dumps. Numerous photographs show typical adjustments and alignment points. It is for anyone concerned with the maintenance of personal computer equipment or peripherals, whether professional service technician, student or enthusiast. Hardback 256 pages. Price £27.00

Newnes Radio and Electronics Engineer's Pocket Book
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Newnes Electronic Assembly Book
Keith Brindley. Hardback 304 pages. Price £11.95

Newnes Z80 Pocket Book
Chris Roberts
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Newnes 68000 Pocket Book
Mike Tooley. Hardback 257 pages. Price £13.95

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R M Marston
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L Baert, L Theuissen and G Vergult

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R M Marston

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DDS operating at around 10MHz (say 10.7MHz) the result is the same. Another spur avoidance assuming the lower level signal is itself spur-free.

A mixer, choose the DDS signal as the high level transmitting but is offset to another frequency in the output of a DDS is not actually used directly for frequency agility and low close-to-carrier noise levels approaching that of a DDS, combined with the freedom from spurious outputs typical of a PLL system.

Reducing rather than avoiding
Various approaches are also possible for reducing rather than merely avoiding spurious output. In those applications where the DDS uses an off-chip D-to-A, spurious signals can be minimised by careful choice of D-to-A unit. For example, the Q2334 provides a 12-bit output to the D-to-A. But as a result of extensive testing Qualcomm currently recommend the 10-bit Sony CX20202A D-to-A in applications using outputs up to the DDS’s maximum output frequency.

The recommendation highlights that in a DDS application, published D-to-A parameters such as glitch energy, integral linearity and settling time tell only part of the story. (At lower frequencies, more D-to-A bits is naturally a better choice — the TRW TDC1012 12-bit D-to-A is recommended for use with the Q2334 at output frequencies lower than 20MHz. Another high performance D-to-A which should be considered for DDS applications is the Tektronix 12-bit TKDA30, which features a 100MHz update rate and 65dB spurious free dynamic range.)

Several workers have described schemes for modifying the mechanism which results in the generation of discrete line spurs. Thus M Bozic reported an arrangement (for use in a hybrid DDS/PLL synthesiser) for applying AM to the output of the DDS. This was done by modifying the look-up values within a conventional 8-bit low frequency TTL DDS. By adjusting the phase of the AM, the amplitude of the unwanted sidebands closest to carrier can be reduced at the expense of increasing the amplitude of other spurs further out where they are outside the PLL loop bandwidth.

In the same forum, M P Wilson and T C Tozer proposed a potentially more versatile scheme. Here, a pseudo random number is added to the output before it is passed to the D-to-A, breaking up the repetitive nature of the error process when there is a fairly simple ratio relating output and clock frequencies. Errors introduced into the D-to-A output are cancelled by the output of a second D-to-A which produces the complement of the pseudo random values.

NRC (noise reduction circuitry) is incorporated in the DDS of Fig. 2 and may be enabled or not as required. It has the effect of reducing the amplitude of discrete line

Several methods can be used to reduce the spurious signals which can appear in the output spectrum of a DDS. Some spurious signals are due to amplitude modulation. Where the output of a DDS is not actually used directly for transmitting but is offset to another frequency in a mixer, choose the DDS signal as the high level LO drive to the mixer and the other translating signal as the lower level ‘signal’ input to the mixer — assuming the lower level signal itself is spur-free.

This is spur avoidance rather than reduction, but the result is the same. Another spur avoidance scheme is the hybrid synthesiser (Fig. 1). Here, a DDS operating at around 10MHz (say 10.7MHz) is used as the reference oscillator of a PLL synthesiser. Using a reference divider ratio of in the range 4 to 6, the system operates with a comparison frequency of around 2 to 3MHz. A variable reference frequency permits a simple single loop design, while the high comparison frequency enables the loop gain to be maintained up to a higher frequency than usual, keeping the VCO noise sidebands in check and permitting frequency changes that are very rapid for a PLL type synthesiser. Frequency settling between PLL steps is achieved by adjusting the reference frequency.

With this scheme, the range over which the reference frequency must be varied to provide continuous interpolation between the steps of the main loop varies inversely with the main loop divisor. Power available in modern microcontrollers means the additional control overhead presents no problem. It is true that the arrangement means that 10Hz steps will in general not be exactly 10Hz. But the 32-bit frequency resolution typical of a DDS will provide more than adequate resolution to ensure that any frequency can be set to well within the frequency accuracy of a typical equipment, even at an output frequency of 1GHz.

The range of frequency adjustment required is only a few tens of kHz, enabling an inexpensive but high-speed 10.7MHz crystal filter designed for the VHF PMR bands to be used. Tests on one of the DDS chips already mentioned showed that with a 40MHz clock, all spurious outputs were greater than 80dB down everywhere within the bandwidth of the crystal filter (though not elsewhere), over the required range of reference frequency adjustment. The result is a synthesiser system with frequency agility and low close-to-carrier noise levels.

In the third part of his series of articles on direct digital synthesis Ian Hickman turns his attention to spurious signals and looks at how to cope with them.
sps at the expense of raising the general noise floor – as was mentioned earlier, the total spur energy tends to be independent of whether it is concentrated in one or a few lines, or in a continuous sea of low level spurs (Fig. 4).

While NRC reduces AM spurs, it cannot suppress them completely and its effect may not always be apparent: eg if operating at a frequency where there is no large spur. One use for the NRC is to permit the use of a cheaper 8-bit D-to-A. The resultant performance then approaches that of a 10-bit D-to-A without NRC.

Handling PM spurs
The spur reduction techniques mentioned so far are aimed at reducing AM spurs, although as mentioned previously (Direct Digital Synthesis, EW & WW, August pp. 630-634), PM spurs are potentially more troublesome, as they cannot be suppressed by limiting. Both AM and PM sidebands appear in pairs equally spaced about the carrier and it is by no means uncommon to find both AM and PM at the same modulating frequency.

Low level AM and PM are orthogonal, with the result that on one side of the carrier the AM and PM sidebands are in phase whereas

Fig. 3a) The SP2002/A accepts clock frequencies up to 1600MHz (1400MHz for the military temperature range /B version) and provides RF outputs up to \( f_{\text{clk}}/4 \), with a choice of sine, triangle and square outputs, each available as an in-phase and quadrature pair with its inverses. This ECL chip runs on -4.5V and includes very fast on-board D-to-A to provide the 1 and Q sine or triangle outputs. 3b) To achieve its very high speed operation in silicon, the device stores only a fraction of the clock cycle. The upper trace shows the device clocked at 10MHz and outputting the result that on one side of the carrier the AM and PM sidebands are in phase whereas

Fig. 4.
**Types of DDS**

Some manufacturers produce DDS chips which provide a sinewave output directly — though it is of course a stepwise approximation rather than a smooth waveform. Such DDSs only need the addition of a frequency setting word input, a clock source and a lowpass filter at the output to provide a complete digital-frequency-command to RF-output synthesiser system. A good example is the GEC Plessey Semiconductors SP2002 (Fig. 3).

Other manufacturers’ DDS chips provide the step values representing an output sinewave in P-bit binary format, for application to a separate off-chip D-to-A converter. In these instances, P is usually in the range 8 to 16 bits. A good example of this approach is the Qualcomm Q2334, which outputs two sinewaves in 12bit binary form. There are advantages and disadvantages to using an internal D-to-A, but it is largely a matter of horses for courses.

For a DDS generating outputs at up to a few tens of MHz, an external D-to-A provides the user with greater flexibility (like choosing a lower resolution or slower but cheaper D-to-A where appropriate); for a DDS accepting clock frequencies up into the microwave region, an external D-to-A is not feasible, due to the delay and skew which would be produced in the longer data lines associated with an off-chip D-to-A converter.

**Fig. 4. Noise reduction circuitry in the Q2334 can reduce the levels of discrete line spurs at the expense of raising the general noise floor. (Reproduced by courtesy of Qualcomm Inc and Chronos Technology Ltd)**

**Fig. 5. Output of an SP2002 clocked at 400MHz with bits 28 and 13 set, giving a demanded frequency of 50.001526MHz (display centre frequency 50MHz, span 100kHz). (Institution of Electrical Engineers)**

**Fig. 6. Illustrating the reduction of phase deviation when a phase modulated signal passes through a frequency divider chain, showing for example how division by four reduces the modulation index by a factor of 4, corresponding to a 12dB reduction in PM sideband level. (Analog Electronics, Ian Hickman, Heinemann-Neuenes).**

on the other they are in anti-phase. This results in a pair of sidebands of unequal amplitude; for example the closest-in pair in Fig. 5 differs by 6dB.

After converting from log to linear (dB to volts), simple arithmetic shows that in this case, one sideband pair has three times the amplitude of the other. It is not obvious whether the sidebands are mainly due to PM, with smaller AM sidebands responsible for the difference in amplitude, or the other way round. Hard limiting would suppress the AM sidebands, leaving the two PM sidebands equal and at an intermediate level between those shown, or both 10dB lower than the intermediate level, respectively. If the AM and PM sideband amplitudes are equal, they will cancel out completely on one side of the wanted output, leaving an isolated spur on the other side.

An isolated spur is indeed often encountered, but it is more likely to be due to an image or alias. It results in both AM and PM, thus hard limiting will convert the single spur into a pair of PM sidebands, each 6dB lower than the original spur.

AM can be suppressed by limiting, but the only way to reduce PM is by frequency division. Dividing the output frequency of a DDS by a factor of two will reduce the PM sideband amplitudes by 6dB, by halving the modulation index — this assumes that the modulation index is small in the first place (Fig. 6).

Of course, the technique buys PM spur reduction at the price of a reduced frequency coverage (but finer resolution) from the DDS, but with GaAs DDS chips such as those from Sciteq (see picture) providing output frequencies up to 300MHz or more, this may not represent a limitation in many applications.

Where it is, the range covered can be restored by up-conversion in a DDS plus mix/filter arrangement. Both upper and lower sideband outputs can be used, selected by appropriate filters. But limitations of practical filters mean that there will be a band just above and below the up-conversion carrier that cannot be used.

The difficulty can be avoided, and the output frequency coverage extended to about three times the available range of the divided DDS output, by using one or other of two up-conversion carriers (Fig. 7). Here, (assuming $LO_2$ is higher in frequency than $LO_1$) the LSB of the former can fill in the gap between the sidebands of the latter and vice versa, providing continuous frequency coverage of 3N, where $N$ is the basic range of the DDS (or the range after division, if this is employed for PM spur reduction). In another application describing PM spur reduction by division, the division process involves squaring up the input sinewave for input to the digital dividers (Fig. 6), thereby suppressing any AM spurs as well as reducing the PM ones. “Division” can be carried out in the DDS itself, simply by limiting the maximum commanded frequency to one half, one quarter or whatever of the rated maximum output frequency.
At least one manufacturer states that this is more effective in minimising PM spurs than using the whole range of the DDS followed by division, especially if the post-DDS reconstruction lowpass filter's cutoff frequency is reduced appropriately. But the approach does not give the finer frequency resolution provided by dividing the DDS output frequency. 

Another scheme for spur reduction (or possibly it might be better described as spur avoidance) might be worth further investigation. The method uses two different clock frequencies, and relies on the fact that when the relation between the output frequency and the clock is a fairly complicated ratio, the spurious energy is dispersed among many lower level spurs rather than concentrated in just one or a few large ones.

Figure 5 shows the output of an SP2002 DDS clocked at 400MHz with FSW bits 28 and 13 set, giving a demanded frequency of 50.384MHz; several spurious signals are visible. If bit 14 or 15 or 16... is set instead of bit 13, the signals all move further and further away from the wanted output frequency, until with bits 28 and 21 set, the closest spur is about 800kHz away (Fig. 8, centre frequency 50.384MHz, span 4MHz).

If bit 13 is now set again (together with both bits 28 and 21) close-in spurs reappear, but only at a lower level, Fig. 9 (span 50kHz). This is in line with the observation that the more complicated the output to clock frequency ratio, the more lines the spur energy is distributed over, and the lower their general level. 

Thus if the 400MHz clock were used when generating frequencies in the region of 53.125, 59.375, 65.625... 96.875MHz and an offset clock of 425MHz when generating frequencies close to 50, 56.26, 62.5... 100MHz, a reduced level of spurious outputs (especially close-in spurs) should be particularly beneficial in a hybrid DDS/PLL application.

DDS sources can perform virtually all of the usual forms of modulation, thus implementing almost a complete transmitter exciter on a single chip. In addition to AM, FM and PM, FSK is simply achieved, with the added advantage over the FEK form that it is phase coherent and constant envelope. Thus FEFSK (fast FSK, also known as MSK - minimum shift keying) is also easily produced. The more complex forms of modulation such as 16-PSK or 64-APK, etc are also relatively straightforward in a DDS system.

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Most readers probably know that Henry Cavendish (1731-1810) was the first to prove experimentally what we call “Coulomb’s law” in the early 1770s. This was long before the French scientist himself announced his work, but Cavendish never published an account of his own researches. The story has intrigued historians of science since 1879 when Maxwell published Cavendish’s electrical researches, some of which had never been disclosed before.

Many hypotheses have been framed as to why Cavendish would not publish his proof of the law of electrostatic force — mostly bearing on Cavendish’s personality. For example, contemporaries speak of his haughtiness and neglect of others’ opinions. But this cannot really be supported.

True, he led a secluded life by devoting himself completely to science. But he did publish about twenty articles. He also invited colleagues to his house to demonstrate his experiments, amusing his guests with an “electric fish” made of wood and leather and placed in a bath with hidden Leyden jars to produce an electric shock.

He let people use his library — and he could cooperate with others as witnessed by his heading a committee on lightning protection.

Professor J. L. Heilbron suggests that Cavendish did not publish his results simply because of the incomplete state of his research, the want of an occasion and a growing interest in chemistry.

The first of these arguments seems to me especially convincing and I believe there might have been purely scientific reasons which kept Cavendish from making public his proof of “Coulomb’s law”.

Coulomb or Cavendish
Charles Augustin de Coulomb (1736-1806) formulated the “fundamental law of electricity” as follows: “The repulsive force of two small [conducting] globes charged with the same kind of electricity varies as the inverse square of the distance between the centres of the globes”.

He stated the same law for unlike changes (the attraction case), experiments with a torsion balance providing support for the law in both cases. Thus, electrostatic force is given by

\[ F \propto \frac{1}{d^2} \]  

where \( d \) is the centre-to-centre distance. Coulomb’s memoirs appeared in 1788.

On the basis of a single null experiment with an uncharged conducting sphere
embodied by two charged conducting hemispheres of a somewhat greater diameter, Cavendish arrived about 1773 at the law

\[ F = \frac{q_1 q_2}{4 \pi \epsilon_0 D^2} \]  

(2)

where \( q_{1,2} \) are the values of charges of infinitesimal geometric size. It is Eq (2) rather than Eq (1) which is known as Coulomb's law. But Coulomb could not help thinking of the case when \( q_1 \neq 0 \) and \( q_2 = 0 \), which is why he did not combine Eqs (1) and (3) established by him into Eq (2) to obtain a real "Coulomb law". He could afford to publish Eq (1) since it followed from a separate series of experiments (without charge division). At the same time, Cavendish could not afford to publish Eq (1) alone since his experiment yielded at once Eq (2) with its paradox which he probably could not resolve.

In connection with the paradox, it is interesting to evaluate the force of interaction between like conducting balls for \( q_1 \neq 0 \) and \( q_2 = 0 \). A comparison can be made by plotting the force of interaction \( F \) (in relative units) as a function of centre-to-centre distance \( D \) expressed as a multiple of radius \( R \) of a sphere (see figure). A straight line represents an idealised Coulomb law where charges \( q_1 = q_2 = q \) of spheres are concentrated at their centres (dependence \( F \propto 1/D^2 \) assumed). The upper solid line represents an attraction for \( q_1 = -q_2 \), and the lower solid line represents the repulsion for \( q_1 = q_2 \). The dashed line relates to the case of particular interest: \( q_1 \neq 0 \) and \( q_2 = 0 \). The latter three dependencies include electrostatic induction. Data used for construction of the curves are shown in the Table.

The dashed line shows that forces of attraction between a charged conducting sphere and an uncharged conducting sphere of the same diameter obey the law \( 1/D \) (the monopole-dipole interaction) quite precisely from \( D = 10R \) to \( D = 3R \), at which point it begins to increase rapidly with decreasing \( D \). The force remains finite even for \( D = 2R \).

Both the graph and table are due to Professor JA Soules of Cleveland State University who obtained them by a numerical method. He has treated \( q_1 \neq 0 \) and \( q_2 = 0 \) upon my request, for which I am especially grateful.

### Correct conclusion

In conclusion, I would like to remind readers of Benjamin Franklin's (1706-1790) experiment and a correct conclusion incorrectly drawn from it by Joseph Priestly (1733-1804). In 1755 Franklin discovered that a cork ball on a silk thread dipped into a charged metal can was not attracted by its walls and, when brought into contact with them, acquired no charge. From a vague analogy with Newton's work on the force of gravity within a hollow sphere, Priestley suggested, in 1767, Eq (1) for the electrostatic force. Professor Soules writes in the cited paper that a theoretical approach is more satisfactory in establishing Eq (1) than any experiment - but, from a modern standpoint only. Indeed, Franklin's experiment confirms Maxwell's equation: \( \text{div} \; D = p \) - a generalised form of Coulomb's law (take a closed surface passing inside walls of can). But in the 18th century, neither Maxwell's equations nor Gauss's theorem had been formulated.

So Cavendish could have rightfully claimed to be the first discoverer of what we call Coulomb's law.

### References

2. Ibid., pp.104-113.
6. LN Kryzhanovski. John Robison: the First Discoverer of 'Coulomb's Law'. Elektrichesvo (Moscow), 1990, No.8, pp.92-94. See also Heilbron, op. cit, pp.465-468. Robinson confirmed experimentally the inverse square law probably in 1769 but did not publish an account of his work until 1801, which is also a nice puzzle.
9. Heilbron, op. cit, p.464

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Fig. 1. This pulse generator offers independent control of frequency and duty cycle over the range 20Hz-200kHz and 0-100%.

Pulse generator with independent F and M/S setting

Using a CD4046 phase-locked loop, this pulse generator accepts independent settings of frequency and duty cycle.

Initially, the VCO in the loop holds pin six, one side of C<sub>1</sub> in Fig. 1, to ground, C<sub>1</sub> being charged by a constant current whose value depends on R<sub>3</sub> and the frequency-setting voltage at pin nine. When the resulting ramp at point B reaches the threshold of an internal inverter, an internal flip-flop changes state, whereupon point B is grounded and point A starts to ramp upwards. When this too reaches the threshold of an identical inverter, the flip-flop again changes state and the cycle repeats.

Since the internal inverters are identical, the ramps at points A and B are also identical. Figure 2 shows the circuit action.

Comparison of the two ramps with a variable reference voltage in the two LM311s produces output 1: mark/space variation is by means of adjustment of V<sub>ref</sub> and frequency setting by way of the control voltage on pin nine of the PLL. Output 2 is obtained by inverting output 1 in the PLL's phase comparator. Frequency is variable from 20Hz to 200kHz and duty cycle from 15% to 100% for output 1 and 0-85% in output 2 with a range of C<sub>1</sub> values from 0.1μF to 100pF.

M S Nagaraj
ISRO Satellite Centre
Bangalore
India

Fig. 2. Waveforms in the pulse generator. Note that the ramp starts from -0.6V, not zero volts, giving a duty cycle range of 15%-100% in output 1 and 0-85% in output 2.

Product detector for AM

A CA3189 FM IF chip makes a good AM synchronous demodulator. The circuit shown provides AGC, an S-meter output and synchronous detection and only needs the RF input. Alternate half cycles of the input to pin nine are inverted by the switching waveform generated in the chip, so that unidirectional half cycles of the modulated carrier appear at pin six and simply need a filter to remove the high frequencies to leave the demodulated AM. Potentiometer RV<sub>1</sub> sets AGC to suit the RF stages used and RV<sub>2</sub> adjusts the input to avoid overload. To start with, adjust the DC at pin six to 3V on the strongest signal.

R Gough
Shenstone Staffordshire

Using a CA3189 FM IF for synchronous detection of an AM signal.
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<td>£495</td>
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<tr>
<td>DYNAPERT MPS11B</td>
<td>£5,900</td>
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<tr>
<td>Pick + Place w/ Feeders</td>
<td>£3,350</td>
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<tr>
<td>CONTACT SYSTEMS 400 Ar/C Cut and Clinch Light Guided Assembly Workstations, Call for details</td>
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<td>AMBOTECH Ropin Axial/DIP Assemble Station</td>
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<td>BLAKEELL L5120 #1 Assembly Station</td>
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<td>MMM ASP 24 Screen Printer Make of</td>
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<td>OMNITAC</td>
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#### Test Equipment

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<td>MARCONI 2019 Signal Generator</td>
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<td>MARCONI 2371 Spectrum Analyser</td>
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<tr>
<td>H.P. 3225A Function Generator</td>
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<tr>
<td>Tektronix 2455 Oscilloscope</td>
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#### ATE Systems

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<td>MARCONI 515 Call for details. Only used 200 hrs.</td>
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<td>MARCONI 510 Two systems available.</td>
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<td>CUSTOM CR1 Router</td>
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<td>ABERRATOR 200B 400MHz</td>
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<td>MARCONI R00 512 Test Points</td>
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<td>GENRAD 2272 1024 Driver Sensor</td>
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<td>GENRAD 2276XP 1088 Test Points</td>
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**CIRCLE NO. 137 ON REPLY CARD**
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187: As 185 except auto ranging. £75.00 plus VAT (£88.13).
285: As 185 except 4½ digit true rms, basic accuracy 0.05%. £89.50 plus VAT (£105.16).

MULTIMETERS (2)
The MX170B and MIC-6E offer low cost measurement yet retain a large number of features. Supplied complete with probes.
MX170B: 3½ digit LCD, compact size, ACV, DCV, DCA, resistance, diode test, low voltage battery test. £18.50 plus VAT (£21.74).
MIC-6E: 3½ digit LCD, ACV, DCV, ACA, DCA, resistance, diode test, buzzer. £33.50 plus VAT (£39.36).

20MHz 2-CH OSCILLOSCOPE
The CS4025 20MHz dual trace oscilloscope offers a comprehensive range of facilities including a high sensitivity vertical amplifier providing from 1mV to 5V/div in CH1, ALT, CHOP, ADD, CH2 modes with inverse polarity on CH2. The horizontal timebase offers a sweep range of 0.5s/div to 0.5μs/div plus x10 sweep expansion and X-Y mode. Triggering can be auto or normal from vert, CH1, CH2, line or external sources with coupling provided for AC, TV-F and TV-L. The CS4025 is supplied complete with matching probes for £295.00 plus VAT (£346.62).

PROGRAMMABLE POWER SUPPLIES
The PPS series of GPIB programmable DC power supplies offer high performance yet are extremely competitively priced using a 16 x 2 backlight LCD and 14 button keypad. All functions and conditions are easily selected and displayed. Overvoltage and overcurrent are selectable as is output enable/disable. Terminals for output and sense are provided on the front and rear to allow easy rack mounting.
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PPS-2322: Dual 0-32V 2A (GPIB) £555.00 plus VAT (£652.13)
**FUNCTION GENERATOR**

The MX2020 0.02Hz – 2MHz sweep function generator with LED digital display offers a broad range of features. Output waveforms include sine, square, triangle, skewed sine, pulse and TTL. Linear and logarithmic sweeps are standard as is symmetry, DC offset and switchable output impedance from 50Ω to 600Ω. The digital display provides readout of the generators' frequency or can operate as separate 10MHz frequency counter. £175.00 plus VAT (£205.63).

**LCR METER**

The MIC-4070D CD digital LCR meter provides capacitance, inductance, resistance and dissipation measurement. Capacitance ranges are from 0.1pF to 20,000pF plus dissipation. Inductance ranges from 0.1nH to 200H plus a digital readout of dissipation. Resistance ranges from 1mΩ to 20MΩ. Housed in a rugged ABS case with integral stand it is supplied complete with battery and probes at £85.00 plus VAT (£99.88).

**FOUR INSTRUMENTS IN ONE**

The MX9000 combines four instruments to suit a broad range of applications in both education and industrial markets including development work stations where space is at a premium. The instruments include:

1. A triple output power supply with LCD display offering 0-50V 0.5A, 15V 1A, 5V 2A with full overcurrent protection;
2. An 8-digit LED display 1Hz - 100MHz frequency counter with gating rates of 0.1Hz, 1Hz, 10Hz and 100Hz providing resolution to 0.1Hz plus attenuation inputs and data hold;
3. A 0.02Hz to 2MHz full featured sweep/function generator producing sine, square, triangle, skewed sine, pulse and a TTL output and linear or logarithmic sweep. Outputs of 50Ω and 600Ω impedance are standard features;
4. An auto/manual 3½ digit LCD multimeter ranging DCV, DCA, ACV, ACA, resistance, and relative measurement with data hold functions.

The MX9000 represents exceptionally good value at only £360.00 plus VAT (£423.00).

**FG SERIES FUNCTION GENERATORS**

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CIRCLE NO. 138 ON REPLY CARD
Temperature transducer

Analog Devices's AD592 is a two-terminal IC that puts out a current proportional to absolute temperature, at high impedance and with 1μA/K sensitivity. It needs no linearisation circuitry, voltage reference, bridge components or cold junction compensation and can be used over the same temperature range (-25°C to 105°C) as other kinds of transducer. Its high-impedance current output makes it invulnerable to the voltage drops and noise encountered on long lines and non-linearity is guaranteed less than ±0.1% over the whole range.

As an example of a very simple application, Fig. 1 shows two circuits for measuring average and minimum temperatures of separated transducers. On the left, currents are added to give the average and on the right the current is proportional to the lowest temperature, since the coldest device limits current through the chain.

Figure 2 converts temperature to a 4-20mA current for use with 40V, 1kΩ systems. The AD592 output is amplified to 1mA/°C and offset to give 4mA/20mA equivalent to 17°C/33°C. Rf is trimmed for correct reading at an intermediate temperature. The AD581 is a 10V reference. Using an AD670 8-bit A-to-D converter, a digital output for a microprocessor is obtained. Figure 3 shows a circuit to resolve 1°C over the whole 130°C span for which the device is rated.

Figure 4 is a temperature controller to operate over the entire 130°C range; Rhigh and Rlow determine the limits settable by Rset. The AD581 keeps the set point constant and maintains 7V across the AD592. Resistor Rbg and C introduce a measure of hysteresis to reduce the effects of noise.

Figure 1. Analog Devices AD592 temperature transducers used to measure average (left) and minimum temperatures of a number of remote devices.

Figure 2. Temperature measurement for a 4-20mA current-loop system, in this case between 17°C and 33°C, although the circuit will measure over the whole 130°C range of the AD592 if the 35.71Ω and 12.7161 resistors are varied.

Figure 3. A thermostat. The 10V AD581 reference keeps the bridge voltage constant. Resistor shown dotted may be needed to guard against noise.
Inexpensive radio data receiver

When the BBC’s Radio 4 long-wave service moved from 200kHz to 198kHz, it was made to carry additional data in the form of phase modulation, to be used for remote time switching for lighting, for example, advertising display updates, radio clocks and even full-blown data transmission. Plessey, in its application note AN86, described a circuit to demodulate received data that can be built at a much lower cost than some available equipment. Plessey’s SL6653 is a low-power (2.5mA at 2.5V-7.5V) IF/AF circuit for FM demodulation, containing mixer/oscillator, limiting IF amplifier and detector and was originally meant for cellular radio, cordless telephones and low-power radio. This and TAB1043 quad op-amp, a fet and a bipolar transistor are the only active devices used.

Data rate is restricted to 25bit/s to avoid interference with the AM broadcast, and is therefore kept within a 0-50Hz band. Thirty blocks per minute are transmitted, each containing a cyclic redundancy check (CRC) error-checking code. Block 29 contains information on time, day, month, year, leap year and local offset. The BBC Research Department at Kingswood Warren, Surrey KT20 6NP has a publication on LF data.

Figure 1 shows the form of the ±22.5° data modulation on Radio 4, from which a 1.8V pk-pk phase signal is to be obtained and Fig. 2 is the radio part of the circuit.

Aerial signal goes to a fet buffer, which provides matching between the aerial and the following crystal filter, a special unit by AEL Crystals Ltd of Horley to reduce the level of interference from switched-mode power supplies in computer terminals and television receivers. Filtered input at 198kHz now goes to the SL6653 limiter, from which it emerges as a square wave at pin 1, is phase-shifted by the quad circuit and goes back to the FM demodulator. Transistor T3 buffers the demodulator output to drive the filter in Fig. 3 and its test point TP2 is also useful in adjusting the tuning of the quadrature circuit.

The first op-amp in Fig. 3 acts as a Sallen and Key low-pass filter to prevent trouble with AM or spikes affecting the phase output. This is followed by an amplifier with a gain of 45 to give a 1.3V-2V pk-pk phase signal at TP4.

Since frequency is a rate of phase change and the data signal is a phase shift, the output from the demodulator is differentiated and an integrator is needed to make a phase demodulator. The third quarter
of the TAB1043 is therefore a simple integrator, its DC reference still being referred back to the quad detector and drift in tuning tracked by the integrator. From this op-amp, the output is the original signal seen in Fig. 1.

A comparator now removes the varying DC component from the signal by comparing a smoothed version of it \((27k\Omega/6.8\mu F)\) with the raw input from the integrator. Output signals consist of two frequencies of 12.5Hz and 25Hz, from which clock and data are recoverable, preferably by using a microprocessor to sample the data to find an edge in the middle of each 40ms clock interval. A rising edge denotes a 1 and a falling edge a 0.

**Plessey Semiconductors Ltd, Cheney Manor, Swindon, Wiltshire SN2 2QW.**
Tel: 0793 518000.

**Fig. 2.** Receiver section of data demodulator. Testpoint 1 is for aerial tuning and Tp2 for quad coil tuning.

**Fig. 3.** Demodulator section. TAB1043 has adjustable open-loop gain and requires the 56k resistor. Adjust the amplifier's 47k feedback resistor to allow for varying Q in the quadrature circuit.
A-to-D & D-to-A converters

12-bit multiplying D-to-A. In one 24-pin narrow dip, Maxim’s Max572 holds four independent multiplying serial 12-bit converters and dissipates 10mW maximum. The converters have 1.5LSB gain accuracy, 1LSB relative accuracy, are monotonic and exhibit a settling time to 0.5LSB of less than 1μs. Each converter has its own reference input and a common 5V supply. Maxim Integrated Products, 0734 945255.

Quad D-to-A. Maxim’s new Max573 quad multiplying 12-bit voltage-output D-to-A converter for 5V systems replaces four separate converters and four output amplifiers; it has guaranteed monotonic 12-bit performance with ±0.5LSB relative accuracy over the commercial, industrial or military temperature ranges for all outputs. With 50mW power consumption, the device offers a 5μs settling time and THD+N is less than 0.024% with 850mV reference signal up to 10kHz. Bandwidth of –3dB is 700kHz. Maxim Integrated Products UK, 0734 945255.

Discrete active devices

Micropower high-side driver. Linear’s LTC1175 quad high-side n-channel mosfet driver draws only 95μA from 5V (15μA when all four outputs are off). It has short-circuit protection and needs no extra components to drive four n-channel mosfet gates to 12V from the 5V supply. Each gate is independently controlled and ramped to eliminate interaction and to reduce RFI and EMI. The short protection comes on in 10μs, but can be delayed to handle difficult loads. Linear Technology (UK) Ltd, 0276 677676.

Small 1A mosfet. Zetex’s ZVN4306A mosfet passes 1.3A continuous current but measures 4mm by 2.4mm by 4.7mm and is believed to be the world’s smallest. On resistance is 0.22Ω at 3A and 10V gate drive. Peak current is 20A, breakdown 60V and dissipation around 1W. With turn-on and turn-off times of 8ns and 30ns, respectively, it is suitable for use in HF DC-to-DC converters. Zetex plc, 061 627 4963.

Transient suppression. Zener/avalanche diode fast-acting voltage clamps from Zetex, the 1.5KE and PEKE, handle large pulse currents and up to 1.5kW and 600W respectively. Voltages available in the 1.5KE series are 6-8-200V, while in the PEKE types the range is 6-8-200V. Both come in unidirectional or bidirectional form with 5% tolerance. PEKE devices operate in less than 1μs. Zetex plc, 061 627 4963.

Linear integrated circuits

Dual comparator. Common-mode range of –4 to 8V and propagation delay of 3ns are features of the Signal Processing Technologies SPT9691 dual JFET-input comparators. Tracking bandwidth is 300MHz at –3dB, open-loop gain 80dB, input OIP4, differential input voltage range ±10V and differential input R 20Ω. No external buffering is needed. Ambar Cascom Ltd, 0208 434141.

Dual op-amp. Input circuitry of Analog’s OPZ575 dual op-amp combines JFET and bipolar techniques to obtain the advantages of both: low distortion and voltage noise from the bipolar circuitry; and fast slewing, low power and wide dynamic range from the JFET. THD+noise is 0.0006%, with 6mW Hz voltage noise density. Current noise density is 1.5μA/Hz and input offset voltage less than 20μV, slew rate is 225μA/μs. Analog Devices, 0932 253320.

700MHz buffer amplifier. Harris’s HFA1110 uses the company’s UHF-8GHz bipolar process to produce a closed-loop buffer amplifier with a 700MHz bandwidth and selectable gain of +1, –1 or +2 with no extra components. Slew rate is 2500μV/μs and setting time to 0.02% is 7μs. A gain error of 0.01%V/V and gain flatness with frequency of 0.3%dB is made to 50MHz make the device very suitable for handling video. Harris Semiconductor (UK), 0276 686686.

Voltage reference. LM4431 is claimed by National Semiconductor to be the smallest ever voltage reference and is contained in an SOT-23 transistor package. No external capacitor is needed. Intended for high-volume manufacturing in areas such as disk drives and personal computers, it has a 2.5V fixed reverse voltage breakdown with 52% accuracy. 0-70degC temperature range, 35μV RMS output noise and 100μA-15mA operating current. National Semiconductor, 0793-697466.

Logic building blocks

Elapsed-time counter. Dallas’s DS1603 elapsed-time counter module counts and records the time during which power is applied to it and the system in which it works. It also functions as a real-time clock and can be reset and used to measure equipment use during a set time. Accuracy is within ±1μs/month and, since it has a 1Hz output, is usable as a clock for other functions. Its three-wire serial link comprises data line, clock and reset. Dallas Semiconductor Corp, 021 782 2156.

PC lua. Super I/O II by National Semiconductor is XT/AT-compatible and is meant for use in i/o-intensive applications. The low-power device offers floppy-disk control for four 2.88Mbyte drives, two UARTs, a bidirectional parallel port, an IDE interface for two hard drives, XT/AT address decoding and configuration registers to select addresses, erasable, disable or power-down. Super I/O III is a pin-compatible unit, but with more powerful uarts. National Semiconductor, 0793-697466.

Memory chips

Fastest 1Mb eprom. Atmel claims its AT27HC1024 1Mb erasable rom, with a read-access time of 45ns, to be the fastest available. Zero-wait-state operation is possible and the device offers the Atmel rapid-programming algorithm for accurate programming in 100μs/byte. Current consumption is 80mA at 10MHz (active) and 8mA (standby). It is organised as 64K by 16bit. Atmel (UK) Ltd, 0276 986677.

Microprocessors and controllers

High-speed correlator. Harris’s H863 contains a 33MHz, multiple configuration binary correlator, a device which compares a reference signal with an input and assigns a score based on the level of agreement between the two. Such a device is needed to detect, recognize or synchronize data among other data or noise in, for example, error detection and pattern recognition.

There are 256 taps, which can be arranged in many different ways, from a single 256 tap to two independent 4 by 32 tap correlators, up to 16 devices being cascaded. Double registers allow new data input while correlation is taking place. Harris Semiconductor (UK), 0276 686886.
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Please quote "Electronics World + Wireless World" when seeking further information.

**Opto sensor.** An alternative CCD image sensors and photodiode array, T712514 integrated opto sensor needs only a 5V supply and a pair of timing pulses. Output video reference and Sin circuitry are incorporated and the devices can be combined in parallel or serially. Data rate is from 10kHz to 50kHz. The image consists of an addressed line of 64 charge-mode pixels, analogue and digital edge. There is also the PC404 evaluation kit containing a sensor, drive board, lens and all clock and interface logic. Texas Instruments, 0234 233525.

**Risc microprocessor.** ARM610, a new member of VLSI's 32-bit risc micro family, gives 12K Drystones at 200MHz to suit any of the 32-bit processor allowing real-time display. ARM610, a new member of VLSI's 32-bit risc micro family, gives 29K Drystones at 261188.

**Optical devices.** High-power IR. Gallium aluminium arsenide infrared filters. Opto Diode will put out up to 6.5W. Three, six or nine chips in each package, working at 890nm, are on T060 gold headers and benfylum oxide substrates for high performance. Herof offers a designers’ data book. Hero Electronics Ltd, 0525 405015.

**Transmissive sensors.** TQ55201/2021 transmissive optical sensors from Telefunken Electronic have an aperture of 0.5mm for high resolution in paper positioning or as the sensors in shatt encoders. They work at a wavelength of 950nm and have TTL-compatible Schmitt open-collector outputs, which rise and fall in 50ns and 20ns at a maximum of 3kHz. The 55201 is a snap-fitting type, while 6201 is screw mounted. Transmitter and receiver are available separately as the TC25 6100. Siliconx Ltd, 0395 30805.

**Colour CCD.** Sony's ICX05SBK-6 is an interface transfer CCD image sensor for use in pal 1/3in colour video cameras. Separate yellow, cyan, magenta and green complementary colour mosaic filters giving 6dB sensitivity improvement over the earlier unit and the use of Sony's hole accumulation diode (HAD) gives low smearing and high anti-blooming. Effective image area is 500 by 582 pixels. The 5021 is a snap-fit type, while 6201 is screw mounted.

**Programmable logic arrays.** Fast, sub-micron gate array, AT800 gate arrays from Amnel are fabricated in 0.8micron process, 11 arrays in the family provide gate counts up to 180,000 and up to 490 pins. Delay: 200ps and supplies from 3V to 5.5V, the devices still operating at 2.4V. Passive components are relevant and the current cell libraries for 1micron ATL designs are compatible. Amnel (UK) Ltd, 0276 686677.

**2000-gate FPGA.** QuickLogic claims that its GL21216 high-speed, 2000-gate field-programmable gate array is the only such device available that will provide zero-wait-state support for 33-55MHz microprocessors. It can be used instead of masked arrays or to integrate high-speed pals. It is organised as a 12 by 16 array, each cell containing a flip-flop and enough logic to form two latches, resulting in 576 storage cells. QuickLogic, USA +1 408 987-2000.

**Power semiconductors.** Power mosfet. Phillips's BUK101-50OL is meant for use in car electronics and is a logic-level power mosfet, protected against overload and high temperature. Salient virtues are 50V off-state drain/source volts, continuous 20V/20A working, 75W dissipation, continuous 150degC junction temperature and a 60mΩ on resistance. Control and logic supplies are derived from the input. Gothic Creion Ltd, 0734 788878.

**Linear regulators.** Three units in the Semtech range of 2A linear regulators produce outputs of 5V, 12V and 15V, the fourth device having an adjustable output from 4V to 30V; all the models have a grounded case. Temperature stability comes from the use of a band-gap reference and the power management circuitry limits internal voltage rise to the rated input voltage maximum of 40V and 20W dissipation. Semtech Ltd, 0592 773520.

**Passive components.** SMT pots. A true surface-mounted potentiometer from Murata, the POT0102, is a multi-turn type capable of withstand wave soldering and cleaning. It measures 6.35 by 6.35 by 4.9mm and has a resistance range of 10Ω to 1MΩ ±10%. Units are rated at 0.25W and have a maximum wiper current of 100mA, working at 300V. Murata Electronics (UK) Ltd, 0252 611666.

**Filters.** Wide-range filter. Two-channel programmable filter from Kemo, the VBF-10, offers a million-to-one range of cut-off frequencies: 0.1Hz-102.3kHz. Each channel is gain-programmable from −11dB to 10dB, can be connected in series or parallel and can be controlled by RS232 or GPIB. Additional units will expand the system to give up to eight pairs of channels and can be internally connected to provide bandpass, bandstop, lowpass and highpass characteristics. All functions are controlled from the front panel. Kemo Ltd, 081 658 3838.
Saw filters. Murata’s first surface-mounted saw filters are known as the SACF series, which are suitable for reflow soldering and organic washing. Murata Electronics (UK) Ltd, 0252 811666.

RFI suppression. Corcom Q filters are meant to reduce RFI in equipment working at 10kHz and above; in particular, switching power supplies. Filters can be mounted on chassis or back panel, with or without IEC connectors. Maximum current rating is up to 6A, depending on the type. The list of approvals includes VDE, CSA, UL and Semco. Sterling Components Ltd, 0753 820753.

Hardware

Heat-sink attachment. A self-locking, solderable stand-off tag from Aavid gives a positive snap-in heat-sink attachment that retains heat sinks in position during flow soldering and organic washing. Murata’s first surface-mounted saw filters are known as the SACF series, which are suitable for reflow soldering and organic washing. Murata Electronics (UK) Ltd, 0252 811666.

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Four-in-one. MX9200 from Saje contains four of the most frequently used instruments in one case: a power supply, a frequency meter, a function generator and a multimeter. The PSU provides 0-50V at 0.5A, 15V 1A and 5V 2A, with an LCD. An eight-digit counter measures 1Hz-100MHz with data hold. Sine, square, triangular, skewed sine, pulse and TTL outputs and a log/linear sweep into 50Ω or 600Ω from 0.02Hz to 2MHz are available. The instrument has a 310mm, medium-persistence trace. Saje Electronics, 0223 425440.

12in oscilloscope. Dual-trace oscilloscope from Thurlby-Thandar has a 310mm, medium-persistence trace and is meant for use with a sweeper to display frequency response. Model 12F displays four traces on the 8kV tube, including two from the sweeper, and the medium persistence traces are taken care of by any flicker. A clamp holds the baseline stable. Sensitivity is 1mV/div. and -3dB bandwidth 10kHz. Thurlby-Thandar Ltd, 0480 412451.

Power supplies

High-voltage converters. Brandenburg’s 3.5kV DC-to-DC converters in the 390 series now have an output ripple less than 300mV pk-pk. 12V versions have been added to the original 24V types. Output is from 10V to 3.5kV, either positive or negative. SW being available at the maximum voltage setting. Temperature coefficient is 100pp/°C and the units measure 95 by 50 by 12in. Saje Electronics, 0279 626777.

Instrumentation

Digital wattmeter. Yokogawa’s 2534 is a single instrument for measurements at DC and in the range 10Hz-20kHz. Its sampling process renders it immune to waveform distortion, so that it can be used in circuitry such as switched-mode supplies to an accuracy within 0.5% of full scale. Three displays indicate voltage, current and power simultaneously, with the ability to integrate the displays to give active power, reactive power and energy consumption. Frequency measurement is available from 4Hz to 22kHz and the instrument has optional GPIB or RS-232C interfaces. Martron Instruments Ltd, 0494-459200.

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On and off-line DSP. For both real-time processing and off-line data reduction, Signalysys’s ACP-store sends digitised signals direct to hard disks or tape and in parallel to a PC. Inmos standard modules provide up to eight channels of anti-aliasing to perfection. The cost of layout design by placing a single function call. Decompression is integrated by way of an existing software development kit. The company also offers SDK v.1.2 Resolution Enhancement, which is capable of code inline filtering and several I/O enhancements. Spox will run on PCs or Sun workstations, the versions of which are available. The GNU C Software development tool kit for DSP56000/1 digital signal processors enables high-level language access to DSP development, by-passing assembly-level programming. The GNU C compiler increases program execution speed by a factor of nearly two and in real-time processing such as filtering or spectral analysis. “Instruments” include two kinds of oscilloscope (“knobs” or “push-buttons”), a data recorder to disk and a spectrum analyser. Filter design incorporates allows one to make digital filters as required and to insert them into the application in use. Bores Signal Processing, 0483 740138.

Image compression. Fractal Transform image compression software from Iterated Systems can be integrated into users’ dos or Windows applications by means of the SDK v.1.0 Software Compressor with a single function call. Decompression is integrated by way of an existing software development kit. The company also offers SDK v.1.2 Resolution Enhancement, which is capable of code inline filtering and several I/O enhancements. Spox will run on PCs or Sun workstations, the versions of which are available. The GNU C Software development tool kit for DSP56000/1 digital signal processors enables high-level language access to DSP development, by-passing assembly-level programming. The GNU C compiler increases program execution speed by a factor of nearly two and in real-time processing such as filtering or spectral analysis. “Instruments” include two kinds of oscilloscope (“knobs” or “push-buttons”), a data recorder to disk and a spectrum analyser. Filter design incorporates allows one to make digital filters as required and to insert them into the application in use. Bores Signal Processing, 0483 740138.

Software

Virtual instruments. Amps from Bores is a combined hardware and software package that provides a Windows-based approach to instrumentation and DSP hardware for analogue I/O and real-time processing such as filtering or spectral analysis. “Instruments” include two kinds of oscilloscope (“knobs” or “push-buttons”), a data recorder to disk and a spectrum analyser. Filter design incorporates allows one to make digital filters as required and to insert them into the application in use. Bores Signal Processing, 0483 740138.

Development and evaluation

PIC16C5X programmer. Low-cost programming for the Arizona PIC16C5X range of microcontrollers is made possible by the ASL programmer, which costs £99. It consists of a free-standing PCB and requires an 18V-30V PSU, connecting to a PC via RS232. PIC software consists of a free-standing PCB and display the only components in use. The whole system is contained inside the PC or in an expansion chassis. Signalysys Ltd, 0296 631306.

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**DESIGN BRIEF**

**Bootstrap base to bridge building**

High input impedances are required for bridge detector circuits used in measuring small capacitances. Ian Hickman bootstraps his way to a solution.

In a bridge detector both inputs of the detector amplifier should have such a high input impedance that even on extreme bridge ratios, for example when measuring very small capacitances, they do not load the bridge arms.

The detector amplifier should also have a very high CMRR (common mode rejection ratio). This is particularly important when the impedances of the lower arms of the bridge are much higher than those of the upper arms, since the difference signal that has to be detected rides on a much larger common mode component.

Bootstrapping is a good way to achieve the necessary high input impedance for such applications — given a suitable circuit design. Simply view a square-wave source via a high series resistance to obtain a quick guide as to whether the bootstrapping is effective over a range of frequencies.

A very high input impedance at 0Hz — a high input resistance — is provided by any jfet input or cmos op amp. For instance the RCA bimos CA3130 op amp which has been around since the 1970s features a typical input resistance of $1.5 \times 10^2 \Omega$ or $1.5 \times 10^2 \Omega$. Input characteristics of some of the wide range of Texas Instruments op amps are as shown in Table 1.

**TLE2061 attraction**

Low input capacitance and high input impedance makes the TLE2061 an attractive choice. This jfet input micropower precision op amp offers a high output drive capability of $\pm 2.5 \text{V (min)}$ into $1000 \Omega$ on $\pm 5 \text{V}$ rails and $\pm 12.5 \text{V (min)}$ into $600 \Omega$ on $\pm 15 \text{volts}$ rails, while drawing a quiescent current of only $290 \mu\text{A}$.

The device operates from $V_C$, supplies of $\pm 3.5 \text{V}$ to $\pm 20 \text{V}$, with an input offset voltage as low as $500 \mu\text{V}$ (BC version), while its decom-

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**Bootstrapping Blumlein**

Bootstrapping is a powerful technique, long part of the circuit designer’s armoury. AD Blumlein is often credited with its invention, in connection with his pre-war work at EMI laboratories developing the 405-line television system. The technique enabled the signal lead from the TV camera tube to its preamplifier to be screened, without adding so much stray capacitance as to reduce the signal’s bandwidth.
Table 1. Input characteristics of TI op amps.

<table>
<thead>
<tr>
<th>Device</th>
<th>C_i, pF</th>
<th>I_{in} (typ at 25K)</th>
<th>R_{in} typ</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC27L9, TLC277</td>
<td>not quoted</td>
<td>0.6nA</td>
<td>1TQ</td>
</tr>
<tr>
<td>TLC2281</td>
<td>not quoted</td>
<td>1.6pA</td>
<td>not quoted</td>
</tr>
<tr>
<td>TLE2021 (bipolar)</td>
<td>not quoted</td>
<td>25µA</td>
<td>not quoted</td>
</tr>
<tr>
<td>TLE2027, TLE2037 (&quot;</td>
<td>8pF</td>
<td>15nA</td>
<td>1TQ</td>
</tr>
<tr>
<td>TLE2061, TLE2161</td>
<td>4pF</td>
<td>3pA</td>
<td>1TQ</td>
</tr>
</tbody>
</table>

**TIME BASE = 500µS**

**CH1 V/DIV = 2V**

**CH2 V/DIV 2V**

![Fig. 3. Jfet input unity gain buffer circuit's output is indistinguishable from its input.](image)

The input capacitance is far more significant than that of the input resistance. Use of guard rings, as recommended in the data sheet, will maintain the high input resistance and will minimise stray capacitance external to the op amp, (see Fig. 5; the similarity to Figure 1 is clear).

Bootstrapping cannot reduce the effect of the device’s internal input capacitance, however. So precede the op amp with a discrete bipolar buffer stage, using a BC108 (Fig. 6). The inadequate input resistance and lower than unity gain with this arrangement is evident on comparing the lower trace with the upper. But the high frequency response is better than in Fig. 4 – which is to be expected as the input capacitance is now only that of the transistor, mainly C_EB or C_{GD} approximately. The data sheets give this as 6pF max, although the Transistor DATA Book (Vol. 1, 1977) gives C_EB typical as 2.5pF. The input time constant is about half that in the circuit of Figure 4.

Bootstrapping boon

On the face of it, the result is hardly an improvement; slightly lower input capacitance has simply been traded for a much lower input resistance. This is where bootstrapping really comes into its own, hauling the input up by its own bootstraps.

Stage 1 involves bootstrapping the BC108’s collector (Fig. 7), which is seen to be very effective in shortening the input time constant, though there is still a shortfall in low frequency gain.

The all-important point to note is that the bootstrapping of the collector only works because there is a separate stage following the emitter follower, providing current gain. The collector cannot be bootstrapped from the input emitter follower’s own emitter, even though such an arrangement has previously been proposed in EW + WW.

Stage 2 extends the bootstrapping to the input emitter follower’s emitter circuit (Fig. 8). Now the output (lower trace) is indistinguishable from the input. The improvement does not extend down to DC – the input resistance at 0Hz being unchanged – but only

![Fig. 5. Guard rings around the input terminals minimise the effect of board leakage and capacitance by surrounding the input pins with copper track at the same potential as the input. There is thus no potential difference to force current through any leakage paths or through stray capacitance.](image)
far it is now possible to push the circuit, replace the 10MΩ input resistor by a string of five 10MΩ resistors. The result is a substantially reduced output shown in Fig. 9 – an unduly rapid collapse, bearing in mind how good the performance had been with 10MΩ series resistance.

Probing around the circuit shows that the emitter swings between –2V and –4V, due to the volt drop caused by the transistor’s base current flowing through the 50MΩ resistor. So the emitter current is totally inadequate. Checking the DC conditions (the first recourse when a circuit is not behaving it ought) and raising the op amp supply rails to ±15V resulted in an output virtually as good as in Fig. 8.

Clearly, properly applied, bootstrapping can raise the input impedance at DC and up to a frequency determined by the op amp’s performance, to such a high level that a 100MΩ source resistance results in no loss in amplitude – ie to an input impedance of 100MΩ or more.

As a matter of interest, the circuit of Fig. 9 (with ±15V rails) can be modified by substituting a BF244 N channel small signal JFET for the BC108. Of course there is no volt drop across the 50MΩ input resistance, and the op amp output voltage sits at a positive level set by the JFET gate source reverse bias voltage at the source current defined by the two 82K resistors.

The JFET’s drain gate capacitance is the best part of 2pF, so the collector bootstrapping is still necessary. But the input resistance is so high that a source circuit bootstrapping capacitor is not needed.

down to a frequency at which the time constant of the emitter bootstrapping circuit starts to be significant.

To extend the bootstrapping down to DC, the emitter circuit bootstrap capacitor would need to be replaced by a zener diode. To see how
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Discount for Educational Establishments
Filtering will remove the input components which cause A-to-D aliasing errors. David Mawdesley* explains why choice is a matter of compromise.

Preventing signals containing frequencies above a certain limit to an A-to-D converter is going to result in aliasing errors in its output. Avoiding components in the input likely to cause aliases is vital — but even if a measured signal is known to have only frequency components below a certain value, spurious effects from the system might appear as higher frequency noise in the signal presented to the A-to-D. Sharp transitions in the measured signal can excite resonances, which may cause aliases, and general system noise and electrical pick-up all contribute to uncertainty.

One common misconception is that the problem can be eliminated with a fast sampling A-to-D card, but in practice this is not a viable option. Increasing the sampling rate causes severe problems due to memory limitations and the lower resolution converters needed to run at these speeds. PCs are limited in their data throughput capacity too, and many data acquisition packages are unable to handle data at higher sampling rates.

Filtering after A-to-D conversion is also not possible, and filtering must be carried out before digitising, in the analogue domain.

Sampling rate
What is the appropriate sampling rate of an A-to-D converter for measuring signals in the frequency range from 0Hz to a chosen maximum frequency \( f_{\text{max}} \)? Theory indicates that this sampling frequency must be at least twice the highest frequency component in the analogue signal. This sampling rate is generally referred to as the Nyquist rate. In turn, the frequency at half the sampling rate is called the Nyquist frequency, and any component above this frequency may appear as an alias. To avoid the possibility of aliases corrupting results of the measurements, an anti-alias filter must be used. A suitable low-pass analogue filter placed immediately before the A-to-D converter can block all frequency components capable of causing aliases from reaching the convertor. Cut-off frequency \( f_{\text{c}} \) of the filter is set to the highest frequency of interest so \( f_{\text{c}} = f_{\text{max}} \). Then, in principle, the convertor should have a sampling rate of at least twice the cut-off frequency of the filter. In practice, the sampling rate needs to be somewhat higher than twice \( f_{\text{c}} \).

Anti alias filters
An anti-alias filter reduces out-of-band alias-producing signals to less than the quantisation threshold of the A-to-D converter — without introducing distortion of the signal’s in-band components and without affecting overall measurement accuracy. The high frequency rejection requirements are determined by:

- Highest frequency of interest \( f_{\text{max}} \).
- Sampling rate, and
- A-to-D convertor resolution.

The highest frequency of interest sets the cut-off frequency of the filter.

\[ f_{\text{c}} = \frac{f_{\text{max}}}{2} \]

Fig. 1. Highest frequency of interest sets the cut-off frequency.

\[ \text{Limit of resolution} \quad f_{\text{c}} = f_{\text{max}} / 2 \]

\[ \text{Nyquist frequency} \quad f_{\text{n}} = \frac{f_{\text{max}}}{2} \]

\[ \text{Sampling frequency} \quad f_{\text{s}} = 2f_{\text{n}} \]

\[ f_{\text{s}} = \frac{f_{\text{max}}}{2} \]

\[ f_{\text{c}} \]

\[ f_{\text{max}} \]

\[ f_{\text{c}} = f_{\text{max}} / 2 \]

\[ f_{\text{n}} = \frac{f_{\text{max}}}{2} \]

\[ f_{\text{s}} = 2f_{\text{n}} \]

\[ f_{\text{s}} = \frac{f_{\text{max}}}{2} \]
Implementation

Even the most esoteric of anti-alias filters will probably consist of standard Sallen-Key or state variable filter stages cascaded to form the required number of poles; switched capacitor types are only a version of the state variable circuit implemented on an IC substrate.

Filter characteristics are determined by the value of the various R and C combinations. Estimation of these values can be most tedious. But fortunately tables (written in handbook and software) are now available for obtaining the values.

Switched capacitor filters offering high performance, repetitiveness without tuning and the ability to move the cut-off frequency at will over several decades (typically 1Hz to 50kHz) are used for most applications. To design and produce an analogue equivalent is virtually impossible other than at very high cost. But these digital filters do have their drawbacks:

- As an input sampling circuit they introduce their own aliasing effects;
- Output is similar to that produced by a D-to-A converter with a clock frequency typically 100 x f_s.

The cut-off frequency imposed on the output — known as clock breakthrough — may be quite substantial.

Filter characteristics

Filters can be grouped into four basic types of frequency characteristics, though all are compromises, tweaked to idealise one or other parameter. Main parameters are pass band gain accuracy, phase response, stop band attenuation and steepness of roll-off (Fig. 2).

Phase response is a function of group delay (the time taken for a signal at a given frequency to pass through the filter), with the ideal being all frequencies take the same time — a linear phase characteristic. When achieved, a signal whose components all lie within the pass band will remain undistorted (as viewed by a scope) after passing through the filter. If the phase response is non-linear then we get all the right frequencies, but they may be in the wrong order.

At first glance, the tendency is to select (Table 2) the characteristic giving the maximum roll-off rate, simply because that is the main characteristic needed from a filter. But Cauer (elliptic) filters which maximise attenuation steepness also have significant stop-band ripple and a very non-linear group delay curve.

For a constant group delay, to give results that are undistorted in the time domain, the Bessel characteristic is the one to choose. Unfortunately, Bessel offers the slowest roll-off rate. If constant gain in the pass band (no pass-band ripple) is the target, the Butterworth characteristic offers just that, at the expense of indifferent performance in other respects.

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implementations of the same type of circuit. “Continuous” is a fancy name for a standard circuit using op-amps, capacitors and resistors. Figure 3 shows the well known Sallen and Key circuit (a) and a biquad filter (b) which can be configured to give a low-pass response of the type needed for anti-aliasing requirements. The problem with these, as many will know, is that the values of capacitors and resistors to be fitted are critical, especially for high performance implementations. Slight variations, either at assembly stage, or due to aging or temperature drift, can significantly affect and degrade performance. Also, once made, cut-off frequency is fixed.

Switched capacitor filters are an implementation of state variable, or biquad, circuits on an IC substrate using analogue switches to produce, in effect, components which can be varied in value. Note that the biquad design comprises several integrator stages as shown in Fig. 4(a), replaced by the circuit shown in Fig. 4(b).

The clock signal alternately closes $S_1$ and $S_2$, and while $S_1$ is closed, the capacitor $C_1$ charges to $V_{in}$, holding charge $Q = V_{in}C_1$. When the switches reverse, $C_1$ discharges to virtual ground, transferring the charge to $C_2$, causing the output voltage to change by an amount proportional to the input signal.

$$\Delta V_{out} = \Delta Q/C_2 = (C_1/C_2)\Delta V_{in}$$

If the clock frequency is fast relative to the input signal, then

$$V_{out} = \int C_1/C_2 \Delta V_{in} \, dt$$

In other words, the integrator’s gain is a function of the clock frequency. Because the characteristic frequency (cut-off frequency) of the biquad filter depends only on the integrator gain, a variable clock frequency can be used to produce a filter with a variable cut-off frequency. In addition, rather than discrete values of capacitors, the circuit uses capacitor ratios which are infinitely better in terms of stability and tracking – especially when integrated onto an IC substrate. As a result really high performance filters can be produced, in an IC outline, which can be programmed to any desired cut-off frequency within the range of operation of the device.

Unfortunately, the drawback to this approach is that the signal is now being clocked through the filter. In effect we have inherited some of the negative aspects of sampled data systems. First, the clock will inevitably break through to the output signal, with the breakthrough typically of the order of 15mV, regardless of output signal level and corresponding to the clock frequency.

Normally, the clock frequency is 100 times the cut-off frequency, so that a relatively simple analogue (continuous) filter applied to the output signal will eliminate the effect. The problem is that this simplistic solution fails if the cut-off frequency is to be varied over a wide range. Secondly, aliasing can become a problem – precisely what we are trying to eliminate.

If cut-off frequency is 1kHz and the clock is 100kHz, simple aliasing theory shows that the breakthrough will be 15mV.
aliases will be apparent if the input signal contains frequencies between 99 and 101kHz (and multiples thereof). To overcome this requires an anti-aliasing filter. Fortunately, this does not mean an ever-increasing spiral of problems. The pre-filtering requirement needs to reduce input signal frequencies around the clock frequency to below the dynamic range of the sampling system. As with the clock breakthrough problem, the solution is simple provided that the cut-off frequency is not to be varied over too wide a range.

Finally, because switched capacitor filters have clocks running through them, overall signal to noise ratio can never match that of quiet, well designed continuous filters. An effective limit is imposed on the dynamic range of any signal acquisition system using these filters and 90dB is normally considered to be the limit for well designed filters of this type.

What is aliasing?
Aliasing is where a high frequency component takes on the identity of a lower frequency. Once created by the A-to-D process, the false signal component cannot be distinguished from a true signal. In some applications, FFT analysis for example, even the threat of aliasing can completely destroy the integrity of results.

Relation to foldover. Aliasing occurs systematically as a result of foldover. If sampling rate is 2X, then foldover frequency is X, the limit set by the sampling theorem. Frequency components below X in the waveform being sampled will appear as they should. A component X+Y Hz will actually appear as the alias X-Y Hz below it. Hence the spectrum display is said to fold over at X.

*Laplace Instruments Ltd, Tudor House, Grammar School Road, North Walsham, Norfolk NR28 9JH. Tel: 0692 500777 Fax: 0692 406177.
The handhelds that endanger eyes

Possible health hazards resulting from long-term exposure to low levels of non-ionising RF radiation remains a controversial and unproven subject. As pointed out last year by Professor E H Grant (King’s College, London and a member of the National Radiological Protection Board: “The evidence for the induction of malignant or other disease requiring a non-thermal mechanism for its explanation is, despite various reports, not hard enough to be taken account of when formulating a Guidance Document”.

On the other hand, there appears to be increasing recognition that the future widespread use of handheld VHF/UHF transceivers – with their small antennas usually held within a few inches of users’ eyes – requires more stringent guidelines than found, for example, in the widely-accepted ANSI recommendation that RF output of 7W or less is not hazardous. Although most handheld transceivers have significantly lower power than 7W, several amateur-radio transceivers are marketed with outputs of around 5W.

Vulnerable eyes
Eyes are particularly vulnerable to the thermal effects of RF radiation. As pointed out by Prof Grant: “A living organism is accustomed to receiving thermal stimuli and, provided these are not too large, the body can deal with them by the normal thermoregulatory mechanisms... More serious than these reversible effects are the irreversible thermal phenomena such as the induction of cataracts due to the irreversible denaturation of the (eye) lens proteins. This is a well known and well documented effect of non-ionising electromagnetic radiation, having been observed for furnace workers and glassblowers before the introduction of protective goggles. To produce it, the temperature of the lens needs to be elevated from the normal 37°C to around 42°C.

One reason why the lens is particularly vulnerable is because it has no blood supply and hence only poor thermal conduction paths. The other reason is the high content of water, both free and bound... Any protection guide must therefore recommend exposure levels which eliminate completely the possibility of irreversible effects and which limit the reversible effects to levels which are generally acceptable”.

Recent work, supported by the Swiss National Science Foundation, by Niels Kuster (Swiss Federal Institute of Technology) and Quirino Balzano (Motorola), underlines the need for a revision of part of ANSI C951-1982. This American standard (widely used in many parts of the globe) excludes all transceivers operating below 1.5GHz and radiating less than 7W from having to be assessed for compliance with basic safety limits based on spatial peak specific absorption rate (SAR). The SAR is the power (in watts) absorbed per kilogram of tissue.

Kuster and Balzano note that portable hand-held communication transceivers are becoming widely used consumer products, with cellular telephones and new digital systems (GSM, DECT etc) expected in the near future.

Revised regulations wanted
Their studies on the SAR of layered plane phantom in the near-field of antennas at frequencies above 300MHz have shown that the spatial peak SAR is related to the antenna current and not to input power. They conclude a detailed appraisal as follows:

“A consequence of this study is that the health safety regulations for hand-held communication equipment must be revised, because the 7W exclusion clause is not always consistent with the ANSI safety limits for the spatial local peak SAR recommended for the controlled environment (8mW/g). For the uncontrolled environment (1.6mW/g), the exclusion is in direct contradiction with the peak SAR limits, shown by the following example. Assume that the feedpoint current of a 7W 1.5GHz transceiver in 2.5cm distance from the eye tissue is increased to about 350mA due to feedpoint changes. The result is a spatial peak SAR, averaged over 1g of tissue, of over 40mW/g.

Further, in the close near field, the SAR is not directly related to the input power but to the antenna current distribution.”

References
1. EH Grant, “Guidelines and standards for exposure in the frequency range 100kHz - 300GHz” ERA Conference Volume.
RF exposure puzzles remain

For more than a decade, the extent of potential hazards arising from exposure to electromagnetic fields has been heatedly debated by those concerned with radio communications, broadcasting, radar and medical electronics. A fresh impetus was given to this subject in the 1980s with publication of epidemiological studies that appeared to reverse earlier work clear RF radiation from any link with cancers. In turn, more recent studies have highlighted other, possibly more significant, correlations of the same rare cancers with the proximity of traffic and with concentrations of radon gas. Other studies have also shown odd and inexplicable correlations between childhood leukaemias and watching black-and-white (but not colour) television and with the use of hairdryers but not other domestic appliances.

A BBC research report by S Wakeling (RD1990/4), Electromagnetic field exposure in broadcast environments, underlines the renewed concern. The areas around broadcast antennas to which a person can safely gain access are being increasingly restricted. Broadcasters face a variety of problems when trying to ensure safe operational practices... The exposure guidelines have become more stringent each time they have been updated... International authorities are tending towards an "as low as reasonably achievable" principle in the light of inconclusive biological evidence which will create more problems in future...

Safety factors are being compounded by incorrect assumptions regarding exposure conditions. The derived field strengths of exposure standards are calculated assuming optimum coupling conditions and far-field, plane wave exposure whereas, in broadcasting, the potential for hazard is generally confined to the near field around the transmitting antennas. Hence the derived field-strength values are inappropriate for determining the SAR (specific absorption rate) levels and thus the actual level of potential hazard.

As an FRA Technology conference, Electromagnetic Fields and Human Health, Dr RD Saunders (NRPB) stressed that while acute exposure to sufficiently intense RF and microwave radiation will induce heating, resulting in detectable rises in tissue or body temperature, the vast majority of people are exposed to much lower field strengths.

There are several possible areas of biological interaction at low levels of exposure which may have important health implications and about which knowledge is limited. Mechanisms of interaction have been proposed but are not established. If there are such effects, then the evidence suggests that they are subtle and may well be masked by normal biological variation, claims Dr Saunders.

Reviewing human studies (including the auditory perception of pulse-modulated microwave radiation -- an established phenomenon) and animal and cell studies including embryo and foetal development, Saunders stressed that: "the evidence from biological experiments that exposure will affect carcinogenesis in humans is far from convincing". He concluded that: "There is some evidence from several research groups that responses to low level ELF fields or to pulse or amplitude-modulated RF or microwave fields only occur within specific frequency and amplitude windows. Some of these responses have been difficult to confirm, and their physiological consequences are not clear at present. In addition, mechanisms of interaction have not been convincingly established. It is important that these studies be continued and that the health implications, if any, for exposed people are determined".

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Dataman's new S4 programmer costs £495
You could have one tomorrow on approval*

If you've been waiting for S4 we have some good news. It's available now. S4 is the 1992 successor to Dataman's S3 programmer, which was launched in 1987. The range goes back through S2, in 1982, to the original Softy created in 1978. Like its predecessors, Softy is a practical and versatile tool with emulation and product development features. S4 is portable, powerful and self-contained. Design and manufacture are State of the Art. S4 holds a huge library of EPROMS, EEPROMS, FLASH and One Time Programmables. Software upgrades to the Library are free for the life of the product, and may be installed from a PROM by pressing a key. S4 makes other programmers seem oversized, slow and outdated. S4 is now the preferred tool for engineers working on microsystem development.

Battery Powered
S4 has a rechargeable NICAD battery. On average, you can do a week's work without recharging. On a single charge, up to a thousand PROMS can be programmed - and charging is fast: it only takes an hour. Normal operation can continue during the charging process.

Continuous Memory
Continuous Memory means never losing your Data, Configuration or Device Library. You can pick up S4 and carry off where you left off, even after a year on the shelf. If the NICAD battery loses all of its charge, RAM contents are preserved by the LITHIUM backup battery.

Remote Control
S4 can be operated via it's RS232 Serial Port. The standard D25 socket connects to your computer. Using batch files or a terminal program, all functions are available from your PC keyboard and screen.

Free Terminal Program
You could use any communications software to talk to S4. But the Terminal Driver program, which we include free, is the best choice. It has Help Screens to explain S4's functions and it sends and receives at up to 115200 baud – that's twelve times as fast as 9600 baud. At this speed a 64 kilobyte file downloads in 9 seconds. There is a memory resident (TSR) option too, which uses only 6k of your precious memory, and lets you 'hot key' a file to S4. Standard upload and download formats include: ASCII, BINARY, INTELHEX, MOTOROLA and TEKHEX.

S4 loads its Library of programmables from a PROM in its socket, like a computer loads data from disk. Software upgrades are available free. Download the latest Device Library from our Bulletin Board.

Microsystem Development
With S4 you can develop and debug microsystems using Memory Emulation. This is an extension of ROM emulation, used for prototype development, especially useful for single-chip "piggy back" micros. When you unpack your S4 you will find an Emulator Lead with a 24/28 pin DIL plug and a Write Lead with a microhook. Plug the EMUlead in place of your ROM. Hook the Write-Lead to your microprocessor's write-line. Download your assembled code into S4. Press the EMULate key and your prototype runs the program. S4 can look like ROM or RAM, up to 512K bytes, to your target system. Access-time depends on S4's RAM. We are currently shipping 85ns parts.

Your microprocessor can write to S4 as well as read. If you put your variables and stack in S4's memory space, you can inspect and edit them. You can write a short monitor program to show your internal registers.

S4's memory emulation is an inexpensive alternative to a full MDS and it works with any microprocessor. Many engineers prefer it because their prototype runs the same code that their product will run in the real world.

Dimensions & Options
S4 measures 18 x 11 x 4 cm and weighs 20 grams. 128K x 8 (1MB) of user memory is standard, but upgrading to 512K x 8 is as easy as plugging in a 4MB low-power static CMOS RAM. The stated price includes: Charger, EMUlead, Write Lead, Library ROM, Terminal Driver Software with Utilities and carriage in U.K. but not VAT.

Money-back Guarantee
We want you to buy an S4 and use it for up to 30 days. If it doesn't meet with your complete approval you will get your money back, immediately, no questions asked.

Call us with your credit card details. Stock permitting, we are willing to send goods on 30 days sale-or-return to established U.K. companies on sight of a legitimate order.

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