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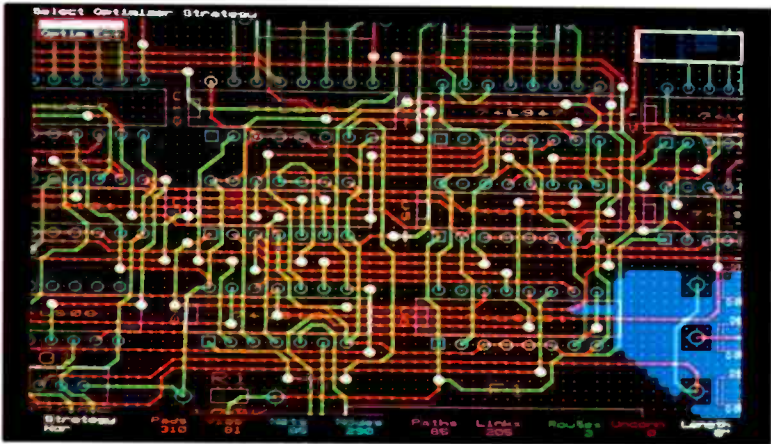




# OrCAD<sup>®</sup> NEWS

Systems Corporation

## More CAD from OrCAD



OrCAD/PCB II, a new printed circuit board layout package, is now available from ARS Microsystems of Camberley with twice the speed and twice the power of OrCAD's original package OrCAD/PCB.

It contains many new capabilities as standard such as design rule checking, post-route optimization

and semi-automatic rip-up and re-route routing for 100% completion. Capacity is doubled to 270 equivalent i.c.s and the package now supports printers.

The price of OrCAD/PCB II is £1795 and includes a years free updates and telephone support.

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## 27,000 users can't be wrong

OrCAD Systems Corporation have shipped the 27,000th copy of OrCAD/SDT III, the world's most popular schematic capture package.



This makes OrCAD/SDT III the best selling of any computer aided engineering package for the electronics industry.

OrCAD/SDT III allows a hardware engineer to quickly create a schematic diagram of his design on his own PC and then to plot it on a printer or plotter. It costs £595 and comes with a years free updates and telephone support.

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## Sycon simulates before build

Sycon Limited of the Science Park, Cambridge have developed an image handling system for use with image analysis hardware.

"This was a very complex design and we used OrCAD's simulator, OrCAD/VST, to check that the design we had in schematic form

## OrCAD has designs on programmable logic

Now available from ARS Microsystems is OrCAD/PLD, a design package for programmable logic devices.

ARS says that OrCAD/PLD integrates with OrCAD's other CAE software in a PC-based system that unifies the design, simulation and documentation of programmable logic devices such as PALs, PLDs and PROMs. It creates an industry standard JEDEC file from a high level specification which can be in a variety of formats. These include boolean equations, procedural state machine programs, truth tables, numerical maps, indexed equations or schematics.

Indexed equations allow a set of related equations to be grouped together. OrCAD claims that this

can often reduce large and complex functions such as synchronous binary counters, barrel shifters and custom multiplexors to a single line of OrCAD/PLD code.

OrCAD/PLD costs £595 and comes with a library of the most popular programmable devices. The price includes one year of free updates and telephone support.

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## Programmable model simulates PAL/PLDs

A software package which creates simulation models of programmable devices is now available from ARS Microsystems of Camberley.

OrCAD/MOD is designed to work with OrCAD's logic simulator, OrCAD/VST. It generates complete timing and simulation models from fuse map files created

in industry standard JEDEC format. This allows the design engineer to fully exercise his design before programming any devices.

The package includes a library of over 300 full specification timing models. It costs £595 and comes with a years free updates and telephone support.

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ARS Microsystems Ltd.,  
Doman Road, Camberley,  
Surrey GU15 3DF  
Tel: 0276 685005.  
Fax: 0276 61524

worked to our original specification before making a prototype. As a result when the PCB came back from the manufacturer it took only ten days to get the board working" said Paul Duesbury, Sycon's Technical Director.

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*Digital recording at Metropolis Studios.  
Photo courtesy Studio Sound. Page 766.*

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What would happen to the world if the chemical industry couldn't make CFCs anymore?

The consequences would surely be serious. We would wipe out a whole family of advanced anaesthetics; halt the manufacture of... refrigerators... cleaning systems... deodorants...?

Of course we wouldn't.

The electronics and semiconductor industry still uses substantial quantities of CFCs but has generally responded well in the search for ozone-harmless replacements and processes. Developments in cleaning systems, the most significant CFC use in electronics, will eventually lead to replacement with water or something equally innocuous.

Chemical companies have reacted quite differently. Their priority has been to work flat out to develop CFC alternatives: hydrofluorochlorocarbons (HCFCs) and hydrofluorocarbons (HFCs). These relatively inert classes of chemicals possess the virtue of direct CFC replacement in refrigerators without alteration to mechanics.

But they cost five times the price of the old compounds and even the best of them reacts with ozone in the presence of UV radiation, albeit at a tenth of the rate of standard CFCs. Yet manufacturers of these proprietary chemicals would also present them as the salvation of the electronics industry.

No wonder the Indian foreign minister spoke out at the Montreal Protocol on protecting the ozone layer, making clear that her country would only sign the protocol if the developed world helped with the enormous cost of providing ozone-friendlier technology. China feels the same way. The developing world has clearly adopted the notion that continuing progress depends on high-tech, expensive, proprietary chemicals for which it will demand financial help. It will get it.

What a marketing coup! The boardrooms of the world's chemical giants clearly viewed a decline in sales of CFCs - also proprietary chemicals - with concern. But they have wrested the situation around to a point where now they are anticipating replacement

sales of patented chemicals costing up to five times as much. How ever much the PR exercise cost, it was worth it.

As Debora MacKenzie, writing in the *New Scientist* points out, there are alternative chemicals for the mass refrigeration market over which DuPont, ICI *et al* have no control. Working fluids such as propane and butane - simple, cheap hydrocarbon gases - actually produce higher efficiency in conventional refrigerators than CFCs or HCFCs. The point has already been proven in a programme taking place at the South Bank Polytechnic to replace CFCs with propane in domestic fridges.

Doubtless the chemical industry will state that hydrocarbon gases represent a hideous fire risk, pointing to the possibility of explosions, the narcotic effect of hydrocarbon inhalation, etc. A reasonable person would counter that by saying hydrocarbon usage is ubiquitous.

We deal with hundreds of litres of propane in bottled-gas heating systems, tanks-full of volatile hydrocarbons every time we fill our cars with petrol, cans-full of the stuff in lawnmowers, decilitres in camping stoves; and just 100 millilitres in a properly designed propane fridge.

A quick calculation suggests that 100ml of liquid propane occupies about 40 litres at room temperature. The average kitchen holds around 25 cubic metres of air so even if the whole lot leaked out this would result in an air to gas ratio of 625:1. A propagating flame needs a maximum air to fuel ratio of 25:1, a most unlikely situation to arise, even with stratification.

One could add that hydrocarbons burn safely to carbon dioxide. Compare that to chlorinated compounds which produce carcinogenic dioxins and neurotoxic agents such as carbonyl chloride.

The multinational chemical companies are not hurrying to spell out the hazards or the alternatives. But their silence amounts to a world-class confidence trick, played on both us and the developing world.

**Frank Ogden**



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# Diabolus ex machina?

Zoologists have often observed that specialisation in the animal kingdom leads to short-term success and long-term extinction. Dinosaurs, especially the huge carnivorous variety, must have put the fear of death into lesser beasts as they lumbered their way around the Cretaceous landscape. By 70 million years ago, however, these kings of pre-history were all dead, victims no doubt of their lack of adaptability to environmental change.

Mankind, by contrast, isn't particularly strong or agile. In fact, he's remarkably unspecialised as animals go. Unlike creatures that grew very large or ran very fast, Man became successful because of his adaptability to live anywhere, eat anything and to make tools and weapons.

This strategy works well when these artificial aids are reliable, but is disastrous when they are unreliable or ill-suited for the task in hand. Thus, while electricity is an immensely useful tool in the battle for survival, the likes of Chernobyl and Three Mile Island are definitely not. The problem, of course, is knowing what technological avenue is safe to venture down and which is not. Worse still from a survival point of view, the stakes grow higher every day; technology that would once have placed only a small subset of humanity at risk now threatens *homo sapiens* as a whole.

With those thoughts as background, two Australian computer scientists, Tom Forester and Perry Morrison, have attempted to assess the extent to which mankind has become vulnerable to computer failure. Writing in *Futures* [June 1990] they conclude that even the most advanced of today's systems are so inherently unreliable that they should not be entrusted with any life-critical operations.

Despite the pervasiveness of computer technology, say Forester and Morrison, "little is known about computer failures except perhaps that they are all too common!"

Famous examples of the vulnerability of computers (many previously cited in this journal) include the time when a faulty 74175 chip caused the scrambling of a B52 bomber squadron in response to what looked like a Soviet ICBM attack. Then there was the loss of the

Mariner-18 and Phobos-1 space probes, both the result of one-line programming errors.

More frighteningly, two cancer sufferers in Texas were given 100 times the radiation that their treatment demanded; both patients died soon afterwards. No-one ever discovered the cause of the problem nor what caused the equipment to flash on its screen the laconic message: "malfunction 54". Similar failures, also involving loss of human life, were five crashes of the USAF's UH-60 Blackhawk helicopter. Only when these crashes were investigated in detail was the cause found – a glitch in the computerised fly-by-wire system.

What frightens Forester and Morrison more than anything is our increasing dependence on computer systems that are inherently unreliable, either because of their complexity or because their size makes testing impossible. The authors argue that even a modest computer of the sort used to monitor a nuclear power station could never adequately be tested. With around  $10^{34}$  possible logic states, any realistic test procedure would take longer than the age of the Universe!

Programming, say the authors of this

spine-chilling paper, is even more fraught with error. They say that it is now accepted that for programs with more than around  $10^5$  lines of code, the chances of introducing a serious error during correction of original errors is so large that only a small proportion of original bugs should ever be corrected!

Solutions do exist in theory. Program verification and software de-bugging techniques are constantly under development. Hardware difficulties can be circumvented. Duplication can always be implemented. Unfortunately, say the Australians, none of these techniques can yet handle programs or equipment of even modest size. In the case of software checking, the maths is often longer than the original programs. This problem, moreover, is unlikely to improve in the short term.

So are we, I wonder, running the risk of entrusting our future to a technology that cannot reasonably be trusted? And if so, will it eventually lead us down the path the dinosaurs followed? There may be no easy answers, but it's not too soon, say Forester and Morrison, for governments, manufacturers and users to ask themselves some highly pertinent questions.

## Ball lightning freshly served

Ball lightning is one of those natural phenomena reported so frequently that it's difficult to doubt its existence. What's often seen is a glowing sphere floating through the air and then disappearing or disintegrating explosively on contact with some conducting object. One report even described such an object about the size of a football drifting down the gangway of an aircraft and then just fading away.

Theories to explain ball lightning have been as diverse as they are numerous, usually involving some sort of stabilised plasma. The only difficulty in these studies has been to trap a lightning ball long enough to study it. . . . Or alternatively to create one.

The latter option has been reported by a team of researchers working for Professor Yoshihiko Otsuki at Tokyo's

Waseda University. Initial reports are lacking in detail, though what the team appears to have done is create ball lightning out of doors using a 2kW microwave oven attached to a tube of copper wire mesh, presumably as a sort of open waveguide.

When switched on (one imagines from a safe distance!) the apparatus produced a glowing ball 2-3cm in diameter that floated along the mesh for about 2 minutes. The colour is said to have changed from white to a dazzling orange during this time.

How repeatable this experiment is and what exactly the ball consists of will clearly have to await publication. If it does prove to be anything more than a simple discharge, it should certainly provide a considerable insight into a most puzzling natural phenomenon.



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CIRCLE NO. 108 ON REPLY CARD



# Radio pollution from Space

According to Dr John Galt of the Hertzberg Institute of Astrophysics, Penticton, British Columbia [*Nature*, Vol. 345 no 6275], electromagnetic pollution from navigation satellites, especially Soviet ones, is seriously hampering radioastronomy. Galt says that when the GLONASS satellite system is complete, it will produce a total of 42 spurious signals within the 1660.5-1668.4MHz band, a part of the spectrum where radioastronomy and passive space research share an exclusive primary allocation. Already strong signals have been identified on 1660.9275, 1661.4900, 1663.2250, 1663.2775, 1664.9600 and 1668.3350MHz. These are in addition to a spurious emission on 1667.4900MHz from a US global positioning satellite in the GPS system.

Up till now, radioastronomers have been largely able to escape man-made radiation by building their telescopes well away from populated areas. Usually also, terrestrial interference is spasmodic, which allows it to be eliminated by integration techniques. Spurious emissions from satellites can't, however, be avoided by either approach, at least not when the offending satellite is above the horizon. So strong are the space-borne emissions that they break into virtually every

sidelobe of even the most directional antenna. Paul Murdin of the Royal Greenwich Observatory says that when a GLONASS satellite is in view the only realistic option for radioastronomers operating in the 1660MHz band is to go and have lunch.

What's particularly disturbing about this state of affairs is that the band in question contains some of the most important cosmological spectral lines, including that of interstellar-OH molecules. Observing these natural emissions, often at the limits of high-gain, low-noise technology, is the only way we shall ever gain a reasonably complete picture of the state of much of the matter that makes up the darker areas of the Universe.

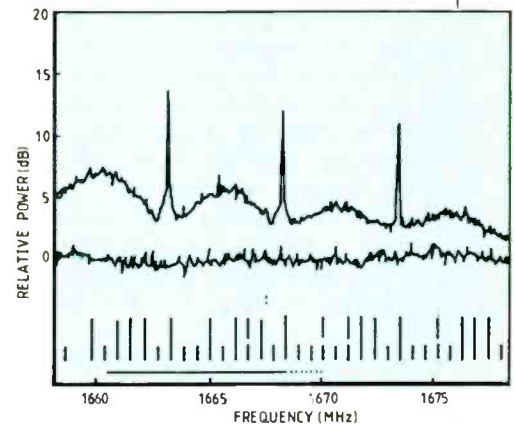
Intrusion by the satellites into the radioastronomy band isn't, of course, deliberate. Galt believes it indicates merely a lack of appreciation by the designers of GLONASS of the extremely low flux levels that radio telescopes are able to detect. Using such a telescope pointed directly at one of the offending satellites, he observed the 10th, 11th and 12th sidebands resulting from modulation of the 1612.125MHz carrier.

For GLONASS, he says, the frequencies of the nth sidebands are given by:

$$1602 + 0.5625m \pm 5.11\text{mMHz}$$

where m varies from 1 to 24 according to the satellite in question.

John Galt says that the US GPS satellites launched since 1986 appear free from these extended spurious sidebands. This implies that, given the necessary technical expertise, it is possible to suppress unwanted emissions within the radioastronomy band. That being the case, he makes a plea for the USSR to clean up its technology before launching any more GLONASS satellites. Otherwise the future of radioastronomy in the 1660MHz band is likely to be grim indeed.



## Did Queen Elizabeth I write Shakespeare?

Who wrote Shakespeare? As with the authorship of many books of the Bible, the answer is not necessarily the obvious one. Ever since the mid-19th century, alternative authors have been proposed for many of the works attributed to the Bard of Avon.

Now, thanks to a computer program developed by Robert Valenza of Claremont McKenna College in California, there's an even more unlikely runner in the Shakespeare stakes - Queen Elizabeth I.

What Valenza did was to use a technique called modal analysis to compare poems attributed to Shakespeare with those known to have been written by twelve contemporary authors, including Elizabeth.

Aided by a grant from the Sloan Foundation, Valenza and his co-worker Professor Ward Elliott spent

three years establishing what they call 'structural relationships' between a selected set of 50 keywords.

Initially the computer selected the 50 most common words found in Shakespeare, an approach which produced no clear-cut results. When it was realised that this group of 50 included unavoidable words such as "and" and "the", a second attempt was made using Shakespeare's 50 next most favoured words. This time the computer produced startling results.

Of all the pretenders to the Shakespearean throne, Edward de Vere emerged "badly wounded". Out also went Marlowe, Bacon and many others. Those who survived this structural relationship test included Elizabeth I (whose modest known output consists mainly of translations of the Psalms), Sir Walter Raleigh and

Faulk Greville, author of an obscure set of sonnets.

Unfortunately (at least for the pretenders), all those who at this stage were still in the running fell down when the computer examined their verbal styles. Shakespeare used far more compound words and only half as many relative clauses as any of his challengers. Exit the Virgin Queen.

Of the poems that are merely attributed to Shakespeare, most also seem to fail these tests. Conversely, at least one collection of unattributed poems comes out as being more Shakespearean than Shakespeare! Ward Elliott says that the former conclusion is perhaps the more reliable.

One thing is sure: as with the authenticity of the Turin Shroud, no classical Shakespearean scholar is likely to let the arguments rest there.

## Listening with light

Laser acoustic techniques developed at the Georgia Institute of Technology which allow scientists to "see" sound and vibration through laser light could lead to new methods for non-destructive testing of aircraft components, noise analysis in mechanical equipment, underwater sound measurement and other potential applications. The techniques use lasers both to generate and measure sound and provide important advantages over other acoustic research methods.

Yves Berthelot, assistant professor of mechanical engineering, and Dr Jacek Jarzynski have developed a laser probe which will be used to study the intricate coupling between vibrations and the radiation of sound from a structure submerged under water. Preliminary tests have been carried out in air to study waves emanating from a vibrating metal beam. An understanding of that coupling could lead to improved techniques for suppressing noise in mechanical equipment.

The probe uses a technique called differential laser Doppler interfer-



*Dr Yves Berthelot and the Georgia laser vibration-measuring probe.*

ometry. First, a beam splitter is used to divide a laser into two beams, which are led into optical-fibre cables. The cables carry the beams to the experimental location, where their paths are crossed at the precise location of the vibration under study.

The light beams are scattered off the structure in all directions, and vibrations on the structure modulate the scattered light, causing measurable disturbances in the interference patterns which normally result from crossing the beams.

Measuring sound waves in water is based on a similar technique. Instead of being scattered by a vibrating structure, however, the light is scattered by microscopic particles in water which oscillate in the presence of sound waves. These moving particles scatter the laser beams and that scattered light can be picked up by a photodiode.

An important use for lasers in acoustics is in the contactless generation and detection of ultrasound to inspect materials for defects. Berthelot and Jarzynski have used an array of optical fibres to guide the laser light over the surface of a material, generating sound waves which move through the material in a narrow sound beam. This sound beam can then be used to generate a detailed picture of the interior of the material.

Because they are carried in optical-fibre cables, the laser beams can be snaked into nearly inaccessible areas, offering advantages over traditional bulky ultrasound transducers.

*Research Notes is written by John Wilson of the BBC World Service science unit.*

## Radio waves reveal monster Black Hole

Australian and US radioastronomers have produced the clearest evidence yet of a black hole at the centre of our galaxy. Although not large by the standards of other black holes in the Universe, its pull is enough to devour a sun every 10000 years.

Black holes, by definition, are invisible; their enormous gravitational attraction prevents even the escape of radiation such as light. It is possible, however, to infer the presence of a black hole from the behaviour of nearby matter in space. Astronomers analysing the movements of stars near the centre of our galaxy have long suspected the presence of a black hole, though the evidence has always been circumstantial.

Observing the centre of the galaxy at optical wavelengths is particularly difficult, owing to the presence of obscuring gas clouds. For that reason, clearer images have had to await studies at radio wavelengths, using high-

resolution interferometers.

Signals from the giant radio telescope array near Socorro, New Mexico, have revealed – after months of computer processing – images showing gas clouds swirling round what can only be a black hole. The images reveal a jet of gas which has every appearance of being the remnants of thousands of stars in the process of being torn apart by immensely powerful gravitational fields. The jet, with the energy of ten million suns, resembles those seen on the edges of black holes observed in other, more distant, but more clearly visible galaxies.

The study, done in collaboration with the University of California, Los Angeles and the Anglo-Australian Telescope team in Sydney, estimates that since the formation of the Universe, our friendly neighbourhood black hole (a mere 25,000 light years away) has devoured no less than a million stars.



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## 77 satellite network may run out of space

Plans for a global communications system based on 77 low orbit satellites have been unveiled by Motorola in the US to mixed reactions. The \$2billion Iridium programme, which the company hopes will be the basis for a complete personal communications network, will be accessible with a handset similar in size to the current cellular telephone.

Motorola says the system will not compete with existing cell networks but will supplement current technology, being preferable in areas where present systems do not operate effectively. But questions are already being asked over whether the shortage of spectrum available to satellite operators could

prove a major hurdle as Iridium will need a large amount of spectrum if it is to prove viable.

Break-even point for the system is predicted to be 700,000 users many of whom will have to be outside low-population rural North America where Iridium's initial market is expected to be.

Seven circular 413 mile polar orbits will be needed for the 77 satellites and handsets will transmit at frequencies in the 1-2GHz area with calls being switched between the orbiting satellites, eventually connecting to the terrestrial telephone network.

Motorola aims to take the role as equipment supplier and is looking for

consortia to run the network.

Internationally owned voice and data communications company Inmarsat, amongst others, is considering the plans, but has already made clear its worries over spectrum availability. At the same time Europe's own progress with its digital cellular system expected to be implemented over the next two years means it will become increasingly difficult for Iridium to reach its target number of users.

Equipment development is already underway and Motorola plans to demonstrate the system with a single satellite next year. If all goes well the company hopes to launch a full commercial service in 1996.



## Solar plane flies on light-weight film

Apart from the determination of the pilot, the attempt by the "Sun Seeker" airplane, to be the first solar aircraft to fly a transcontinental flight across the United States was largely made possible by a new solar material developed by Sanyo Electric. The company's Amorton solar film was applied to the wings and tail to drive an electric motor powerful enough to propel the one-man aircraft over its seven-days cross-country journey.

The light-weight solar cell film material is only 0.12mm thick and is

flexible enough to form a small tube 10mm in diameter which can be shaped into three-dimensional surfaces not possible with fragile single or polycrystal cells or conventional glass/stainless steel substrate flat panel cells.

In addition, the film's light weight yields a power-to-weight ratio of 200 m w/g, ten times that of conventional glass-type cells. Sanyo says applications include solar powered aircraft, satellites, dirigibles, cars and boats. Fifteen patents are pending in Japan and two in the US.

## Philips and Matsushita agree on D2B

Philips and Japan's Matsushita have formed a joint venture, D2B Systems Co Ltd, for development of the standard for the domestic digital bus.

Philips will have a 75% share in the new company, MEI 25% and managing director will be Coco Ciocan of Philips.

D2B data control system for audio/video and related consumer products should ease control and functionality of interconnected products. Products from different companies will function as an integrated system if the products are supported by the D2B system.

Thomson Consumer Electronics, of France, and Sony Corporation have also agreed to actively support and promote the standard.

## Intel's 1992 goal

Intel Corporation has said it is to eliminate chlorofluorocarbon (CFC) use from its worldwide manufacturing processes by 1992. Intel instituted a CFC tracking program in 1987 to assemble data on its worldwide use. Since then, using control, conversation, and alternative manufacturing methods, the company says it has reduced its CFC use by approximately 30%.

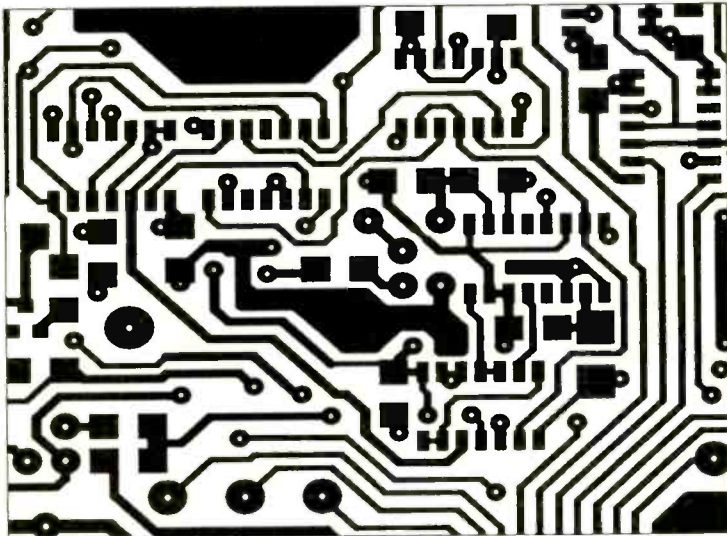


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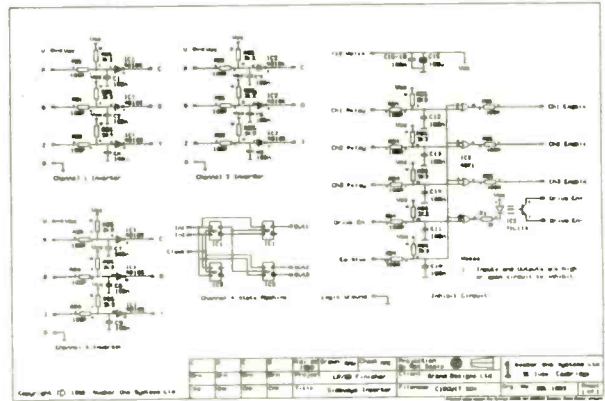
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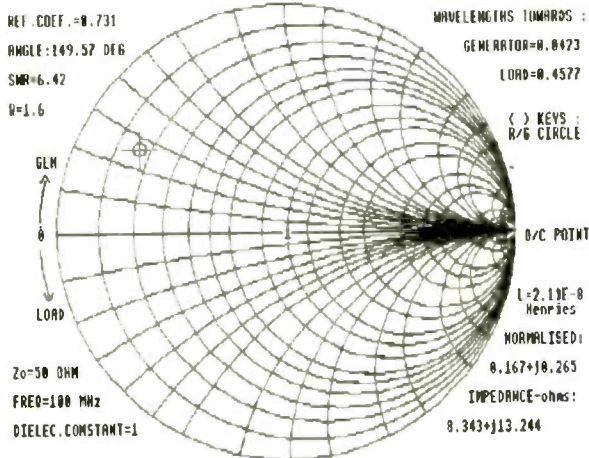
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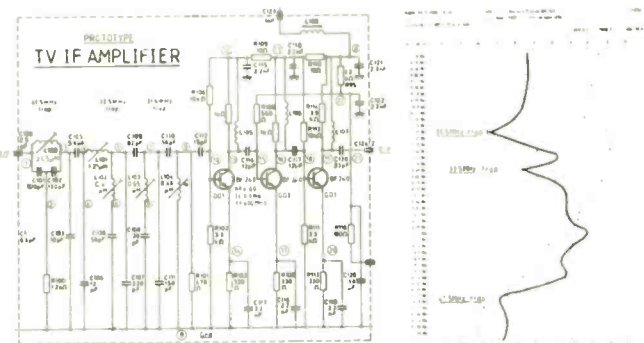
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## Has IBM seen the writing on the wall?

Most computer users have now learned to love their mouse, at the same time looking forward to the day when they can simply talk to their machines. So there may be a rather short queue for the latest interface being developed at IBM — the pen and paper.

Hand-written character recognition is nothing new, but what has caused researchers at IBM's Thomas J Watson Research Center to become so excited is because their experimental "Paperlike" interface is showing success in recognising run-on handwriting in real time.

The goal is recognition of natural, cursive, writing so that handwriting and gesture recognition could provide a way of interacting with computers, becoming as popular as the keyboard and mouse.

To communicate with the computer a user writes with a stylus on a transparent digitising tablet placed over a flat liquid crystal display. The path of the stylus on the surface — the writing — appears as electronic ink on the display directly below.

The ability to recognise touching or even overlapping characters in real time has been speeded up by analysing each character in terms of "strokes" rather than by trying to recognise whole characters.

Strokes are then matched against templates and labelled to describe the possible characters they might represent. If the sequence of strokes corresponds to components of a particular character then the character has been recognised.

A single template can represent a stroke common to a number of characters such as the downstroke of a B, D, E, F or H and recognition can begin as soon as the stroke is made without waiting for the whole character to be completed. The system will adapt to a writer through "training" of the interface, not the user.

Much work still remains to be done before the system is ready. But the real question researchers might ask themselves is whether there will be anybody left who can remember how to hold a pen by the time this interface makes it into the market-place.



## Message in a bubble

Laptop-users on the move have always been faced with a dilemma when it comes to hard copy. Should you output work immediately on a fairly basic-quality portable printer, or waste valuable minutes waiting until you reach the office to laser print your Inter-City musings?

But all that worry could soon be consigned to the past, because Canon has launched a portable printer for the travelling executive that fits inside the briefcase yet promises near laser quality through exploitation of bubble jet technology.

Bubble jet printers are so called because an electric element in each nozzle in the print head heats up ink to vapourise it, causing a bubble to form. The sudden expansion results in a jet of ink being forced out of the nozzle. As the bubble cools and contracts it creates a vacuum pulling in more ink in a cycle so fast that thousands of bubbles can be

created per second.

The technology is particularly suited to semi-conductor manufacture because the print head is made up of rows of nozzles, heaters and electrodes deposited on silicon in a similar way to microchips.

Measurements of the Canon BJ-10e are 310mmx216mmx48mm — around A4 in size — and weight, with the rechargeable battery pack, is 2.1kg. But resolution of the unit is 360dpi, which should be good enough for those corporate pie charts and graphics as well as text. The printer can be customised to control image density, auto-sheet feed, page length and character set, and emulation and graphics modes can be selected. Pitch includes 10,12,17cpi or proportional spacing in either Courier or Elite.

Canon says the printer should suit both the portable computer user, the small office or even users of home computers.

Price is £345, or £399 with paper feed.

## Ethernet controller update

Production volumes of Advanced Micro Devices' Am79C900 second generation local area communications circuit for 802.3 Ethernet are now available. The Ilacc (Integrated Local Area Communications Controller) circuit combines the functions of two of AMD's first-generation Ethernet circuits, the SIA and Lance, to provide an upgrade for manufacturers using any 32-bit microprocessor, while

promising the industry's smallest footprint.

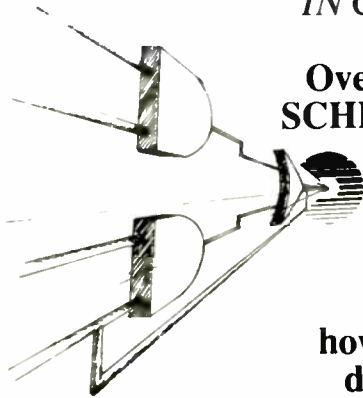
Common design elements should allow Ethernet equipment manufacturers to upgrade 16-bit software based on AMD's first-generation Lance solution to Ilacc with ease.

The company says the circuit has been designed to cut six months off probable upgrade development time.



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## Fast forward on video chips

Samples of Motorola's high speed version of its 56000 digital signal processing DSP chip should be available shortly. At 80MHz the 16bit device is three times as fast as any of its current chips and will aid development of the company's interactive video chip set for Philips. The device is designed to handle 40 million instructions per s. four times present performance.

Very fast DSP chips are needed for the compact disk interactive (CDI) system which relies on extensive processing to compress information for efficient storage. The aim is to use CDI for storing video pictures, text and computer graphics on compact disks.

Architecture of Motorola's new device is similar to 32bit versions, allowing some parallel processing. The CDI chip set will combine a 56000 with a 68000 processor, with custom data compression chips.

● Latest chip to come out of Motorola's standard product stable is the 96002 "Media Engine". At \$750 a piece, it offers an 800,000 transistor system, including eight internal 32-bit buses, and three parallel execution units.

IEEE floating point arithmetic and a DMA controller are included, allowing the execution of a 1024-point real FFT

in less than 0.8ms by the 33MHz, 165Mops device.

Two external 32-bit ports, with their own internal data bus (X and Y), feed data from two separate memory spaces. The ports have separate data, address, and control lines, and allow linear arrays of 96002s to be connected without glue logic so it can function as a floating point co-processor for chips such as the 68040 and 80486.

Multiplexors decide which of the three internal address buses and five data buses get access to the ports, effectively changing system architecture according to application.

The five on-chip data buses are X and Y data, a program bus carrying instructions and op-codes, a general purpose global data bus and a separate bus for the on-chip DMA controller.

The ALU has ten 96-bit registers and uses IEEE 754 standard floating point representation in an effort to get the chip designed in as a co-processor.

Because much DSP processing consists of performing a repetitive operation on large blocks of data, the chip includes a hardware loop facility. The address generation unit (AGU) is also angled toward accessing blocks of data quickly, handling the creation of structures like circular queues and fifos

without ALU overheads. The 512 word on-chip program memory space can be updated on the fly using the DMA controller, effectively creating an instruction cache.

Such a huge chip, with a parallel instruction set, is bound to be a headache to program and an on-chip emulator is provided giving access to debugging facilities. Code from the existing 56k family is largely compatible with the 96k instruction set.

## Robert Noyce

Electronics has lost one of its leading lights with the death from a heart attack of Robert Noyce, co-inventor of both the silicon chip, and microprocessor.

Noyce, who was born in 1928, led the setting up of Fairchild Semiconductor and pioneered development of the planar process by which chips are made. It was his name which, jointly with Jack Kilby of Texas Instruments, appeared on the patent for the first chips.

In the 1950s he worked under Nobel Prize winner William Shockley developing the earliest transistors. In 1957 he left Shockley to set up Fairchild, where, as well as gaining the chip patent, he was instrumental in pushing forward the work which gained patents for mos and c-mos technology.

Eleven years later he set up Intel, with Gordon Moore and Andrew Grove.

By 1971, Intel itself had played a full part in the development of microprocessors, srams, drams and proms, and gained an edge in c-mos technology which remains to this day. Noyce maintained that the key to this advantage was the fact that he and his two co-founders ran the company as a technological meritocracy.

In more recent years, Noyce campaigned actively for US government support for high tech industries. In his role as head of Sematech, America's chip production consortium, he argued that because Japanese companies received government support a true free market in technology did not exist.

He always maintained that if the US was ever to regain its world leadership in electronics funding from Washington was vital.

## Spectrum reviewers call for evidence

The spectrum review committee set up by the DTI earlier this year to examine current and future civil and military use of the radio frequencies from 3400MHz to 30GHz has called for evidence from those working in the sector. The committee, chaired by Sir Kenneth Corfield, formerly of STC, is due to report jointly to the Home Secretary and Secretaries of State for Trade and Industry, Defence and Scotland by May next year.

Investigation of the microwave spectrum was initiated by the DTI as the second stage in an analysis of radio spectrum usage, and followed acceptance by the government of recommendations contained in the first stage report published last year which

looked at demands on 470-3400MHz range.

The DTI said that the Stage 1 report had "stimulated widespread discussion" of the future requirements and options for the key frequency range of 1-3GHz and was confident that this new review would likewise reveal "fresh challenges" for the UK and ensure "we continue to lead the field in making effective and efficient use of this scarce nature resource at these higher frequencies".

*Submissions should be sent immediately to Radio Spectrum Review Secretariat, Room 508, Radiocommunications Agency, Waterloo Bridge House, Waterloo Road, London SE1 8UA.*

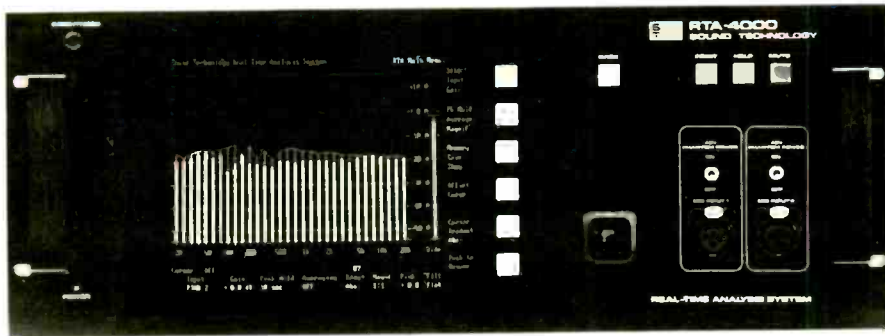
Those original recommendations, apart from making clear the need to look at the microwave sector, emphasised that frequency planning ought to maintain a long term perspective, but that in many areas the freedom for action is limited by international treaty obligations. However the committee found there was considerable scope for improvements in the way that radio spectrum is managed.



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# Sound mosfet design

**M**osfet amplifiers undoubtedly present a tantalising prospect for simple circuitry. Unfortunately, practical application requires careful consideration of their many foibles. But my aim here is to stimulate thinking about possible improvements to fet power amps, and describe two new avenues of development. Each produces a practical result, though neither should be regarded as a foolproof recipe for success.

Power-amplifier design is as prone as any other branch of audio to folklore and confusion. One of the less extreme myths holds that high levels of negative feedback are "A Bad Thing" because they require heavier compensation for HF stability, leading to low slew rates and generally indolent and sluggish behaviour.

As far as it goes this is true. But only a poor designer would lose all sight of slew rate while adjusting amplifier compensation. Despite much study of TIM, DIM, SID, "internal overload", "delayed feedback" and the rest, everything comes back to slew rate.

If an amplifier can reproduce a 20kHz sine wave at full amplitude without excessive distortion (say under 0.1%) it can be regarded as blameless in respect of speed. Apply as much feedback as is decent, but always keep an eye on stability and slew rate.

## Design fundamentals

Ground rules for this design study require DC output coupling, one preset only (for quiescent current) and as simple a circuit as possible.

In the current audio market, almost



After three decades of study is there anything more to learn about power amplifiers?  
Definitely yes, says Douglas Self

any technological approach appears to be acceptable (an idiosyncratic hybrid with valves driving power fets is one recent design<sup>1</sup>), with the possible exception of capacitor output coupling.

While problems can include capacitor distortion at LF (of the real and measurable kind<sup>2</sup>) and perhaps grounding difficulties, the overwhelming simplicity of this method still has its attractions; the almost unnatural reliability of the capacitor-coupled Quad 303 should be mentioned at this

point.

But a designer must still prove that he knows what a differential pair is, and DC coupling has therefore been adopted. However, remember that proper offset protection is not a trivial problem, as the cost of a reliable output relay and DC detection circuitry can add 30% to amplifier electronics costs.

A relay seems unavoidable, as my own experiences with kamikaze crowbars have been distinctly unhappy, though I would not claim this to be a definitive judgment. So a simple unregulated power supply looks to be the best. I realise this brings me into head-to-head confrontation with Mr Linsley Hood<sup>3</sup>, so I shall quickly explain my preference.

Putting expensive power semiconductors in a high-current dual supply can easily double an amplifier's electronic-component cost and there is much more to go wrong.

Ensuring PSU HF stability can be difficult, and the PSU compensation required, threatening a steadily rising output impedance versus frequency, can lead to some awkward amplifier stability problems.

Finally, the unregulated supply can deliver more power on a transient basis — which is exactly what is required for audio.

The price to be paid for unregulated simplicity is the attention to be paid to the amplifier's supply-rail rejection. But since it is physically impossible for the voltage on large reservoir capacitors to change very quickly, this rejection need only be extremely good at low frequencies.

The excellent supply-rail rejection of



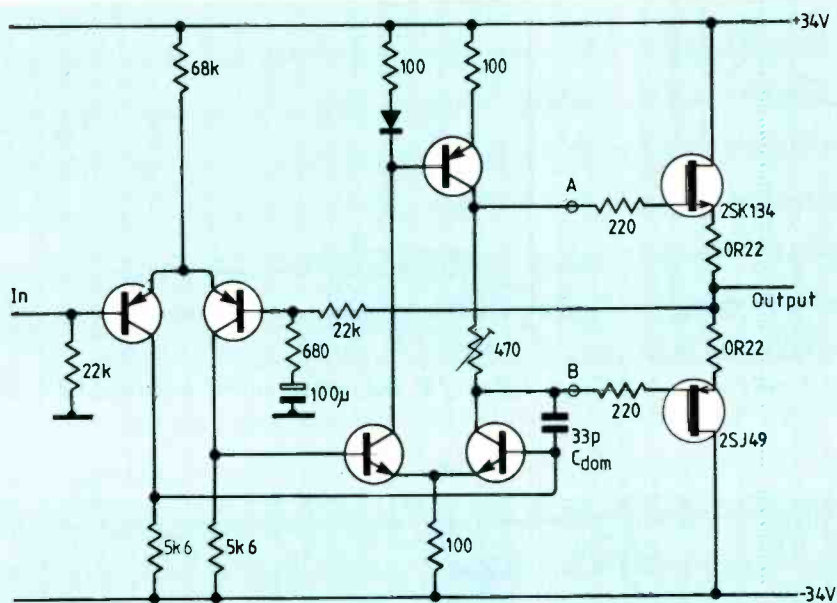


Fig. 1. Standard mosfet power amplifier configuration.

IC op-amps — and a power amplifier is, after all, only a big op-amp -- shows the problem to be distinctly soluble, although I admit that op-amp PSRR often differs markedly between the two rails, and usually declines above 1kHz. This sort of difficulty can be simply solved in a power amplifier with a little RC decoupling.

Harmonic distortion should be kept as low as possible, but without spending significant money specifically on its reduction. THD in commercial equipment varies more widely than any other performance parameter, ranging from 0.003% to 1% at similar powers<sup>4</sup> with the most expensive units often giving the worst performance.

In marketing circles, there are clearly two routes to take: make the THD vanishingly small to show you know what you're doing; or make it poor and imply that this very practical parameter has been sacrificed in favour of some intangible and unmeasurable sonic benefit.

I have always gone for the former and so have concentrated on linearity as being the prime determinant of amplifier topology.

Distortion performance is not easy to specify completely, ideally requiring a spectrum analysis of every combination of level, frequency and load impedance. But this is not practical and so I have summarised it as THD plotted against frequency, into 8Ω, at different levels where appropriate.

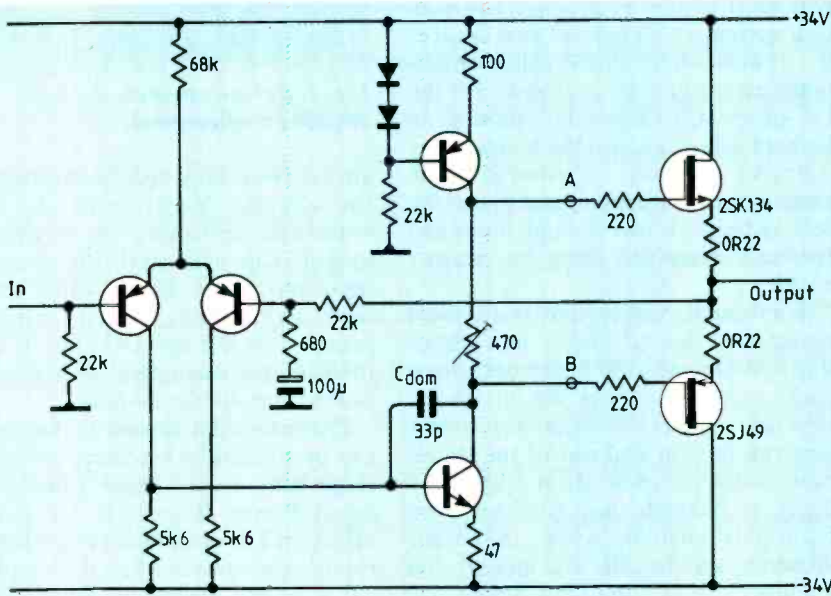
Pros and cons of mosfet output devices have been thoroughly ventilated<sup>5,6</sup>, but one point needs qualification. They have been praised for having a large crossover region

between the two halves of a Class B stage, but my experiments show this to be a very dubious advantage.

Mosfet outputs, with or without the augmentations described below, may be uncritical of quiescent current setting, but this really means that nothing is exactly right. Bipolar stages, with sharper crossover regions, do at least make it obvious where to set the quiescent current, providing it is set by observing the distortion residual — and it certainly should be.

Mosfet distortion residuals typically present a rather gnarled appearance,

Fig. 2. Standard bipolar power amplifier configuration, using mosfets.



with plenty of harmonics at least to the seventh. Though it runs counter to conventional wisdom, in my experience complementary-pair bipolar residuals tend to be smoother.

Another vital point is that mosfet complementary-pairs are rare, not particularly complementary, and definitely more expensive than the profusion of strictly N-channel devices intended for switching.

### Determining performance

Mosfet power amps have suffered more than most branches of technology from "application-note cloning" though some original designs have been published, ranging from the complex<sup>7,8</sup> to the very complex<sup>9</sup>. But these are well worth ferreting out, though perhaps unattractive commercially.

The "standard" mosfet amplifier circuit (Fig. 1) differs from the equally standard bipolar-style circuit (Fig. 2) mainly in possessing a sort of push-pull/current-mirror configuration in the voltage amplifier stage, probably intended to provide better charge/discharge of the mosfet input capacitances. This stage is sometimes called the pre-driver, but it is less confusing to call the first full-voltage-swing stage the voltage amplifier stage, or VAS.

The first question to be asked is what improvement is made by this push-pull arrangement (Fig. 3). The linearity is not very different and the benefit at HF is not startling. As always in science, it pays to be sceptical.

Given that the simpler bipolar configuration of Fig. 2 is workable, there are established ways to improve its overall linearity and some of these are

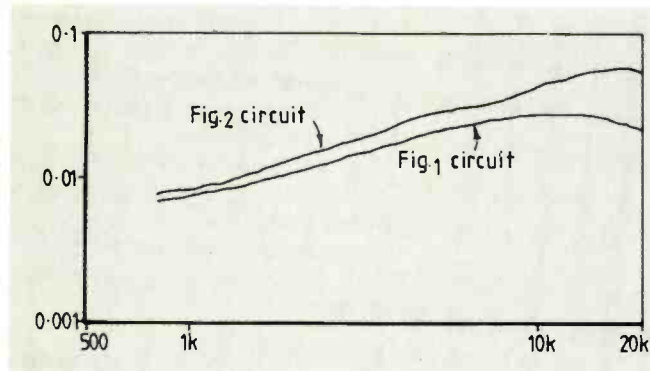


Fig. 3. THD vs frequency for examples of Fig. 1 and Fig. 2. 10V RMS into 8Ω.

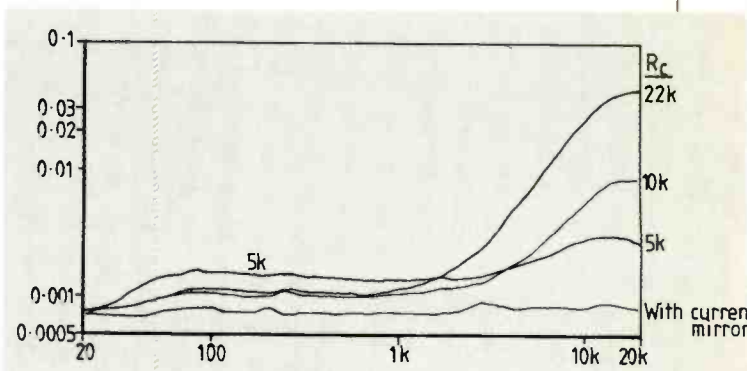


Fig. 5. Effect of  $R_c$  and current-mirror, input and VAS only.

shown in Fig. 4.

Linearity can be enhanced simply by increasing open-loop gain (Figs. 4a and b) or a cascode arrangement (Fig. 4c) which attempts to linearise the VAS by eliminating Early effect. Cascode arrangements are relatively ineffective at reducing distortion in power amplifiers, since the Early effect seems to be dominated by non-linear loading of the high impedance at the interface with the output stage (points A and B).

The added emitter-follower and current-mirror enhancements (Figs. 4a and 4b) work because the input pair act as a transconductance amplifier (voltage-difference in, current out) feeding a VAS that is basically a Miller integrator, thanks to the dominant-pole capacitance  $C_{dom}$ .

Emitter-follower  $Tr_3$  increases open-loop gain by enhancing the current-gain of the VAS. The current mirror does the same thing by doubling input-pair transconductance; also slew-rate is greater and symmetrical (30V/μs was obtained) as the input stage can now sink current as effectively as it sources it. Furthermore, input collector currents are kept balanced, valuable if the DC offset at the amplifier output is to be kept within acceptable bounds (say  $\pm 50mV$ ) without adjustment. The input collector currents, and hence the base currents drawn through input and feedback resistors, must be roughly equal.

Total input pair current is a critical parameter, since it affects input-stage transconductance and hence open-loop gain, and also defines the maximum slew rate, setting the maximum current that can flow in and out of the dominant-pole compensation capacitor  $C_{dom}$ . Though not obvious, the input-pair current is an important influence on the HF stability of the amplifier. Power amplifier design has

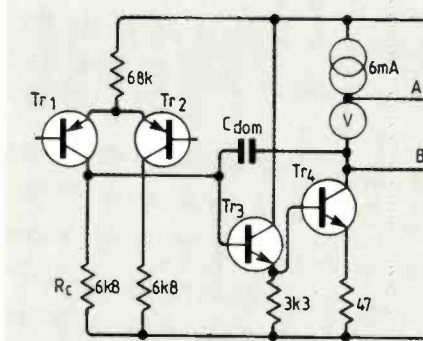


Fig. 4a. Added emitter-follower.

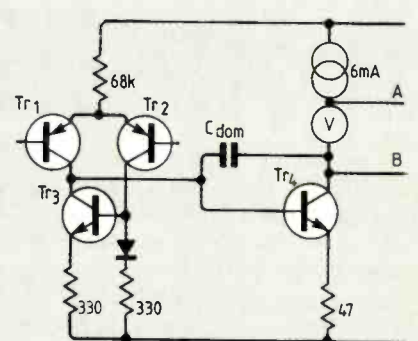


Fig. 4b. With current mirror.

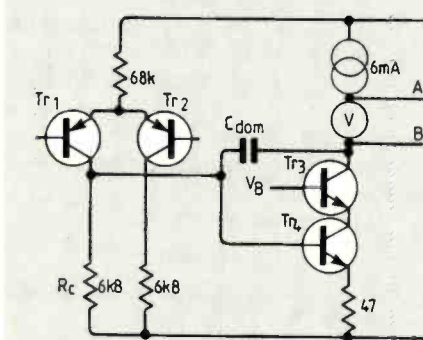


Fig. 4c. Cascode version.

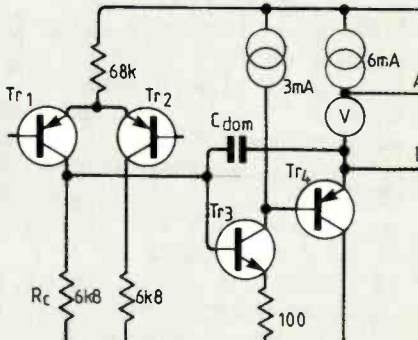


Fig. 4d. With buffer stage.

Fig. 4. Enhancements to the basic amplifier configuration.

always been impeded by the fact that the crucial VAS, with its high-impedance collector, has to drive an output stage with markedly non-linear input impedance. The resulting interaction means that, when distortion occurs, it is not clear whether it arises in the output stage itself, or at the VAS due to non-linear loading.

Distortion not caused by the output stage can be studied by replacing the output stage with a very linear Class-A voltage-follower. Resistor  $R_c$  has a strong effect on HF distortion (Fig. 5) with a clear improvement when  $R_c$  is replaced by a simple diode/transistor current

mirror. This underlines the crucial nature of the interface between the input pair and the VAS.

Similarly, the output stage can be tested in isolation by driving it directly from a low-impedance oscillator<sup>6</sup> and this technique was used to study the two output arrangements described below.

Neither method, however, allows study of the VAS/output interaction directly. One strategy for side-stepping this problem is to use a unity-gain buffer between the VAS and the non-linear load of the output stage (e.g. emitter-follower  $Tr_4$ , Fig. 4d).

This has not been pursued with mosfets, but I have used it in a commercial design for a bipolar quasi-



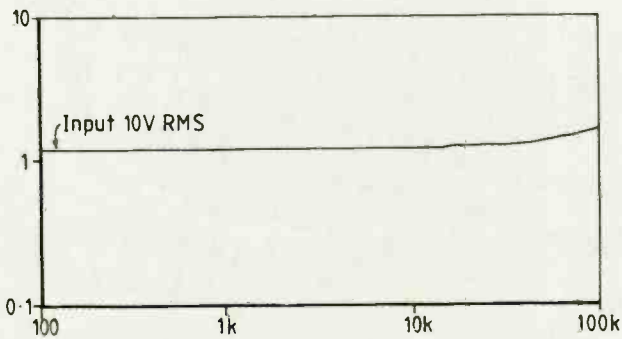


Fig. 6. Quasi-complementary output stage only (open-loop) showing almost flat THD. 8Ω resistive, measurement bandwidth 22-7500Hz.

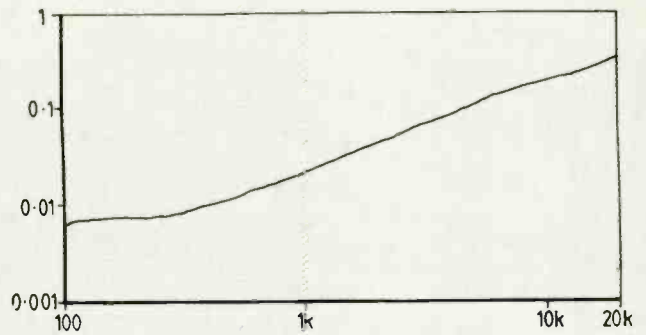


Fig. 7. Complete quasi-complementary amplifier (closed-loop). 10V RMS into 8Ω. (Bandwidth 100-80kHz.)

complementary amplifier. It proved effective at reducing distortion and is an approach which seems unfairly neglected.

Reducing costs

In the search for a better amplifier, two routes were examined. The first is to reduce the cost of a mosfet power amp by using two N-channel devices in a form of quasi-complementary output stage.

The second is to increase linearity and improve quiescent stability by using bipolar drivers with local feedback around each output fet.

The quasi-complementary approach is directly analogous to that used in the early days of transistor amplifiers; a P-N-P transistor is combined with an N-channel fet to emulate a P-channel

fet, and this works very well.

The output devices are now the same (promising bulk-buying economy) and can be chosen without reference to complements. That used was the IRF530, offering 100V, 14A, and 75W in a TO-220 package, a pair costing £5.00 against £9.50 for the 2SK134/2SJ49 pair. Open-loop distortion of the output stage alone driven from a low impedance was shown (Fig. 6) to be 1.1%.

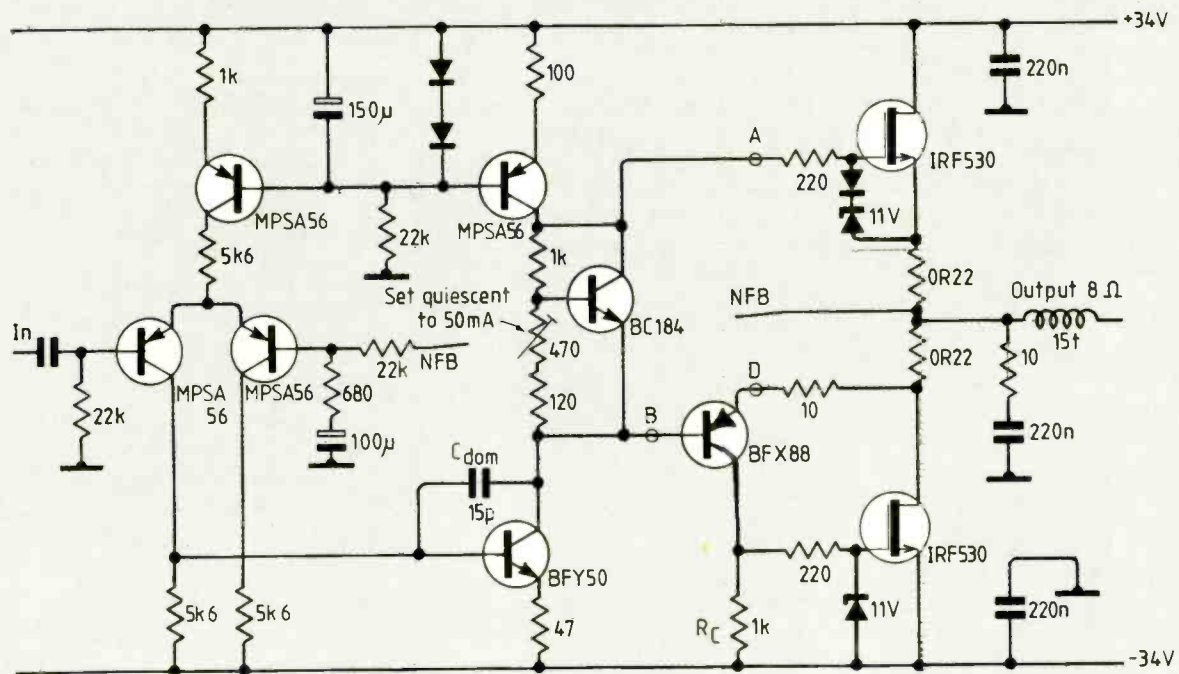
Closed-loop performance (Fig. 7), (yielded by the practical circuit shown in Fig. 8) demonstrated that, predictably, output symmetry is not wonderful, and crossover effects on the residual were clear.

Fig. 8. Practical circuit for quasi-complementary amplifier.

But this performance is acceptable from such a simple and economical circuit, and could almost certainly be improved at minor cost by adopting added emitter-follower and/or current mirror.

Tests showed that the value of  $R_c$  is non-critical, so there seems no difficulty in driving the bottom mosfet gate capacitance.

Quiescent setting is by transistor bias-generator; this is purely a regulator, and is not thermally coupled to the output devices. In an attempt to improve output symmetry, a Baxandall diode<sup>10</sup> was inserted at point D in the driver emitter. Sadly, THD was unchanged, despite the dependable improvement that this modification gives in bipolar quasi-complementary designs.



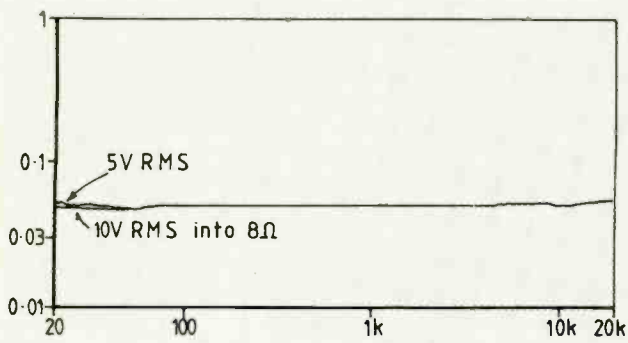


Fig. 9. Hybrid output stage only, operated open-loop.

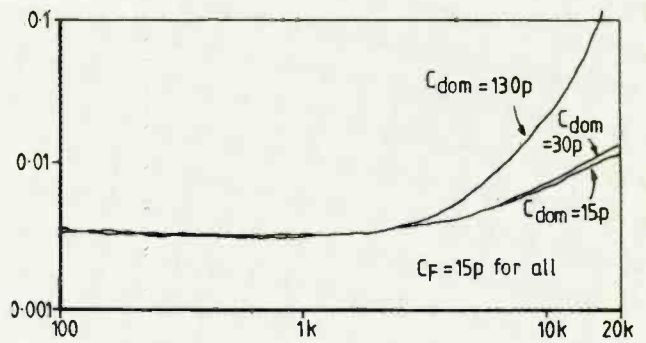


Fig. 10. Hybrid amplifier (closed-loop) with varying values of  $C_{dom}$ . 16V RMS into 8Ω.

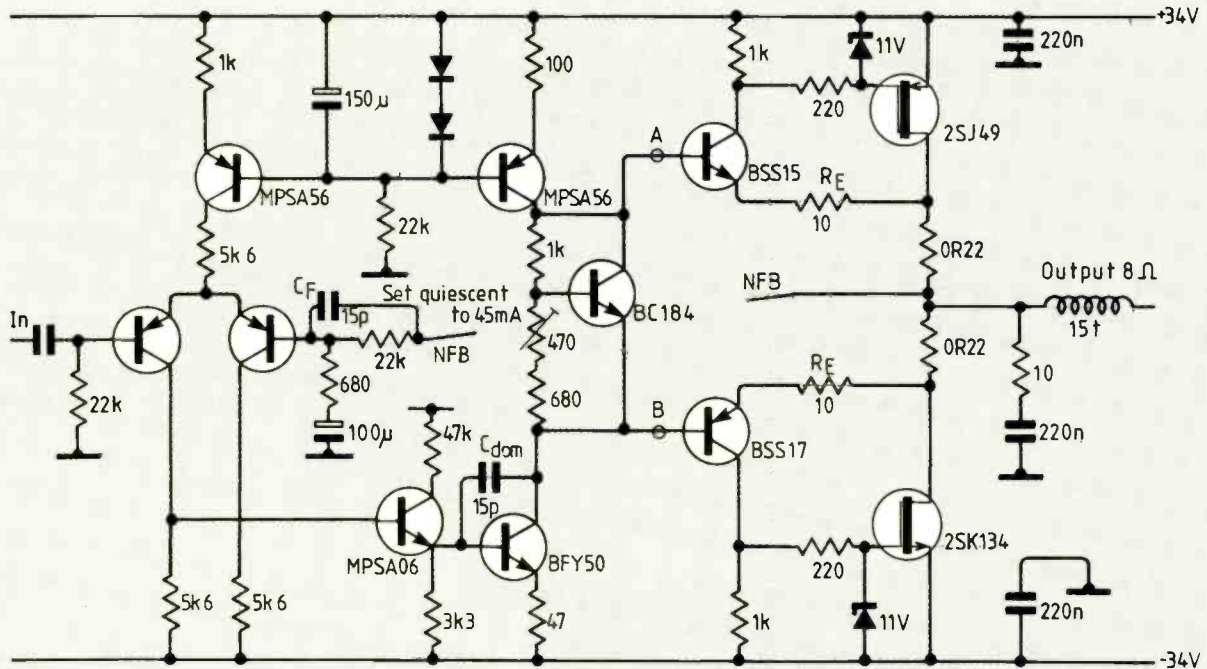


Fig. 11. Practical circuit for high-quality hybrid bipolar-mosfet amplifier.

Reducing distortion

If performance outweighs economy, a true complementary output pair is retained, with local feedback linearising each mosfet<sup>6</sup>. An important variable here is the value of emitter-resistor  $R_e$ . A high value increases output distortion, since it reduces the feedback factor within each hybrid bipolar-mosfet loop, while a low value makes quiescent-current setting unduly critical. As a compromise, 10-22Ω works well.

Figure 9 shows the output stage alone in open loop giving 0.05%, and Fig. 10 shows closed-loop performance as given by the practical design in Fig. 11, plus the effect of varying  $C_{dom}$ .

An emitter-follower is added to increase the feedback factor, and  $C_f$  is now needed for HF stability with  $C_{dom}=15pF$ . The compensation is not necessarily optimised for all possible real-life loads.

Distortion across the band is now very low. While it is desirable to define the closed-loop bandwidth of any audio device, do not put a simple RC filter at the input, as this makes the bandwidth dependent on the output impedance of the upstream equipment.

The temptation to implement it by increasing  $C_f$  should also be resisted, because if it is large enough to provide a suitable roll-off, there is a danger that it will induce mysterious VHF instability in  $Tr_2$  — a common effect. It is only revealed by distortion that vanishes at the touch of a cautious finger.

I have not tried to give the final word on this subject, though I hope it illuminates a few new directions. The use of current mirror topology in particular looks promising. ■

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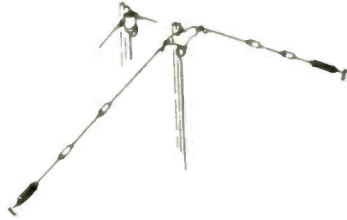
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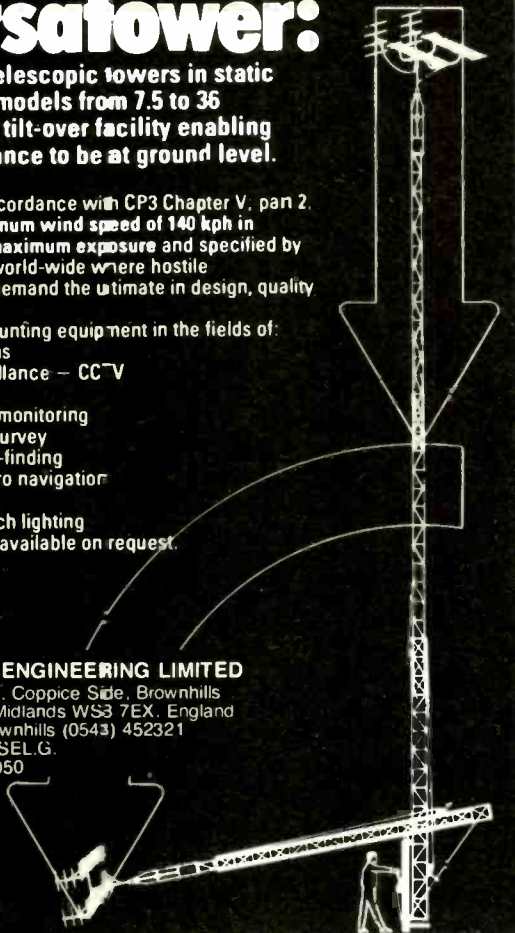
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Packet Radio AX 25, 50 to 1200 Baud  
Hell: Synchronous/asynchronous all speeds  
Fax: Weather charts, photographs with grey scales at 60, 90, 120, 180, 240 rpm  
Morse: Automatic and Manual with speed indication  
Press DPA: F7b spec., 300 Baud ASCII  
Wirtschaftsdienst: F7b spec., 300 Baud ASCII  
Sport Information: F7b spec., 300 Baud ASCII  
Autospec Bauer: ITA 2 including both modes  
Spread 21 and Spread 51  
Duplex ARQ AMrac ITA 2  
TWINPLEX F7b-1 and F7b-2 Duplex ARQ ASCII

Baudot: ITA 2 plus all types of Bit inversion, at any speed  
ARQ: CCIR 4/8, CCIR 825 mode A  
ARQ-S: ARQ 1000S  
ARQ-Swe: CCIR 518 variant  
ARQ-E: ARQ 1000, ITA 2-p Duplex  
ARQ-N: ITA 2 Duplex  
ARQ-E2: CCIR 519 ITA 3  
ARQ-6: 5/6 character 90 and 98  
TDM 242: CCIR 242 2/4 channels  
TDM 342: CCIR 342 2/4 channels  
FEC-A: FEC 100(A) ITA 2-P FEC Broadcast  
FEC: 3-FEC CCIR 025, 476-4 mode B Sitor Amtor  
FEC-S: FEC 1000S ITA 3

All modes in preset and variable user-defined speedrates and shifts.

Three options are available to use with the Code 3 and consist of:

- 1: OSCILLOSCOPE, this facility displays the measured frequency versus time, including split-screen, storage and non-storage modes at £25.
- 2: PICCOLO MK VI (Everybody wants this facility, but it's only on offer from Hoka), the well-known multitone-mode at £60.
- 3: LONG-TIME AUTO-STORAGE in ASCII (up to several days) £25.

Plus many other special codes. Send for details, price on application.

Along with the many facilities listed, the analysis section of the Code 3 offers you a wide choice of unique facilities such as: a built-in low frequency spectrum-analyser for shift measurement and tuning, plus precision speed measurement up to 0.001 Baud resolution. Other tool-facilities include Speed Bit analysis, Speed Measurement, Character Analysis, Auto-correlation of MOD and RAW signal, Bit Analysis. All these state-of-the-art features are included in Code 3 to assist the experienced user.

All options are available from the main menu, saving or loading to or from hard or floppy disk in Bit form (no loss of unknown signals), hard copy with printer, on-screen tuning indicator and very easy to use Help-files.

Warning. The actual use of parts of this program may be illegal in some countries and any liability in this respect is disclaimed.

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CIRCLE NO. 138 ON REPLY CARD

# Sound by numbers

Studios without tapes? Home audio so good you can hear the record producer biting his nails over equipment quality? Stan Curtis looks at the reality of digits

There are no less than seven digital audio formats in common use by studios and broadcasters, with various sub-types appearing through manufacturers "stretching" the format to improve performance.

The situation would be impossible were it not for the fact that a lot of these formats are used in specialised applications, where commonality is less important, and that most equipment has inputs and outputs that match the internationally agreed AES/EBU bus specification. So the equipment can be treated as a "black box" recorder and the actual storage medium ceases to be important unless the recording is carried from studio to studio.

The oldest format still in use is the pulse code modulation digital audio processor such as the ubiquitous Sony PCM-1630 which converts, encodes and then records the signal on a modified NTSC standard U-format video cassette recorder. Up to 75 minutes of recording is possible of 2-channel audio with 16bit quantisation.

This is popular because of its wide availability and relatively low-cost hardware, though it can no longer be considered state of the art. However, to the frustration of recording engineers, it is in almost universal use for CD mastering and most commercial CDs will have their music signal passed through this equipment at some stage.

A direct descendant is the 8mm video-based multi-channel recorder used by Akai in their A-dam recorder. This remarkable machine costs a moderate £16,000 and records 12 channels of 16bit digital audio on an extremely compact 8mm video tape. Only 17 minutes of recording is possible, but this is adequate for most music recordings.

Akai's format, in common with digital audio tape format, uses eight-to-ten modulation and a double Reed-Solomon code for error correction; but there the resemblance ends. A-dam has a 40mm diameter head drum with a tape wrap-around of 221° and a 78.586mm/s tape speed. DAT relies on

a 30mm diameter drum with a 90° wrap around (to minimise tape wear and tension) and the much slower tape speed of 8.15mm/s to record two channels of audio.

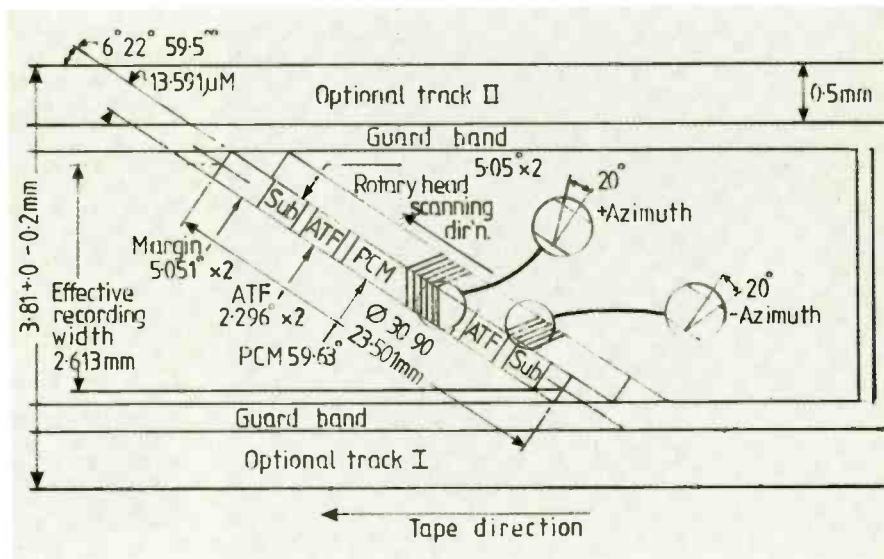
Small studios entering the digital audio field on small budget have turned to A-dam, particularly as up to three units can be linked together to give synchronous recording of 36 channels. There were some early reports that it was prone to "incorrectable" errors but various software upgrades seem to have overcome this problem.

DAT started out as a consumer tape product for enthusiasts, never intended for professional use. But its comparatively low cost and excellent performance meant it was inevitable that professionals would soon be using DAT machines as stereo master recorders.

Initially the only machines available were domestic models modified with "XLR" connectors and sometimes balanced audio inputs and outputs together with AES/EBU compatible digital connections. But Sony, amongst others, accepted the situation and released a series of professional DAT recorders. These models are considerably more expensive than the modified domestic models, so it is hardly surprising that many professional users continue to buy and use the latter.

Two key features professional machines, such as the Sony PCM-7050, do have is the ability to edit and to carry time-code signals. The latter facility allows audio and video reference signals to synchronise the DAT machine to other equipment, such as VCRs, and to other DAT players in what is termed a chase synchronisation mode.

Fig. 1. DAT tape format







*Fig. 2. Soundcraft 32000 recording console at Black Barn studio, Ripley, Surrey. Desk is an analogue design, but is used with multitrack digital equipment.*

This enables two DAT machines to be locked together. In normal mode, playback can start automatically when the DAT locks to the incoming time code signal; in chase mode the DAT continues the chase after the reference signal (in its absence), allowing perfect synchronisation between the two recorders even when drop-outs and variations occur to the master time code signal.

The DAT format encodes to 16 bits with a 48kHz sampling frequency and generates a data rate of 1.536Mbit/s ( $48,000 \times 16 \times 2$ ). To this is added error correction information to compensate for tape drop-outs, bringing the data rate up to 2.46Mbit/s. Also added are control bits (sub-codes) which help locate a particular segment, giving a final data rate of 2.77Mbit/s.

The recording process uses a helical scan of 23.501mm length on a 3.81mm wide tape. The 30mm diameter drum has two heads and the record/playback signal is recorded or played back 50% of the time. See Fig.1.

Claimed advantages of this system are that the 90° wrap means only a short length of tape is in contact with the drum, reducing tape wear and

allowing high-speed searching. Low tape tension can be used, increasing head life, and if four heads are fitted they can be separated by 90° to allow simultaneous signal monitoring.

The record/playback signal can be converted to a high-frequency signal of 7.5Mbit/s, overcoming some of the low-frequency losses of the rotary transformer and also increasing the rotary head signal-to-noise ratio.

Some of the details on the six DAT formats now available are given in Table 1.

Portability has proved to be a major attraction of DAT, where a unit such as the Sony TCD-D10 PRO — a mere 2.0kg (including battery) and 253×55×191mm — has all the professional connections and interfaces and full DAT performance.

Broadcasters like it because they can often record the music for a full programme on one tape, eliminating the repeated loading and cueing-in of vinyl disks "on air".

Confidence is such that many record producers regularly take a DAT machine to recording sessions. It is run in parallel with the master recorder producing a "safety" copy, of a stan-

dard suitable for eventual use, and providing a high-quality recording that can be auditioned at home prior to editing.

### Tapeless studio

For many engineers, the ideal has always been a tapeless studio with an absence of machines which suffer mechanical problems. Such an installation may soon be here with the advent of hard-disk recording based on a Macintosh, Atari or a PC computer linked to a high-capacity disk drive.

With the availability of low-cost computing power such systems are rarely used for just recording; instead considerable processing is possible including editing and mixing.

One example of a stand-alone hard-disk recorder is the German DI-REC-T modular 32-channel unit built up from blocks of eight tracks, each of which offers 12.5 minutes of recording time. It also handles some processing, including time compression and expansion, has 16bit Delta Sigma A-to-D conversion with 64 times oversampling and 18bit D-to-A with eight times oversampling.

But the tapeless medium of the 1990s



# Professional Solutions Limited

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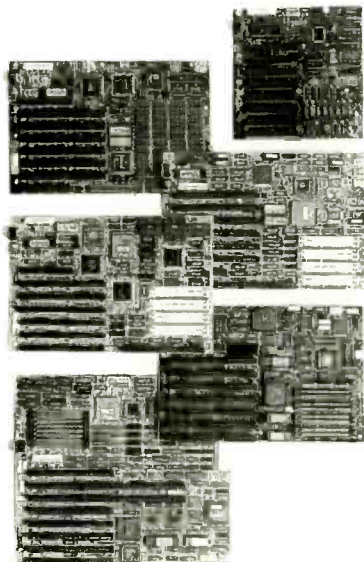
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						0	1	2	4	0	21	32	49	68	115	150
8088	12	2.8	1	-	8/0/0	42	102	-	-	395	615	649	715	759	-	-
80286	10	13.5	4	-	2/5/0	89	149	235	389	455	675	715	785	829	-	-
80286	12	16.5	8	-	2/6/0	119	179	239	359	545	765	805	875	919	-	-
80286	16	21.5	8	-	2/6/0	159	219	315	399	595	815	855	925	969	-	-
80286	20	27.0	8	-	3/4/0	229	329	389	549	679	-	935	999	1049	1379	1489
80386SX	16	21.0	8	-	2/6/0	299	369	419	539	725	-	985	1049	1095	1419	1529
80386	20	27.5	16	-	2/6/0	499	579	659	789	839	-	1139	1169	1215	1539	1649
80386	25	34.0	16	-	2/6/0	575	665	745	875	925	-	1225	1255	1299	1625	1735
80386	25	43.0	16	64	2/6/0	765	849	935	1065	* 1359	-	-	1689	1735	2059	2169
80386	33	58.0	16	32	2/6/0	1019	1099	1189	1319	* 1615	-	-	1945	1989	2315	2425
80386	33	59.0	32	128	0/6/2	1439	1529	1599	1739	* -	-	-	2405	2449	2769	2885
80486	25	114.0	16	64	2/6/0	2039	2125	2209	2399	* 2639	-	-	3009	3239	3335	3445
80486	25	114.0	32	128	0/0/8	3569	-	-	3869	** -	-	-	4659	4699	5025	5135

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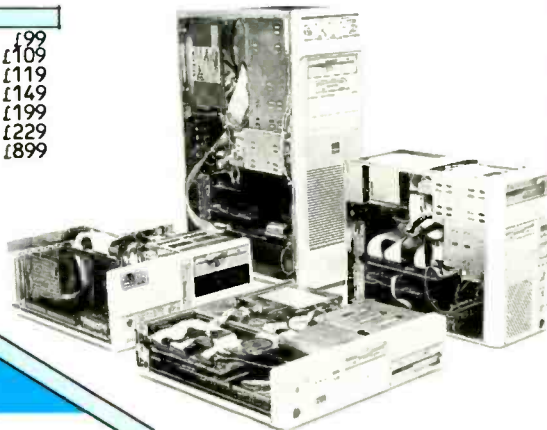
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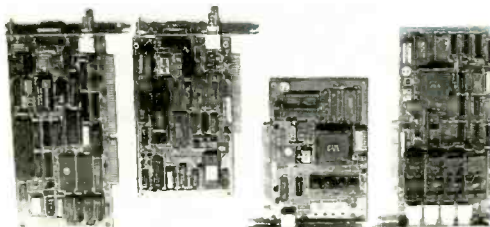
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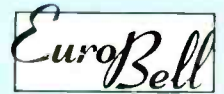




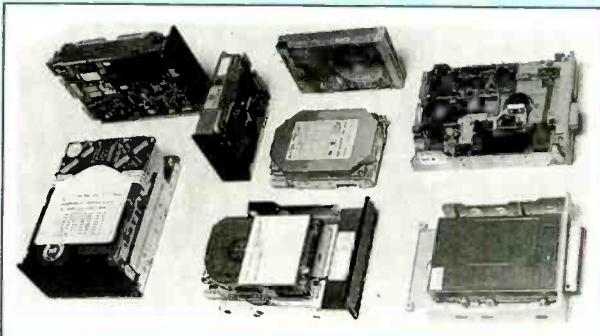
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**COMPLETE SYSTEMS - MOTHERBOARDS - DISC & TAPE DRIVES + CONTROLLERS  
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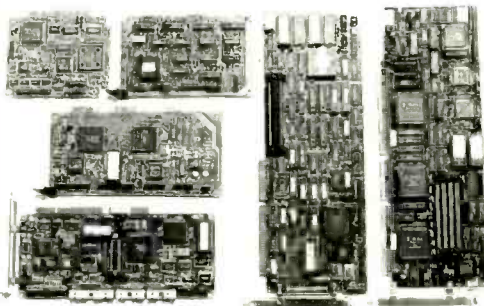
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Colours	16	256	16	256	16	256				
Y	Y	Y	Y	Y	Y	Y	256	OAK		89
Y	Y	Y	Y	Y	Y	Y	512	PARADISE		135
Y	Y	Y	Y	Y	Y	Y	512	TSENG		159
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Table 1. Alternative DAT operating modes (Sony)

Mode	Mode I	Mode II	Mode III	Mode IV	Mode V	Mode VI
	Standard mode	Option 1	Option 2	Option 3	Pre-recorded tape	
		Compatible with satellite broadcasting A mode	Long-time mode	4-channel mode	One-to-one normal track	High speed wide track playback only
Available channels	2	2	2	4	2	2
Sampling frequency	48kHz	32kHz	32kHz	32kHz	44.1kHz	
Bit numeral of quantisation	16bit (linear)	16bit (linear)	12bit (non-linear)	12bit (non-linear)	16bit (linear)	
Transmission speed	2.46Mbit/s	2.46Mbit/s	1.23Mbit/s	2.46Mbit/s	2.46Mbit/s	
Sub-code capacity	273.1kbit/s	273.1kbit/s	136.5kbit/s	273.1kbit/s	273.1kbit/s	
Modulation system	8-10 conversion				8-10 conversion	
Error correction system	Dual Reed Solomon				Dual Reed Solomon	
Redundancy	37.5%	58.3%	37.5%	37.5%	42.6%	42.6%
Tracking system	Area split ATF				Area split ATF	
Tape width	3.81mm				3.81mm	
Tape depth	13µm±1µm				13µm±1µm	
Tape in use	Metal powder					Oxide ape
Tape speed	8.15mm/s	8.15mm/s	4.075mm/s	8.15mm/s	8.15mm/s	12.25mm/s
Relative speed	3.133m/s	3.133m/s	1.567m/s	3.133m/s	3.133m/s	3.129m/s
Standard drum specs	∅30, 90° lap				∅30, 90° lap	
Drum revolution	2000 rpm	2000 rpm	1000 rpm	2000 rpm	2000 rpm	
Track pitch	13.591µm				13.591µm	20.41µm
Track angle	6°22'59.5"				6°22'59.5"	6°22'59.5"
Head azimuth angle	±20°				±20°	
Recording time	120 min. (tape depth of 13µm)  180 min. (tape depth of 10µm)	240 min. (tape depth of 13µm)  360 min. (tape depth of 10µm)	120 min. (tape depth of 13µm)  180 min. (tape depth of 10µm)		120 min. (tape depth of 13µm)  180 min. (tape depth of 10µm)	80 min. (tape depth of 13µm)  120 min. (tape depth of 10µm)
Cassette size	73mm×54mm×10.5mm				73mm×54mm×10.5mm	

Table 2. Comparison of recording formats

	Dash	Prodigy
Audio channels	24 (48 dbi density)	32
Tape speed		
48kHz sampling	30ips 76.2cm/s	30ips 76.2cm/s
44.1kHz sampling	70.01cm/s	76.2cm/s
Tape width	half-inch 12.7mm	one-inch 25.4mm
Recording time with 14-in reel	1hr	1hr
Longitudinal data density	1.152Mb/s	0.896Mb/s
Bit length	0.6616µm	0.8505µm
Data redundancy	33.3%	32.6%
Track width (normal density)	0.24mm	0.29mm
Gap width	0.20mm	0.27mm

adopted by Otari and Telefunken. Both began life with 16bit quantisation, a sample rate of 48kHz, and a tape speed of 30in/s (76.2cm/s).

One notable difference between the two (Table 2) is that at its lower sampling rate (44.1kHz for CD) Dash runs at a lower tape speed (70.01cm/s), so that recording wavelengths are independent of sampling frequencies.

With Prodigy, lower sampling frequencies mean less data are stored on a given length of tape so that recording wavelengths are inversely proportional to sampling frequency. Obviously the formats are incompatible, creating problems in an industry where the client may want to record the master in one studio and then mix and edit in another country.

As a result, the industry has polarised with the Dash format now seemingly holding dominance.

By March this year some 680 Dash machines had been installed, all, bar a handful, being manufactured by Sony.

Originally the Dash format had 28 tracks on half-inch tape with 24 used for audio. But recently Sony introduced the PCM-3348 machine which records 48 audio tracks on the same size tape.

Compatibility with the old standard is achieved through double density recording. Tracks 1 to 24 are located in their normal positions on the tape so that they can be reproduced on a standard 24 track machine. Audio tracks 25 to 48 are then recorded in between the normal density tracks to give a maximum of 52 tracks made up of 48 audio, one control, one for time-code, and two cue tracks.

All the data applicable to one digital audio channel (16bit audio data, sync words, error detection bits, and error correction bits) are recorded on a single track and so each track on the Dash machine is independent and fully

looks set to be the optical disk and at the forefront of activity are Akai with their DD1000 optical magnetic recorder storing up to 50 minutes of stereo digital audio.

To write data, a laser heats up spots in the recording layer of rare earth elements (usually gadolinium and terbium). A weak magnetic field created near the hot spot by a biasing magnet allows the layer to be magnetically polarised.

When the disk cools it retains this magnetisation. Data is read by laser light, reflected from the disk, which is polarised depending on the magnetic polarisation of the layer. (The Kerr effect)

Disks give 297 or 325Mbyte of storage on each side of a 5.25in disk, have an access time of around 95ms and data can be transferred at about 5Mbit/s.

But despite these advances in the music industry, the overwhelming proportion of music is recorded on big multi-track tape recorders, only a small

percentage of which are digital audio machines. High cost, an unwillingness on the part of record companies to pay extra for digital recording work, and the memory of bad experiences with early digital audio recorders have all contributed to slow take-up.

There has also been the inevitable battle between two alternative formats, tending to slow down the widespread acceptance.

However, studios must supply what clients demand, almost regardless of cost, so the day is now close when every major studio will have available one of the big 24, 32, or 48-track digital audio master recorders.

### Digital multi-channel

Two digital audio multi-channel formats are in popular use; Dash (digital audio stationary head) system developed by Sony (c1983) and since adopted by Studer, Matsushita and Teac; and Prodigy developed primarily by Mitsubishi (c1985) and since



protected.

With the Prodigy format, each audio-channel track carries only the 16bit audio data, sync. words, and error detection bits. The error correction bits, known as P and Q words, are stored on their own separate tracks with two error correction tracks needed for every eight audio tracks.

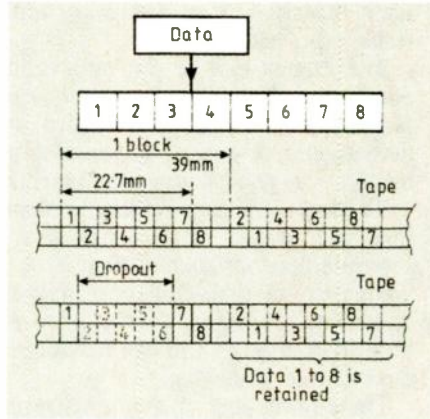
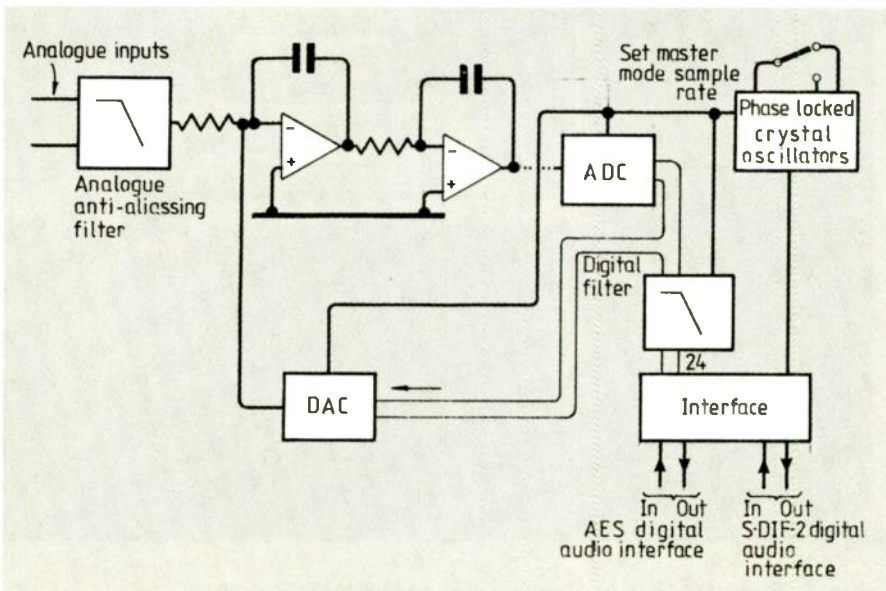
A 32-channel Prodigy machine has 32 digital audio tracks, eight error correction tracks and five auxiliary tracks, making 45 in total. Pulse code modulation (PCM) is used for digital audio data and pulse width modulation (PWM) for auxiliary data. All 45 tracks are the same width with the same space between them.

Both formats use the cyclic redundancy check code (CRCC) giving a very high probability of error detection during playback.

Conflicting claims are made for the reliability of the two processes though Prodigy, with its lack of a reliance on a single track, is potentially the most reliable. In fact Mitsubishi claims its 32-channel machine could lose up to eight tracks due to tape dropouts, tape damage, or clogged heads, before there is any noticeable loss in audio quality.

Mitsubishi's X-880 32-channel machine is the most advanced Prodigy model and can be supplied with a chase synchroniser permitting locking to a video source, or to another Prodigy recorder for synchronous recording of up to 64 audio tracks. In this mode, locking is accurate to the period of one

**Fig. 4. Data Conversion Systems' 20bit A-to-D can give dramatic improvements in sound quality.**



**Fig. 3. Dash-M format allows tape splices to be accommodated without interpolation.**

digital audio word ( $\pm 20\mu s$ ).

The Dash format now offers several variations beyond the original specification. Double density recording for increasing the number of channels is one enhancement, but on some models there is also a choice of tape speed.

Tracks can be traded for speed and hence longer recordings can be made or a saving made on tape: fast — 76.2cm/s, one track required; medium — 38.1cm/s requiring two tracks; or slow 19.05cm/s, four tracks.

"Twin-Dash" is a new variant, where data is written in two different permutations in different places on the tape. As a result burst errors of up to 39mm length can be completely corrected and tape splices can be accommodated without interpolation.

It is ideal where absolutely no errors can be tolerated or where extensive use, with likely increased wear, of the

original master tape is anticipated.

Lack of a "headroom" on performance between studio mastering equipment and home systems used to reproduce recordings is an area of growing concern to recording engineers. Both use 16bit quantisation, and the difference between a 48kHz sampling rate and one of 44.1kHz is hardly significant. It is more of a nuisance than anything because a conversion has to be made when mastering for CDs.

Yet by the time the signal has been through editing, mixing and some processing with likely truncation at each stage, there is going to be a definite loss of signal quality.

Indeed it has been the availability and general use of digital workstations that has prompted demands for a higher performance standard. An examination of the recording formats and of the AES/EBU interface format shows that the slot allocated to the digital audio data can accommodate 24 bits.

Agreement has been reached that 20 of these bits can be used for the audio (and potentially 22 bits) so there has been a move towards 20bit recording.

Manufacturers such as Sony and Mitsubishi are expecting to offer 20bit A-to-D converters in the coming months. But at present the only proven unit is the DCS900 made by Data Conversion Systems in Britain, using a 128 times oversampled front end followed by a decimating digital filter (FIR type with a -110dB stop band rejection) and an output truncated to 24bits. The converter's noise floor is nearer to 18bits (-105dB) but signal information is still present in the noise.

My own experience is that the improvement in sound quality between 16bit and 20bit recordings is little short of dramatic and cannot be overstated. It is a pity that at present there are no means of offering such improvements to the home market.

Mitsubishi have also tackled the problem of signal bandwidth, and machines such as the X-86 can operate with a 96kHz sampling frequency extending frequency response beyond 30kHz with 16bit quantisation. But it is difficult to use this extra performance when much audio equipment is only designed for use with the 48kHz sample rate.

### Dealing with digital editing

One of the earliest problems of digital audio recording was postproduction, primarily editing. At the time of first generation 3M PCM recorders there

were no digital editing mixers and even cross-dubbing between two machines required conversion of the signal back to analogue because of the difficulty in adequately synchronising two asynchronous data streams.

For a time 3M offered an editing aid — a flat glass cylinder containing a magnetic fluid which would align itself with the recorded magnetic domains. It made "razor blade" edits possible but demanded great skill and patience for success.

Initially the design of an editing "workstation" was very demanding. Too much capital would be tied up in using two recording machines so the video technique of synchronising machines via a "rock and roll" editor was not popular.

Instead material would be taken from one or more tracks and rerecorded onto a spare track on the same tape. What was needed were two short-term memories where the two pieces of music (to be edited together) could be stored, and from which they could be read using a single clock; together with a suitable processor circuit.

This processor comprised two multiplier digital volume controls and an adder to mix the two signals. Multiplying signal A with progressively smaller coefficients forced its level to drop. At the same time signal B would be multiplied with progressively larger coefficients so causing its level to rise. Add signals A and B together and arrange for the two sets of coefficients to change over a defined time period and the cross fade is born, with the output signal changing smoothly from A to B.

Only a fixed linear cross-fade used to be possible, but recently designed processors permit the fade to be customised to operate over any chosen time frame and to follow a variety of laws.

Early editors used discrete TTL circuitry and were complicated and expensive. But from these, two distinct types of workstation have developed. The most complex is the dialogue/effects workstation — a multi-track recorder with a hard-disk in place of tape, combined with a digital mixer and editor.

**Workstation editors**

By far the most popular is the AMS Audiofile and over 300 are now installed in studios around the world. The Audiofile allows audio signals to be recorded, edited and auditioned through eight outputs represented graphically on the monitor screen as

eight "tracks" of an imaginary multi-track tape machine.

The "tape" can be put into various conventional modes including play, fast-forward, rewind and record with all activities ostensibly proceeding just as with a normal audio tape machine.

The key difference is that the recordings are stored on a hard disk as separate files or "cues". What is re, whenever any time-code information is locked to the signal (as in video and film production) it too will be stored as data in the same file.

Depending on the configuration, several hours of audio can be stored on disk and small segments of dialogue, sound effects and music can be stitched together to form a continuous sound track.

Broadcast stations and video production houses like this aspect because they can edit the video while shunting any audio material that may be required into the Audiofile. Then, when the final video "cut" is ready, a matching sound track can be reconstituted from all the bits and pieces scattered around as files on the hard disk.

Latest generation of this workstation has even faster processing through use of transputers and now up to 20 "tracks" are available for use. For archiving or back-up against the evil day of hard-disk crash, AMS offer a removable magneto-optical read/write disk.

At the top end of digital audio production systems is the £150,000 Lexicon Opus with the emphasis on

random access to the vast number of files containing audio recordings. Opus encompasses the functions of a 99-track digital recorder, an audio editor and a 12-channel digital mixer.

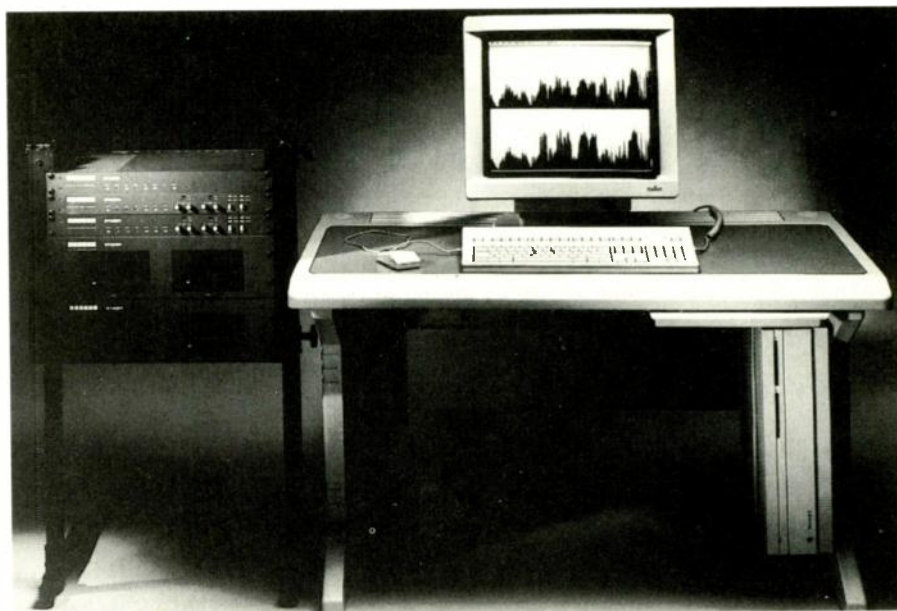
Storage is an 800MB Winchester hard-disk allowing about 120 track minutes (for example 60 tracks each two minutes duration) of recording with the option to add three further on-line 800MB disks, giving a total of 480 track minutes.

Back-up and archival storage is provided by a 2.3GB capacity 8mm helical scan tape cartridge, derived from the popular 8mm video format. Powerful error-correction algorithms allow "bit perfect" storage of up to six hours of audio on one low-cost tape.

Recent Opus enhancements enable material to be input from all analogue and digital recording systems (up to 28 may be connected at any one time) and for extensive equalisation, filtering and processing to be applied in the digital domain.

Source material is loaded into memory and located in a directory termed a "reel". Each reel has between eight and 99 separate "tracks" storing one or more files or "segments".

Each segment represents a section of audio source material defined by its start and end points. So although the internal operations are very much those of computer processing, the user is dealing with familiar terminology and can scan the tracks across the monitor screen until the desired segment is found just as though it were a real tape.



*Fig. 5. Studer DYAXIS hard-disk digital audio production system.*



The whole system is extremely flexible and the user can build up layers of audio material (the "mix") then edit-in various segments to produce the final audio track synchronised to any audio, video or film industry time codes. Or an operator can construct a time grid on the screen and move around the various segments to any desired time location.

Its outstanding advantage over the traditional — and still popular — razor blade editing is that original source material remains intact and can be recalled at any time. Yet up to ten variations of each edit can be stored and subsequently auditioned before selection.

Gains in flexibility and productivity through Opus are such that the film and broadcast industries have found that the admittedly high purchase price can be soon recovered.

### Producer preferences

So far, the type of workstation described is best at holding thousands of short segments of sound which can be quickly accessed and repositioned in time relative to each other to form a complete sound track.

But this is not normally what the music industry wants. Quite often there may be 20 or 30 takes of the same piece of music and to save time (and hence money) the producer may choose the first 20 bars from one take and then join them to the next 60 bars from another take. Theoretically there is now nothing to stop the joining together of the best bars from each take to produce a flawless recording.

So anyone can now sing a hit record — a good voice no longer being required, as each line could be sung separately and then joined up later. But the difficulty comes in making the edits inaudible in an otherwise very high quality recording of music.

Editing together the dialogue of several actors' voices is a demanding task, but the joins are less likely to be heard than they would in a music recording. For many studios the solution has been the Desktop Audio System from the aptly named Sonic Solutions company.

This system couples the ubiquitous Macintosh to the Sonic Solutions processor card, carrying four Motorola 56000 series DSP chips, and a Winchester disk drive. The power of this system lies in its software and so the operator will see little on the desk other than the Mac computer and a screen-full of graphical interfaces and icons.

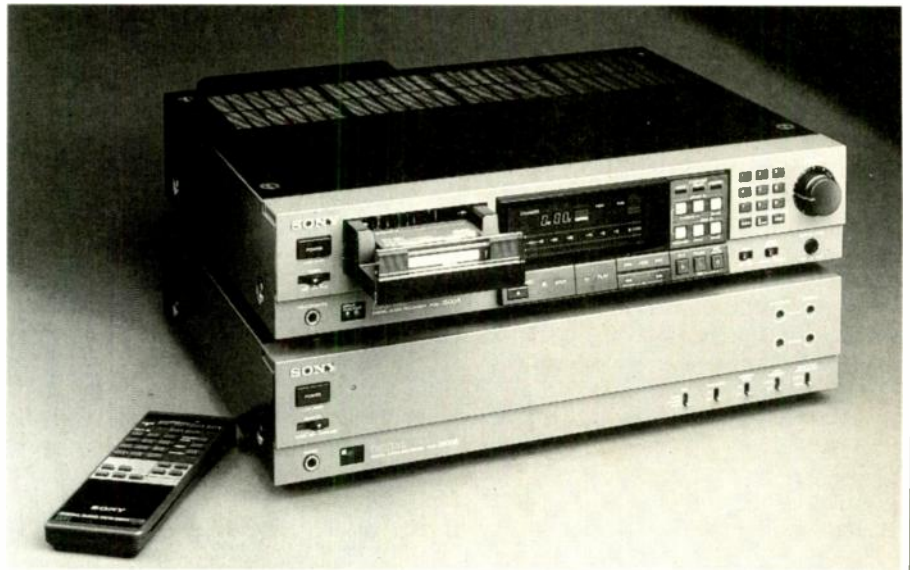


Fig. 6. Sony PCM-2500 professional DAT recorder.

Each hard disk holds two track hours and four drives can be connected with up to six mono channels simultaneously read and written to the disk.

An added advantage is that all disk transfers take place in background mode, causing no interference to foreground editing and processing.

One feature offered by Sonic Solutions is the NoNoise system to remove tape hiss, vinyl record surface noise, and unwanted hums and buzzes all "without affecting the original programme material".

To date, over 100 CD reissue projects have had the NoNoise treatment including many great jazz recordings from the 1920s which without processing would only have been saleable to the most fanatical of collectors.

The remarkably straightforward process begins with an analogue-to-digital conversion of the original recording, to be stored on hard disk. First the clicks and other impulsive noises are removed by locating them on the music waveform (displayed on the screen) then an algorithm interpolates the now missing piece of signal by analysing the material before and after the click or dropout.

Background noise level then has to be adjusted. The noise signature of the recording is analysed by finding a short portion with none of the wanted signal present, such as the first few seconds of the recording, and then the system samples this residual noise into 2000 frequency bands. At its simplest the system then subtracts the noise from the (music+noise) programme to leave just a clean music signal.

Unfortunately this "automatic"

mode is not always successful and so a wide range of manual adjustments can be made; the quality of the end result very much depends upon the skill of the operator.

A large amount of computing power is required by the process and with some 53 million computations required for each second of material the original system was built around a Sun workstation.

Now the task can be handled by a dedicated processor board carrying four 56001 DSPs working with 24bit data word-lengths.

The latest option to be offered by Sonic Solutions is a recordable CD system developed in association with Start Lab — a joint venture of Sony and Taiyo Yuden. It integrates the Sony CDW-W1 optical recorder and the "That's" write-once optical recording disk.

Full compatibility is ensured through the disk meeting the CD "Red Book" specifications, and uses a layer of organic dye which changes optical characteristics when scanned by a laser beam at a power of 5 to 6mW.

The system works well, though there remain the obstacle of price, since blank disks cost £29 each in the UK. But there is also the tantalising problem that, when used on a badly aligned CD player whose laser current has been set too high, the disk could be overwritten and the contents destroyed.

We would then have the expensive "write once — read once" disk which would probably be too costly even by the standards of digital audio. ■

# SOUND CONCEPTS

Advances in technology have made it possible to design loudspeakers which embody concepts previously thought to be impracticable. David Berriman reviews recent developments.

**A**part from the occasional inspired creation, loudspeaker design does not progress in leaps and bounds, but develops by degrees. This conceals the very real progress which has been made since the 1930s, when Rice and Kellogg sliced contraceptives to make the roll suspension on their then revolutionary moving-coil drive unit. Little did they know how far-reaching in influence their invention was to become. This article explores a few of the more recent advances in loudspeaker technology, many of which are developments of what has gone before.

One of the main objectives of high-fidelity sound reproduction is the achievement of greater bass extension and/or greater efficiency from small enclosures. There are, of course, very real theoretical limitations to bass extension and efficiency with conventional reflex and sealed box enclosures and claims of breakthroughs should be treated with suspicion.

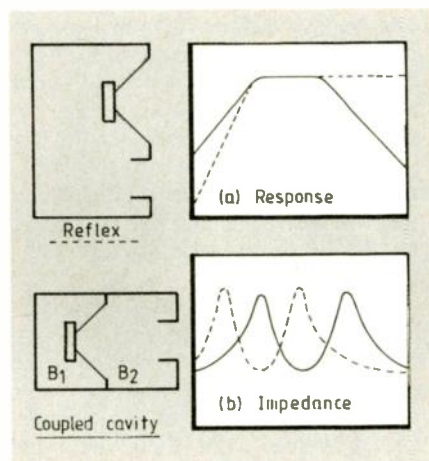
## The coupled cavity

This form of bass loading has been popularised by KEF more than any other manufacturer<sup>1</sup>. Though ostensibly similar to reflex loading, KEF's coupled-cavity system is really a sealed box enclosure, coupling the woofer to the room by way of an air cavity and a port, as shown in Fig. 1.

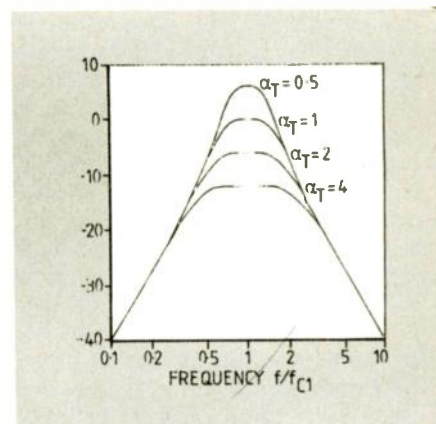
The coupled cavity provides the high efficiency of a vented box with a second-order low-frequency roll off, providing the improved transient response of a closed box, but with more output. The vent is tuned to within the pass band of the woofer and reduces

cone excursion, thus reducing distortion and improving power handling. KEF claims that it is superior in distortion and power handling to either reflex or sealed-box loading. A glance at the curves shown in Fig. 2 shows how versatile the coupled cavity can be; the 0dB reference is the output of the woofer in a box, but without the cavity.

Tuned cavity systems can thus be fine tuned to trade efficiency for band-



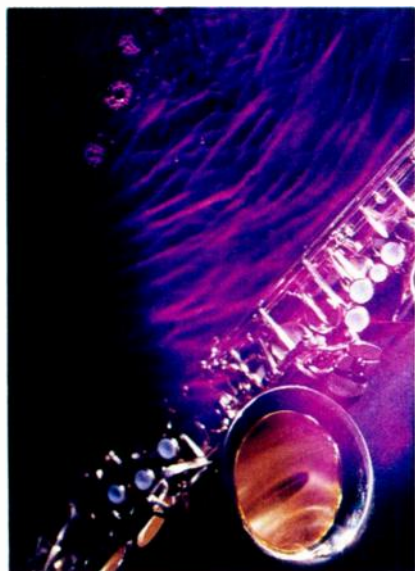
**Fig. 1. KEF's coupled-cavity system compared with a reflex type. The cavity serves as coupling element from driver to room, providing second-order LF roll-off for better transient response.**



**Fig. 2. Response of coupled-cavity system of Fig. 1. Varying compliance ratio of inner and outer cavities varies bandwidth and efficiency.**

width by varying the total compliance ratio  $\alpha_T$ . For very compliant woofers, this is simply the ratio between the inner and outer cavity volumes ( $\alpha_T = V_{B1}/V_{B2}$ ). Thus, a large  $\alpha_T$  gives wide bandwidth and reduced sensitivity, while a small  $\alpha_T$  gives increased output over a narrower band and can substantially boost the output. Because the cavity has a bandpass response, it acts as a natural filter, thus simplifying crossover requirements and avoiding the necessity for very high-value inductors in series with the woofer.





When the woofer low-pass filter cut-off is close to the system resonance in a conventional sealed box or reflex system, the crossover components interact with the woofer/cabinet motional impedance at resonance to interfere with the crossover filter shape. Due to simplified electrical filtering, the coupled cavity can avoid the worst of these problems, while obviating the need for high DC resistance inductors in series with the woofer.

KEF has had great success with loudspeakers using coupled-cavity loading and similar forms of loading have been used by Bowers and Wilkins and Acoustic Research to get deep bass from small sub-woofer boxes. It appears to be a system that, for once, really does deliver what is claimed.

### Third-order loading

This is a very simple method of creating a system with a third-order, high-pass frequency response from a second-order sealed cabinet by feeding the woofer through a series capacitor. Figure 3 shows that, if aligned correctly, the combination extends the frequency response deeper than would be expected from the box size.

Reflex enclosures can achieve a simi-

lar response, but they have a fourth-order roll off which, potentially, has a poorer transient performance and a lack of woofer-excursion restraint at frequencies below the vent tuning. Third-order loading gives the advantages of reflex systems without the problems; their one disadvantage is the large-value series capacitor (usually a few hundred microfarads). It can be argued that this should not affect the sound if the component quality is high enough, but with the kind of electrolytic component which cost and space limitations dictate, there is inevitably some loss of sound quality.

### Active servo technology

This is a phrase coined by Yamaha, which describes the use of overall

positive electronic feedback to create a negative output impedance at the amplifier output to counteract the electrical impedance of the loudspeaker unit. Providing a negative output impedance to improve damping is not a new technique<sup>2</sup>, but with AST Yamaha claims to achieve a significant improvement in bass extension compared to conventional reflex loudspeakers.

Yamaha's description of how of the system works is sketchy; the company's publicity merely claims cancellation of the voice-coil resistance, as shown in Fig. 4, dramatically increasing the driving force on the diaphragm. This is achieved by monitoring the current through the loudspeaker by sensing the voltage across a small value resistor in the earth return from the loudspeaker. To maintain an accurate feedback ratio and ensure stability, the sensing resistor is a small coil of wire designed to have a similar resistance versus temperature characteristic to the loudspeaker voice coil.

Positive feedback therefore holds the current feed to the woofer constant in the bass region, where the rise in impedance due to motional impedance normally limits the current (and hence the force available to drive the cone). This results in increased voltage drive where impedance is a maximum and reduced drive voltage where impedance is at a minimum.

AST is designed to work only at frequencies below around 200Hz. Because each loudspeaker has its own characteristics, the feedback must be tailored to suit the loudspeaker in question; there is additional frequency compensation both to tailor the frequency response of the speaker system and to ensure stability. Yamaha sells the electronics and loudspeakers as complete matching systems. AST is in contrast to many other feedback systems which rely on acceleration or displacement sensors fixed to the woofer diaphragm in order to detect cone movement. The AST unit looks like a conventional reflex loudspeaker.

With AST, Yamaha claims to make

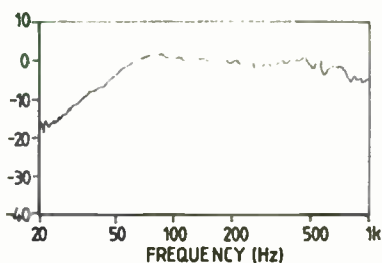
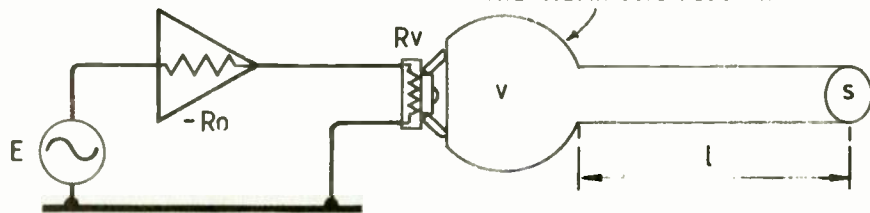


Fig. 3. Effect of feeding driver through series capacitor. Top curve shows 10in driver in sealed box with no capacitor, while below is curve for same driver with 600 µF capacitor.

Fig. 4. Yamaha's active servo technique, which is claimed to cancel DC resistance of voice coil and increase driving force on diaphragm.

### The Helmholtz resonator



$$\text{Driving force } F = B \cdot L \cdot i = B \cdot L \cdot \frac{E}{R_v + R_n}$$

$$\text{Speaker Q factor } Q = \frac{R_v - R_n}{(B \cdot L)^2} \sqrt{m_e \cdot S_e}$$

$$\text{Resonance frequency } f_p = \frac{C}{2\pi} \sqrt{\frac{1}{l \cdot v}}$$

- B: Magnetic flux density (T)
- L: Voice coil effective length (m)
- i: Driving current (A)
- E: Driving voltage (V)
- R<sub>v</sub>: Voice coil electric resistance (Ω)
- R<sub>n</sub>: Driving impedance (Ω)
- m<sub>e</sub>: Equivalent mass (kg)
- S<sub>e</sub>: Stiffness of unit and cabinet (Nm)
- C: Acoustic velocity (340 m/s)
- v: Port area (m<sup>2</sup>)
- l: Port length (m)
- v: Chamber capacity (m<sup>3</sup>)

the reflex system work much more efficiently by rigidly controlling the woofer, making it much stiffer, so reducing losses to the vent/box Helmholtz resonance via the woofer and increasing vent output compared to a normal reflex enclosure. Whether similar ends could be achieved by other means (for instance, using a larger magnet) is open to debate, but the Yamaha AST models do give very deep bass for their box and woofer size. Even Yamaha cannot, however, overcome the limitations to cone excursions which occur at low frequencies with very small bass cones.

### Equalisation

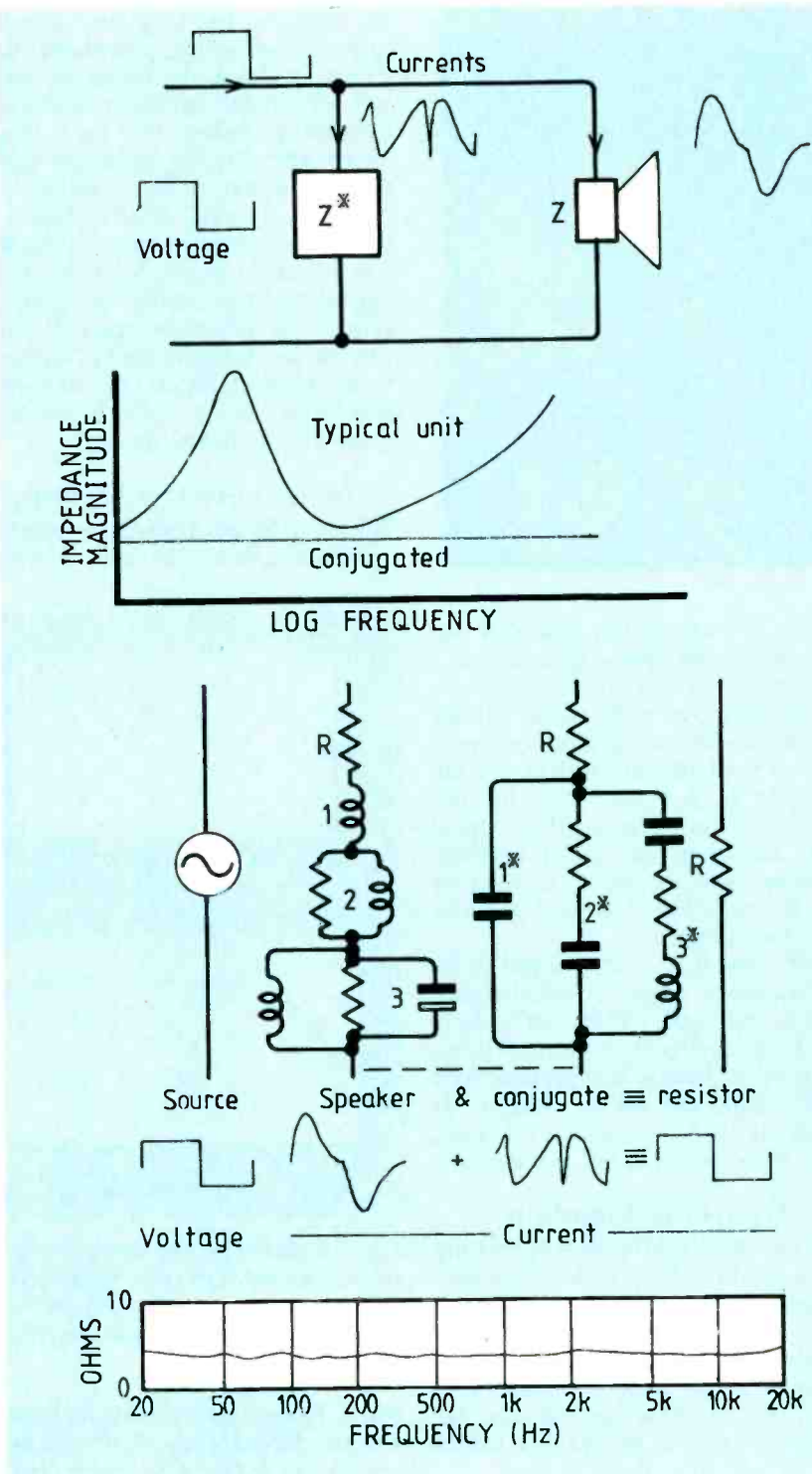
Another way of getting deeper bass from loudspeakers is to equalise the output by boosting the input to the loudspeaker electronically to compensate for the woofer's natural low-frequency roll off. This must, of course, be done very carefully to avoid over-driving the woofers below resonance, causing driver or even amplifier overload. KEF has used this technique very successfully with its KUBE equalisation modules, which rely on the limited low-frequency spectra available from most source material and also on the low distortion and high power handling of their coupled-cavity bass loading. It's certainly not a technique for general use.

### Conjugate load matching

Loudspeaker systems present an electrical load which is, of course, far from resistive. This is due not only to the complex impedance of crossover networks, but also to the electrodynamic behaviour, inductance and losses in moving-coil drive units, which can result in large peak currents and place extra demands on the power amplifier. With long cable runs, deviations from the nominal modulus of impedance can also affect the frequency response of the system.

Non-resistive impedance characteristics of drive units also wreak havoc with crossover filter design. As a result, much of this has to be done empirically — or with the help of computer-aided design software.

To overcome these various problems, KEF employs conjugate matching (Fig. 5) in which the impedance of crossovers — and sometimes drivers — is compensated in both modulus and phase by additional, conjugate, reactive and resistive elements. This makes the overall loudspeaker system essen-



**Fig. 5. Conjugate matching used by KEF, in which crossover impedance is compensated by the circuit shown to provide essentially resistive characteristic, as shown in bottom trace.**

tially resistive, as seen by the amplifier, and eliminates the problems outlined earlier.

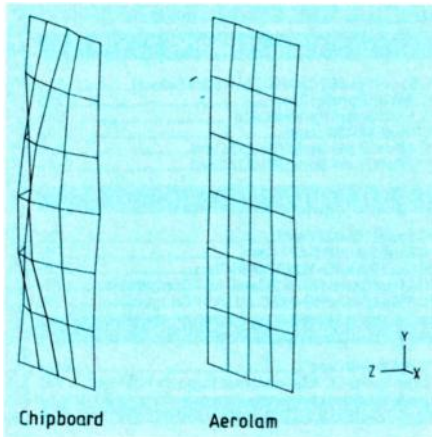
It does, however, result in a substantially more complex crossover network,

carries a cost penalty and, some would argue, a potential sonic loss, since so many components are needed. These will add distortion which, though small, may be audibly significant in high-performance systems unless designers are exceedingly careful.

### Vibration analysis

Celestion was one of the first companies to employ laser Doppler interferometry to measure the velocity of





**Fig. 6. Laser Doppler interferometry used to analyse panel vibration. This is normally depicted by a moving graphics display.**

loudspeaker diaphragms at many points and to use this data to construct moving graphic images of cone vibration. It has now applied this technique to loudspeaker panel-vibration analysis, using new software running on a fast Hewlett-Packard work station<sup>3</sup> to measure the amplitude and velocity and phase of vibrations across a wide range of frequencies at all points of a mesh on the panel.

Vibration at any one point can be viewed as a simple plot of vibration velocity versus frequency, which helps to locate trouble spots, or the structural analysis software can be run in moving graphics mode, as shown "frozen" in **Fig. 6**. This pictorial presentation should help to pinpoint the sources of unwanted panel flexure and to select the most effective positions for internal bracing or damping. **Figure 7** shows the vibrations in an aluminium honeycomb "Aerolam" cabinet (SL700 type) and a braced chipboard cabinet (SL6-S type).

The traditional technique of using a lightweight accelerometer glued to the panel can only tell the designer about one point at a time. It's a very useful technique and provides a lot of information, but not as clearly as the laser system.

### Dealing with panel resonance

That loudspeaker panel resonances contribute significantly to the "sound" of loudspeakers is now more widely recognised than ever before; if their amplitude can be reduced, the clarity of reproduction is greatly enhanced. So, having found the resonances by measurement, how do designers deal with them?

Most manufacturers use bracing to raise the frequency of resonances, while also reducing cabinet "breathing" at low frequencies. Traditionally, heavy damping materials, such as bitumen, bitumised fibre, or fibre-board materials have been employed, but have been going out of fashion on the grounds that, while they reduce high-frequency resonances, they also add mass without increasing stiffness, thus reducing the frequency of resonances and increasing their Q.

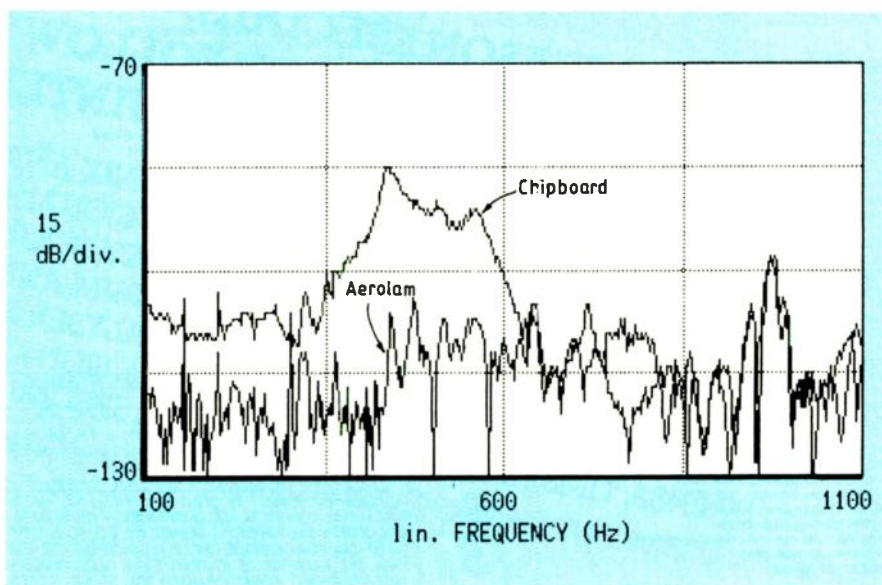
One method which does not incur this penalty is the bonding together of two stiff materials, which have different resonance properties and damp each other's resonances rather than shifting them down in frequency. The resulting composite baffle is also very stiff — not having the high stiffness-to-weight ratio of exotic materials like Aerolam, but much less expensive.

This is a technique used by Acoustic Research on their dual-density baffles. **Figure 8** shows how the vibration modes can be substantially reduced, compared to those in a standard chipboard front panel. The difference can be as much as 10 or 20dB at some frequencies, while the vibration after the transient stimulus is much more rapidly damped.

### Drive-unit cone technology

One can trace the ancestry of modern cone drive units to the early cone-type loud-speaking telephone receiver. Moving-iron armatures gave way to

**Fig. 7. Plot of vibration against frequency for an aluminium honeycomb Aerolam cabinet (lower trace) and a chipboard type.**



moving-coil motor systems, but the cone shape — ideal for rigid, light diaphragms — is still with us.

We have seen paper (excellent strength/weight ratio but poor self damping and variability), Bextrene (consistent, low coloration, when treated and moderate stiffness) and polypropylene, (excellent internal damping, but poor strength) used widely in commercial systems. Other materials with various pros and cons, such as woven carbon fibre or polyamide fibres, have also been pressed into service. Clearly, there is no such thing as the ideal cone material, but designers keep searching.

**Injection moulding.** One development from Infinity is to injection mould cones using a polypropylene and carbon-fibre mix injected at the apex. This is claimed to combine the excellent self damping of polypropylene with the reinforcement provided by radially oriented carbon fibres. Designers can also add strengthening ribs or vary cone thickness, whereas conventional vacuum forming is limited to using flat sheet, which can stretch during the forming process.

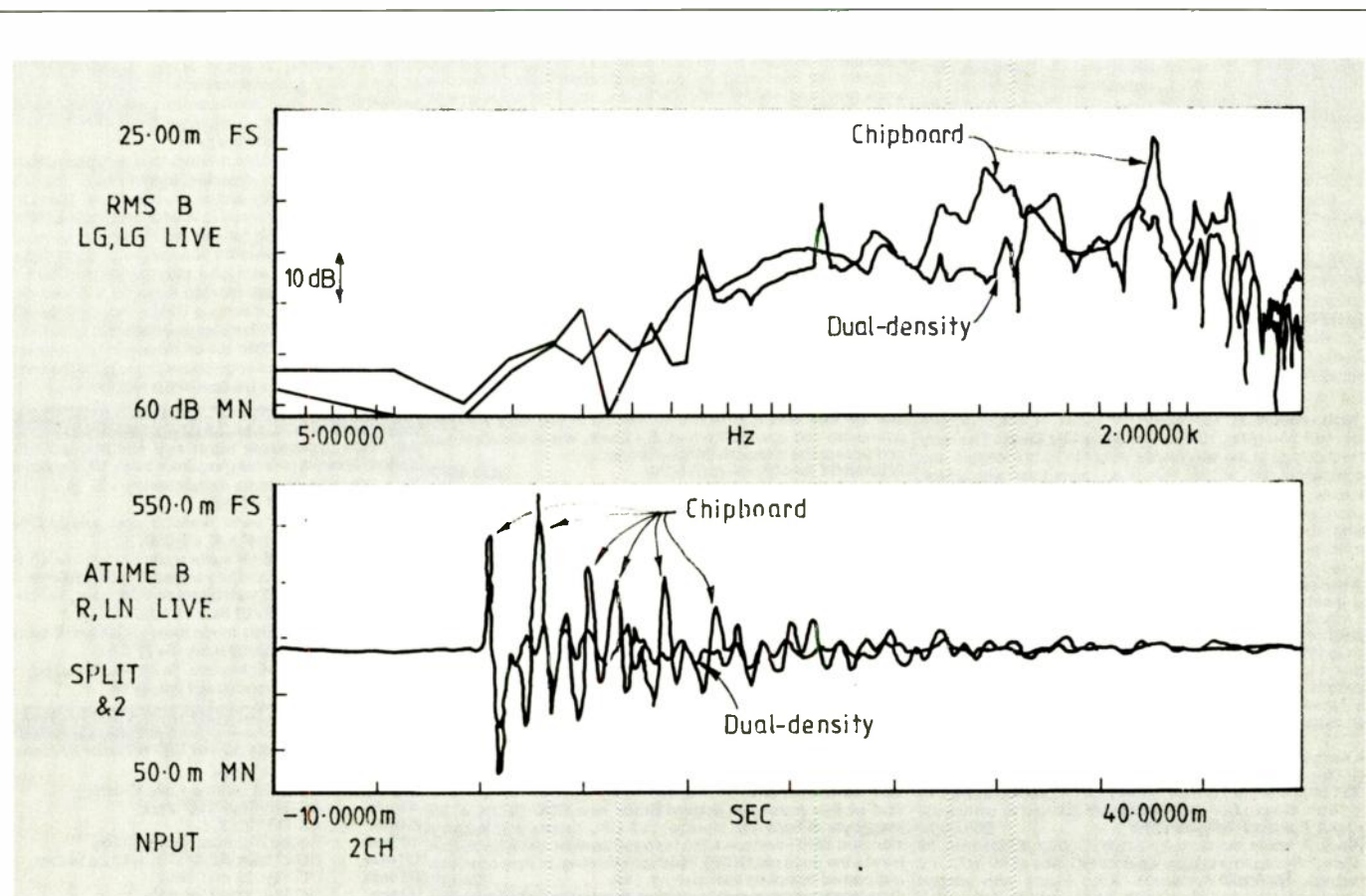
**Metal diaphragms.** Since dome drivers were introduced by AR in the 1950s, there have been domes made from paper, cloth, plastics films and glass fibre, to name only a few. Metal domes were first introduced in the 1970s by Yamaha in its seminal NS 1000 loudspeaker. In this model, both mid-frequency and tweeter domes were fabricated from vacuum-deposited beryllium.

Metal-dome technology was later given a push towards the mass market









**Fig. 8. Acoustic Research composite baffle vibration analysis. Top curve shows amplitude/frequency trace of chipboard and dual-density baffle and lower result is transient response of the two materials.**

by Celestion, with the copper dome of the SL6 and, more recently, the easier-to-make and more sensitive aluminium dome units in the SL6-S, SL700 and DL models. Many other manufacturers quickly followed in Celestion's footsteps, so that there is now hardly a manufacturer who does not offer this form of tweeter.

Metal domes have the advantage that, instead of breaking up (deviating from perfect-piston behaviour) at around 5kHz, like plastic or cloth domes, a good metal dome stays pistonic and provides a smooth frequency response to beyond 20kHz. Typically, the first break up of a good metal dome is at around 26kHz, where the ringing is very pronounced. This is beyond the audio range and should therefore be inaudible — provided no stimulus causes intermodulation distortion products to be thrown back down into the audio band.

**Metal-cone woofers.** Woofers have been slower to take the metal route, though there have been many metal-cone woofers in the past. There were, for instance, the GEC metal-cone unit from the 1950s, the Jordan modules from the 1960s and, more recently, the E.J. Jordan and Bandor metal-cone drivers. It took Acoustic Energy to capture the imagination recently with

its little AE1, followed swiftly by the Monitor Audio Studio 10.

Is this the start of another trend? Only time will tell. Metal cones can stay pistonic up to a much higher frequency than conventional cones but, like metal domes, can ring. Unlike domes, this ringing is in the audio band, even if it is beyond the handpass of the woofer crossover. The Acoustic Energy and Monitor Audio cones are both made from anodized aluminium which has a soft centre and hard outer skins — a sandwich structure which is claimed to damp resonances. Both also feature straight-sided cones.

This is the strongest possible cone shape and stays pistonic to a high frequency, which means that the whole of the cone radiates together until the first break-up mode. However, this is bad news for directivity, because large diaphragms beam at high frequencies. One advantage of a flared soft cone is that it can be made to "shrink" with increasing frequency. If only the area around the voice coil radiates at the crossover point with the tweeter, it

makes for a smoother change over of directivity. Flared cones, in general, are also far less prone to severe ringing.

Cost is the main drawback to metal cones. The diaphragms are easily damaged in production and so this technique is unlikely to reach the wide audience that metal domes have, unless a reliable method of mass production is developed.

That completes this brief overview, which is by no means complete. Who knows where loudspeaker design will head in the future? Moving-coil drive units will be with us for many years and will undoubtedly undergo further refinement. Electronics will serve an increasing rôle, with active equalisation, crossovers and bass-enhancing techniques becoming more commonplace as an increasingly discriminating public demand reduced size, higher quality and better value for money. ■

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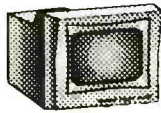


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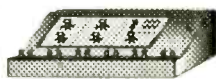
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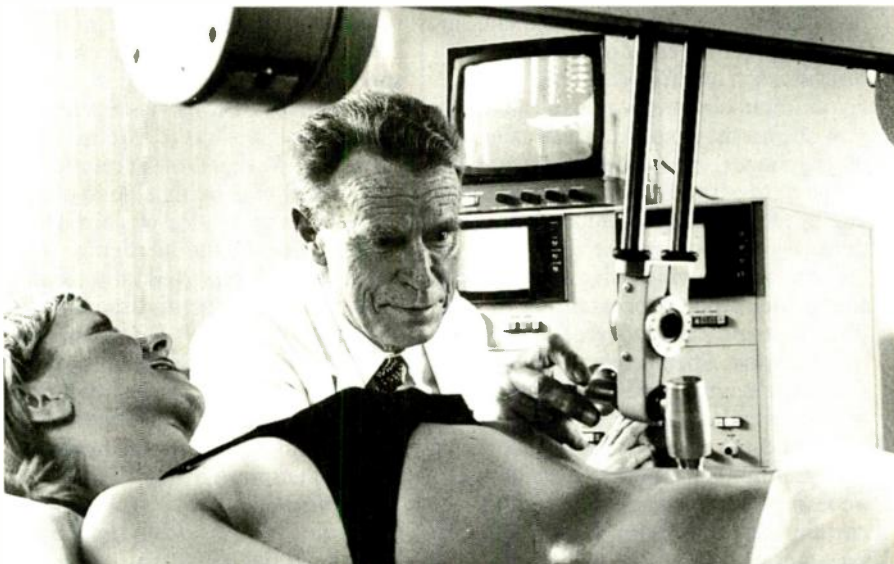


Possible hazards as well as beneficial uses of EMFs were some of the topics discussed at a May conference at Birmingham's National Exhibition Centre, on the novel subject of "Electromedicine – an emerging science".

Dr Richard Bentall, from the University of Maryland, spoke about the use of radio frequencies in wound healing. He described a particular RF dressing that he had developed, which starts to work as soon as it is exposed to light. Attached to the body, it lasts three weeks and is suitable for surgical wounds. The RF antennae operates using a 26MHz carrier wave, modulated at 1000Hz, with an 80 $\mu$ s pulse width, and producing a power density of 73 $\mu$ W per square centimetre. Dr Bentall postulated that the likely mode of action of the signal was by influencing the chemical reactions and enzyme systems in cell membranes which control ion pumps across membranes.

A particular delight to hear was the lecture by Professor Yuri Gulyaev, of the Institute of Radioengineering and Electronics at the Moscow Academy of Sciences. His talk focused on his attempts to produce a computerised "functional tomography" of the fields and radiations generated by the physiological homeostatic systems of the body, to develop new non-invasive methods of functional diagnostics. The six kinds of such fields are:

- Infrared thermal electromagnetic radiation, which characterises the temperature of the skin, determined mainly by capillary blood flow.
- Radiothermal microwave EMR, which supplies information about the dynamics of thermal fields inside the living body.
- An electric field which reflects bioelectric activity in the brain, heart, muscles and other internal organs. Besides this, electric fields around the body are connected to an electric charge on the highly resistive epidermis layer.
- A magnetic field which reflects more directly than the electric field bioelectric activity of internal organs, since it is not screened by the electrically conductive tissues of the organism.
- Chemiluminescence, in the near-infrared and optical regions of EMR, which provides knowledge about the saturation of tissues by oxygen, anti-oxidant status, etc.
- Acoustic radiation produced by



*Will the patient be as happy with some of the proposed unconventional treatments?*

## ELECTRICITY IN MEDICINE

Electromagnetics are playing an increasing part in modern medicine, not just in diagnosis but in treatment. Simon Best reports on a revealing conference

different kinds of noises inside the organs – heartbeat, lung movement, blood flow murmur, intestines and stomach peristalsis, etc. There is also acousto-thermal radiation in the ultrasound wavelength region which characterises temperature distribution inside the organism.

Prof Gulyaev then described the types of functional image taken in order to pinpoint changes in health by comparing "before" and "after" images. Pre-diagnosis of cancer was possible, he said, due to a 3° rise in temperature in a specific body area or organ. Magnetic field images can be used to study the heart and the possibility of infarctions by showing changes in the poles of the magnetic field produced by scar tissue around the

heart. In the brain, thought changes produce a discernible change in the magnetic field of the order of 1pT.

Finally, Prof Gulyaev described work on the use of 1-10mm waves in microwave therapy. Stomach bacteria have been influenced using specific frequencies and their resonances, from which the Professor concluded that the effects are not thermal. The irradiation appears to act like a trigger since an increase in intensity brings no change in effect. Amplitude- and frequency-modulated waveforms are very effective whereas ordinary sinusoidal waveforms are not. Short, strong pulses produce the strongest effect.

Large areas of the body may be irradiated, though a Kiev group is experimenting with a waveguide to locate and irradiate specific acupuncture points. Among the diseases apparently cured, according to Prof Gulyaev, are stomach ulcers, psoriasis, hypertension, skin melanoma, womb neck erosion and infected wounds.

Work on the effects of EMR on cells involved with wound healing was presented by Dr Mary Dyson, who works with teams at the United Medical and Dental Schools at Guy's Hospital, and at St Bartholomew's Hospital. Low-intensity red light and

pulsed magnetic fields (PMF) have been apparently successful, she said, in speeding up the repair of chronic injuries such as varicose veins. Experiments by the two teams have now shown that exposing cells called macrophages, involved in the repair process, to certain wavelengths of light and infrared radiation at low energy densities can increase the release of growth factors, which then stimulate the further repair processes of fibroblast and keratinocyte proliferation. Specifically, they found that wavelengths of 660, 820 and 877nm stimulate the proliferation of keratinocytes, and a wavelength of 880nm inhibits the process. It was not necessary, Dr Dyson discovered, at certain wavelengths for the radiation to be coherent.

Pulsed magnetic fields were also found to be able to stimulate keratinocyte proliferation, again with frequency "windows" having an increasing or decreasing effect. Dr Dyson observed a maximum effect at 16.7Hz and 5.1mT. Using a sinusoidal waveform, a maximum effect occurred at 16.7 and 60Hz, with a peak at 45Hz and an inhibitory effect at 75Hz. Using either light or PMFs, which were also found to affect the behaviour of mast and endothelial cells, such effects were greatest in cells grown in adverse conditions, such as after injury, particularly in chronic lesions.

Increasing our knowledge of what happens in epilepsy through the amazing powers of magnetoencephalography (MEG) is the special interest of, and was the subject of the talk by, Dr Peter Fenwick, from the Institute of Psychiatry at London's Maudsley Hospital. MEG is the study of magnetic fields arising from neural structures within the brain and measured just above the surface of the scalp, using a Superconducting Quantum Interference Device (SQUID). Fields coming from the brain are in the order of 5-200fT a million times weaker than the Earth's magnetic field. MEG fields are generated by high density, intracellular current flow and pass through the brain, skull and scalp without distortion. Thus, theoretically, magnetic measurement can produce an undistorted picture of the underlying magnetic sources. Such measurements are then used to try to model mathematically the most likely location and characteristics within the brain of the magnetic source generator or

dipole. The deeper the source, the more difficult it is to model, and the greater the number of sources, the less specific the models will be.

Dr Fenwick's work has attempted to answer the question of whether the MEG could exceed the standard EEG's ability in being able to pick up deep discharges in the temporal lobes of epileptics and model them.

Dr Fenwick reported that, using three patients with intercranially implanted electrodes, he had in fact been able to pick up spikes not seen by an EEG. Currently, he is attempting to correlate such MEG observations with sources and activity on the brain's surface measured by the EEG.

On the question of possible hazards. Dr Leslie Hawkins, from the Robens Institute at the University of Surrey, focused on electromagnetic fields from environmental sources. Fields around such sources vary considerably; close to an electric blanket the electric field may be 5-600V per metre, whereas within the right of way of high-voltage lines similar fields of 5-10kV per metre are the norm.

Of those studies that have looked at possible hazards, Dr Hawkins found that 60 per cent show a higher relative risk for central nervous system tumours, particularly in the occupational setting. Those reporting on childhood tumours showed on

**"As little as two days' exposure of two-day-old eggs is sufficient to produce abnormalities in brain tissue."**

average a doubling of the risk, though this still represented a very small increase in actual numbers, effectively from 1 to 2 in 10000.

The effects of EMFs on chick embryos was the subject of the next talk, by Dr Jocelyn Leal of Hospital Ramon Cajal in Madrid. Different studies performed *in vivo* on chick embryos have shown that early embryonic processes can be modified by weak, extremely low frequency, magnetic fields. As little as two days' exposure of two-day-old eggs is

sufficient to produce abnormalities in brain tissue.

In the so-called Henhouse Project, in which six laboratories around the world used the same methodology and type of chicks to conduct the same experiment, five out of the six results showed that weak AC magnetic field exposure led to early death, irreversible abnormalities in developed organisms, an increase in the level of abnormalities in embryos and a change in the orientation of the organisms.

Again on the question of increased leukemia and EMF exposure, Dr Ray Cartwright, of the Leukemia Research Institute at the University of Leeds, noted that to date, 16 occupational studies have been published, producing an overall average risk of 1.2, i.e. 20 per cent (statistically significant). For acute myeloid leukemia the risk increased to 1.5.

But such data was difficult to interpret, according to Dr Cartwright, since the contribution of other known workplace chemicals and carcinogens was unquantified. Future studies already planned or underway would involve larger samples, better exposure assessment and dosimetry, as well as identifying and controlling for the degree of risk arising from the father's occupation.

Dr Cartwright was followed by Dr Brian Maddock, from the National Grid R&D Centre in Leatherhead, Surrey, who discussed EMFs and exposure measurement.

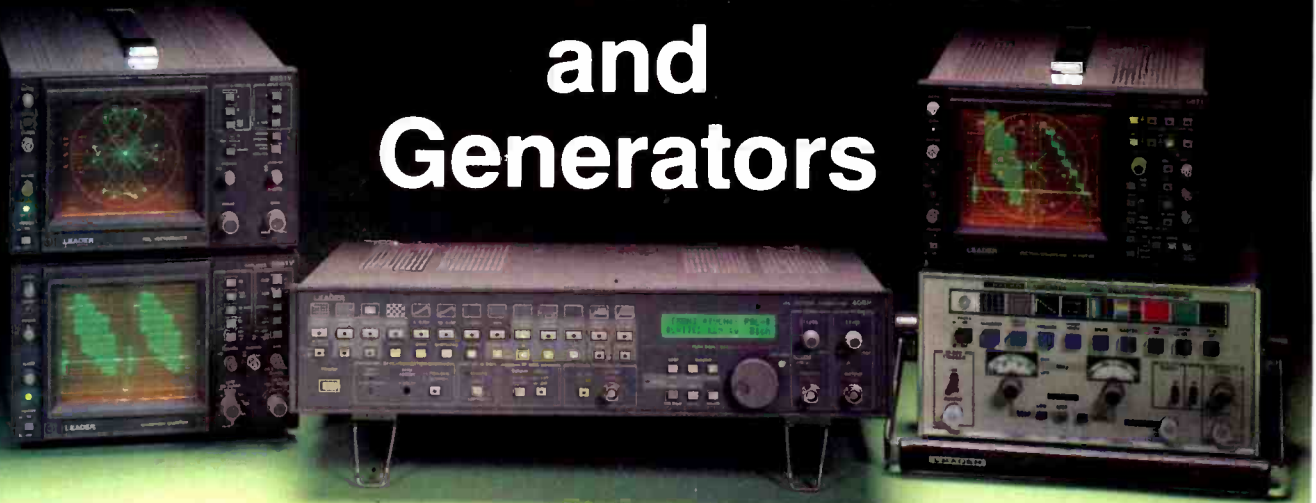
The National Grid is currently involved in monitoring the magnetic climate in the UK, using van-mounted apparatus to measure fields in the street and thus calculate nearby domestic fields, whose strength has been found to be directly related to net variations in the field generated by the underground cables. Portable meters are also being used by 200 staff volunteers to assess exposure at home and at work, the latter seeming from early results to provide the greater exposure.

The conference was sponsored by the journal *Hospital Equipment & Supplies*, owned by MBC Ltd, and organised by its editor, Susan Black. Coordinator was Dr Richard Dixey, director of the Bioelectric Research Laboratory at St Bartholomew's Hospital, London, who gave the opening address. Plans are already underway to hold a second such event next year. Contact Susan Black for further details: 081-837 1212. ■





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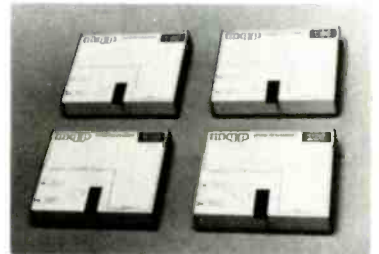
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# INTERFACING WITH C

## PART 5

Howard Hutchings concludes the subject of convolution with a program for graphical display of the convoluted output and embarks on the design of digital filters

To conclude the subject of convolution, it might be of interest to use the graphics routines outlined in Part 3 to display the convoluted output. A suitable program is given in Listing 4.2.

```

/*****
 * GRAPHICAL CONVOLUTION *
 *****/
#include<stdio.h>
#include<graph.h>
main()
{
int i,j,k,m,n;
float x,h;
float input [40];
float impulse [40];
float output;
/*-----
  CLEAR ARRAY
  -----*/
for (i=0; i<=20; i++)
{
input [i]=0;
}
/*-----
  READ IMPULSE DATA AND
  IMPULSE RESPONSE
  -----*/
printf ("Enter No. of i/p samples: 20 max");
scanf ("%d",&n);
printf ("Enter i/p data");
for (i=20; i<=20+n-1; i++)
{
scanf ("%f",&x);
input [i]=x;
}
printf ("Enter No. of samples in impulse
response: 20 max");
scanf ("%d",&m);
printf ("Enter impulse data");
for (j=1; j<=m; j++)
{
scanf ("%f",&h);
impulse [j]=h;
}
__lineto (200,100);
__moveto (0,199);
__lineto (0,0);
/*-----
  CONVOLUTION
  -----*/
for (i=20; i<=20+n-1; i++)
{
output=0;
/*-----
  RESET SUM TO ZERO
  -----*/
for (j=1; j<=m; j++)
{
output+=input [i-j+1]*impulse [j];
}
}
/*-----
  SCALE AND PLOT CONVOLUTED O/P
  -----*/
__moveto ((i-20)*10,100);

```



### Interfacing with C

An accompanying set of 49 source code C listings presented with this series is now available on disk, price £25.50+VAT. We will shortly be publishing a book "Interfacing with C" written by Howard Hutchings and based on the series, but containing additional information on advanced processing techniques. We are now accepting advance orders, price £14.95.

Prices include post and packaging. Please make cheque or company order payable to Reed Business Publishing Group and send to Lindsey Gardner, room L301, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. Credit card orders can be phoned through on 081-661 3614 (mornings only).

```

__lineto ((i-20)*10,50*(2-output));
}
/*-----
  CONFIGURE VIDEO MODE AND DRAW
  AXES
  -----*/
__setvideomode (__DEFAULTMODE);
__setvideomode (__MRES4COLOR);
__clearscreen (__GCLEARSCREEN);
__moveto (0,100);

```

### Applying the program

Using the program, we can predict the digital output of any linear signal processor without the need for analysis in the complex-frequency domain. Clearly, this is a useful vehicle with which to confirm and consolidate certain rules or concepts, previously presented as statements of fact. The following list of suggestions is by no means exhaustive and you may wish to try your own investigations, particularly in the light of subsequent work. **Aliasing.** If you have time, demonstrate the effect of processing a signal composed of insufficient samples. Adopt an ordered approach, select an input waveform and observe the processed output. Progressively decrease the number of samples until aliasing occurs.

**Operator z.** Additional insight into the meaning of the z-transform as a time-shift operator is provided by placing a zero at the origin of the z-plane, as in Fig. 4.6. Each term in the series expan-

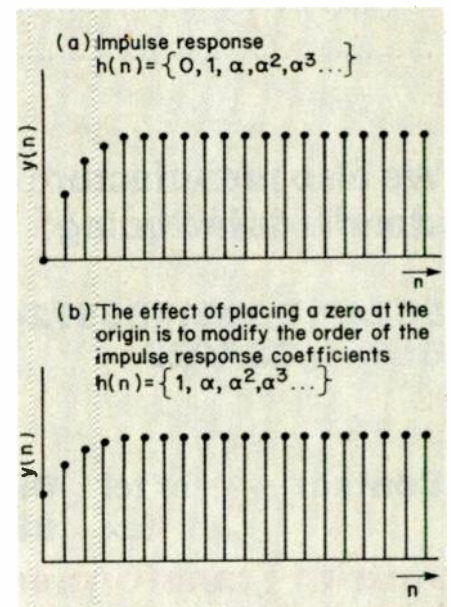


Fig.4.12. Unit step response. At (a) is the response  $h(n)=0,1,\alpha,\alpha^2,\alpha^3\dots$  and (b) shows that the effect of placing a zero at the origin is to modify the order of the impulse response coefficients.

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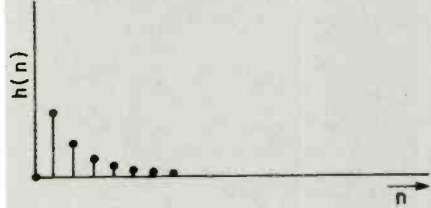
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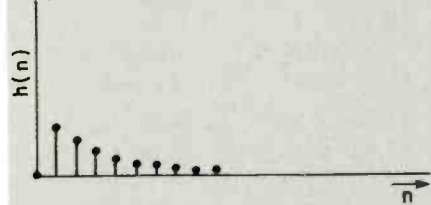
sion will be multiplied by  $z$ , modifying the order of the impulse-response coefficients. The revised impulse response sequence will be 0.5, 0.25, 0.125, 0.0625, ... We elected to demonstrate the effect on the processed output by convoluting the unit-step, as shown in Fig. 4.12.

Vary the coefficients of the impulse response. Increasing the time constant while keeping the sampling interval constant will modify the low-pass char-

a) Impulse response recurrence relationship  $y(n)=0.5y(n-1)+0.5x(n-1)$



b)  $y(n)=0.7082y(n-1)+0.25x(n-1)$



c)  $y(n)=0.917y(n-1)+0.0625x(n-1)$

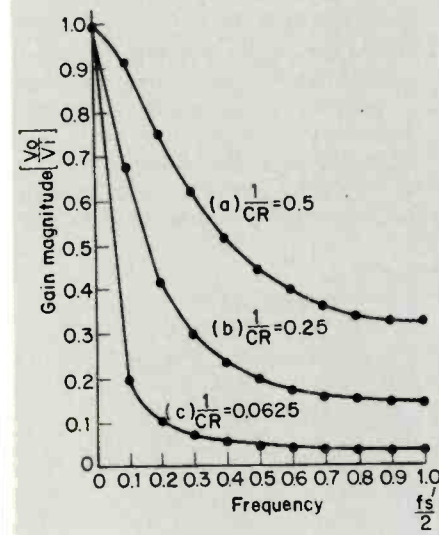
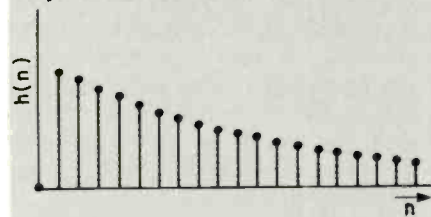
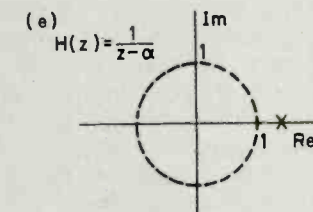
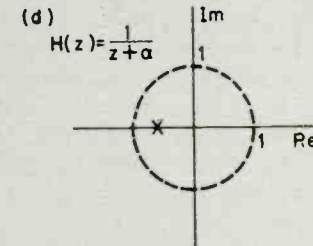
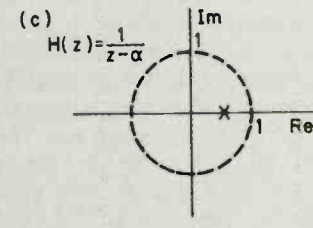
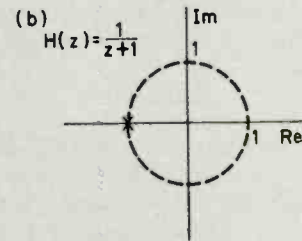
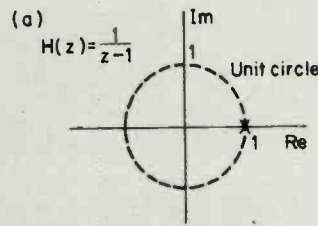


Fig.4.13. Increasing the time constant has the effect of reducing bandwidth and extending impulse response. Response (a) shows recurrence relationship  $y(n)=0.5y(n-1)+0.5x(n-1)$ .

Pole locations on z-plane



Impulse response obtained by convolution

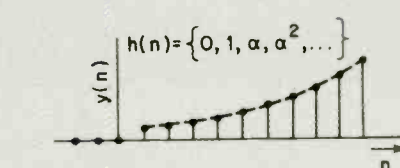
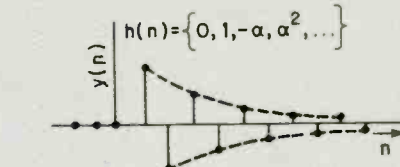
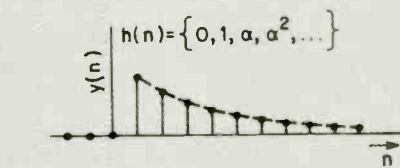
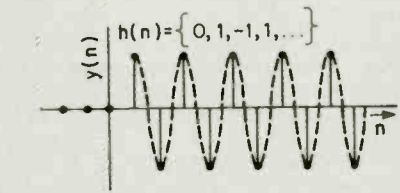
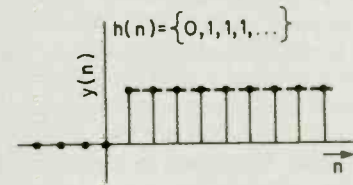


Fig.4.14. Pole locations on the z-plane in left column; impulse response obtained by convolution at right.

express the transfer function as a power series. We chose to convolute the impulse response  $h(n)$  with the unit-sample using listing 4.2. Notice the effect of the pole at  $(1,0)$  has been to integrate the unit sample, transforming the processed output into a unit step. The delay of one sampling interval could be eliminated by locating a zero at the origin.

The other limit of stability on the real axis is the pole  $(-1,0)$ . System response to a unit sample is a delayed sinusoid, oscillating at half the sampling frequency, as shown in Fig.

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4.14(b). Locating the pole at  $(\alpha, 0)$  ensures a first-order low-pass response, already examined in detail. A typical impulse response is shown in Fig. 4.14(c). Making  $\alpha$  negative by situating the pole at  $(-\alpha, 0)$  results in a first-order high-pass characteristic. The impulse response coefficients alternate in sign and oscillate at half the sampling frequency, as shown in Fig. 4.14(d). Pole(s) must be located within the unit circle for stability. Making  $\alpha$  greater than unity produces an exponentially increasing impulse response and an unstable system, as in Fig. 4.14(e).

**References**

1. P. A. Lynn, *An Introduction to the Analysis and Processing of Signals*, Macmillan, 1982.
2. *Electronic Signal Processing*, T326, O.U. Press, 1984.
3. W. H. Press, B. P. Flannary, S. A. Teukolsky and W. T. Vetterling, *Numerical Recipes in C*, Cambridge University Press, 1988.
4. H. J. Hutchings, Convolution-time-domain signal processing, *Electronics & Wireless World*, February 1988.

**Table 4.2.** Convolution is the name given to the ordered combination of multiplication followed by summation.

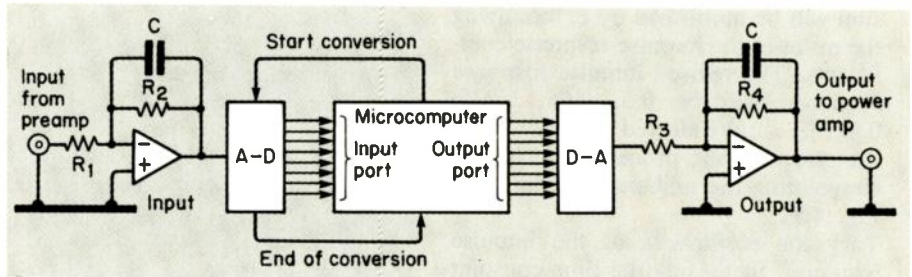
t=0	t=T	t=2T	t=3T	t=4T	Response due to
$x_0h_0$	$x_0h_1$	$x_0h_2$	$x_0h_3$	$x_0h_4$	$x_0$
	$x_1h_0$	$x_1h_1$	$x_1h_2$	$x_1h_3$	$x_1$
		$x_2h_0$	$x_2h_1$	$x_2h_2$	$x_2$
			$x_3h_0$	$x_3h_1$	$x_3$
				$x_4h_0$	$x_4$
<b>Column Sum</b>					
1	$y_0 = x_0h_0$				
2	$y_1 = x_0h_1 + x_1h_0$				
3	$y_2 = x_0h_2 + x_1h_1 + x_2h_0$				
4	$y_3 = x_0h_3 + x_1h_2 + x_2h_1 + x_3h_0$				
5	$y_4 = x_0h_4 + x_1h_3 + x_2h_2 + x_3h_1 + x_4h_0$				

**Digital filters**

The rapid growth of micro-electronics and personal computers has meant that the characteristics of low-pass, band-pass and high-pass filters can be readily implemented in software form. This article describes the behaviour of a variety of digital filters in terms of convolution, impulse response, amplitude and phase response, using only elementary mathematics.

Much of the necessary groundwork — sampled data signals and convolution — has already been covered in Chapters 3 and 4. Examining the principles which support the design before presenting applications will encourage you to experiment.

Digital filters have numerous attrac-



**Fig.5.1.** Representing an analogue filter by a digital technique. Low-pass filter at input avoids errors due to aliasing, while that at output smoothes steps in processed signal.

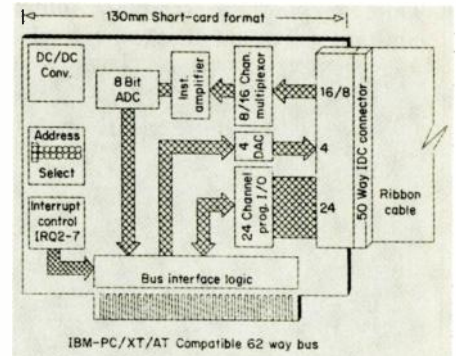
tions: weight, size, cost and flexibility favour the digital filter. Its response is independent of component tolerances, does not require alignment and is immune to temperature variations. Simply modifying the program changes the filter characteristics and it is possible to achieve results that are impractical using the analogue counterpart.

Certain filters are only possible using digital techniques. Alternatively, the characteristics of well-proven analogue designs — Butterworth, Chebychev — can be represented in digital form by means of the bilinear transform. In the interest of clarity, I shall concentrate initially on z-domain designs, believing that the added abstraction of the bilinear transform increases confusion, in addition to generating tedious algebra.

Figure 5.1 shows how an A-to-D converter, computer and D-to-A converter may be connected to achieve the necessary processing. The input peripheral is preceded by an anti-aliasing filter, while the output peripheral drives a simple low-pass filter which reconstructs the sampled signal into analogue form.

**Peripheral hardware requirements**

Fast analogue to digital conversion is straightforward using the Blue Chip Technology general-purpose I/O card ACM-44, shown in Fig. 5.2. As usual, the base address is selectable in the prototyping region, thereby avoiding bus contention. The analogue input section features a software-controlled, 16-channel single-ended or 8-channel differential multiplexer. Full-scale input voltage is link-selectable in the ranges 0–2.5V, 0–5V or 0–10V. A-to-D conversion is achieved using the fast Analog Devices AD7820, an 8-bit half-flash converter. Software control is



**Fig.5.2.** Blue Chip Technology general-purpose I/O card, used here for fast A-to-D conversion. The card is compatible with PC XT/AT computers.

particularly elegant; strobing the A-to-D by writing to the input data port initiates conversion, which is completed in 1.56µs, making testing for end-of-conversion unnecessary. Generous provision for D-to-A conversion is provided by four 8-bit converters, the output voltage being selectable in the ranges 5V or 10V full-scale. In addition, the board provides a single 8255 PPI. The port map and register model is shown in Fig. 5.3.

**Auxiliary maths co-processor**

Real-time digital filtering requires that a signal should be sampled, processed in some way and finally output to the real world before the next sample becomes available. Using a PC keeps the external hardware to a minimum, but relies very heavily on software for

Address	Function
Base	Select analogue input channel
Base+2	Start conversion(write) Analogue input value(read)
Base+3	Timer control
Base+4	Analogue output channel(0)
Base+5	(1)
Base+6	(2)
Base+7	(3)
Base+8	Digital I/O port A
Base+9	Digital I/O port B
Base+10	Digital I/O port C
Base+11	Control register

} AD7820  
} 4-8-bit d-to-a converter  
} 8255 ppi.

**Fig. 5.3.** Port map and register model of I/O card.



signal manipulation, which is traditionally slow.

Standard XT/PCs using 8086/8088 processors can add two numbers together in about 1 $\mu$ s and multiply in about 25 $\mu$ s. The faster AT/PC, using the 80286 processor, performs the same addition roughly twice as quickly, while multiplication is more than seven times as fast. Despite these impressive computational figures it is possible to improve performance significantly by complementing the standard processor with an auxiliary maths coprocessor. It is difficult to be precise about what speed improvement to expect — the actual calculation is likely to suggest 50 to 100 times as fast, but the program housekeeping and coprocessor overheads are likely to reduce this advantage to the 5 to 20 times range.

The XT-compatible 8087 coprocessor, or AT-compatible 80287 numeric data processor, is a 40-pin chip which simply plugs into the socket provided on the main system board. As its name suggests, the coprocessor combines with the architecture of the host processor to augment both the speed and precision of numerical computations. The increased speed is due to the more extensive register model, from which the software builds up the calculation. Increased accuracy is due to the operands being held in 80bit-wide registers, in a format called temporary real, precise enough to guarantee 18-decimal digit accuracy. Operational details of these registers are beyond the scope of this book — to the C programmer the coprocessor is transparent, no special functions being required; simply write your program and leave the host processor to worry about the details.

### Conversion of sinusoidal signals

This program, Listing 5.1, is designed to be used with the digital signal-processing system shown in Fig. 5.1. Sinusoidal signals in the range 0-5V are input through the A-to-D converter and processed in real time by the program in the computer, before being output in real time through the D-to-A converter, conditioned in the range 0-5V full-scale. The processed signal is finally fed into a power amplifier and speaker system.

As a confidence check, or benchmark, it is worthwhile processing data from the input peripheral through the computer to the output peripheral, with no signal conditioning at all.

Listing 5.1. Sinusoidal digital signal processing.

```

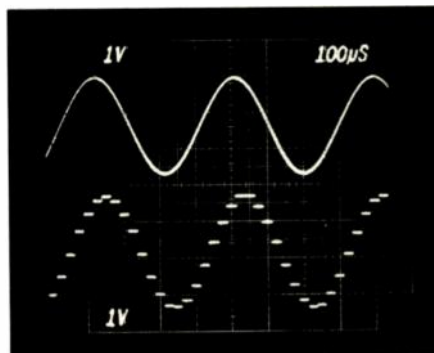
/ *****
*   SIMPLE DIGITAL SIGNAL   *
*   PROCESSOR 25 MICRO-SEC *
*   SAMPLING INTERVAL     *
***** /
#include<stdio.h>
#include<conio.h>
#define BASE 768
main()
{
  unsigned int contents;
  outp(BASE,1);
  /* -----
  SELECT I/P CHANNEL
  ----- */
  start:outp(BASE+2,0)
  /* -----
  START CONVERSION
  ----- */
  contents = inp(BASE+2);
  /* -----
  READ I/P PORT
  ----- */
  outp(BASE+4,contents);
  /* -----
  WRITE TO O/P PORT
  ----- */
  goto start;
}

```

Although this program may not appear to do a great deal, it should be regarded as a useful test bed, checking the hardware connections together with the software. As a matter of routine, I always try to keep it simple, before checking out more ambitious systems and software. All too often I find that time spent confirming the obvious pays dividends later on, when things don't work as expected.

Successful digital signal processing requires the sampling frequency to be at least twice the highest signal frequency present. This is an important parameter, the practical limits being determined by the choice of software and the characteristics of the A-to-D converter. May I remind you that C is fast, and running listing 5.1 with the aid of a math co-processor makes it very

Fig. 5.4. Output of the D-to-A converter with a 2.5kHz sine input and sampling frequency of 40kHz.



fast, resulting in a sampling frequency of 40kHz. The effect of digitally processing a 2.5kHz sinewave using this system is shown in Fig. 5.4, in which the 25 $\mu$ s sampling interval is clearly visible.

Programming is often an iterative process. In this case, the strategy is first to make the program work, then to make it well behaved and finally to make it fast. Listing 5.1 features the goto statement, although repetition could have been achieved with an infinite for loop as indicated in Part 1. Replacing the unconditional jump structure as suggested resulted in no measurable improvement in sampling rate.

It is worth spending a little time investigating the characteristics of the digital approximation to the input sinewave. Figure 5.5 shows the output from the D-to-A in greater detail. Each step of the 2.5kHz sinewave is composed of a sample of duration 25 $\mu$ s, equivalent to the sampling rate of the digital system. Using a spectrum analyser we may determine the harmonic content of the staircase output — the Fourier spectrum is shown in Fig. 5.6. Typically, there is a substantial component at 2.5kHz, which routinely would be unique. However, the stepped nature of the sinewave introduces significant components at higher frequencies. These appear as sidebands symmetric-

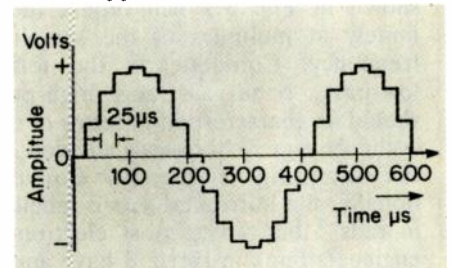


Fig. 5.5. Output of the A-to-D in greater detail. Each sample is 25 $\mu$ s in duration, equivalent to the period of the sampling frequency.

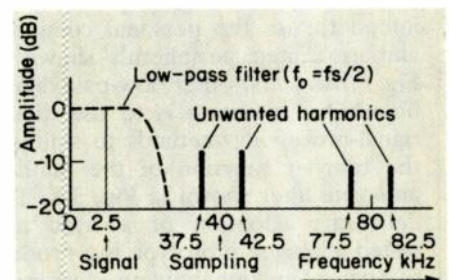


Fig. 5.6. Spectrum of the A-to-D output. Stepped nature of output generates harmonics, which are removed by the low-pass filter.

cally displaced around integer multiples of the sampling frequency. Examine Fig. 5.6 carefully and you will see how the low-pass filter connected across the output of the D-to-A removes these unwanted harmonics, leaving the required sinusoid.

Before we become immersed in the fine detail of digital filtering, a few words on strategy would be appropriate. Expressed simply, the object is to use digital methods to simulate the filtering methods previously achieved using combinations of resistance, inductance and capacitance. Progress is made by concentrating on the intended system response, conveniently described by the transfer function. In this way we avoid being distracted by the electrical characteristics of the individual components.

A digital filter is usually a subroutine of the main program, one which accepts sample values, processes them in real time and then returns samples representing the filtered output. The algorithms used in the subroutine determine the particular parameters of the filter, such as cut-off frequency, Q-factor and rate of roll-off.

Care must be exercised when interpreting the frequency characteristics of digital filters. The periodic nature of linear sampled-data systems ensures that the frequency-response curves shown in Fig. 5.7 will repeat indefinitely at multiples of the sampling frequency. Consequently the terms low-pass, band-pass and high-pass should be characterised in terms of the cyclic or signal frequency divided by the sampling frequency. Conventionally, the horizontal axis is labelled in  $\text{rads}^{-1}$  but, since most electronics engineers think in Hertz, I have annotated the horizontal axis as  $\omega T$  radians, where  $\omega T = 2\pi f_{\text{signal}}/f_{\text{sampling}}$ .

### Analogue and digital filters

As a more challenging problem we intend to use the personal computer and associated peripherals shown in Fig. 5.1 as a first-order, low-pass digital filter. Our intention is to use digital signal-processing methods to simulate the transfer function of the familiar analogue filter shown in Fig. 5.8. The deliberate adoption of a tried and tested analogue prototype is a productive way of making rapid progress using digital methods, because we can easily anticipate the likely form of the processed output.

The filter will be implemented in

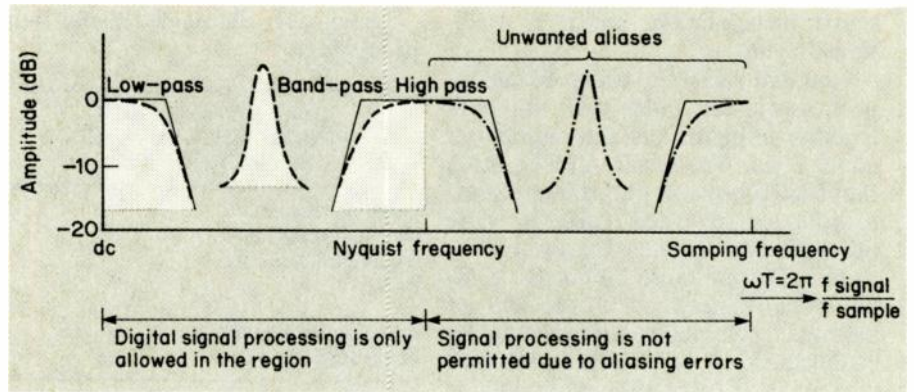


Fig. 5.7. Response of three types of digital filter. Curves repeat at multiples of sampling frequency; processing not permitted beyond Nyquist frequency.

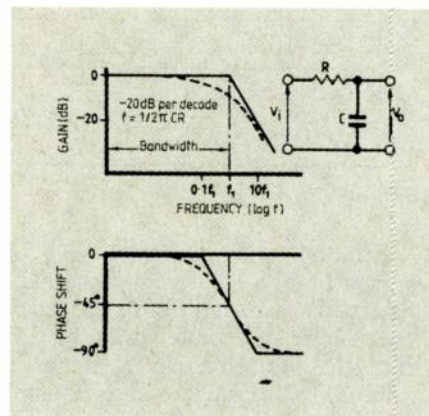


Fig. 5.8. Simple, first-order, low-pass analogue filter has time constant  $CR$  seconds. Low frequencies are processed with negligible amplitude and phase modification.

software by an algorithm within the computer which effectively convolutes the sampled sequence  $x(n)$  with the impulse response of the filter  $h(n)$  to produce the processed output sequence  $y(n)$ . As illustrated previously, convolution is the name given to the ordered combination of multiplication and summation.

The analogue signal presented to the A-to-D will be processed into a series of discrete samples. To avoid aliasing it is necessary to sample at a rate which is at least twice the Nyquist frequency (twice the highest frequency present).

Suppose the sampled signal can be represented by the sequence of pulses  $x(0), x(1), x(2), x(3), x(4)$ , each of which is separated from its neighbour by the fixed interval  $T$ , the sampling time. Each sample pulse in turn will stimulate the filter, which responds with a train of weighted output pulses. If the memory of the filter is long enough, there will still be a vestige of the previous history of weighted out-

puts, even as the current pulse is being processed.

Our intention is to demonstrate the effects of processing a square wave when the fundamental frequency is close to the cut-off frequency of the filter. Referring to the characteristics of the analogue filter shown in Fig. 5.8, it will be clear that beyond the break frequency the amplitude of the input signal is reduced at a rate of  $-20\text{dB}/\text{decade}$ . The amplitude attenuation is accompanied by a progressive phase lag over the range  $0.1f_1$  to  $10f_1$ , the latter approaching  $-90^\circ$  as the frequency tends towards infinity.

Most of the preliminaries have already been covered in Parts 3 and 4 of this series; we intend to build on these results and investigate the form of processed output obtained by convoluting a sampled square-wave with the impulse response shown in Fig. 5.9.

To evaluate the rest of the terms in the sequence, continue moving the reversed impulse response to the right, as in Fig. 5.10, until neither of the two sequences overlap. My results are

- $y(0) = 0.5$
- $y(1) = 0.75$
- $y(2) = 0.875$
- $y(3) = 0.4375$
- $y(4) = 0.6875$
- $y(5) = 0.8125$
- $y(6) = 0.8750$
- $y(7) = 0.4375$
- $y(8) = 0.1875$
- $y(9) = 0.0625$

These are plotted in Fig. 5.11, in which the exponential nature of the output waveform suggests that the digital signal processing is similar to that produced by the simple low-pass analogue filter shown in Fig. 5.8.

Convolution in the time domain corresponds to multiplication in the frequency domain. This processing operation is equivalent to multiplying the frequency spectrum of the signal by the



Fig. 5.9. Sampled input is represented by sequence of pulses separated by fixed interval T. Linear processor characterised by impulse response sequence.

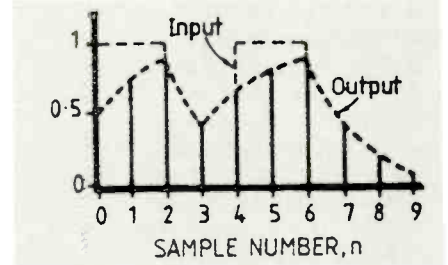
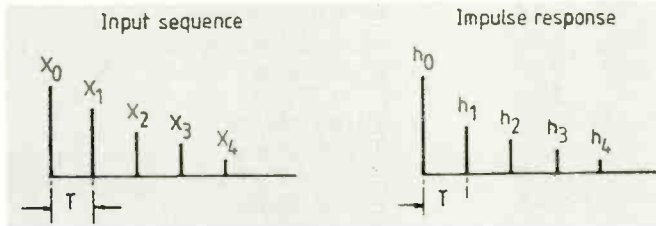


Fig. 5.11. Signal processing reduces certain high-order harmonics and introduces some time delay. Remaining harmonics sum at output to produce familiar exponential response.

contents of the signal on those of the filter demonstrates that a significant number of harmonics are contained within the pass-band of the filter. Although the amplitude attenuation in this range is small, there is still appreciable phase delay; the overall effect is to produce a little exponential rounding of the leading and trailing edges of the processed output, as in Fig. 5.12(b). Reducing the bandwidth of the filter while keeping the frequency of the input signal constant, as seen in Fig. 5.12(c), results in significant amplitude attenuation and almost constant phase delay of 90°.

**Correction**

In the article in this series on convolution (August, 1990), two errors occurred which made complete nonsense of the argument. The errors were no fault of Mr Hutchings. Immediately below Fig. 4.6 on p.698, the expression should read  $y(t) = tCR e^{-t/CR}$ ; in the centre column of p.701, seven lines from the bottom, the equation should be  $y(t) = 1/(1 - e^{-t/CR})$ .

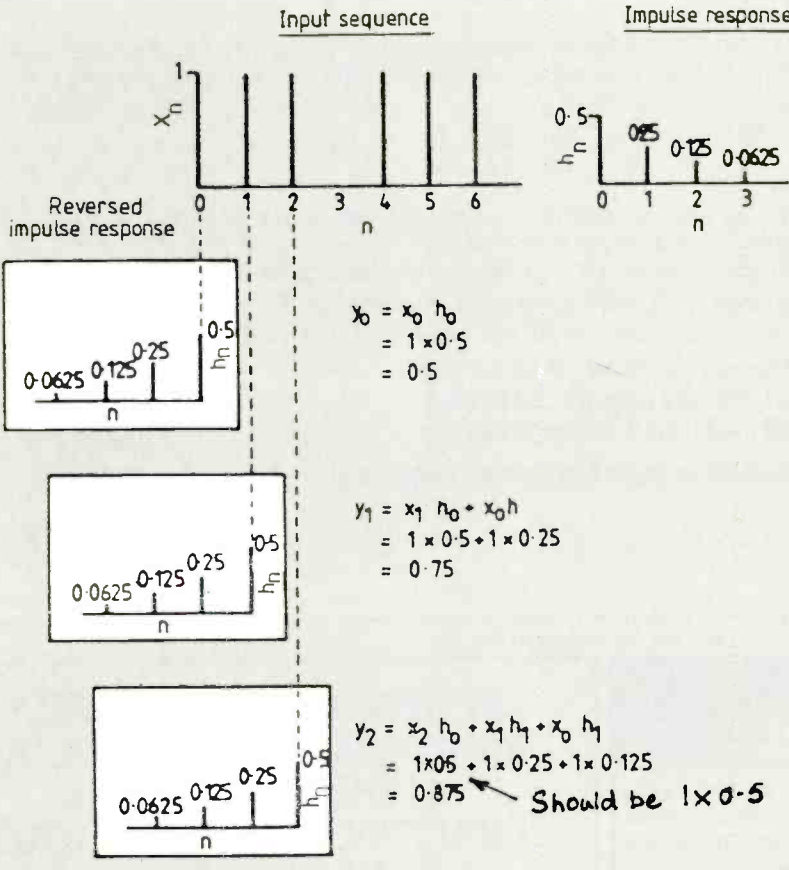


Fig. 5.10. Graphical convolution of sampled square and impulse response is obtained by reversing impulse response under sample of current interest. Sum of coincident cross-products is convolution of that sample and impulse response of processor.

system frequency response. the product corresponding to a filtering operation. Much of this is vividly illustrated by the Fourier series description of the square wave, amplitude  $\pm 1V$ , together with the frequency response of the first-order, low-pass signal processor. Figure 5.12 shows the spectral characteristics, demonstrating the equivalence in processing operations in the time and frequency domains.

Figure 5.12(a) shows how the input square wave can be decomposed into a sinusoidal fundamental, together with an infinite number of odd (in phase) harmonics. Superimposing the spectral

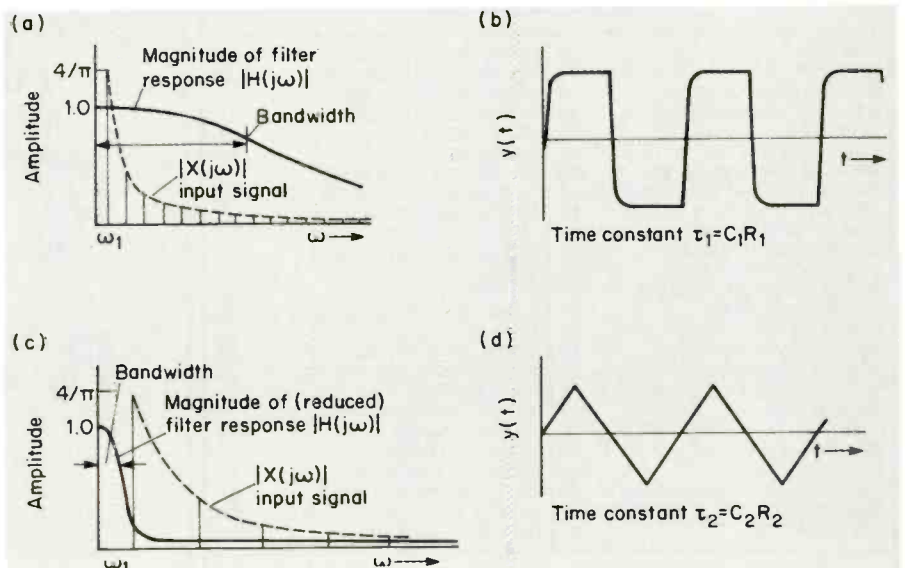


Fig. 5.12. Multiplication in frequency domain corresponds to convolution in time domain. Effects of reducing bandwidth of filter while keeping input square-wave frequency constant are shown in frequency (a)(c) and time (b)(d) domains.

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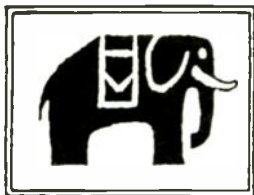
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ELECTRONICS WORLD + WIRELESS WORLD September 1990



**M**odern solutions for instrumentation problems involving personal computers are generally based on one of three main approaches: using internally fitted expansion cards which are simply plugged into a free PC expansion bus slot; using an external rack with plug-in expansion cards; or using separately enclosed modules (which may, if desired, be stacked) connected to a controlling PC by RS232 or IEEE488 bus systems.

Internally fitted cards generally offer the lowest cost approach to realising a PC instrument. The disadvantage of this technique is that it necessitates internal fitting and, since there may be few free slots available, the future expansion capability may become somewhat limited.

An external rack system allows the PC bus to be extended so that standard PC expansion cards may be fitted into an external card frame. This system is, however, relatively expensive and is generally only appropriate where large-scale expansion is envisaged.

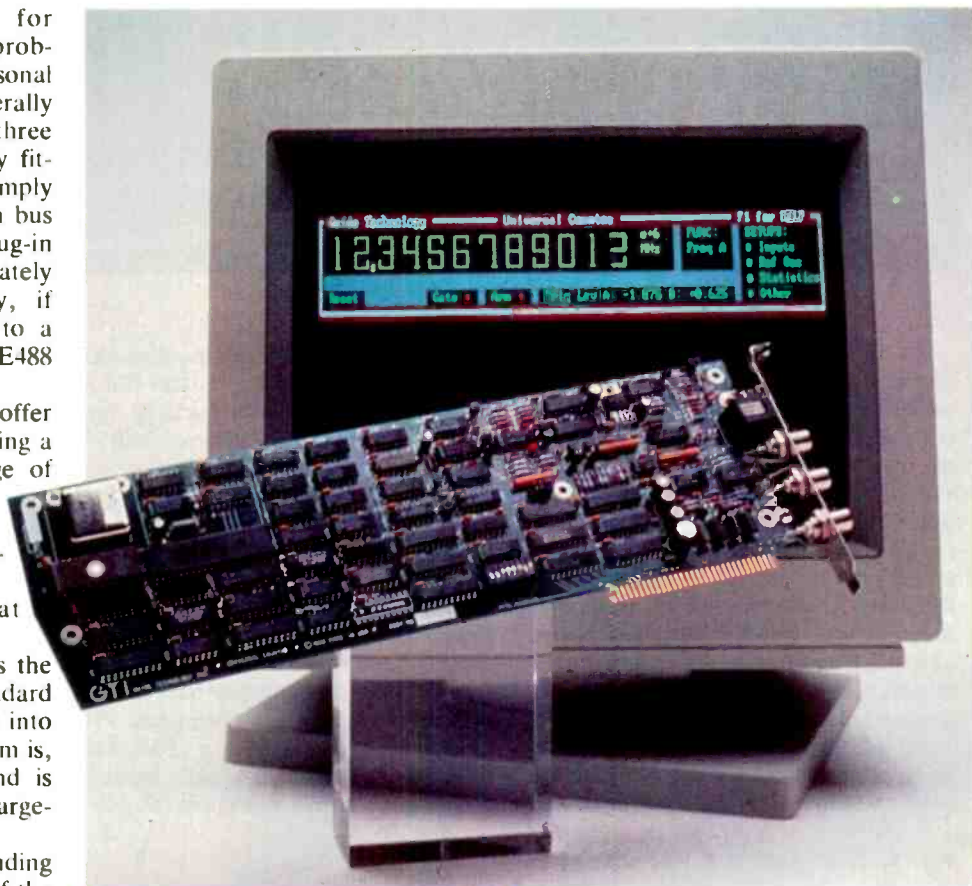
An alternative to that of extending the PC bus beyond the confines of the system enclosure is that of making use of a proprietary I/O bus such as Metabyte's MetraBus. Such systems generally provide for between one and 32 I/O boards mounted in standard rack enclosures, but they can be relatively expensive when only limited expansion is required.

Separately enclosed modules, which may be interfaced to a PC by means of the RS232 or IEEE488 bus, provide the third of this trio of potential solutions. With the exception of a front panel display and controls, separate PC instrument modules usually resemble the conventional standalone instruments which they replace.

### PC instruments

The availability of a huge range of expansion cards designed specifically for instrumentation and data acquisition has rendered the PC an obvious choice for a multitude of standalone applications, and several manufacturers have developed a range of unboxed PC instruments which emulate conventional items of test equipment, such as digital voltmeters, digital frequency meters, etc.

PC instruments offer many advantages over their conventional counterparts. They are more flexible and adaptable, and measurements may be



# GT200 Universal Counter

Mike Tooley tries an internally fitted, full-size expansion bus card for automated measurement

automated under programmed control. Furthermore, considerable savings can be achieved by the elimination of redundant hardware such as displays, operator controls, and the like.

PC-based instruments also offer very significant cost savings when compared with more cumbersome IEEE488 bus-based instrumentation systems. A typical PC-based system for the acquisition of analogue voltages can, for example, be realised for less than 50% of the cost of a similarly specified system based on IEEE488 hardware and software.



Fig. 2. Virtual front-panel layout of the GT200.

As an example of the use of a PC instrument, consider an application in which the output frequency of an oscillator has to be monitored accurately over a long period of time. This task can be accomplished using a conventional digital frequency meter with readings taken at appropriate intervals and logged on paper, a graph showing the long-term variation of frequency then being drawn. The alternative approach using a PC instrument involves simply fitting a digital frequency meter expansion card to a standard PC or PC-compatible and using simple software (in conjunction with the driver(s) supplied with the

card) to automate the measurement and store the results in a data file for import into an analysis package, such as DADiSP. (This theme will be expanded later in this review.)

### Enter the GT200

The GT200, fitted internally as a full-size PC-compatible expansion bus card, is manufactured in California by Guide Technology Inc. Having previously been with Hewlett Packard, the founders of this company have a background in precision counters. The GT200 thus has something of an established pedigree which rapidly becomes obvious when the instrument is put to

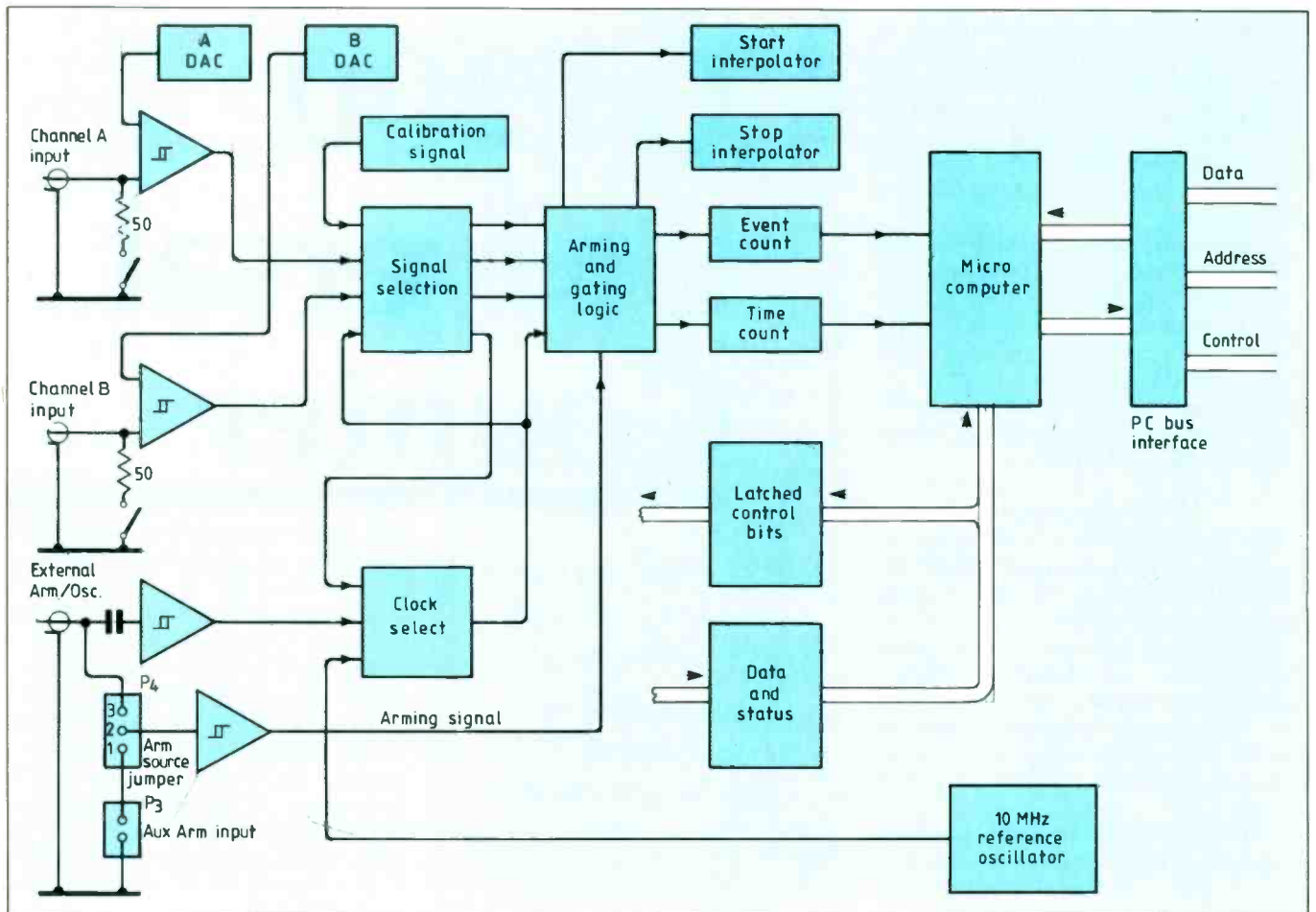
use.

The minimum system requirements for the GT200 card are an IBM PC, XT, AT (or 100% compatible) with PC-DOS or MS-DOS Version 2.0 or later. The system must be fitted with at least 256kbytes of memory and have at least one floppy disk drive. With the current version of the virtual front panel software, a Microsoft-compatible mouse is required (see later).

The GT200 is supplied together with a device driver (GT200.SYS) and virtual front panel software (VIRT.EXE) on floppy disk. The disk also contains software which assists in setting the base address switch and includes a program which allows users to test the GT200's programming commands.

In addition, sub-directories are provided which contain sample source-code programs written in Basic and C. The user is encouraged to browse through the sample programs and try running them to see the results. The C programs provided were compiled with Microsoft C V5.1 while the Basic programs were tested with Microsoft Quick-Basic.

Fig. 1. Simplified block schematic of the GT200.





A simplified block schematic of the GT200 is shown in Fig. 1. The GT200 measures input signal frequencies using the most accurate technique available — reciprocal counting coupled to time interpolation — with the primary benefits of improved accuracy and reduced measurement time. Fast measurements with high accuracy yield more information concerning the stability of a signal, and the GT200 is able to compute the drift rate, mean and peak-peak jitter of a signal in the time that a conventional counter takes to measure frequency.

The GT200 offers the following facilities:

- Frequency measurement from DC to 100MHz, with automatic pre-scaling above about 1MHz (note that this does not result in a loss of resolution)
- Fast frequency measurement (a special mode for high-speed data acquisition which allows up to 2300 measurements per second)
- Period (single and multiple)
- Time interval (i.e. the elapsed time between "start" and "stop" events — the time interpolation technique employed results in a resolution of 100ps and is equivalent to that of a conventional counter with a 10GHz clock rate)
- Time interval with delay
- Pulse width (with selectable polarity)
- Auto trigger (which may be enabled or disabled via both the virtual front panel and the GT200 command language)
- Arming (in which a measurement time window can be selected)
- Paced and single measurements
- Acquisition mode (in which data is placed directly into a memory array without the usual overheads required to communicate results back to an application program via DOS)
- Statistics (including mean, standard deviation, maximum and minimum measurements within a sample block)
- External arming, oscillator input and gate signal output
- Save/recall setup information (a special file allows the GT200 to power up in a specific state other than the normal default configuration)
- Maths functions (these allow the GT200 to offset and normalise the measurement data before display)
- User-defined units (these allow the virtual display to represent some parameter other than that being measured).

### Virtual front panel

The GT200's virtual front panel, Fig. 2,

## Programming the GT200

Three smaller sub-programs (max(), min(), and mean()) are declared at the beginning of the main program. The array, freq(), which will contain the returned data from the digital frequency meter, is then dimensioned to provide storage for a total of 100 values which will later be read from the GT200 at 10-second intervals.

The user is then prompted to enter the oscillator reference, truncated to include only the first six characters, and the ambient temperature used for the measurement.

The GT200 digital frequency meter is then associated with channel 1 for output and 2 for input. The instrument is initialised to measure frequency using input A, with timeout and gate times of 4 seconds and 0.2 seconds, respectively.

The program then waits for the user to indicate that he is ready to begin a measurement by hitting the RETURN key. Once the key has been hit, the program takes 100 readings of frequency, placing each returned reading into the freq() array. The time between readings is set at 10 seconds by means of the wait command. Times and corresponding frequency

readings are displayed on the screen on each pass through the main FOR ... NEXT loop so that the user is kept informed of the current state of measurement.

When the main loop has been completed, the two communications channels are closed. Thereafter, the performance data for the oscillator in question is sent to the printer (with calls to the three sub-programs which determine the maximum, minimum and mean frequency values). The total frequency drift is calculated by subtracting the minimum from the maximum frequency.

Finally, the data is stored in an ASCII file. Note that the filename is constructed from the concatenation of the first six (or fewer) characters of the oscillator reference and the ambient temperature entered by the user, together with the file extension .DAT. The file is opened for output (via channel 3) and all 100 values stored in the array are written to it. The channel is then closed.

The three sub-programs, max(), min(), and mean(), are quite straightforward and need no further comment.

emulates the front panel layout of a conventional instrument and contains a large 12-digit seven-segment display, together with various buttons and pull-down menus accessed by the mouse. It is worth stressing that the current version of the GT200 virtual front-panel software requires a Microsoft-compatible mouse. The software will not operate via the keyboard.

The display is logically arranged, and status indicators are provided so that the user is made fully aware of the current condition of the instrument. The display is particularly user friendly, and users will soon find their way around the instrument without having to refer repeatedly to the instruction manual.

### Documentation

The manual supplied with the GT200 is one of the best that I have seen for an instrument of this type. The manual comprises approximately 70 spiral-bound A4 pages and is divided into five sections, entitled "Installation", "Functional Description", "Virtual Front Panel Operation", "Controlling the GT200 with Program Commands", and "Applications". This last is some-

what misleadingly named since it only refers very briefly to high-speed data acquisition and could very usefully be expanded to introduce some representative applications for the unit, together with hints and tips for software writers.

The manual is very clearly laid out and contains several useful diagrams which explain the operation of the virtual front-panel display in a clear and simple manner.

Each programming command is explained in some detail with sufficient information for the programmer to develop effective software which makes full use of the facilities on offer.

### Programming the GT200

The control program sends commands to the GT200 driver as character strings through standard DOS file write operations. Several conventions must be obeyed when incorporating commands into programs (e.g. individual commands must be separated by semi-colon, carriage-return or line-feed delimiters). Commands are not case-sensitive and may be abbreviated for convenience — the minimum acceptable abbreviations for each command

Fig. 3. QuickBasic program for long-term stability measurement.

```

REM Long-term oscillator test program
REM First declare the sub-programs
DECLARE SUB max ()
DECLARE SUB min ()
DECLARE SUB mean ()

REM Dimension array to store the results
DIM freq(100)

REM Get oscillator reference
CLS
INPUT "Enter oscillator reference: "; ref$
LET ref$ = LEFT$(ref$, 6)
INPUT "Enter ambient temperature: "; temp$
osc$ = ref$ + temp$
REM Initialise digital frequency meter
OPEN "GT200$" FOR OUTPUT AS #1
OPEN "GT200$" FOR INPUT AS #2
PRINT #1, "init; timeout 4; function frequency A; gate 0.2"

REM Start collecting readings
PRINT "Hit <RETURN> to start measurement ..."
WHILE r$ = " " r$ = INKEY$
WEND
FOR time% = 0 TO 99
  PRINT #1, "reset"
  INPUT #2, freq(time%)
  PRINT "Time = "; 10 * time%; " sec. Frequency = "; freq(time%); "Hz"
  PRINT #1, "wait 10"
NEXT time%
CLOSE #1
CLOSE #2

REM Calculate and print statistics
LPRINT
LPRINT "Performance data for oscillator ref: "; ref$
LPRINT "Performance measured at: "; temp$; " deg.C"
max
LPRINT "Maximum frequency: "; maxfreq; "Hz"
min
LPRINT "Minimum frequency: 0.2 "; minfreq; " Hz"
mean
LPRINT "Mean frequency: "; ave; " Hz"
LPRINT "Frequency drift: "; maxfreq - minfreq; " Hz"
LPRINT

REM Save data in ASCII file
LET file$ = osc$ + ".DAT"
OPEN file$ FOR OUTPUT AS #3
FOR time% = 0 TO 99
  PRINT #3, freq(time%)
NEXT time%
CLOSE #3
END

SUB max
  SHARED freq()
  SHARED maxfreq
  maxfreq = 0
  FOR i% = 0 TO 99
    IF freq(i%) > maxfreq THEN maxfreq = freq(i%)
  NEXT i%
END SUB

SUB min
  SHARED freq()
  SHARED minfreq
  minfreq = 1E+09
  FOR i% = 0 TO 99
    IF freq(i%) < minfreq THEN minfreq = freq(i%)
  NEXT i%
END SUB

SUB mean
  SHARED freq()
  SHARED ave
  total = 0
  FOR i% = 0 TO 99
    total = total + freq(i%)
  NEXT i%
  ave = total / 100
END SUB

```

are listed in the manual. As an example, FREQ may be used for FREQUENCY, FU for FUNCTION, and so on.

GT200 commands are incorporated in normal program statements such as: PRINT #1, "fu freq a; gate 0.01" (BASIC) or:

fprintf(COUNTER, "fu freq a; gate 0.01"); (C) Note that the foregoing have identical effects on the GT200 card.

For those who may wish to enter and test commands directly, without having to write program code, a program is supplied on the distribution disk called TRY—CMDS.EXE. This program allows immediate execution of commands entered from the keyboard so that response can be investigated.

A particularly flexible numeric entry format is associated with GT200 commands. This allows standard free format conventions. For example, commands will accept either fixed-point or floating-point numbers and the exponent (E) character can be entered in either upper or lower case. As an added bonus, if an integer value is expected the driver will accept a floating-point number and convert by truncation.

### In use

I tested the GT200 installed in a DSC Turbo AT-compatible microcomputer with 40Mbyte hard disk, Microsoft bus mouse and Windows operating system front-end. The sensitivity of the instrument was measured using a Hewlett Packard VHF Signal Generator and was found to be better than 120mV RMS below 80MHz (using input A in its terminated state). Surprisingly, the instrument gave reliable indications to



just over 140MHz with an RF input level of approximately 150mV RMS. At below 30MHz the sensitivity appeared reasonably constant in the region of 85mV RMS.

### An application

Having confirmed the performance specification of the GT200, I must confess to being somewhat reluctant to return the instrument to its UK distributor. After all, here was the solution to a number of my measurement problems, and I was not going to part with the unit until I had put it to some real work.

At the time, my workbench was, as usual, littered with a number of prototype voltage-controlled oscillators which I was developing for use in conjunction with a synthesised HF receiver. Since the GT200 was already installed in my workshop PC, I decided to harness the power of the instrument and automate the lengthy task of carrying out performance measurements on each oscillator.

The VCO output frequency (in the range 40 to 60MHz) had to be measured every 100ms for the short-term stability measurement, and every 10s for the long-term stability measurement. Rather than make use of the GT200's inbuilt statistical functions, I decided to store results of each set of measurements in an appropriately named ASCII file for later import into a statistical/graphical analysis package.

In the meantime, the software was required to determine a number of fairly basic performance indicators for each prototype unit including: maximum and minimum frequencies during the measurement period; mean frequency over the measurement period; and total frequency drift during the measurement period. The entire set of measurements and statistical calculations was to be repeated at various ambient temperatures — 0°C, 20°C and 40°C. This task would have required considerable manual effort if it had had to be carried out using a conventional digital frequency meter, but was an ideal candidate for automated measurement.

Separate programs were developed to determine the short-term and long-term VCO characteristics. Microsoft QuickBasic was chosen as the vehicle for the software development and the code was subsequently compiled in order to create a standalone executable (EXE) program. Figure 3 shows the complete listing of the program developed to carry out the long-term

Fig. 4 Sample printed oscillator performance data generated by the program shown in Fig. 3.

Performance data for oscillator ref: HXO	
Performance measured at:	20 deg. C
Maximum frequency:	5.016576E+07 Hz
Minimum frequency:	5.015442E+07 Hz
Mean frequency:	5.015941E+07 Hz
Frequency drift:	11336 Hz

VCO measurement. This was developed and made "up and running" in less than an hour.

The notes in the accompanying box are provided for the benefit of those who may be unfamiliar with programming techniques. I suspect they will be of benefit to readers who may be wondering about the degree of complexity of the software required to drive the GT200. I hope they will help to dispel some of the mystery and show how easy it is to develop a fully functional, though somewhat unrefined measuring application.

During the measurements, the GT200 behaved impeccably and the unit was instrumental in greatly reducing the time required to carry out the investigation. Further statistical analysis, based on the mean and standard deviation of the measured results, yielded some further information. A typical printed oscillator performance summary is shown in Fig. 3.

### In conclusion

The Guide Technology GT200 is an exceptionally versatile instrument which reflects the state-of-the-art in PC instrumentation via expansion cards. Card performance matches or exceeds that of many of today's conventional standalone instruments, and offers significant advantages in terms of the ability to make automated measurements without the need to revert to the more complex solution of using the IEEE488 bus. The GT200 can be highly recommended as a superbly engineered product which offers the user tremendous flexibility in use. We will hope to see many more products from this particular stable.

The GT200 Universal Counter costs £1182 (exc VAT) and is available from Amplicon Liveline at Centenary Industrial Estate, Brighton, East Sussex BN2 4AW. Telephone: 0273 570220. A high-stability, oven-stabilised 10MHz frequency reference (GT300) is also available which reduces, by a factor of 500, inaccuracies caused by temperature. ■

### BOOK REVIEW

**Electronic Display Devices**, by Shoichi Matsumoto (ed.). The display devices in question are exclusively of the flat-panel variety and include LCDs, electrochemical types, plasma panels, electroluminescent displays, vacuum fluorescent displays and LEDs, with a chapter on special types.

Although this is a very comprehensive work, it is not in the least superficial. It treats the chemical, physical and electronic aspects of all the devices covered in considerable detail, with enough applications information to illustrate their use. John Wiley, 380 pages, hard back, £39.95.

### Modern Electronic Test

**Equipment**, by Keith Brindley. This covers a broad canvas, since it deals with the majority of test gear likely to be encountered by the average technician or engineer. In ten chapters, the author describes the principles and design of analogue and digital meters, oscilloscopes, signal sources, spectrum analysers and digital instruments at a fairly introductory level, although in sufficient detail for readers not conversant with any particular type of equipment.

The largest section of the book, which recognises the advent of automatic test equipment, is the chapter on buses.

Part 2 of the book is concerned with application, describing the measurement of components and signals.

Appendices cover displays (CRTs, moving-coil meter movements and LCDs) and optical-fibres. Heinemann Newnes, 261 pages, hard back, £12.95.

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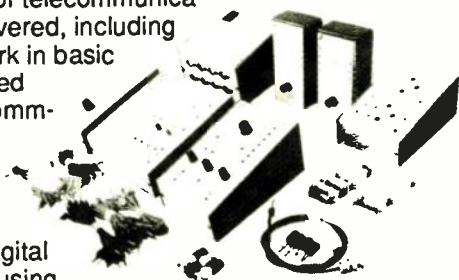


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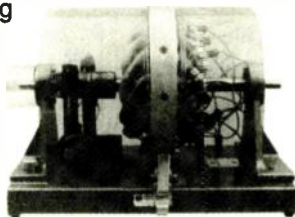


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CIRCLE NO. 100 ON REPLY CARD

# isvr

**APPLIED DIGITAL  
SIGNAL PROCESSING**

**SHORT COURSE:**

**1-5 October 1990**

(in association with  
Brüel and Kjaer (UK) Ltd)

INSTITUTE OF SOUND &  
VIBRATION RESEARCH

Further information from  
Maureen Strickland,  
ISVR, Univ. of Southampton,  
Southampton SO9 5NH  
Telephone (0703) 592274  
Facsimile (0703) 593033



**VENUE:** Institute of Sound and Vibration Research, University of Southampton.

**FEE:** £825 - to include course notes, use of laboratory facilities, coffee, tea, lunch, informal evening, course dinner. Accommodation is *not* included.

**REGISTRATION** will be at 0845 on Monday, 1st October in Room 3.02 Tizard Building. Please return registration form by Friday, 14th September at the very latest.

*Intended* for engineers and scientists who wish to keep abreast of modern methods of signal processing. The material will be of particular benefit to engineers in industry and from research and teaching establishments and to those who may need to evaluate the application of digital computer technology and digital data analysis to realistic problems.

Since the study of signal processing is very much a practical subject, emphasis is placed upon the use of demonstrations and laboratory sessions to illustrate the lecture material.

It should be noted that whilst *applications* are the motivation for the material covered and are stressed throughout, the treatment may be considered to be of an advanced nature. Basic Fourier techniques are covered on the first day, but the treatment is rapid and it is recommended that participants have some familiarity with Fourier methods. Fundamentals are emphasised throughout to ensure sound understanding. A grasp of engineering mathematics would be helpful to derive full benefit from the later part of the course.

**Applied Digital Signal Processing** is a five-day short course intended (i) to describe the fundamentals of digital data analysis of deterministic and random signals; (ii) to introduce advanced topics in digital signal processing which are now applied in many fields; (iii) to consider applications of the theory to practical problems in order to demonstrate the use of these methods. The material includes data acquisition, effects of sampling, the estimation of spectra, frequency response functions and coherence functions. Digital filtering and its applications, including adaptive filtering and deconvolution, are described. Hilbert transforms, the cepstrum and their application, multidimensional signal processing, 2D signal processing, the analysis of non-stationary signals and analysis of nonlinear systems comprise the latter part of the course, thus forming an introduction to more advanced methods of signal processing.

### Features of the Course:

- **Hands-on Experience** - the course includes laboratory sessions using the Brüel and Kjaer 2032 and 2034 two-channel analysers and also the computers in the ISVR.
- **Demonstrations** - The lecture material will be supplemented with practical demonstrations.

### Lecturers

Dr. S.J. Elliott, Professor J.K. Hammond, Dr. P.A. Nelson,  
Dr. C.J.D. Pickering, Mr. P.R. White - ISVR  
Dr. P. Davies - Purdue University, USA  
Dr. R.K. Otnes - Time Series Associates, USA

CIRCLE NO. 101 ON REPLY CARD



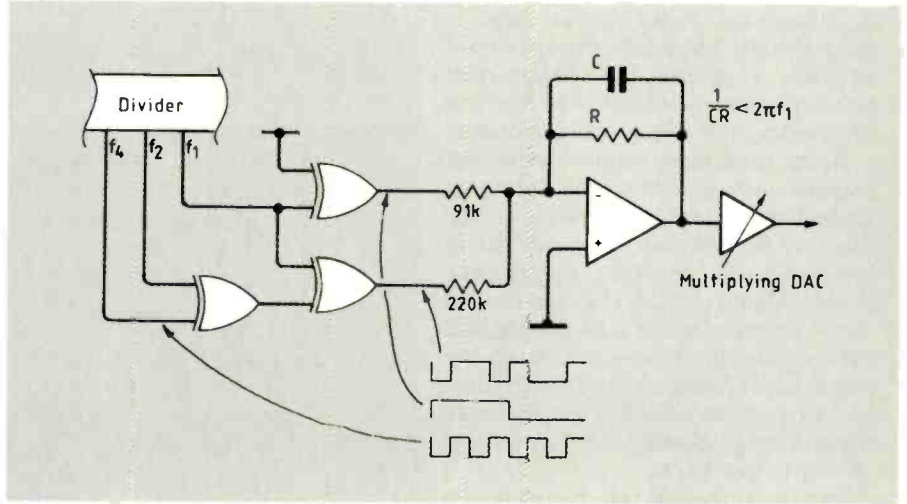
# Square-to-sine converter using Walsh functions

This circuit shapes a square wave into a sine wave over the range 1kHz to 500kHz. After several other methods had been considered, it was decided to use a low-pass filter followed by a variable gain stage.

The multiplying D-to-A converter acts as a programmable-gain amplifier; when the fundamental of the square wave and its harmonics all lie on the sloping part of the filter response, they are attenuated in a fixed ratio proportional to frequency. The gain stage then restores the level.

Odd harmonics (even ones are not present in a square wave) have relative amplitudes of 1, 1/3, 1/5, 1/7 . . . , which are attenuated in the filter by 1, 1/3, 1/5, 1/7 . . . , so that the residual amplitudes were 1<sup>2</sup>, 1/3<sup>2</sup>, 1/5<sup>2</sup>, 1/7<sup>2</sup> . . . The RMS value of the first three is 12% of the fundamental and needed to be reduced.

Since the square waves were generated by a digital divider, frequencies f<sub>2</sub>, f<sub>4</sub>, f<sub>8</sub> were available, but not the odd frequencies. An eight-point Walsh transform of the required sine wave is



made up of a fundamental sequence 11110000 added to 0.414 of 01101001, which was verified by taking the Fourier transform of the resulting signal, in which fundamental, 7th and 9th harmonics had an amplitude of 1.17 of the square wave and the 3rd, 5th, 11th and 13th all cancelled completely. RMS distortion was about 2%.

In the circuit shown, the Ex-Or gates generate the two waveforms, which are added in the summing amplifier, its summing resistors being in the ratio 91/220 - only 0.1% away from the required value.

David Gibson  
Leeds  
West Yorkshire

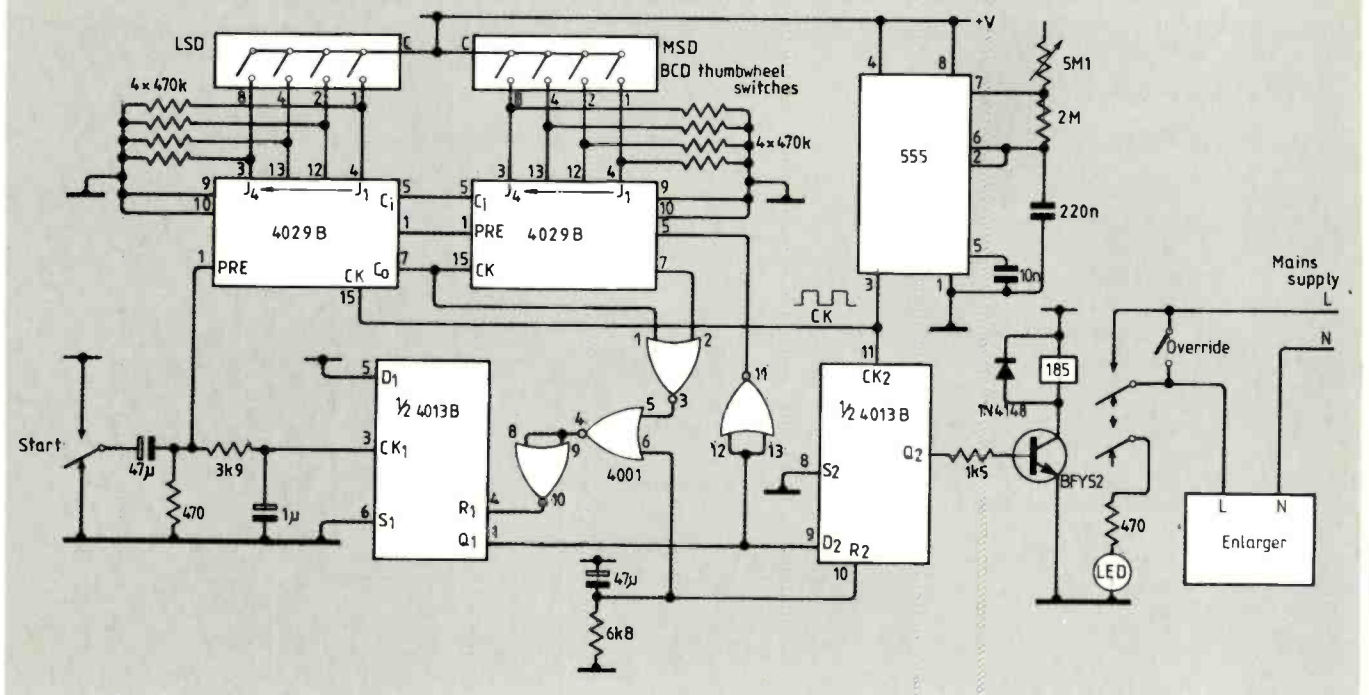
## Digital seconds timer

The timing period of this timer (1 to 99s) is set by two thumbwheel switches. An eight-bit BCD timer counts down,

having been preset to the switch values by the start switch. A 555 timer acts as a free-running oscillator to provide the clock, with a period of 1s. Two D-type flip-flops control start and stop and the

output drives a relay, with led indication.

D. Ibrahim  
Charlton  
London SE7



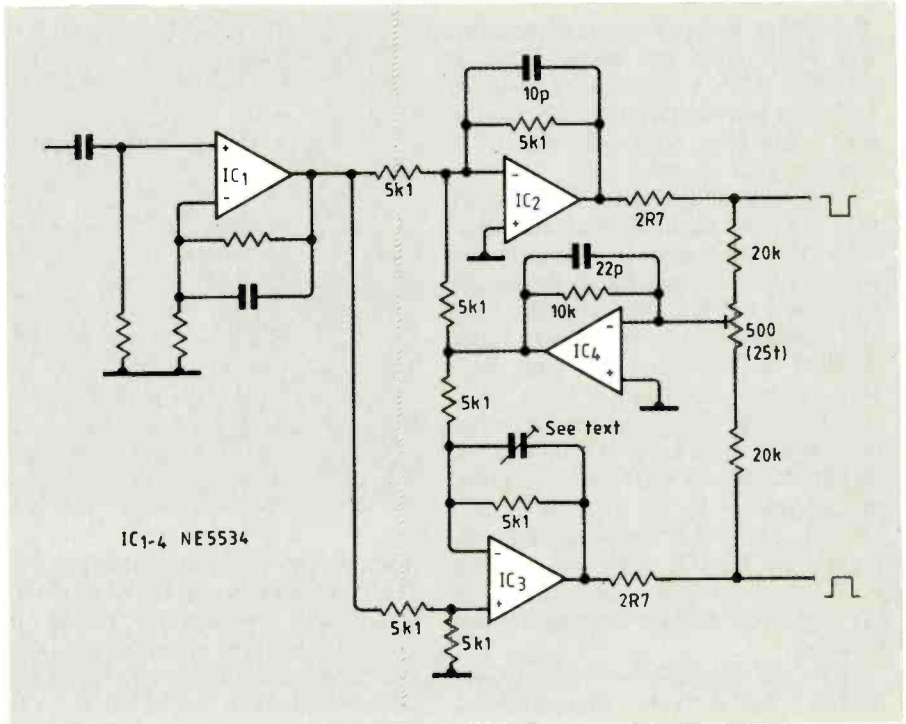
## Electronically balanced audio output stage

A differential audio output stage is electronically balanced in output level and has a precise 180° phase relationship between outputs, with the aim of avoiding the use of a transformer.

Apart from these requirements, the amplifier must, when one output is grounded, increase the level at the other by 6dB without too much rise in temperature. Output impedance should, ideally, be less than the professional requirement of 20Ω per leg and the outputs should swing close to the power rails. Noise and distortion must be low and the circuit must be stable when driving balanced lines, in particular capacitive ones.

The most widely used circuit, by Peter Leunig, uses cross-coupled negative feedback to reduce the gain of each amplifier by 6dB; when an output is grounded, feedback to the other half is removed, its gain increasing by 6dB. Leunig's circuit needs closely matched resistors and, even then, an output balance of better than 45dB is difficult to obtain. In the unbalanced condition, with no output shorted, distortion increases from 0.002% to 0.5%.

In my circuit, each amplifier is set for unity gain; in the balanced mode, the contribution from the feedback amplifier is zero. If one output is grounded, a signal appears at the output of IC<sub>4</sub>, which is applied as positive feedback to the amplifier in use,



increasing its gain. To avoid oscillation, the increase in gain is kept to 5.95dB – the difference between that and 6.02dB being negligible.

The main advantage over the Leunig circuit is the improvement in balance, particularly when one amplifier has adjustable feedback capacitance. This should be variable over a wide range,

say 5-50pF, to take account of layout variations. With careful trimming, an imbalance signal of at least -75dB is obtainable, low frequencies being below -100dB.

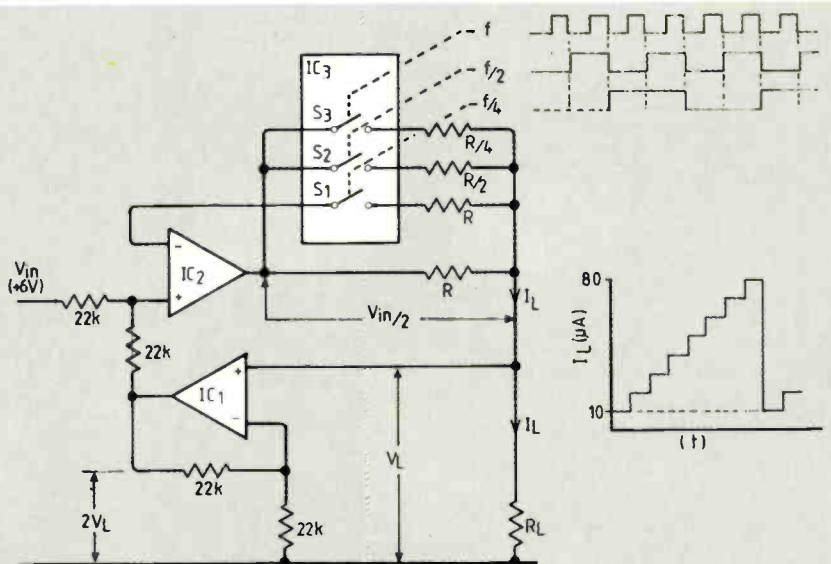
Barry E. Porter  
Philip Drake Electronics Ltd  
Welwyn Garden City  
Hertfordshire

## Stepped-ramp current source

An accurate source was needed to provide base currents in a transistor curve tracer.

In the circuit shown, IC<sub>1</sub> and IC<sub>2</sub> maintain a fixed voltage ( $v_{in}/2$ ) across R<sub>x</sub>, where R<sub>x</sub> is composed of the four switched resistors R-R<sub>4</sub>. The current I<sub>1</sub> depends on the value of R<sub>x</sub>, which varies from 37.5kΩ to 300kΩ in steps of 37.5kΩ as the c-mos switches are activated by clock pulses f, f/2 and f/4. The ramp increases in steps of 10μA up to 80μA.

Dhananjay V. Gadre and  
Rudreshwar Sen  
University of Delhi  
India



R = 300k ± 1%  
IC<sub>1, 2</sub> = 741  
IC<sub>3</sub> = CD4066



# Simulation on a Budget Avsim51

John Mosely uses the Avsim51 to simulate 8051 development — and finds he has almost too much of a good thing.

**W**orking for a small electronics company developing processor based control systems, I was asked to extend a previously designed 8051 circuit. It looked a simple enough task with an average pile of peripherals, a little glue and about 4K of code.

But as I wrestled with interrupts that wouldn't, pointers that didn't, and no documentation to fall back on, I realised I needed help. An in-circuit emulator was an obvious aid though at several thousand pounds, it was never an option. What I really wanted and, more to the point, could even have afforded was a CPU simulator. Perhaps if the Avsim51 PC software simulator — built around a windowed display showing the registers of an 8051 and allowing the user to examine or modify them — had been available I would have had a few less sleepless nights.

In these days of powerful risc 32-bit controllers it may seem odd to look at a development tool for an 8-bit device. But commercially the 8051 is one of the most important processors on the market. Manufactured by a number of companies, including Intel, Philips and Siemens, the 8051 micro-controllers are the undisputed kings of the micro-controller world.

Hundreds of variants have captured more than 40% of the 8-bit market and while 16 and 32-bit controllers (the later usually risc systems) are more

glamorous, commercially they are much less significant. The 16-bit market is about 1/40th the size of the 8-bit sector, and the power-user 32-bit field is smaller still.

## Need for 8051 simulators

Ideally any serious 8051 project (or its derivatives) would have a proper in-circuit emulator as the main development tool, reducing development time, increasing software confidence, saving wasted time and money. But for many small companies or self-employed engineers, costs are prohibitive and even renting is too expensive.

With the 8051's internal timers, counters, parallel and serial I/O ports and a large amount of on-chip ram, often a single-chip solution is the goal, with on-board rom or eprom. 8051-family devices can be an elegant solution for the engineer, also making economic sense.

Unfortunately there are problems, one of which is access to internal facilities. It is even more difficult than usual to debug a program running from internal memory, with an inaccessible and invisible bus structure.

With no debugging aids the program can only be tested by running the target system at full speed and observing the state of the user-controlled I/O lines. Engineers must use experience to find what the processor is doing and time can be wasted blowing programs with silly typographical errors, most of which could be spotted if the user could single-step through the code.

The Avsim51 goes a long way to handling these problems.

## System Considerations

Hardware constraint will not be a limiting factor on use of Avsim51 as all that is needed is a PC, 128K of ram, one floppy drive and text graphics.

The program is supplied as a set of four files on a standard 5.25in floppy and is simply installed by creating a subdirectory, copying across the four files and running.

I ran this review on a generic AT with EGA graphics and a 40MB drive and the only niggle was that the program does not automatically set up the mouse, though this should pose no problem for serious users of the program. On my 12MHz machine the program could be configured to run too fast to be followed; nothing is gained from using a 386.

## Using the Program

The Avsim51 simulates in memory the hardware of the target processor,

including all registers, ports, memory and internal peripherals, and assembled code can be executed while the state of the processor is observed ( a "virtual CPU").

Code can be run at various speeds, or the user can single step and observe the effect of each op-code on the registers, pointers and memory contents of the chip.

Avsim also provides a symbolic debugger. Break points or pass points (with a variety of options) can be set to control the flow of code, and registers, memory contents or peripherals can be examined or changed. So the user can debug code and see precise results.

An embedded control system can make it difficult to work out what is wrong — often memory within the chip is used, so that it is virtually impossible to trace execution of the program from outside.

Hardware and software are developed together, and where there is a problem it can be difficult to decide where to place the blame. But a simulator allows examination of the program isolated from any hardware considerations.

Avsim51 is run and loaded with the assembly language program and associated symbol table, translating address and registers back to meaningful labels and symbolic names.

There are various options for loading, allowing the simulator to read program files from the Avocet cross assemblers (XASM or AVMAC) or from another cross assembler which can produce code in Intel (.HEX) or Motorola (.MIK) data formats. These can be read as ram- or rom-based programs, which can or cannot be modified.

But there is one aspect of the package that can only be described as unimpressive.

A separate program has to be used for assembly as Avsim is purely a debugger and simulator — the "patch" assembler is included for minor modifications only. So a typical engineering cycle would be: use the word processor to write program text, shut it down. Load and run the assembler and linker to translate to object code then shut that down. Run the simulator to find the errors and correct the simpler ones using the incremental patch assembler. Repeat until there is a more severe error then shut down the debugger, run the WP, correct the error, close the word processor. Load the assembler.

Anyone used to powerful integrated

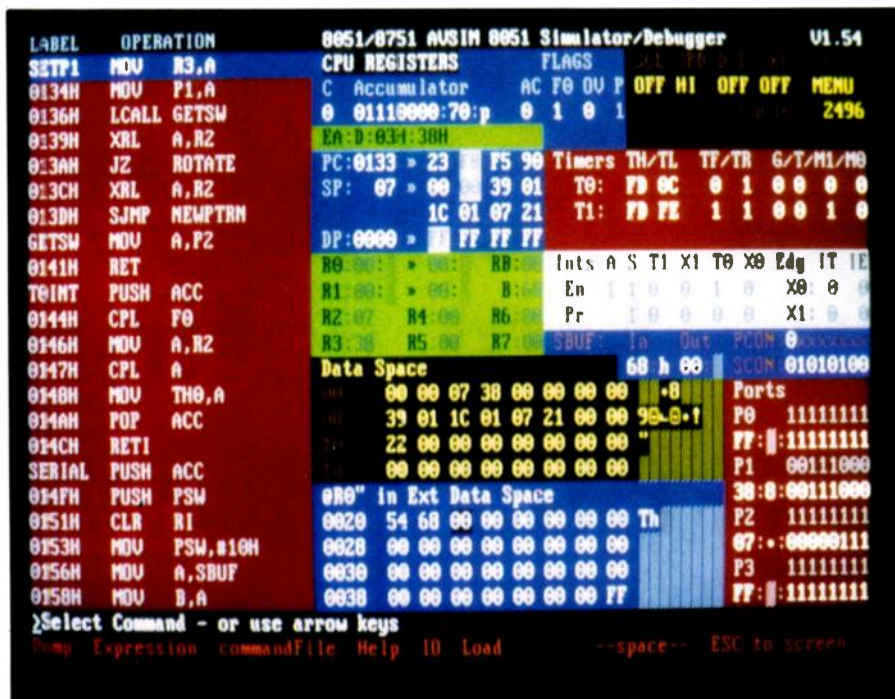
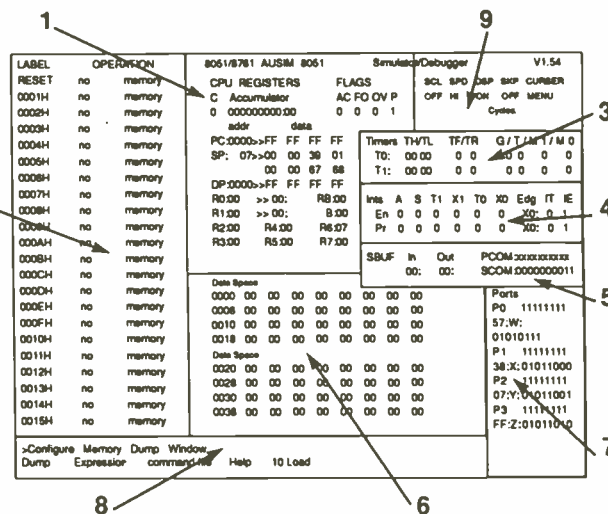


Fig. 1. The Avsim screen as it appears to the user. It provides everything that a developer could wish for although the sheer quantity of information makes it confusing. Interpretation requires a map (Fig. 2 below). The numbers shown relate to functions described on the opposite page.



programming environments (Turbo Debugger, Microsoft C etc) and perhaps spoiled by them, will agree that development is painful enough without wasting half the time switching software and waiting for it to load.

Cycling through three different programs, all with different command structures, menus and approaches is infuriating, and inevitably, the user ends up using the assembler's save command while in the word processor, or vice versa.

Diverting attention to concentrate on driving the tools does not help solve the development problem and the question must be asked why, in the nineties, do people provide a package that only does half the job?

### Impressive display

Once the Avsim is loaded and running there is a single master screen used throughout for displaying and controlling nearly all aspects of the system (Fig. 1).

Last two lines of the screen are the command area, where the user controls operation and behaviour of the simulation, with remainder of the screen displaying the status and operation of the target 8051 processor.

Surprisingly these two areas are completely separate, with the <esc> key used to toggle between them. This is a little annoying and can cause the odd problem as there are some functions that are only accessible from within one window, even though they may also be



required from the other (eg evaluate an expression).

The display area is the key to the program and very impressive it is too. The simulator can act as a screen editor with the cursor keys used to move through the windows or within memory spaces.

If the cursor is on a modifiable area then keying a number will load that location with a new value. So register contents or memory spaces can be observed and updated instantly to see "What If?". For example what if the accumulator held the value 55H?; what if the serial port reads in 'C?; does this section of code correctly trap out-of-bounds values?; does the loop terminate properly when the counter reaches zero?

Single stepping through the program is controlled by <F1> which runs a single instruction per cycle. Single stepping can be very illuminating, as a scroll bar descends through the program code section, watching registers and memory locations change on command. Even more revealing is how the contents of flags and status words alter — superb for detecting those silly errors when you got confused on parity!

If the single step mode is useful, then the Undo command, <F9>, is a dream undoing the previous instruction and returning the location to its previous value (whether it is the preceding byte or the jump instruction which caused a shift in program flow). Memory, registers and flags are all taken back to their earlier state and it is even possible to back-track past an interrupt or the arrival of an external input.

Obviously, a hardware emulator could never hope to provide this function — definitely one up for the software side.

By default the Undo buffer is 20 instructions long so that you can step back 20 times, but buffer size can be reset and on a 640k machine it can easily be increased to 1000 deep.

The simulated program can be run continuously, at a variety of speeds. <F1> starts or stops execution, while <F5> steps between three speed options. Slowest operation is approximately two opcodes per second, which is around the speed of repeated single steps and could be used to similar effect. Full speed is approximately 300 instructions per second, far too fast to follow on the screen, and normally used with the break point feature to race along until something unusual occurs.

Medium speed comes, logically enough, in between at say 10 codes per

second and is a pleasantly relaxing speed for observing flow of program execution and gaining a good grasp of how it is behaving.

The abilities to single step and undo instructions are exceptionally powerful debugging tools, and these alone probably justify the program price. Together with the facilities for continuous running and break points (described below) this program should be invaluable in simulating a micro-controller's program.

## Display Area

The display shows nine major areas on the screen at once, all colour coded — and all very cramped. Top centre area of the screen (Area 1 in Fig. 2.) holds the main registers and flags of the CPU. It shows the accumulator, program counter, stack pointer and data pointer. The 8051 core has four separate banks of eight registers — for working storage, data operations or bit manipulation — and the currently active register bank is also displayed.

A column on the left of the screen (Area 2) displays the section of program being executed. In particular it shows the 32 lines of code centred on the current line and, for each line, gives the address, symbolic label (if there is one), op-code and arguments. Triangular markers show any break points or pass points set for that section of the program.

The next three areas in the diagram show the contents of hardware control registers. These are the timers (area 3) and the interrupt registers and flags (area 4). In both cases it is easy to examine the contents of a location, or see what would happen in the event of a timer overflow or an interrupt arriving. Just move the cursor to the relevant bit, set or clear as appropriate, and restart the simulation to see what happens: effortless and very useful.

Below these is area 5 containing

### High level alternative

Avocet has released a version of Avsim51 for high level C use which is also claimed to remedy many of the problems mentioned here. AvCase is an integrated set of tools combining a C crosscompiler, editor, assembler, simulator and debugger within a unified environment. The distributors claim the new system is similar in use to the Borland Turbo style environment, with popup windows displaying different information, all controlled by standard keystrokes (<F1> for help, <F8> for step etc). Price is £1375 + VAT from Computer Solutions Ltd.

contents of the serial port's transmit and receive hardware.

The large area in the bottom middle of the screen (area 6) shows two separate 32-byte windows of data memory space. These can be used to examine anywhere in system memory, on or off-chip. Usefully, if these are pointed to by an indirect reference (eg from RO or the DP) the appropriate byte will be high-lighted. A separate region of the screen (area 7) shows latch settings and contents of the four ports on the CPU, making it clear whether they are configured for input, output or a mixture and what they are doing. This can be apparent from using a 'scope on the physical chip leads. But the display soon becomes eminently preferable for detecting those odd, subtle bugs or glitches that are normally impossible to detect.

Last two areas display the command line menu and the simulator's modes of operation and program status.

Cursor keys or a mouse will navigate around the screen, or express keys move directly to a given point; Ctrl-P goes to the PC, Ctrl-O gets to the overflow flag and so on. Also convenient and well thought out is the way some editing keys modify the contents of a register; + will increment a location, INS will complement a bit or byte and Ctrl-Home will zero a window and reset all the bytes.

My personal feelings are that though the master screen displays everything you could ever need to know about the processor, it actually shows rather too much as there are very few applications where all that information is wanted, continuously, all at once. As a result the screen can look busy and confused, making it hard work to follow.

I don't think I'm alone in debugging systems by concentrating on one area at a time. When I'm testing interrupt handling, I'm only interested in the enable and priority registers, interrupt flags and the program flow.

I don't want to see memory and data pointers and timers and the serial buffer and the ports, though I suppose I shouldn't complain about having too much information.

Perhaps I have been spoiled by using Borland Turbo systems and programs on the Mac, but I would certainly have preferred a windows environment, where I could control which regions are displayed.

That said, the current screen provides all the information that an engineer needs, with well designed access and a high degree of control.

## Command Area

The command area is used to control the Avsim program and PC, and works on a succession of sub-menus, with a new list appearing when a selection is made.

Some menus go to four or five layers deep which can be a little difficult to navigate, but are (generally) logical though rather cramped by being forced into two lines at the bottom of the screen. Given that the program forces access to the two screen areas separately, using <esc> to toggle between them, a pull-down menu system would have been easier to use and less old-fashioned. But not too many grumbles here because, while not perfect, the system is usable and a lot better than the cryptic command line parameter style still all too common in emulators.

Options allow search, clear or fill memory; reset processor or program; and control of system options.

A large variety of break points (stop execution on condition) and pass points (count number of times condition is met) allow easy setting of dynamic break points that stop execution when the program first reaches a particular location, but which are then cleared.

For example, running at full speed until a suspect routine is called, then carefully single stepping through it is a useful facility. Or "sticky" break points can be set permanently.

Other options allow detection of when a register hits a value, or trapping of indirect access to memory.

Just reads, just writes, or either can be detected separately, and I have never before used a hardware emulator that offers such a comprehensive range of options and variants. These are impressive and undoubtedly valuable.

The pass point (count) facilities are equally versatile. They don't display the elegant histograms of some systems but do offer an excellent way of measuring and optimising program performance, checking loops are running the correct number of times, or how often interrupts occur.

There is also a miniature assembler for program patches or minor changes to code. It can only assemble short sections of program and does not support any of the pseudo-ops or high level functions of a powerful assembler/linker. But it does allow variations in a program, trial of alternatives or correction of small bugs. Padding out code with no-ops to allow for this kind of modification, is a good idea.

A full assembler would have been better, but the Avsim assembler is

Avsim51 costs £375 + VAT from Computer Solutions Ltd, Canada Road, Byfleet, Surrey KT14 7HQ. Telephone 09323 52744.

System needs are undemanding and any PC with at least 128K ram, a single floppy and text graphics should be suitable.

undeniably useful and would be enough to correct the majority of common errors.

## More variety needed

One of the major attractions of the 8051 range is its variety. Benefits of a standard, familiar, instruction set and architectural core can be combined with a huge range of on-chip peripherals — the "pick-and-mix" approach to system design.

Philips, who claim to have the widest range of devices, offer more than 170 different versions of the processor including chips with additional timers, on-board multi-channel A-to-Ds, fast capture registers, high output current drivers etc.

So the Avsim's limitations in this respect are a little disappointing. Only the most fundamental parts are available; the standard 8051/2 and 8031/2 and cmos variants.

These six will certainly cover most applications, and while all possibilities could never be included, more choice would be an advantage. Some variants are rare but others such as the 552 are widely used, and I especially missed support for an I<sup>2</sup>C interface.

The full title of the software package examined in this review is Avsim51 which emulates a number of 8051 series micros. Other Avsim packages emulate Motorola, TI, Zilog, Intel and Hitachi processor families. Each family requires a separate Avsim purchase.

We can hope that the next version of the simulator will have a more extensive library of components.

## Documentation

The manual consists of 170 A5 pages, clearly numbered and indexed, supplied in a three-ring binder, with chapter separators. Options and commands are clearly described and plenty of examples are included.

A thorough demonstration program is included on the disk which reads in data from a serial port while running a flashing light sequence display. At about 150 lines of code this isn't a huge program but it does demonstrate timers, serial port access and interrupts and even includes a potential bug

where the stack pointer can overflow into bank two space. Used with the Tutorial section of the manual it covers most of the features of the program in a thorough and helpful way.

However, being walked through the demo did reveal a few discrepancies which had me confused for a while. For example, occasionally a new menu option or whole sub-menu would appear. The reason is that the manual describes version 1.2, while the program is v1.54. In these days of DTP it surely can not be that difficult to update a manual or at least include an errata sheet.

But to be fair to Avocet, none of the changes appeared significant and there was a READ.ME file on the disk which, once I'd thought of looking for it, solved the problem.

On-line help is there but is somewhat rudimentary, usually doing no more than rewording the menu option and so only really being useful as a memory jogger.

Overall, documentation is competent, well-organised and helpful. This should be unremarkable, but it is disgraceful how many programs are still produced with documentation so appalling as to render it unusable. Technical software seems especially prone to this.

## Summary

Avsim is an impressive package which works well and provides all the features a user might want. It offers a good range of functions and the interactive display of the processor is invaluable. The single step/undo facility, in particular, is particularly useful and the program will undoubtedly save a lot of development time.

On the negative side, implementation does let the program down. Menu structure is clumsy and old-fashioned, and would be improved by pull-down style displays. Similarly, the main display area is cluttered and hard to follow, where pop-up windows would make everything a lot clearer. Finally the system would be vastly more useful if it was integrated with the assembler/linker and a simple text editor.

In summary, the Avsim would be a valuable addition to the software toolkit of any engineer developing systems on the 8051. It's a pity about the old-fashioned user interface but at the price it can be justified if it saves just one day of an engineer's chargeable time and I'm certain that it will save infinitely more than that. ■



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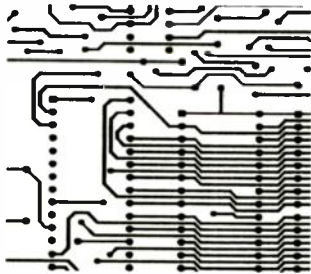
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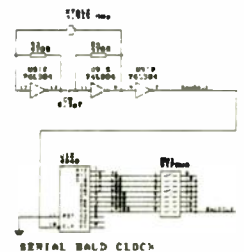
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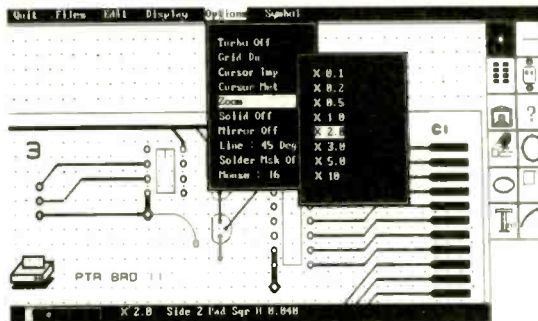
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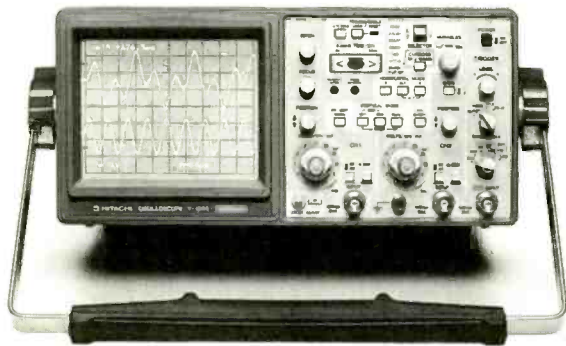
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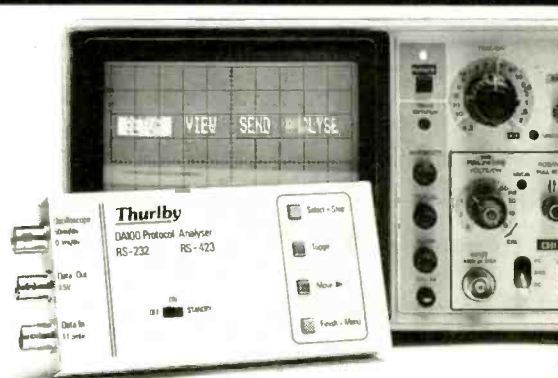
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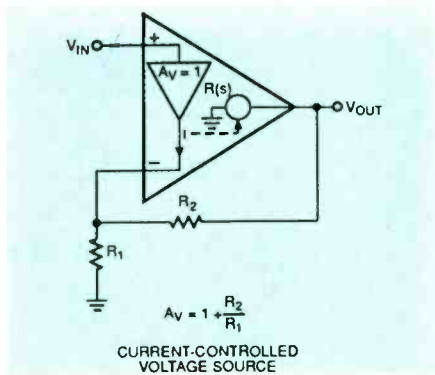


Fig. 1

and feed current into  $R_2$ , which equalises the current in  $R_1$  and replaces the current from the buffer. Closed-loop gain is  $(1 + R_2/R_1)$ , so that the assumptions normally made for op-amps still hold good: namely that voltage between inputs is effectively zero and that current into the inputs is zero. The value of  $R_2$  is kept constant at  $820\Omega$ , gain being set by the value of  $R_1$ .

Figure 2 shows a non-inverting amplifier. At low gain settings, with  $R_1$  high in value, the stray capacitance at pin 2 across  $R_1$  causes a low-frequency open-loop pole which peaks the frequency response. A series resistor,  $R_c$ , at the non-inverting input reduces the peak. With gain high,  $R_1$  is low in value and the pole is too high in frequency to have much effect. The practice of using

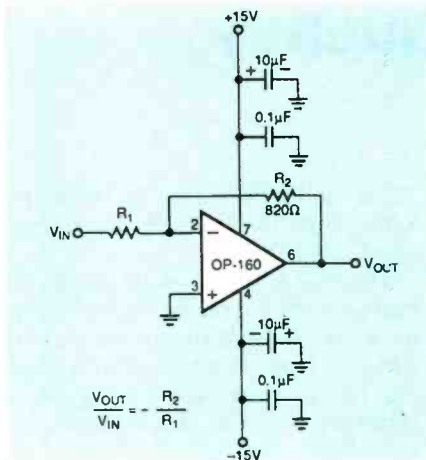


Fig. 2

a capacitor across the feedback resistor, as used in voltage-feedback amplifiers, causes instability in current-feedback types.

Used as an inverting amplifier, as shown in Fig. 3, the device is exactly the same as a voltage-feedback device, the gain being set by  $-R_2/R_1$ .

Since, for stability, the feedback impedance is assumed to be non-varying in a current-feedback amplifier, the feedback capacitor in an integrator would normally cause instability. The circuit of Fig. 4 shows a resistor  $R_F$ , which maintains a minimum value of feedback impedance at higher frequencies. At lower frequencies, the

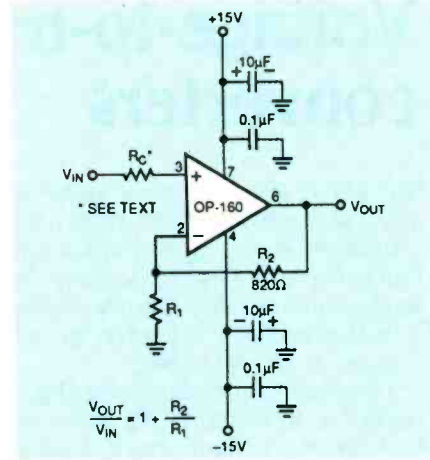


Fig. 3

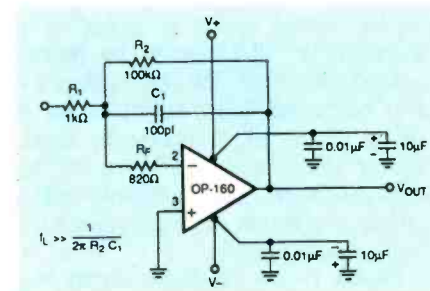


Fig. 4

overall feedback increases, but not enough to affect performance. Bourns Electronics Ltd, 90 Park Street, Camberley, Surrey GU15 3NY. Telephone: 0276 692392.

## Optical-fibre transmitter-receiver

Philips's 74F3037 FAST line driver is a quad two-input Nand and is intended for low-cost optical communications at over 170Mbaud, depending on the length of the cable. A 1km link will operate at an output pulse width distortion of less than 15%.

The Hewlett-Packard HFBR-1402.4 led is much harder to turn on than off, so that the 74F3037 fast, high-level turn-on and high pull-up current is needed in this application. The peaking

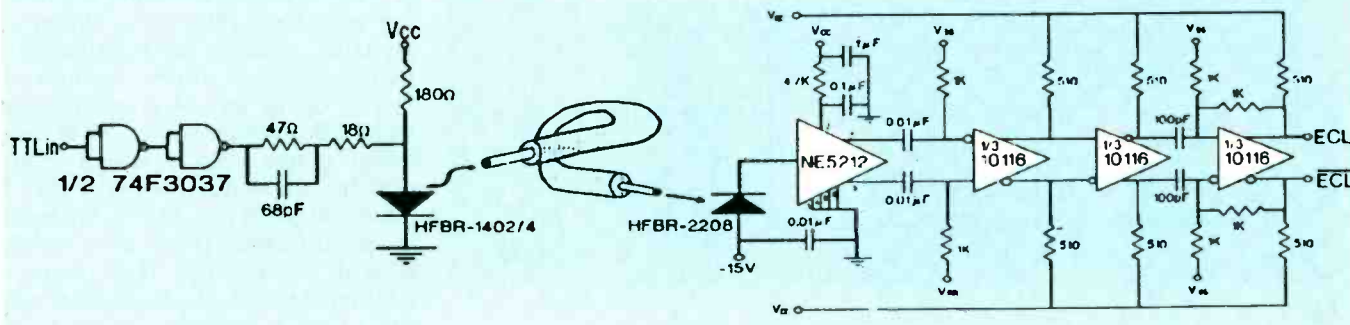
capacitor compensates for the led's slow turn-on and peaks its light output during both on and off transitions

For reception, an H-P HFBR-2208 photo pin diode drives a Signetics NE5212 transimpedance current differential amplifier, which is followed by a Signetics 10116 triple ECL line receiver. The amplifier's internal feedback resistance of about  $7k\Omega$  converts the photon-generated currents from the pin diode into a 100mV differential

output voltage. Output of the circuit is at ECL logic levels.

Philips recommend that multilayer PC boards be used, with ground paths as short and as wide as possible to keep induced ground noise to a minimum. All supply pins are decoupled with 0.1-0.33µF ceramic/tantalum capacitors.

Philips Components Ltd, Mullard House, Torrington Place, London WC1E 7HD. Telephone: 071-580 6633.







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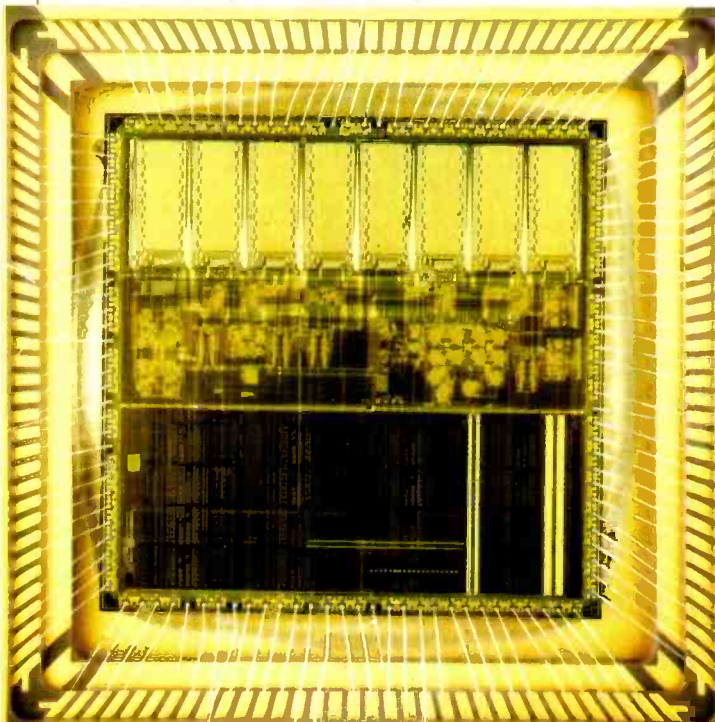
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suitable for automotive applications, where its  $V_{CE0}$  of 120V is capable of withstanding load-dump transients without added protection. Zetex plc, 061-627 4963.

## Digital signal processor

**Floating-point DSPs.** Two new devices for the TMS320 DSP family provide 32-bit floating point performance at fixed point price. The TMS320C31 has been designed for a wide variety of applications, including high speed modems, voice recognition systems, transcoders, multimedia, robotic control, and disk servo control. The TMS320C30-26 is suitable for high performance 3-D graphics, realtime, high-resolution image compression and video conferencing. Texas Instruments, 0234 223252.

## Linear integrated circuits

**Voltage regulators.** The RX5RA cmos range includes a reference voltage supply error amp, control transistor and a resistor network designed to control output voltage. Any device from the range can be ordered with specified voltages between 2.0V and 6.0V in steps of 0.1V. Accuracy is guaranteed at  $\pm 2.5\%$ . The voltage dropout is typically 60mV at  $I_{out} = 1.0mA$ . Power consumption is low at  $1\mu A$  at  $V_{out} = 3.0V$  (typ). Micro Call Solutions, 0844 261500.

## Logic building blocks

**Low-skew clock driver.** The MC88915 low-skew phase-locked-loop clock driver is the newest member of a family of high-performance cmos clock driver ICs. This clock driver uses phase-locked-loop techniques to

synchronise the precision output frequency and phase onto the Input positive edge of a reference clock. The MC88915 device is also capable of frequency multiplication, meaning that the precision low-skew outputs can run at an exact multiple of the Input reference frequency. This combination of capabilities offers designers of the highest speed cisc and risc systems the most flexible yet economical PLL clock driver function available. Motorola Inc, 0101 602 962 2085.

## Memory chips

**High-speed cache module.** The Turbocache486 is an optional second-level cache memory module said to increase the performance of i486 microprocessor-based computer systems by up to 15%. It is a highly integrated, single-socket module giving computer manufacturers the flexibility to offer several configurations of the same model. Production will start in the winter and prices (1000-piece) will be £214 for the 64Kbyte model and £286 for the 128Kbyte model at 33MHz. The 25MHz modules will be £179 and £250 for the 64Kbyte and 128Kbyte models respectively. Intel Corporation (UK) Ltd, 0793 696000.

**25ns Megabit sram.** Fast access, 25ns, is the aim of NEC's 1Mbit static ram family, uPD431000LE, now being shipped in sample quantities. Two configurations, 1048576  $\times$  1 bit and 262144  $\times$  4 bit, each offer a choice of 25ns or 35ns access times. The family is fabricated using low-power 0.8 $\mu m$  double aluminium cmos technology and more than 6 760 000 circuit elements are integrated on a chip measuring 14.48  $\times$  5.92mm. NEC Electronics (UK) Ltd, 0908 691133.

**Quad port ram.** The PDSP16520 quad port ram is designed for use in high-performance dataflow systems such as those found in digital signal processing (DSP) and fast Fourier transform (FFT) applications. It contains a total of 16Kbits of dual port static ram, arranged in four 256  $\times$  16 bit segments. These segments are supported by two 16-bit input buses and two 16-bit output buses, with each memory quadrant accessible from any of the Input and output ports. All address, data, and control inputs, together with data outputs, are fully registered. Memory cycles are initialised by this system clock, with possible rates up to 20MHz. Plessey Semiconductors, 0793 518000.

## Microprocessors and controllers

**Faster 20MHz Z80 CPU.** A new Zilog 20MHz Z80 CPU is claimed to be twice as fast as any other 8-bit microprocessor, and has a peak execution time of 5 MIPS. The Zilog device can simply be inserted into the current system board with a suitable crystal to allow the system to run at twice its original speed. The 20MHz unit is fully code compatible with Z80 architecture and allows users to retain their software. Celds, 0734 585171.

**Improved graphics controller.** An improved G300B colour video controller offers faster, higher-resolution graphics. Variable pixel depth allows it to address the valuable Apple add-in board market, giving it a wider appeal. The G300B is a highly integrated device combining the functions of a 256  $\times$  24-bit colour look-up table, a programmable video timing generator, a micro port, a 4:1 multiplexed pixel port, a triple 8-bit video DAC, and a software programmable phase-locked-loop, all in a single 84-pin PGA or 100-pin ceramic quad flatpack. Inmos Ltd, 0454 616616.

## Optical devices

**Photon-counting photodiode.** With a noise figure of just 2  $\times$  10<sup>-13</sup>W/√Hz, the TIED57 avalanche photodiode is suitable for use in photon-counting applications. Given a 50 $\Omega$  load, this high-speed silicon sensor is capable of 500ps switching and it features a photocurrent gain of more than 600. Having a low breakdown figure of 170V the TIED57 runs cooler than competitive photodiodes, which helps to minimise noise. The TO18-packaged device responds to light over a 500 to 1100nm band and exhibits a capacitance of typically 1.2pF. Bulk dark current of the detector is typically 5pA while surface dark current is at most 10nA. Isocom Ltd, 091-257 4994.

**2A optocoupled triac.** The IL428 optocoupled triac is claimed to be the world's first capable of delivering 2A at 55°C without any additional cooling. It consists of a GaAs infrared led optically coupled to a phototriac chip, all encapsulated within a 4-pin SIL package of 23  $\times$  20  $\times$  25mm. Its sensitivity is such that high Input currents of less than 8mA (typically 4mA) are sufficient to permit currents of 2A to be efficiently switched. The IL428 has a 600V blocking voltage which allows control of off-line voltages up to 240V AC, with a safety factor of more than two. It can also withstand an insulation test voltage of 7.5kV in a static dV/dt ratio greater than 10kV/μs. Norbain Technology, 0734 864411.

## Programmable logic arrays

**Faster PLA design.** Fulfilling the promise of programmable gate arrays, the Plus Array architecture and Plustran design system allow designers of high-performance systems to develop 40MHz systems in less time and for lower cost than with existing programmable products and design systems. By eliminating placement, routing and fanout dependencies (traditional bugbears of asic design), iterative cycles are eliminated and timing is 100% predictable. Since the Plustran design system interfaces with industry-standard design tools, learning curves are eliminated, further shortening design time. According to maker Plus Logic, months can be eliminated from



system design with this approach. Abacus Electronics Ltd, 0635 36222.

**Asic master arrays.** Six master arrays have been added to the "Sea of Gates" family. Their densities, combined with the four already available, now offer ten complexities ranging from 5376 to 177408 gates (2 input NAND).

Fabricated using 1.0µm cmos-6/6A technology, they provide the design engineer with the density and speed required for complex macro functions using large ram or rom blocks. Up to four 16-Kbit blocks of ram can be integrated per chip, and the propagation delay time for an unloaded gate is only 270ps. NEC Electronics (UK) Ltd, 0908 691133.

#### Third-generation gate arrays.

Flexcell, a new gate array family with a unique architecture, claims gate density up to 250 000 gates, with gate utilisation of 50 to 80%, and a three-to-one improvement in ram density over competitive products. A programmable polysilicon layer is used for connections within gates and for limited-length stub routing into routing channels. A 0.8µm L-effective (1µm drawn) cmos build process enhances its high density and high performance. National Semiconductor, 0049 8141 103 245.

**66MHz EPLDs.** The 66MHz Cypress Semiconductor CY7C330 EPLD claims a 20% improvement in performance over the earlier 50MHz family. Housed in 28-pin PALs, these new EPLDs offer more I/O than the former 24-pin devices. The CY7C330 family is targeted at higher-performance synchronous, asynchronous and combinatorial designs. By tailoring the architecture of each device to a specific type of application, unused circuitry normally present in conventional general-purpose PLDs can be removed. Pronto Electronic Systems Ltd, 081-554 6222.

**Asic design kits.** The Visula Plus VGT200 design kit provides engineers with complete design-entry and verification for VLSI's VGT200 series gate arrays. All relevant design software is fully validated by the silicon vendor and the VGT200 gate array provides customers with 1K to 60K used-gate capability. The PCB-level simulation enables the design of asics that are not only correct to their individual specification but are also correct within the PCB environment. Faults that would not normally be detected until both the asic and the PCB had been manufactured can now be eliminated at the design stage. VLSI Technology, 0908 667595.

**1200V power amplifier.** The PA89, claimed to be the industry's smallest high-voltage amplifier, will deliver 75mA and will operate from supply rails from ±75V to ±600V. Output will swing more than 1kV p-p with full voltage applied. It requires only two high-voltage resistors to set the gain, plus a current-limiting resistor recommended for safe operation. Bandwidth for full-power operation is 10kHz for 300V p-p, 3kHz for 1kV p-p. Microelectronics Technology, 0844 278781.

# PASSIVE

## Passive components

**Low-impedance capacitors.** For applications where low loss combined with high reliability is important, the small physical size and very low impedance of the LXF series miniature electrolytic capacitors makes them suitable for switch-mode power supplies and converters. At 100kHz, a 35V 2700µF LXF capacitor, for example, has an impedance of at most 18mΩ. In all there are 800 models in the series with values ranging from 56 to 8200µF and voltage ratings from 10 to 50V in five steps. In switch-mode power applications heat produced by these capacitors is minimal due to their low impedance. Besides reducing losses, cool running results in a longer working life. Even at 105°C, these capacitors last between 5000 and 10,000 hours depending on can size. ECC Electronics (UK) Ltd, 0628 810727.

## Connectors and cabling

**18 twisted pair cable.** A cable combining 18 twisted pairs, designed for connecting computers and peripherals operating at up to 3Mbit/s, replaces 18 coaxial lines and is constructed from 0.126mm<sup>2</sup> solid tinned copper conductor, is dual insulated with semi-rigid PVC over a layer of foamed polyethylene and weighs up to 50% less than coaxial cables. Alpha Wire Ltd, 081-751 0261.

**BNC connector.** A new version of the BNC connector is designed for use in data communications and other applications where the connector body needs to be insulated from earth. The PCB-mounting insulated connector, with polyester body, eliminates the risk of earthing through instrument cases. Belling Lee Ltd, 081-363 5393.

**Gender changers.** Mini-connectors for changing the gender of D connectors enable secure male/male or female/female connections to be made without changing existing cable terminators. 9-pin, 15-pin and 25-pin male/male and female/female connectors can be

**High-speed VHF network analyser, the R37521 from Advantest**



supplied. Interconnections Ltd, 0483 797418.

**D-Sub connectors.** A range of non-magnetic/filter D-Sub connectors is qualified to European Space Agency ESA/SCC and Mil-C-24308 requirements. They are designed for applications such as satellites where added protection against electromagnetic interference is required, or where low residual magnetism is wanted. Souriau (UK) Ltd, 06285 24981.

## Crystals

**Surface-mount crystal.** Housed in a minute ceramic package measuring only 6.1 × 2.9 × 0.85mm, a new 32.768kHz crystal is suitable for applications where board space is paramount. The design allows the crystal to withstand high temperature soldering at 250°C for up to 30 seconds. Ultrasonic cleaning can be used. Frequency stability is ±100ppm over the standard operating temperature range of -10 to 60°C; frequency tolerance at 25°C is ±30ppm maximum. Designated the IQSXC, the unit features an ESR of 100kΩ max. and a drive level of 1µW. IQD Ltd, 0460 77155.

## Displays

**Alphanumeric message panel.** Microprocessor controlled alphanumeric message panel indicators display one line of 20 characters (models 144-120 and 288B) or two lines of 40 characters (model 288). The panel meters have a light green fluorescent display, 16,000 character storage, serial and parallel interfaces and networking capability. Messages are programmed into the unit via a serial interface using a PC, programmer or terminal. Up to 255 different messages can be stored, selected by the machine or process control system. Amplicon Liveline Ltd, 0273 570220.

## Filters

**Custom filters.** A custom filter design service allows specified filters to be

designed using high fundamental frequency crystals up to 350MHz or with low overtones to 500MHz beyond the limits of popularly used devices. Filters can be designed with very wide bandwidth and low insertion losses. Euroquartz Ltd, 0460 76477.

## Hardware

**PC-bus card cage.** The IPC-6010 PC-bus card cage is intended for OEMs and system integrators wishing to build PC-bus hardware into custom chassis of their own. It consists of an open-style frame incorporating an eight-slot passive PC-bus backplane with keyboard and power supply connector, a hold-down clamp for vibration protection, an integral 8Ω PC speaker, and PC-style rear blanking panels for unused card slots. Price is £181. Integrated Measurement Systems, 0703 771143.

## Instrumentation

**VHF band analyser.** The R3751 series VHF band network analyser can measure amplitude, phase, group delay, and impedance in the 10Hz to 300MHz frequency range at high speeds. In production line measurement, speeds of 100ms/span (201 points) are possible, helped by the partial variable sweep function. A built-in BASIC controller allows the user to analyse measurements and enables automatic measurement by creating data processing programs from an external keyboard. Advantest UK Ltd, 081-336 1606.

**Battery monitor.** The CS3231 monitors battery condition by pulse loading and sampling the voltage at predetermined intervals. It connects directly to the power source and compares its voltage to an internal value. An external LED alerts the user to a low voltage condition. A second output is provided for an optional healthy status indicator. An interval timer generates a repetitive test pulse, loading the power source by up to 100mA. Clere Electronics Ltd, 0635 298574.

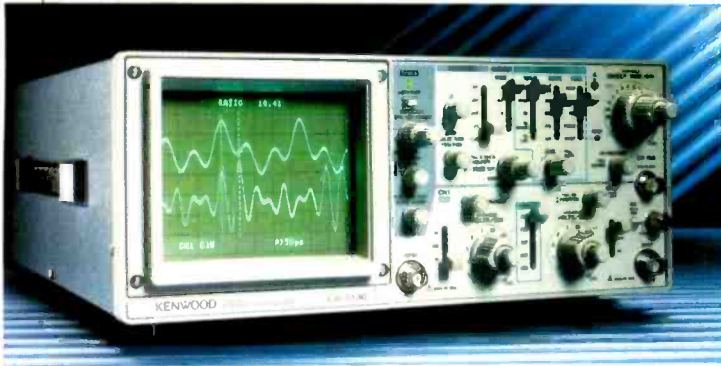
**8/16-bit logic analyser.** A fifth member of the HP 1650 family, the HP 1654B logic analyser, has 64 channels with 100MHz timing analysis and 35MHz state analysis, and is designed to provide a low-priced logic analysis solution for electronic design engineers working with 8- and 16-bit microprocessor-based systems. Like others in its family, it features 100MHz transitional timing analysis on all channels; 35MHz state analysis; advanced pre- and post-processing analysis for state and timing data; a simplified user interface that provides users with only valid choices and eliminates menu hopping; full programmability via either HP-IB (IEEE-488) or RC-232C; and built-in disk drives for easy storage and

retrieval of setup and measurement data. Hewlett-Packard Ltd, 0344 763767.

**10MHz handheld oscilloscope.** The Tektronix 222 digital storage oscilloscope is a rugged, handheld unit



## NEW PRODUCTS CLASSIFIED



**Kenwood CS5130 40MHz oscilloscope from Thurlby-Thandar**

with a 10MHz bandwidth and 10Ms/s sampling rate. It measures  $86 \times 159 \times 252$ mm, weighs 2kg, and can store up to four front-panel set-ups. Up to four waveforms may be acquired and transferred to a PC via the RS232C interface for later analysis. A 100ns glitch capture is featured for fast-occurring, elusive events, and an auto trigger automatically locates trigger points and selects the correct voltage level needed to capture a waveform. IR Group, 0753 580000.

**Signal generator.** The SMHU Model 58 signal generator will have all the facilities of the SMHU (52) plus features of special interest to GSM, PCN and DECT customers. It covers 100kHz to 4.3GHz with 0.1Hz resolution and provides a very flexible approach to the demands of communication systems. It meets requirements as diverse as MPT (CEPT) radio testing, frequency hopping applications, radar and telemetry link testing. Phase noise is as low as  $-150$ dBc with spurious down to 100dBc. This makes the SMHU suitable for automated receiver spurious response measurements. Test runs are reduced from over one day to only four hours due to the 1ms settling time. Rohde & Schwarz UK Ltd, 0252 811377.

**LED colour sensor.** A low-cost colour sensor relying wholly on electronic components is about the size of a cigarette packet. Four LEDs of different

**Wall-mounting power supply from Eltek**



colour sequentially illuminate a specimen to be identified. A photodiode measures the intensity of the reflected light and a downstream microcontroller encodes and stores information for subsequent reference. Physical separation of sensor and information processor allows the probe to be kept small so that it is now possible to reach measuring points that were previously inaccessible. Siemens plc, 0932 752323.

**40MHz digital oscilloscope.** The CS51320 is a 40MHz dual trace oscilloscope with cursor measurement, screen readout, and delayed time base. Cursor measurement reads voltage difference, time difference, frequency, ratio, and phase which with set-up parameters may be displayed on the screen. Vertical sensitivity can be varied between 5mV/div and 5V/div over the full bandwidth. Higher sensitivities of 1mV and 2mV/div are available up to 15MHz. Timebase sweep times are variable between 0.2 $\mu$ s/div and 50ms/div on the B time base. A  $\times 10$  magnifier gives a maximum sweep speed of 20ns/div. Cost is £775 plus VAT including two probes. Thurlby-Thandar Ltd, 0480 412451.

**Protocol analyser.** The DA100/101/102 low cost protocol analyser is a diagnostic tool for solving problems with asynchronous serial data communications systems such as the RS232. The DA100 provides baud rate analysis, data word format analysis, data monitoring (ASCII or Hex), triggered data capturing, and test data generation. The DA101 LCD unit can display up to 32 characters of alphanumeric. The DA102 RS232 'breakout box' provides a convenient means of making connections into an RS232 system, and features full breaking and patching of 25 lines, data monitoring of the transmit and receive lines via the DA100, and level monitoring of the 11 most commonly used other lines. It also provides pulse stretching and latching capabilities. Thurlby-Thandar Ltd, 0480 412451.

### Interfaces

**Flexible I/O interface.** The UM6522 versatile interface adaptor (VIA), for personal computer systems, features expanded handshake capability for positive control of data transfers

between processor and peripheral devices, including bi-directional data transfers between VIAs on multiple processor systems. It contains a pair of very powerful 16-bit interval timers, a serial-to-parallel/parallel-to-serial shift register, and input and output data latching on the peripheral ports. Control of peripheral devices is handled primarily through two 8-bit bi-directional ports, and a serial data port is provided. The UM6522 at 1MHz and UM6522A at 2MHz are available, operating from a single +5V power supply and available in a 40-pin dual-in-line package. Microelectronics Technology, 0844 278781.

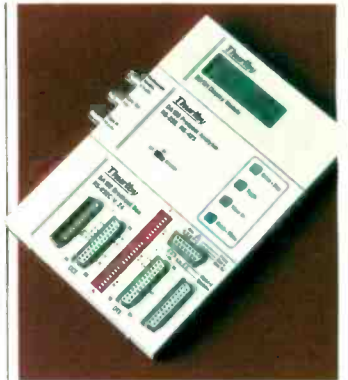
### Power supplies

**Miniature mains transformers.** A family of low-cost, highly compact encapsulated mains transformers has been developed for PCB applications in which the high density and low profile of components are important factors. The LP-Series transformers incorporate dual primary and secondary windings mounted separately on a UL-approved laminated board. This is encapsulated in a resin-filled thermoplastic casing, flash tested at 5kV, having a pin arrangement suited to through-hole soldering onto the host PCB. The series consists of seven different versions with ratings between 2VA and 30VA, each providing dual outputs at 6, 9, 15, 18 or 24V; primary and secondary windings may be wired in series or parallel to achieve the voltage output and current required for a given application. JPR Electronics, 0582 410055.

**Triple output converter.** The NFC25 series of 25W triple output DC/DC converters meets BTR2511 requirements and, with its wide input and much improved input filter, is said to be ideal for high power density card-mounted purposes. The NFC25 features a wide input range of 36 to 72V DC, and is supplied in a compact  $3 \times 3$ in package, with 80% guaranteed efficiency. Triple outputs allow system designers maximum flexibility in device/chip selection, and the new device benefits from remote on/off control, a self-contained input Pi network filter, no derating up to 60°C, and high isolation of 500V DC. Computer Products Pwr. Conv., 0234 273838.

**Wall-mounted power supply.** The SMPS 600 series of switch-mode power supplies is fully BABT-approved and meets all European standards for safety and conducted RFI. They provide a reliable source of DC power for a range of demanding industrial and commercial applications. With high operating efficiencies of around 90%, these 600W modules can be used with portable and stationary equipment with or without battery back-up. They are also short-circuit proof and automatic current limiting, and softstart is built in as standard. Eltek UK Ltd, 0442 219355.

**18-32V converters.** Each DC/DC converter module in the new PKY2000



**Protocol analyser by Thurlby, the DA100/102**

family features a wide input span of 18 to 32V combined with an MTBF of up to 80 years. Through the use of high-frequency quasi-resonant technology, these low-profile modules combine high efficiency with high power density. Capable of handling 75, 100 or 150W, the card-mounting PKY2000 modules are available in a variety of popular fixed outputs from 5V to 48V. They exhibit power densities of up to 2.1W/cm<sup>2</sup> and either 3750 or 1500V input-to-output isolation rating. All modules in the family are designed to meet CSA C22.2 No 220, IEC380/950 and UL1012/478 safety standards. Ericsson Components AB, 0203 553647.

**Adjustable power supply.** Intended for use in telecomms equipment and battery-charging applications, the NS700 is a high efficiency, single output, switch mode power supply with a 48-60V adjustable output and output power of 700W convection cooled or 900W forced-air cooled. It is available in a choice of mechanical formats (L chassis, optional mesh cover or mesh cover with integral fan), operates from 240 or 110V AC, and measures 300  $\times$  175  $\times$  75mm (112mm with integral fan). Power fail, DC OK, clock sync, current share, inhibit and shutdown functions are fitted as standard. Other features include remote sensing, built-in soft-start circuitry and output protection against accidental short or open circuit. Farnell Instruments Ltd, 0937 619611.

**S-interface transformer.** Believed to be the first ISDN S-interface transformer in the world to pass the stringent requirements of both BS6301 (1989) and CCITT recommendation I.430, the TTW 4601 is fully encapsulated and passes the BS6301 specification for reinforced isolation, 6mm creepage distance and 6kV isolation, while maintaining the industry standard footprint. DC resistance, interwinding capacitance and impedance characteristics exceed I.430. Filtran Ltd, 0494 444044.

**Miniaturised voltage references.** Claimed to be the ultimate in miniaturised voltage references, the SR12D and SR25D are the first in a new series of voltage reference ICs to be offered in a standard SOT-23 package. This surface-mount package



has only three pins, enabling it to take up less than 25% of the board area taken up by a normal SO-8 surface-mount package. They provide a precise voltage output of 1.23V and 2.50V respectively, by using the bandgap principle. Other important features include low knee currents of typically 80µA for the SR12D and 60µA for the SR25D. In addition, the low temperature coefficients mean that the voltage is stable over the operational temperature range of -40°C to +85°C. Typical unit price for SR series (tape and reel), in quantities of 1000, is £0.46. Plessey Semiconductors Ltd, 0793 518000.

**Radio communications products**

**Cellular radio circulator.** The new CE series circulator is primarily designed to act as a protection device for amplifiers in cellular and cordless telephone systems in both handsets and base stations. Located between the system's transmit and receive circuitry, the circulator stops reflected power (due to any mismatches that may occur) from re-entering the amplifier's outputs and destroying it. In essence, the device is analogous to a mechanical valve, allowing power to be transmitted in one direction only. Maximum insertion loss ranges from 0.7 to 1.2dB. VSWR figures lie within the range 1.5-2.0, and all three versions have a minimum isolation value between 10 and 14dB. Input power is specified as 2W for the PCB-mount variant, while the two surface-mounting types are rated at 10W. All have input impedance of 50Ω and operating temperature ranges of -35 to +85°C. Murata Electronics (UK) Ltd, 0252 811666.

**Switches and relays**

**Miniature microswitch.** Automated production techniques should enable the ITW Series 19N microswitch to offer low cost, improved and consistent quality levels for high volume applications, according to the distributor. The spring-and-blade switch is offered with a variety of operational forces and a choice of auxiliary actuators as standard, such as roller and leaf lever. Custom levers and brackets are also available, as are multiple pole "ganged" versions. H-Squared Electronics Ltd, 0462 815115.

**Mini rotary switches.** A new range of miniature rotary switches, the DM series, designed for particularly small spaces, is believed to include some of the smallest rotary switches currently available. Due to their compact (10mm<sup>2</sup>) nature and RF screening, they are suitable for use in instrumentation, military communications and testing equipment, and other applications where space is at a premium. The switches have a choice of 10 or 16 positions and can be supplied with either stainless steel or nickel-plated mild steel spindles. They have long operational life expectancy (>10,000 cycles) and temperature tolerance of -40 to +85°C. Features include BCD,

Gray and hexadecimal coding and a balanced positive indexing, in addition to sealed spindle and panel options with maximum leakage ratings of 1ml per hour. WASP Ltd, 0705 453711.

**Transducers and sensors**

**Temperature compensated accelerator.** Model 3110, a general purpose solid-state piezoresistive accelerometer, has built-in application and temperature compensation, with 0.5 to 4.5V DC output range. For use where small size, high performance and low cost are needed, the 3110 features a silicon micro-machined accelerometer, and tempco. over 0 to 50°C. A single supply is required and FS output is ±2V, about a 2.5V offset. It is designed with built-in damping, and goes down to a DC response with a wide usable bandwidth. EuroSensor, 071-405 6060.

**Pressure sensors.** A semiconductor pressure sensor series manufactured by Copal Electronics consists of two variants: a diffused semiconductor type and a thin-film semiconductor version. The first is a mid-range pressure

sensor (0.1 to 10kg/cm<sup>2</sup>) developed as a result of the combination of circuit and semiconductor production technology. The thin-film version is a high-range pressure sensor (20 to 350kg/cm<sup>2</sup>) developed through the combination of circuit and thin-film forming technology. Both are available from EuroSensor and are available in gauge, differential, absolute and gauge (vacuum) pressures. Tanminster Ltd, 071-253 8859.

**Vision systems**

**Single-chip 2D convolver.** The PDSP16488 is a fully integrated, application-specific image processing device for use in realtime digital video systems. It can be used to remove noise and aliasing effects, or to enhance edges for pattern recognition purposes, and perform as a two-dimensional convolution between the pixels within a video window and set of stored coefficients. It supports pixel rates of up to 40MHz, and has eight internal line starts, which allow a single device to support window sizes of up to 8 x 8. Plessey Semiconductors Ltd, 0793 518000.

COMPUTER

**Computer board level products**

**Process control PC cards.** A range of IBM-PC/AT compatible plug-in cards is designed specifically for process monitoring and control rather than laboratory data acquisition. The cards provide relay outputs, opto-isolated I/O or current loop analogue I/O through 37-way D-sockets at the rear of the PC chassis, and are said to be ideally suited to process control applications where a PC is being used to replace conventional PLCs. Other applications include adding auxiliary control and monitoring functions to SCADA systems. The cards do not use any custom chips and all parts are mounted in turned pin sockets, said to make field servicing much easier. Fairchild Ltd, 042121 6527.

**PC voltmeter card.** A 4.5 digit digital voltmeter card plugs directly into an 8-bit PC slot. It is fully isolated and provides DCV, true RMS AC and DCR measurements. Programmable input ranges are between 200mV and 200V, AC and DC; programmable precision current source between 0.1mA and 10mA for four-wire resistance measurement and programmable conversion rate between 2.5 and 10 readings/s. A software package is provided to operate the card, which, including software, is priced at £375. Integrated Measurement Systems, 0703 771143.

**Digital signal processing.** The DSP244 has been developed for use in defence and industrial applications where compact or "ruggedised" solutions may be required. Its most

important design feature is that the memory (including internal memory) appears dual-ported to the VME bus. This allows the board's memory to be directly addressed as part of VME system memory and removes the need for software to manage data transfers between the DSP244 and application software. Signal Computing Ltd, 0483 579900.

**Data acquisition boards.** Data acquisition boards usually require manual adjustment of jumpers, and potentiometers. But once installed within the base address set, the DT2831 series continuous-performance boards need never be removed to reset any hardware attribute. Calibration and configuration, software-driven from the keyboard, include single-ended or differential input selection, input gain, input and output coding and ranges, selection of DMA channels for continuous performance, interrupt level, and calibration of A/D and D/A converters. Even the A/D calibration is handled automatically from software-driven controls, totally eliminating the need for manual calibration. Data Translation. 0734 793838.

**Data communications products**

**FDDI lan chipset.** A highly integrated, next-generation FDDI lan chipset meets the rapidly expanding market requirement for very-high-speed fibre-optic networks. The five-chip set claims the industry's highest level of performance and functionality. The ICs feature a full-duplex architecture, an essential requirement for self-testing network stations, and are claimed to

provide consistent interfaces to software, require minimal software involvement in operations, and provide integrated support for management functions. National Semiconductor, 0044 793 697 473.

**Software**

**Data acquisition software.** Microscope is a data acquisition software program for use with the PC26A 12-bit, 16-channel ADC and PC30A 16-channel ADC, 4-channel DAC, parallel I/O counter-timer cards. It has a "live" graphic display which shows the signal before, during and after capture. A Lotus-style menu system makes operating fast, flexible and simple. Sampling durations range from 32ms to 8mins, on one to four channels. Keyboard or external triggering is user-selectable and a movable cursor provides an easy readout for voltage and time values. More detail may be obtained by expanding the screen view. Channels may be moved vertically and features include: oscilloscope and chart recorder modes; measure, expand, data-comparison, shift traces on screen and trace overlay; and storing multiple traces in memory. A graphics printer output is provided plus the facility to read/write ASCII and binary files. Amplicon Liveline Ltd, 0273 570220.

**Serial communications software.** COMBIOS communications bios software is designed for adding interrupt-driven serial communications to IBM/PC/XT/AT computers and compatibles, comprising a memory-resident suite of RS232 device drivers. During loading the user specifies which COM ports and interrupts are to be used. Once loaded into memory the user's program communicates with COMBIOS via software interrupts. COMBIOS receives any characters from the serial port into a 100-character input queue (one queue per port), allowing the user's program to ignore the serial port for a while without losing any characters. COMBIOS is independent of the programming language, supports serial ports at any I/O address and any of the standard baud rates, bits per character and number of stop bits. Amplicon Liveline Ltd, 0273 570220.

**Fastest Easy-PC.** Easy-PC, known for its redraw speed, after a complete re-appraisal of the screen-drawing algorithms now draws complex layouts up to ten times faster. At the same time the keyboard handler has been rewritten to accept a wide range of international keyboards, including the widely used French, German, Italian, Spanish and US/UK English versions. A direct character code input option ensures that the entire alphanumeric PC character set can be included in layouts and schematics, regardless of the national keyboard in use. Easy-PC can be used in the design of boards up to 430mm square, with up to eight copper layers and two silkscreen layers per board. Number One Systems Ltd, 0480 61778.



# PIONEERS



EH Colpitts - one of the "great" telephone engineers (courtesy of AT&T Archives).

EH Colpitts

Telephones,  
oscillators and the  
push-pull amplifier

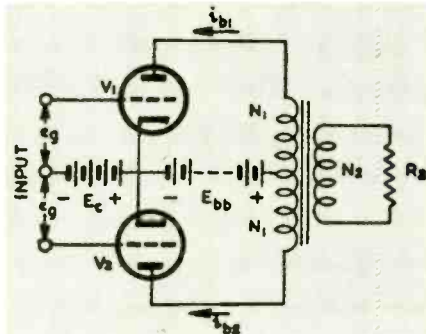
WA Atherton

**T**hink back to when oscillators were something new to you and exciting and you will probably recall the names of two of the great telephone engineers who worked for the Bell Telephone system in the first half of this century: Colpitts and Hartley.

The Colpitts and Hartley oscillators have survived long after their inventors died. Today they are transistorised and can be stabilised by quartz crystals, but they are still recognisable as the fundamental circuits invented during the First World War.

Edwin Henry Colpitts was born on January 9, 1872, at Pointe de Bute in Canada, though he was sometimes described by his contemporaries at AT&T in terms that virtually claimed him as an honorary American.

*Colpitts is credited with inventing the enduring push-pull amplifier in 1912.*



A bachelors degree with honours from Mount Allison University, Sackville, New Brunswick, was followed by another at Harvard in 1896, and a masters the next year after completing a postgraduate course in physics, mathematics and engineering. He continued at Harvard for another two years as an assistant to a Professor Trowbridge in the Physics Laboratory, until joining the American Bell Telephone Co in 1899.

For the next 38 years he served the Bell System in one capacity or another, steadily rising through the ranks until he retired in 1937 as Vice-President of Bell Telephone Laboratories.

But it was up to about 1920 that most of his efforts were directly involved with hands-on engineering or scientific contributions to telephone engineering. From then until his retirement he held positions which were mostly executive, leaving little time for direct contributions to engineering.

When Colpitts began his career with Bell telephones were no longer new, though much of the science-based work which led to vastly improved performance still lay in the future.

In 1924 Frank Jewett, Chief Engineer at Western Electric, wrote: "Almost from the day he entered the modest laboratories in Boston, Colpitts took a prominent part in the solution of the problems which were to revolutionise telephonic and telegraphic communication." Colpitts, he continued, was a central figure in the fundamental work which lifted the art of telephone engineering to a higher plane and established it as a science on a firm foundation of exact knowledge.

As well as exact knowledge, exact measurements were now required. The methods and instruments which George A Campbell and Colpitts developed for measuring high-frequency alternating currents were to play a big part in the development of telephony. Colpitts himself "made many of the first high-frequency deter-



minations on lines and apparatus".<sup>1</sup>

In this period up to 1907, under Campbell's direction, Colpitts worked long and hard on the development and application of loading coils to open wire and cable circuits, first suggested by Heaviside but patented by Pupin in 1899. "To those of us who were privileged to witness and occasionally to take part in this work there comes to mind many a picture of Colpitts in the early morning hours hard at work in some test room or far afield in sunshine or storm on a line inspection," wrote Jewett.<sup>1</sup>

Jewett also recorded for us the contribution that Colpitts made to solving, what he called, the threat to the very existence of long distance and even local telephone services in the first few years of this century. That threat was the inductive interference brought about by the introduction of alternating current for the propulsion of trolley buses and trains.

Colpitts threw himself into the work, "sometimes in the laboratory, but now more frequently in rough clothes in the mountains of Pennsylvania or the brush of Georgia or in rubber boots in the winter mud of Indiana." In the end solutions to the problems were found by joint collaboration with Westinghouse power engineers. Jewett credited Colpitts "in large measure" with helping bring about the closer understanding between communication and power engineers which came about in the first two decades of the century.

In 1907 the Bell System was reorganised and Colpitts moved to the Western Electric Company (part of Bell) in New York. There he began his climb up the administrative ladder, first as head of the Physical Laboratory, later as Director of the Research Laboratories (1911) and eventually as Assistant Chief Engineer (1917). The technical highlights of that period for Bell were the transcontinental telephone line of 1914, the transatlantic radio telephone experiments of 1915,

and of course the introduction of the thermionic valve to experimental and practical engineering. Colpitts was involved with them all.

When he transferred back to AT&T in 1924 as the newly appointed Assistant Vice-President (Development and Research) he was described eulogistically as possessing a keen analytical ability, the creative imagination of the thoroughly trained physicist, a direct approach, and an integrity of intellect. These personal characteristics received even further career reward in 1934 when Bell's research laboratories merged and he became Vice-President of the Bell Telephone Laboratories.

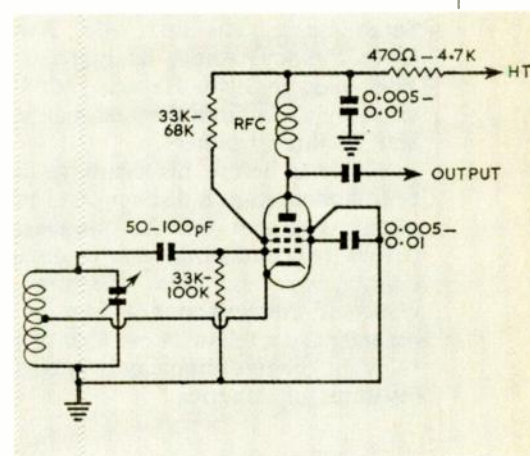
### Oscillator

The Colpitts oscillator is one of the standard circuits of electronics and has been so almost from the day of its invention. Research engineers at Bell began their development work of the new triode (De Forest's audion) and its use in circuitry in 1912 when AT&T paid De Forest \$50,000 for the right to use the triode as a telephone repeater. In 1914 they paid another \$90,000 for the radio receiver rights to the triode, marking the start of electronic circuits.

Progress was rapid in the early years. The first important circuit was the positive-feedback, or regenerative, amplifier and 1913 saw many claimants to its invention in both America and Europe. Patent litigation in America dragged on for 20 years.

But Colpitts invented one of the most famous and enduring of electronic circuits – the push-pull amplifier – on November 4, 1912.<sup>2</sup> Two years later came a circuit for producing and modulating high-frequency oscillations. This was an extension of work per-

*Early Colpitts oscillators – such as the shunt fed circuit (left) and an arrangement for use in radio receivers operating at 100MHz (right) – can still be recognised as the basis for modern circuits.*



*Hartley's oscillator was announced a month before Colpitts's in a period of rapid circuit development.*

formed by G A Campbell, also at Bell, to discover the causes of "singing" in telephone amplifiers. Then, in March 1915, came the Colpitts oscillator, a month after Hartley had revealed the circuit named after him.

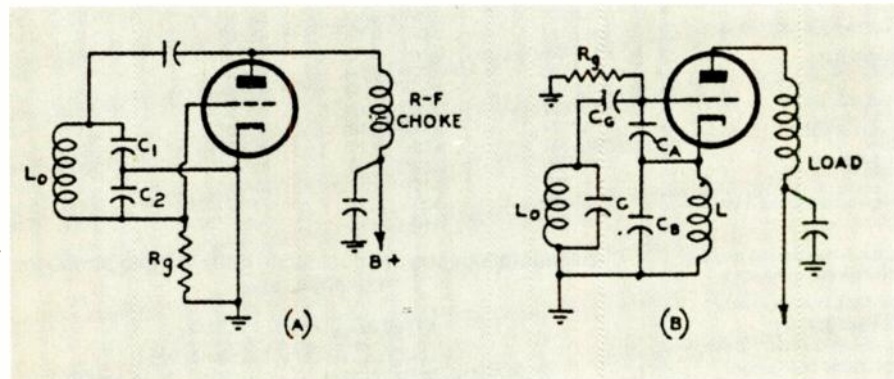
During the First World War Colpitts served on the staff of the Chief Signal Officer of the American Expeditionary Force. He spent several months in France in 1917 helping to establish a Signal Corps research laboratory.

In the Second World War he was recalled from retirement to work on submarine warfare, specifically on echo ranging systems and attack directors as "Head Technical Aide" of Division 6 of the National Defense Research Committee. For this effort, on April 5, 1948, he received the Medal for Merit, the USA's highest civilian award. The citation stated that it was for "exceptionally meritorious conduct in the performance of outstanding services to the United States from June 1940 to June 1946".

It seems ironic that before the war he had received a Japanese award, the Order of the Rising Sun, for a series of lectures he gave in Japan for the Iwaware Foundation.

In 1941 he also found time to accept the position of Director of the Engineering Foundation. This body, a joint agency of four US engineering societies, had been set up in 1914 for "the furtherance of research in science and engineering and the advancement of engineering and the good of mankind". It would seem that a man of Colpitts's calibre does not retire easily.

Colpitts died at the age of 77 at his home in Orange, New Jersey, USA, on March 6, 1949, after a lengthy illness and was survived by his second wife,



## PIONEERS

Sarah Grace. His first wife, Annie Dove Penney, whom he married in 1899, died in 1940. He was also survived by a son from the first marriage and by three brothers.

But long before his death he had been honoured as a distinguished telephone engineer of the pioneering period of continental and transcontinental wire and radio telephony, a respected administrator, holder of 24 patents, and a fellow or member of the relevant engineering and scientific institutes of America.

### R V L Hartley

No account of Colpitts's work would be complete without a mention of Ralph Hartley, who invented the complementary oscillator.

Hartley graduated from the University of Utah in 1909 to become a Rhodes Scholar at Oxford, graduating with a BA in 1912 and a BSc in 1913. He joined the laboratories of Western Electric in September 1913 and was in charge of early development of radio receivers for Bell System's radio telephone tests of 1915. By then he must

have met Colpitts who was in charge of research there. It was at this time of radio receiver design, in a period of rapid circuit development, that Hartley revealed the oscillator named after him on February 10, 1915.

During the First World War Hartley suggested that the human sense of direction is perceived by the phase difference between sound waves reaching the two ears, one set of waves having to travel further than the other. After the war his interests turned more towards voice and carrier transmission and telephone repeaters, first at Western Electric and then at Bell Telephone Labs.

Hartley is also remembered for his major contributions to Information Theory. He was the first to state the law named after him relating information to bandwidth and time: "The total amount of information which may be transmitted over a system is proportional to the product of the frequency range which it transmits by the time during which it is available for the transmission." This was first published in February 1926 although he had been working on it for several years. A fuller

account, "Transmissions of Information", was given at an international meeting in Italy in 1927 and further published in 1928. Hartley's work on Information Theory followed that of Nyquist and "provided the guiding rules for transmission engineers for 20 years" until the next major advance in 1948 when Claude Shannon included the effects of noise in the system.

In 1929, at the age of 40, illness forced Ralph Hartley to give up work and it was ten years before he could return, as a consultant on transmission problems. During the Second World War he worked on various projects, most notably on servo-mechanisms for radar and fire control systems.

He retired from Bell Laboratories in 1950, holding 72 patents, and lived with his wife at Summit, New Jersey. He died at the ripe old age of 81 on May 1, 1970.

#### References

- 1 FB Jewett & EB Craft, *Western Electric News*, April 1924.
- 2 MD Fagen (Ed), "A History of Engineering and Science in the Bell System," Vol 1, Bell Labs, New York, 1975.

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## Signal discharge

"Mains Signalling" (*EW+WW*, June 1990) detailing the application of the Philips/Sigmetics NE5050 notes the importance of the signal isolating transformer and its requirement to meet BS415. Unfortunately the Toko transformer cited is unlikely to meet this standard in both isolation and creepage/clearance.

A more suitable transformer is available from Vacuumschmelze (VAC ZKB 490/255). Experimenters should also be aware that the 1 $\mu$ F line coupling capacitor can retain an uncomfortable amount of charge when unplugged from the mains and should be shunted by a 1M $\Omega$  mains rated resistor to provide a discharge path.

In practical application the 1N4744A Zener diodes will be too slow to provide adequate protection of the IC from mains spikes and should be replaced by high speed transient suppressors such as the General Semiconductor TransZorb SA15A.

Finally the article omitted to mention the British Standard BS 6839 for mains signalling equipment.

Michael J. Meakin  
Fairford  
Glos.

## Sound quality

I was amused by Mr Baxandall's long letter in June *EW+WW* concerning testing of amplifiers (p.522). While I would not accept Martin Colloms as the only reference for deciding on quality of sound, I find much of what he says to be correct and a lot of what Mr Baxandall says to be incorrect. That is my experience after having listened to hi-fi reproduction for the past 45 years.

Despite what was said in the letter, backed up by technical theory, I can detect the difference in sound quality of various amplifiers made to his, Peter Walker's and David Hafler's criteria.

I am afraid all three are living with closed minds; measurements alone do not

## Facts not pax

I must register a protest at the increasing tendency of *EW+WW* to devote space to social and moral concerns and to the obvious anti-military bias in some comments. I have been a subscriber since 1936 and know many of my generation obtained much of their education from your journal.

But I believe that most readers, at least in the past, read *EW+WW* for technical information, not to be preached to, and it is offensive to those who at some time in their careers have worked in defence electronics. I am as proud of my

four years as a radar technician in the Royal NZ Air Force as of my subsequent career in medical electronics. Those who are worried about the wider social issues can read all they wish to elsewhere, and if they are concerned about the use of technical developments they should complain to the politicians not the engineers.

On behalf of all technophiles please keep *EW+WW* technical and leave the worrying to the social workers.

G. S. Brown  
Auckland 5  
New Zealand

determine the quality of sound.

Finally, most hi-fi consumers know that Mr Baxandall is incorrect. If not, why did Quad change from valve to transistor amplifiers (if they sound the same) and why does everybody not buy only Quad amps if there is no better as he implies?

G. Stanley  
Potters Bar  
Herts.

## Smooth sampling

I read Part 3 of your series "Interfacing with C" (p.512, *EW+WW*, June 1990 article) with particular interest, as the application examples concerned the handling of observations taken by sampling data-streams where noise may be present. I would like to draw attention to work done by R. G. Brown in his book "Statistical Forecasting for Inventory Control".

Inventory management systems require a simple, storage-economical method for deriving an average (with or without correction for trends) to be used for calculating control levels for individual stocked items. As these may run into thousands, the need to keep data storage requirements down is clear.

Exponential smoothing is one of the simplest solutions, often appearing in texts on materials management but not often in

statistics books.

In its simplest form, the technique estimates the average value of a data stream whose "smoothness" in terms of noise suppression is controlled by a single parameter. The effect is to regulate the number of past observations that will have some influence on the estimate. But it only requires that the previous value of the estimate and the controlling parameter be stored.

This "smoothing constant" has a value between 0 and 1. A preferred version of Brown's algorithm is:

New estimate = old estimate +  $\alpha$   
(new sample - old estimate).

I give below simple modifications to the coding of the two-term moving averager to convert it into an exponential smoother. This is equivalent in effect to the five-term algorithm which make the simplicity of the method clear. They are:

```
Add
#define ALPHA 0.333
Substitute
float new_input, old_average, average
then Add, immediately following.
old_average=0
Substitute
average=old_average+ALPHA*(new_input-old_average)
printf("Average o/p:%f\n", average)
old_average=average;
/*
SMOOTH DATA
.....*/
```

the last few lines replacing the SHUFFLE DATA sequence.

(For more information on smoothing constants and number of intervals in equivalent moving averages, see reference<sup>1</sup>.)

Two words of warning in the use of averaging (whether by moving average or by smoothing). First, the outcome of the process is an estimate of the underlying value of the signal being observed at a time earlier in the life of the data stream than the latest observation. In the case of a moving average, the delay introduced is half the range encompassed. If a two-term averager is implemented, the delay is one sampling interval, if five then 2.5. But the delay introduced by exponential smoothing in the kind of situation envisaged in the article, is probably not significant.

Second, I have chosen a start-up value of zero for the old average. For the kind of application chosen, this means that the average would behave like the movement of a well-damped moving-coil meter. If small alpha (high damping) is being used, then a better approximation of the likely average value should be used. Watch for under-damped movement too, either by giving overshoot or by decaying oscillations in the face of start-up, impulsive or change-of-level situations.

As an introduction to the basic smoothing technique Brown gives one as good as any I have seen. But a selection of later useful sources is also available<sup>2,3,4,5,6</sup> (the last two given are advanced).

My intention is to bring to the notice of interested readers a simple method for managing noisy data which is equivalent to taking moving averages but is programmable, in that its effect can easily be varied over a continuum without having to modify sequences of coding.

John D. Ryan  
Department of Computing  
Manchester Polytechnic.

### References

- 1 Brown, R.G., "Statistical Forecasting for Inventory Control", McGraw-Hill, 1959.
- 2 ICI, "Short-term Forecasting", ICI Monograph No. 2, Oliver & Boyd, 1964.
- 3 Lewis, C.D. (ed), "Operations

Management in Practice". Philip Allan, 1981. (Chapter 14, contributed by Lewis, gives an excellent summary of the simpler variants.)

4 Johnson, D. and King, M. "BASIC forecasting techniques", Butterworths, 1988. (This also describes the commoner techniques with example programs written in BBC BASIC.)

5 Kendall, M.G., "Time Series", Griffin, 1973.

6 Makridakis, S., Wheelright, S.C. & McGee, V.E., "Forecasting Methods and Applications", (2nd edition), Wiley, 1983.

## Heard it before

With reference to John Linsley Hood's article "Audio Preamplifier Design" (*EW+WW*, June, p.505), the circuit of Fig. 8 was first published in *EW+WW* by engineers working at Rolls-Royce in Derby.

It was later used by Naim Audio in a moving-coil head amp for Linn Products.

G. Nalty  
Derby

## Oops!

Allow me to correct one or two small errors and misprints in my "Preamplifiers" article (*EW+WW*, June).

At the beginning, p505, a hyphen was omitted from the "0.5 - 2V RMS" probable power amplifier input signal requirement, which rather changed its effective meaning.

There was also some slight confusion on p507, where  $R_1$  ( $R$  load) got mixed up with  $R_1$  while  $R_1/R_3$  appeared mistakenly as " $R_1/R_3$ ".

Finally, on p509, in talking about Quad's ingenious two-transistor head amp circuit, the text referred to microphone inputs — this should have read m.c. p.u. inputs.

J. L. Linsley Hood  
Taunton  
Somerset

## Stop hissing at VIPER

I have been very concerned about recent notices in the press regarding the VIPER microprocessor designed by scientists at the Royal Signals & Radar Establishment, Malvern, in the following respects.

First, the notions of "proof" and "verification" and how these terms are applied to VIPER have not been properly grasped by some journalists. VIPER is not "guaranteed" to be free from design errors, but its rigorous development, which has included the use of advanced mathematical methods known as Formal Methods, has resulted in a microprocessor with a higher level of assurance that errors are not present than can be given to any other commercially available microprocessor. This is a very positive, remarkable and significant achievement which is obscured if one looks at VIPER in terms of what has *not* been achieved. It's rather like the difference between the pint pot which is either half-empty or half-full depending on whether a negative or positive attitude is adopted.

Second, further work is needed in the verification of VIPER, always will be needed, and always will continue during the life of the device. Techniques, methods and tools for the formal verification of hardware and software are subjects of a great deal of interest and innovative research and development. This process has produced some very tangible and applicable results, and is ongoing. For so long, therefore, as there is a VIPER microprocessor, it will be an object of improvement.

Third, the Report of Dr. Phil Bennett of The Centre for Software Engineering Ltd., "VIPER: A Perspective", commissioned by Charter Technologies Ltd., includes some very helpful and positive statements and conclusions which have largely been neglected by some reporters in favour of some which are more sensational. The Report is only one reviewer's view of VIPER among many we have received, and opinions do diverge.

The most positive points to emerge from Dr Bennett's study, however, confirm and agree with them all, and they are that VIPER is a remarkable achievement which has advanced work in formally proving microprocessor hardware, that the VIPER proofs are not flawed, and that

VIPER is a useful device for any safety-critical application for which its performance characteristics are suited. These points, it was hoped, would emerge in press comments on the Report and it is for this reason that Charter Technologies Ltd. agreed to its release.

Last, VIPER is currently in use in a number of research projects and applications and I can categorically state that to my knowledge no problems of any kind whatsoever have been found with the chip, let alone "errors".

Digby A. Dyke  
Charter Technologies  
Worcester

## A matter of opinion

While I support the *EW+WW* policy of printing anyone's opinion on any subject, however remotely connected with electronics/engineering/science, please could you ensure that the article is written as such and not put forward as fact. I refer to the latest outburst from the "subjectivist tendency", *vis*. Ben Duncan's article, "Better CD".

The article contains various errors, and points are put forward as fact which have no scientific substantiation — proof by assertion.

Mr Duncan gives a description of the P/M 2 op amp output filter. He states, "Op amp IC101 . . . acts as an integrator to smooth the out the rapid current transitions." This is not correct.

"The next stage is plainly a Sallen and Key filter" (by which I presume he means a Sallen and Key topology with a Butterworth characteristic) is also not correct. The second stage is of Sallen and Key topology, but if Mr Duncan would care to work through the maths he would find that IC<sub>101</sub>, IC<sub>102</sub> implement a three-pole low-pass Bessel filter. They cannot be taken in isolation.

Referring to the omission of the inductor from the second stage, Mr Duncan states: "The inductor has been omitted because parasitic elements will ultimately cause a notch, . . . with accompanying step changes

in the phase and group-delay curves." What parasitics can cause such a notch? Presumably we are talking of frequencies above the 176kHz primary notch. Could Mr Duncan provide us with a frequency response plot showing these "notches"? What in the analogue domain can produce a "step" change in anything? What is the audible effect of phase and group-delay changes above 176kHz? Proof by assertion.

" . . . [An] inductor will be prone to pick up the RF fields . . . " "Will be"? We are given no figures to show what improvement was obtained purely by omitting this inductor.

" . . . [The] DAC receives and decodes offset binary, which contains the polarity code." Offset binary is unipolar. There is no polarity code, 2's complement contains the polarity code, in the MSB generally. The DAC receives 2's complement data in P/M players.

"Both op-amps are potentially operating under large-signal conditions for positive audio peaks, then approaching no-signal conditions for negative-going peaks. Consequently, a variety of distortion and error mechanisms will be non-monotonic, i.e. lopsided." The op-amps are differential devices and have no knowledge of where or what ground is, or what no-signal (in this context) conditions are. I cannot even imagine what lopsided non-monotonic distortion and error mechanisms are!

Yet again the slew rate myth has resurfaced, and the NE5532/LM833 type devices are rejected on this parameter. The slew rate of a 741 used carefully is adequate for many audio applications. If I am wrong, then perhaps Mr Duncan can provide the calculations showing that the slew rate of the NE5532 is inadequate. I suspect that if the LM833 were not made by National but by "Wonderlin Semis" or whoever, and came in a "linear crystal oxygen-free audio-grade epoxy package", then all slew rate considerations would disappear and its sonic virtues would dominate. Or



perhaps my cynicism is getting the better of me now.

There was a time when unusual or novel assertions printed in *Wireless World* were accompanied by a mathematical or other scientific analysis. I am afraid I have now lost all patience with the subjectivist tendency. Articles such as Mr Duncan's should not be presented in a journal of the standing of *EW+WW* as science fact, but consigned to the popular hi-fi press where such pseudo-science is accepted as the norm.

N. Humphrey  
Hillegom  
The Netherlands

## Critical ear

I would like to make a few comments in reply to Peter Baxandall's "Put To The Test", letter (*EW+WW*, June, p.522).

I have considerable respect for Peter's engineering abilities and would not presume to criticise his work. However, he has taken it upon himself to criticise mine.

Based on practical experience, I and my listening colleagues routinely report on significant sound quality differences and provide scales of merit on a wide variety of audio equipment. As a matter of record I have published some 2800 reviews on high fidelity equipment, the vast majority comprising both listening tests and a thorough technical lab test and analysis.

It is also a matter of record that most subjective parts of these tests are not done under unsighted controlled conditions and indeed finance for such testing is out of the question. But a significant proportion are conducted under unsighted conditions and good consistency is shown.

Peter is selective in his choice of test examples, referring to "two amplifier assessment trials". In fact, around 10 specific amplifier trials have been conducted, many in connection with published group reviews rather than as an end in themselves.

As Peter's letter has been edited I assume that the major trial I organised at an AES meeting in London in 1985 is the subject of his later statistical discussion. Peter chooses to

deny the results while the *Hi-Fi News* statistician's opinion was positive; well you could say you can prove anything with statistics!

Peter might just as well deny that a wine taster can identify the origin and the year of a good wine, or that a musician could not tell a Stradivarius from an Amati. Neither are usually subject to the rigour of blind testing yet most of us accept the views of such experts in their respective fields.

When different types of passive components are themselves a source of sound quality differences, the contention that "good" amplifiers must sound the same if operated within their limits is untenable, since commercial amplifiers generally contain very different arrangements of various kinds of components.

Subtle differences between components such as capacitors are measurable and audible, and yet are not generally included in equivalent circuits or modelled in the overall design of high fidelity amplifiers.

There is insufficient space to cover all the tests carried out, or the widespread support given by the high fidelity industry world wide, whose main interest is better sound. Does Peter Baxandall still need to imply that my subjective reporting is at best unreliable and unverifiable, and at worst, imaginary? He surely cannot think that the body of talented musicians, designers and critics all working in the quality audio field are all fooling themselves? Why is it that an expert in one field so often feels competent to give expert opinions on someone else's speciality? Consistent, perceptive subjective analysis is a vital part of the review and the design of high quality audio equipment.

Listening acuity is not a magic gift except for a lucky few. It is a learned skill which may be taught by example and improved by practice. Unsighted testing is also helpful in keeping up the standards. When Peter has as much practice and practical hands-on experience of equipment as I have, then he can demand again that I prove my published opinions.

M. Colloms  
London

## X-ray vision

Cleveland Medical Physics Unit contends (*Letters*, April, p.334) that X-ray radiation is not a potential health hazard for VDU operators. This proposition can be shown to be suspect by using their own information.

Their data shows a VDU operator receiving a dose of 10 millirems in 25 weeks. My estimate based on US National Institute of Occupational Health and Safety information gives 30 millirems.

Given that it is agreed by researchers, including nuclear industry groups, that the probability of health damage is directly proportional to the dose, then the difference in any case is not relevant. Since 30 millirems is deemed by the medical profession to pose a significant risk to pregnant women then 10 millirems can also be expected to pose a risk.

Incidentally, 10 millirems in 25 weeks is 10% of the 100 millirems that the Cleveland Medical Physics Unit states to be the background radiation in the same period, not the 1% claimed in the letter.

The theory of biological damage due to ionising radiation is unsatisfactory as it is based on the undoubtedly false premise that damage is proportional to absorbed dose of radiation. This is then used to equate the effects of very high energy cosmic radiation with lower energy radiation from X-ray and other CRT/VDU-type sources.

Apart from X-rays VDU devices produce significant radio wave energy. Crude estimates show these may exceed safety levels for such radiation adopted in the USSR, and must be added to any X-ray risk.

My contention that children and women who may become or are pregnant should not operate VDU equipment thus remains valid. Suitable safety precautions for VDU equipment should include keeping it as far as practicable from the operator, not using colour unless essential and the use of suitable shielding – or using a different type of display for computer work.

J. A. Corbyn  
Marlborough  
Wiltshire

## Misrepresentation

Far from "proposing a method for suppressing dissident authors," as John Ferguson asserts in his letter (*EW+WW*, July 1990) my letter (May 1990) aimed to engender discussion of unconventional views. My own theme for the piece had been "A forum for heterodoxy," and I suggested that it might be helpful if a panel of engineers and scientists could "study and report on" some of "the heterodox but often plausible ideas" that are aired from time to time in *EW+WW* and elsewhere.

To imply that panel members "in the mould of Sir Fred Hoyle . . . and Eric Lathwaite" would suppress dissenting views is ludicrous, especially as both these gentlemen have felt their own views have often been misrepresented or suppressed. Raymond Harrowell  
Milton Road  
Cambridge

## Tilted Cap

In the interests of my own, not to mention *EW+WW*'s reputation for accuracy, please can I correct two errors which appeared in the published version of my article Micro-Cap III under test (*EW+WW* July 1990) pp. 629-633).

On the first page, column 3, the dos editor is RPED (RaPid text EDitor) not PRED as appeared.

Also the captions to the pictures on p633 have become garbled. Both captions refer to the lower picture.

The upper picture is the DC analysis of emitter follower output stage at different temperatures.

Ben Duncan  
Tattershall  
Lincoln

## Iron curtain call

How about *EW+WW* pioneering an appeal to engineers and engineering companies to donate good surplus electronic equipment to the emerging East European countries? Imagine how many first-generation microcomputers are sitting on shelves. Jeffrey Burton  
Tunbridge Wells  
Kent

**P**hase noise largely determines the reciprocal mixing specification of communications receivers. Wide-band noise mixes with off-channel signals to produce an in-band mush which can swamp a wanted weak signal. Anything which can be done to reduce the oscillator wideband noise contribution will improve the ability of the set to resolve weak signals in the presence of strong ones.

Synthesiser phase noise is also very important in satellite communications systems. Here the phase noise figures need to be included when calculating the link budget, and poor phase noise properties in transmitter or receiver mean that higher power amplifiers or higher gain aerials are needed.

Phase noise can be critical in certain radar applications. While the basic non-coherent pulsed radar systems are not sensitive to it, other forms, such as Doppler radar, are affected, since any noise which is offset from the carrier will appear as clutter on the screen.

Since phase noise is important, it must be taken into account in the initial design stages. The synthesiser can then be made to meet its performance requirements from the outset without the need for costly and time-consuming redesign.

### Phase noise

There is always some noise present on any signal, and it manifests itself both as amplitude noise and phase noise. However, the amplitude component is usually small and has little effect, so it is normally ignored. This is not so in the case of phase noise.

Essentially, phase noise can be considered as short-term instabilities in the phase of a signal which result in the signal being phase-modulated, giving noise sidebands which stretch out either side of the signal. These sidebands can easily be displayed on a spectrum analyser, often appearing as in Fig. 1. However, in the case of a synthesiser the contour of the noise spectrum is modified from this by the action of the loop.

Since the display only shows the sidebands caused as a result of phase

# Synthesiser noise

The phase noise characteristic of frequency synthesisers is a fundamental design parameter. It greatly affects the performance of the complete system.  
By Ian Poole.

modulation, they can be assumed to be symmetrical either side of the signal. At this point it is worth noting that if a carrier is modulated in both amplitude and phase by a signal, the amplitude of the resultant sidebands will not be of the same amplitude either side of the carrier. When the sidebands are symmetrical, it means that it is only necessary to measure the level of one sideband. Generally this is measured in terms of dBc/Hz - i.e., the power in a 1Hz bandwidth relative to the carrier at a given frequency offset.

Alternatively, phase noise can be considered in terms of integrated phase jitter and measured in RMS radians. Although this approach is not used as often, it is sometimes more convenient, particularly if phasor calculations are to be performed.

### The loop and noise

Noise is generated by every element in a synthesiser loop, but the way in which the noise is seen at the output depends on where the noise is generated. This means that the overall loop noise is the sum of the noise from a number of different sources, each making contributions to a greater or lesser degree at different frequency offsets from the carrier.

To illustrate the ways in which noise from different parts of the loop affects the output, take two examples: the reference and the voltage-controlled oscillator. First, look at the reference. Figure 2 shows that the signal, with its noise, enters the phase detector, the noise from the signal appearing at the output of the detector and then enter-

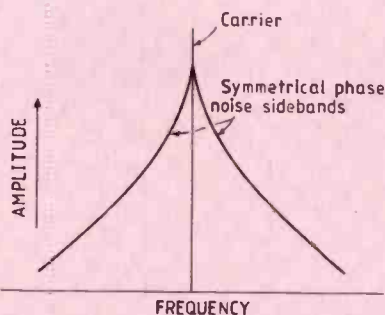


Fig. 1. Phase noise causes phase modulation, which gives noise sidebands on either side of the carrier.



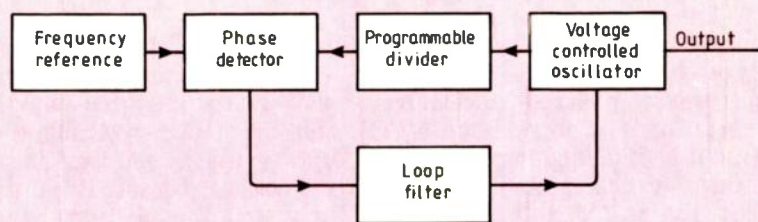


Fig. 2. Basic phase-locked loop. Noise from the reference appears at the output if it lies within the loop bandwidth, that from the VCO being reduced.

ing the loop filter. Here any noise which falls below the loop bandwidth (the point where the loop gain falls to zero) will not be attenuated, but any above this frequency will be. Any noise at the output of the filter will appear at the control terminal of the VCO and be modulated onto the output signal, so that noise from the reference will only appear on the output if it is within the loop bandwidth.

The result of noise generated by the VCO itself is different. Again, the noise will pass through the loop filter if it is within the loop bandwidth. This time it has the effect of counteracting the phase noise generated by the VCO, but this can only occur within the loop bandwidth. As a result, VCO-generated noise is reduced within the loop bandwidth, but remains unaltered outside it.

Similar arguments can be applied to any element in the loop, showing that noise from the phase detector, dividers and any other signals mixed into the loop appear within the loop bandwidth.

Using this information it is possible to build up a picture of the noise contour of the synthesiser. Generally the output from a synthesiser will look like that in Fig. 3, but to apply this to the design of the synthesiser it is necessary to take a closer look at each element in the loop.

**Voltage-controlled oscillator.** The noise performance of the VCO is particularly

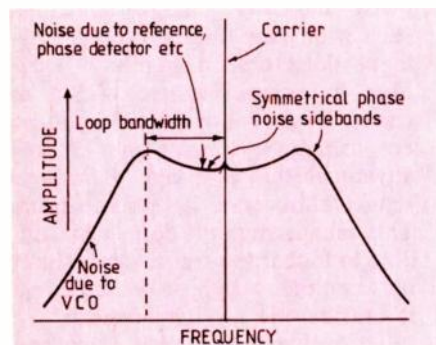


Fig. 3. Typical noise contour from the output of a synthesiser.

important because the performance of the synthesiser outside the loop bandwidth is governed by it. Furthermore, decisions about the loop bandwidth, and even sometimes the phase detector comparison frequency, may depend on the performance which can be obtained. Figure 4 shows a typical VCO noise performance; at large offsets from the carrier the noise is flat; closer in towards the carrier it rises. Initially the slope is 20dB/octave, increasing to 30dB and more, closer in.

As part of the design function, it is necessary to assess the actual noise performance of the oscillator. A number of ways exist to do this, of which probably the simplest is to place the oscillator in a loop having a bandwidth

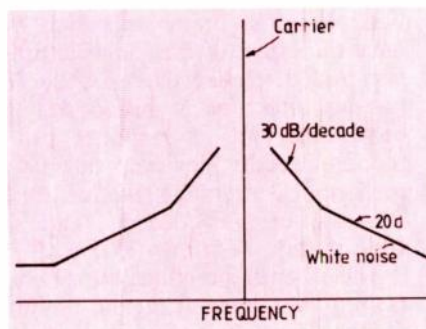


Fig. 4. Noise performance of typical VCO.

much narrower than that of the synthesiser in which it is to be used. The VCO frequency can then be held constant while standard analyser techniques are used to plot the response. The drawback of this method is that the noise plot obtained is only valid at frequencies greater than the loop bandwidth.

**The reference.** The noise performance of the reference or frequency standard follows the same outline as that of the voltage-controlled oscillator, but its performance is considerably better. There is a number of reasons for this, principally because the Q of the quartz

resonator is very much higher than anything which can be obtained in the voltage-controlled oscillator.

It is not particularly difficult to achieve figures of  $-110\text{dBc/Hz}$  at 10Hz offset and  $-145\text{dBc/Hz}$  at 1kHz. Although a crystal standard with this performance would be satisfactory for many applications, it may be necessary to have lower noise versions if very large figures of multiplications are required in the loop, together with a very clean output. In cases like these it is possible to obtain oscillators which may be better by a factor of 10dB or more, but they are very costly.

**Phase detectors.** Phase detectors come in many different forms using several basic circuit configurations. Even so, they can be split down into analogue types using mixers as the basic element, and digital types using logic circuits in any one of a number of configurations. It is possible to analyse the noise performance of the phase detector mathematically<sup>2</sup>. If this is done an idealised characteristic can be obtained. Usually this is found to be relatively flat away from the carrier, rising as the frequency falls. This will result in the noise contribution of the phase detector rising close in to the carrier.

**Frequency divider.** Divider noise appears within the loop bandwidth, along with the reference and phase detector noise. Normally, its level is such that it is masked by the noise from the other sources and it is ignored. But it should not be totally forgotten.

Unfortunately, divider noise can be difficult to estimate because manufacturers do not specify figures for their devices. The only real solution is to measure the noise itself, remembering to take a number of samples of the device. In common with the phase detector, c-mos and TTL are much quieter than ECL. Another point to remember is that, as the frequency is being divided, the earlier devices in the chain will have less effect than the later ones.

**Loop response.** In addition to the loop bandwidth itself, the overall response of the loop is important to the noise performance. This, too, is determined by the characteristics of the filter.

Whatever type of filter is used, the basic requirements for loop stability mean that the loop gain must fall at 20dB/decade (6dB/octave) or less at the unity loop-gain point. Provided this

point is met, a large variety of filters can be employed, but the form of filter, its response and break points must be known. This will affect the rate at which noise components will be attenuated either side of the loop unity-gain point.

**Effects of multiplication.** Since noise is generated at different points around the synthesiser loop it is necessary to relate each source of noise to the output of the VCO. It has already been mentioned that the loop response will affect this by allowing noise from different parts of the loop to affect it at different offsets from the carrier. In addition to this, the multiplication factor (i.e., the ratio of the final output frequency to the comparison or phase detector frequency) must also be taken into consideration.

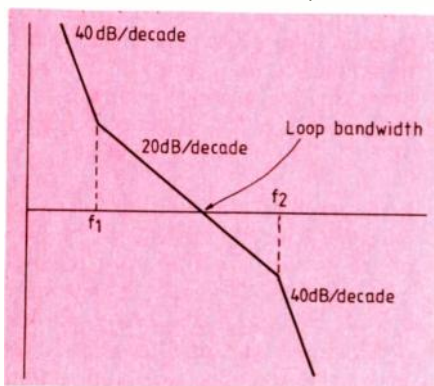
The effect of multiplication is very important because the phase noise is markedly degraded when a signal is multiplied. Phase noise is degraded by a factor of  $20\log_{10}N$ , where  $N$  is the multiplication factor.

Phase-locked loops are, in essence, just programmable frequency multipliers and so some of the noise sources within the loop will be affected by this. Not only is the noise of the reference multiplied by this factor, but so is the noise generated by the phase detector.

## Overall performance

Having looked at the noise contributions of each element in the loop, and also the response of the loop to those sources, their overall effect can now be analysed. This can be done mathematically, but it is usually easier and sufficiently accurate to plot the results. This approach gives a pictorial view which quickly highlights the possible problems and determines the overall response.

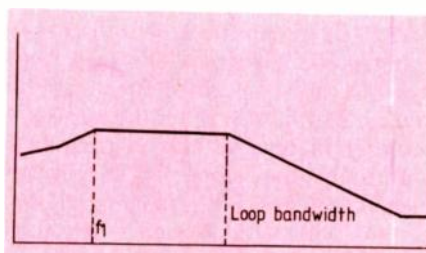
The first step in this approach is to



**Fig. 5. Loop response, showing filter break points.**

plot the loop response (Fig. 5). To do this a knowledge of the filter break points will be required, but they can easily be obtained from the loop design requirements or initial calculations. The next stage is to add the VCO noise; outside the loop bandwidth it is unaffected by the loop, but once inside the loop bandwidth its effect will be attenuated by the loop, first at a rate of 20dB/decade. Further in towards the carrier, as the loop gain increases it will be attenuated at a rate of 40dB/decade. However, to counteract this, the VCO noise increases. The overall effect is shown in Fig. 6.

Having done this, the effect of the reference can be plotted. To do this the



**Fig. 6. Overall effect of VCO noise, attenuated by the loop inside the loop bandwidth.**

basic response of the reference must have the effect of the loop multiplication added. Unlike the VCO the loop has no effect on it inside the loop bandwidth and its response can be plotted directly. However, outside this the loop will attenuate its effect, first at the rate of 20dB/decade, and then 40dB/decade as shown in Fig. 7.

The other major contributor to noise is the phase detector; again, the effect of the loop multiplication must be added. Then it can be plotted in the same manner because the loop has no effect inside the loop bandwidth, but attenuates the noise outside it. Figure 8 shows the effect.

When combining each of the curves to produce an overall figure it is necessary to calculate the RMS sum of the individual contributions, because the noise sources are uncorrelated. Once this has been done, a full picture of the expected noise performance can be realised. It is then possible to optimise the loop bandwidth within the other design constraints to give the best noise performance. If this does not produce suitable results then parameters like the reference frequency, multiplication factor and even the number of loops within the synthesiser can be altered so that the performance specification is

met.

## Noise reduction

An analysis of the synthesiser noise will show that of the three major contributors the frequency standard or reference is usually the least important to the designer because it is often bought in as a ready-made item. Improving its performance is normally a matter of specifying a better item. But the VCO and phase detector are not so easy. They are at the heart of the synthesiser and their design often determines whether the synthesiser as a whole is a success or not. This means that their design and optimisation is of great importance.

## Phase detector noise

It has already been shown that the phase detector noise can have a very significant effect on the synthesiser noise performance within the loop bandwidth. This is particularly true where there is a large divider in the loop and the VCO is operating at many times the phase detector comparison frequency. There are three main causes of noise in a phase detector: noise due to the basic noise floor of the detector itself; noise arising from the deadband effect; and noise resulting from imperfect decoupling and isolation. Each of these causes will be analysed in turn and suggestions made for improving them.

**Noise floor.** Any phase detector will have a certain amount of thermal noise associated with it. Generally, the levels of noise are very low but, in view of the multiplication effect of the loop, they can become quite significant. The noise is generated from thermal noise in the resistive elements as well as shot noise in the active devices. When considering phase detector noise, contributions from any amplifiers in the loop filter circuits should not be forgotten.

There are two different types of phase detector, analogue and digital, each with their own advantages. Analogue detectors are generally used at high frequencies where digital ones cannot be used. Digital phase detectors are usually less noisy and have the advantage that they can be frequency-sensitive as well as phase-sensitive. This means that the loop will still be able to lock if the frequency difference between the two phase detector signals is outside the loop bandwidth.

To optimise the noise performance of an analogue mixer, correct setting of the input levels to the mixer is essen-



tial. Ideally, the signal on the local oscillator input should be close to the "specified" level and the level on the signal input should be close to the maximum specified. In this way the best possible signal-to-noise performance can be achieved.

In the case of digital phase detectors the actual family of detector can have a marked difference. Edge-triggered

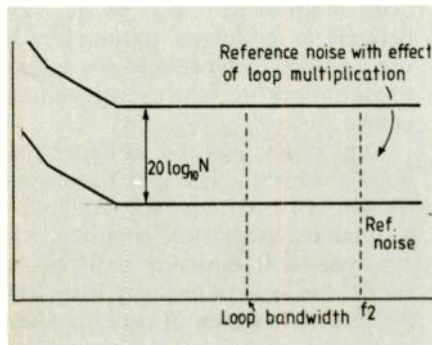


Fig. 7. Reference noise, which is not attenuated by the loop inside its bandwidth.

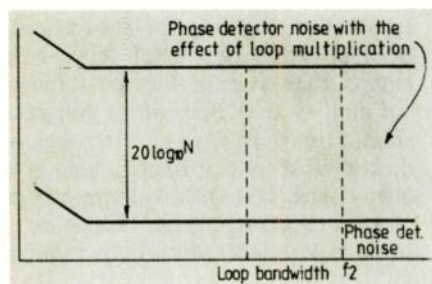


Fig. 9. Noise from phase detector, with multiplication.

detectors, like the dual D-type shown in Fig. 9(a), have a better noise performance than the simpler exclusive-Or versions shown in Fig. 9(b). On top of this the logic family has a marked effect. With its high current consumption, ECL proves to be the noisiest; after ECL, however, the other logic families are surprisingly similar. TTL, with its large switching spikes, should be avoided, as the spikes are likely to introduce noise into other parts of the circuit. The best type of device to use is one of the families of c-mos now available.

Finally, the noise contribution from any amplifier used as part of the loop filter must be considered. The noise from this amplifier can generally be reduced to acceptable levels by simply using low-noise devices together with standard audio noise-reduction techniques.

**Dead zone noise.** The digital tri-state type of phase comparator is probably

the most common type in use, and it has several advantages which make it an ideal choice for many applications. A typical circuit contains two D-type flip-flops and a Nand gate. There are also several IC versions available as phase detectors in their own right or as part of synthesiser ICs. These circuits are more complicated but offer extra facilities, such as lock detectors and the like.

The operation of the basic dual D-type detector is fairly straightforward. The flip-flop outputs go high on the leading edge of the signal of the clock input; once both flip-flops are high the Nand gate resets both D-types and the process repeats. The mark-space ratio on the outputs represents the difference in phase between the two signals, which can easily be converted into a tune voltage with a little extra circuitry.

This type of phase detector normally works very well. It has the advantage over some types of detector that it is frequency- as well as phase-sensitive, so the loop will still lock if the frequency difference of the two comparator signals is outside the loop bandwidth. This is not so if an analogue or mixer type of detector is used.

The main disadvantage of this type of detector is seen when the system has settled and the loop is in lock. Under these conditions the detector generates noise because of what is called the dead zone. The noise occurs because large changes in detector gain occur when there is no change in tune voltage and there are no leakage currents. In this state the pulses coming from the detector tend to zero, giving zero detector

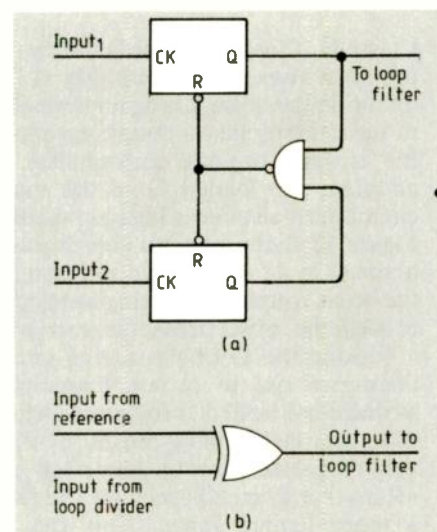


Fig. 9. Dual D-type edge detector (a) offers better noise performance than ex-Or type shown at (b).

gain.

The easiest way to overcome the problem is to add a small amount of leakage into the system. In a current-driven system this can be accomplished by placing a large-value resistor from the tune line to zero volts. Although this takes the phase detector out of the dead zone, it does have the effect of raising the level of the sidebands due to the phase comparison frequency. This results because of the increased energy required from the phase detector pulses, which can be reduced by improving the filtering in the tune line.

Another way is to introduce a small delay into the reset line for the two D-type flip-flops (Fig. 10). This delay should be small, but a little larger than the reset times for the flip-flops.

**Decoupling and isolation.** The physical layout of the phase detector and the decoupling on the supply rails can have a marked effect on the noise perform-

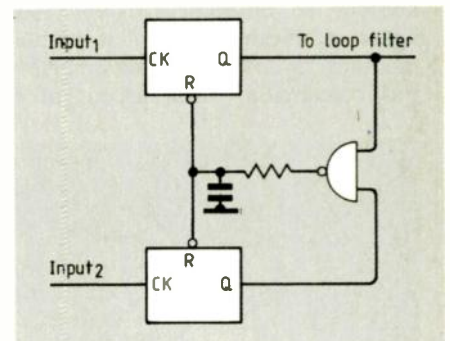


Fig. 10. Small delay in reset line to the D-type flip-flops avoids problem of "dead zone" in loop.

ances of a synthesiser. Even small amounts of crosstalk, by transmission along supplies or by pickup, can degrade the performance quite noticeably. Fortunately there is a number of general guidelines which can be followed to ensure the best performance is achieved.

The obvious first step is to add supply decoupling to any integrated circuit in the phase detector – and for that matter in the whole of the synthesiser. However, in the phase detector it is particularly important. Because of this the decoupling capacitor should be placed directly across each IC, as in Fig. 11. The connections should be made to the supply and 0V pins by the shortest route, and not to the supply rail and earth plane, which could lead to cross coupling of noise from other ICs. The capacitor type and value should obviously be chosen to give the optimum performance, but it is also

worth considering the use of a small-value series resistor or choke to improve the performance still further.

When using phase detectors like the dual D-type ones containing several logical function blocks, it is advisable to use separate packages in each case. This reduces noise from crosstalk between different areas of the phase detector.

Finally, care should be taken in the layout to ensure that the two input signals are kept separate and do not interact. This can be done by physically separating the two lines, or using some form of screening in extreme cases.

## Oscillator noise

The noise performance of an oscillator can vary quite widely between one design and another. It is an area where major reductions in noise can be made if the circuit is designed correctly. The implementation of the circuit is also very important.

Noise in an oscillator arises for a number of different reasons. Noise figure and thermal noise play an important part, as do flicker noise and AM to FM conversion. Each aspect of the

contribution to the final noise contour of the oscillator has to be analysed and addressed in turn if the best performance is to be obtained.

**Far-out noise.** At very large frequency offsets from the carrier, flat or white noise predominates. Although the level of it is normally well down on the carrier, it can still present significant problems in some instances. For example, some co-sited transmitter and receiver systems may run simultaneously and will require low levels of far-out noise as well as close-in noise to prevent interference.

This far-out or white noise depends on factors like the noise figure of the oscillator and any amplifiers. There are two approaches to its improvement. The first and most obvious is to improve the noise performance of the oscillator by reducing the noise floor. To accomplish this a low-noise active device must be used, and must be run under optimum noise performance conditions. One major area which must be considered is in ensuring the correct input match is achieved for the device.

The second approach is to increase the power level of the oscillator. As the noise floor of the system will remain roughly the same, a significant increase in the signal-to-noise ratio can be achieved. In theory this method works very well, but there are a number of pitfalls. The main one is that at high levels there is a much greater tendency for spurious signals to be generated. In addition, there is an increased likelihood of different modes of oscillation arising across the frequency range, resulting in discontinuities in the tuning.

**Closer in.** Closer in towards the carrier the noise rises, as shown in Fig. 4. To minimise the noise it is again necessary to have the oscillator circuit optimised for its signal-to-noise performance. In addition, the loaded Q of the tuned circuit must also be as high as possible. Figure 12 shows how an improvement in the Q by a factor of two will result in the break frequency  $f_b$  being brought in to half the offset from the carrier.

Raising the Q of the tuning circuit does give rise to certain limitations. Voltage-controlled oscillators which have very large tuning ranges, by their very nature have low Q; conversely this means that a high-Q oscillator will have a more limited range. This can be overcome in many instances by switching elements within the oscillator, or switching between different oscillators

to achieve the desired range. Although this solution is not the most easy to implement, it does have the advantage that it can be used as a form of steering if this is required.

**Flicker noise.** Still closer in towards the carrier the noise rises at a higher rate: 30dB/decade or 9dB/octave. This is due to flicker or 1/f noise, present on any oscillator and with effects that cause both amplitude and phase noise because it modulates parameters like the transconductance and the junction capacitances in the semiconductor device.

This noise can be reduced in a number of ways. The first is to increase the level of low-frequency feedback. In a standard transistor circuit a small un-bypassed emitter resistor can reduce the level of noise by 10 or 20dB. Similarly a low base or gate impedance should be used for low frequencies to further reduce flicker noise.

The choice of device is also important. In theory, fets are supposed to give a poor flicker-noise performance. In practice, this has not been found to be true and they often give better results than normal bipolar devices.

Finally, the operating conditions should be adjusted to give the optimum flicker noise performance. This is not always easy as figures are rarely provided in manufacturers' literature, so some experimentation will be required.

**AM to PM conversion.** In many oscillators AM to PM conversion mechanisms can give a major contribution to phase noise. The mechanism arises because amplitude modulation of the oscillation from a number of sources modulates the internal capacitances within the active device.

Reduction of this noise can take two forms: the first is to ensure that capacitance changes in the circuit cancel one another out; and the second is to ensure that amplitude modulation does not occur. One major cause of this noise arises from poor or ineffective supply line smoothing. In some instances people have used two regulators solely for the oscillator; while this may be an extreme, a single regulator just for the oscillator together with a simple filter to remove the last remains of any noise or spikes is certainly advisable.

**Choice of active device.** Some mention has already been made of the choice of active device within the oscillator. However, it is still worth summarising some of the required characteristics.

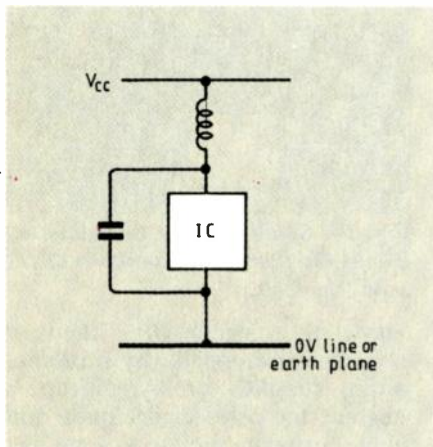


Fig. 11. Decoupling must be placed directly across IC pins to avoid crosstalk. Addition of small choke may also improve matters.

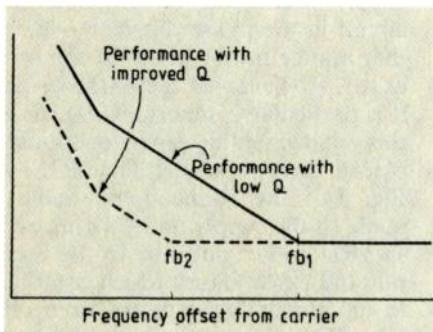


Fig. 12. Reduction in break-point frequency  $f_b$  by increasing tuned-circuit Q.



First, the device should possess a low noise figure. On top of this, careful consideration should be given to matching the impedances for the optimum noise performance. A choice also has to be made between the use of a bipolar device or a field-effect one. Bipolar transistors are often used and perform well, but j-fet devices can give improvements. One reason for this is that the real part of their input impedance is very high and this reduces the loading on the tuned circuit. Additionally, j-fets have a good noise figure, due in part to the very low input noise current.

**Physical restraints.** Screening can have a marked effect on performance. In essence, an oscillator is a very high gain amplifier, so even a small amount of pickup can be reflected in a marked degradation in noise performance. Accordingly, screening of the oscillator is essential in every case.

Earth-plane layouts can also change the performance. If relatively large currents are flowing in the earth plane, they can lead to a certain amount of pickup in the oscillator. To overcome

this problem, large currents can be routed along different tracks. An alternative is to section a portion of the earth plane off for the oscillator by making an "island", which can be connected to the main earth plane by a single track. In this way large currents will not flow across the earth plane for the oscillator.

Microphony can be a problem, particularly in mobile applications. To overcome this, mechanical rigidity is of the utmost importance. Coils should always use formers, and the wire should be secured to the former to prevent any movement. Also, all components should be firmly mounted onto their boards. Where printed lines are used in the oscillator the board must not be allowed to flex. The board can be strengthened, and possibly the screen could be used to fulfil this function as well. Alternatively, a thicker board can be used, although this is not always the ideal solution because thicker boards are not standard and require the use of larger tracks for transmission lines of a given impedance.

Summary

Although a rigorous mathematical approach can be used to predict the noise performance of a synthesiser, this graphical approach has the advantage that it gives a relatively quick prediction. It is also easy to interpret and can be easily modified to show what result any modifications to the synthesiser might produce.

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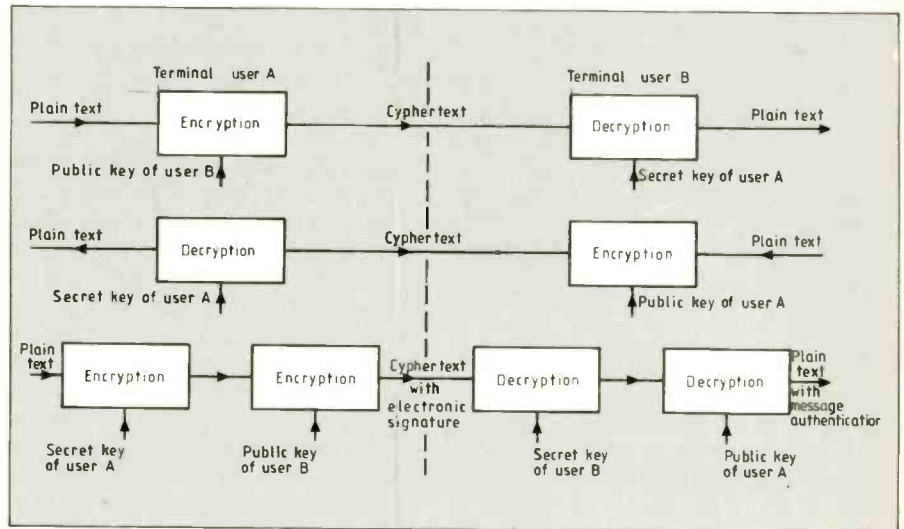
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# Attacking RSA public-key cryptosystems

In an item entitled "Defeating hackers" (*EW+WW* January 1989, p97), I noted that the success of an international group of computer scientists, organised by Arjen Lenstra of the University of Chicago and Mark Monasse of the DEC Research Centre, who factored a 100-digit number into two large prime numbers using the free time of some 400 computers in parallel, represented a potential threat to the security of the RSA (Rivest-Shamir-Aldeman) public-key (two-key) cryptosystem.

RSA has survived, while a number of other public-key systems have been shown to have inherent weaknesses that make them vulnerable to skilled cryptanalysis. RSA is still widely regarded as computationally secure, provided that a large number of digits are used in the keys. It is increasingly being used for sensitive communications and for financial transactions.

As R.J. Read has pointed out (*Electronics & Communications Engineering Journal*, November/December 1989, pp263-270), "Computer processing is becoming so powerful and fast that the  $2^{56}$  combinations offered by the 56-bit



**Basis of public-key (double-key) cryptosystems, with double-encryption providing message authentication. Public keys can be widely published, but the secret key is known only by the user. No key distribution is needed.**

key of the DES system (standardised by the American National Bureau of Standards in the 1970s) may well soon, if it has not already done so, render DES insecure. A possible replacement for DES, already used in the electronic

funds transfer at point of sale UK system, is RSA.

"RSA requires two separate keys: a public key and a secret key. This system overcomes any need to distribute the secret keys used for decrypt-

## The declining phase of solar cycle 22

It now seems virtually certain that the peak of solar cycle 22 was reached in the autumn of 1989. Unless this cycle exhibits an unusual double-peak of high solar activity, we can now expect activity to decline steadily (though less steeply than during its rise in 1987-88) until about 1994.

Maximum levels of solar activity seem to have been increasing gradually (although not consistently) over the past 400 years, but both the duration and amplitude of future cycles have so far proved impossible to predict accurately. In *EW+WW*, August 1988, I noted, "The extreme difficulty of making accurate medium- and long-term predictions of optimum frequencies has long haunted HF broadcasters - particularly during the early years of a new solar cycle, owing to the large and unpredictable variations in the maximum magnitude of successive cycles. Cycle 22, now recognised as having begun in September 1986, has seen activity rising rapidly in fits and starts. It now seems likely to rise to record or near-record heights despite a number

of earlier predictions that this cycle would have a low maximum".

The item drew attention to the belief of Dr Geoffrey Brown (University College of Wales, Aberystwyth) that, by basing his prediction on the number of abnormal quiet days (AQDs) during the declining period of Cycle 21, he could forecast that Cycle 22 would have a high peak sunspot number of  $174 \pm 35$ , with a maximum in  $1990 \pm 1$ . He had found the relationship between AQDs and the magnitude of the following peak to hold good back to 1885, the earliest year for which data is available. In practice, this forecast seems to have proved accurate, with monthly sunspot numbers in late 1989 around the very high figure of 180, making it the second highest peak on record.

Furthermore, as T. Mathews and D. Venkatesan (University of Calgary, Canada) have pointed out (*Nature*, 14 June, 1990), the second half of 1989 experienced a unique series of increases in cosmic-ray intensity reaching the Earth due to solar flares,

representing the most intense particle production by the Sun since continuous monitoring of cosmic-ray activity by neutron detectors began in 1957.

Peak periods of solar activity are not marked only by greater numbers of sunspots and solar flares but, as a consequence, by extreme ultra-violet (UV) radiation, X-rays and protons, and by geomagnetic storms on Earth. Normally we are well protected from the high-energy particles, but it has been claimed that the levels experienced in the final months of 1989 were such that there was a potential hazard to passengers in aircraft flying at heights of 10 to 15km, as well as in spacecraft. Whether the depletion of the ozone layer could increase the number of high-energy and UV particles reaching the ground to hazard levels, if the peaks of solar activity continue to rise, is still a matter of speculation.

Dr Douglas Gough (University of Cambridge) has noted (*Nature*, 28 June, 1990), "Observations have long revealed that the Sun is an oscillating body. There is an expectation that its oscillation frequencies may change in



tion. The keys exist in pairs, but knowledge of the public key gives no indication of the secret key. Hence the public key, as its name implies, may be widely published. The sender uses the receiver's public key to encrypt the message for transmission. The resulting cyphertext cannot be decyphered by knowledge of the public key alone. Only the receiver is able to decypher the message by using his secret key."

The security of RSA depends essentially upon the practical computational impossibility of factoring very large numbers. As a public-key system it overcomes completely the major problem of key distribution of DES and other established cryptosystems. The disadvantage of RSA is that, until recently, it has been very much slower to encypher and decypher traffic than with DES. R.J. Read, however, has pointed out that the speed of encryption with current ICs is increasing to the point where the speed of RSA can now be comparable with DES.

A further significant advantage of RSA is the ability to establish "authorisation" by positively identifying the sender from his "electronic signature". For this the sender encrypts the plaintext using both his own secret key and

the receiver's public key.

As noted in my January 1989 item, 100-digit key numbers for RSA were regarded as computationally secure, but following the work of Lenstra and Monasse, it was recommended that at least 150 digits should be used, since this would require 100 000 times more computer power to factorise than a 100-digit number.

However, Lenstra and Monasse have continued with their project. *Nature* (28 June, 1990) has now reported their success in factorising into three prime numbers one specific form of 155-digit number ( $2^{512} + 1$ ) using 1000 linked computers and six weeks of computational time, based on a mathematical procedure invented by the British mathematician John Pollard.

While Pollard himself believes that this success does not imply that 150-digit RSA keys are no longer to be considered computationally secure, since the work covers only one form of number, Monasse now believes that \$200 million would buy enough computer time to crack any 155-digit number in a year. "It is possible that the ability to factor a new class of numbers up to 155 digits may weaken other types of numbers," he claims.

parallel with the solar cycle, but a lack of long-term data has led to diverse and ambiguous conclusions. . . . The 11-year cyclic variation of magnetic activity, first seen as a change in the sunspot coverage, is the most obvious manifestation of solar variation. Although the cycle has been the object of continued quantitative investigation since the pioneering statistical analysis of G.V. Yule (*Phi Trans R Soc*, 1927) more than 60 years ago, we still do not understand its origin".

### Sunspots, solar cells and vandals

The effect of solar activity on satellite solar-cell power supplies is of considerable practical importance. With conventional silicon photovoltaic cells, the output of a solar panel is likely to reduce to about 70% of its initial value during an average seven years in space, with the highest rate of degradation during the peaks of solar activity. Cells based on gallium arsenide (GaAs), and even more so on indium phosphide (InP), have significantly higher resistance to solar radiation, though both are more expensive to fabricate.

GaAs solar cells are in limited production by EEV at Chelmsford. InP cells have been flown in the US Navy's LIPS3 satellite and more recently in one of the University of Surrey's small experimental/amateur-radio satellites. InP cells have been under development for several years at Newcastle-upon-Tyne Polytechnic and have been tested for radiation resistance at RAE Farnborough.

Although the powering of terrestrial low-power television transmitters has made little progress in the UK since the IBA-BBC experiments in the early 1980s, based on the use of combined wind-solar generators, RAI in Italy has built up more than 12 years of experience in the use of photovoltaic generators for rebroadcast stations. The original plastic-sheet covering of the panels has been abandoned due to reduction in transparency caused by UV radiation and damage by birds. Now the silicon cells are housed in a highly transparent tempered-glass shell, covered in turn by an ethylene-vinyl-acetate weatherproof coating which also helps protect the cell from UV radiation.

## EMC and 1992

The DTI is continuing its efforts to prepare industry to meet the stringent requirements of the far-reaching European Community's EMC Directive No 89/336/EEC, due to come into force on 1 January, 1992. All apparatus which is liable to cause electromagnetic disturbance, or the performance of which is liable to be affected by such disturbance, comes within the scope of the Directive.

All EM frequencies are covered, as are all EM phenomena, although manufacturers have a choice of complying with the relevant harmonised EMC standards or meeting the "essential requirements". Most firms are expected to choose the standards route, as this can be self-certified for equipment other than telecommunications terminal equipment and radio transmitters. The only exempted products are those subject to other directives, and self-built amateur radio equipment.

In October 1989, the DTI issued some 15 000 copies of a 24-page consultative document, "The implementation in the United Kingdom of Directive 89/336/EEC on electromagnetic compatibility", inviting comment. Several hundred responses were received, including a number from trade associations on behalf of their members. Three main causes of concern were expressed.

**Scope.** There was much support for the proposal that components and installations be exempted. It was also felt there should be a "grandfather clause" exempting existing product lines for a number of years. As it stands, the directive applies to all production leaving a factory after implementation of the directive, regardless of whether the design predated this. Some makers believe the cost of testing and redesigning would make existing products uneconomic.

**Standards.** There was concern that the UK standards would not be available soon enough. It was felt there should be a specified period between the adoption of a standard and its coming into force.

**Test facilities.** There was concern at the projected shortage of independent UK test facilities, and it was felt that manufacturers should be able to apply for "competent body" status.

*RF Connections is written by Pat Hawker*



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The programmer comes with an interface card that plugs into any free slot of your PC. There is no DMA channel to worry about and it occupies limited I/O space. The programmer socket box is connected via a ribbon cable to the back of the interface card so that the socket box is external. After the interface card is installed the PC never need be opened again.

## SOFTWARE DRIVEN

All software for the programmer is supplied on 5¼" low density disk. The software can be copied onto hard disk using the DOS copy command. Programs are supplied for the various features and are menu driven. All programming is done from the menu, no hardware switches are needed. Just select the type and manufacturer and the programming is done automatically.

## SUIT ALL PC'S

The programmers will run on any compatible IBM machines such as XT's, AT's, '386 and '486. Whether it be AMSTRAD or COMPAQ the programmers will work. The software is text only monographic so is compatible with any machine.

## FEATURES

The menu driven software is a full editing, filing and compiling package as well as a programming package. Save to disk and load from disk allows full filing of patterns on disk, to be saved and recalled instantaneously. Device blank check, checksum, program, verify, read and modify are all standard features. Hex to bin file conversions included for popular file formats including Intel, Motorola etc.

## MODELS

### PC84-1, -4, -8

Eprom programmers only. The variant is only gang size. The -4 and -8 gang will program multiple EPROMs simultaneously. Device sizes are from 2716 to 271000 both C and NMOS. ZIF (zero insertion force) sockets are used, as with all models.

### PC83

PAL programmer only. Will program most 20 and 24 pin types including the 16 L, R, X and 20 L, R, X4, 6, 8 and 10.

### PC82

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A unique feature is the testing of logic parts such as 74LS393 etc. The PC82 can check and identify parts. Already programmed is the TTL test vectors and software is supplied to write vectors for any unique chip.



## DEVICE GUIDE

	PC84	PC83	PC8
EPROM 2716, 32, 64, 128, 256, 512, 1024 Vpp 12.5, 21, 25	✓	—	✓
EPROM 27C16, 32, 64, 128, 256, 512 1024 Vpp 12.5, 21	✓	—	✓
EEPROM 2816, 16A, 17, 17A, 64A, 256A	✓	—	—
Selection of speed algorithm fast, intelligent etc.	✓	—	✓
Byte splitting for 16 and 32 bit files.	✓	—	✓
BPROM 32x8 TO 406x8 63S08C, 7C28X, 7C29X	✓	—	—
MPU 8748/49/50/51/C51/52/C252 inc. Encryp, lock bits	✓	—	—
PAL 10, 12, 14, 16, 18, 20, L, R, X, P, 2, 4, 8, 10(20&24 pin)	✓	✓	—
CMOS EPAL C16L8, R8, R6, R4	✓	—	—
EPLD 20G10, 22V10	✓	—	—
Industry Standard JEDEC Files	✓	✓	—
Device testing TTL, CMOS, & SRAM	✓	—	—
Self test.	✓	—	✓
Hardware config. available for software design.	✓	✓	✓

## PRICE LIST

PC84-1 1 Gang Eprom	£139
PC84-4 4 Gang Eprom	£199
PC84-8 8 Gang Eprom	£299
PC83 Pal Programmer	£275
PC82 Universal Programmer	£469

All pricing includes software, interface card, socket box and full instructions.

(Prices do not include VAT or carriage)

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## TTL, CMOS, DRAM & SRAM TESTING

PC82 can test and verify any TTL/CMOS logic chip, DRAM & SRAM. The software will also identify a TTL chip. Do you have a few TTL chips aside not knowing whether they are working?

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