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Teaching women a lesson

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First the good news. Secretary of State for Education John MacGregor has wrested a further £500 million from the Treasury to shore up the education system.

The bad news is that funding isn't a complete answer to the malaise which runs through schools and colleges.

Girls want to be vets, doctors and lawyers. Boys expect to be lawyers, doctors and vets. Hardly anyone – with the exception of overseas students – considers engineering as a worthy profession.

College lecturers working in electronics and engineering departments will tell you that their immediate problems aren't connected with funding. This wasn't always the case. Economic constraints have forced closure. The Physics Department at Bangor was compelled to auction its equipment and close down its activities. UMIST, with a worldwide reputation for engineering technology transfer, a powerhouse of innovation, had to implement savage cuts. Even so, courses in physics, electronics and engineering remain unfilled.

The same university teachers will tell you that UK course students who do apply for engineering courses habitually lack a proper foundation in basic maths; they seldom possess an appreciation of calculus for instance. Overseas students – typically around 25 per cent of intake – seem better equipped.

The basic education received in Hong Kong, Singapore and other Far Eastern countries provides an apparently excellent grounding for an engineering degree. This student sector takes a disproportionate number of Firsts and Upper Seconds even though, in the opinion of their teachers, the sector's basic aptitude is no greater than the British counterpart. In the words of one lecturer, it is simply that the British students "like to spend more time in the bar."

Female engineering undergraduates are even more scarce than decent degrees. It is not untypical for a year's intake of 60 students to include just four women. The fault for this, like everything else, rests firmly with the primary and secondary education system. Sex discrimination lies at the root of everything which is wrong in engineering education although it is by no means clear where the discrimination starts.

The circular logic runs like this. The vast majority of primary school teachers are women who themselves received an arts rather than science based education. This promotes a firm link between gender and subject matter in the pupils they teach. It also implies that personal enthusiasm, so necessary in effective teaching, is more likely to be tilted towards arts than sciences.

The secondary education system employs a greater percentage of men, mostly engaged for science and sports. This simply serves to reinforce the link between gender and occupation. Girls quickly get the idea that engineering science is not for them. Boys wishing to pursue engineering are unlikely to have received a rigorous grounding in basic science from an arts based primary school. It is hardly surprising that engineering faculties don't see too many well qualified British students of either gender.

Since the universities produce so few women engineering science graduates, there are correspondingly few available to the primary education workforce. The logic wheel turns full circle.

Engineering faculties are trying to help themselves by offering four year courses: students spend the first year on foundation science and maths, the so called access course. The Government, alarmed at the collapse of A Level science, has agreed to fund this in full. However, it cannot be a complete answer.

There is only one solution. Science must be taught more effectively at the lower education levels and without regard to gender.

Frank Ogden

Tuning into an earthquake

It's hardly surprising to find the Japanese applying electronics to the art of earthquake prediction; they do, after all, have more than their fair share of both. Until now though, the performance of most systems has fallen far short of practical usefulness. From memory, the best idea so far has involved attaching a pair of croc. clips to a pot plant and measuring the potentials!

The latest and somewhat more scientific approach comes from the Japanese National Research Institute for Earth Science and Disaster Prevention and the Communications Research Laboratory in Tokyo. It's based on the frequent anecdotal reports over the last ten years of bursts of electromagnetic radiation preceding seismic or volcanic activity.

In their recent paper (*Nature*, Vol. 347, No 6291) Yokio Fujinawa and Kozo Takahashi explain how systematic research has been hampered by high urban levels of noise, which effectively drown any signals of seismic origin. They therefore set about developing a novel electrode system to measure only the vertical component of the underground electric field in a deep borehole. This configuration, they say, is very effective in reducing signals caused by lightning discharges and other atmospheric phenomena. Such atmospheric signals reverberate between the Earth and the ionosphere in a waveguide mode that generates predominantly horizontal underground fields. A system responsive only to the vertical component was therefore assumed to provide a useful degree of discrimination.

What Fujinawa and Takahashi did was to install two electrodes, one an insulated steel pipe 603m below the surface and another a 40m diameter circle of earthed wire immediately above the steel pipe and one metre below the surface.

Electromagnetic signals were recorded in the range 1–9kHz over a period of several months, during which local seismometers recorded a number of sizeable earthquakes. There were enough seismic and volcanic events to make possible a valid statistical comparison between the mechanical and electrical signals.

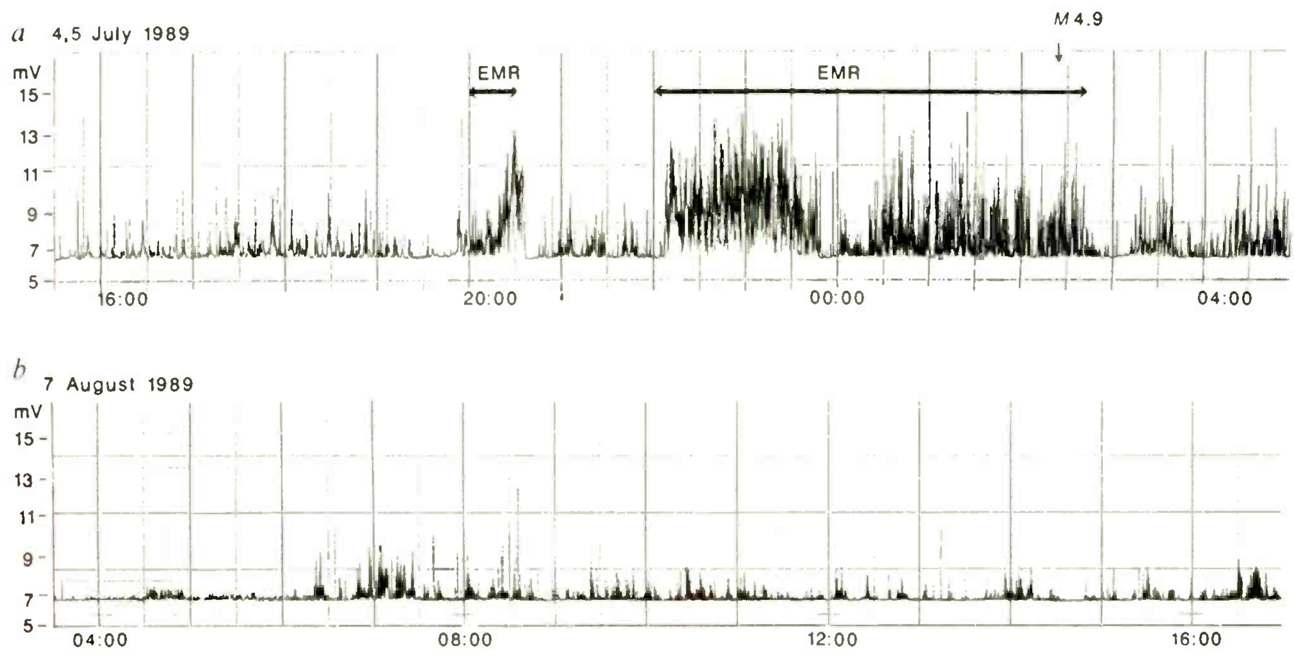
Perhaps the clearest example of premonitory radiation, shown in the figure, is where large bursts of ELF/VLF energy were detected six hours before a magnitude 4.9 earthquake that took place 100km south-west of Tokyo on 5th July, 1989. This anomalous radiation consists of large pulses, mostly around 50ms in duration, much longer than the 5ms pulses normally associated with atmospheric phenomena. Examination of the chart recordings showed other similar examples of advance warning signals, often 10 hours or more before following earthquake.

Unlike the experiments with potted plants, this latest approach to earthquake prediction has a very sound theoretical basis. Several laboratory experiments on rocks indicate that, prior to catastrophic fracture, numerous "microfractures" occur which cause electron expulsion and positive charge accumulation. The rate at which these microfractures open up then determines the character of the resulting electromagnetic radiation. The Japanese recordings show evidence both of intermittent radiation which they attribute to fracture of hard-crystal rocks and continuous radiation, possibly from volcanic intrusion.

Altogether, this new research indicates that it should be possible to predict shallow earthquakes, reliably several days in advance.

Other monitoring stations are now being set up in Japan to increase reliability and also to open up the possibility of precise source location using measurement of phase differences between the stations.

Radiation pattern before and after Tokyo earthquake of July 5, 1989 at (a), compared with normal radiation. Picture by courtesy of **Nature.**



Semiconductors for waste disposal

Chemists in Wales and the USA have found that it is possible to harness semiconductors to break down organic waste and convert it into harmless by-products. The semiconductors in question are based not on silicon or exotic III-V compounds, but on a humble everyday material, titanium dioxide. TiO_2 is the white pigment which now replaces lead compounds in paint.

Andrew Mills of the University College of Wales in Swansea explained on the BBC World Service programme *Science in Action* how semiconductor waste disposal grew from earlier experiments in photochemistry, the holy grail of which is to use sunlight to split water into unlimited supplies of hydrogen and oxygen. This aim is still dogged by the need for complex catalysts and by problems of efficiency.

Given semiconductor material like titanium dioxide it is possible, though, to harness the high-energy photons of UV light to perform other chemical reactions, notably the breakdown of many noxious and vile-smelling industrial waste products. Mills says that TiO_2 will mineralize most organic pollutants, converting them harmlessly to carbon dioxide and water.

The process is remarkably similar to what happens in a photovoltaic cell, where the light energy separates electrons and holes across a potential barrier. But where a photocell needs a refined structure with lead-out wires to generate electricity, the behaviour of semiconductors in photochemical cells is much simpler — in theory at least.

An electron-hole pair, separated by a barrier, constitute potential energy, not just in the electrical sense but also in the chemical sense. (Think of a rechargeable cell where electrical and chemical energy can be interchanged). Andrew Mills and his fellow workers have exploited the fact that a spare electron is a chemical reducing agent, whilst a hole is a powerful oxidizing agent.

To make use of the oxidizing properties of holes, any spare electrons must first react chemically with oxygen from the atmosphere, something that can easily be arranged by aerating the mixture. The holes then behave just like any other powerful oxidizing agent such as bleach or ozone. The difference is that, while ozone or bleach are very effective at destroying organic wastes, they are also potentially dangerous or unpleasant. Semiconductor waste disposal on the other hand is a relatively safe helping hand for some of the mechanisms by which chemicals break down naturally in the environment.

At present, Sandia National Laboratories in the USA are developing some of these ideas with a pilot industrial-scale plant for destroying benzene and other organic solvents. The hope is that titanium-dioxide coated surfaces could be made to work in conjunction with artificial sources of UV light. It might also be possible to run a cheaper system in which less toxic or volatile chemicals could be pumped into lagoons containing TiO_2-coated substrates. In that way the small amounts of UV in sunlight could carry out the decomposition in a slower, albeit cheaper process.

Andrew Mills, however, shares with your columnist a greater interest in bogs than in lagoons. He suggests, tongue in cheek, that some enterprising manufacturer could coat the inside of a toilet bowl with a layer of titanium dioxide. The addition of the UV lamp

under the seat would then ensure the instant demise of all those germs and other unmentionables that lurk in and around the bend. Clever idea, Dr Mills, but how do you explain away sunburn on the parts that even foreign holidays cannot reach???

Inverse square law rules OK

The inverse square law, hated by generations of schoolkids, is something most engineers instinctively take for granted. Whether it's radiation from a point source or forces between bodies, the same relationship between amplitude and distance seems to apply.

In recent years, however, there have been numerous suggestions that gravity may violate the inverse square law. Physicists have even proposed a fifth fundamental force of nature that could be disturbing the nice simple Newtonian formula describing the attraction between two bodies. Research described in these columns (June, 1988, March, 1989) has provided tentative evidence of the existence of a very weak force that operates over intermediate distances and which could be responsible for deviations from the well-established laws of gravity.

One of the classical experiments appeared to show a consistent variation from the expected measurements as a standard mass was weighed at different depths down a 1000m deep mine in Australia. Obviously, these deviations could have been due to measurement errors or to incorrect assumptions about the mechanics or geology of the Earth. Frank Stacey and his researchers did, however, consider all the possible sources of systematic error and found that the deviation from the inverse square law simply wouldn't go away.

Now a similar experiment has been reported (*Phys. Rev. Lett.*, Vol. 65, No 10) by a team from the Lawrence Livermore National Laboratory and the California Institute of Technology. The holes they used were a cluster varying in depth from a few hundred metres to 4km that have been drilled in the Nevada desert to characterise the geology prior to underground nuclear weapons tests. Every parameter of the experimental holes was measured and corrections made for the terrain and even for the state of the tides.

When the measurements of gravity were made at various depths, the deviation from the inverse square law turned out to be greater, not less than that previously reported by the Australian workers. It was, however, consistent between the different holes in the Nevada desert.

The fact that the departure from theory differs between the two research groups is considered to be good news. Had the two teams recorded identical departures from the inverse square law, it would have been tempting to resurrect the now-discounted suggestions of a non-Newtonian force of gravity. As it is, the Americans believe there has been no evidence of departure from the laws of classical physics. What the groups have probably been measuring are systematic uncertainties caused by density anomalies deep within the Earth. That being the case, they conclude that such anomalies are likely to exist anywhere around the Earth where such experiments are attempted.

It looks, therefore, as if what we all learned about gravity in O-level physics still has many years to run. Moreover, if there are any minor infringements of the inverse square law, a radically new set of experiments will be needed to uncover them.

Venus unveiled

After a series of nail-biting technical hitches the American space probe Magellan has sent back some of the most amazing pictures of the planet Venus. Huge craters and rivers of solidified lava indicate that Venus was, and probably still is a very active planet geologically. Unlike the Earth, where water and ice have eroded the rocks, Venus has some spectacularly jagged mountains and valleys.

In one respect we're extremely fortunate to have these pictures, because Magellan was plagued with difficulties soon after completing its tortuous 1.5 billion kilometre journey to Venus. After a test orbit in which the radar system was instructed to look down onto the planet's surface, radio contact was lost with Earth. Fourteen hours later, when contact was re-established, NASA engineers pieced together what had happened.

The first fault is thought to have been the result of a high-energy cosmic ray hitting and damaging a computer that keeps a continuous check on the performance of two other on-board computers. As a result, a back-up system was activated and it too failed. Magellan, which is supposed to orientate itself by locking onto the star Sirius, locked onto another star and ended up with its antennas pointing away from Earth.

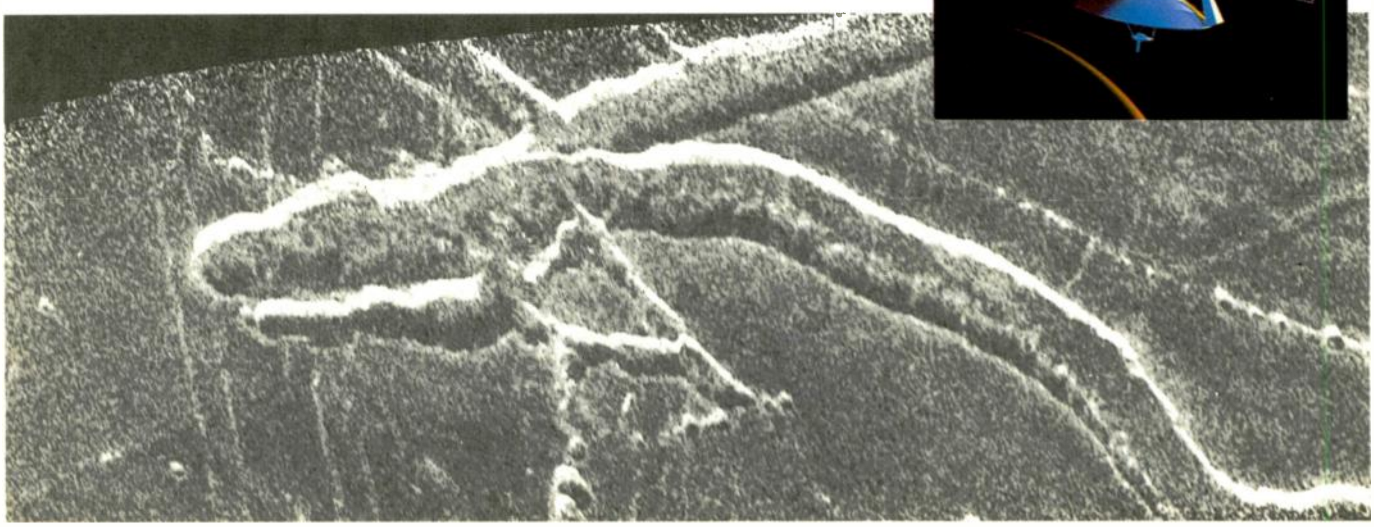
When this happened, the spacecraft first turned its solar panels towards the Sun to maintain its electrical supplies and then began sweeping the sky with its antenna. This is a standard recovery procedure which ensures that contact will eventually be re-established.

Fourteen hours later, contact was re-established, only to be lost again five days later. Up to that point NASA engineers had been trying to read out the state of the on-board memories to try and discover precisely what had gone wrong. This they did using a low-gain antenna that can only send data at a slow rate.

Fortunately, the same fail-safe procedure enabled contact to be re-established, though the fact that Magellan orientated itself incorrectly twice suggested the possibility of a software error somewhere in the system. For the time being, and to avoid a repetition, ground controllers have sent commands to disable the part of the fault protection system that appears to be generating the glitches.

Radar pictures taken through the visually impenetrable clouds that permanently shroud Venus are truly spectacular. Let's not forget, however, the very considerable engineering involved in getting them here. Servicing a sophisticated computer system millions of miles away is no mean feat!

Research notes is written by John Wilson of the BBC World Service



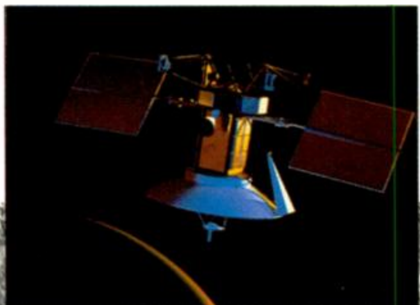


Image taken from the first set of radar data collected by Magellan, showing fault-bounded troughs in the Lavinia region of Venus. Area in picture is 28km wide, 75km long. Right, an impression of the Magellan spacecraft approaching Venus. Pictures by courtesy of NASA.

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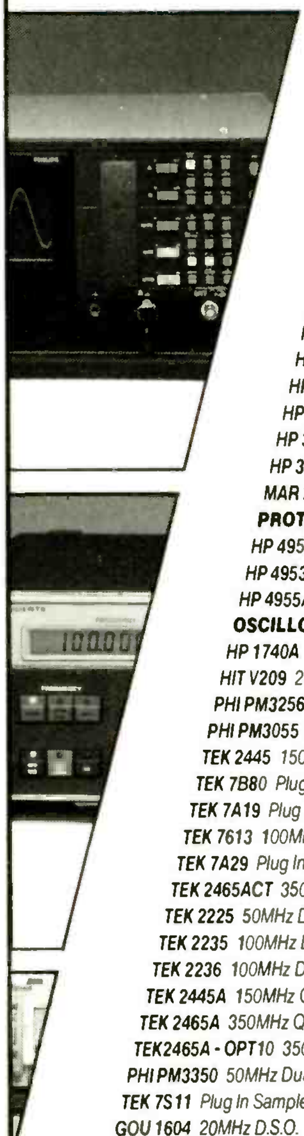

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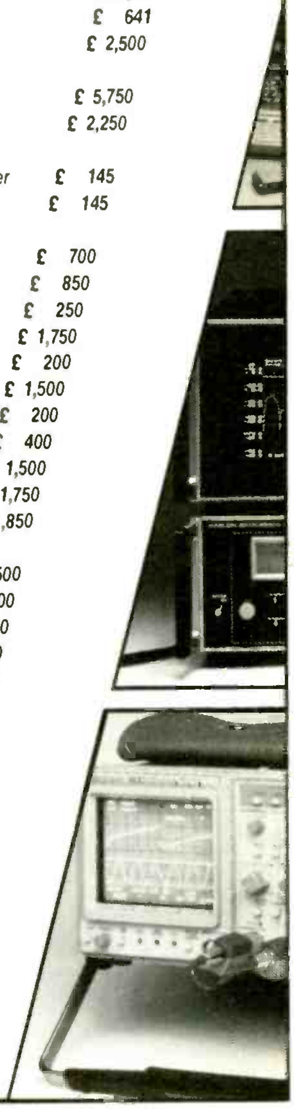

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CIRCLE NO. 128 ON REPLY CARD

Lasers on wafers

IBM's researchers believe the company will have integrated lasers onto semiconductor logic devices and used them in computer systems in the next two years. The fabrication process, developed at the US giant's Zurich research labs, is now being added to its manufacturing lines.

Various techniques are used to make the devices, but few of them are exclusive to IBM. Only the scanning tunnelling microscope (STM) used to check the devices and a polishing process are proprietary.

IBM is not the only company to have integrated lasers and logic. AT&T's Bell Labs demonstrated optical data processing using so-called photonic integrated circuits earlier this year using similar technology.

IBM sees the devices as the solution to data transmission between parts of a mainframe distributed between different sites. Earlier this year it demonstrated a data link which could transmit and receive 1Gbyte/s using a serial data stream. Parallel data moving at that rate is hard to synchronise so that bits on different lines arrive at different times.

The chips are made using gallium arsenide. The high electron mobility allows the logic parts to run at much higher speeds than silicon devices. The lasers are easier to fabricate using gallium arsenide because layers of indium can be grown to form the light sources.

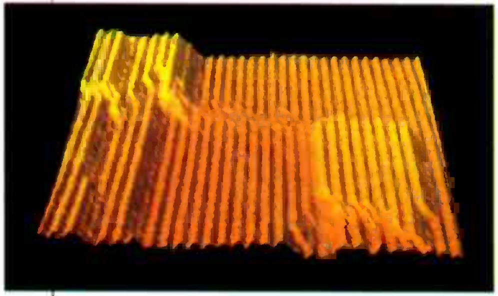
The lasers are grown using compound beam epitaxy (CBE) in which solid elemental sources are heated and molecules deposited onto the semiconductor surface. The devices follow the multiple quantum well structure already widespread among laser makers.

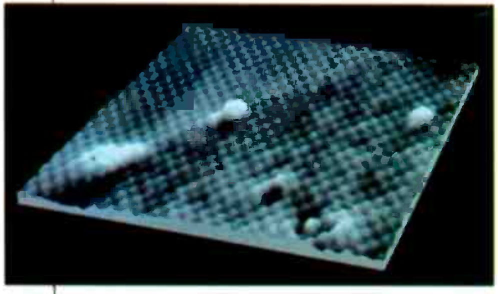
The real difference between other lasers and these devices comes after the structures have been grown. Instead of forming the lasing cavities by cleaving the crystals, IBM etches grooves in the wafer surface.

The edges of the etched grooves are then polished to form mirrors. This part of the process gives IBM an edge over other companies like STL which also has submicron semiconductor etching technologies.

A second advantage with the polishing technique is that it leaves the lasers on the wafer. Each device can be tested without having to be handled individually and the yield should also be improved.

Atomic structures under the STM: individual atoms on the surfaces of materials picked out by IBM's microscope. Top picture shows the grooves produced by etching the edges of laser structures. Picture of the DNA-recA protein complex (middle) is fuzzy because the material is an insulator, so charge builds up on the surface, impairing the STM. Contrast this effect with that in the bottom picture, which shows the atomic structure of a gold surface





Special microscope is key

The STM has been used to map the characteristic luminescence of the quantum wells across the surface of the laser.

Quantum wells can be found by moving the tip of the STM across the surface until an electron from the tip falls down a hole. That electron will then cause light in the form of a photon to be released. The distance from the centre of the well which will cause the same effect is a measure of the luminescence of the well.

Careful characterisation and full wafer testing should eventually lead to higher production yields. The Zurich researchers have now handed the work over to developers in the US who will turn it into a repeatable production process.

At the moment IBM has run full wafer testing on lasers built on 2in wafers. The next stage is to use 3in wafers with just lasers on them and to test devices with mixed logic and light sources.

The company will then go into production of the devices. The prototype receiver used in the 1Gbyte/s trial included 8000 transistors as well as the photodiode. The latter consisted of two multiple quantum well structures next to each other without the lasing mirrors. The receiver had a sensitivity of −22dBm.

Rob Cawey, *Electronics Weekly*

OBITUARY

W.A. SCOTT MURRAY BSc, PhD

Sandy Murray died last April after a number of illnesses, aged 64.

He will be remembered by readers of *Wireless World* during the 1980s as one of a group of "heretics" who were making serious enquiries into the way that modern physics was going since Einstein published his relativity theory: his Heretics Guide to Modern Physics series of articles was published in this journal in 1982 and resulted in lively correspondences and articles by others of the same persuasion.

Sandy Murray started his career as a Dartmouth cadet and served in the Royal Navy during the second half of WWII, after which he took a first degree with honours in physics at Manchester under Prof P.M.S. Blackett and a second in the radio astronomy: whilst at Jodrell Bank he discovered the Faraday rotation of radio waves in the ionosphere.

He joined the Royal Radar Establishment in 1954, where he was instrumental in the reception of the first-ever transatlantic satcom signals in the UK and later designed and directed the Malvern satellite tracking radar. He retired from the Scientific Civil Service in 1982. A.M.

Static dat joins audio battle

The hi-fi industry now has another standards battle on its hands. The R-dat system, with rotating heads, versus DCC, a digital compact cassette which records with stationary heads.

The Japanese are backing R-dat, with decks just reaching British shops. Philips developed DCC, and now has the backing of all the major record companies except CBS. Of course Sony, owner of CBS, has a heavy investment in R-dat. Although DCC will not be ready for sale until 1992, the possibilities for market confusion are already obvious.

The Philips announcement came after nine months of rumour and speculation. Philips had been secretly "selling" the idea of DCC to the record companies who are notoriously loose-tongued. Record company executives are also notoriously ignorant of technical matters, so it is hardly surprising that the leaks were very garbled.

The long-awaited formal announcement from Philips was brief and said very little, except that DCC relies on "revolutionary coding" techniques.

The national press and media have been slow to see the significance of Philips' announcement. There was no consolidated press release. Philips referred only to "major companies" supporting the system. The major record companies (Polygram, BMG/RCA, EMI and WEA) never have, and probably never will have, any interest in, or contact with, anyone outside the showbiz and music press.

So far only one hardware company, Tandy of the US, has backed DCC. Tandy has a downmarket image in the audio world and has never taken press relations seriously. Also the last time Tandy made an announcement of future technology, it was to promise the Thor recordable CD system. Tandy's share prices benefited but Thor never appeared.

Japanese sources believe that Matsushita, maker of Panasonic and Technics equipment, wants to support Philips on DCC but is hamstrung because the Japanese government fears commitment to DCC would slow sales of R-dat machines. In mid September a joint Philips/Matsushita announcement was still on the cards. But in early October Philips went it alone.

If Matsushita follows, then other Japanese majors (including Sony) are likely to do so too, in domino fashion. Then DCC might make national news.

The new DCC cassette will be the same size as a conventional analogue audio cassette, but styled quite differently, with a closed top and sliding tape cover. The tape inside the cassette will be the same as the chromium dioxide video tape sold in bulk to duplicators of VHS video cassettes.

The recorder will have a conventional stereo pair of heads for analogue recording and playback, and in addition, a solid state head for digital recording. This head is divided into 16 very narrow segments, spread across the width of the tape. Each head segment is itself divided into two parts, a magneto-resistive element for playback, and magneto-inductive for recording.

Although DCC follows the traditional format of recording on one half of the tape width in one direction and then on the other half in the other direction, DCC is not a flip-over format. The cassette need not be taken out and turned over. DCC has been designed from day one for auto-reverse.

The 16 head segments lay down, and play back from, 16 very narrow parallel tracks spread across the tape width, 8 for each stereo pair. Tape speed remains the same as for conventional cassettes, 4.75cm per seconds.

At this low speed, and with only eight parallel linear tracks per stereo pair, it is impossible to record the several Megabits per second needed for 16-bit linear PCM with control sub-codes and error correction as in the case of CD. DCC relies on a new coding technique, called precision adaptive sub-band coding (pasc) which has been developed mainly as a method of broadcasting digital stereo over conventional radio channels for digital audio broadcasting (dab).

The pasc processor samples the signal at the standard digital recording frequences of R-dat, 32kHz, 44.1kHz and 48kHz, and then analyses the content of the sound, right across the frequency range. Where signals are audible to human ears, precise coding is used. Where signals are likely to be inaudible, less precise coding, with fewer bits, is used.

This drastically reduces the data rate. Philips claims that with pasc, DCC can offer the equivalent of 18-bit digital code, which is two bits (12dB) better than CD or R-dat. Philips says DCC allows a dynamic range of 110dB which gives sound quality "equivalent to that of compact disc".

Barry Fox

Sony's 55ES R-DAT player. A fight on its hands?

AM stereo gets UK hearing

AM stereo broadcasting could at last be about to take off in the UK. Two local radio stations, Orwell in Ipswich and Capital in London, look set to be on-air with test transmissions by the end of the year.

Receiving stereo on the AM band is a familiar concept to radio listeners in the US, where two alternative systems exist. Of these, C-Quam, pioneered by Motorola, is proving the most attractive, mainly because of the company's ability to produce single microchips which will handle the broadcasts, and hence to beat its rival, Kahn Communications, on receiver price.

Meanwhile, the AM band in the UK is becoming progressively less popular with listeners who, where possible, choose the better reception and stereo capability of FM broadcasts. Figures released by the IBA this year show that, for the first time, FM is "predominantly used" by more listeners than AM. But C-Quam produces perceptibly better audio performance than standard AM, and so could wean UK listeners from low-cost, lower-quality AM receivers.

Orwell started test broadcasts in June, and Capital is understood to be waiting only for Department of Trade and Industry approval before commencing its tests. The BBC and the receiver manufacturers are currently taking a "wait and see" attitude, but there can be little doubt that, if the Independents popularise the system, Auntie and the equipment makers will not be far behind.

C-Quam maintains compatibility with existing radios by transmitting the sum of the two stereo channels as standard AM, and phase modulating the stereo information – the difference between the two channels – onto the existing carrier. This scheme avoids the hiss problems associated with weak FM stereo reception and takes advantage of AM's more even coverage of its service area to reduce localised loss of reception – useful for mobile reception.

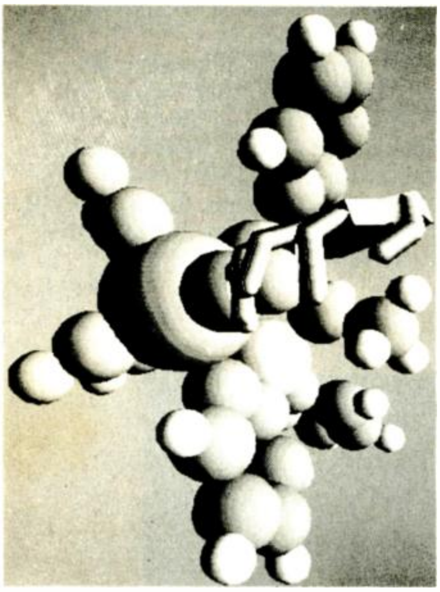
Leading-edge software

ARS Microsystems' dV/dt software allows designers of digital circuits to sketch and analyse timing characteristics on a PC. The package costs less than £700 and does not require a netlist or behavioural models, so can be used before the schematic stage of design. Signal edges are displayed on-screen in the timing diagram, with maximum and minimum uncertainties defined by the user. Clock speeds, propagation delays and wait states can be interactively varied, so that designers can look at the effects of, for instance, speeding up the entire design, or using cheaper components. Such changes ripple through the entire timing diagram, without the need to re-analyse the system completely. Common-path and common-part analyses are available.

The package could be particularly useful in the design of bus-based systems, such as VME or Nubus, where timing between boards needs to be verified to ensure the proper granting of bus requests, interrupts and so on.

Virtual vision blurs reality

"Not living in the real world", is a criticism often levelled at anyone not having his or her feet firmly fixed to the ground. But Bristol-based systems designers Division Ltd hope that their own promise of an alternative reality where users can enter and interact with a computer-generated three dimensional universe will have very practical down-to-earth applications.



Picking up and manipulating "atoms" by hand is possible in virtual reality.

The principle of the system is that an operator, watching a three dimensional image on a stereoscopic viewer, is able to move around inside a machine-generated "virtual reality" simply by movements of the head. In this way computer generated objects and scenes can be looked at from any viewpoint so that the user has the illusion that they are solid and "real".

Adding to the reality, the movements of the user's hand can be translated into three dimensional movements within the virtual reality allowing interaction with the computer images. So for example in a computer model of a room, a user could reach out, turn the computer generated handle and "open" the door.

Applications ranging from fluid dynamics to molecular modelling are thought possible, though the Division system is not yet being used in a practical situation. However Salford University's Advanced Robotics Research company is expecting to use a system to help develop its design of complex robot remote control.

The basic component of the system is a terminal providing a physical interface between the user and the computer environment. Input and output channels include the visual display channels, tactile input, audio channel etc.

Hand and head movements are captured through the wearing of sensors, for example a glove interface, and speech too, can be used to interact with the computer world.

The extremely large processing requirements for a full system mean that a single, or even limited number of processors is going to limit performance and Division is pursuing parallel architecture to support existing and future requirements.

A complete distributed virtual environment system (DVS) consists of a network of different virtual environment terminals and a single application server such as a Vax.

"Radiation at work" debate heats up

There is good reason to believe that workers in jobs with high exposure to non-ionising radiation are facing increased health risks, says Dr John Dennis, ex-Assistant Director of the National Radiological Protection Board.

Speaking at a London seminar dealing with the subject of NIR exposure at work, Dr Dennis focused on the evidence linking an increased exposure, to workers with an elevated risk of brain tumour. He estimated a 33% increased risk, from current research, but said this was still low compared with the higher risks from car accidents and other activities.

The increased risk of leukemia in electrical and electronic workers Dr Dennis assessed at 20%, indicating an absolute excess risk of 10 per million per year, but compounds in the workplace may also contribute to this higher risk, he said.

Dr Dennis also considered the likelihood of miscarriage in women using VDUs more than 20 hours a week. In the US a Congressional Office of Technology Assessment has recently concluded that emerging evidence no longer allows categorical assertions that there are no risks from very low frequency (VLF) and extremely low frequency (ELF) radiation.

As yet there are no international standards for VDU exposure levels, although the Swedes seem to be leading the way, allowing ELF and VLF electric and magnetic fields of 25V/m and 2.5mG, and 2.5V/m and 0.25mG respectively.

In the case of microwave irradiation, Dr Dennis' assessment of existing studies was that no particular risk has yet been substantiated. Nonetheless, new evidence could suggest that exposure guidelines between 30 and 300MHz, where maximum coupling with the human body occurs, should be reduced.

Regarding residential exposure, Dr Dennis discussed the work of Wertheimer and Leeper, and Savitz, and calculated that by setting the figure given for the relative risk against the measured fields from their data, the percentage of childhood leukemia in the US due to magnetic fields reduces to 2.5-10%, rather than the 10-15% originally assessed by Savitz. The difference in overhead versus underground residential distribution of electricity between the US and UK produced considerably lower magnetic fields in UK homes, he said.

The seminar was organised by Dale Electronics, manufacturer of electromagnetic spectrum monitors.

Simon Best

IBC '90: year of HDTV

For the last IBC to be held in Brighton, HDTV formed a major core of both the technical papers and many of the exhibition stands.

Apart from better quality images, there were other unusual consumer boxes on the Hitachi stand. The Lap watch VCR is a portable £1300 multi-standard receiver/VCR built to the VHS format, with a 5in LCD colour display. The Hitachi video printer (£1500) is capable of grabbing a video frame from either RGB or PAL inputs and producing a print priced at about 40p per copy, in about two minutes.

Ferguson offered a wide screen 1250 line TV receiver consisting of French circuitry and an Italian CRT. This is expected to retail at about £3000.

The 36in diagonal, 16:9 aspect ratio tube displays the standard PAL signal using line doubling to achieve improved picture quality. The receiver is equipped with a control function so that the viewer can switch between the standard 4:3 and wide screen formats to suit the transmitted signal. Also included are features that allow a second image to be displayed either as picture-in-picture (pip) or picture-outside-picture (pop). The receiver design is compatible with current standards and upward compatible with 1250 line 50Hz MAC.

It was clearly stated and demonstrated that the European PAL standard was not yet ready to lie down and give way to another system, MAC or otherwise. Improved definition (I-PAL), Extended definition (E-PAL), Quality PAL (Q-PAL), and even I-PAL-M, a modified and phase error compensated system were all explained. The BBC demonstrated a system described as (Weston) Clean PAL that had been derived from technology developed within the Eureka-95 project. This was said to give rise to a range of possible PAL enhancements. The PAL-Plus group and others reported on the advances made with the ghost cancelling receiver, a feature that has benefits for both vision and teletext signals. The fact that a MAC system produces better quality pictures and is easily extendable to high definition, seems to carry less import when the high level of capital already invested in the PAL system is taken into consideration.

The automated VCR programming concept has been further enhanced by a BBC development. The system uses teletext to broadcast a label to accompany each programme. These labels are transmitted about once each second while a programme is running. A VCR equipped for this system stores a list of the wanted labels, plus network source, with the time window in which the programme is expected. When the recorder finds a match between wanted and broadcast labels, recording starts and continues until a change of programme generates a change of label. The VCR then switches off.

Making it big in Europe: Eureka HDTV. But will it become more than simulated pictures?

Intel's 80X86 processors, chosen as the heart of the IBM PC, seem to be impossible to keep out of the news at the moment. Latest developments include law suits, portable PCs and imitations.

Litigation involves Intel's rival chip-maker and erstwhile collaborator, AMD. The two companies set up a technology agreement in 1982, but the relationship deteriorated very soon afterwards, and now Intel is trying to stop AMD making its own version of the 80386. The whole messy business has been referred to an independent arbitrator, who has released a preliminary conclusion and has now set about working out who gets what. Every time the arbitrator delivers a judgement, both sides claim victory, so it is not surprising that, this time round, Intel said that it was "pleased that the judgement does not require the transfer of the 80386", whilst AMD promised to go for $500 million compensation and seek transfer of the 386 in the next arbitration phase.

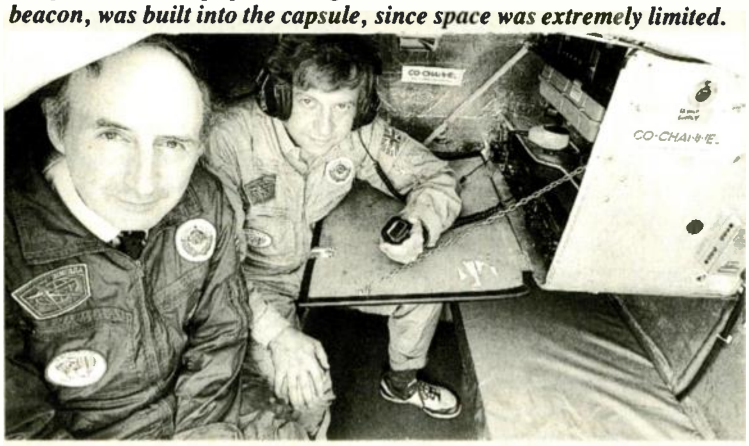
AMD has sampled a 386-compatible product, which it describes as "a miracle of re-engineering". In response, Intel has taken out an injunction forbidding AMD's use of the "386" tradename. Doubtless, the whole dispute will rumble on and on.

Just to drive home the rivalry, the two companies chose the same day to launch products based on flash eproms – reckoned to be the next great thing in non-volatile memory technology. AMD's effort is a 1Mbit chip with an access time of 90ns, built in the 1micron technology used for its eproms and eeproms. Intel, slightly further advanced, has come up with a range of credit-card-sized storage devices based on its own flash chips, with capacities of up to 4Mbyte. The company says that these could replace floppy and hard disks in many applications, and demonstrated a PC-compatible card reader, based on the same form factor as a standard disk drive.

Again, portable computers will be a major target, since the cards are solid state and can be read without all the physical trouble of spinning a disk drive, leading to much lower power requirements. The cards stand up to rough treatment much better than magnetic media.

AMD's engineering department has obviously been working hard; not content with the "miracle" 386, the company has come up with two products which put many of the features of an IBM AT onto a single chip. The Am286ZX is aimed at the desktop market, while the Am286LX adds power management to allow it to be used as the basis for portable computers. Production of 12MHz and 16MHz versions of the chips is scheduled for early next year, with 20MHz parts to follow.

Encapsulated radio: Don Cameron (left) and Gennadi Oparin testing radio equipment in the capsule of their hot-air balloon, which made the first hot-air flight from Britain to Russia. Co-Channel Electronics of Avonmouth supplied their own HF and VHF radio equipment, with satnav, Decca Navigator and a position transponder from other companies. This equipment, together with an automatic search beacon, was built into the capsule, since space was extremely limited.



At the higher performance end of the market, AMD has produced a floating-point version of its 29000 risc processor, dubbed the 29050. The idea is to get the chip into embedded applications, particularly those involving graphics processing such as laser printers, where the company says it expects to see several design wins in the first half of next year. The 40MHz part is pin-compatible with the existing 28k type devices and has on-chip memory management, emphasising AMD's aim of making risc work with low-cost dynamic memory. On-chip cache, however, is limited to 1kbyte.

Within a couple of weeks of AMD's chipset announcement, Intel had come up with one of its own. The 80386SL consists of a 20MHz 386 core, cache controller, main memory controller, PC/AT and ISA bus interface, coprocessor interface and power management on a single chip. Support comes from the 82360SL, which handles functions such as serial and parallel communications, DMA, hard disk control, and memory refresh. Once again, the focus is on notebook and laptop computers, so other new low-power support chips such as flash memory chips, keyboard controller, and a modem chipset, have been added.

Another company on the trail of Intel-based PC chipsets is Chips and Technologies, which has come up with several new products and a new European headquarters to go with them.

Chips says that the European PC market looks set to outdo both the US and Pacific rim in coming years, with particular emphasis on industrial computing. Hence the new base, which is in Switzerland. The products include a 3-chip set which will allow OEMs to build 80386DX-type PCs using only 15 components, plus memory. Direct-mapped cache and processing speeds of 25 and 33MHz make this a fairly high-performance beast, although Chips describes it as "entry level".

Also on offer are 80386SX types, including the Chipslite family, designed for the growing laptop and portable markets. These include on-chip flat-panel graphics, mouse and communications port controllers, as well as power management.

Looking forward to busy lines

Voice, data and video services at the end of a telephone? In the following series of articles Richard Wilson assesses fibre optic developments in the pipeline.

Over the last twenty years digital telephony and optical fibres have radically changed the way we communicate. But we have still only exploited a tiny proportion of the full potential of optical communications.

Current high speed systems carrying seven and a half thousand simultaneous telephone calls on a single strand of glass are impressive enough.

But in theory the optical fibre has a bandwidth of around 150 Tera Hertz — 150 000 000 000 000Hz — the equivalent of 20 million television channels or more than two billion digital telephone connections.

The practical challenge is to incorporate this ability to carry large volumes of information, into fibre networks that connect directly to customers' premises. Radio transmission techniques first developed over 50 years ago may hold the key.

Researchers at British Telecom's Martlesham Research Centre are using coherent optical techniques analogous to super-heterodyning in radio transmission as a solution.

At present, over half of BT's trunk telephone network uses fibre optic transmission in a technique, perfected over the last ten years, called direct detection.

Data is transmitted over the fibre by changing the optical intensity of a light source or laser. At the receiving end the optical data train is converted back into an electrical signal with output directly proportional to the optical power falling on the photo-detector. The lower the received power the harder it is to decipher the electrical data.

As the optical signal travels through the fibre it becomes attenuated and the data pulses broaden because different wavelengths of light travel at different speeds through the glass. This limits the amount of information and distance it can be carried.

Coherent approach

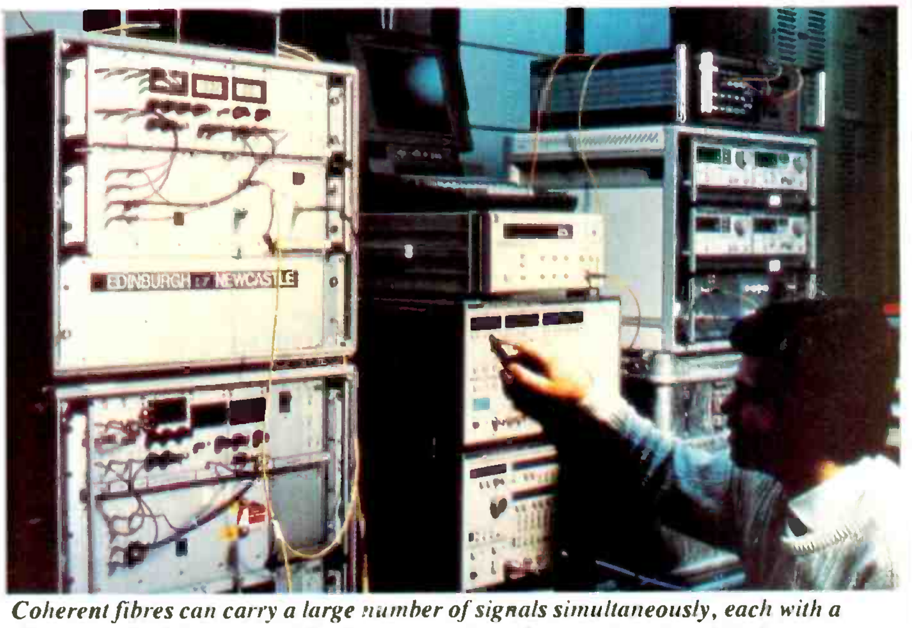
Direct detection systems under development can achieve data rates of 2.4Gbit/s — equivalent to 25 000 simultaneous telephone calls. But attenuation and dispersive pulse broadening means the optical signal must be electronically reconstituted every 50km or so.

However BT researchers have shown that coherent optics will create a new class of system with 1000 times the information carrying capacity.

The advantage of using coherent optical techniques, according to Dr Roger Steele, a researcher in BT's coherent optical systems group at Martlesham, is that they make more efficient use of the fibre's full optical bandwidth.

Single wavelength light is used to transmit a data train along the fibre, with the opto-electronic detector which converts it back into electrical data used in a way analogous to a heterodyning radio receiver.

The incoming optical signal is combined with a second monochromatic signal generated by a laser in the receiver. The photodetector acts like an electrical mixer circuit, its output proportional to the combined power of the two optical signals. In this way the incoming signal can be boosted. A 20-fold enhancement could extend the transmission lengths for 2.4Gbit/s to over 100km.



Coherent fibres can carry a large number of signals simultaneously, each with a discrete optical frequency. The time may arrive when you tune in a telephone as you would a radio. The picture shows a BT experimental coherent optical link between Edinburgh, Galashiels and Newcastle.

Another advantage of coherent systems is the amount of information that can be carried. Coherent techniques allow different optical channels to be supported in the same fibre.

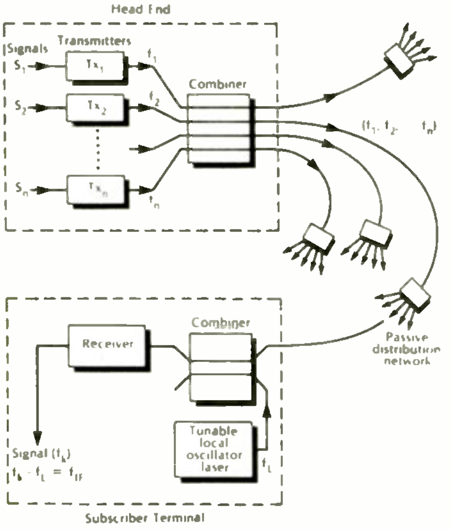
Last year BT demonstrated a coherent optical system that transmitted two data channels each operating with light of a different wavelength via an optical repeater 200km between Edinburgh and Newcastle. Each channel carried a 622Mbit/s data train, enough to handle almost 8000 telephone calls.

To prevent interference between the channels the wavelengths of light used were 7GHz apart, but even fibre with a usable bandwidth of 50 000GHz could support 7000 separate data channels.

Such information carrying capacity, when it is introduced into the public networks could transform our view of the telephone.

Looking maybe 15 years into the future Dr Peter Cochrane, a BT strategist for optical networks, draws a picture of a coherent optical network without telephone exchanges where a range of voice, data and video services are available to the customer on what will be called a passive optical network.

Customers select which of the services they require and they then tune their receiver to the necessary wavelength, much the same as they would a radio receiver. With the enormous capacity of the optical medium such a passive optical network would meet all our communication needs both for business and leisure activities. From videophones and computer networking to high definition television and high speed facsimile, all services will be available through a single optical fibre connection.



In a wideband distribution network using "tuned" coherent transmission, customers can obtain different services by selecting wavelengths on their receiver.

£20bn investment

Major investment is required to create a fibre network that connects to every home and office, perhaps £20bn will be needed for the UK. But technologists are not waiting for the politicians to make up their minds and are already tackling the technical problems.

As BT's Dr Steele points out, one of the immediate stumbling blocks is to find a laser with the required spectral purity. "The ideal source hasn't yet been invented," he says.

But Dr Steele believes that the distinction between coherent techniques and traditional direct detection methods is not so clear-cut as first thought. He is working on a system offering the characteristics of coherency but using commercially available lasers and optical filters.

Using a tunable filter to select the wavelength Dr Steele claims that 10 channels can be created using existing laser sources. A second filter would improve resolution to 100 channels.

With the possibility of the first "coherent-like" systems appearing in the UK network before the end of the decade, maybe it isn't too fanciful to picture a time when we'll tune our telephones like our radios. ■

A twist in the tale of optical fibres

Twisted pairs matching optical networks in performance? A lot more than copper is at stake.

Photons are rapidly replacing electrons as the world's favourite communications medium. Whether it is a transatlantic cable or a data path between microprocessors in a super-computer, optical fibre seems to hold all the answers for our communications needs.

But recent developments in the US are suggesting that copper and the familiar twisted pair may yet have a resurgence of popularity.

For over 100 years copper cable has been the commonest way to connect electronic equipment. From telephone to personal computer, information has been exchanged over two intertwined copper wires, the twisted-pair. Cheap and reliable, it met most of our needs until pushed to carry more data than it could physically support. Then the world discovered optical fibre.

Fibre vs copper

Fibre has everything going for it: theoretically it has thousands of times the capacity of copper, is less prone to electrostatic interference and is very difficult to tap into.

But costs of fibre, electro-optic transmitters and receivers restricted use to high-performance systems in the long-distance telephone network. In computer networks requiring less than 20Mbit/s data rates, copper won over fibre every time.

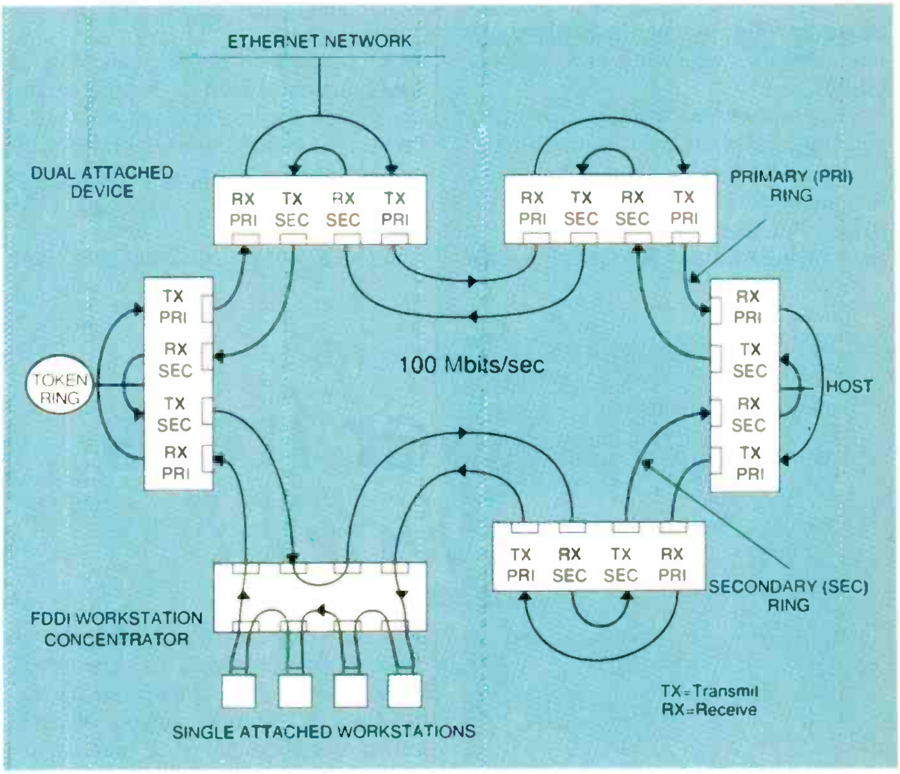
Since the mid-1980s local area networks (lans) and computer companies have stuck by copper with 10Mbit/s Ethernet championed by DEC and IBM's alternative Token Ring networks. But with computer power rising many lans are now hitting the performance limit. For example "You can flood Ethernet with one Unix server or even a powerful PC", says Jeff King, lan product marketing manager at BICC Data Networks.

In the late 1980s networking companies started getting serious about fibre lans. The technology was available but a standard interface protocol was needed that would steer a safe course through the mine-field of multi-vendor computer networks.

FDDI emerges

For the last two years the US standards body Ansi and some 80 computer

Nearly all FDDI's 100Mbit/s bandwidth will be available through improved protocol. Ansi is expected to complete the FDDI standard early next year.



vendors have wrestled with the problem and the result is FDDI — fibre-distributed data interface (see box). This is a standard high-capacity 100Mbit/s communications backbone supporting a large number of lans, using a range of computer hardware and protocols.

Although the standards process is not fully complete companies like Fibronics of the US believe the situation is stable enough to offer FDDI products. "First applications of FDDI are in the large data processing environments, namely the DEC and IBM sites", predicts Ian Milne, managing director of Fibronics (UK). But key to FDDI's future success is the endorsement and the announcement of products by the likes of DEC", he adds. But FDDI may not have things all its own way; copper is fighting back.

In July two US companies succeeded in persuading Ansi to consider modifying the proposed FDDI standard to allow for use of copper in place of fibre as a transport medium. ChipCom of Massachusetts and Synoptics of California claim to have demonstrated data transmission at the FDDI data rate of 100Mbit/s over 100m of shielded twisted-pair cable.

ChipCom's engineering director Don Saussy sees a 100m transmission length as the target which will make FDDI/twisted-pair an attractive alternative to fibre for 90% of all lans. To achieve this ChipCom's system electrically filters the data before transmission, to compensate for high- and low-frequency distortion as the signal passes down the cable.

There were two problems to be solved: first the poor high-frequency response of the twisted-pair meant the transmitted signal had to be shaped so that the overall response of the system was flat. Second, the FDDI coding scheme created a low-frequency problem because its signal value was non-zero at DC, or zero frequency.

According to Saussy this is solved in a fibre system by using capacitive coupling into and out of the optical transmitter and receiver. In an all-copper system this would create electromagnetic emission difficulties so ChipCom were forced to use transformer coupling to allow for the DC response, requiring additional low-frequency filtering.

While Ansi mulls over the claims, which now have the backing of DEC according to ChipCom's Saussy, other FDDI manufacturers are playing down their importance.

Jeff King of BICC simply does not believe 100m transmission over a twisted pair is practical. "It might be possible up to 50m, but it won't work on unscreened cable which will radiate like crazy".

Saussy responds that radiation is a concern but tests on shielded cable up to 100m complies with the strict West German VDE emissions standard.

Fibronics' Ian Milne warns about the false economy of non-fibre lans, "It is all about the cost of ownership over a 10-year period: although fibre systems

What and why of FDDI

FDDI fibre distributed data interface: what it does is to put a high speed 100Mbit/s communications backbone into companies using computers on local area networks (lans). What it is, is a proposed hardware and software standard for implementing this backbone in most of the leading computer environments.

An FDDI backbone uses an optical fibre ring with two contra directional data paths each running at 100Mbit/s. The dual bus ring can be up to 100km in length supporting a maximum of 1000 access points, or 500 if they are connected to both data paths for improved reliability.

Current systems use multimode fibre and low-cost light-emitting diodes as optical sources and will support 2km of fibre between connections. There are plans to extend this by using more expensive single-mode fibre and higher-power laser diode sources.

The standard has been created to be compatible with existing lan protocols, and specifically the most common ones Ethernet and Token Ring. As well as providing interworking between protocols and equipment from different suppliers, FDDI has the capacity to meet the need for increased throughput on computer networks running high-performance workstations and supporting ever-increasing numbers of users.

Most of FDDI's 100Mbit/s information carrying capacity is available to users through the implementation of an improved token protocol which could mean a 12–20-fold increase in data throughput compared to traditional Ethernet or Token Ring networks. Part of this improvement is due to the use of a data coding scheme which is more efficient than the Manchester coding format used on Ethernet and Token Ring protocols.

So far FDDI is only three-quarters of the way towards a fully-fledged standard, but this has not stopped many manufacturers from introducing products. Most are convinced that the hard work in creating the standard has been completed and that all that remains is approval of network management software — and that can be back-engineered if necessary.

are a little more expensive to purchase ultimately they win on the lower cost of maintenance, reliability and upgradability".

There is an enormous amount of twisted-pair in today's computer networks and it is this which at the end of the day could be the biggest asset to companies like ChipCom and Synoptics; introduction of fibre will be slow.

Prospects for FDDI

Most manufacturers indicate that the first market for FDDI is not in the lans on which the computers sit, but in creating a broadband backbone which will continue to support the copper sytems such as Ethernet and Token Ring.

Jeff King of BICC believes it will be at least another year before FDDI starts to make an impression on the market for networks connected directly to workstations. Maybe the development of higher performance copper systems such as those of ChipCom and Synoptics will make it all the more difficult for FDDI to extend its market once the backbone networks are in place. ■

Man-power frees local networks

Metropolitan public networks could take the "local" out of lans while moving a step closer to a broadband future.

In Britain most of the long-distance telephone network uses optical fibre, with many routes capable of carrying 565Mbit/s — equivalent to four high-definition television channels or 7500 simultaneous telephone calls. But final connections to all homes and most offices is by old copper cable technology limiting data to a trickle at only 64 000 bit/s.

Companies and institutes are already sharing their processing power and databases on local area networks (lans) and taking advantage of fibre optics. Meanwhile the new FDDI – fibre distributed data interface offers a 100Mbit/s communications backbone that can support high-speed applications such as diskless workstations and display of animated graphics. But these optical lans hit a performance bottleneck when they use the public telephone network or even dedicated 2Mbit/s lines to connect to networks in other buildings and locations.

The solution is a broadband optical fibre connection to every home and business, an ambitious plan and one which could take 20 years to realise in Britain and at a cost of some £20bn.

First lan, now man

But there are now signs that the world's business computer users may not need to wait that long. In North America the demand by companies to send several million bits of data per second between buildings in different parts of cities has led to development of a new class of high-capacity wide-area optical fibre network, the metropolitan area network (man).

The significance of mans is that they offer the high information-carrying capacity and flexibility of lans but on a geographic scale over a network operated by public telephone companies or large private data network operators.

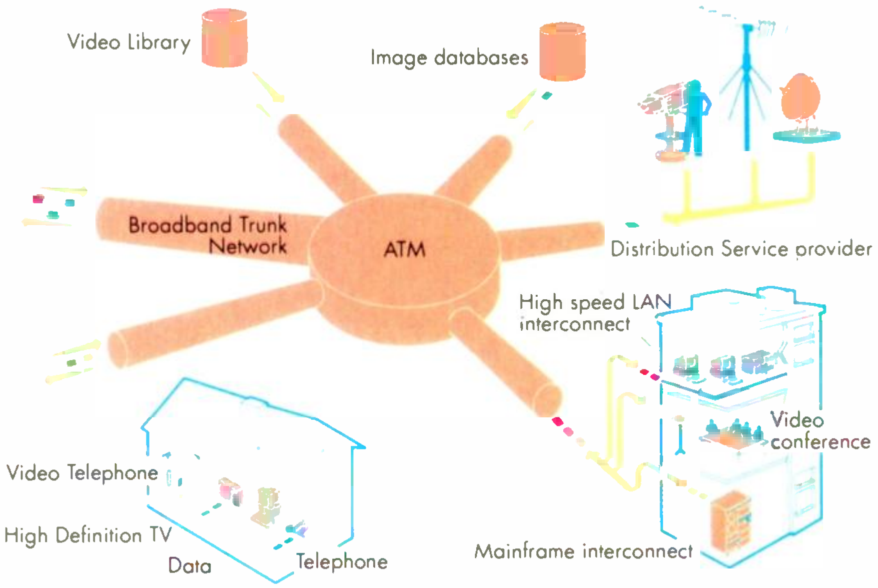
Company computer networks will be able to connect to a 140Mbit/s communications spine extending across a city — or even further. Users will be able to access remote databases, retrieving 1Mbyte of data in less than a second, or transmit an A4-page containing approximately two million bits of information in under half a second. Through mans these features will all be available on what is a public data network.

The network uses a distributed switch architecture, giving the user greater control of network management than is common on current public data networks, and also offers an open systems interface to most software environments.

This distributed queue dual bus (DQDB) architecture was developed by the University of Western Australia and Telecom Australia, and a private company, QPSX Communications, set up to license the design. Now manufacturers such as Alcatel of France and Siemens of West Germany, are already trialling mans in North America.

Dual bus architecture means it can support full bi-directional communication between nodes on the network, for dedicated point-to-point connections or shared operation in an open bus configuration. High transmission rates are achieved using data packets asynchronously switched around the network

Asynchronous transfer mode (ATM) makes the best use of high capacity fibre optic systems and could integrate broadband and narrowband services in a single digital network.



The ATM future integration of broadband and narrowband services in a single digital network within 125μs time-slots. Just as a train of carriages move from one station to the next, the "train" of time slots carry data from one computer terminal to another.

The amount of data that can be carried in any frame of time slots depends on the bit rate of the buses and typical fibre optic mans will support bit rates up to 140Mbit/s.

Asynchronous transmission

Mans' other importance is that they represent the first step towards broadband networks of even greater information carrying capacity using asynchronous data transmission in an asynchronous transfer mode (ATM).

Public networks carry digital information using synchronous transmission so that the amount of data that can be carried over a connection in the network is unchanging even when it is not needed. Wasted network capacity results. Using the railway analogy, it is like having long empty trains running all day on the railways though they are only full for short periods in the rush-hour.

With asynchronous transmission the network capacity can more easily be adjusted to meet demand, making better use of high capacity fibre optic systems.

Long-term the goal is to build broadband fibre networks based on asynchronous transmission. Operating at multigigabit data rates these will solve all our communications bottleneck problems with capacity to spare to offer high-definition TV services in the home. But the enormous cost of building this broadband network means it will only happen if network operators can justify investment in terms of new business.

The importance of mans is that over the next five years they will meet the need for high-speed computer/computer communications, at the same time providing network operators with the next commercially viable step towards a bottleneck-free broadband future. ■

European network

The distributed queue dual bus (DQDB) architecture originally developed in Australia has been adopted as the basis of an American standard for mans. The IEEE802.6 protocol has already led to the swift development of man products, now being trialled in North America and appearing in Europe next year.

Two European manufacturers, Siemens and Alcatel, have developed systems based on the 802.6 standard which will be used in two German pilot networks in Munich and Stuttgart. They will operate at up to 140Mbit/s and will connect computer networks within an area 50km across to high-performance mainframe computers and databases. Typical applications could include the transmission of medical X-ray scans between hospitals or in industry with the transfer of computer-aided design (cad) data.

Like the German Bundespost, both British Telecom and Mercury Communications are sure to recognise the importance of mans for meeting the business needs of companies in the UK. The appearance of operational mans in Europe has prompted the European standards body to act quickly and produce a draft standard before the end of the year.

True, nothing ever happens without a standard. The trick is to create the standard before the networks are built.

Testing assertions

My letter in the June 1990 issue about subjective amplifier assessment having produced some further correspondence (August and September issues), I feel that a reply is called for.

My letter was triggered off by John Linsley Hood's articles in the November and December 1989 and January 1990 issues, in which my name appeared several times. I pointed out that in my article Audible Amplifier Distortion is Not a Mystery in your November 1977 issue, to which he referred, I did not in fact describe the substitution test he mentioned, but rather a nulling or differential test, which I credited to Peter Walker. (When my diagram for this was redrawn, the mixing resistors in the op. amp. input were inadvertently omitted.)

I pointed out that such a nulling test enables one to listen to all the imperfections of an amplifier at their true volume level, or at a higher level if desired, while it is handling a programme under normal working conditions but without the quite large masking effect of the programme itself. This, I stated, gives one *greatly increased aural discrimination*, so that small defects may be heard that would be missed by even the most "golden eared" listener, such as Martin Colloms may well be, when listening in the ordinary manner. With sufficiently good amplifiers, no imperfections at all can be heard.

Martin Colloms reviewed the Hafler XL-280 amplifier in *Hi-Fi News*, June 1987, using a switching unit provided by Hafler that enabled him conveniently to carry out the above nulling or differential test and also to perform a comparison test involving listening either to the direct-path sound or to that coming via the amplifier under test. The Hafler amplifier passed the nulling test – no imperfections could be heard – nor could any differences be heard on the comparison test. Nevertheless, Martin says, another amplifier, which did not do so well as the Hafler on the nulling test, was a higher scorer "by our established presentation methods for sound quality" – which involve comparisons made without a switching unit and therefore with longer time intervals between them. Martin does not deny the validity of the nulling test, saying that the initial puzzlement was resolved when it was found that comparisons made with the Hafler switch unit still present showed no audible differences, whereas when done in his usual manner, the amplifier differences were quite evident.

Even if the above quality degradation by the switching unit and extra connections was genuine, which seems extremely unlikely, it still does not explain the nulling test result. How can an amplifier *with no audible imperfections* – for the switching unit can hardly have made them *less* audible than they really were – sound worse than one with easily audible imperfections? It should be, of course, that the amplifier thought to sound superior had imperfections of a kind felt to constitute an improvement on mere faithful amplification, which leads to the point made at the beginning of my June letter about what constitutes the proper criterion for a reference power amplifier.

Mr Stanley asks why Quad changed from valve to transistor amplifiers in the late 1960s, and I can assure him that this had nothing whatsoever to do with sound quality and everything to do with economy and reduction in size and weight. He says Peter Walker, David Hafler and I are living with closed minds, suggesting that we believe in measurements alone and not in listening tests. However, if he will carefully re-read my letter, he will see that it is virtually all about listening tests, for the nulling test is very much a listening test. I do find it rather displeasing to be classified as an objectivist, since I am very interested in music and do quite a lot of recording of professional concerts, which involves much critical listening to the subtleties of reproduced sound.

Though I do not like having to say this, it does seem to me that the people with closed minds are those such as Messrs. Colloms and Stanley who simply refuse to face up to the accumulated evidence of many carefully carried out independent subjective amplifier assessment trials, such as the *Stereo Review* one I mentioned in my letter. Another very carefully carried out subjective amplifier investigation was described in the American magazine *Audio Amateur*, 1/1980. More recently my attention has been drawn to a 1988 presentation to the Chicago Section of the AES by Thomas Nousaine, entitled *Blind Tests Exposed*, in which the results of 18 published investigations are taken into account.

All the above investigations have shown that provided sufficient care is taken to ensure very accurate matching of signal levels, together with the avoidance of any form of overloading and/or hum, then when a sufficient number of tests

Fax and pax

With respect to the letter from G.S. Brown in the September 1990 edition of *EW&WW*, I am moved to make the following observations.

I read your periodical for information, but am also aware of the fact that it is very easy to get carried away with any new technical development, praising the technical ingenuity of it whilst forgetting that it has to exist in a world with real people. Your magazine is one of the few that does carry discussions of the wider issues of electronics technology. You should be praised for that, and I do hope that you will carry on doing so. There are few other widely accessible journals that carry items of interest for "those who are worried about the wider social issues".

All of us in this field and in other fields of technological innovation *should* be worried about the effects of our work on the world. We have to live in it, our kids do, and, with any luck, so do our grandchildren. It's very easy for us to ignore the wider issues, but I feel strongly that we shouldn't have an ostrich-like attitude to these matters because, whilst protecting the head, the ostrich does tend to leave the rest of itself open to being shot at. So, please keep up the work; your mix of technical and ethical is spot on as far as I'm concerned.

Joe Pritchard,
Systems Consultant
Sheffield
West-Yorkshire

Crossover distortion

I would like to add a few words on the article Reducing Crossover Distortion by Mr. Michael McLoughlin (*EW+WW*, October 1990).

I agree that most of the crossover problem may be dealt with by applying more feedback. But, from **Fig. 3**, it is evident that there is also a direct feed-forward signal path from the Tr_1 the emitter to output. Also, at crossover, Tr_3 and Tr_1 form a second complementary pair which is active for most of the time the signal spends in crossover region. If Tr_1 current is increased (by reducing R_3) the distortion may be further reduced.

Another point is the audibility of the crossover spikes. In my article I have shown that much more harm is done by secondary effects of feedback-loop bandwidth modulation and instantaneous feedback cut-out than by the spikes themselves. Actually all too often we have seen audio amplifiers with small heat-sinks and output-stage emitter degeneration resistors of 1ohm or greater and quiescent current of 50mA or less and open-loop bandwidth of 100Hz or less. A good class B amplifier is the result of design compromises in all performance aspects, including thermal stability. I like Mr. McLoughlin's idea of avoiding the thermal runaway problem by zeroing the quiescent current, but the **fig 3** circuit may not be then regarded as a typical class B output stage.

Erik Margan
Ljubljana Yugoslavia

are carried out with a proper understanding of statistical procedures, the panels of judges are found to be unable to distinguish one well-designed amplifier from another. The amplifiers do not have to be very expensive, for a very high price is more likely to be indicative of unenlightened and extravagant design than of true virtue.

Martin says I chose to deny the results of his 1985 trial at the AES, while the statistician's opinion was positive. This is not a fair comment, because I made no such denial. All I did was to point out that if the number of "similar" and "different" presentations had been made equal, there would have been no need for the statistician to have prefaced her remarks by saying she had assumed that if there was no difference between the amplifiers then the probabilities of obtaining "similar" or "different" answers would be 50:50. The assumption is certainly not a safe one to make, so that the validity of the final result becomes dubious unless the kinds of presentation were correctly proportioned, and Martin has still given no information on this point. Mentioning this *possible* shortcoming in the trial procedure does not constitute a denial of the result.

I find myself in total agreement with all the views expressed by Douglas Self in two excellent articles – one in your July 1988 issue and one in *Hi-Fi News*, August 1988, and a letter from him and P.W. King in *Hi-Fi News*, August 1986 also casts doubts on the soundness of the procedure in Martin's 1985 trial.

One cannot help noticing, over the years, that Martin has several times come up against the results of carefully organised independent trials that do not support the validity of his "established presentation methods for sound quality", but that he has been only temporarily influenced by them. His aim seems to have been to search for any evidence that will justify his rating system, rather than to adopt an unprejudiced attitude of trying to find out what is the truth about these matters.

Martin asks "Does Peter still need to imply that my subjective reporting is at best unreliable and unverifiable, and at worst, imaginary?" This is a fair question which deserves a carefully considered and non-evasive answer. The answer is "yes"! Nulling tests, the results of independent subjective trials such as the *Stereo Review* one, my own experiences in critical subjective quality assessment over many years, together with a fairly full professional understanding of the many subtleties of modern amplifier design, leave me with no possible grounds for giving any other answer.

The notion that the main interest of the world high-fidelity industry is better sound strikes me, I much regret to say, as highly naïve, for I'm afraid the main interest in the larger part of this industry today is in making a profit in any way it can whilst fooling the customer into believing that the aim is ever better sound. There are, fortunately, still some firms which are splendid exceptions to this sordid state of affairs, but a member of one of these told me there are times when he almost feels ashamed to belong to the industry.

Encouraging a belief in significant differences between expensive amplifiers, in the audible differences between different types of passive components, cables, connectors, etc. no doubt helps to promote sales, even if no actual sonic benefits results. Imaginative reviewing helps all this along and provides plenty of work for the reviewers.

With regard to passive components, I know of no genuine evidence whatever to suggest that these are ever a source of audible quality differences in any normal well-designed amplifier. Indeed, in a good amplifier with plenty of overall negative feedback, the *only* passive components that could conceivably have any effect on sound quality would normally be the two resistors in the β-arm, and decent resistors of adequate rating simply do not produce quality degradation – with a large margin to spare. (In a high-output-impedance current-drive amplifier I designed for KEF Electronics Ltd., a 0.22Ω wire-wound resistor used for current-monitoring was found to produce about 0.06% odd-harmonic distortion, which was surprising. Investigation ultimately established that the distortion was caused by B-H curve effects in the ferrous end caps. Such effects are quite negligible, however, with the types and values of resistor used in the feedback network of more normal amplifiers.)

It is true that most practical capacitors have an impedance which is more complex than that of an ideal capacitance – this has been known for many decades – and that, by rigging up an appropriate balanced circuit with two different types of capacitor in it, queer frequency responses and step responses may be produced, and their effects made audible if desired, as Martin Colloms has done. But to conclude from this that the sound quality of practical power amplifiers must therefore be audibly affected by the choice of capacitor types is an appalling example of totally unjustified extrapolation. The only attributes required for a coupling capacitor are that it should be free from significant leakage and should have a sufficiently low impedance over the whole audio spectrum. Who says this impedance ought to be that of an ideal capacitance? I can see no argument at all in favour of this.

The degree of absurdity that can be reached by the "passive component brigade" is illustrated by the statement made by Martin in his letter in *Hi-Fi News*, March 1990, ". . . it is not all that difficult to hear performance differences between single 100Ω resistors used as the input loading for a fine moving-coil cartridge". This is definitely total nonsense, and anyone who can believe it can clearly believe and say almost anything. I suspect that Martin, on reflection, must really know it is nonsense. As it stand, I am afraid it is liable to detract greatly from the general credibility of Martin's other writings.

I think that, just like myself, Martin and his associates are not actually all that good at judging very small and subtle differences in sound reproduction, especially when the presentations are well spaced out in time. All human beings have limitations in these respects, even if regarded as "golden eared", and are, moreover, highly subject to psychological influences of various kinds. I suggest that it is quite unrealistic for Martin to feel that he is somehow an exception to all this.

Peter J. Baxandall
Malvern
Worcs.

Deja view

It's always rewarding to learn your articles provoke further thought and generate feedback (J.D. Ryan, Smooth sampling, September 1990).

Certain parts of Mr Ryan's argument could be presented more incisively using sequences together with z-transforms, thereby removing ambiguity. Unfortunately the filter analogy of a moving coil meter, presented as a damped second-order system is incorrect. Perhaps this note will provide a sense of direction and encourage you to re-read the text more critically. I must confess that the suggested references were all new to me, Brown's algorithm I had never heard of.

When faced with a fresh problem or new challenge I subconsciously ask "Have I seen it before"? The suggested/preferred form of the algorithm:

New estimate = old estimate + α (new sample – old estimate)

looked suspiciously similar to the recurrence relationship which characterizes a first-order low-pass digital filter. Expressed in terms of sequences:

$$\hat{y}(n)=\hat{y}(n-1)+\alpha(x(n)-\hat{y}(n-1))$$

(The cap or hat symbolizes an estimate)

Converting from sequences to transforms, we may express the transfer function of the filter H(z) as:

$$H(z)=\frac{Y(z)}{X(z)}=\frac{\alpha z}{z-1+\alpha}$$

Clearly, the system pole is situated on the real axis, located where $z = 1-\alpha$. Naturally for low-pass filtering the range of the "smoothing constant" will be $0<\alpha<1$, not 0 to 1 as advertised. I'm not being pedantic, if you've got time check out the effect on the impulse response. For stability the system pole should lie within the unit circle, in this case the limits of stability are exclusively real determined by $z = \pm 1$. Obviously the range of smoothing constant commensurate with a well behaved system will be $0<\alpha<2$. For values of smoothing constant in the range of $1<\alpha<2$, the filter exhibits high-pass characteristics, the impulse response oscillating at half the sampling frequency.

Remembering that $z = e^{sT}$, we

substitute and commute between domains to obtain the location of the s-domain pole (T is the sampling period).

$$s = \frac{\ln(1-\alpha)}{T}$$

As usual the time constant of the filter is the reciprocal of the system pole. Obviously small values of α give rise to a large time constant and the filter can only track or follow trends slowly, without overshooting the steady state value.

I hope this note helps to put the record straight and encourages readers to think about the statistical analysis of data in signal processing terms.

Howard Hutchings
Humberside College of Higher Education
Hull.

Clipped-sine Fourier analysis

The analysis of a clipped sine wave is not often found in the standard texts, at least in those I have to hand. The results of a little DIY work may be of interest to other readers.

Asymmetrically clipped sine wave. Figure 1 shows the wave $y = v\sin x$ with the negative half-cycle clipped to the value $-v/C_n$ and the positive half clipped to v/C_p. Clipping is usually referred to in terms of "dB clipping"; in this case,

$$dBp = 20\log C_p dB$$
$$C_p = 10^{dBp/20}$$

and

$$dBn = 20\log C_n dB$$
$$C_n = 10^{dBn/20}$$

The onset of clipping in the positive half-cycle occurs at an angle α radians. When

$$x = \alpha,\ y = v\sin\alpha = v/C_p$$
$$v/C_p = v\sin\alpha$$
$$\sin\alpha = 1/C_p$$

or

$$\alpha = \sin^{-1} 1/C_p.$$

Similarly,

$$\sin\beta = 1/C_n$$

or

$$\beta = \sin^{-1} 1/C_n.$$

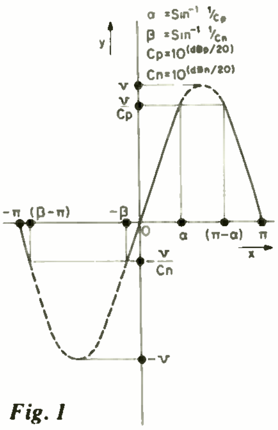


Fig. 1

Note that, with no clipping, $C_p = C_n = 1$ and $\alpha = \beta = \pi/2$; with infinite clipping $C_p = C_n = \infty$ and $\alpha = \beta = 0$; with symmetrical clipping, $C_p = C_n$ and $\alpha = \beta$.

The Fourier equation for the waveform in Fig. 1 is

$$y = \frac{v}{\pi}\left\{\left[\cos\beta - \cos\alpha + \left(\frac{\pi}{2} - \alpha\right)\sin\alpha - \left(\frac{\pi}{2} - \beta\right)\sin\beta\right]\right.$$

$$+ \left[\alpha + \beta + \frac{\sin 2\alpha}{2} + \frac{\sin 2\beta}{2}\right]\sin x$$

$$+ \left\{\frac{1}{n_e(n_e-1)}\left[\cos(n_e-1)\alpha - \cos(n_e-1)\beta\right]\right.$$

$$+ \frac{1}{n_e(n_e+1)}\left[\cos(n_e+1)\alpha - \cos(n_e+1)\beta\right]\cos n_e x$$

where n_e is even

$$+ \left\{\frac{1}{n_o(n_o-1)}\left[\sin(n_o-1)\alpha + \sin(n_o-1)\beta\right]\right.$$

$$+ \frac{1}{n_o(n_o+1)}\left[\sin(n_o+1)\alpha + \sin(n_o+1)\beta\right]\sin n_o x\Bigg\}$$

where n_o is odd, $n_o \neq 1$.

Two special cases are of interest: the symmetrically clipped wave and the half-cycle clipped wave.

Symmetrical clipping. Figure 2 shows the sine wave with equal positive and negative clipping. Angles α and β are equal and dBp=dBn.

The Fourier equation for Fig. 2 is

$$y = \frac{2v}{\pi}\left\{\left(\alpha + \frac{\sin 2\alpha}{2}\right)\sin x\right.$$

$$+ \left[\frac{\sin(n_o-1)\alpha}{n_o(n_o-1)} + \frac{\sin(n_o+1)\alpha}{n_o(n_o+1)}\right]\sin n_o x$$

where n_o is odd, $n_o \neq 1$.

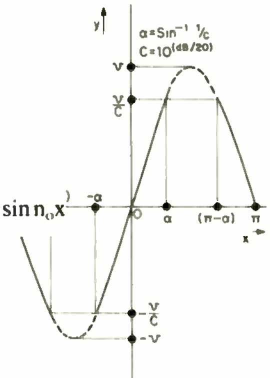


Fig. 3

There are no even harmonics in this case.

Half-cycle clipping. The sine wave of **Fig. 3** is clipped on the positive half-cycle only. Here, $\beta = \pi/2$ and dBn=0. The relevant equation is

$$y = \frac{v}{\pi}\left\{\left[\left(\frac{\pi}{2} - \alpha\right)\frac{\sin\alpha}{2} - \cos\alpha\right]\right.$$

$$+ \left[\alpha + \frac{\pi}{2} + \frac{\sin 2\alpha}{2}\right]\sin x$$

$$+ \left[\frac{\cos(n_e-1)\alpha}{n_e(n_e-1)} + \frac{\cos(n_e+1)\alpha}{n_e(n_e+1)}\right]\cos n_e x$$

where n_e is even

$$+ \left[\frac{\sin(n_o-1)\alpha}{n_o(n_o-1)} + \frac{\sin(n_o+1)\alpha}{n_o(n_o+1)}\right]\sin n_o x\Bigg\}$$

where n_o is odd, $n_o \neq 1$.

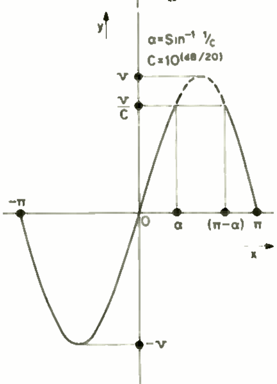


Fig. 2

This reduces to the classic half-wave rectifier Fourier equation when α=0 and the odd harmonics disappear.

James E. Diggins
South Ascot
Berkshire

Harnessing neural networks

Neural networks are more than a laboratory curiosity. They find applications in medical diagnostics, weather forecasting, financial markets. They have the power to make sense out of patterns. Nick Beard and Antonia Jones explain.

Software engineering advances such as 4GLs have made software cheaper and quicker to develop. Nevertheless, a number of areas remains where the 'software bottleneck' is a problem – it's easier to see an application than to code and debug it. A principal difficulty is the so-called 'knowledge acquisition bottleneck' that slows the construction of artificial intelligence and robotics applications.

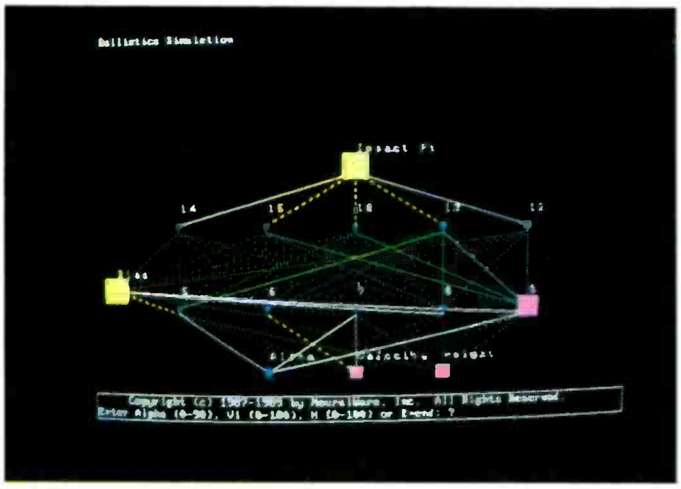
Exhaustively stating the rules required by artificially intelligent systems to deal with all possible circumstances is effectively impossible, even if the principles could be extracted from experts in the first place. Biological systems deal with such problems in a remarkably robust fashion – and they do not need to be programmed, learning instead from experience. The pattern recognition, motor control and memory feats of the world of biology are so impressive it makes obvious sense to try to understand and reproduce the mechanisms involved. The goal is reverse engineering the brain. The result is neurocomputing.

Basics

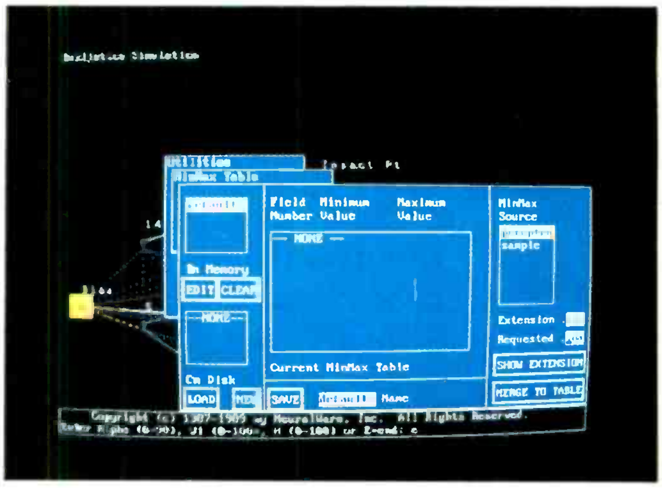
Artificial neural networks are densely interconnected webs of simple processing units – hard-wired or software simulated – that are not programmed but instead learn to solve problems. Such systems mimic physiology by representing neurones (nerve cells) as individual nodes or units. Each unit receives signals from many other units. If the necessary threshold is reached, the unit sends a signal to other units. (See box: what happens in a node?). All the processing in a neural network is carried out by these units – there is no 'executive' or 'overseer.' Networks are trained on data for which 'the right answer' is known, after which they should be able to generalise what they know, responding correctly to novel data. They represent a powerful alternative method of computing and have already found a wide range of applications.

Pattern recognition. An archetypal neural network application is pattern recognition. Almost any pattern recognition problem can be cast in a form suitable for neurocomputing, and the list of examples is very long. Neural nets have not solved all the problems of difficult pattern recognition tasks, but are now a valuable addition to the armoury. For example, they have been used in sonar target classification,

A ballistics simulation using Neural Works software. This network can predict an impact point within 5% of the figure expected by classic calculation.



The PC platform provides a relatively easy method of setting up networks. However, even with user fine tuning from entry fields like these, software nets run slowly.



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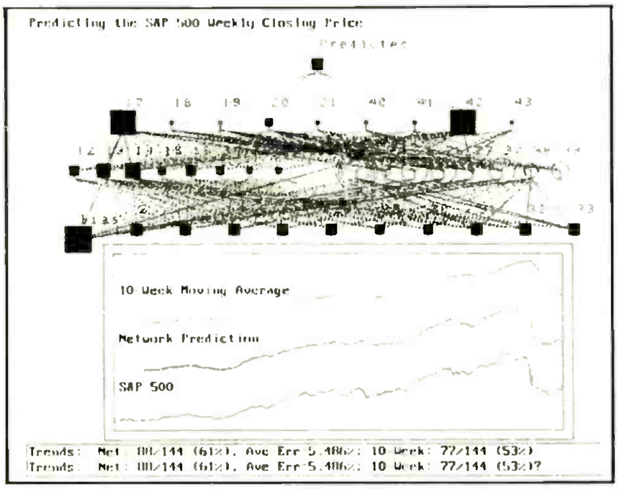

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DAF70	1.75	EF95	1.40	PL519	5.85	1T4	0.75	6F12	1.60	12K7GT	1.15
DAF96	1.35	EF96	0.65	PL802	6.60	1U4	1.25	6F14	1.15	12K8GT	1.25
DET22	32.80	EF183	0.75	PY80	0.90	2X2A	3.80	6F15	3.40	12Q7GT	1.15
DF92	0.95	EF184	0.75	PY81	0.75	3A4	1.30	6F17	3.10	12SH7	1.25
DF96	1.15	EF812	0.75	PY81/800	0.85	3AT2	3.40	6F23	0.75	12SJ7	1.40
DH76	1.15	EFL200	1.85	PY82	0.75	3B28	17.50	6F24	1.15	12SK7	1.45
DL92	1.70	EH90	0.85	PY88	0.60	3D6	1.15	6F33	10.50	12SQ7GT	2.20
DY86/87	0.65	EL32	0.85	PY500A	2.10	3E29	21.85	6FH8	18.80	12Y4	0.70
DY802	0.70	EL34	3.25	QQV03/10	5.95	3S4	1.70	6GA8	0.65	13D3	2.80
E92CC	1.95	EL34*	9.50	QQV03/10	7.50	4B32	35.00	6GH8A	1.95	13D6	0.90
E180CC	9.80	EL82	0.70	QQV03/20A		5R4GY	4.85	6H6	1.60	19AQ5	1.85
E1148	0.75	EL84	1.35		27.50	5U4G	1.85	6J4	1.95	19G3	11.50
EA76	1.60	EL86	1.45	QQV06/40A		5V4G	1.90	6J4WA	3.10	19G6	10.35
EB34	1.15	EL90	1.75		28.50	5Y3GT	3.45	6J5	2.30	19H5	38.00
EB91	0.60	EL91	6.50	QQV06/40A*		5Z3	4.85	6J6GT	1.80	20D1	0.80
EBC33	2.20	EL95	1.80		46.00	5Z4G	2.20	6J6	2.20	20E1	1.30
EBC90	1.20	EL504	2.30	QV03/12	7.40	6/30L2	0.80	6J6W	2.80	20P1	0.60
EBC91	1.15	EL519	7.70	QY4 400	101.60	6AB7	1.85	6JE6C	9.15	25L6GT	1.90
EBF80	0.75	EL821	7.50	SP61	3.20	6AC7	1.80	6JS6C	9.15	25ZAG	1.80
EBF89	0.80	EL822	11.50	TB205/400	88.30	6AG5	0.60	6JU6	6.35	85A2	1.40
EC52	0.65	ELL80SE	4.50	TT21	47.50	6AK5	1.90	6K7	2.20	85A2*	2.55
EC91	5.20	EM80	1.50	TT22	45.00	6AK6	2.85	6KD6	13.75	572B	56.35
EC92	5.55	EM87	2.85	TY-125A	85.30	6AL5	0.60	6L6	7.80	807	3.45
ECC81	1.25	EY51	0.90	TY 400A	94.20	6AL5W	1.50	6L6GC	9.60	807*	4.30
ECC82	0.95	EY81	1.10	UABC80	0.75	6AM5	6.50	6L6GT/C	2.90	811A	13.50
ECC83	1.50	EY86/87	0.75	UBF80	0.95	6AM6	1.60	6L18	0.70	812A	32.00
ECC84	0.60	EY88	0.65	UBF89	0.95	6AN8A	3.80	6LD20	0.70	813	28.50
ECC85	0.75	EZ80	0.80	UCC84	0.85	6AQ5	1.75	6LQ6	9.15	813*	44.00
ECC88	1.25	EZ81	0.80	UCC85	0.70	6AQ5W	2.90	6Q7G	1.50	829B	16.00
ECC189	1.20	GM4	11.05	UCH42	4.60	6AS6	1.15	6SA7*	1.80	829B*	24.00
ECC804	0.65	GN4	6.30	UCH81	0.75	6AS7G	4.95	6SG7	1.80	866E	14.95
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ECF804	4.50	GZ34	2.80	UF85	1.45	6BA6	1.75	6SN7GT	4.35	955	1.10
ECH35	2.75	GZ37	3.95	UL84	1.50	6BA6*	2.20	6SQ7	3.20	956	1.20
ECH42	1.65	KT77**	16.10	UM80*	2.30	6BE6	1.75	6SR7	4.60	6060	1.95
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ECH84	0.90	N78	9.90	UY82	1.10	6BG6G	2.65	6X4	1.50	6136	2.80
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ECL82	0.95	PCL82	0.95	VR105/30	2.75	6BQ7A	3.95	6Y6G	2.80	6336A	33.35
ECL85	0.95	PCL84	0.85	VR150/30	2.75	6BR7	4.80	6Z4	1.75	9001	1.40
ECL86*	1.20	PCL86	0.80	X66	4.95	6BW6	6.10	7ZA	1.90	9002	6.50
ECLL800	17.50	PCL805/85	0.95	YL1210	11.50	6BW7	1.50	9D6	2.15	9003	8.50
EF9	3.80	PD500/510	5.60	Z749	0.75	6C4	1.20	11E2	19.50		
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Image compression. Nets have been used to find efficient representations to enable image specifications to be compressed for transmission. The network was able to retrieve a high-fidelity reconstruction of the image after transmission. (See diagram).

System modelling. Chaotic systems – dynamic systems that are theoretically deterministic but unpredictable in practice – are commonplace. An example is the weather. Many such systems are often treated as random, but if the underlying dynamics can be gleaned, better predictions might follow than statistical methods would suggest. Neural nets are sometimes able to extract the underlying dynamics, and make effective predictions. An obvious application of such forecasting is economic modelling, where the technique has been used to better effect than moving-average predictions.

What happens inside a node?

There are no explicit memory or processing locations in neural networks. Memory and processing capacity are implicit in the interconnections between the nodes. Also, there is no overall supervisor, each node having the same simple features. It is the combined effect of many such nodes acting in concert that gives neural networks their power. A node receives signals, transforms them and sends signals on. Not all the sources of signals will be of equal importance, so a weight – a measure of this importance – is attached to each connection. It is by varying these connection strengths that networks learn. The various inputs to a node are each multiplied by their respective weights and the results added together for the node input total.

As in real neurones – nerve cells – connections may be stimulatory or inhibitory, and in artificial networks this means simply positive or negative weights or signals. The input is then transformed according to the network transfer or activation function. This is usually a sigmoidal curve function, though many varieties of function have been studied, such as step and linear functions. Generally, all that matters is that the function be continuous and non-linear. The mathematics of this observation are beyond the scope of this article, but interested readers are referred to McClelland and Rumelhart (1986). In summary, if the function is discontinuous, then it is non-differentiable, which interferes with the development of the training algorithm (see box Back propagation). If it is linear, then the advantages of multiple layers are lost (see box The hidden layer).

It is important to distinguish between two phases of network operation: learning and recall. These are determined by whether or not the node interconnections weights are variable.

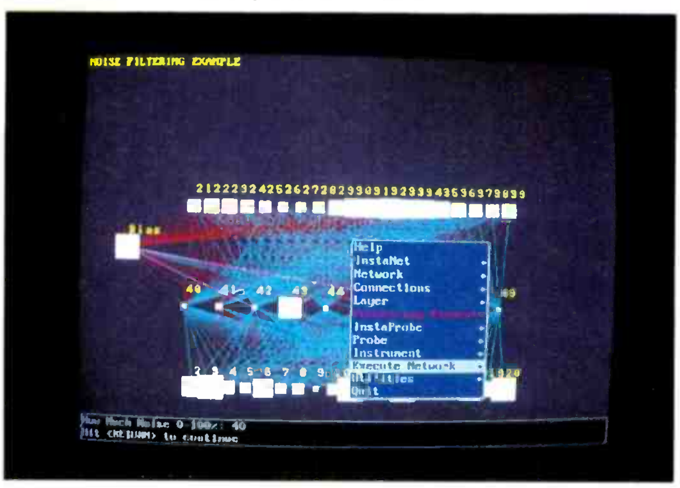
Getting the job done

The process of developing a neural network remains something of an alchemic business. Nevertheless, some principles are emerging. The first question, as in any software development programme, is to decide precisely what you want the system to do. With neurocomputing, this means "asking the network the right question", teaching it a meaningful classification system. For example, in training a credit-rating network, it is better to teach it to classify cases as "lend", "do not lend" or "refer" than to predict an accurate loan risk probability. Further questions include: what network paradigm should be used? Should it be supervised or unsupervised? How should the data be represented? Should the application be fresh-coded, or is an off-the-shelf package available?

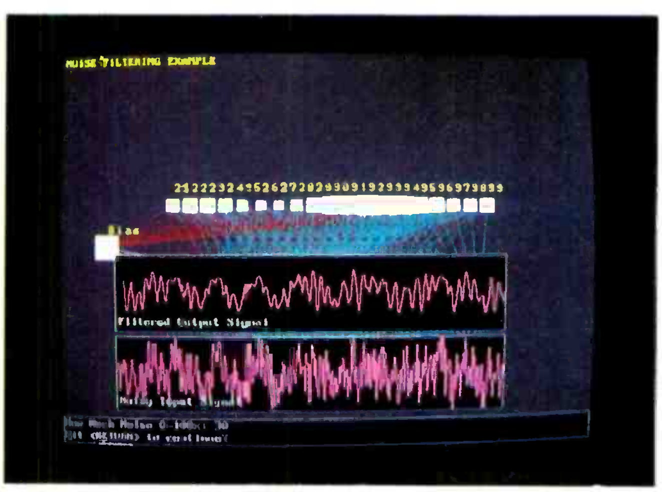
There are a number of different paradigms to choose from, each with distinct strengths and weaknesses. A network is defined by three attributes: the network architecture ('wiring diagram'), the transfer function (formula individual units use to process signals), and the training algorithm (the method by which the interconnections are adjusted in the light of experience). For detailed discussion of these, readers are referred to Wasserman (1989).

A further distinction is between supervised and unsupervised nets. Unsupervised nets are simply presented with data, and self-organise without any external guidance (such as from the programmer). One example is the Kohonen topologising network. This is a matrix of units with interconnections that are stimulatory to near neighbours but inhibitory to more distant units. This is deliberately 'wired' after the human cerebral cortex. On presentation of each item of the input data, the interconnection weights of the maximally responding node are updated. There is no 'correct answer', the weights are changed by some fraction of the difference between the weight and the input signal. The network converges on a 'feature map' of the data used to train it. One example of an application for these networks is

Noise filtering with Neural Works. The input and output layers use the same number of processing elements so that the filtered signal may be accurately reconstructed.



Results of processing: the lower trace shows the original trace with 30% noise addition, the upper trace the filtered result.



the phonetic typewriter, already being implemented commercially.

In contrast, supervised networks use sample vector pairs (input and output) which are presented to the network in sequence. Desired outputs must be known, unlike unsupervised nets. A training algorithm is applied to the network to adjust the inter-node connection strengths and effect learning.

The simplest supervised network is the perceptron, which was developed in the 1950s by Frank Rosenblatt. This is a network with only one layer of adjustable connections, and can learn to classify patterns into two categories. It has significant limitations, however, which were recognised by Marvin Minsky and Seymour Papert. Their book, *Perceptrons*, effectively stopped neural networks research for two decades. Readers interested in a more detailed history of neurocomputing are referred to Simpson (1990). (See box: hidden layer.)

The hidden layer

There are usually three types of node: input, output and hidden. These are arranged in layers, usually fully interconnected between layers – i.e. each node is connected to every node in the adjacent layer. Input layers have their activation set by the user: this is the data input. These input signals propagate through the network until a signal is formed at the output layer. So the user has 'direct access' to the input and output nodes. However, in between are the hidden nodes. These are necessary for the network to form 'internal representations' of problems. Without them, there are severe limits on the types of problems that nets can solve. Specifically, they are unable to classify items that are not linearly separable (see Fig.1). The classic example is the exclusive-Or (XOr) problem (A or B but not both). To solve XOr (and similar) problems, more layers are required, to enable the network to build an internal representation of the problem.

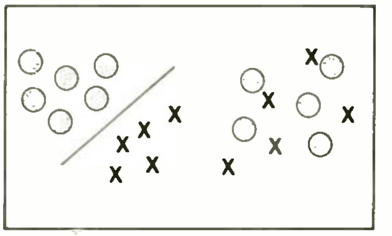


Fig. 1. simple nets can only solve simple problems

However, the user has no direct connection with the hidden nodes, so training them is difficult: how can we know how these nodes should behave? According to Minsky and Papert, seeking such solutions was likely to be a sterile project. In fact, solutions to this problem prompted the resurgence of research and investment in neural networks in the last decade. One of the most successful has been the back-propagation of errors method, (see box Back propagation), another is simulated annealling.

Solutions

Several techniques were developed which did overcome earlier limitations. Back-propagation of errors, (see box: back-prop) has proved a reliable 'work-horse' approach. Back-prop nets are multi-layered perceptrons, with a gradient descent learning method that also finds weights for hidden layers in the network. Patterns are presented to the input layer of the network, producing a random output because all the initial node-interconnection weights are random. These weights are then modified by the back-propagation algorithm. The difference between the random output and the desired output is used to derive an adjustment factor which is then propagated back through the network, changing the weights. The network error gradually converges on a solution – as a set of weights that produce the desired output for all the training data is found. The network should then have generalised – and be able to classify patterns it has never 'seen' before.

A fast variant of back-prop is the functional-link network, where the dimension of the pattern representation space is expanded. An example is where additional inputs are provided to the network, using trigonometric functions applied to the raw impute data multiplied by factors of π.

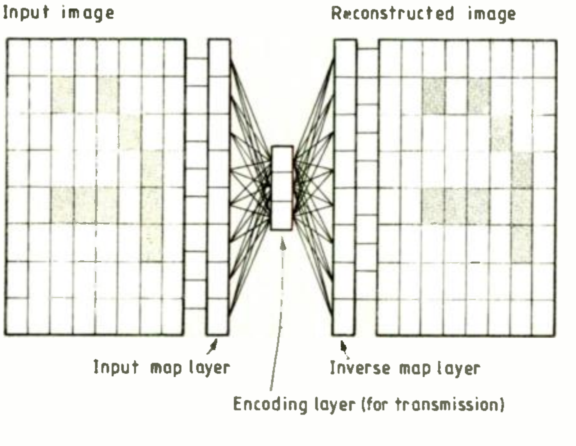
For example, if the input pattern is (x_1, x_2, x_3), we may instead use $(x_1, x_2, x_3, x_1x_2, x_2x_3, x_1x_3, x_1x_2x_3)$ or some pruned subset of these parameters. The obvious disadvantages of this approach is that the scale of the input layer can rise dramatically. However, the resulting network learns very quickly, and if the dimensional enhancement is carried out appropriately, only a single layer network is needed.

A network does not always immediately converge on the ideal solution. The output error may settle on a stable high-error value, or else may oscillate wildly between high and low error states. The process of training a network is one of searching an "error surface" for the set of interconnection weights that will solve the problem. This "surface" is in fact a high-dimensional space, with each dimension representing the weights for a particular node. Networks are trained by some means of determining the lowest error point in the space.

Nets in hardware can perform image compression and reconstruction with a useful degree of accuracy.

What happens?

The basic operation of neural networks is classifying patterns. This is roughly equivalent to 'curve fitting' in the high-dimensional space, though in a fashion that is not yet susceptible to rigorous mathematical analysis. A problem when training a network on complex datasets is 'false minima'. The training process involves searching an error 'surface' by gradient descent, and the network can sometimes get stuck in an error pit that is not a sufficiently low error to give a useful solution. One approach is to add noise to the weights at each learning cycle, to jolt the network out of false minima when necessary. Oscillating weights are com-



batted by adding an extra term – called momentum – to the error signal (see box on back prop) in the learning algorithm, to keep the network moving rapidly towards the required solution, but slowing it down as it begins to converge and becomes more sensitive to weight changes.

Data representation

With a singlee layer of input nodes, data representation requires some thought. Is the representation to be digital or analogue? The choice depends on the type of data involved, and its suitability to a digital representation. In addition, an analogue representation makes less sense if the output nodes use a clipped (threshold) transfer function.

The next choice is between local and distributed representations. Representing the 26 letters of the alphabet with a local representation would require 26 digital nodes, each one representing a different letter. A distributed representation could represent the numbers 0 to 8 with three nodes using binary coding. There are variants on these themes, such as using a 'histogram' representation along the input layer. A local representation requires less learning by the network.

It is not always clear how a network has solved a problem, and so its conclusions must be checked empirically. At least a third of the available data should not be used in training the net, and should be retained for testing.

Back propagation

Back prop is one of the most widely used methods of training neural nets. This was developed independently by several people, but was made widely known after cognitive scientists Rumelhart, Hinton and Williams described it in *Nature* in 1986. It had the immediate effect of answering Minsky and Papert's criticisms of perceptrons that had stifled neural network research.

In order to train a back-prop net, a series of patterns for *which the correct answer is known* is presented to the input layer of the network. This could be state of the stock market for which the next days' prices are known. After each pattern in the series, the actual output of the network (which will usually initially be random) is compared with the desired output. This difference is 'fed into' a formula based on the first derivative of the network transfer function, to derive an error signal – positive or negative – that is then added to all the nodes in the network.

This method will gradually minimise the output error, though it is only guaranteed to find the local minimum, not the global minimum. Repeated attempts at training the net may be necessary to optimise its performance.

"It is not always clear how a network has solved a problem and so its conclusions must be checked empirically"

Software: program or purchase?

A frequent question when about to embark on any project is 'package or bespoke'? Should you buy off-the-shelf software, or code-up from scratch? There are no simple answers. If the goal is to produce working nets quickly and with the minimum of fuss, then it makes sense to use one of the commercial packages. An examination of commercial software provides insight into the development process.

NeuralWorks. NeuralWorks Professional-II is an advanced network development environment, available for PCs, Mac, Sun workstations or N-Cubes. It is mouse-and-menu driven, enabling a wide variety of customisable networks to be selected and configured to any particular application. An outstanding feature of the software is the documentation, which contains a text-book-quality introduction to neurocomputing as well as a detailed description of how to use the software.

The networks 'provided' within NeuralWorks include: Adaline, ART1 (adaptive resonance theory), BAM (bidirectional associative memory), numerous back-prop variants, counter propagation nets, Hamming, Hopfield, Madaline and Perceptron networks, and many others.

The opening menu includes help, Instanet, and various network definition options (layer, unit, connection, etc). Instanet is a quick way to get started. It provides ready-made constructions of most of the common neural net paradigms, which are readily user-definable to fit particular applications.

The network is initialised with random or user-defined weights, and then needs to know the title of the training data files. A further menu option is used to display an 'Instrument', which is a graphical representation of any of the network parameters. Commonly this will be the output layer error, but other values can be displayed if of interest.

Data preprocessing will almost always be required in neurocomputing applications. For example, when data items are absent some alternative value is needed, usually the mean for that field. NeuralWorks minimises the trauma of I/O handling. Node transfer functions expect input values between 0 and 1, and usually constrain the output to that range too. This can be an added complication to the data preprocessing stage, but NeuralWorks helps by scanning input files to find the minimum and maximum 'real world' values to produce a 'MinMax' chart. The user can then specify the range of values to be presented at each input field. Scales and offsets are calculated automatically. To make life even easier, NeuralWorks accepts data in numerous formats, including "*.PRN" as used by Lotus 123 and Excel, binary, and its own ASCII-based format. Users can write their own I/O functions, to be called by NeuralWorks.

A recent addition to the program is the *User-defined Neurodynamics* add-on, which allows advanced users to develop their own summation, transfer, output, error and learning functions in C, and to link them to NeuralWorks. Samples are provided to suggest methods of implementing novel functions.

NeuralWorks is a serious package, for real applications. It would as well serve a neurocomputing lab as it would an industrial computer consultant operating in this field (and there are an increasing number of them!). NeuralWorks can be also used in conjunction with the *Designer Pack*, which takes networks that were trained and tested in the NeuralWorks development environment, and turns them into C source code. As the product promotional leaflet notes: *I did it on my PC but the boss wants it on the mainframe!*

NeuralWorks is an extremely powerful package, offering a good combination of flexibility and functionality. It places neurocomputing properly in the world of real engineering. ■

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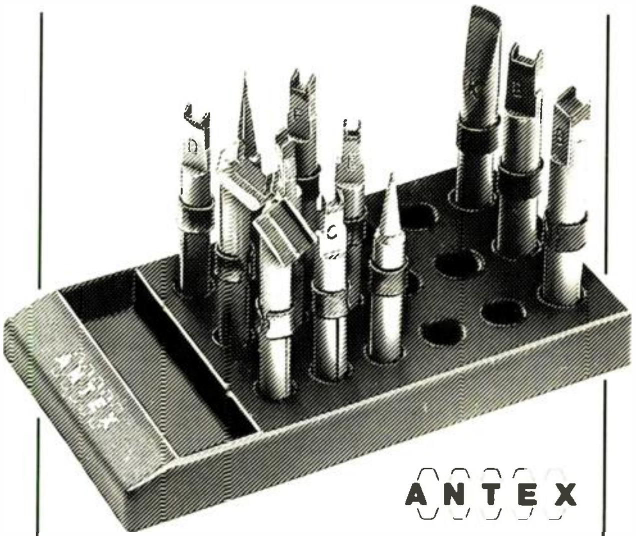

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Neural nets and fuzzy sets

An evaluation kit from Tubb Research demonstrates the application of a MD1210 fuzzy set comparator, which uses a neural network to compare data with known patterns.
Steven Franks

The Fuzzy Set Comparator evaluation kit is based on the MD1210 chip from Micro Devices, which allows the comparison of an unknown set of data against several known patterns to find the closest match even (or especially!) when the data doesn't match exactly.

MD1210

In the MD1210 chip, a serial input data stream is compared with patterns previously stored in memory — ram, rom or both. If the input stream is not too different from one of the stored patterns, a match is declared (see **Fig. 1**).

Each chip compares its input with up to eight patterns, and up to 32 chips can be interconnected to compare simultaneously 256 patterns with one unknown. Each pattern may be up to 64K bits long (longer with extra hardware), and can be formatted as words from 1 to 8 bits wide; the chip takes care of mapping, say, an 8K by 8-bit image into the 64Kbit memory. MD1210 performs many comparisons in parallel and at high speed, the unknown input pattern being accepted at up to 20Mbit/s.

An unusual aspect of the 1210 is that it uses a neural network internally to identify the nearest matching pattern. Surprisingly, it doesn't use the network in the matching process directly, but as a replacement for conventional logic to determine the least of eight 16-bit accumulators. An incoming pattern is converted to parallel words, and compared, word by word, with the known patterns stored in memory.

A difference value is accumulated for each of the known patterns, as the sum of the absolute difference between the known and input words. Thus, after the unknown pattern has been input, each of the known patterns will have a 16-bit value which indicates how close it was to the input pattern. The "winning" pattern is the one with the lowest closeness value, provided that it is not greater than a preset threshold value.

The neural network, which is entirely pre-programmed to perform its task, and cannot be altered, performs this final comparison of eight 16-bit values, together with the threshold

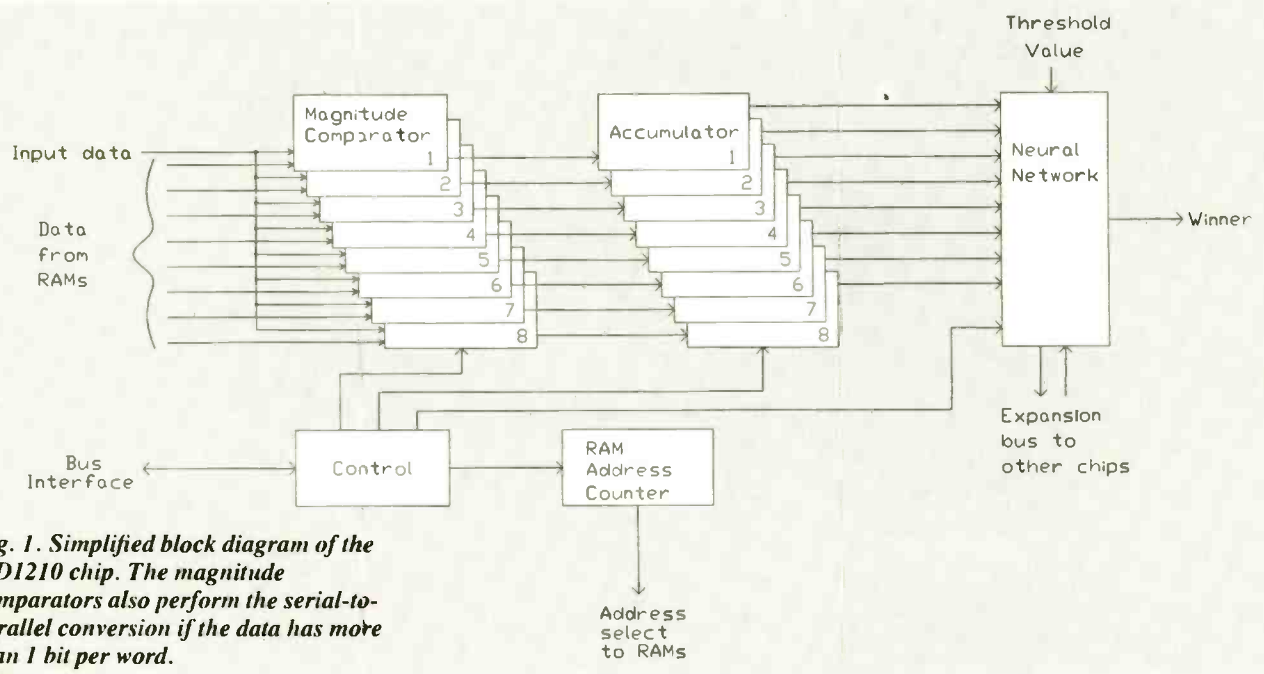


Fig. 1. Simplified block diagram of the MD1210 chip. The magnitude comparators also perform the serial-to-parallel conversion if the data has more than 1 bit per word.

value and those from any other connected 1210 chips. It is interesting to see the technology appearing in this way, as a means to an end rather than the core around which the rest of the system is based.

Evaluation kit

A PC card carrying one MD1210 chip and software that runs under Windows version 2 compose the kit. Run-time Windows is supplied for those people that do not already have it. There are 64Kbit of ram for each of the eight channels and a video input that can supply the "unknown" data, which can be stored for later recognition.

Documentation takes the form of a data sheet for the 1210 and a manual for the kit in the form of a spiral-bound book containing installation instructions, an overview of the 1210, a section on Fuzzy Logic theory, a full description of the hardware and a series of experiments that demonstrate the 1210. However, some of this is superseded by a UK update, which sometimes makes it hard to find information easily. Update UK1.00, which does not correspond with the software, came with the kit and caused some confusion, but Tubb Research was prepared both to post and to fax the correct version (UK1.01).

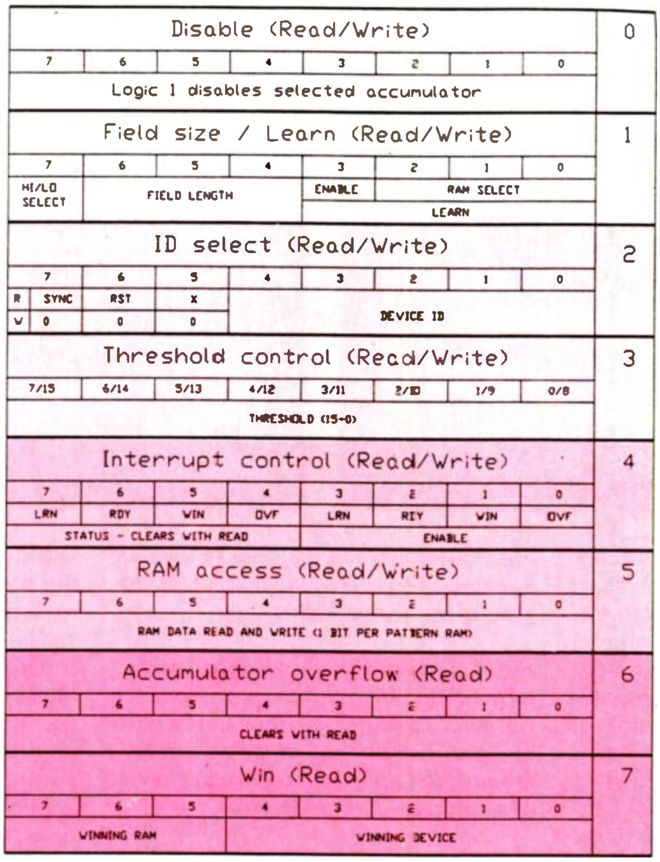


Fig. 2. MD1210 register set. The eight accumulators can also be read, so that the chip needs a total of 16 addresses. Bit 7 of register 1 controls access to the high and low bytes of 16-bit values.

Software

Running under Windows allows the software to present a pleasant face to the world. It allows a wide range of control, from bit manipulation of the 1210 registers through to demonstrations of the chip's abilities, using pictures. The diversity of commands would be confusing if it were not for the experiments described in the manuals, which give clear demonstrations at all levels.

A main screen always shows the current contents of all the 1210 registers, which can be changed merely by overtyping with new values (**Figs. 2** and **3**). The system defaults to showing control registers in binary, and address and counter registers in hexadecimal, but allows hex. and decimal respectively as an option.

Apart from setting the registers, the screen allows control of the mode of the 1210. In normal use, a comparison would take the chip through at least three of its four modes: reset, which does what its name suggests; data entry, which allows the input of unknown data; and report, which tells the chip to perform the comparison of the accumulators. The fourth mode, wait, is entered at any time — including between bits of input data —, to allow any synchronisation required. In the kit, data entry is from the video input, a disk file or one of the rams; in this last case that ram would normally be excluded from the comparisons.

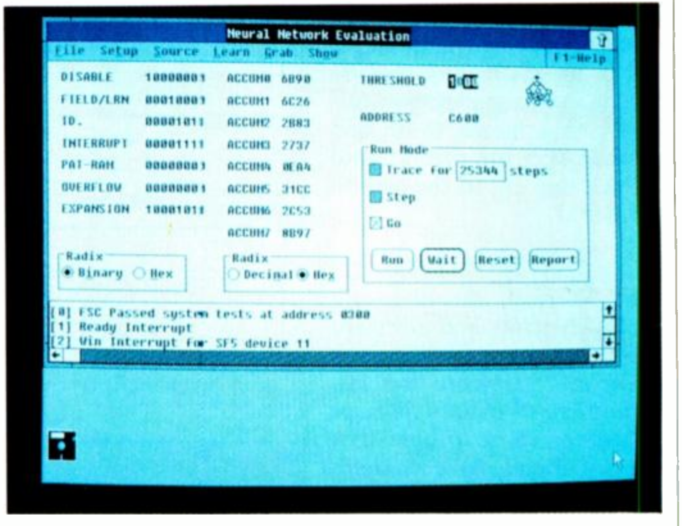
Another scrollable window, attached to the main window, shows a history of interrupts generated by the chip. Although the card can generate true interrupts, under the Windows software these are disabled and the 1210 registers polled to produce this information. The number of interrupts remembered was a little unpredictable (perhaps it is dependent on memory) and, when scrolling back, the first few lines of the list always contained rubbish. However, it never failed to recall at least a dozen messages, which would be enough for most purposes.

In the 1210, any one of the ready, overflow, learn or win conditions triggers interrupts, which can be selectively disabled. Overflow occurs during the data entry mode if any of the accumulators cycles past FFFF(hex), although the chip will automatically remove the accumulator from the comparisons. A learn interrupt is caused by an incoming data stream that has been written to ram not matching any existing data (i.e. a new picture has arrived). Ready and win interrupts are self-explanatory.

One can open further windows to display the contents of each of the pattern rams. If system memory allows, all eight can be on screen at once, although this leaves very little screen area for anything else! This is only of real use when working with the video input (or the sample images supplied), but does give a distinctive pattern for other data. Video input is monochrome only, but the pictures can be displayed in mono or false colour, as in **Fig. 4**. The system maps each of the grey levels to a different colour, which surprisingly results in a better display than the straight monochrome image.

To load the pattern rams, the chip has a "learn" variation of the data entry mode, which channels the input data into a selected ram; comparison with the other rams can be performed simultaneously. In the development system, the software allows many or all rams to be loaded from different files in one operation and gives the rams the name of the file from which they were loaded.

Video input provides an excellent example of the capabilities of the chip. It grabs 192 samples per line, every other line, in the odd frames only, the samples being in the form of 2-bit grey scales. This sampling method reduces the data to fit into 64Kbit, but still leaves (just) recognisable pictures. Having learned several pictures, the chip will decide whether live input from the camera matches any of the known scenes. Despite the fact that the kit runs the 1210 at nowhere near full speed, matching is effectively instant; the only delays are caused by updating the on-screen display of the incoming image, if present. It is here that a fast processor and display card are highly



desirable, as they both significantly affect the screen update rate.

Since there is rudimentary control of contrast and no brightness adjustment at all, the interface supplied would not be suitable for a final production system. However, as a demonstration of the 1210, it is quite spectacular and I had no difficulty in connecting a camera. Synchronisation was not perfect with videotape output, but with the adjustments provided (hardware contrast control and software for synchronisation), the camera performed perfectly.

Using the development kit, incoming pictures can be learned into memory and subsequently stored on disk. Stored pictures can be printed (using any printer supported by Windows), but the system does not appear to allow for the grey-scale information, with the result that printed output does not exactly match the data the chip is "seeing". Given that the pictures are small, it would be better to enlarge the printed area by a factor of two in each dimension to allow a simple dithering technique to show the four levels of grey.

Fig. 3. Main screen. Register values can be changed by overtyping, except the top bytes of the accumulators.

Fig. 4. Images displayed in mono and false colour. Default size is optimised for fast screen updates, but they can be sized and stretched like any window. "Linda" is one of the sample images, which are all of employees of Micro Devices.

While being transferred to and from disk, any picture may have noise added to it in 0.01%, 0.1%, 1% or 10% increments, as in **Fig. 5**. This is used to demonstrate matching when no video source is available and is a good demonstration of non-exact matching. The chip was most impressive in its ability to recognise correctly pictures buried in noise, although in a real-world application this would depend on the images to be recognised being sufficiently dissimilar.

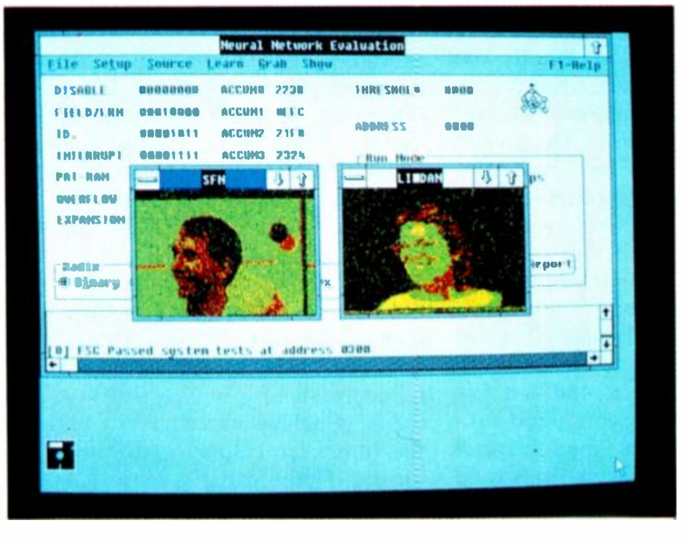


Fig. 5. Testing pattern matching ability with video picture material. The development board could happily sort out pictures with up to 10% added noise superimposed on the signal.

The development system concentrates on the video images, because these provide a good demonstration of the 1210. However, there is full support for those wishing to experiment with their own data. A separate application note describes modifications to the video interface to accept other signals and full circuit diagrams (including listings of the pals) are included.

Software drivers are provided in source form and are very comprehensive, including a number of routines which are not directly relevant to the 1210, but which might prove useful. The interface code used in the development kit is also included, as a working example. All the code contains enough comments to be readable to a competent C programmer and is in Microsoft C 5.1 (apart from a minor excursion into 8086 assembler for the display example), but should be transportable to other systems with little effort. The manual is at pains to point out that the code is non-proprietary, and may be modified and used as desired without incurring royalties.

Applications

MD1210 is probably at its best in a dedicated (or turnkey) system, rather than being added to a general-purpose computer such as a PC. Any system that performs pattern matching could benefit, although the best gains would be where the patterns to be matched are at least several kbit in size.

Used directly with raw data, the chip has many applications based on pictorial input, either from a video camera or a flat-bed scanner. Possibilities that spring to mind include production-line quality-control systems, especially those where slight variation is acceptable, such as in food or confectionery production, simple character-recognition systems and paper currency recognition. Systems could also find use in medical or biochemical laboratories to automate routine tests. Non-pictorial uses might include noise analysis of machinery to detect faults before complete breakdown — an application that is currently very expensive to implement.

One problem with all the comparisons is that the chip cannot cope with "offset" data when the object in a picture is slightly to the left or right of the learned pictures. However, in many cases it may be possible to eliminate this by pre-processing the data; for example, rather than attempt to match speech input directly with "known" words, the speech could be analysed into sound type and length, and this data compared with known values. Similarly, rather than comparing pictures of fingerprints directly, which would not allow for stretching or other distortions, one could analyse relative positions of ridges, and match the resulting data.

System requirements

The FSC evaluation kit requires at least a PC capable of running Windows, i.e. 512K memory and a graphics screen. A mouse is recommended. To make best use of the kit, Tubb recommend a minimum of an EGA screen and a 12MHz i286 processor and they claim excellent results from a 16-bit VGA screen with a 25MHz i386.

Conclusion

This kit is one of the best I have encountered; it has been well thought through to provide an excellent introduction to the 1210 chip. Documentation would be improved by incorporating the addenda into the main book, but the existing organisation is not a major drawback. The kit makes it very easy to learn the capabilities of the 1210, and it can answer most, if not all, of the small but important detailed questions that always crop up during the design and testing of a product.

The MD1210 chip itself is a capable device, which can perform fuzzy comparisons which would be prohibitively expensive to implement any other way. I would prefer to have a parallel input function, although this would need extra pins. They could be found by changing the memory interface to a multiplexed form suitable for dynamic memories and the chip could then also provide the refresh function. However, this would make interface to roms more difficult, so there are arguments for both sides.

I would recommend anyone who thinks they may have an application for this chip to get the evaluation kit. Even if you don't use the chip after all, you can have fun learning about it! ■

Supplier

The FSC evaluation kit costs £499 + vat and is available from Tubb Research Ltd., 7a Lavant Street, Petersfield, Hampshire GU32 3EL Telephone: (0730) 60256 Fax: (0730) 60466

Lose the CFCs; keep the profit

The ozone layer is under attack by chlorofluorocarbons used by the electronics industry, among others. Debora MacKenzie points out that ozone-friendly alternatives could make financial sense

The electronics industry is at the heart of the struggle to save the earth's ozone layer. Companies that make semiconductors use ozone-destroying chemicals that, under a UN agreement, will be illegal in ten years. Some firms are panicking, some are trying to ignore the inevitable and more are desperately awaiting substitutes — which chemicals companies will be happy to supply, at a price.

Others have looked beyond the old processes and discovered that what is good for the ozone can also be good for corporate profits.

Ozone depletion

Ozone (O_3) is often portrayed as a "bandwagon" issue promoted by a fashionable environmental movement. It is not; it is the layer of gas in the upper atmosphere that shields life on earth — all life, from people, to the algae in the sea that produce our oxygen — against harmful rays from the sun. Ozone is destroyed by chlorine. Several chemicals invented in the 1950s, notably chlorofluorocarbons (CFCs), have turned out to be remarkably good transporters of chlorine to the upper atmosphere. Scientists have proved beyond any doubt that these chemicals are destroying the ozone layer.

Ozone has already diminished by an average of 3% over the whole planet, with heavier losses over the temperate zones of the northern hemisphere and so much damage over Antarctica that it is called an "ozone hole". As a direct result, increased amounts of deadly ultraviolet light are already hitting the earth's surface. Ultraviolet that normally gets through is enough to cause suntan and sunburn; increased amounts will cause damage ranging from cataracts and skin cancer to dead wildlife and damaged crops.

In 1987 scientists working for the UN convinced many of the world's nations to sign a treaty limiting the production of chemicals that destroy ozone. Last June, in the face of yet more worrying scientific evidence, many more countries signed up. They strengthened the treaty so that most of the worst chemicals will be banned by the year 2000.

Printed-board cleaning

This leaves electronics firms in a bind. After assembly, electronic circuit boards must be cleaned of dirt and grease, and particularly of the residues of solder flux. Such debris can cause shorts and malfunction. Many firms use CFC-113 as a cleaning fluid, since it is a good solvent, easy to handle and chemically inert. It is also responsible for

Semiconductor makers: looking to water to save the ozone layer?

16% of the ozone damage so far. It will be illegal in ten years.

Some companies, and surprisingly some of the most innovative when it comes to products and marketing, have reacted as though they had lost a favourite toy. The Japanese electronics industry officially "sees no effective solution other than conservation of CFC-113 . . . within ten years". This means using it, but keeping it from evaporating readily.

That is probably the best short-term way to cut emissions of CFC-113. The US Environmental Protection Agency says taking more care with CFC-113 can "cut the cost of operating the solvent machines in half". Margaret Kerr, head of safety at Northern Telecom, Canada's largest electronics manufacturer, says replacing manual cleaning procedures with closed, automated cleaning machines cut consumption of CFC-113 from the usual two kilograms per square metre of circuit board to half a kilogram.

This might cut emissions in the short term, but CFC-113 is long-lived and hard to destroy, and eventually must end up in the ozone. Recognising this, the ozone treaty bans both its manufacture and trade. Not even products made with CFC-113 will be legally exportable to countries that have signed the treaty, which include all of Europe and North America, Japan, the Soviet Union, Australia, India, China and others. This provision, and the looming export problem it entails, seems to have gone unnoticed in Taiwan, which has held out against signing the treaty and recently invested in production facilities for CFC-113.

Instead of such stonewalling, other electronics firms are hoping to be rescued by the companies that brought them CFC-113 in the first place. "As an industry, we are leaning on our chemicals suppliers, hoping they will come up with substitutes," says the environmental manager of one American semiconductor company.

Chemicals suppliers, despite feverish research over the past few years, have not yet produced an alternative. CFC-113 is used because it is stable, but it is this very property that allows it to persist in the atmosphere long enough to reach the ozone. Substitutes in the same family of chemicals that do not harm ozone must therefore be less stable.

This means that they are not the simple "drop-in" substitutes companies want, but require investment in different handling facilities, notably to prevent combustion. This is true of HCFC-141b, a hydrochlorofluorocarbon produced by the British firm ICI. The American company Du Pont makes HCFC-141b more stable by blending it with methanol and another new relative of CFCs, HCFC123.

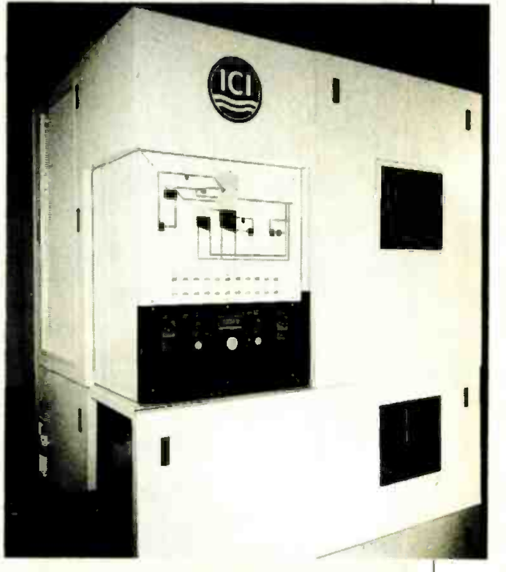
There are problems with both approaches, beyond the investment required for new equipment. One is that the new relatives of CFCs are less damaging to the ozone, but not wholly safe; HCFC-141b can cause 10% as much ozone depletion per molecule as CFC-113. Scientists are also finding that these chemicals share another unhappy property with CFCs: they are powerful greenhouse gases, and add to the global warming now worrying scientists.

Hence, the new CFC substitutes themselves could well be banned under impending versions of the ozone treaty, or under treaties now in the works that will limit greenhouse gases. This may turn out to be no bad thing for electronics firms, since the substitute chemicals and blends are all patented. Chemicals firms are being discreet about prices, but admit they will cost some three times as much as the old CFCs.

This stands in stark contrast to estimates compiled this year for the UN on the costs of adhering to the ozone treaty. The US Environmental Protection Agency estimates that replacing CFC-113 with water-based cleansers, instead of chemicals similar to CFCs, could require an investment, for each cleaning machine, of $10–13,000. But then, the annual operating costs of the machinery fall by $1800 to $25,000, which means that even the most expensive new equipment will have paid for itself in five or six years, something that would not be true of the new equipment required to handle HCFC-141b.

Introducing water-based cleansers does require some thinking, because none is a universal substitute for CFC-113. Some are better suited to some applications. They include simple deionised water, squirted at high pressure, or mixed with alcohols or detergent-like solvents called saponifiers. Such mixtures can be cleaned and

Plugging the leaks



The chemical industry takes the view that water-based cleaning processes cause pollution problems of their own. Aqueous cleaning creates effluent comprising a mixture of water, cleaning chemicals and oily residues. While there is more contamination in the cleaning fluid than the rinse water, the latter is discharged in large volumes. Chlorine-contaminated dirty water in bulk is expensive to purify before discharge.

ICI advocates the use of sealed, volatile solvent cleansing chambers (shown in the photo) to remove manufacturing residues. These chambers release only small volumes of solvent to the outside world through the use of solvent recovery systems. This, claims ICI, could allow the use of CFCs and related compounds with minimal damage to the environment.

Ozone-friendly profit

Environmental groups declared last year that creative, money-saving options to ozone-damaging chemicals are being neglected, because "private investment into alternatives (to CFCs) is disproportionately controlled by the CFC-producing companies who are overemphasising the development of close variants of the current chemicals". One can hardly blame the chemical companies for this. Du Pont and ICI can make no profit selling small volumes of propane to refrigerator manufacturers, or deionised water or propanol as a cleaning solvents to electronics firms.

Those consumers will make the final decisions about what technology is adopted to replace CFCs. In the end it may depend on how much access they have to information about alternatives to CFCs that are cheaper, safer, and more profitable, if not for the chemicals industry, then for the users. Alternatives will, by law, have to be found. In electronics, it is already clear that alternatives to CFC-113 are available that will cost less, protect ozone better, pay for themselves faster, and perhaps even work better than the replacements on offer from your usual chemical supplier.

The semiconductor industry uses significant quantities of hazardous chemicals and has long been aware of environmental safety issues.

recirculated to avoid problems with disposal of waste water.

Sweden has pledged to rid itself of CFC-113 by next year. Husamuddin Ahmadzai, of Sweden's National Environmental Protection Board, says the best results in Swedish factories have been obtained with alcohols, such as ethanol and isopropanol, which are cheap and plentiful. They are also flammable, but using enclosed cleaning machines filled with nitrogen defeats this problem. The solvents are so cheap, he says, that equipment pays for itself by saving what would have been spent on CFC-113.

Swedish companies are also trying to avoid the cleaning process altogether, says Ahmadzai, by using laser welding or conducting glue instead of solder. Low-solid soldering fluxes that leave less residue can be used without cleaning, for any circuit board that can tolerate contamination of up to the equivalent of one microgram of salt per square centimetre of board. Aqueous cleaning leaves one-fifth of that, while alcohols exceed the exacting US military standard, says Ahmadzai. Kerr, of Northern Telecom, says some circuits need not be cleaned to as high a standard as they often are.

Northern Telecom is one of several companies experimenting with Bioact EC-7, owned by AT&T and developed by PetroFerm, a company based in Florida. It is a water solution of terpenes, which are oily chemicals extracted from orange peel; Kerr says it can work better than CFC-113. It is flammable, but enclosed cleaning machines solve the problem. Since such machines are also necessary for other means of cutting CFC-113, such as preventing evaporation or switching to HCFC-141b, companies could find it more profitable to switch straight to aqueous cleaning and use a cheaper solvent.

Such lateral thinking, away from dependence on the same chemicals companies that sell CFCs, has been rare in the response of industry to the ozone treaty. One reason for that could be an innate reluctance to abandon long-established buying practices or to invest in new technology. It could also be that the researchers working on innovative solutions to the replacement of CFCs are not in big, well-funded, well-publicised chemicals companies, whose interests lie with a new generation of patented chemicals.

Refrigerators

Replacement of CFCs as coolants in refrigerators, for example, is widely assumed, even by advisors to the UN, to depend on the next generation of chemicals similar to CFCs. Like the proposed substitutes for CFC-113 as a solvent, the substitutes for banned CFC-12 or CFC-11 as refrigerants are themselves damaging to ozone or they are greenhouse gases. At the very least, they are going to be three times as expensive as the chemicals they are meant to replace.

This is not true of propane, a simple hydrocarbon that is a more efficient transporter of heat in cooling equipment than CFCs. The refrigeration industry used to use propane, but abandoned it when CFCs were invented; the ten or more litres of propane coolant that an average home refrigerator then contained was a fire hazard. Modern refrigerators contain only about 100ml of coolant, however, making propane once again a cheap, attractive option.

It has not been considered by major companies, says John Missenden, head of the Institute of Environmental Engineering at South Bank Polytechnic in London, because of "entrenched attitudes" in the refrigeration industry. He thinks propane can be used as the coolant in an average refrigerator without hazard, pointing out that there is often more propane in a table-top cigarette lighter. And propane, Missenden notes, costs a mere 50p per kilogram, while HFC-134a, the replacement for CFCs proposed by the chemicals industry, will cost £30 per kilogram.

HFC-134a is also a greenhouse gas. This September, an international panel of scientists advising the UN strongly recommended that such substitutes for banned CFCs, even if they do little to deplete ozone, be avoided, or they will contribute heavily to global warming. This dims the long-term prospects for HFC-134a.

The same story of neglect is true of another technology, absorption refrigeration, in which common chemicals such as water and ammonia can transport heat. Such refrigerators make no noise, because they do not use mechanical compressors to re-condense the coolant and release its heat. Instead, it is absorbed by another chemical, such as lithium bromide. Georg Alefeld, of the Technical University of Munich, says absorption refrigerators can even run on less energy than standard models.

Insulating materials

Half the CFCs in a refrigerator, and 21% of all CFCs, are in plastic foam, used as insulation, packaging and upholstery. The chemicals industry has proposed HCFC-123 and HCFC-141b to replace the banned CFC-11 now used to puff up foams. Both can deplete ozone and are greenhouse gases. HCFC-141b is flammable.

The European Isocyanate Producers Association, which groups the major foam producers in Europe, says it has cut its use of CFC11 by 70%, partly by using water as well as CFC to blow the foam. It says HCFC-123 and HCFC-141b will allow the foam industry to reduce the damage it does to the ozone by 95%. The West German parliament has already called for such chemicals to be regarded as interim measures, for use only until the year 2000, however, because they do hurt ozone.

Simple carbon dioxide can be used to blow flexible and rigid foams. It increases the width of rigid foams needed for insulation by about 5%. This is not a serious penalty in home refrigerators, though it would slightly reduce the capacity of an insulated truck or freight car. Kabelwerk Eupen, a West German firm, has developed a process in which a chemical reaction generates carbon dioxide and monoxide to puff up flexible foam.

Most promising for insulation is the development, in California and elsewhere, of vacuum panels that are more efficient than foam in insulating refrigerators and can pay for themselves in energy savings. This also means more fuel efficiency, in turn reducing the pollution from coal and oil; the US government estimates that it could save billions of barrels of oil a year if people just used more efficient refrigerators. ■

Current-feedback op-amp

OPA603 from Burr-Brown is a high-speed current-feedback operational amplifier which can deliver ±10V signals into 150Ω loads at up to 1000V/μs and at an output current of ±150mA. The current-feedback technique yields constant bandwidth and settling time over a large range of gain settings.

In general, the OPA603 behaves as a conventional op-amp; a feedback network on the inverting input controls closed-loop gain. The difference is that the impedance of the network also controls open-loop gain and frequency response. **Figures 1** and **2** show the feedback resistor values against closed-loop gain for maximum bandwidth and minimum peaking. As can be seen from the left vertical axes, bandwidth varies only between about 35MHz and 55MHz with gain from 1 to 100.

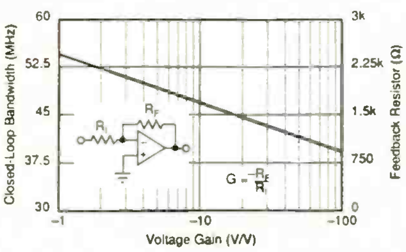


Fig. 1. Bandwidth and feedback resistor against inverting gain.

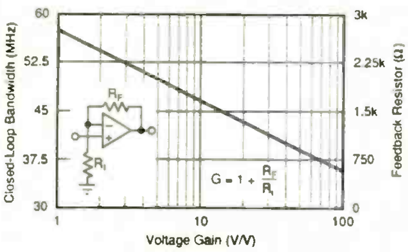


Fig. 2. Closed-loop bandwidth and feedback for a non-inverting amplifier.

Since open-loop gain is controlled by feedback impedance, the dynamic characteristics can be tailored to fit given requirements. For example, lower feedback resistance gives wider bandwidth, a peakier response and a greater pulse overshoot; the increased open-loop gain afforded by the lower feedback resistance also gives lower distortion. Higher feedback resistance

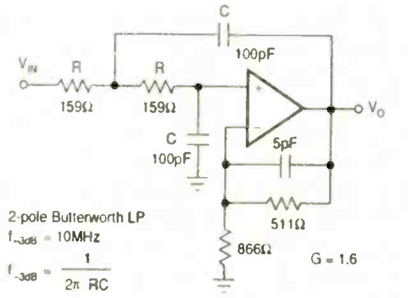


Fig. 3. OPA603 in a 10MHz low-pass Butterworth filter.

gives an overdamped response with very little peaking and overshoot — useful for driving capacitive loads. A capacitor in parallel with R_F reduces frequency-response peaking and takes a value of 2 to 10pF, depending on closed-loop gain and load characteristics; too large a value may cause instability.

Figures 3,4 and **5** show examples of low-pass and high-pass 2-pole Butterworth filters and a 10MHz band-pass filter using the OPA603. Burr-Brown points out that power supplies must be decoupled by a parallel combination of 0.01μF ceramic and 2.2μF solid tantalum capacitors close to the IC pins or, in high-current use, 10μF instead of the 2.2μF may improve matters.

Burr-Brown International Ltd, 1 Millfield House, Woodshots Meadow, Watford, Hertfordshire WD1 8YX. Telephone 0923 33837.

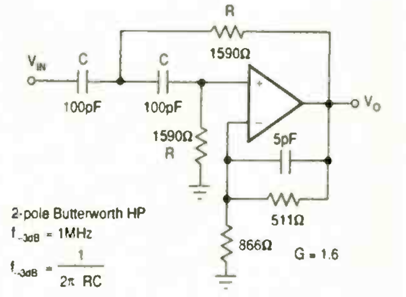


Fig. 4. Two-pole Butterworth high-pass filter, with-3dB point at 1MHz.

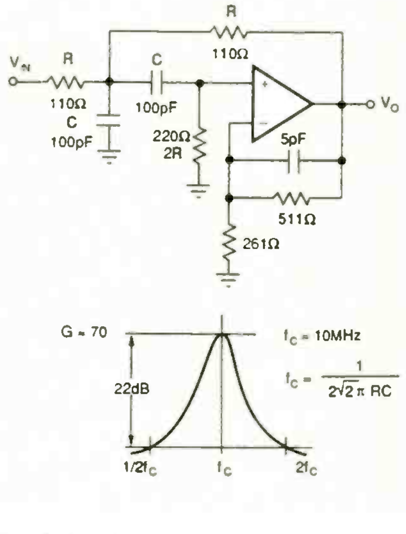


Fig. 5. Combination of low-pass and high-pass filters produces band-pass type with cut-off at 10MHz.

PCB tracks as transmission lines

Motorola has published a note (AN1051) on the design of printed-circuit boards for high-speed digital circuitry, taking into account the transmission line effects produced by the tracks, depending on their length and the rise or fall times of the devices. Delays or ringing caused by these effects sometimes result in unpredictable behaviour, causing designs that work well in simulation to perform at less than their best in practice.

A track should be treated as a transmission line if the smaller of the rise or fall times of a device is less than twice the propagation delay along the track. If that is so, the effects of the line are not masked during the transition times of the device.

The note provides a detailed examination of the forms of track found on boards, methods of calculating their characteristic impedances and propagation delays and both lattice diagram and Bergeron plot procedures for analysing the transmission line. It also includes a description of methods of terminating the line to minimise the ringing and delays.

Finally, nearly half the 70-page publication presents a large number of worked examples.

Motorola Ltd, European Literature Centre, 88 Tanners Drive, Blakelands, Milton Keynes, MK14 5BP. Telephone: 0908 614614.

Motor drive ICs

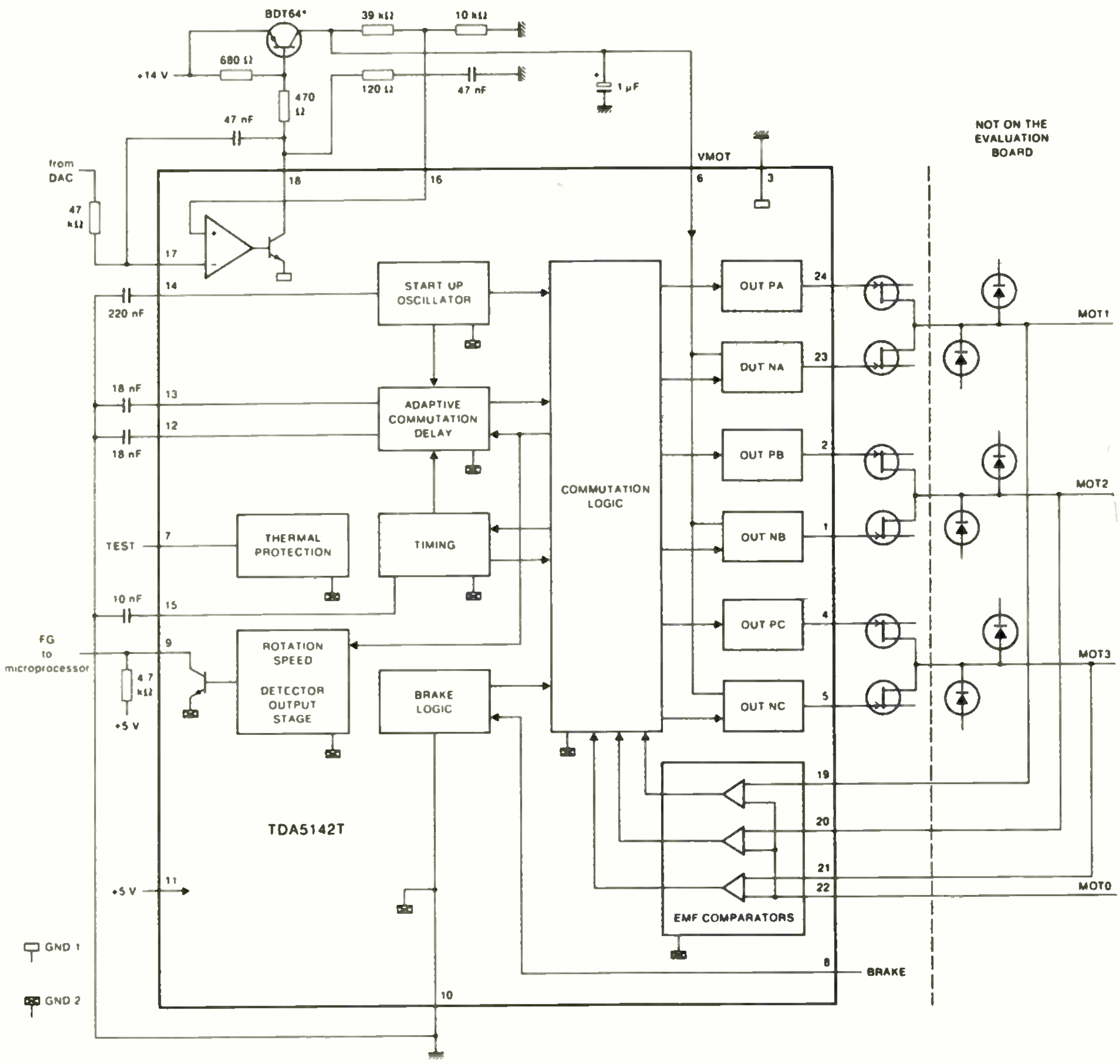
A range of single-chip drive circuits from Philips, described in Technical Publication IC 008, provides full-wave drive for permanent-magnet motors in hard-disk drives and video recorders.

This type of motor is attractive for computer, entertainment and car application, since there are no brushes to wear or arc. They are efficient, accelerate rapidly and run at high speed. Their chief drawback is the need for electronic commutation and rotor position detection using Hall sensors.

In the Philips devices, the commutation timing is determined by the ICs and remains correct regardless of the type of motor or load. No rotor position sensing is needed, since timing is determined by sensing zero crossings of the back EMF generated by the three stator windings during their non-energised periods. In addition, all these ICs have an accurate digital tachometer output and some can provide position information from an external pickup coil for monitoring tape position in a VCR scanner head. Each IC also has an uncommitted amplifier (OTA) for motor speed control by regulating the supply to the output drivers, input being either PWM or an analogue voltage or current.

The diagram shows an evaluation board using the TDA5142T, which provides three-phase, full-wave drive for three pairs of external push-pull driver transistors. It is meant for use with continuously running, unidirectional, high-current motors such as those in mainframe hard-disk drives. The OTA speed-control amplifier is current fed.

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



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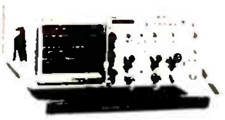

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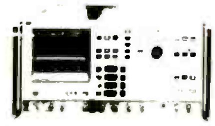

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Current sources and sinks

Application guide AN-165 from Burr-Brown is a compendium of preferred circuits for sources and receivers, floating sources, transconductance amplifiers, mirrors and transimpedance amplifiers, using the REF200 dual current source and current mirror IC and one or more op-amps.

Each current-source cell in the REF200 supplies 100μA on the application of 2.5V or more, with a drift of less than 25ppm and at an output impedance of more than 500MΩ. Temperature coefficient is zero. An internal block diagram is shown in **Fig 1.**

Using the basic 100μA current source, one can make a source or sink of any value. For example, the 50μA sink in **Fig. 2** uses the mirror and one of the sources, the input current dividing equally between input and output, while in **Fig. 3** a current sink subtracts 50μA from a second 100μA source to give a 50μA source. To obtain a floating 200μA source, parallel the two sources in the IC, or drive the mirror with this source to get a 100μA sink.

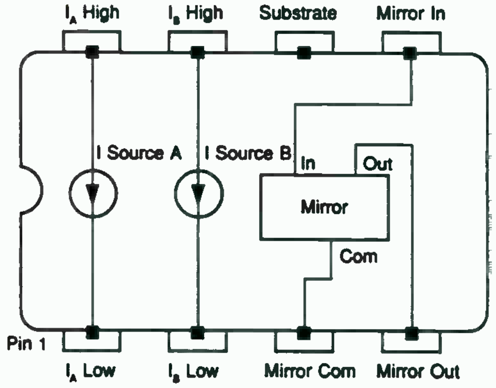

Fig. 1

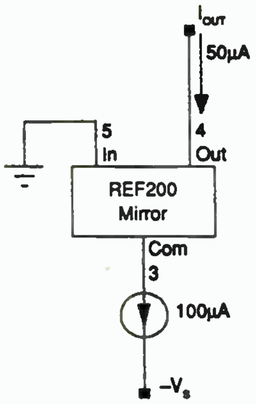

Fig. 2

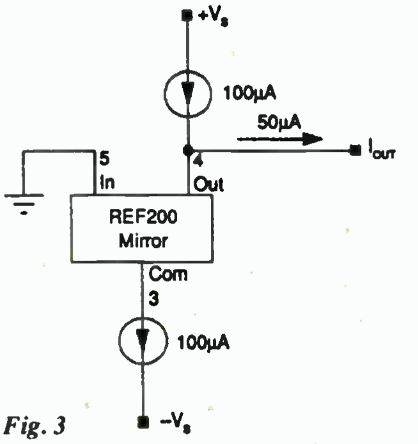

Fig. 3

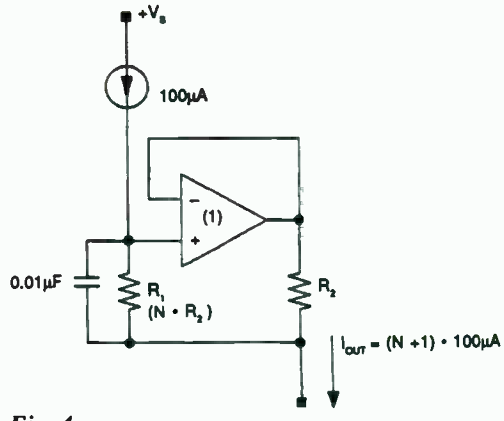

Fig. 4

The circuit of **Fig. 4** supplies a source of any value more than 100μA; the reference current forces a voltage of $R_1 \times I_{ref}$ at the non-inverting op-amp input, the same voltage appearing across R_2. If R_1 is $N \times R_2$ output current is $(N+1)100μA$. If the voltage drop across R_1 is large enough, the current source will swing to the negative rail. Turn the circuit upside down to get a current sink.

For currents of virtually any value use the circuit in **Fig. 5** which will give a current of $N \times 100μA$, when R_1 is $N \times R_2$. For example, if R_1 is 100Ω and R_2 is 10MΩ, the current is 1nA; for 10kΩ and 1kΩ the output is 1mA. Again, inverting the circuit gives a current sink.

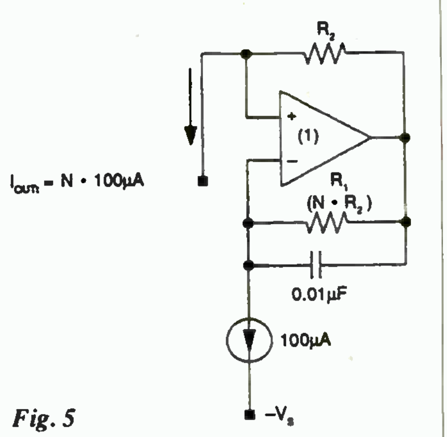

Fig. 5

To obtain a floating current source of greater than 100μA, use the circuit of **Fig. 6**, which is almost the same as that of Fig. 4, except that R_2 is driven by a mosfet. Since no current flows in either the gate of the mosfet or the op-amp inputs, all the current entering the resistors leaves them and the source is completely floating.

The application guide goes on to describe a large variety of sources and sinks, with many applications in precision comparators, instrumentation amplifiers and current-to-voltage converters.

Burr-Brown International Ltd, 1 Millfield House, Woodshots Meadow, Watford, Hertfordshire WD1 8YX. Telephone 0923 33837.

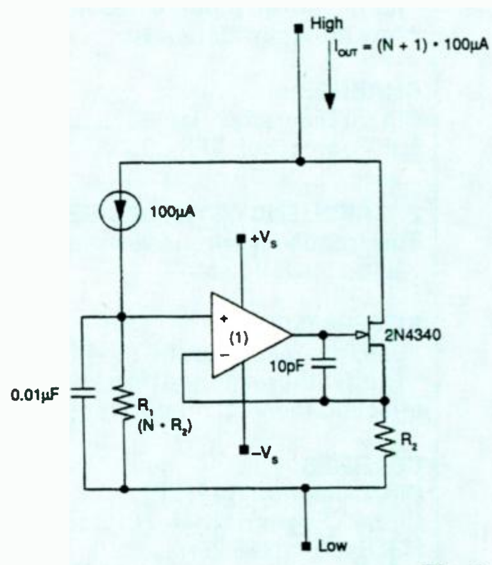

Fig. 6

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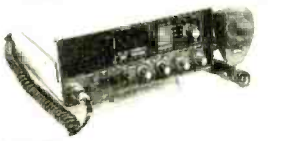

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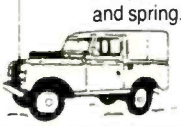

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INTERFACING WITH C

PART 8

Transferring between time and frequency domains can help to clarify the characteristics of a signal. Howard Hutchings demonstrates Fourier analysis, using the discrete transform as an introduction to the FFT, to be described later.

Horner's five thumb postulate: Experience varies directly with equipment ruined.

Fourier transforms using a PC

The impressive computational power of 16-bit machines, together with the increased efficiency of the fast Fourier transform, makes spectral analysis a challenging proposition using a PC. The data capture with graphics routine outlined in Chapter 2 provided a useful time-domain chronicle of the signal. In certain circumstances, however, it may be advantageous to preserve this information in a complementary form and present it as a frequency-domain record.

Electronics engineers routinely use Fourier transforms to examine the effects of noise or bandwidth on the signals being processed through a particular system. The central idea is quite simple. Spectral analysis decomposes a signal into its constituent frequencies and records the amplitude of each component in the frequency-domain. Most periodic phenomena exhibit interesting characteristics when investigated in terms of frequency. The usual concern in electronic signal analysis is with time- to frequency-domain transformations, although numerous other applications exist. These include calculating heat distribution in the core of a nuclear reactor, testing for bias in the generation of random numbers, music waveform analysis, mechanical vibration/signature analysis, avionics, oceanography, and many others.

No matter how unusual or audacious the application, it is really the behaviour of a linear system in the frequency domain that is being examined. Analogue systems are pre-

Interfacing with C

An accompanying set of 57 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.
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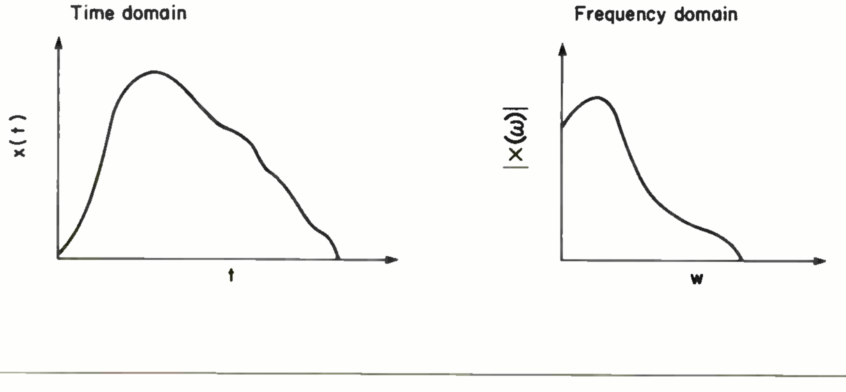

Fig. 6.1. Using the Fourier transform, a continuous signal x(t) expressed as a function of time may also be described as a function of frequency X(ω). Spectral analysis decomposes a signal into its constituent frequencies and records the amplitude of each in the frequency domain.

dominantly linear; if the amplitude of the input signal is halved, then so is the output, with no change in signal shape. Analogue non-linearity is associated with additional, unwanted harmonics – hence the interest in Fourier methods. Digital systems work well, despite being highly non-linear; indeed the non-linearity adds to the robustness of the design. Investigating the characteristics of a signal, or the behaviour of a system, from a different perspective is analogous to looking at a problem with a fresh pair of eyes. Facts which are unclear or hard to grasp in one domain are often clarified in another. This is a familiar theme pursued throughout this book. This chapter aims to demonstrate Fourier analysis using a PC.

Discrete Fourier transform DFT

The relatively straightforward discrete Fourier transform has been chosen as an initial example because it may be programmed directly and because, conceptually, it underpins the fast Fourier transform FFT which will be presented later. The object in each case is to evaluate how the energy of the time-domain signal x(t) is distributed in the frequency domain.

Commuting between domains requires the mathematical scaffolding provided almost 200 years ago by Jean Baptiste Joseph Fourier. For continuous signals:

$$X(\omega) = \int_{-\infty}^{\infty} x(t)\, e^{-j\omega t} dt$$

where $X(\omega)$ = the frequency transform

$x(t)$ = the signal to be transformed

ω = the frequency variable

t = the spatial variable

$j = \sqrt{-1}$

To realise the Fourier transform on a digital computer, the continuous signal x(t) needs to be replaced by the snapshots x(n) taken by the a-to-d converter. Under the discrete Fourier transform, integration is replaced by the finite weighted summation:

$$X(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n) \exp\left(\frac{-j2\pi mn}{N}\right)$$

$$m = 0,1,2, \ldots N-1$$

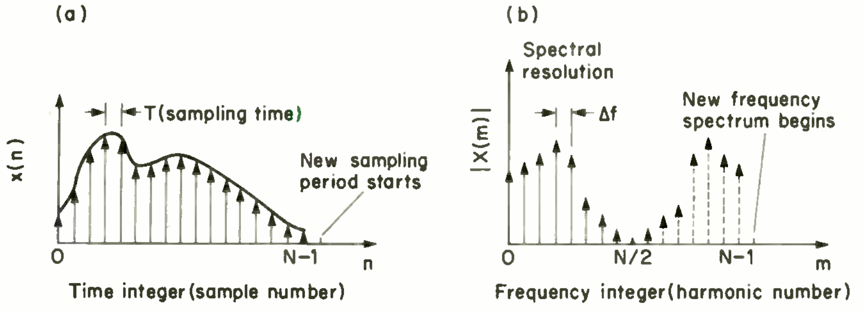

Fig. 6.2. Diagram at (a) is sampled data signal represented by N snapshots, each separated by sampling interval T. Discrete Fourier spectrum is at (b), in which spectral resolution δf is interval between ordinates, 1/NT, where N is number of samples and T sampling interval. For example, using Microsoft C and the AD7820 half-flash converter, sampling frequency was 40kHz. If 128 samples are captured, spectral resolution is 312.5Hz, so a digitised 625Hz sine wave would be seen as a single ordinate at third harmonic number.

Make sure you understand the reality behind the abstraction of this expression. The discrete Fourier transform is an approximation to the continuous Fourier transform, made up of N samples of the signal x(n). The integers n and m are analogous to the spatial and frequency variables (t and ω respectively).

A compelling method of addressing the core of the algorithm lies in writing effective software to describe the transform. The frequency transform X(m) is a complex number made up of the real and imaginary coefficients:

$$ar(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi mn}{N}\right)$$

$$ai(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi mn}{N}\right)$$

where $X(m) = ar(m) - jai(m)$

In many applications, the mean-square power is the quantity of most significance. Visualise this as the modulus of the frequency transform squared or, alternatively, as X(m) multiplied by its complex conjugate X*(m). Hence the mean-square power may be written as:

$$|X(m)|^2 = [ar(m)]^2 + [ai(m)]^2$$

As, no doubt, you have observed, it is easy to let the mathematics get in the way of the physics. I find the expression for mean-square power is a refreshing reminder of what the Fourier transform is really doing. If the interval between samples in the time domain is T seconds, and N samples are captured for subsequent frequency-domain processing, then the spectral resolution (δf) is simply the number of Hertz between ordinates in the frequency domain. Spectral resolution is an important parameter given by δf = 1/NT. For a fixed sampling rate (T), good resolution requires the capture of many samples, usually N > 128. The discrete Fourier transform calculates the magnitude (mean-square power) of each frequency component from m = 0 (d.c.) to m = δf times N (the sampling frequency). When running listing 6.1 to test the algorithm, notice that frequencies from d.c. to half the sampling frequency are unique. Frequencies greater than half the sampling frequency are images folded about the line $f_s/2$.

Listing 6.1

```
/ ********************************** /
/*        ELEMENTARY 8 POINT        */
/*          DFT TRANSFORM           */
/ ********************************** /
#include<stdio.h>
#include<math.h>
#define PI 3.14159
main()
{
int m, n;
double real_sum, imag_sum, mean_sq_
power;
float x[8];
/*------------------------------------
DECLARE SIZE OF ARRAY AND DATA
TYPE
------------------------------------*/
for(n = 0; n <= 7; n++)
{
x[n] = sin(2 * PI * n / 8);
}
/*------------------------------------
SYNTHETIC DATA
DFT ALGORITHM STARTS HERE
------------------------------------*/
for(m = 0;m <= 7;m++)
```

```
{
real_sum = 0;
imag_sum = 0;
mean_sq_power = 0;
for(n = 0;n <= 7;n++)
{
real_sum += x[n] * cos(2 * PI * m * n / 8) / 8;
imag_sum += x[n] * sin(2 * PI * m * n / 8) / 8;
}
mean_sq_power = pow(real_sum, 2) +
pow(imag_sum, 2);
/*------------------------------------------------------
     COMPUTE MEAN SQ. POWER BY
  SQUARING AND SUMMATING REAL AND
       IMAGINARY COEFFICIENTS
------------------------------------------------------*/
printf("%d\t%f\t%f\t%f\n", m, real_sum,
imag_sum, mean_sq_power);
/*------------------------------------------------------
   PRINT: m  ar(m)  ai(m) mean sq. power
------------------------------------------------------*/
}
}
```

Developing and explaining the program

Listing 6.1 demonstrates principles. The complications of truncated data capture are avoided by generating a synthetic waveform — in this case, one complete cycle of a sinewave. This is stored as eight samples in the array x[n] and identified by the square brackets. The size of the array and the data type of the stored members must be declared in advance. In this program, the construction float x[8] reserves space for 8 decimals. Each floating point element occupies 4 bytes.

Data capture, followed by sequential storage, figures prominently in many signal-processing applications. Subsequent programs will compute the Fourier transform using data captured via an A-to-D converter. Consequently, the size of the declared array must be modified to accommodate the increased number of samples, typically 256 or more. Real-time data logging frequently requires high sampling rates, so the structure of the software will be improved by storing the output of the A-to-D in an array of the declared type int. This more primitive construction represents each stored element using only two bytes, thus ensuring faster throughput.

For the purpose of comparison, a Basic data logging program is included, together with an equivalent C construction. Both are littered with comments as an aid to comprehension.

Data logging software structures

(a) Anatomy of a Basic program

```
100 BASE = 768 : REM BASE ADDRESS OF
I/O CARD
110 DIM X(256) : REM DECLARE SIZE OF
DATA STRUCTURE
120 FOR N = 0 TO 255
130 OUT BASE + 2, 0 : REM START
CONVERSION
140 X(N) = INP(BASE + 2) : REM READ I/P
150 NEXT N
```

(b) Comparable construction using C

```
#define BASE 768
int x[256];
/*------------------------------------------------------
  DECLARE SIZE OF ARRAY AND DATA
               TYPE
   SELECTING THE PRIMITIVE "INT"
   ENSURES FASTER THROUGHPUT
------------------------------------------------------*/
for(n = 0;n <= 255;n++)
{
outp(BASE + 2, 0);
/*------------------------------------------------------
          START CONVERSION
------------------------------------------------------*/
x[n] = inp(BASE + 2);
/*------------------------------------------------------
 READ ADC AND STORE SEQUENTIALLY
------------------------------------------------------*/
}
```

Returning to listing 6.1, the exponential term in the discrete Fourier transform is expanded to express X(m) as the sum of the real and imaginary coefficients: ar(m) and ai(m) — called real_sum and imag_sum respectively in the program.

To compute the mean-squared power, square the real and imaginary coefficients before evaluating the sum. Surprisingly, this can be a problem using C. A belt and braces approach might lead to the equation mean_sq_power = real_sum * real_sum + imag_sum * imag_sum. This is correct but laborious.

Fortunately, Microsoft C includes the function pow( ), which is a contraction of power. An inspection of the program should make it clear that the construction pow(real_sum,2) squares the variable real_sum. Notice that both mean_sq_power and real_sum are declared as doubles. The effects of running the program are shown in **Table 6.1**.

Table 6.1 The results of a Fourier transform using an 8 point DFT computation

sample no.	ar(m)	ai(m)	mean sq.power
0	0	0	0
1	0	0.5	0.25
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	−0.5	0.25

Graphical spectral analysis

Looking at columns of figures soon becomes tedious, and commercial spectral analysers usually display the computed frequency spectrum visually. The following example — a simple modification to listing 6.1 — is designed to be run through an EGA card and colour monitor. Regard the program as a testbed, an opportunity to consolidate facts and to watch the Fourier transform in action. As usual, program development is simplified with bottom up design as the intention is to add colour graphics to the tried and tested DFT algorithm.

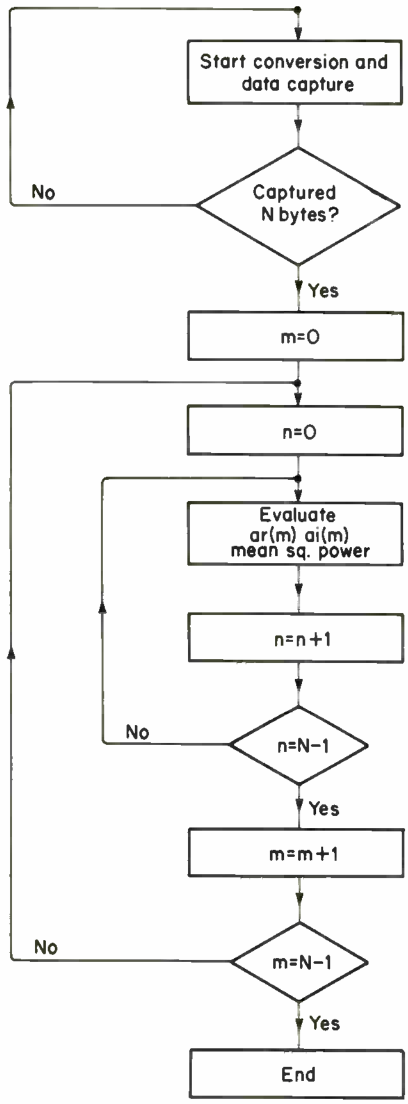

Fig. 6.3. Flowchart describing elementary 8-point DFT transform.

However, at this stage, the complication of real-data capture is avoided. Instead, the sampled data is generated synthetically inside the PC. The reasons for this are really quite practical. It is easy to simulate the output from the a-to-d without the confusion of external hardware and still be conof external hardware and still be confident of the characteristics of the sampled signal. Furthermore, Microsoft C's rich set of mathematical functions will be exploited to generate a wide variety of input signals.

```
/ *********************************** /
/*       INTRODUCTORY DFT WITH         */
/*         COLOUR GRAPHICS             */
/ *********************************** /
#include<stdio.h>
#include<math.h>
#include<graph.h>
#define PI 3.14159
main()
{
struct videoconfig screen_size;
int N, n;
double m;
double real_sum, imag_sum, mean_sq_
power, rms;
float x[128];
start: _settextposition(20, 20);
printf("Select No. of samples (128max)");
scanf("%d", &N);
/*-----------------------------------------------
        ENTER NUMBER OF SAMPLES
-----------------------------------------------*/
_setvideomode(_DEFAULTMODE);
_setvideomode(_HRES16COLOR);
/*-----------------------------------------------
                EGA MODE
-----------------------------------------------*/
_clearscreen(_GCLEARSCREEN);
_setbkcolor(_GRAY);
_getvideoconfig(&screen_size);
_setlogorg(screen_size.numxpixels/4,
screen_size.numypixels/2);
_moveto(0, 0);
_lineto(320, 0);
_moveto(0, 0);
_lineto(0, -90);
/*-----------------------------------------------
            DRAW X & Y AXES
-----------------------------------------------*/
_settextcolor(3);
_settextposition(4, 8);
_outtext("r.m.s. power");
_settextposition(14, 50);
_outtext("Frequency (Hz)");
/*-----------------------------------------------
        COLOUR AND POSITION TEXT
-----------------------------------------------*/
for(n = 0;n <= (N - 1);n++)
{
/*-----------------------------------------------
  LOCATE SYNTHETIC DATA HERE SEE
       TEXT FOR SUGGESTIONS
-----------------------------------------------*/
}
for(m = 0;m <= (N - 1);m++)
{
real_sum = 0;
imag_sum = 0;
for(n = 0;n <= (N - 1);n++)
{
real_sum += x[n] * cos(2 * PI * m * n / N) / N;
imag_sum += x[n] * sin(2 * PI * m * n / N) /
N;
}
mean_sq_power = pow(real_sum, 2) +
pow(imag_sum, 2);
rms = sqrt(mean_sq_power);
/*-----------------------------------------------
 TAKE SQUARE ROOT OF MEAN SQUARE
 POWER TO IMPROVE GRAPHIC DISPLAY
-----------------------------------------------*/
_setcolor(14);
_moveto(320 * m / N, 0);
_lineto(320 * m / N, -100 * rms);
/*-----------------------------------------------
     PLOT AND SCALE FREQUENCY
           SPECTRUM
-----------------------------------------------*/
}
goto start;
}
```

Understanding the logical system of coordinates

The Microsoft C graphics library is contained in the header file graph.h. It supports two coordinate systems to identify a particular pixel location. Previous use of the physical system of coordinates in the graphics programs described in an earlier section restricted attention to positive values of x and y. This program extends our command of Microsoft C graphics and manipulates the logical system of coordinates. Inspect **listing 6.2** carefully, and notice that a little more video housekeeping is required to get started. The function _getvideoconfig( ) is used to obtain information about the current graphics environment. In this case, the configuration information (the number of pixels along the x and y axes) is contained in the variable screen_size. To set the logical origin (the point 0,0) at a specific pixel location on the screen, use the function _setlogorg( ). **Fig. 6.4** contains the details relevant to the video mode _HRES16COLOR made up of 640×200 pixels, with sixteen colours. Once the origin is established, increasing x moves the pixel horizontally from left to right across the monitor. But increasing y moves the pixel vertically downwards, which is mathematically unconventional. This should explain why the y coordinate is preceded by a negative sign in the function _lineto( ).

Applying the DFT program

Digital-signal processing can still provide one or two surprises for the unwary. Use this simple DFT with graphics program as a controlled environment with which to understand a few of the limitations of your computer and a-to-d converter.

In the real world, we are unlikely to capture a whole number of input signals, deliberately truncate the input data and observe the effect on the computed spectrum. Be inquisitive. Increase the number of samples and see if this results in any improvement. Look closely at the characteristics and spectra of sinusoids and repetitive-pulse waveforms. Recognise that continuous signals such as sinewaves are

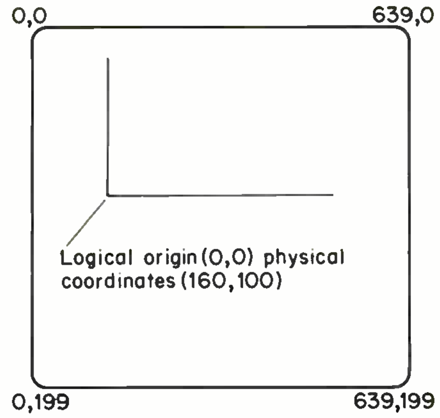

Fig. 6.4. Selecting the video mode _HRES16COLOR provides 640×200 pixels. Function _setlogor(screen_size.numxpixels/4, screen_size.numypixels/2) moves the logical origin (0,0) to pixel coordinates (160,100).

characterized by a discontinuous frequency spectrum, the spectral energy being concentrated at a single-spot frequency. Conversely, discontinuous functions such as squarewaves, which change abruptly with time, have a continuous spectral envelope. Use software to generate isolated pulses and examine the spectrum. Reduce the pulse width and observe how the spectral energy becomes extended in the frequency domain.

It is really quite remarkable just what can be achieved using a few lines of imaginative software. The following examples are intended to develop an instinct for spectral analysis. They will encourage you to experiment and acquire a feel for what a transform looks like and how it behaves. Each of the following functions is software-generated and the pseudo-sampled data is stored in the array x[n] prior to processing using listing 6.2.

Streamlining the arithmetic using the fast Fourier transform

Running **listing 6.2** is fun, but the DFT does have its limitations — you probably noticed that processing time increased as the number of samples was increased. The complexity of the calculation is proportional to N^2 where N is the number of samples. I hope you were critical and examined the computed spectral display carefully, particularly when processing a non-integer number of cycles (**listing 6.4**). Spectral spreading was evidently a problem

Listing 6.3

```
/*--------------------------------------------------------
USING THIS GENERATING FUNCTION THE
GRAPHICS AGREE WITH THE THEORY
--------------------------------------------------------*/
for(n = 0; n <= (N-1); n++)
{
x[n] = sin(20*PI*n/N);
}
```

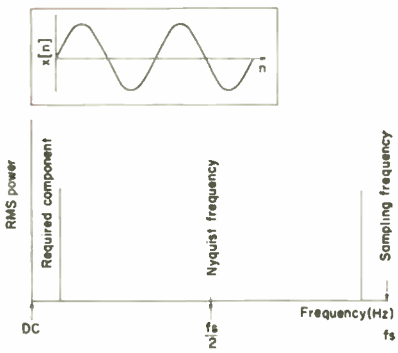

Fig. 6.5. Using software to generate ten complete cycles of a sampled sine wave produces a single weighted impulse of energy where m=10, with an image folded at half sampling frequency. This component can be interpreted as negative frequency usually associated with classical analysis.

Listing 6.4

```
/*--------------------------------------------------------
THIS GENERATING FUNCTION
DEMONSTRATES THE EFFECTS OF
SPECTRAL SPREADING
--------------------------------------------------------*/
for(n = 0; n <= (N-1); n++)
{
x[n] = sin(19.9*PI*n/N);
}
```

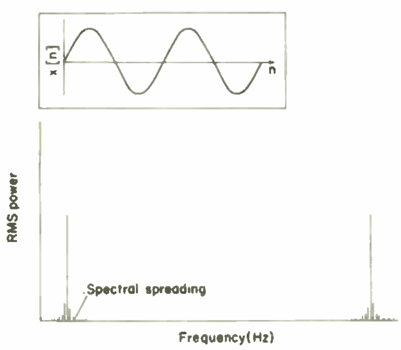

Fig. 6.6. Fourier transform treats each data set as periodic, hence discontinuity due to processing non-integer number of cycles results in spectral spreading. Known more evocatively as "picket fence effect" or "leakage".

Listing 6.5

```
/*--------------------------------------------------------
NOTICE HOW A DISCONTINUOUS TIME
DOMAIN SIGNAL IS TRANSLATED INTO A
CONTINUOUS FOURIER TRANSFORM
--------------------------------------------------------*/
for(n = 0; n <= (N-1)/8; n++)
{
x[n] = 5;
}
for(n = (N-1)/8; n <= (N-1); n++)
{
x[n] = 0;
}
```

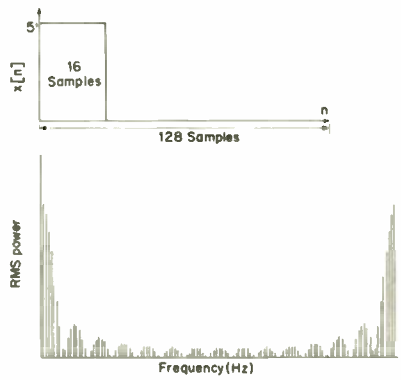

Fig. 6.7. Synthetically generating sample square wave, pulse width 1/8 total period. Spectral envelope is continuous and rich in low-frequency components. Signal is characterised by infinite number of harmonics, but certain spot frequencies contain no spectral energy.

Listing 6.6

```
/*--------------------------------------------------------
NARROW PULSES OCCUPY LARGE
BANDWIDTHS
--------------------------------------------------------*/
for(n = 0; n <= (N-1)/16; n++)
{
x[n] = 5;
}
for(n = (N-1)/16; n <= (N-1); n++)
{
x[n] = 0;
}
```

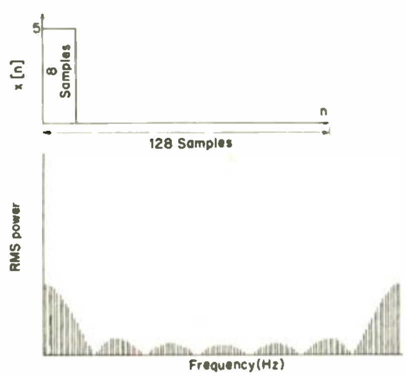

Fig. 6.8. Decreasing pulse width reduces amplitude of spectral energy and extends frequency response, demonstrating need for large bandwidth in high-frequency pulse circuits.

Listing 6.7

```
/*--------------------------------------------------------
THIS GENERATING FUNCTION HAS
APPLICATIONS WHEN PROCESSING
RANDOM NOISE
--------------------------------------------------------*/
for(n = 0; n <= (N-1)/64; n++)
{
x[n] = 5;
}
for(n = (N-1)/64; n <= (N-1); n++)
{
x[n] = 0;
}
```

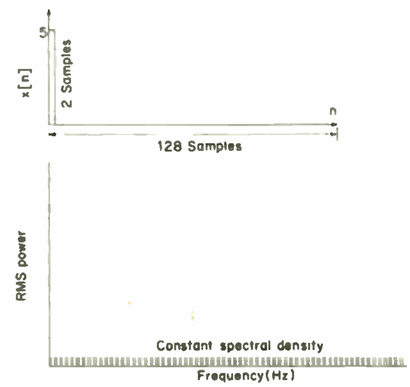

Fig. 6.9. Progressively reducing pulse width by modifying FOR loop ultimately gives good approximation to impulse function. Processing through DFT demonstrates that spectral energy is constant in frequency domain.

which could be reduced simply by increasing the number of samples.

The fast Fourier transform is not a new transform. It is an algorithm which, when applied to a data set of 2^N samples, reduces the number of multiplications from N^2 to $N \log_2 N$. This is a huge saving of computation time. Its existence generally became known in the mid 1960's. It followed the matrix theory of J. W. Cooley and J. W. Tukey, who returned to the computation of "schedules" originally undertaken at Los Alamos as part of the Manhattan Project. Retrospectively, it is acknowledged that a few clever people had been using the FFT as early as 1942 (refer to Brigham for details).

How many multiplications?

Examination of the DFT algorithm, together with the relevant C program, indicates that approximately N complex multiplications and about the same number of additions are required to calculate the frequency coefficient for a particular value of m. Since there are N/2 unique spectral components, the total number of multiplications

Listing 6.8

```
/*-------------------------------------------------------
      DECAYING EXPONENTIAL SIGNAL
-------------------------------------------------------*/
for(n = 0; n <= (N-1); n++)
{
a = 0.0392156;
/*-------------------------------------------------------
   DECAY FACTOR a IS RECIPROCAL OF
          TIME CONSTANT
-------------------------------------------------------*/
x[n] = 2*exp(-a*n);
}
```

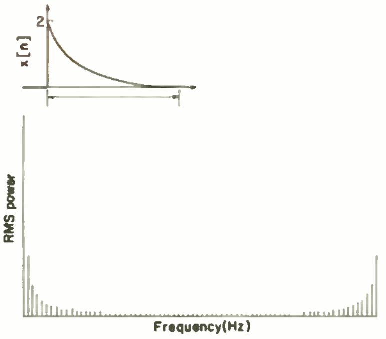

Fig. 6.10. Processing pulse through limited-bandwidth system introduces exponential rounding of leading and trailing edges. Listing 6.8 generates decaying exponential function, decay factor chosen to allow pulse to fall to zero for N=128. Try decreasing time constant, observing wider spectrum.

Table 6.2 Comparing the number of computations required for DFT and FFT.

Number of samples N	DFT N^2	FFT $N\log_2 N$
8	64	24
16	256	64
32	1024	160
64	4096	384
128	16384	896
256	65536	2048
512	262144	4608
1024	1048576	10240

required to compute the complete spectrum is approximately N^2. This is a considerable calculation for a large number of samples, even on a PC. Now for the good news — many of the calculated coefficients are redundant and can be factored out. Evaluating the DFT by hand is an exercise in tedious calculation. Nevertheless, insight into the inner workings of the FFT only comes with real understanding of the more straightforward DFT. Modern notation tends to present the DFT in the form:

$$X(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\, W^{mn}$$

$$m = 0,1,2, \ldots (N-1)$$

$$W_N = \exp\left(\frac{-j2\pi}{N}\right)$$

Listing 6.9

```
/*-------------------------------------------------------
  ANALOGOUS TO THE STEP RESPONSE
      OF A SERIES R-L-C CIRCUIT
-------------------------------------------------------*/
for(n = 0; n <= (N-1); n++)
{
a = 0.0392156;
/*-------------------------------------------------------
       1/a IS THE TIME CONSTANT
-------------------------------------------------------*/
x[n] = 2*exp(-a*n)*sin(20*PI*n/N);
}
```

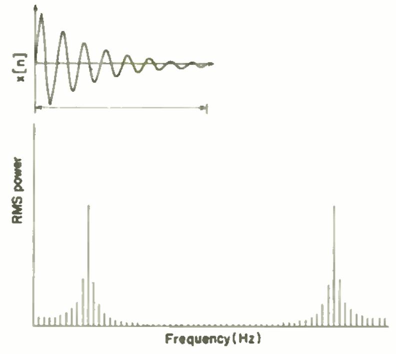

Fig. 6.11. Program of listing 6.9 generates sine wave modulated by exponentially decaying envelope, generating frequency-domain model of damped second-order system. Examine effects of varying time constant.

Contrary to appearances, this does improve comprehension and demonstrates coefficient redundancy. To understand the mathematics, consider the behaviour of the complex coefficient W_N for eight sampled values ie. N = 8. W_8 is raised to the power mn, where m and n are integers in the range 0 to 7. The repetitive nature of the algorithm results in the calculation of W^{mn} being carried out 64 times. However, examination of the tabulated coefficients reveals only eight unique terms, the result of the integer product mn over the range 0 to 7. Restricting the number of samples to eight makes pencil and paper confirmation relatively painless. This can be shown using an Argand diagram (**Fig. 6.13**) where the calculated coefficients are represented as rotating phasors. The 8-point DFT multiplication table 6.3 should help with the calculation. If you have time, use the DFT algorithm in conjunction with Table 6.3 to confirm the results of listing 6.1.

The fast Fourier transform recognizes that many of the calculations are redundant and uses a decimation process to bisect the data array until only two-point transforms remain. Look at

Listing 6.10

```
/*-------------------------------------------------------
  THESE WAVEFORMS LOOK DIFFERENT
    BUT SOUND IDENTICAL, OUR EARS
 THROW AWAY THE PHASE INFORMATION
-------------------------------------------------------*/
for(n = 0; n <= (N-1); n++)
{
w = 2*PI*n/N;
x[n] = sin(w) + sin(3*w)/3 + sin(5*w)/5 +
sin(7*w)/7 + sin(9*w)/9;
}
```

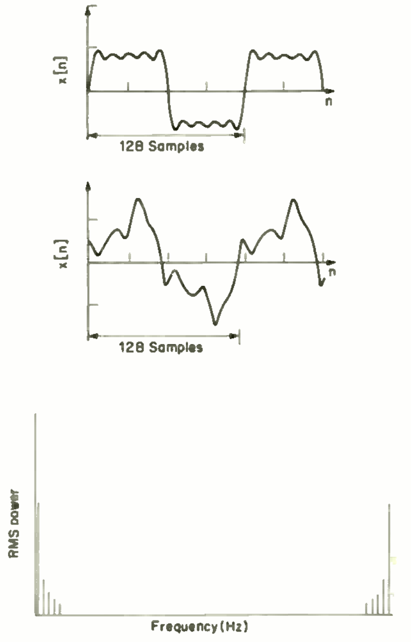

Fig. 6.12. Spectral analysis contains no information on phase of time-domain signal. Listings 6.10 and 6.11 generate two apparently different waveforms, (a) and (b) respectively, which have identical spectral characteristics, as seen at (c).

Listing 6.11

```
for(n = 0; n <= (N-1); n++)
{
w = 2*PI*n/N;
x[n] = sin(w) + sin(3*w)/3 - sin(5*w)/5 +
sin(7*w)/7 - sin(9*w)/9;
}
```

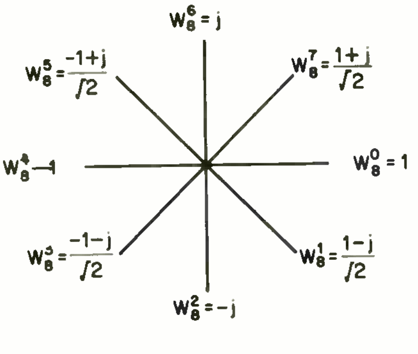

Fig. 6.13. Geometrical interpretation of complex coefficient W_8^{mn} as a rotating phasor.

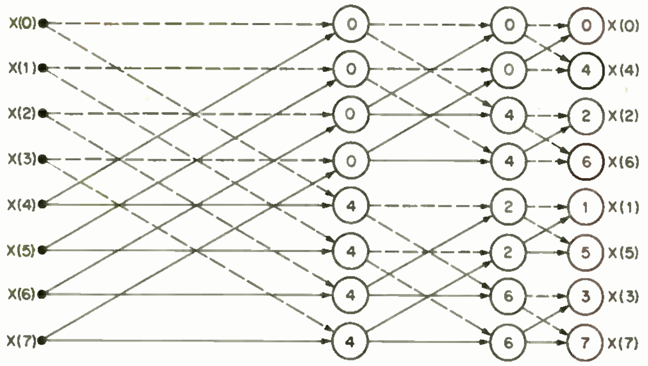

Fig. 6.14. Butterfly diagram for fast Fourier transform of an 8-element data array. Two paths entering a node are combined by forming sum: dotted line + (node coefficient) multiplied by solid line. For example, output of second row, second column is X(1)+W0.X(5). Repeat procedure until processed output appears in final column.

Table 6.3. Evaluating complex coefficient, or "How to learn your eight- times DFT table".

	Values of m							
	0	1	2	3	4	5	6	7
0	1	1	1	1	1	1	1	1
1	1	$(\frac{1-j}{\sqrt{2}})$	$-j$	$-(\frac{1+j}{\sqrt{2}})$	-1	$-(\frac{1-j}{\sqrt{2}})$	j	$(\frac{1+j}{\sqrt{2}})$
2	1	$-j$	-1	j	1	$-j$	-1	j
3	1	$-(\frac{1+j}{\sqrt{2}})$	j	$(\frac{1-j}{\sqrt{2}})$	-1	$(\frac{1+j}{\sqrt{2}})$	$-j$	$-(\frac{1-j}{\sqrt{2}})$
4	1	-1	1	-1	1	-1	1	-1
5	1	$-(\frac{1-j}{\sqrt{2}})$	$-j$	$(\frac{1+j}{\sqrt{2}})$	-1	$(\frac{1-j}{\sqrt{2}})$	j	$-(\frac{1+j}{\sqrt{2}})$
6	1	j	-1	$-j$	1	j	-1	$-j$
7	1	$(\frac{1+j}{\sqrt{2}})$	j	$-(\frac{1-j}{\sqrt{2}})$	-1	$-(\frac{1+j}{\sqrt{2}})$	$-j$	$(\frac{1-j}{\sqrt{2}})$

the signal flow diagram **Fig. 6.14**, and notice that the effect of the algorithm has been to scramble the order of the output data. Write both the input and output data in binary form, and it will be apparent that the scrambling is not random but a mirror image of the input — where the results are placed in bit reversed order.

Having covered the discrete Fourier transform in this part, Howard Hutchings goes on next month to deal with the fast Fourier transform, including the use of a PC as a real-time spectrum analyser

Thermistor temperature gradiometer

Negative temperature-coefficient beau thermistors, such as the GL23 from RS Components, have a thermal time constant of between 19 and 20 seconds. Response time of such thermistors can be reduced considerably by using them in conjunction with operational amplifiers in a closed feedback loop. A bridge configuration is, perhaps, the simplest one to implement; for example, in the diagram Th_1, with negligible self-heating when kept at 20°C, has a resistance of 1.5kΩ. With a current of 5mA, self-heating will reduce its resistance to 250Ω.

Hence, if the bridge is roughly balanced and the feedback loop of IC_1a is closed, the inputs will detect the error signal[1] and force the output to reduce it to zero, via the change of resistance of Th_1 due to self-heating. Any further changes in the temperature of Th_1 will result in corresponding changes in the output as the feedback loop tracks the error signal. The mechanism is linear to ±1% in the temperature range 0-30°C and gives an output of 200mV/°C. For a wider temperature range, non-linearity must be expected. A slew rate of 1V/s is obtained without the use of stabilising networks.

A useful application is in the measurement of temperature gradients. A single-chip quad op-amp such as the LM324 with a high gain and internal frequency compensation may be used. IC_{1a} and IC_{1b} drive the thermistors, IC_{1c} being a difference amplifier. Magnitude and sign of the output define the gradient between the thermistors.

Initially, both thermistors are kept in ice and the trimmers are adjusted to obtain zero output when both temperature and gradient are zero. When in use, the thermistors must be protected against draughts, since stray variations in temperature appear as noise[1].

A. de Sa
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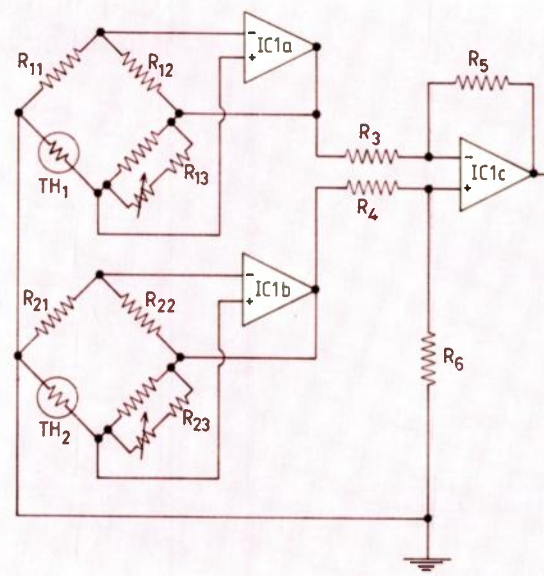
Reference
1. Principles of Electronic Instrumentation (2nd edn) 1990. Edward Arnold.



Circuit diagram of the gradiometer.
$R_{11}=R_{21}=1K\Omega$; $R_{12}=R_{13}=R_{22}=R_{23}=560\Omega$; TH_1, TH_2 are GL_{23} thermistors (RS stock no. 151-029), $R_3=R_4=R_5=R_6=47K\Omega$, I.C (1a), I.C (1b), I.C(1c) is a single chip operational amplifier LM324 (National Semiconductors). Trimmers across R_{13} and R_{23} consist of 560Ω fixed resistor in series with a 5KΩ variable.
Power supply ±15V, 100mA.

Battery-status indicator

The circuit shown indicates the low-voltage condition of a battery by flickering the led D.

Normally, the supply voltage is high enough to maintain the transistor in its ON state and the micropower timer does not receive enough voltage to operate, the led being OFF. As the supply voltage falls to about 3V, the transistor base current becomes too small for conduction, its collector voltage now being high enough to operate the timer, which will work with a 2.7V supply and which is arranged as a 10Hz astable multivibrator. When, therefore, the battery voltage falls to a point set by the potentiometer, the led flickers at 10Hz.

Power consumed by the XR-L555 is only about 1mW (1/15 of that for the normal 555), so that it does not seriously affect battery life. The circuit is designed for operation at 4.5V, but is easily modified for other supplies.

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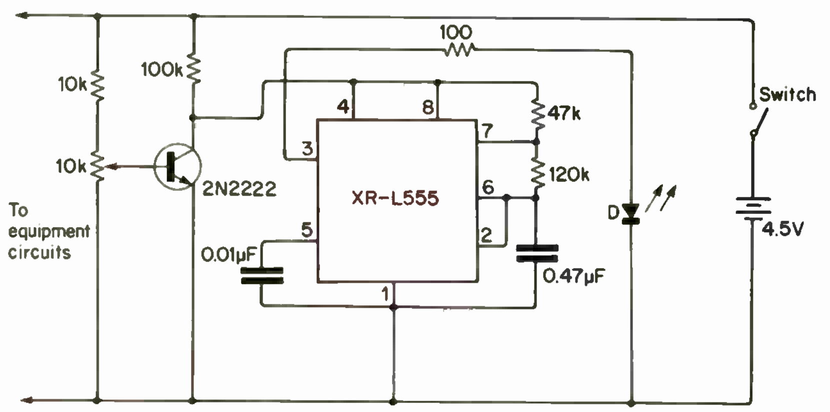

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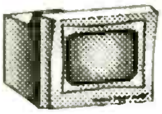

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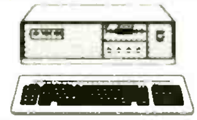

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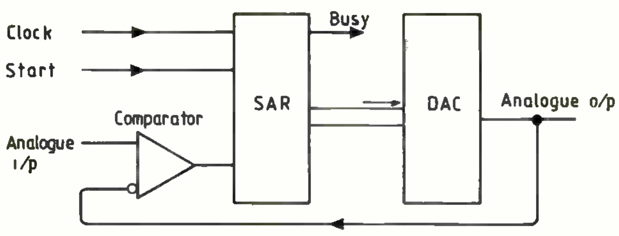

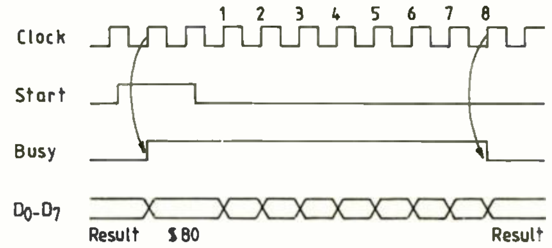

Sample-and-infinite-hold

I needed a sample-and-hold circuit to capture an analogue value and hold it without drifting for some hours. No charge-storage method can do this and an ADC driving a DAC with an input latch is expensive for more than eight bits. The successive-approximation type of ADC is constructed from a digital register and a DAC in a feedback loop; if the output of this DAC were available, then a separate DAC would not be needed, thus reducing the cost. Unfortunately, no ADC could be found with this feature, so I decided to build an ADC using a successive approximation register (SAR) and a DAC formed from a simple R/2R network. The resulting device is shown in the block diagram.

Referring to the timing diagram, the SAR is first synchronously reset to 1000,0000 by holding the START input high, whilst applying a positive clock edge, which also sets the BUSY output high. A-to-D conversion process begins when START returns low. The 1000,0000 output is converted to analogue and compared with the input signal in the comparator, the result of the comparison being fed to the CMP input of the SAR. On the next clock edge, the SAR outputs a one in bit 6, and the result of the comparison in bit 7. The new output is therefore 1100,000 or 0100,0000, which is converted to analogue, and the process continues. With each clock pulse, the SAR 'homes in' on the result; after the 8th clock pulse the BUSY output goes low and the conversion is complete. The SAR now holds the converted value, and the output of the DAC is equal to the analogue input voltage.

The practical circuit uses a 22V10 PAL device for the SAR and an R/2R SIL network for the DAC. The R/2R network does not have to be particularly accurate, since the digital output is not used externally; the digital code will suffer from errors due to resistor tolerances and saturation voltages at the PAL outputs, but the feedback from the analogue output to the input effectively removes these. Long-term drift of the PAL output voltages limits the number of bits that can usefully be used for very long holding periods. R/2R networks are available in SIL packages, but if you build your own, note the value of the grounded resistor – it is 2R, not R.

```
"Logic Equation Section"
DEFINE
lsb6  =        /d6 * /d5 * /d4 * /d3 * /d2 * /d1 * /d0,
lsb5  =        /d5 * /d4 * /d3 * /d2 * /d1 * /d0,
lsb4  =        /d4 * /d3 * /d2 * /d1 * /d0,
lsb3  =        /d3 * /d2 * /d1 * /d0,
lsb2  =        /d2 * /d1 * /d0,
lsb1  =        /d1 * /d0,
lsb0  =        /d0;
BEGIN
ENABLE (d0, d1, d2, d3, d4, d5, d6, d7, busy);
d7  =  /start +  ((            d7 * cmp) * (busy * lsb6) + d7* /(busy * lsb6));
d6  =  /start *  ((d7 * /d6 +  d6 * cmp) * (busy * lsb5) + d6* /(busy * lsb5));
d5  =  /start *  ((d6 * /d5 +  d5 * cmp) * (busy * lsb4) + d5* /(busy * lsb4));
d4  =  /start *  ((d5 * /d4 +  d4 * cmp) * (busy * lsb3) + d4* /(busy * lsb3));
d3  =  /start *  ((d4 * /d3 +  d3 * cmp) * (busy * lsb2) + d3* /(busy * lsb2));
d2  =  /start *  ((d3 * /d2 +  d2 * cmp) * (busy * lsb1) + d2* /(busy * lsb1));
d1  =  /start *  ((d2 * /d1 +  d1 * cmp) * (busy * lsb0) + d1* /(busy * lsb0));
d0  =  /start *  ((d1 * /d0 +  d0 * cmp) * (busy       ) + d0* /(busy       ));
busy = start + busy * /d0;
END.
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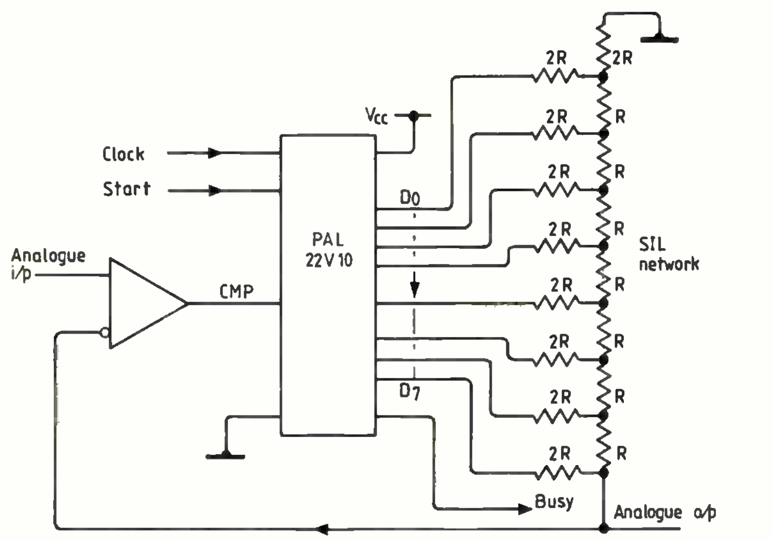


The table shows a listing of the logic equations used to program the PAL. This has been simplified from the original, which included pins to enable devices to be cascaded to 16 bits. The test bit is shifted up the register using the rule that 'if this bit and all the lower bits are zero, and the next higher bit is one, then make this bit a one'. Results are latched using the rule that 'if this bit is a one, and all the lower bits are zero, then latch the result into this bit'. The tricky part is to define what happens to the registers when no change is required. This is the function of the last 'feedback' clause on each line.

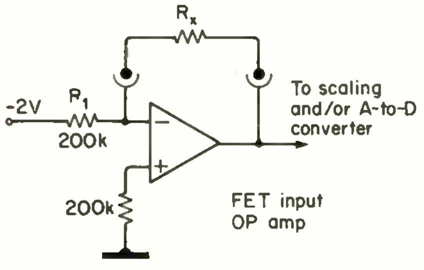
David Gibson
Leeds
Yorkshire

Digital milliohmeter

Ordinary 3.5-digit multimeters do not have the resolution needed to measure very low resistance values; consequently, a DMM will not measure anything under 1Ω with any degree of accuracy.

When an unknown value resistor R_x is connected between the output of the op-amp and the inverting input, the negative feedback holds the inverting input at 0V or virtual ground. Since R_1 has a fixed voltage of 2V across it, the current through R_1 is constant and flows through R_x to give an output voltage which is sent to the succeeding A-to-D converter. Obviously, this current is too small to produce an apreciable voltage drop across an R_x of less than 1Ω.

A solution to this problem is to pump a relatively large current through R_x and to use a DVM to measure the voltage drop across it. In this design, current of 1A was chosen to avoid conversion factor; readings are in direct units. For example, if the measured voltage drop is 36mv then R_x V would equal 36mΩ

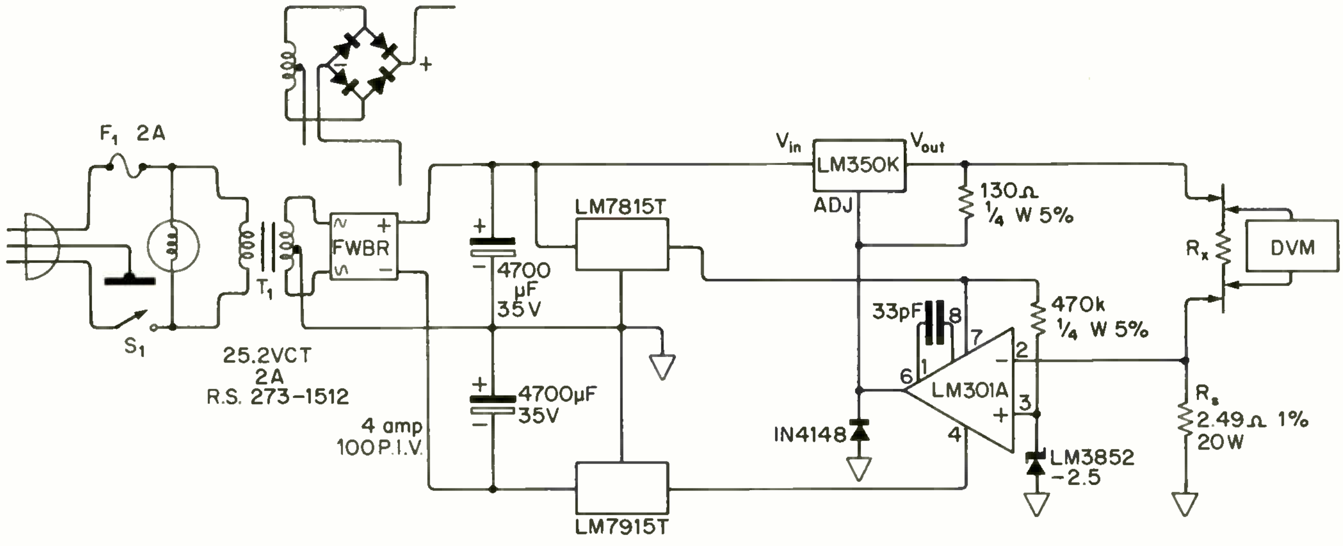


The LM350K is an adjustable positive voltage regulator capable of supplying 3A over a 1.2 to 33V output range. Its output is the voltage of the adjustment terminal plus 1.2V; if the adjustment terminal is grounded the device will act as a 1.2V regulator.

A current of 1A is pumped through R_x by the LM350K and is sensed by R_s, a 2.49Ω resistor. With 1A flowing through R_s, a voltage drop of 2.49V will appear at the inverting input of an LM301A op-amp, which is configured as a DC error amplifier, the 2.5V reference voltage at pin 3 being provided by an LM385Z-2.5 precision reference. Since the op-amp, regulator and R_x comprise a negative-feedback control system, the voltage at the inverting input of the LM301A is equal to V_{ref}. Therefore, 2.5 volts will be maintained across R_s, forcing 1A of current to flow through RX. The maximum size of R_x is limited by the LM350K's output voltage minus 2.5V.

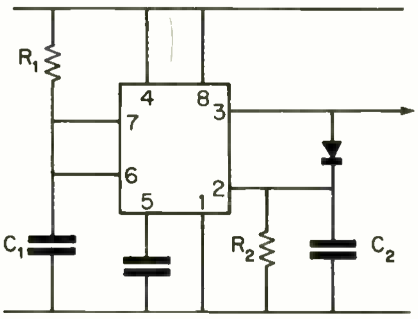
A 1N4148 diode is used to clip any negative voltage from the op-amp. The LM350K is required only to provide 1A and the power dissipated by R_x is only 2.49 watts, yet I used a 20 watt resistor. These components were deliberately oversized so that very little thermal drift would occur.

Mike McGlinchy
Los Altos
California
USA



555 with less than 1:1 M/S ratio

In the arrangement shown, a 555 will operate as an astable multivibrator with less than 50% duty cycle.



The high-output state is timed by R_1C_1, while R_2C_2 time the low state. To gate the output, return R_1 to a gating signal instead of the supply line. If pin 4 is connected to the supply, pin 3 remains high when the gating signal is low, first going low at the end of the first R_1C_1 period. If it is connected to the gating signal, pin 3 stays low when the gate is low.

D. Bridgen
Santiago
Chile

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ACTIVE

Asic

Micron arrays. Five libraries for the recently launched CLA 70000 family of 0.8μ channel-less cmos gate arrays offer 4900 to 256 000 total gates in nine different array sizes. 70% utilisation achievable with double layer metallisation. A triple layer option increases this to 90%. Up to 256 000 raw gates provided as a channel-less 5V array with less than 5μW per gate/MHz power dissipation. Gate delays around 420ps (NAND2 Fanout-2). GEC Plessey Semiconductors, 0793 518000.

Discrete active devices

Mobile coms transistors. Siemens BFP180 series silicon RF transistors are suitable for DECT and PCN applications, and are available in both SOT23 and SOT143 configurations. BFP181 has a transition frequency of 7GHz, and a noise figure of 1.2dB measured at 800MHz. Maximum collector current is 20mA. Figures for BFP183 are 8GHz, 1.2dB and 65mA. Siemens plc, 0932 752320.

High-current complementary transistors. With a current rating of 1A continuous, the PNP FMMT551 and NPN FMMT451 transistors can dissipate 425mW at 25°C. Current gain for both devices is typically 50 at 1A collector current, rising to 100 at 150mA. Saturation voltages are 0.35V (PNP) and 0.25V (NPN) at 500mA collector. Zetex plc, 061 627 4963.

Digital signal processor

Pythagoras processor. PDSP16330 Pythagoras processor converts cartesian 16 + 16-bit, two's complement or sign magnitude data into 16-bit magnitude and 12-bit phase. Magnitude output may be scaled by 2, 4 or 8 and phase output represents a full 2 × π field. Three state output and independent data for simplified interfacing. Dissipation less than 800mW when operating at 25MHz. Plessey Semiconductors Ltd, 0793 518000.

Linear integrated circuits

12-bit multiplying D-to-A. DAC7802 is a dual 12-bit, four-quadrant, multiplying unit with output settling to 0.01% of full scale within 0.4μs typical, 0.8μs maximum. High speed digital latches. Burr-Brown International Ltd, 0252 510054.

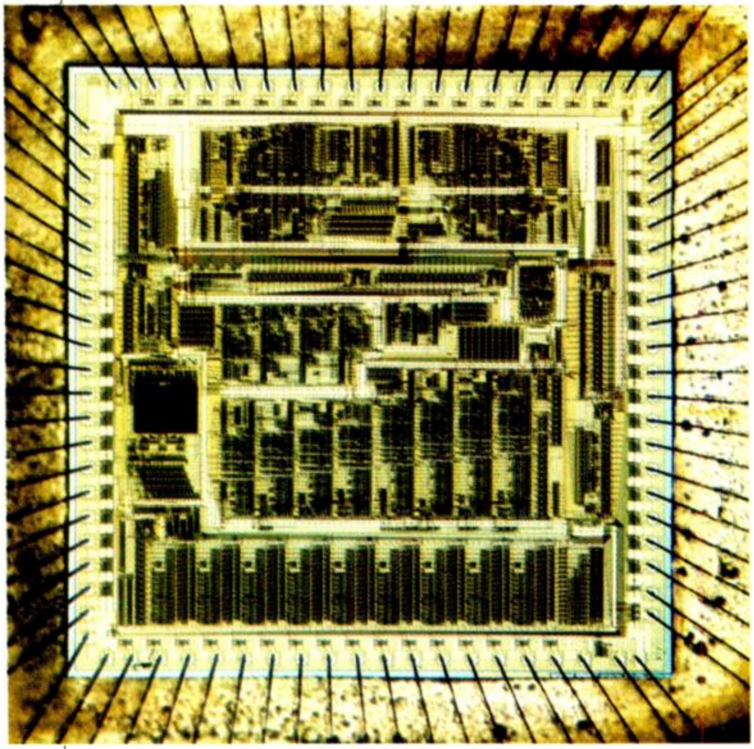
Power packed buffer amp. The Elantec EL2009 provides continuous output currents of over 1.0A into a 10Ω load, at 90MHz. The 3dB bandwidth associated with a 50Ω load is 125MHz. Applications include video distribution amplifier, fast op-amp booster, flash A-to-D converter buffer or motor driver. Microelectronics Technology, 0844 278781.

Logic building blocks

AT chip set. METL has released UMC's Mortar chip set for building a PC AT from three VLSI devices, eight logic components, memory and processor. 4Mbyte of on-board memory supported using standard 80ns drams for zero wait state operation at 12MHz. 120ns drams for one wait state operation at 12.5MHz. Landmark speeds are 15.9MHz at 12MHz operation and 16.5MHz at 12.5MHz. Microelectronics Technology, 0844 278781.

Delay timer. The 74HC/HCT5555 cmos timer and oscillator provides stable, programmable, delay periods from 100ns to several days. The 5555 contains a 24-stage binary counter, oscillator, a retriggerable or non-retriggerable monostable, a power-on reset and a master reset circuit. Signetics Company, (408) 991 2000.

Cartesian-to-magnitude/phase processor, the PDSP16330 from Plessey.



Memory chips

1Mbit eprom 70ns. The CAT27HC010 access times are 70/90120ns. Operating from a single 5V supply (read mode), it consumes 80mA active and 1mA on standby. High speed programming is 100μs/byte using 12.5V and the quick pulse algorithm. MMD Ltd, 0734 313232.

Sram. The CXK7701J 1Mbit cmos high-speed latched cache sram, is optimised for use with Intel's 82385 cache controller for 20, 25 and 33MHz 80386 devices. Access times are 30 (J-30), 35 (J-35) and 45ns (J-45) and output enable times 10, 13 and 16ns. Housed in a 52-pin plastic leaded chip carrier (PLCC). 5V supply. Sony Europe GmbH, 0784 466660.

Optical devices

Fixed optical attenuators. LCS-PATC series with 1m pigtails allows connection of a variety of connectors. The compact in-line single/multimode products are designed for use with D4; FC and FC/PC; ST and ST/PC; SMA905 and SMA906 connectors. The LCS-BUD series are configured into a bulkhead adaptor design with either FC, ST or d4 bulkhead adaptors. Fibre Optech Ltd, 0767 600800.

Passive components

Resistor networks for dram damping. The 4800P range of surface-mount resistor networks now includes 20-pin and dual-terminator versions available with gull-wing leads for easy mounting on 8.9mm wide land patters. Tape-and-reel or tube packaging. Bourns Electronics Ltd, 0276 692392.

Cermet trimmers. The 12-turn Mepcopal 8026 series industrial-type 0.25in square trimmers have cermet resistance elements with infinite resolution. Sealed aga nst moisture in a vibration proof housing. Meets AC and HF requirements of MIL R-22097 and MIL-R-39035. Greenwood Electronics, 0734 595843.

Ceramic capacitors. Class 1 JKE capacitors, available from 1 to 680pF, promise accurate temperature compensation. Working voltages up to 3kV in five steps. The disc-type capacitors' temperature coefficients range from 0±60ppm/°C (NPO dielectric types) to −750±120 (N750). Young Electronic Services, 06285 31417.

PASSIVE

Connectors and cabling

Twist-to-flat cable. Colour-coded cable allows mass termination of standard 0.050-in insulation displacement connectors (IDCs). 28 AWG gauge wire with 7/36 stranded tinned copper conductors and PVC insulation. 0.007in laminated film applied to one side helps dimensional stability. Twisted lengths of 18in alternate with 2in flat sections long. Alpha Wire Ltd, 081 751 0261.

IC sockets. AMP DIP socket connectors, in either standard or low force options, are available in 6-40 positions. All standard insertion sockets have dual wipe selectively plated contacts in UL 94 V-0 rated polyester housings. Suitable for high board densities. Gothic Crellon Ltd, 0734 788878.

Displays

DPM module. The MDM350 with ±199.9mV full scale and optional scaling has auto-zero, auto-polarity and over-range indication; single-ended, differential or floating measurements; digital display hold and a high stability bandgap reference. A multi-turn scale control provides for readouts in engineering units. Martel Instruments Ltd, 0207 290266.

Hardware

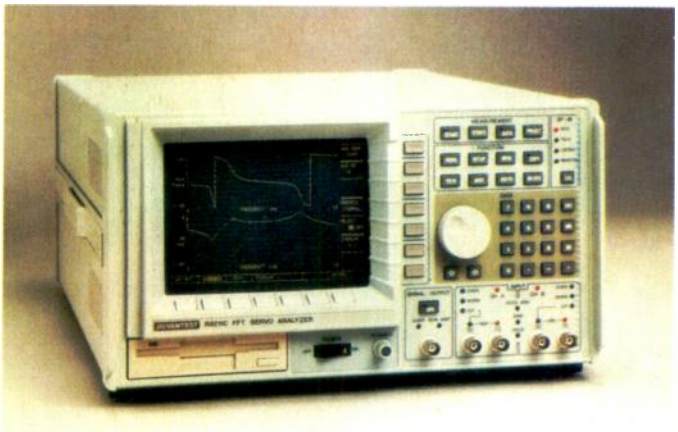
Four-module din controls. A standard version three- or four-way multisocket Dis-board with integral DIN 43 880 housing will accept any standard DIN rail mounting module up to four modules wide. Aphel Ltd, 0788 832488.

SM plastic chip carriers. The surface mount chip carrier socket accepts post-moulded plastic chip carriers conforming to Jedec specification MO-047. The sockets offer a protective package in both through-board and surface-mount configurations for vapour-phase soldering. High-pressure contact eliminates gold plating. Methode Electronics,

Backplanes for VME-bus and STE-bus. These backplanes are supported by ancillary components including termination networks and extender cards. Reliable maintenance even under full loading is claimed through multilayer construction. Noise-critical lines are fully surrounded by screening. Press-fit technology employed. Sub Rack System Products, 0279 418401.

Instrumentation

R9211C FFT analyser. Servo-analysis functions include curve fit and frequency-response synthesis. The instrument uses swept sine sweep to achieve an inter-channel amplitude difference of ±0.1dB and a phase difference of ±1.0°. Internal summing amplifier and a servo-measurement function with frequency table included. Advantest, 081 336 1606.



Advantest R9211C FFT servo analyser.

Alternating voltage calibration. Model 4920 alternating voltage measurement standard can measure signals from 1Hz to 1.25MHz with total uncertainties to ±28ppm in stand-alone measurement mode, ±14ppm in AC/DC transfer mode (one year ±5°C). Datron Instruments Ltd, 0603 404824.

VME-bus analyser. Vbat board, plugged into any VME system, can continuously monitor all bus traffic, screening for protocol violations. It allows designers of VME boards to check compliance and provides simple debugging.

Temperature and humidity indicator. Operating from a standard 9V battery, the Model 525 lightweight portable instrument provides temperature and humidity readings via a single LCD display. Detachable sensor connected by 1m coiled cable. Range +10 to +140°C. Relative humidity from 2 to 98%. Hartley Measurements,

Multi-channel recorder. The M2000 records most engineering parameters in real time or individual signal storage. The recorder uses digital print techniques on to low cost thermal paper. Interfaces with analogue input signals through individual conditioning channels which will operate with most sensors. Sensor excitation supplies are included. Micro Movements Ltd, 0734 730200.

Time to voltage converter. The TVC 501 converter measures pulse width, pulse periods and signal-to-signal delays. Time-interval measurement is instantaneously converted to voltage. The resulting waveform can be viewed real-time on any oscilloscope. It will convert up to 2.5million consecutive timing measurements per second. Tektronix UK Ltd, 06284 6000.

Test signal generator. The TSG has two independent oscillators, continuously variable via the front panel. A frequency and level meter ensure these are set up accurately. There is a pulse generator section, where the mark and space time can be set. Overall length of pulses is also selectable. Tele-Products Ltd, 0904 659583.

Interfaces

Keyboard for medical system. A membrane keyboard has been introduced, designed for advanced ultrasound medical systems. It combines both membrane and electro-luminescent technology, w th embossed polyester overlays, polyester tactile domes and RFI shielding. Dart Electronic Controls, 0296 24478.

Production equipment

Durable protective wrist strap. The Charge Guard 2240, a Speidel "Twist-O-Flex" metal expansion band, has an insulating capped exterior to overcome fear of burn or shock associated with non-insulated metal bands and jewellery. Spring-loaded snap system holds the ground cord securely. 3M Static Control Systems, 0234 268868.

Power supplies

Pluggable switched mode supply. The PK120 Trivolt supply offers 5V at 12A and ±12 to 15V at 2A. Packaging is either a 3U, 14HP cassette module or a 6U, 8HP cassette for uses in systems based around either single or double Eurocard sizes. cla med efficiencies >75%. BICC-Vero Electronics Ltd, 0703 266300.

Cigarette pack sized converter. The PWR-82400 triple output DC/DC converters (3.2 × 2.4 × 0.6in) operate over −55°C to +125°C, supply 5W, and give a power density of 19.4W/in^3. The series has been expressly designed not to derate to zero at maximum temperature. ILC Data Device Corporation, 0635 40158.

Lithium round cells. Varta's high capacity manganese dioxide round cells, of bobbin construction, are designed for low rate discharge. Laser welded sealing for a ten year seal life. Operating range is −30 to +75°C with short term excursions to −40 to +85°C. Varta Ltd, 0460 72320.

Production test equipment

Interceptor for board testing. Interceptor runs on IBM compatibles to troubleshoot on linear or digital ICs and other types of components including capacitors and wound components. DCA Technology, 0730 60699.

Three point approach to testing. The QA XX08 three needle point, spring loaded test probes are designed for diagnostics of returned printed circuit boards and assemblies. High point forces will penetrate any patina build-up around the test pads during field use. 0.25 and 0.4-in probe travel sizes; interchangeable in the same industry standard socket configuration. Teknis Ltd, 0344 780022.

Radio communications products

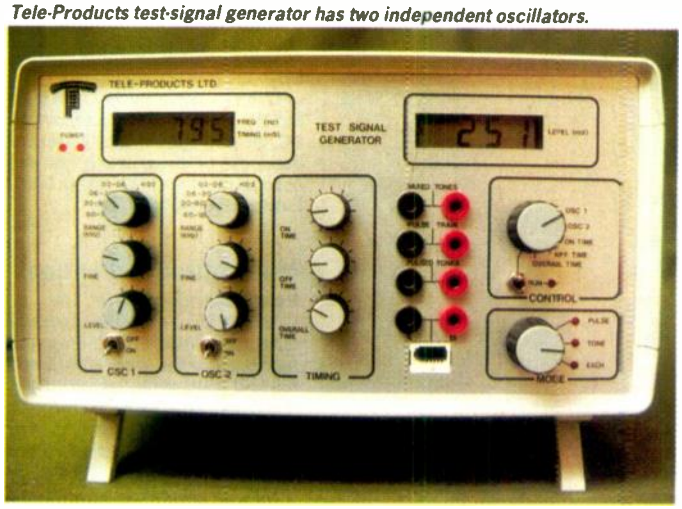
ATE for RF receivers. Carston Electronics' HP 8642B, with highstability time base option, is programmable via HP-IB (IEEE 488), and allows testing to be fully automated. The 8642B ranges from 100kHz to 2.115GHz and provides SSB phase noise at 20kHz offsets of −13dBc/Hz at 1GHz. Carston Electronics, 081 943 4477.

Transducers and sensors

Precision pressure transmitter. The BL flush diaphragm pressure transmitter is a two-wire component receiving excitation voltage and transmitting current output over the same pair of cables. Signal output is the standard 4 to 20mA into 0 to 2000Ω loop resistance. Control Transducers, 0234 217704.

VME-bus and STE-bus backpanes from Sub Rack System Products.

Tele-Products test-signal generator has two independent oscillators.



Silicon pressure sensor. The MPX5100D is a 0-15psi, signal-conditioned output sensor integrating the sensing element, offset calibration, temperature compensation circuitry and signal amplification on a monolithic silicon chip. It is said to be the first rail-to-rail integrated pressure sensor. Output scale calibrated from 0.5V to 4.5V. Motorola Inc, 0101 602 952 3856.

Miniature loadcell. Model 31 miniature loadcell's tripled stack design eliminates off-axis loading and false load measurements. Welded stainless steel construction. Typical diameter is 19mm. Mechanical overload stops, precision calibration to 0.15% stabilising diaphragms and pressure compensation included. RDP Electronics, 0902 57512.

COMPUTER

Computer-aided design

Microwave design system. Microwave Musician handles front-to-back design of monolithic microwave circuits and hybrid devices. Schematic capture, libraries, simulator interfaces and microwave-specific layout and physical verification tools included. Libraries of theoretical or ideal microwave components, and foundry components are available. Cadence Design Systems, 0628 826821.

PCB design. A suite of cad/cam tools for electronics engineers from Excitech is made up of four programs under the name Satcam; schematic capture, circuit board layout, post processing, and a database containing symbols and packaging information. Autocad drawing editor. Excitech Computers, 0635 66767.

Circuit synthesis program. RFSynthesist from Ingsoft runs on the Macintosh. Calculations included are filter synthesis, transmission line characteristics from physical dimensions, synthesis of microstrip lines, and coupled transmission line characteristics in stripline and microstrip configurations. Use alone or with RFDesigner. Ingsoft, 010 1 416 730 9611.

Layout software packages. Stand-alone layout packages provide the interface between Pads-PCB and electronic and mechanical cad and cae packages, available for five on-way Pads-PCB interfaces, three two-way interfaces and four general purpose converters. Lloyd Doyle, 0932 245000.

Computer board level products

Digital I/O card. CIO-DIO 48 low-cost high density board (for PC/XT/ATs) is an enhanced compatible equivalent of the Metrabyte PIO 12/PIO 24. It is actually is one PIO 12 and one PIO 24 together on one half length card. Amplicon Liveline Ltd, 0273 608331.

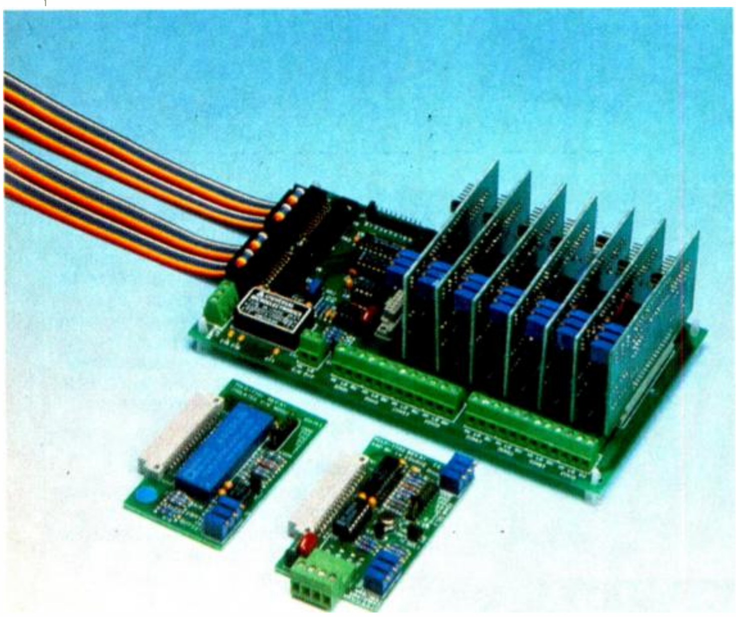
Fast series das boards. The Fast series high speed, precision, analogue input boards for IBM PC/AT compatibles offers speeds from 14-bit, 1 and 2MHz, to 16-bit 1MHz and complements the existing 12-bit boards. Four differential input channels with software programmable ranges and four-channel simultaneous sample and hold. Optional memory for on-board storage. Consort Electronics, 0252 871717.

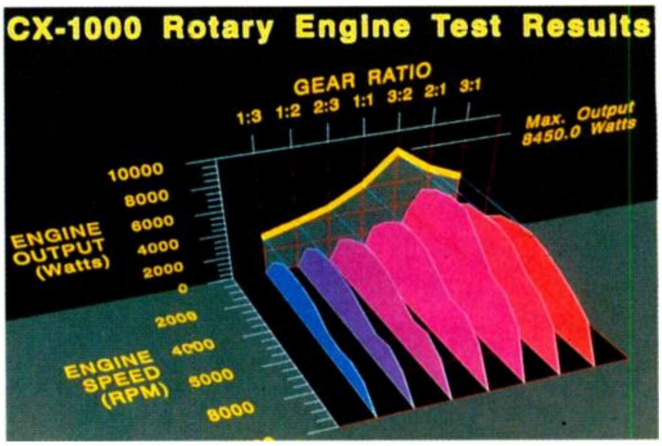
Signal conditioning modules. The PCLD-770 links industrial sensors to PC data acquisition cards. Carrier board includes a cold junction sensor, multiplexer and screw terminals. Eight DIN sockets mate with separate signal conditioning modules. Breadboard module available. Ten PCLD-770s can be linked to one PC card, providing 80 differential inputs from one PC slot. Fairchild Ltd, 042121 6527.

Data communications products

Vehicle identification system. The two-digit encoder will send a 190ms DTMF burst at the end of each over with a unique identity. Operates on any two-way radio system. CDS Ltd, 0256 83528.

Sensor conditioning modules in carrier from Fairchild.





Version 6.0 of DI-3000 graphic programming tool from Precision Visuals.

Multiplexer for Unix systems. Designed to turn standard 386 or 486 AT compatibles into a high performance multiuser Unix or Xenix system, the PC01 is the first 16-line multiplexer board supporting speeds of 38.4kps on all lines with minimal host degradation. Emulex Ltd, 0734 772929.

Development and evaluation

Z80 debugger. The SourceZ80 supports the IAR/Archimedes C compiler and Ashling's CT series of in-circuit emulators. It includes automatic synchronisation of source code and disassembled code windows, evaluation of the addresses and offsets of all system variables, and continuously updated variables display. Ashling Microsystems, 0628 773070.

8-bit development system. The teletest 8 8-bit system from Hitex is configurable for most major microprocessors (determined by a replaceable personality card and outboard processor cable). Real-time emulation with eight hardware triggers, on-the-fly retrieval of external program variables and 8k cycles by 72-bit tracing. Optional 1Mbyte of emulation memory. Hitek (UK) Ltd, 0203 692066.

16MHz in-circuit emulator. The EB78320 Mini IE, supports the uPD78320/322 microcontroller family at 16MHz. Designed for use with a host PC, the package includes a full-screen debugger, 64kbytes of user ram and an optional real-time trace board. NEC Electronics, 0908 691133.

Mass storage devices

Rewritable optical drive. The RS9200E/2 is a 650Mbyte optical disk drive, using standard 5.25-in optical cartridges, writes at 150kbyte/s and reads at 450kbyte/s. It is aimed at memory-hungry applications. Magneto-optic media can handle over 10million write/erase cycles. 25-year life. Data Peripherals (UK) Ltd, 0785 57050.

Software

Asic design goes Solo. ES2's PC version of its Solo 1400 v3.0 software has most of its capabilities but runs on IBM-AT compatibles. It has a 32-bit Definicon coprocessor card. Chips can be designed for manufacture by ES2 in either 1.7 or 1.1μm c-mos. The library includes basic cells, macro cells, I/O cells, 74 series equivalents, analogue cells, and compiled megacells of rom, ram and PLA. ES2, 0344 525252.

Fast file finder for PCs. Fleetfinder combines hardware and software to quickly locate a file. It uses direct memory access to scan a hard disk looking for selected words and is faster than a software only search. Fleetwood Systems, 0829 40552.

Enhanced windows connection. Concurrent access to applications residing on large computers and personal computers running in a graphical operating system is possible with Windows Connection Version 2.0. It integrates host sessions and workstation applications running in the Microsoft's Windows 3 environment, giving users easy-to-use graphical interface. Supports IBM Application System/400 (AS/400). IBM UK Ltd, 0705 321212.

Bus monitor. The GPIB-410 is the enhanced IEEE488 GPIB bus monitor and analyser package, main improvement being that it can capture data in background. In foreground mode, it can dynamically update its capture buffer display. Users can see most recent bus transactions as they occur. Analysis and editing features include detailed device addressing information, fixed cursor positioning, and store data buffer retrieval from disc. National Instruments, 0635 523545.

Graphics programming tools. Versions 6.0 of the DI-3000 and DI-3000 XPM graphics programming tools for Unix promise increases in application development productivity through more than 100 new customer-requested enhancements and features. Precision Visuals, 0895 35131.

Distorting power supplies

When is crossover distortion not crossover distortion? When it comes from the power supply, says Greg Ball

Class B, and to a lesser extent class AB, amplifiers are notorious for the generation of switching or crossover distortion at high frequencies, related to the switching speed of their push-pull output stages. These distortions are present as a spray of high-frequency harmonics and much effort has been expended by designers in reducing or eliminating these audibly objectionable distortions.

While some manufacturers espouse the need for pure class A operation in their promotional literature, others have concentrated on reducing the levels through the use of class AB, higher speed devices such as mosfets and innovative circuit techniques. Here, I wish to draw attention to another, often overlooked, source of a similar type of distortion which is generated as a result of the class B amplifier's interaction with the power supply impedance and which could easily be mistaken for crossover distortion when observed in the residual distortion waveform.

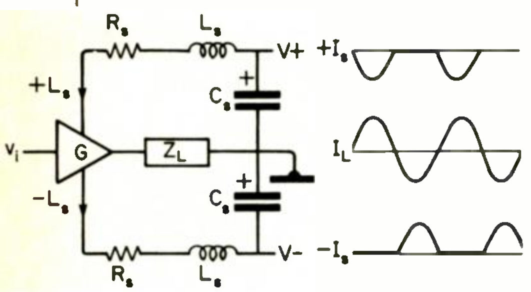


Fig. 1. Typical class B amplifier, with parasitic resistive and inductive impedances from power supply and wiring, which draws the currents shown.

Figure 1 shows a typical Class B amplifier interacting with its power supply when driven by a sine wave, where v_i = vsin2πft, G is amplifier gain, R_s and L_s are resistance and inductance of wiring, fuse and capacitor, C_s is pure power-supply capacitance and Z_L is the complex speaker load impedance Z_L (f,ϕ).

The input signal V_I is amplified by G and applied across the load as GV_i sin2πft, demanding a current from the class B output stage of $I_L=(GV_i/Z_I)\sin 2\pi ft$. This output current is drawn from the positive or negative power supply for half the output waveform cycle, depending on the phase angle of the load, resulting in the supply-current waveforms shown for $+I_L$ and $-I_L$. These half-wave-rectified current waveforms are shifted in phase from the original output waveform according to the phase angle of Z_L.

Fourier analysis of these supply current waveforms shows them to be rich in higher harmonics of the fundamental frequency f as follows.

$$\begin{aligned} I_L = & Gv_i/Z_L \\ & +(Gv_i \sin\pi\ ft\ 1Z_L \\ & -2Gv_i/\pi Z_L[\cos 2(2\pi ft)/3 \\ & +\cos 4(2\pi ft)/15 \\ & +\cos 6(2\pi ft)/35 \\ & +\cos n(2\pi ft)/((n-1)(n+1))\ldots] \\ & (n\ \text{even}) \end{aligned}$$

Simplifying the coefficients with $I=Gv_i/Z_L$ and truncating this infinite series at the tenth harmonic of f as the higher terms become less significant, gives

$$\begin{aligned} I_L = & 1/\pi \\ & +1/2[\sin\omega t \\ & -0.424\cos 2\omega t \\ & -0.084\cos 4\omega t \\ & -0.036\cos 6\omega t \\ & -0.02\cos 8\omega t \\ & -0.013\cos 10\omega t] \end{aligned}$$

The first term constitutes a DC level shift due to the single-sided current being drawn from each power supply. Remaining terms are harmonically related and compose the half-wave-rectified supply-current waveforms, the coefficients of each representing its level as part of the waveform makeup.

Supply impedance interaction

A typical capacitor-smoothed power supply with wiring and fuses could have a supply impedance as seen at the amplifier module of Z_s, which is frequency-dependent, as shown in **Fig. 2.** Above a frequency f_r its impedance is no longer capacitive but resistive or, worse, inductive. In many commercial power amplifiers this may occur at relatively low frequencies.

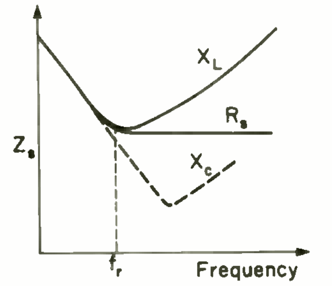


Fig. 2. Variation of supply impedance with frequency.

Consider the case where f_r=4kHz, the test sine-wave frequency used earlier is 2kHz so that its 10th harmonic occurs at 20kHz and we have the worst-case inductive-supply impedance. The voltage developed across

Table 1. Effect on gain at each harmonic frequency of power supply impedance.

Frequency	2kHz	4kHz	8kHz	12kHz	16kHz	20kHz
Phase	+26.6°	+45°	+63.4°	+71.6°	+76°	+78.7°
Gain	1.12	1.42	2.23	3.16	4.123	5.10
Harmonic	fundamental	2nd	4th	6th	8th	10th

the supply impedance due to $+I_L$ or $-I_L$ depends on the supply impedance Z_s at each frequency and Table 1 shows the effect on each harmonic individually of the rising impedance with frequency.

Applying the effect of this supply impedance Z_s to the individual terms in the harmonic series for the supply currents yields a similar series for the voltage developed across the supply impedance due to the pure sine-wave output from the amplifier, thus

$$V_s \text{ modulation} = K[\sin(\omega t+26.6) -0.54\cos(2\omega t+45) -0.17\cos(4\omega t+63.4) -0.1\cos(6\omega t+71.6) -0.074\cos(8\omega t+76) -0.59\cos(10\omega t+78.7)]$$

where K is a normalising constant on the magnitude of the fundamental and the phase shifts applied are those for an inductively rising power-supply impedance.

Plotting this function as in **Fig. 3** shows the transformation of the half-wave-rectified supply current waveform (a) into a supply-voltage modulation waveform (b) resulting from the inductive supply. This latter waveform is superimposed on the DC supply voltage. As can be seen, this voltage waveform is enriched with high-order harmonics of the fundamental output frequency f (2kHz in the example), with the second harmonic being present to 54% and the 4th, 17% of the level of the fundamental.

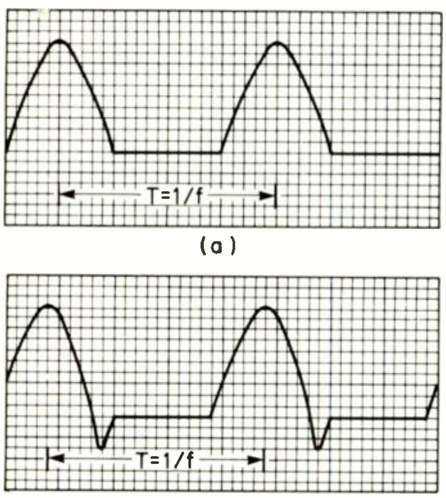


Fig. 3. Supply-current waveform at (a) and consequent supply-voltage modulation.

Power-supply rejection ratio

Practical amplifiers are not totally insensitive to power supply modulation, a measure of their insensitivity being their power-supply rejection ratio (PSRR) which is generally expressed in decibels. In a typical amplifier, the PSRR is a function of the design and may be a very high figure (say over 150dB) or a much lower figure, depending on the designer's awareness of PSRR as a factor in achieving the desired level of perform-

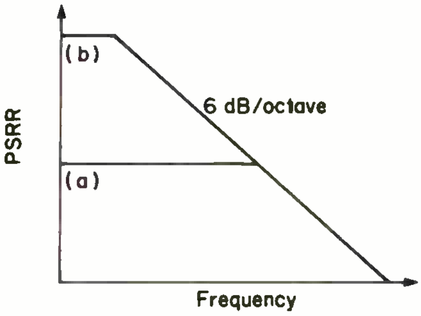


Fig. 4. PSRR of open-loop amplifier. Curve at (a) is that of low-feedback design, while (b) is a curve for high-feedback amplifier of similar gain/bandwidth.

ance and his ability to achieve an adequate figure.

Almost invariably, the PSRR of an amplifier falls with open-loop gain at high frequency at typically 6dB/octave, as shown in **Fig. 4**. In an attempt to cover extremes of design philosophy, I have shown two curves, (a) being typical of low-feedback designs and (b) more characteristic of high-feedback designs of similar gain/bandwidth product. While those in curve (a) may have relatively poor PSRR at low frequencies and thus be very sensitive to power-supply impedance (capacitance) for acceptable low-frequency performance, curve (b) is characteristic of operational-amplifier design techniques and, for the purposes of our argument, constitutes the worst-case condition.

This type of PSRR response is decreasing at 6dB/octave throughout most of the audio spectrum and substantially alters the harmonic structure of the power-supply voltage modulation. Associated with this 6dB/octave decrease in PSRR is a fixed 90° phase shift (well above the corner frequency) which affects all harmonics equally and is thus added to the fixed phase shift for each harmonic. Because the PSRR decreases at 6dB/octave with increasing f, we can consider this as, in effect, extra gain for the higher harmonics and the effect on our truncated Fourier series for the supply voltage modulation is shown in Table 2.

Applying this emphasis to the supply-voltage harmonic series, normalised to unity for the fundamental, gives the harmonic structure of the waveform which is presented at the amplifier input through the finite PSRR of the amplifier, is amplified by the gain G and appears across the load.

$$v_{iPSSR}=(K/PSRR)\,[\sin(\omega t+116.6) -1.08\cos(2\omega t+135) -0.68\cos(4\omega t+153.4) -0.6\cos(6\omega t161.6) -0.59\cos(8\omega t+166) -0.59\cos(10\omega t+168.7)]$$

The higher harmonics have been heavily emphasised by comparison with the original half-wave-rectified supply-current waveform. Plotting this function and also that for the same function with the fundamental frequency subtracted give the results in **Fig. 5**.

The two curves and the series for v_{iPSRR} show that the second-harmonic component is of similar level to the fundamental, while all the higher order harmonics considered in our truncated series are at 59% to 68% of the level of the fundamental. This signal (reduced to a magnitude dependent on the level of the PSRR at f) will be amplified by the gain G to appear at the output across the loudspeaker load. Even with an output stage free from crossover distortion, a waveform as in Fig. 5(a)

Frequency	2kHz	4kHz	8kHz	12kHz	16kHz	20kHz
Gain	1	2	4	6	8	10
Harmonic	fundamental	2nd	4th	6th	8th	10th

Table 2. Effect on gain at each harmonic frequency of power supply impedance.

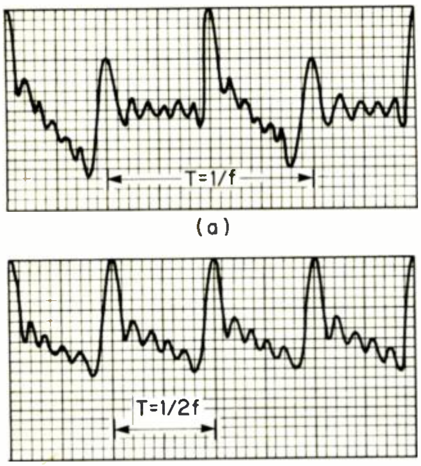


Fig. 5. Input voltage at amplifier input due to PSRR (a) and the residual waveform after subtraction of fundamental.

will appear at the output and, if a THD analyser is used, at frequency f the residual in (b) will be present.

Common power supply

Many commercial power amplifiers use a power supply which is common to both channels, as in **Fig. 6**. In this case, there will be a degree of interaction between the two channels due to common power-supply impedance and, while the cross-talk introduced may be at an acceptable level, it may be well below the level of harmonic distortion introduced in each channel by the mechanism described earlier. The presence of any significant level of crosstalk gives a rough indication of inadequate PSRR in the amplifier proper, since the common supply impedance is likely to be only part of the overall supply impedance seen by either channel.

As the common components of the supply are usually only the reservoir capacitors, with good design these can remain capacitive to well in excess of the audio frequency range, thus eliminating the harmonic emphasis due to supply fuses and wiring in the crosstalk waveform. The capacitive impedance (assuming low ESR and ESL) will reduce, at 6dB/octave, the harmonics in the half-wave-rectified supply-current waveform which develop the supply-voltage modulation on the capacitors, but they will resurface in the other channel due to the 6dB/octave emphasis resulting from its declining PSRR. Thus the injected crosstalk waveform will have the same makeup as the $-I_l$ waveform earlier.

$$v_{cross}=K[\sin\omega t - 0.42\cos2\omega t - 0.084\cos4\omega t - 0.036\cos6\omega t - 0.02\cos8\omega t - 0.013\cos10\omega t \ldots]$$

A plot of this, shown in **Fig. 7**(a), is that of the half-wave-rectified current waveform shown earlier. Crosstalk, however, is generally considered to be pure-tone fundamental appearing in the adjoining channel due to a signal in the first, while the remaining injected harmonics are not considered, despite their presence at substantial levels. If there is a crosstalk figure of, say, 66dB at 5kHz, there will be −73.5dB (or 0.021%) of 10kHz component and −87.5dB (or 0.004%) of 20kHz, due solely to a pure tone of 5kHz in the adjoining channel. The waveform, with the fundamental pure-tone crosstalk subtracted, looks like the graph in **Fig. 7(b)**.

This introduction of harmonics to the pure-tone crosstalk is for best-case, high-quality (negligible ESR and ESL) reservoir capacitors and is only dependent on the PSRR of the amplifier declining at 6dB/octave with increasing frequency. While not all amplifiers have a declining PSRR to emphasise the harmonics in the current waveform, not all power-supply capacitors exhibit pure capacitive reactance at high audio frequencies, particularly large single types, so this is far from a worst case.

While interchannel crosstalk waveforms are easily observed in the output of the undriven channel, intra-channel higher-harmonic distortion waveforms induced by the power supply are not and could easily be interpreted as part of the crossover distortion. Since the supply impedance seen by each channel will generally be higher and different in nature to the pure common capacitance, this source of distortion will probably be substantially higher than the crosstalk in proportion to the ratio of Z_s to X_c at any given frequency. No account has been taken of impedance variations in the loudspeaker load impedance (unknown), Z_L (f,φ), which could easily exacerbate the problem if there were substantial dips in its impedance at higher frequencies, resulting in higher current demand from the supply.

This distortion mechanism, responsible for generating a spray of high-order harmonics in response to a pure-tone sine-wave, input is deemed responsible for masking the spatial and timbral detail in an audio signal and is likely to contribute to the perceived harshness of many class B (and low-bias class AB) designs.

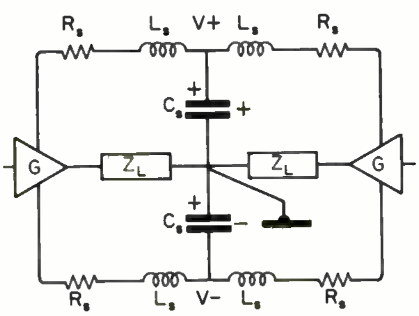


Fig. 6. Stereo amplifier with common power supply, impedance of which causes crosstalk.

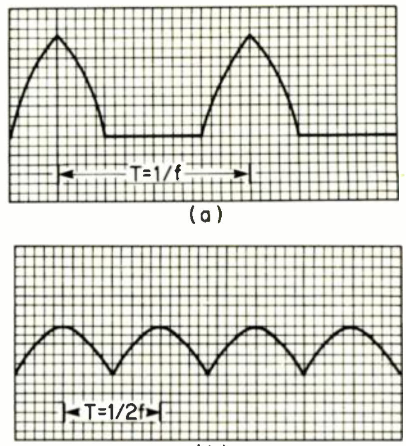


Fig. 7. Crosstalk components resulting from a pure sine wave input waveform (a) and waveform with fundamental pure-tone subtracted.

Reducing the problem

The rectified waveform can be completely eliminated very simply by having the output stage operating at a current always in excess of that demanded by the loudspeaker — i.e. by operating the amplifier in pure class A! Since no high harmonics are then generated in the power supply, the distortion is eliminated. This solution is impractical in many applications and certainly where high power and cost-effectiveness are required. Crosstalk will still occur, but can be eliminated by using separate power supplies or monoblock construction.

Worthwhile improvement can be achieved by using multiple, paralleled power-supply capacitor banks (of smaller types with better high-frequency characteristics), eliminating supply fuses and using short, heavy supply-to-module cable runs. Some manufacturers use massively oversized transformers and capacitor banks for a further small improvement at great size,

weight and cost penalty. For example, a four-times oversize power supply can achieve a 12dB improvement, but this is usually swamped at high frequencies by practical wiring needs. This approach is common among manufacturers who subscribe to the low loop-gain, low-feedback concept (now moribund) where the PSRR is poor at low frequencies and substantial improvement is experienced in bass performance where supply capacitance easily dominates supply impedance.

Active regulation of the power supplies with low-impedance regulators is an alternative, expensive method of reducing power-supply impedance, which can achieve far lower supply impedances at low frequencies, but is rarely as effective as a quality capacitor bank at high frequencies due to stability requirements, particularly in high-power applications. Substantial supply-voltage losses occur, which are wasteful of amplifier dynamic headroom and produce an amplifier which is less capable of responding to the power demands of modern musical programme.

Once the mechanisms are properly understood, a more elegant solution is possible, with virtually perfect isolation being achievable at minimal cost, and depends on a very high PSRR in the amplifier proper so that all power-supply-borne interactions are prevented from appearing at the amplifier input at any significant level. These interactions can easily be reduced by 30, 40 or even 100dB simply and inexpensively by competent design and reduced to well below the spot noise floor of the amplifier. Given the controversy surrounding a trained ear's ability to perceive distortion below the noise floor, this is considered a worthwhile goal. This design approach in no way compromises dynamic headroom and desensitises the module to supply wiring, fuses or capacitance.

Elimination of this audibly nasty distortion permits performance of a standard commensurate with the best class A monoblocks in a class AB common-supply stereo power amplifier, while retaining the full dynamic headroom of the design.

This distortion mechanism, responsible for generating a spray of high-order harmonics in response to a pure-tone sine-wave input, . . . is likely to contribute to the perceived harshness of many class A designs

PIONEERS

Walter Schottky 1886–1976 Barriers, defects, emission, diodes and noise.

Tony Atherton

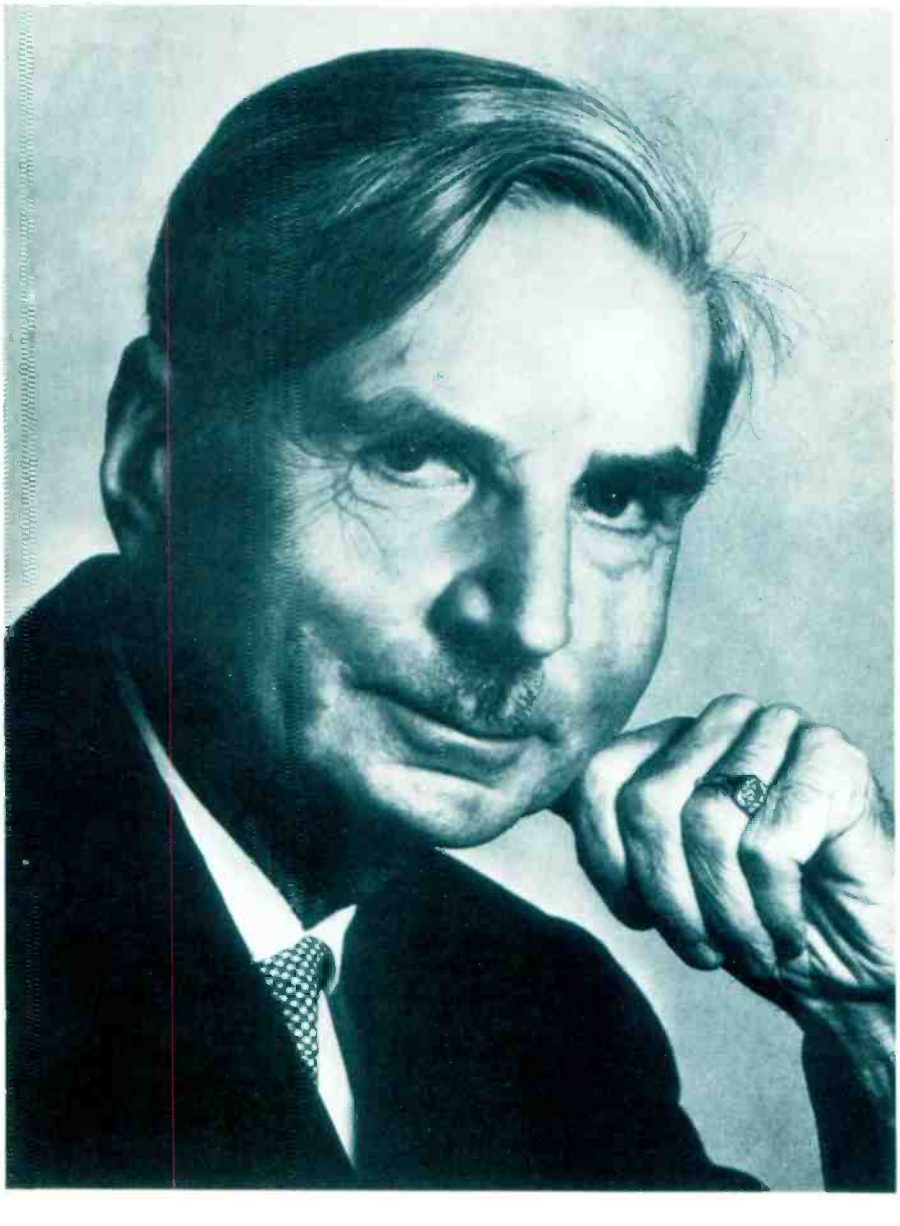
In the parlance of electronics engineers, "Schottky" has passed from being a man's name into being a technical term in very wide use. That is not a unique honour but it is perhaps an accolade which stands above medals, awards and citations from learned societies, prestigious as such things are. Walter Schottky's name is associated with thermionic emission, noise, defects in semiconductors and the Schottky diode. It is perhaps best known now in the context of Schottky TTL (Transistor-Transistor Logic), so named because of the modification of standard TTL by the addition of a metal-semiconductor or Schottky diode.

Schottky's career spanned the ages of both thermionic valve electronics and solid-state electronics, and he made major contributions to both. He worked in both industrial and university research laboratories, and was known as a modest and selfless character who avoided the centre stage.

He was born on July 23, 1886 in Zurich, Switzerland, but he spent his life in Germany. He died on March 4, 1976 in his 90th year, at Pretzfeld (near Erlangen), the town to which he had retired in 1958. His death came just two years after his old employer, Siemens, had begun commercial manufacture of Schottky diodes for microwave use.

Schottky's father, Friedrich, was a university mathematician. As a result of his career move from Marburg to Berlin, Schottky attended schools in both places and entered the Humboldt University in Berlin in 1904, where he studied physics. In 1912, he was awarded a doctorate in Berlin for his thesis on the Special Theory of Relativity which Einstein had announced only seven years earlier. Schottky's tutor was Max Planck, the originator of the Quantum Theory and a man at the heart of much of modern physics. Schottky could hardly have wished for a better start to a career as a physicist.

After receiving his Ph.D., Schottky went to Jena, some 45 miles south-west of Leipzig, where he worked under



Walter Schottky (1960), courtesy of Siemens AG.

Max Wien. It was here that he turned away from relativity theory and turned to what was to become his life's work — the interaction of electrons and ions in vacuum and solid bodies. To put it another way: electron physics.

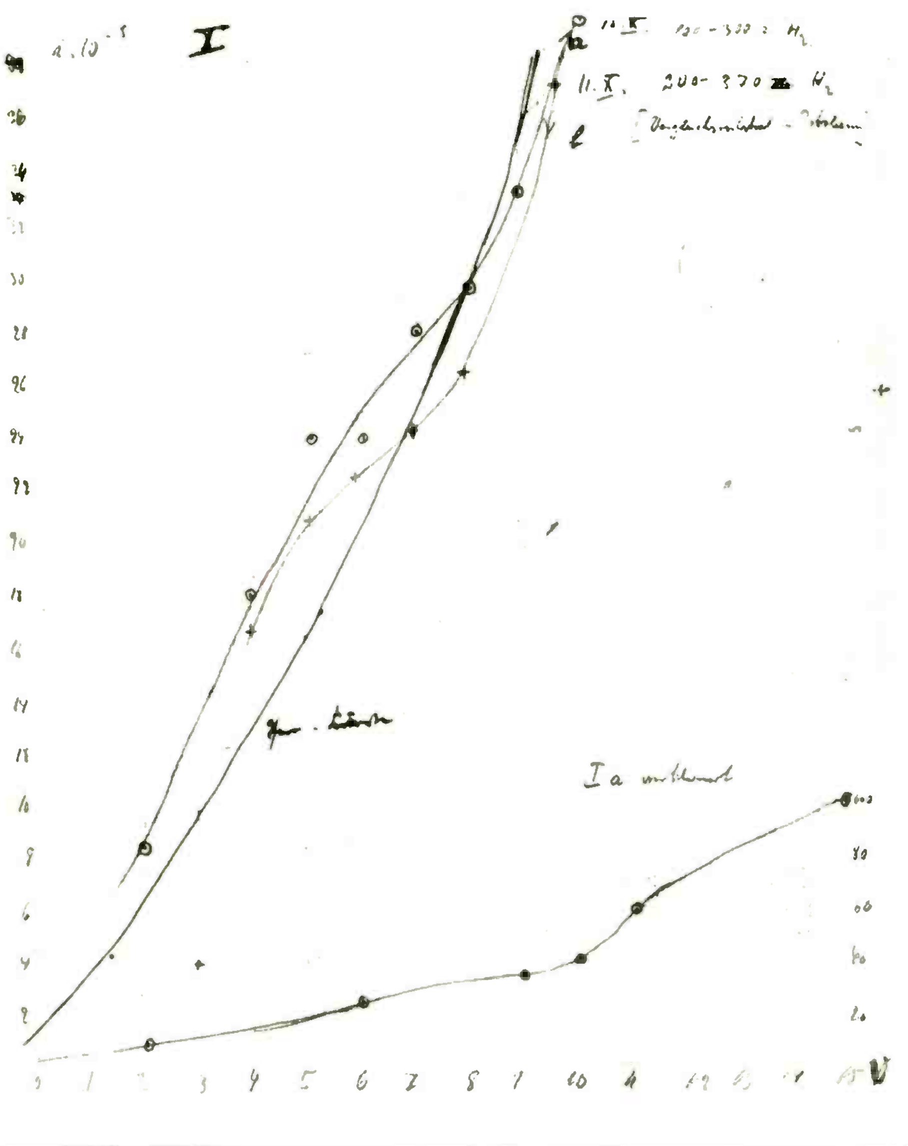
For the next 15 years his career pattern was to be one of movement between university and industrial research. Finally he settled for industrial research with Siemens AG.

The pattern began with a couple of years with Max Wien at Jena, after which he joined the Siemens industrial research laboratories in Berlin, staying there until 1919. In 1920 he returned to university life, this time under Wilhelm Wien at Würzburg. It was there that he qualified as a university lecturer. W. Wien is chiefly remembered for his work on black-body radiation, for which he received the Nobel Prize in Physics in 1911. After three years with Wien, Schottky advanced his academic career, becoming Professor of Theoretical Physics at Rostock. He was then in his late thirties. Finally in 1927, at the age of 40 or 41, he moved for the last time, back into industrial research, rejoining Siemens AG. There he stayed until his retirement.

Three-halves law

Schottky's achievements can be loosely divided into two phases: the first being research into vacuum electronics and the second, starting in 1929, covering semiconductor electronics. Of course, there were side issues to these two generalisations, some of which would alone have guaranteed him a place in the history books. The invention of the ribbon microphone was one, the superhet another.

Schottky's original curve showing the $V^{3/2}$ law for the thermionic diode (1913), courtesy of Siemens AG.



The ribbon microphone dates from 1924 and was invented jointly with Erwin Gerlach. They used an extremely thin concertina ribbon of aluminium placed between the poles of a permanent magnet. Reversing the physical effects led them to invent a ribbon loudspeaker as well, also using a thin ribbon of aluminium. The invention of the superhet is usually credited to the American Edwin Armstrong, but Schottky independently discovered the same principle of the superheterodyne with IF amplification in 1918. Coming second, it would seem, does not provide lasting fame, except perhaps in one's home country.

At Jena, where Schottky began his work on electron physics, he performed both theoretical and experimental studies of the space-charge effects of electrons emitted from cathodes in vacuum tubes. In 1913/14, at about the same time as Irving Langmuir in America, he independently discovered the basic law relating the current in a valve to the applied voltage; the $V^{3/2}$ law. Here, at least, he gained more lasting fame than with the superhet; it was a pioneering achievement and would have established him as a leading physicist. It may also have helped to determine his temporary career move to Siemens in 1915.

Noise

At Siemens, Schottky further developed his interests in electronic valves. Though he was there only from 1915 to 1919, he seemed to reel off a series of discoveries or inventions. His invention of the screen-grid valve or tetrode (which apparently he originally called the protection grid tube) was a major invention in electronics yet, in the light of hindsight, it was possibly overshadowed by his prediction of thermal and shot noise, two of the fundamental classes of noise in electronic devices.

During the early years of electronic circuitry, especially around the period of WWI, engineers and physicists were trying to solve problems involved in making better vacuum valves. Whilst many of the problems were related to design and manufacturing techniques, such as inadequate vacuum pumping, mechanical resonance, poor welds and the like, the fundamental problem of noise was gaining recognition. Some scientists were trying to discover what the ultimate performance of valve amplifiers might be, once all manufacturing problems were solved and only fundamental problems of physics remained. J.B. Johnson and Harry Nyquist, Swedes working at Bell Laboratories in America, were to provide some of the answers in the 1920s, but the classic paper on noise in valve amplifiers was published by Walter Schottky in 1918 in Germany.

More than 50 years later, Johnson was to remark on the fact that a paper of such quality and technical importance should come out of a Germany facing military defeat and economic collapse[1]. In fact, though the paper was published in 1918, Schottky had been working on the problem of noise since 1915.

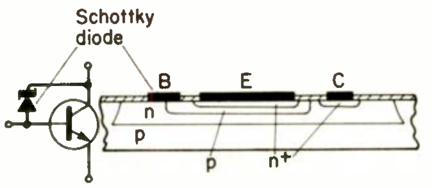
Schottky had reached the conclusion that there would be two sources of noise of a fundamental nature in an amplifier. The first would occur in the input circuit and would result from the random motion of charge caused by the thermal motion of the molecules in the conductors. This we know as thermal noise, Schottky called it the *Wärmeffekt*. Because this noise originated in the input circuit it would be amplified and appear at the output. He deduced that it would be proportional to the Boltzmann constant (k) multiplied by the absolute temperature. In the mid-1920s, Johnson experimentally identified thermal noise and Nyquist analysed the discovery mathematically, producing a formula of 4kT watts per unit of bandwidth, confirming Schottky's deduction.

Schottky called his second fundamental source of noise, suggested in his 1918 paper, the *Schroteffekt*. This, he suggested, would be internal to the valve and would be caused by the randomness of the emission from the cathode and the randomness of the velocity of the emitted electrons. We know it as shot noise and it was first experimentally identified and measured in Schottky's laboratory[2]. Later studies showed it was linked to factors such as the material and design of the cathode. Better understanding of these sources of noise led to better valves and, in the semiconductor age, to better solid-state devices.

This work on noise and thermionic emission in valves represents one of the great periods of Schottky's work. It was near simultaneous with his more engineering contributions of valve and circuit developments, notably the superhet. The next great period of his work was to be with semiconductors, but before that he turned his attention to thermodynamics.

Throughout the 1920s Schottky gathered material which eventually appeared in 1929 in a book on thermodynamics. It was written in collaboration with H. Ulich and C. Wagner and presented the thermodynamic theory of solids with very low impurity content or with small deviations from stoichiometry. It led him naturally to the study of semiconductors.

His other achievement of the period was in finding a wife. He married Elizabeth Lintz in 1923. They had three children.



Cross section of an integrated Schottky diode connected in parallel with the collector-base junction of an integrated n-p-n transistor. B is the diode, anode and the transistor base contact.

Schottky diode

The Schottky diode is made from a junction between a metal and a semiconductor instead of a junction between two pieces of semiconductor. Metal-semiconductor junctions are also used for non-rectifying (ohmic) contacts to semiconductor devices.

Ferdinand Braun is usually credited with the first systematic study of metal-semiconductor rectifiers, work which was published in 1874. Point-contact metal-semiconductor rectifiers were used from the early years of this century, but it was not until 1931 that the theory of current flow in semiconductors was placed on a modern basis by A.H. Wilson. Seven years later, Schottky published his diffusion theory of current transport in metal-semiconductor junctions. It was from this theory that modern understanding grew, hence a metal-semiconductor diode is usually known as a Schottky diode. Their importance lies in the speed with which they can be switched off from the saturated state. Being majority carrier devices they do not suffer from the minority carrier storage problems which slow down p-n junction switching.

In thermionic valves, the current emitted from the metal cathode into the vacuum depends, in part, on the metal's work function. Schottky discovered that this work function was lowered from its "normal" value by the presence of image forces and by the electric field at the cathode. This effect became known as the Schottky effect. In practical thermionic diodes it meant that, even when the current saturated, there would still be some increase in current if the anode voltage was further increased. However, unless very high anode voltages were used the Schottky effect could be neglected.

If we regard the filament in a thermionic valve as part of a metal-vacuum "junction" then the Schottky effect theory can be extended to a metal-semiconductor junction. The "barrier lowering" (as it is then called) that takes place is less than in the equivalent metal-vacuum "junction" but the effect is profound. Schottky used this as the basis of his explanation of the metal-semiconductor rectifier, work that was published in 1938. Other work by H.A. Bethe, Neville Mott, B. Davidov and others further clarified the conduction processes within metal-semiconductor rectifiers, but even so the term Schottky diode seems to be used synonymously with metal-semiconductor diode.

Two further examples of Schottky's vision are worth recounting: one to do with electronics, one not.

Schottky's obituaries recount that, in 1929, whilst studying semiconductors, he perceived or anticipated what we now call "holes"[3]. He wrote: "To a certain extent the places available for conduction electrons are occupied by static electron space charges and thus the passage of conduction electrons is blocked." These static space charges he called "defect electrons". It was another two years before Werner Heisenberg clarified the phenomenon of holes using quantum mechanics. Again Schottky's work paralleled that of someone else. Rudolph Peierls, at Bell Telephone Laboratories, conceived the same idea — also in 1929.

The final example of Schottky's vision relates to man's use of natural resources. In the preface to his 1929 book on thermodynamics he commented: "The time when man could dispose freely over the resources of energy and materials given to us by Nature will one day appear to belong to an era past, probably in the lifetime of our children." The world is now witnessing the truth of that prophecy.

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CFA: working assumption?

Is it possible to synthesise the Poynting Vector directly? CFA designers M C Hately, F M Kabbary and B G Stewart claim innovation in compact aerial systems.

Radio antenna design has traditionally been based on techniques stemming from Hertz's original use of resonant half-wavelength rods. But Poynting vector synthesis, and the crossed field antenna are demonstrating good early results for an alternative approach.

In the crossed field antenna an intense electric field is stimulated using one half transmit power, and an intense magnetic field is separately stimulated using the other half of the power. The two fields are carefully synchronised in time and crossed in geometry so that together they synthesise a powerful electromagnetic wave according to the theory of the Poynting vector:

$$\mathbf{S}=\mathbf{E}\times\mathbf{H}$$

This is a vector equation stating that S, the radiated power density in W/m^2 is the vector cross product (symbol ×) of the electric field **E**, in V/m, with the magnetic field **H**, in A. turns /m. The fields employed are intense, but the crossed field antenna is small, typically 3% of a wavelength. The initial wavefronts generated are therefore correspondingly small, but like all unconstrained waves they naturally expand.

Waves created by the CFA are thus just as useful for radio communication as the waves generated by classical antennas.

Previously the circular magnetic field has been stimulated by a capacitor. This was done to ensure the field lines of the E field were not "shorted out" by zero-resistance current-carrying conductors lying in the electric field zone. The approach was based on stimulating a magnetic field by a capacitor following the Maxwell law.

$$d\mathbf{D}/dt = \nabla\times\mathbf{H}$$

meaning that a vector curl H results from there being a change of displacement charge with time. In other words, an RF electric field causes an RF magnetic field with all the geometric properties of the curl.

To cover fully the principles of the CFA in the patent application, the concept of origination of the magnetic field by a stimulating coil has been covered — and does work to a certain extent. But for first production and experimental versions, development effort has been concentrated on forms of CFA using a D-plate capacitor to originate the magnetic field.

Experiments commenced with HF antennas small enough to be carried through a doorway, using fields of sufficient intensity to radiate the full power allowed by the UK amateur licence (400W PEP). A few initial calculations showed that 400W waves from a small device did not need unreasonably high voltage values, and later measurements confirmed that plate voltages are of the order of 300V. The Maxwell form of CFA is also

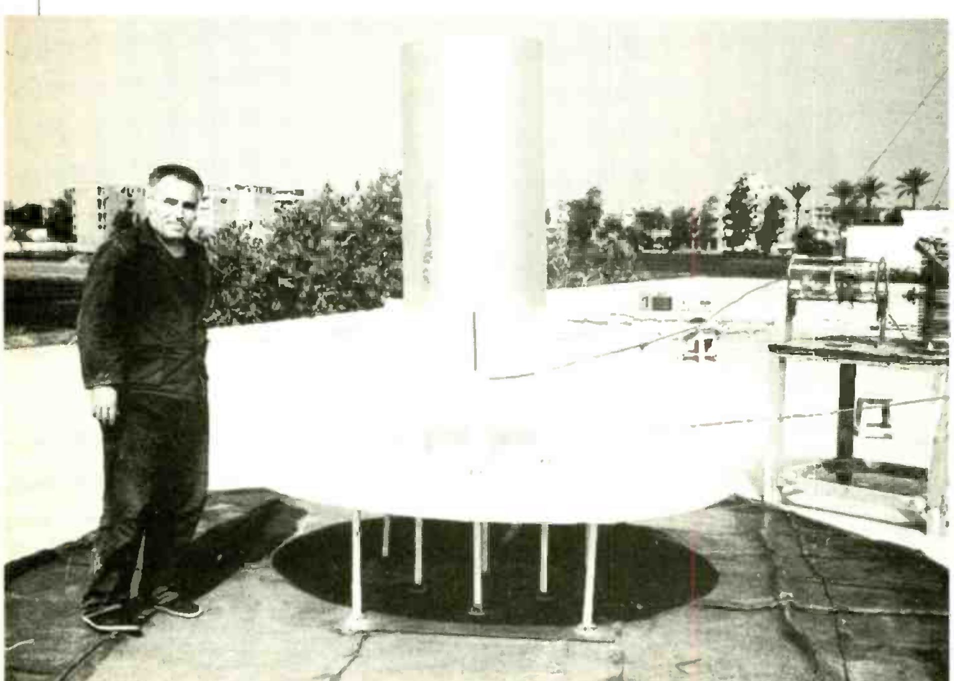


Fig. 1. Experimental medium-wave ground plane CFA radiating 25kW on 350m under test in Egypt.

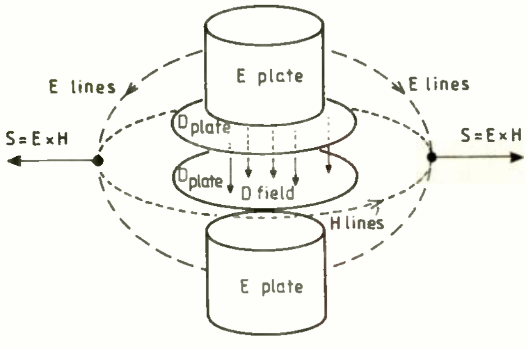


Fig. 2. Barrel-shaped crossed field antenna.

EMC-friendly and not likely to be a danger to users or nearby electronic equipment.

Barrel shaped CFA

When radiating from a small device, wavefronts are small, almost spherical, so the fields are curved.

Unfortunately early experiments used a straight-line electric-field layout, and did not work. When the stimulator electrodes were changed to initiate curved electric fields the antenna immediately became active, with the appropriate phase delay in the feed system.

Very quickly the "barrel shape" structure **(Fig. 2.)** was evolved as the optimum shape for generating omnidirectional vertically polarised radio waves.

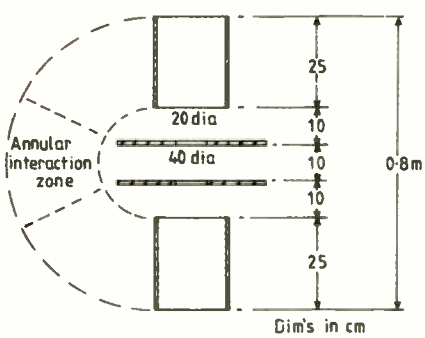


Fig. 3. Dimensions of the barrel-shaped CFA for HF.

In the barrel-shaped CFA the Poynting vector is synthesised in an annular "interaction zone" **(Fig. 3.)** around the centre of the device which is usually mounted upright. From the interaction zone a stream of vertically polarised waves leave and travel outwards to infinity at the velocity of light.

The antenna has circular symmetry in the horizontal plane, so the polar diagram of the intensity of radiation in the horizontal plane is a circle around the antenna.

The vertical radiation pattern has a broad maximum in the equatorial plane (provided the antenna is being supported far enough above ground) and there are two minima, one above and one below the CFA.

In space the CFA has the classic doughnut shape of the dipole held well above ground. Although it is less than a metre high it is possible to radiate any frequency from 2MHz to 30MHz; wavelengths from 150m to 10m.

In fact the CFA's size means it is tempting not to hold it at the right height, and to try to radiate from near the ground with wavelengths many times its mounting height.

But the CFA cannot defeat nature and the result of mounting at a small fraction of the wavelength radiated, is partial cancellation of the radiation to low angles of elevation. This is due to destructive summation with the anti-phase signal from the bottom half of the device reflected off the ground.

Ground plane CFA

To overcome the problem of radiating long waves from ground height, a form of CFA has been designed in which the CFA is bisected, and the lower half replaced by a reflecting surface; a ground plane **(Fig. 4.)** An addititonal advantage of the GP CFA form is that the feed system to the E plate is unbalanced and hence ideal for direct connection of coaxial cable. Unfortunately the requirement for plate-phase independence demands a transformer, so one is fitted in the D-plate feed and coax is again used.

A hollow cylinder forms the E plate with a single disc electrode forming the D plate. A ground plane, of area about $1m^2$, behaves as the common field-termination surface against which both the E field and the D field are expressed. The magnetic field stimulated around the D plate must flow above the ground plane (eddy currents will keep it away) and the E field cuts and crosses it at right angles. The ground plane CFA operates successfully giving low VSWR figures at the common input port even when the antenna is radiating wavelengths as large as 20–80M plus, and from zero height or low situations, on buildings.

Figure 5 shows the general HF-range ground plane CFA kit for amateur use and commercial evaluation.

Fig. 5. HF ground plane CFA kit for evaluation.

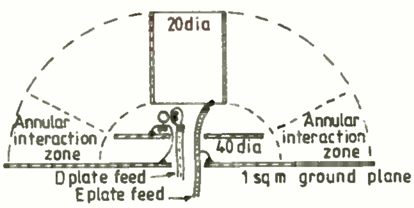
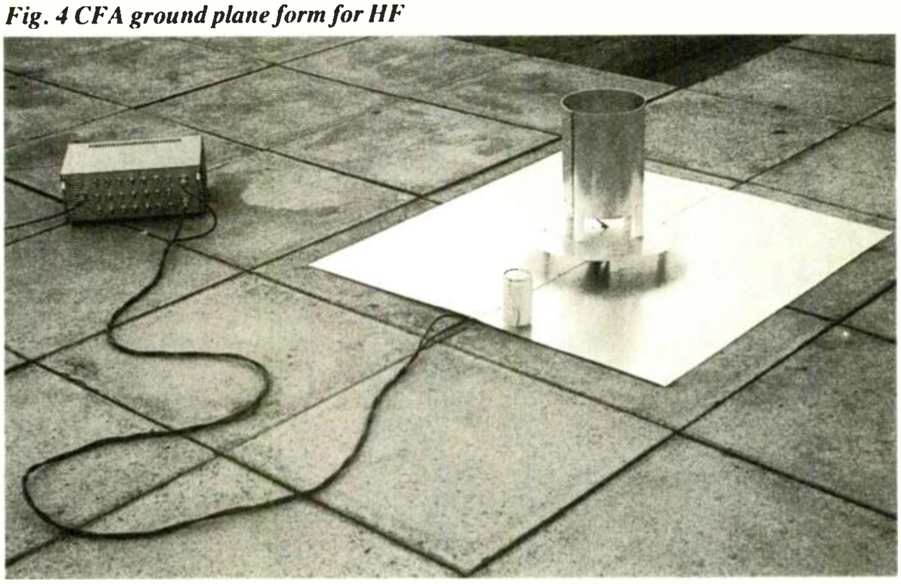


Fig. 4 CFA ground plane form for HF



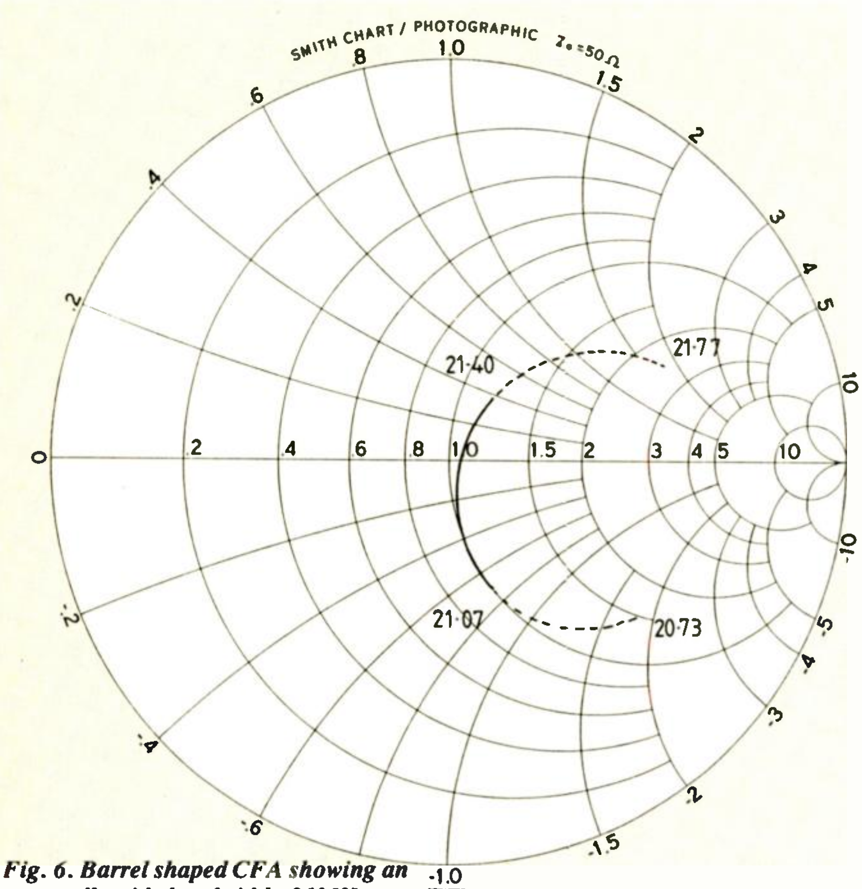


Fig. 6. Barrel shaped CFA showing an unusually wide bandwidth. 21MHz.

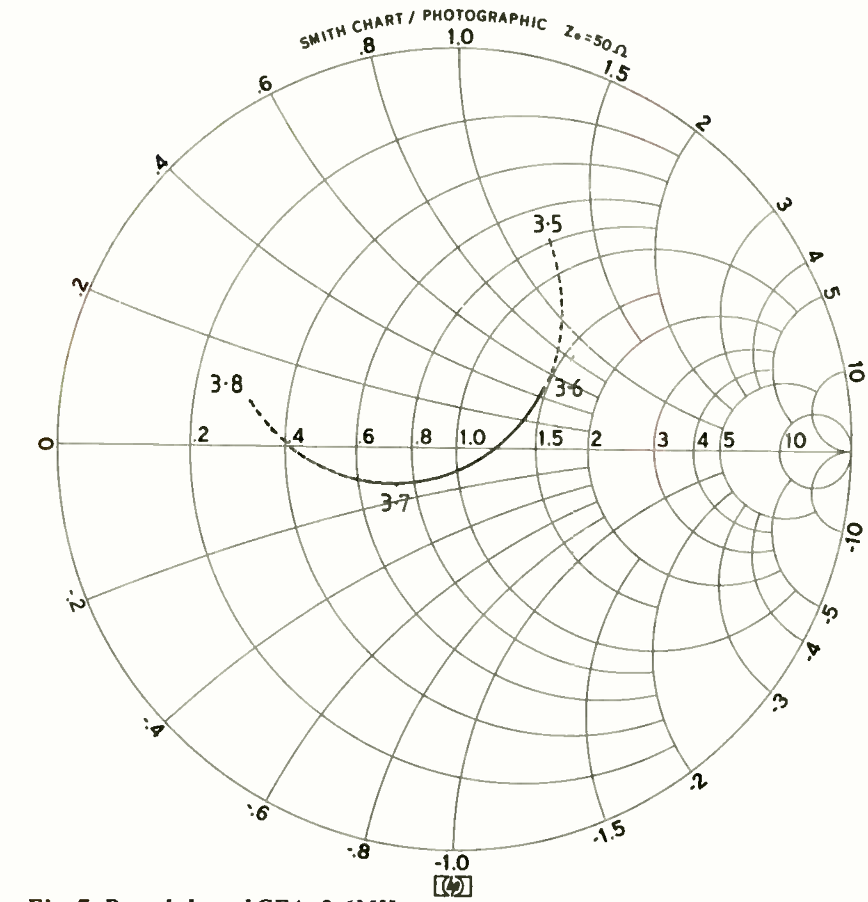


Fig. 7. Barrel shaped CFA. 3.6MHz.

Input impedances

When the CFA is operating, input impedances seen at the two separate electrode input ports are moderately valued and contain resistance, which is itself a cogent evidence of real radiation. The plates may be fed either directly or by using a step-up or step-down transformer. For feed via coaxial cable, primaries are normally constructed as isolating coils.

The input impedance of prime interest to the antenna user is not that at the electrodes, but that at the single feeder entering the phasing unit. Provided the phasing unit is well designed it can produce voltage magnitudes and phases able to synthesise the Poynting vector around the CFA somewhere in the interaction zone. The common feeder impedance then is close to 50Ω.

When the wavelength becomes very long compared with the physical size of the CFA it is more difficult to adjust the "in-phase" situation for the incoming fields at the interaction zone. In fact if the antenna is set up to radiate say 10MHz and then the transmitter frequency changed, the error in phase angle caused by change in the phasing unit internal impedances becomes evident first in depreciation of the field synchronism at the interaction zone. For a given CFA, the interaction zone size is fixed. Proportion of the band which is in phase relates to the size of the interaction zone as a proportion of a wavelength. Thus the longer the wavelength, the more critical must be the phase accuracy to produce interaction at the zone.

Working bandwidth

Fortunately Maxwell types of CFA are not nearly as narrow band as might be expected. Field stimulators are capacitors and therefore when they go off tune, they both tend to change in the same direction so the resulting error between them is minimised. Had a coil been used for stimulus of the magnetic field, the phase errors would have been opposite and their difference, presumably, more severely affected by frequency change.

A typical Smith chart of the measured single feeder input impedance normalised to 50Ω on a network analyser shows a band of frequency around 21MHz and an unusually wide bandwidth (**Fig. 6**). The antenna used was barrel shaped with dimensions given in Fig. 3. For operation anywhere within the amateur telephony band of 21.15 to 21.45 it is unnecessary to alter the phasing control of the antenna. At a much lower frequency, 3.6MHz (80m), the boundaries of the input SWR rising beyond 1.5 to 1 are surprisingly wide at about 200kHz (**Fig. 7.**).

Figure. 8 shows the input impedance of the ground plane atenna again at the 3.6MHz band where bandwidth is defined to be the frequency band with SWR 1.5 to 1 or less.

As an experiment the phase accuracy of the feed stimuli were deliberately upset by known angles and the power radiated noted. Output power versus electrical degrees phase error plotted for the full range of frequencies of HF (**Fig. 9.**) clearly confirms that the phase accuracy requirement becomes more severe as frequency goes down, at longer wavelengths. **Figure. 10** shows the effect of deliberate phase error on the single-feeder SWR measurements demonstrating that the CFA is a comparatively easy device to adjust.

CFA vs conventional

Two questions inevitably arise; if the CFA fields are so modest, why are the fields around a classical antenna so fierce and extensive? And if the CFA is so small, why do classical antennas have to be so large?

The answer to the first lies in the cycle by cycle inefficiency of classical wire antennas revealed in the typical Q of the average half-wave dipole of around 10. Almost all the energy stimulated by the classical antenna is stored in the induction fields (alternately electric then magnetic) and returned to the system four times each cycle. Only a fraction of the induction field is radiated.

In the CFA most of the energy gets away as radiated field each cycle.

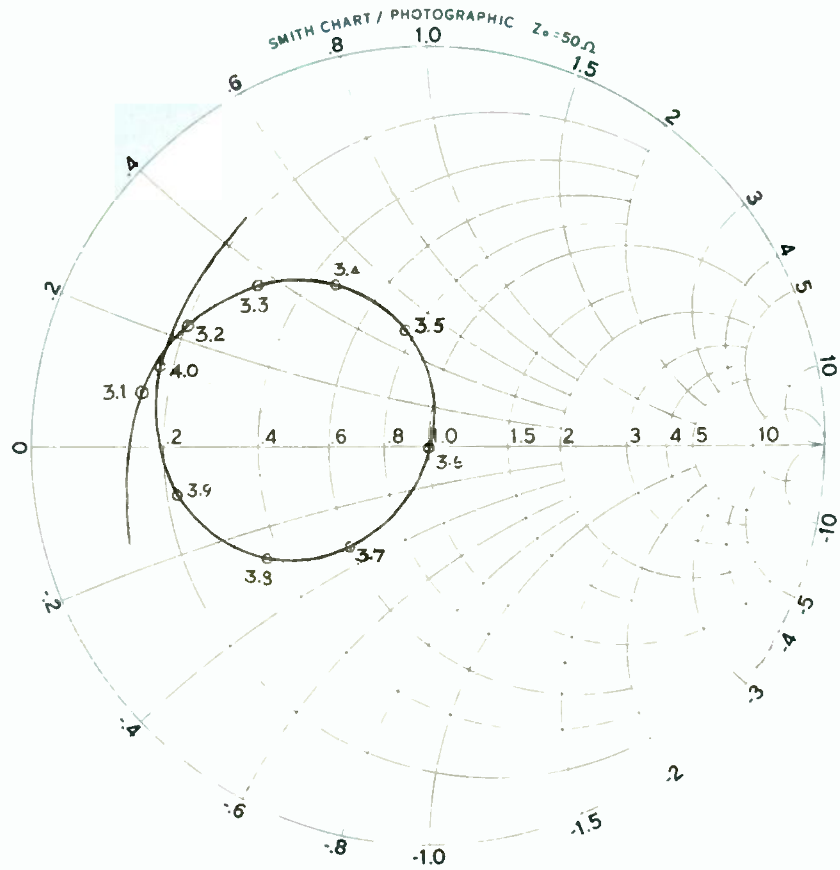


Fig. 8. Ground plane CFA. 3.6MHz.

There is a very small induction field around the device; the interaction zone field(s). This can be verified by experiment or by consideration of the values of SWR — almost 1 for correctly phased input energies. The phasing unit can typically arrange correct phase for the feeds over a 10 to 1 frequency working band.

The second question concerns correct timing of the two field components to produce the Poynting vector.

It is a feature of the CFA that the crossed and superposed E and H fields have to be carefully synchronsied in phase. This is achieved by splitting the power into half at the phasing unit, passing the two halves into separate, adjustable 45° phase lead and phase lag circuits, and then feeding to separate stimulating electrodes.

In contrast to the CFA, the classical antenna cannot achieve field time-synchronism close to itself (cf a resonant wire where current maximum and voltage maximum occur a quarter of a cycle apart). But if the antenna wire is large enough, it can achieve field phase synchronism for that part of the induction field fluxes which are located a significant distance away — a fortuitous accident ensuring success.

It may be explained using **Fig. 11.** The magnetic field flux spreads from the wire in a radial manner. But the electric field lines spread from the conductor parts well away from the centre of the wire antenna along circumferential paths. So they are longer and experience more delay.

Consequently only a small fraction of the electric and magnetic lines achieve synchronism, occuring within an annular region some λ/π about (0.318

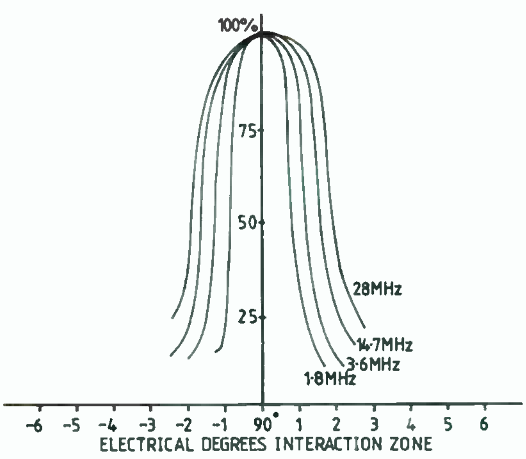


Fig. 9. % radiated power vs plate phase difference shows phase accuracy requirement becomes more severe as frequency goes down.

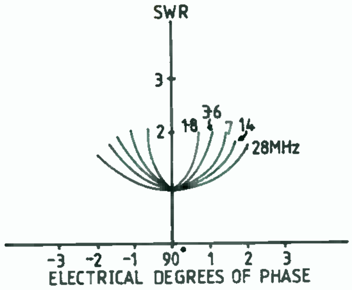


Fig. 10. SWR plotted against plate phase differences suggests the CFA is comparatively easy to adjust.

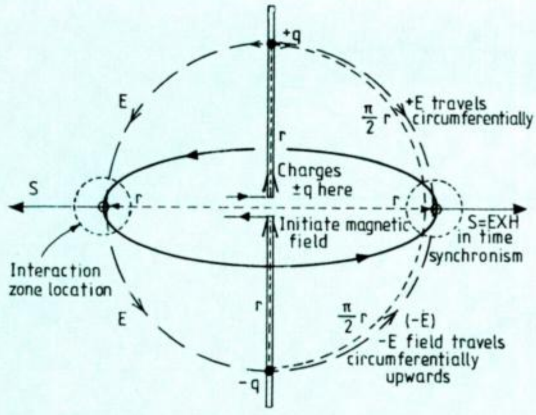


Fig. 11. Radiation by a half-wave dipole.

Phase advance is +time; phase delay is −time. All effects move with velocity of light c.

The crossed fields successfully launch a Poynting vector from a comparatively narrow annular interaction zone (IZ), distance r from the dipole, where the phase error is zero. It is desired to calculate r.

E has come from charges ±q stationary at the instant shown, distance r along the conductors, having entered the dipole time +r/c before, from the balanced feeder on the left. The E field travels circumferentially around the paths $\pi/2$ r long and arrives at the IZ delayed by additional time $-\pi r/2c$.

H has come from moving charges ±q which entered from the feeder half a cycle earlier; at time $+\lambda/2c$. This magnetic effect has expanded radially, distance r, to reach the IZ as shown also delayed by −r/c.

Totalling all the effects to zero time error, r can be calculated:

$$0 = +\frac{r}{c} - \frac{\pi r}{2c} + \frac{\lambda}{2c} - \frac{r}{c} \qquad \frac{\lambda}{2} = \frac{\pi r}{2}$$

$$0 = -\frac{\pi r}{2c} + \frac{\lambda}{2c} \qquad r = \frac{\lambda}{\pi}$$

wavelength) away from the wire.

It is not surprising then that cycle-by-cycle efficiency is so poor; most of the intensely field-stressed volume near the wire contains energy that cannot co-synchronise to synthesise a Poynting vector and fly away as a wave. Every quarter cycle the induction-magnetic or induction-electric fields collapse back to the antenna giving it self inductance and self capacity.

By contrast the properly adjusted CFA has good cycle-by-cycle efficiency, a low Q, wide bandwidth, and fair efficiency with comparatively low plate voltages. Performance limitations of the CFA are set by impedance and phase variations with frequency.

Given a sufficiently adaptable phasing unit, a single CFA can be adjusted to radiate any frequency, within a decade (or more), and is, in this sense, an aperiodic antenna.

Equivalent CFA circuit

Two points should be noted:

1. If either of the fields ceases, the radiation stops.
2. If the phase of the feed to one of the electrodes is reversed, the action ceases, because the electrodes develop high impedance and refuse to accept power. The CFA does not pile up energy inside itself as has been suggested.

A proper equivalent circuit for the CFA has not yet been evolved but will be the electrical equivalent of a chemical reaction or a thermodynamic change of state. Departure of power to space from the two interacting fields represents a unique form of load. The prime fields interact to produce radio waves which fly away to the infinite energy sink of space. An appropriate equivalent circuit must behave in a manner exactly similar to these unusual characteristics.

Broadcasting tests

Successful experiments are proceeding in Egypt with the use of the ground plane form of the CFA for medium wave broadcasting at approximately 0.85MHz (wavelength 350m). Figure 1 shows an experimental ground plane CFA adjusted to radiate 25kW. The original antenna used for this service was a tuned monopole about 75m high. Transmission is satisfactorily received in day-light at a range of 90km, and has a wider band width than the mast and its tuning unit.

The CFA total height is 2m and the ground plane is only 4m in diameter. Ground conditions at the site are normal moist earth, as the locaton is in the Nile delta area.

In a letter, Mahmoud Khattab, Head of Projects at the Egyptian Radio and Television Union has reported some initial results:

"The half-balanced CFA using a ground plane could be designed and adjusted successfully to get an input pure resistive impedance of 34Ω. 50Ω (or more) antenna input impedance can be easily reached by the same arrangements. . .

"In our case the transmitter output impedance was 250Ω, matched to the ground plane CFA radiating 25kW at MF, with no power reflection.

"More field measurements and signal monitoring with modulation are under evaluation at different locations."

"Transmission is satisfactorily received in daylight at a range of 90km, and has a wider bandwidth than the 75m mast and tuning unit"

Receiving capabilities

Does the CFA receive? In short yes. Receiving properties display characteristics of the electromagnetic wave having been analysed; just as the transmitted waves have been synthesised. The phasing unit setting affects the received signals, the setting for maximum received signal is the same as that for low SWR at the input to the phasing unit and maximum transmitted power. Any station using the CFA for transmit can always hear the target stations. The CFA is therefore a practical two way radio communication antenna.

Future applications

The CFA will be of immediate interest for radiating from city centre sites on HF, for example diplomatic and amateur stations. MF broadcasting applications are also expected to develop rapidly since it is small enough to be sited on a building in the centre of a city, and so will be more appropriate to provision of a satisfactory service. Highest signal strengths will be where they are required — in the city centre where RF noise levels are highest.

Radiating to a city from outlying suburban sites, necessary for siting huge antennas for efficiency and protection of nearby listeners from strong induction fields will be unnecessary.

On long wave, LF antennas can be made more efficient, wider in bandwidth and less fussy in tuning, than present antennas.

Experiments are proceding with users of modest powers at LF for navigation aids.

ELF users may be interested when the system is fully proved, since their antennas are very large, expensive and inefficient.

It is also apparent that since waves emanating from the CFA are so small, they can be deflected by a small reflector. Experiments have been performed using a CFA 20cm in size radiating on the 15m amateur band, located at the focus of a 1.5m parabolic dish. The result was not only front to back ratio but also directivity.

Before the CFA, sources of radiation were always so large that this experiment could not be attempted. The traditional belief that a surface must be a large fraction of a wavelength before it can be used to reflect radiation will require modification: "a reflector must be a large fraction of a *wave-front* before it can reflect energy".

Frequency re-use

Crossed field antennas look to have major advantages over conventional antennas in terms of size, efficiency, and lower working voltages. The CFA is not a resonant antenna as its structure is substantially smaller than the radiated wavelength, and it is low Q and broad banded.

Fundamental differences to conventional wire antennas mean it is not surprising that the CFA has attracted hostility from some experts. However the fact that it works, indicates its basis is credible. Furthermore, the theory may be said to have passed the most severe test of a new hypothesis in that it can be used to design new devices.

Poynting vector synthesis has universal application as a design method for compact, efficient, electrically-small antennas, with demonstrated successful application at MF and HF, and experiments at VHF and LF. The technique could provide the solution to the difficult problem of efficient ELF radiation.

In addition the property of small-reflector directivity introduces some interesting possibilities. For instance a medium wave broadcaster could achieve frequency re-use. For example in the north-midland of a country, a ground plane CFA (probably only 4m in size) radiating 300m set on the north side of a flat reflecting screen some 20m high and 20m wide, would direct most of the radiation northwards and provide a service for the audience speaking the language spoken by the people in the north.

In the south-midland (say about 100km distant) a ground plane CFA radiating the same frequency set on the south side of a flat reflecting screen of similar size would direct most of its energy southwards simultaneously providing a different language service for the south region.

On short wave a moving reflector-CFA system could be used to radiate to different target areas at different times of the day. As the CFA can be phased to radiate any frequency, within a decade, even changes required night-to-day can be accommodated, all on the same antenna on a small site, or on a city roof top. ■

Reference

1. Maxwell's equations and the crossed field antenna. F M Kabbary, M C Hately, and B G Stewart, *Electronics World & Wireless World*, March 1989 pp. 216 to 218.

BARGAIN BLOWING

A PC hooked up to a PROM/PLD programmer cuts costs — but is it cost-effective? Brian Frost reviews the Dux LabTOOL vs MPE's Powerlogic development system.

Since my review of programming equipment in the August issue, other similar items have been brought to my attention. This review features two low-cost programmers that are suitable as engineering support tools and in low-to-medium volume production.

There is now a wide variety of low-cost programming equipment available for the complete range of programmable logic devices and low-cost PLD programmers are now turning into stable products with a good range of device support.

These two products are examples of this, but each addresses the problem of programming devices in a different way: the first instrument is a universal programmer from Dux (UK) capable of programming both eproms and PLDs; and the second is a PLD-only programmer from MPE, which comes as a complete logic-development kit. They are both intended as low-cost support tools for engineering support or small-scale production and both use a PC-compatible computer as a host for their dedicated plug-in cards.

This approach, of employing a specialised PC plug-in card to control the programmer operation, has become very popular and it is easy to see the reason: it allows the programming equipment to use the PC's internal power supply and, more importantly, it eliminates the need to place any "intelligence" within the programmer hardware circuitry. By contrast, the microprocessors found in traditional programming equipment are mainly present to service the often serial communication link used to transfer data between the user's computer and the programmer itself. Additional features on such devices, such as local displays or keyboards, only build on this existing micro capability.

In contrast, equipment dedicated to a PC (or any other computer for that matter) does not possess the portability of traditional RS232 communication, but does have simpler hardware and offers more interactive software that does not suffer from the imposition of a slow data link. With the simpler hardware, costs are now such that, even with a dedicated PC, the total package price can be lower than that of many previous stand-alone products.

Dux XP6005 LabTOOL

As described, this unit follows the common presentation format used by the lower-cost programmers which is to provide a special PC plug-in card, together with connecting cable which provides power and logic control signals to the external programmer. Although incompatible with any other equipment, this link avoids the need for a power supply in the programmer and does not stretch I/O resources such as RS232 or parallel ports.

My first impressions of this device were good: the programmer unit is sturdy, has a single 40-way socket clearly labelled for various device footprints and is easily accommodated within existing desk space alongside an existing host PC XT or AT.

Documentation is good, a brief introduction indicating that the unit accepts most of the programmable logic devices currently available, both PLDs and eproms, as well as providing some testing on traditional logic and memory parts. Although the unit originates in Taiwan (from a company called Xender), the manual was not, as is often the case, translated from Chinese into broken English and contains a comprehensive section listing

Dux XP6005 LabTOOL universal programmer for eproms and PLDs. Socket is labelled with device types.

exactly what you should have to hand in the package.

The specialised PC card does require you to find a free slot inside the PC and to ensure that the selected address used for the programmer does not conflict with any existing PC accessories. Two separate parts make up the package, the programmer module itself and an "Adapter package", both of which are needed to install and use the programmer, although the intention would appear to be that future, additional programmer "pods" could be supplied for use with a common PC card.

Following the installation procedure, I inserted the card into the PC and connected the cable, which was a little disappointing in that, at full stretch, it only just reached around to the front of my full-size PC; I like to use this PC mounted vertically under the desk and would have preferred a cable of about 1.5m to allow this. I connected the programmer pod, switched on the PC and was reassured by a successful boot-up. Fairly often, one is confronted by a message such as "Hard Disk Failure", or "Cannot load command.com, system halted", but there were no problems here and I proceeded to install the software.

Installation impasse

This was where the first snag appeared: the manual stated that "a PC with 5.25" disk drive and hard disk is required". No problem here. However, the software installation program said "Insert disk #1 into drive A and disk #2 into drive B". I do have a drive B, but it is a 3.5in drive, common on many ATs. As a result the software happily saw that my drive B existed and promptly fell over when expecting to be able to read the second 5.25in floppy in it. The falling over was not too helpful either, with the system hung, drive light on and a re-boot needed to start.

This gave me cause to think. I decided that the best approach would be to go into my PC setup menu and tell it to pretend that it did not have a drive B, which might allow it to do what all self-respecting single-drive PCs do about drive B, which is to prompt for a disk change in drive A. This did not work, since the PC bios could see the drive B anyway and I was not prepared to go one stage further and start disconnecting drive cables.

I decided to cheat. I would take the second disk, copy it to a 3.5in disk and be able to use both drives as requested. This worked but took ages, since disk 2 contained numerous device files; I was consoled by the thought that there cannot be more than 128 files in a root directory. One last try: disk 1 in Drive A, type "XP6005" and return.

Yes! It worked, but a note to software authors about installing software: bear the average, simple-minded user in mind when designing your software. I spent about 30 minutes on this problem and I use very advanced PC techniques every day. At the very least, such problems cause more telephone calls to the supplier than necessary, they cause annoyance and tag "low-cost" equipment with a poor image. If you must supply an automatic installation program, at least explain how to take short cuts. For example, I found later that if I copied the entire contents of both disks onto the hard disk the program would run with no problems immediately.

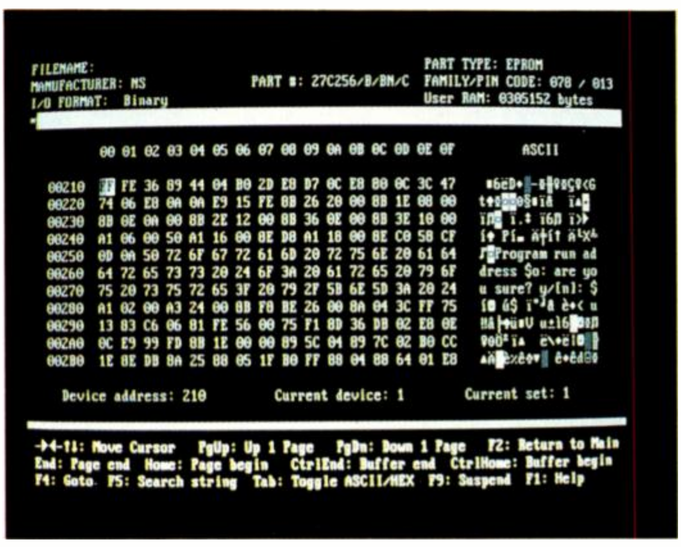
Running the software identified the programmer hardware and displayed the opening menu. Software menus were adequate, if a little garish. There is no colour and the program has an annoying habit of leaving the "typematic" (software key clicking) on after you leave it. All the important features of the software *are* here, though. Help is available on each menu choice by pressing F1, and all device types with which the unit is compatible are available from within the one menu shell, both eproms and PLDs.

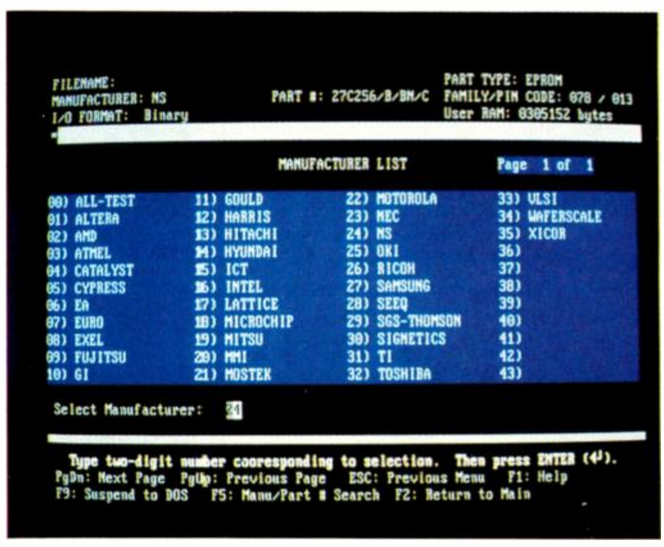
Operation

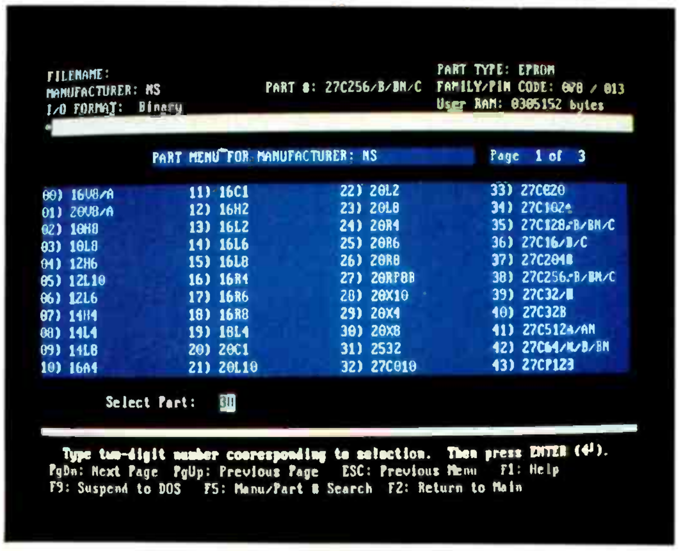
Devices are selected by first choosing manufacturer and then choosing the type number from the presented menu; there is a useful type-number search facility too. I prepared two data files for programming: one a PLD JEDEC file intended for a 16V8 logic device and another 32Kbyte eprom binary file. Selecting a National Semiconductor PLD 16V8 from the list gave me an error message that this file was not available, but I was prompted to insert the relevant disk into the drive "D:/PROJECTS/PROG" which, of course, was rather difficult. Manually copying the disk files from the remaining two disks into my hard disk directory cured the problem.

With the 16V8 PLD selected, I was able to load my JEDEC file into memory and program the device. I was very pleased to see that test vectors can be applied to the device. This feature is not popular with low-cost equipment and yet it is an important aid to the production of correctly functional devices. Test vector checking PLDs is in addition to the read-back verification that is done immediately after programming the device, and operates by applying 1s and 0s to the input pins while monitoring the device outputs to

LabTOOL eprom dump display (left). Devices are selected by manufacturer and type number, picture on right being the list of makers.







List of devices, in this frame from National Semiconductor.

check that the logic operation gives the expected results.

Test vector information is contained within the PLD JEDEC file and is generated by the designer as a list of expected outputs against the required inputs. Many of the more expensive items of programming equipment can accept this test vector information and use it to test the device functionally, following programming and verification, but it is only recently that this capability has been seen in the lower-cost tools. This software allowed me to select whether to verify fuse map only, test vector check only, or to check both.

I found it annoying that I could not get the software to load the vectors from my JEDEC file. I was able to see a blank vector table on the screen, which I could edit and insert vectors manually, but when I loaded my file the vectors remained empty. A call to DUX established a minor modification to the JEDEC file to cure this problem, which underlines the usefulness of having a supplier close at hand. Basic PLD programming features such as load, erase and program worked well, although I did become tired of the arcade-style sounds that accompany the success or failure of an option and would have liked to find a way of disabling the sound.

Programming time was around 2s for the 16V8 at 8MHz. This is slightly slower than the other equipment reviewed previously, but by no means a problem.

To check the programmer's capability to handle much larger amounts of data, I turned to its eprom functions, using a National Semiconductor 27C256 256K eprom for the test. I could not find the exact type number from the many presented, but chose the nearest. Hesitant about this, I would have liked to see the exact programming conditions for the device; for example, the V_{pp} programming voltage and the algorithm about to be used. The 32K binary file took about 5s to load and translate into the program memory buffer. Choosing the (P)rogram menu, the usual eprom options were displayed, for example data start and end address, data width and verification options. To read the device took 20s (at 8MHz), with another 20s for a repeat read which verifies the device. Programming took 140s, with a further 10s to verify.

It is here that it would be useful to see the programming algorithm being used, since this time may not be the optimum for this device. However, my experience of universal programmers is that they often have a speed penalty compared to dedicated eprom programmers when handling eproms, since for each of the many locations to program, the pin patterns for address and data need to be generated in software to allow for the many non-eprom device pinouts available in the one fixed-wired socket. This lookup operation often competes with the programming algorithm as the dominant factor in program execution time. As an example, I set my PC to its full speed (25MHz) and the programming time on the same device droped to 62s.

To investigate the handling of large memory devices, I chose a very large eprom device, the 27C4001. This requires a lot of memory, and I found that the memory I had available was not sufficient, despite having both free EMS and extended memory available on the machine. The need to cater for devices larger than the memory available is presumably the reason for this software's ability to read and write directly from device to disk.

As well as the necessary features for device programming, the software also provides the ability to test traditional logic devices and memory parts. While this feature is not likely to be a great use to most users, it does demonstrate the versatility of the unit. Of more relevance is the calibration software, which both tests and calibrates the unit, allowing the user to set up the programmable voltages on device pins.

Supplier

The unit supplied is the XP6005 LabTOOL universal programmer from DUX (UK) Ltd, Bovinger House, 172 Winchester Rd, Four Marks, Alton, Hants, GU34 5HZ. Telephone 0420 63724. Cost of supplied package: £776 + vat.

Conclusions

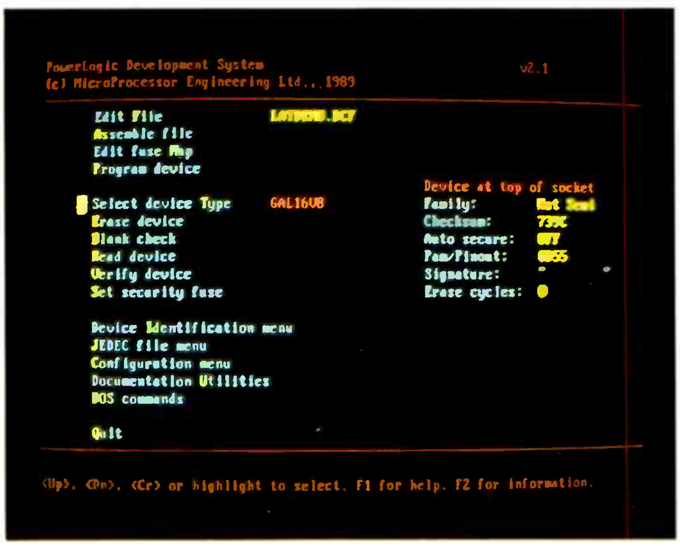
The DUX XP6005 is a nicely built unit with a lot of device capability, ideal for the lab., but also adequate for limited production programming. The software has all the necessary facilities but its use and feel is only average and this rather lets down the nice hardware.

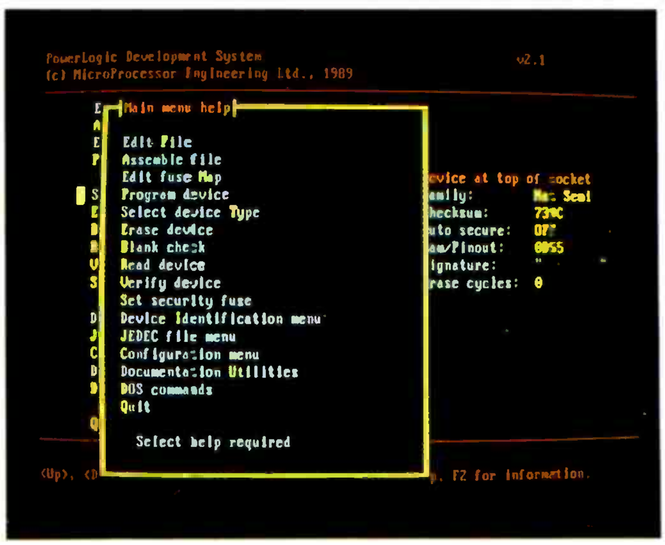
MPE PowerLogic development system

This programmer operates on the same principle as that previously described, being intended for installation within a PC-compatible computer. It comprises a PC plug-in card with a small programming "pod" containing a zero-insertion-force socket for the device to be programmed, but differs from the previous system in that it is not a universal programmer as such, but has been focused on a group of the newer, erasable programmable logic devices such as the 16V8 or EP300.

This focus has allowed the designers to supply software that both programs these devices and allows the user to generate the required programming information directly entered from logic equations by using the supplied logic assembler. This approach differs from that conventionally adopted, where the user purchases a programmer with data file-import facilities and is expected to provide the necessary software tools to generate the data files such as CUPL,

PLD-only development system from Microprocessor Engineering, intended for newer devices such as the EP300. Below (left) is the opening menu of Powerlogic and, on the right, the "help" menu.





ABEL or PALASM for generating logic device files.

Installation of the card is quite easy although, as with all internal PC card systems, a possible conflict of I/O addresses should be avoided. The unit comes set to the IBM prototype card address of 300(hex), but can be easily changed if required. That even these simple problems can occur was demonstrated by my installed software refusing to see the card after installation. I had not checked the DIL switch to confirm the default address as specified in the manual and subsequent inspection showed that the switch was set for 380(hex), possibly due one switch bit having been knocked during my installation.

With this corrected, the software, "PLDS", identified the card and displayed its opening menu. Choosing the Select Device Type option, I was presented with a menu of the newer, often erasable PLDs, such as the 16V8 and 5C031. My initial reaction was that, by comparison with the other programmer products, this list seemed a poor selection. Examination of the device types chosen, however, showed that all were of the newer EPLD types, with each device capable of being programmed to operate as one of the many early bipolar parts, where some 20 different devices used to be required. For example, the newer 16V8 PLD architecture is able to replace directly any of about 20 of the old bipolar metal-fuse PALs such as the 16L8, 16R8 and 16R6 and is also electrically eraseable. Where the user does not need to retain capability for these older devices, it makes good sense to standardise on one of these newer parts and eliminate the need to stock a mixture of devices.

A reduced device count has also allowed MPE to concentrate on supporting all of these devices with their logic assembler, included in the package, which avoids the need to obtain third-party PLD software tools to enable you to translate your source logic equations into JEDEC files for programming and is therefore ideal for users just getting started in programmable logic. This assembler software is supplied separately to the traditional programming software and generates JEDEC files that are then imported into the software for device programming.

Programming software is easy to use, is menu driven and provides help at each step. It is fast and I understand that it is written in Forth, in which MPE have been specialists for some time. I used the same existing JEDEC file of one of my 16V8 PLD designs as used for the previous test, which was originally produced by the logic compiler CUPL. Loading the file was easy and showed attention to the housekeeping tasks that become important when such a device is used regularly, such as the facility to list directories away from the current one.

"With simpler hardware, costs are now such that, even with a dedicated PC, the total package price can be lower than that of many previous stand-alone products."

As the file loaded, its header was displayed in a window which allows you to check that it is the correct file, but I found that, with my 386 at its default speed, the lifetime of the information was too short to be of use. With PC speeds constantly increasing and disk caches and ram disks becoming common, the range of users' speed capability is widening all of the time.

With the file loaded and the device in the socket, programming took about 6s at 8MHz, falling to 2s at 25MHz. Repeated programming of a batch of parts was very easy, with only a single key press necessary for each programming operation.

A very useful feature of this software that I would like to see provided on other systems is the ability to run the programmer software from a batch file, thereby "automating" the programming processes. For all the virtues of PLDs, with their flexibility and versatility, this can too easily be undone at the last minute by a simple error in the hands of inexperienced or careless users during programming. Driving the programming process from a batch file allows one simple filename to set all of the important setup parameters, leaving the user merely to insert the device in the socket and press P.

Since it is intended to be used with the supplied logic assembler, the programming software has options to transfer to either your own named editor or the MPE assembler itself. This transfer worked very cleanly and made for a very tight loop of edit/assemble/program operations. There are other useful support facilities, such as the ability to print an outline of the final device, ideal for subsequent logic probing. The logic assembler itself took under 1s to assemble a 16V8 source file.

A facility that is missing is an ability to perform test-vector checking, an omission in which this unit is by no means alone. I am sure that a number of users will wish to use the MPE unit with their own JEDEC files instead of the supplied logic assembler, particularly as they graduate to the more complex (and expensive) PAL software tools. These often contain existing test-vectors and although the fuse-map verification after programming does provide good confidence of a successfully programmed device, there have been situations where problems with the fuse-map generation by particular design tools have shown up at the point where the (correct) test vectors did not provide the expected device outputs following successful programming and verification.

While the incidence of this is low enough to argue against the need for test vectors, I know from personal experience that they really do concentrate the mind wonderfully and almost always result in a successful PLD going into the PCB simply due to this technique of applying a software logic-probe to the design before any hardware has been tested. If the decision is maintained to leave the test vector checking out of the programming process, then it really should be by provided within the logic assembler as a simulation tool.

Conclusions

Powerlogic is a neat unit. It only programs a limited number of the newer PLDs, but the devices are well chosen, newer parts with a lot of capability. All the software is good, robust and fast. The logic assembler provides a complete logic development package and there is no need to purchase anything else. It is ideal for users new to PLDs, but it does lack the simulation capability of more traditional PLD tools.

Supplier

The unit supplied is the MPE PowerLogic development system from Microprocessor Engineering Ltd, 133 Hill Lane, Southampton, SO1 5AF. Telephone 0703 631441. Cost of supplied package: £495 + vat. Additional device pods (e.g. for Cypress 22V10 device) £145+vat.

OFDM opening way to digital broadcasting?

At IBC90 it was clear that the digital modulation scheme of orthogonal frequency division multiplex (OFDM) is now seen by UK and European broadcasters as offering a most promising technique for delivering broadcast digital signals to the home, or to moving vehicles, even under severe multipath conditions. OFDM comprises a large number of carriers equally spaced in frequency, with each carrier digitally modulated (for example, using QPSK). The spectrum of each modulated carrier is arranged to overlap the spectrum of its neighbouring carrier in such a way that the information content of each carrier is mutually orthogonal. OFDM is spectrally very efficient and very tolerant of the short-term echoes that can prove a major barrier to digital broadcasting from terrestrial transmitters or from space to car receivers.

As noted in *EWW* (March 1989, page 316) the cofdm system developed by CCETT (OFDM with convolutional coding C), France, was successfully demonstrated at Geneva during the WARC-ORB88 conference in conjunction with the German-developed mascam (Masking-pattern adapted subband and multiplexing) audio bit-rate reduction technique which enables a complete high-quality stereo sound programme to be carried as a 256kbit/s multiplexed digital system.

Cofdm was designed to overcome the multipath changes in amplitude and phase of a signal received in a moving vehicle. It is claimed to be virtually free of the multipath and inter-symbol interference that impairs digital reception in the presence of short-term echoes.

Information to be transmitted is split into a large number of elementary narrow-band channels, as increasingly used in telecommunications transmissions. A fast Fourier transform is used to process the channels in both the modulation and demodulation subsystems. Convolution coding is used in conjunction with a Viterbi maximum-likelihood decoding algorithm to give a coding gain in excess of 20dB at a bit error ratio of 10^{-3}.

At IBC90, C.P. Bell and J.H. Stott (BBC) reported trials of mascam/cofdm in south London this year from Crystal Palace with an on-channel repeater (active deflector) at Kenley using the French/German Geneva demonstration equipment. Active-deflector techniques with a relay using the same frequency channel as the main station are possible because codfm makes constructive use of multipath reflections.

As currently implemented, the system carries up to 16 stereo programmes, plus a data channel, in an overall bandwidth of 7MHz, but it is also foreseen that further development would permit at least 12 stereo programmes in a 4MHz band, giving appreciably better spectrum utilisation than current FM pilot-tone stereo analogue transmissions.

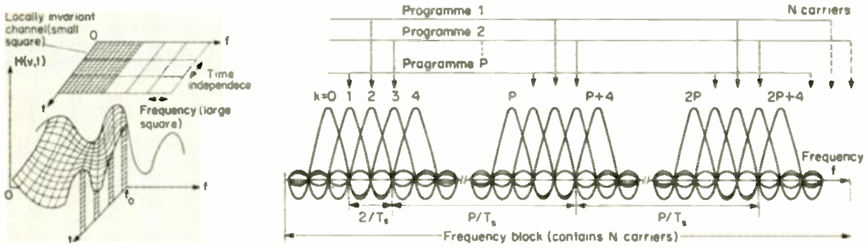
BBC tests have confirmed that mascam/cofdm would be capable of satisfying the stringent requirements for high-quality reception of digital audio signals from either satellite or terrestrial transmitters even in a mobile situation. The BBC paper concludes: "Collaborative studies to define the system fully and to implement the receiver as a consumer product are continuing within the Eureka 147 project, much encouraged by the favourable findings of a range of broadcasting tests recently conducted across Europe". EBU is seeking a digital audio broadcasting (dab) frequency in the range 1 to 3GHz, suitable for reception on car radios.

Reception quality of the Crystal Palace tests showed that quality, in general, was uniformly high except close to the coverage limit, where the onset of failure tended to be total. However, during static assessments in fringe conditions, reflections from large moving vehicles had a significant effect. In the coverage area, the system was found capable of operating satisfactorily in multipath conditions which caused in-band amplitude variations exceeding 20dB in the RF spectrum.

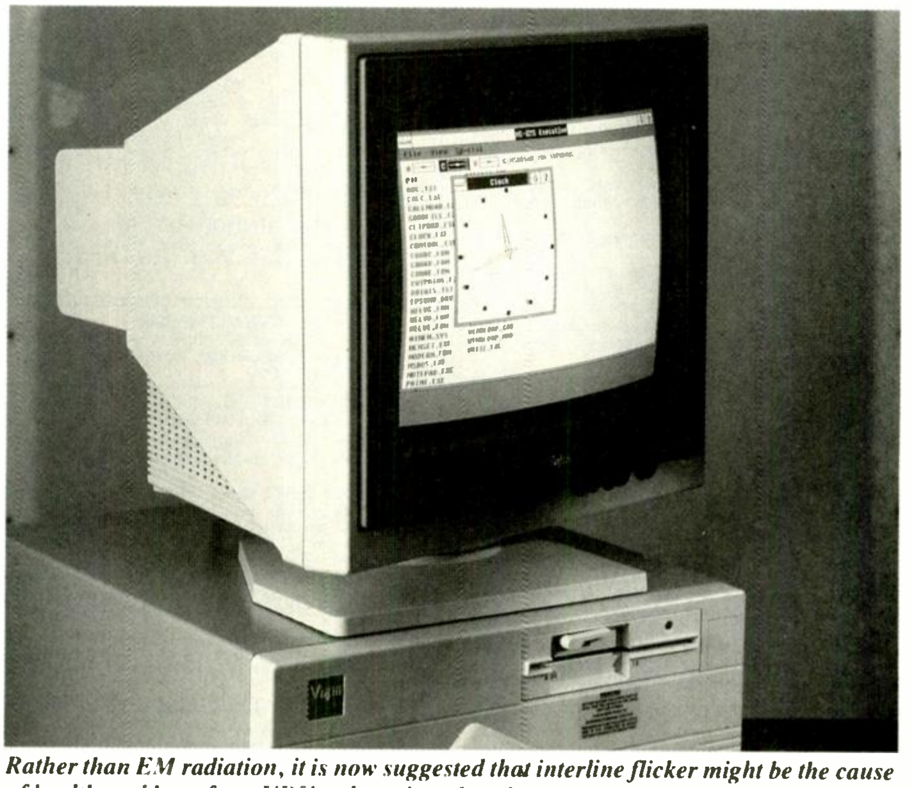
The adoption of OFDM techniques to provide digital-video TV signals to the home from terrestrial 8MHz "taboo" channels is being investigated by the IBA Engineering Division (shortly to become National Transcommunications) with 625-line TV plus stereo sound and teletext signals contained in a 13.5Mbit/s digital multiplex. In this application, OFDM is not only extremely bandwidth-efficient but allows its spectrum to be tailored to minimise interference both to and from existing PAL transmissions in adjacent channels.

The project is clearly at a less advanced stage than the digital audio broadcasting project and the chances that it will ever be implemented in the manner envisaged by Arthur Mason at IBC90 must be considered as less than a racing certainty, since there are rival demands for use of the taboo UHF channels. Receivers would have to cope not only with the new and complex decoding of the digital signals, but also the handling of conventional PAL analogue signals. There would seem, however, to be little doubt that, technically, the compression of a TV broadcast channel into a 13.5Mbit/s bit stream using such techniques as motion-compensated hybrid discrete cosine transform (DCT) coding is feasible and could be delivered to homes – at least those equipped with reasonable receiving antennas – by means of OFDM technology.

Channel frequency-time response for mobile reception (left) and spectrum arrangement for interleaved, multi-carrier sound signals using OFDM techniques.



TV flicker and the VDU



Rather than EM radiation, it is now suggested that interline flicker might be the cause of health problems from VDUs when viewed at close range.

For years, the controversy over possible hazards to computer users arising from suspected electromagnetic radiation from VDUs has dragged on, much of it dating back to the early 1970s when some models of American colour TV sets were shown to radiate X-rays at levels above the then accepted safety level. Although this was often ascribed to the cathode-ray tube, in fact the prime cause was the so-called damper-diode (efficiency diode) in the EHT generating circuit. This problem was never experienced in Europe, where even the early valve colour sets were found to radiate only negligible ionised radiation, but the idea that VDUs emit significant levels of ionised radiation dies hard. More recently, it is being suggested, with no convincing evidence, that low-frequency, non-ionized radiation could explain those studies that have indicated (though not consistently) that there may be an increased rate of miscarriages and general health problems among those whose work involves many hours in front of a VDU screen.

There is, however, an alternative possibility that is receiving increasing attention. This suggests that stress, migraine headaches, nausea, etc. may be the result, not of EM radiation, but flicker at the 50Hz or 25Hz (interline) rate that is present when a CRT display is viewed relatively close to the screen.

Medical circles recognized many years ago that a small minority of people are particularly sensitive to flicker (photo-sensitivity) and that some sufferers from epilepsy could have attacks triggered by sitting close to high-contrast TV screens or when approaching the set to adjust controls. More recently, migraine headaches have sometimes been ascribed to TV flicker or the 100Hz striking rate of fluorescent strip lighting.

For example, in January 1988, a report in *The Observer* noted that Dr Arnold Wilkins of the Applied Psychology Unit of the Medical Research Council at Cambridge had said that fluorescent lighting flicker affects only a small number of people, though these could suffer considerably. He believed the problem could be overcome by fitting the more expensive "non flicker" lamps powered by 15kHz switched-mode power units, which cause the lights to "strike" at 30kHz.

At this year's meeting of the British Association, Dr Wilkins returned to this subject and expressed his belief that viewing text as presented on VDU screens could aggravate headaches, eyestrain and dizziness. He pointed out that we read text by making a series of accurately positioned eye movements, but that the 50Hz pulsations of VDU text disrupt this process: "When words are closely spaced horizontally and vertically, there is little unambiguous global information to guide the eye at the level of detail used for controlling eye movements; the text is more or less homogeneous . . . the appropriate spacing of words is therefore critical for clarity" he added.

The Applied Psychological Unit is currently extending their work to evaluate whether VDU screens made of coloured glass ease the perceptual problems of computer script.

It may well be that further investigation of the effects of barely perceptible flicker, both from strip lighting and from TV/VDU displays, could prove more rewarding than the present concentration on the potential hazards of low-level electromagnetic radiation. Just why, for instance, are a few people so much more sensitive to flicker than others? To what extent would these benefit from the use of HDTV techniques providing displays with 100Hz progressive (sequential) scanning?

Another alternative to EM radiation affecting some keyboard/VDU operators is the still-controversial medical condition RSI (repetitive strain injury). While some doctors still refuse to accept that RSI really exists, there seems some evidence that it is the re-emergence of what was once known as "telegraphist's cramp", or more colloquially as "glass arm" or "brass arm". This affected a minority of Post Office telegraphists using manual keys in the days before the introduction of the teleprinter — although a few cases of teleprinter "keyboard cramp" were experienced in the 1930s. It seems that such "cramp" or RSI tends to affect people who do relatively monotonous, repetitive work while under stress in a fixed position. The risk factors appear to be bad working posture, high frequency of hand movements, often coupled with a degree of forceful exertion and stressful, poorly organised work processes. Telegraphists' cramp was rare, affecting only one or two per cent of telegraphists, but it could be severe enough to force an operator to give up the job altogether. ■

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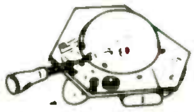

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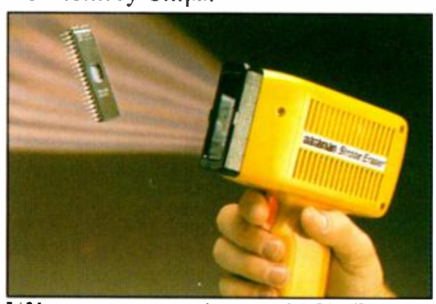

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