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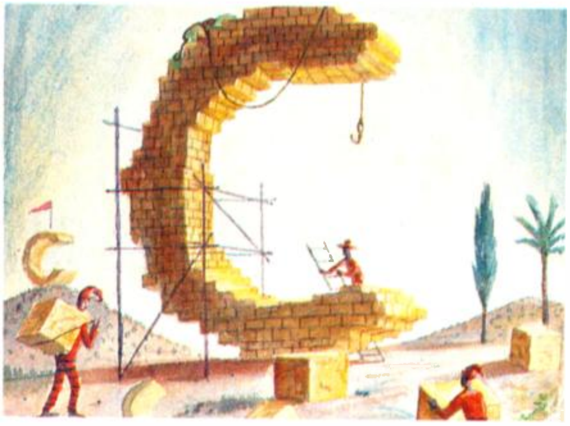

REGULARS

In next month's issue. Compact Disc electronics may not be the wonder of science which the manufacturers purport it to be. Ben Duncan investigates the shortcomings and looks for solutions.

Roger Dewell describes recent advances in medical electronics. In particular, he examines the role of signal processing in NMR and computer tomography. Plus the second part of our series "Interfacing with C", a guide to the language for electronics engineers.

CIRCLE NO. 118 ON REPLY CARD

Comic relief

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"What on earth do you mean 'Who is it going to fight?' Just because it's called 'European Fighter Aircraft', it doesn't actually mean that it has to fight anybody . . . No, we're not going to use it to attack the Germans now they've opened up the Berlin Wall . . . Really, Ingham, you should save that sort of off-the-record comment for the rat pack."

Ingham, looking dejected, skulks off to a corner of the room occupied by the television set. There is a knock on the door. Ingham growls menacingly. Ingham is a Rottweiler.

"Get that please, Dennis." Dennis shuffles off into the pastel decorated hall. He returns with a captain of industry.

"Lord Weinstock, Margaret."

"Evening, Arnold. I'm delighted that you could spare me the time to sort this out. I am rather concerned that we should be seen to practice as well as preach the spirit of free enterprise.

"The House seems to be getting a bit restless about your series of mergers and buy-outs. It thinks that you could stitch up the MoD through lack of competition . . . No, I'm sorry, Arnold. We've absolutely no intention of privatizing Parliament. Well . . . Not until we've floated Electricity."

Ingham, who had previously contented himself with gnawing a leg of the television, starts tearing up a copy of *The Independent*.

"Look, Arnold. It was bad enough when you got together with Siemens and divided up Plessey. Nice George Younger. That business upset him terribly at Defence. It meant a reshuffle. I had to put someone in at the MoD for whom life was infinitely worse . . . That's right. Tom King, from the Northern Ireland office.

"This Ferranti nonsense really is the last straw. How those buffoons could let themselves be taken to the cleaners for £200 million by a bunch of spivs from Silicon Valley, I really don't know.

"Then, just to compound it, you come along, dip into the GEC cash mountain, buy up the Ferranti radar business and scoop a £2bn euro-fighter radar contract. It's going to take a lot of explaining."

Ingham rolls over onto his back, spits out the paper, and resumes the attack on the television.

"Arnold, What do you mean 'I'm doing you a favour'? Just because you save 6000 people in Scotland from losing their jobs doesn't mean that you acted in the National Interest. Most of them don't even vote Conservative."

"Now come along you two."

Lord Weinstock and Mrs Thatcher turn to Dennis, previously un-noticed, somewhere at the back of the room. Mrs Thatcher glares.

"I've been thinking . . . Remember that Nimrod thingy you were involved with, Lord Weinstock? How about taking those GEC radar sets out of mothballs and fitting them in the European Fighter Aircraft? I don't suppose that they will work any better than they did in the Nimrods but at least you will be able to blame the Italians . . ."

"Dennis, do be quiet."

"Yes, dear."

Lord Weinstock bids them goodnight and leaves.

"Ingham, I've got it! We simply tell our people that, with the advent of 1992, we no longer have to worry about national monopolies because of competition from Europe.

"For instance, we can defend the GEC monopoly in airborne intercept by pointing to the open competition from continental defence contractors . . .

"What do you mean, Like who? Siemens, of course."

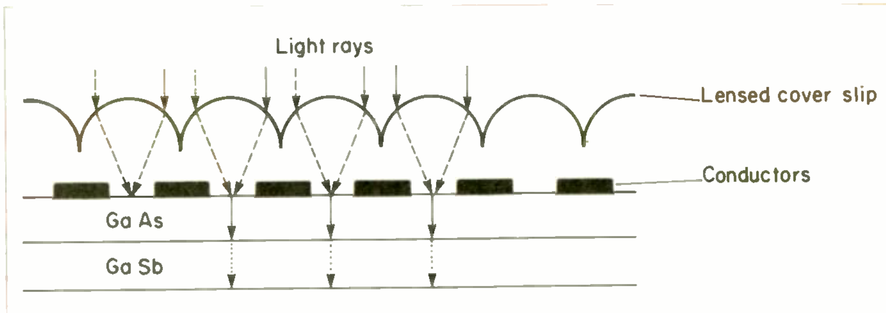
Ingham looks puzzled, closes both eyes and goes to sleep.

Frank Ogden

Bright future for solar power

Whether it's because of the bad press increasingly suffered by the nuclear and coal-burning utilities or just pure coincidence, there's been a lot of recent development in the world of photovoltaics. No longer are solar cells just the province of pocket calculators, remote settlements and spacecraft. Several recent achievements suggest that in future we will be directly tapping just a little bit more of the prodigious output of our friendly cosmic fireball.

To list just a few of the latest developments, it's worth noting the present efficiency record for unassisted silicon photovoltaic cells set by M. Green *et al* at the University of New South Wales in Australia. Given a standard level of illumination of 1kW/m² (about the most you're likely to get, even in Oz) Green and his colleagues [*Applied Physics Letters* Vol. 55 No 1363] have achieved a 23% efficiency for power in versus electricity out. It's important to emphasize the standard irradiation condition because higher efficiencies can be achieved using sunlight concentrated by mirrors or lenses. This is not because of the concentration per se but because photovoltaic efficiency improves as the light level rises. Figures near 30% can be achieved at 100kW/m² input. A second significant development that takes the absolute efficiency record to 37% uses a novel two-layer design in combination with a special optical cover slide to concentrate the light.



The idea of using two layers was originally pioneered by Sandia Laboratories tv overcome the spectral limitations of a single material. Gallium arsenide, with its large bandgap of 1.42eV is more efficient than silicon (1.2eV) at converting photons into electricity, though -this very property means that low energy (infra red) photons are inevitably wasted. Sandia therefore constructed a cell with a gallium antimonide layer underneath the GaAs. Gallium antimonide has a bandgap of only 0.72eV and can therefore utilise the IR wavelengths that would otherwise represent a loss in overall efficiency.

This basic structure, when further developed by the Boeing High Technology Center in Seattle, results in the composite design shown in **Fig 1**. Its 37% efficiency figure derives from a combination of the double layer, the cover slide and the fact that it operates at flux levels considerably higher than normal sunlight.

All this might seem a long way removed from everyday applications of solar cells, especially in view of the expense. It's therefore worth reminding ourselves about the parallel progress towards cheap mass-produced photovoltaics. Companies like BP Solar have, for example, exceeded 16% efficiency with commercial modules. Costs have likewise tumbled by almost an order of magnitude over the last decade, leading to a considerable growth in the market photovoltaics.

Given the increasing environmental unacceptability of many other forms of power generation, this trend is more than likely to continue, not just for pocket calculators, but for multi-megawatt industrial installations. As Robert Hill of Newcastle Polytechnic observes (*Physics World Vol 3 No 1*) "Even in the UK it is now cheaper light a garden shed or telephone box with solar energy than to run a mains cable more than 20m or so".

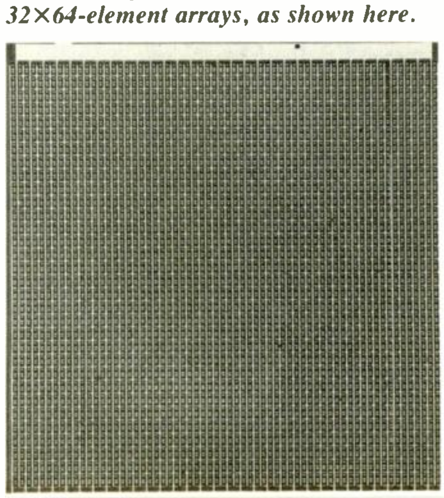
Optical chips for supercomputers

AT&T Bell Laboratories have developed a photonic IC which can process 2Kbit of optical data in parallel.

Structurally the photonic IC consists of an array of 32 by 64 cells, where each cell is what Leo Chirovsky of the Lightwave Devices Laboratory calls a reflective mode, symmetric Self Electro-optic Effect Device (S-SEED). The S-SEED has a differential optical input that takes 5μm diameter light beams (at 20μm spacing) and a differential output that yields modulated beams with contrast ratio of 5:1.

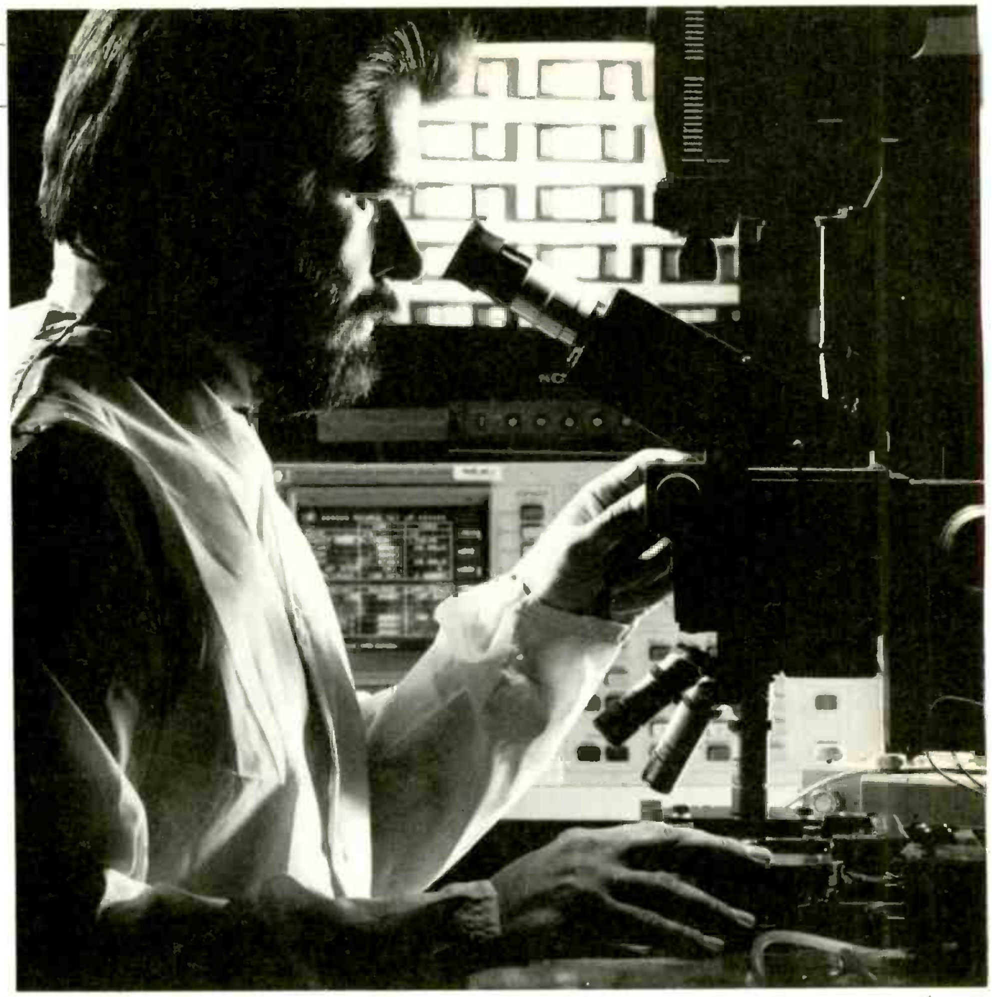
Invented originally in 1984 by AT&T, the S-SEED has been perfected to the point where 2048 of the 20μm×4μm cells can be reliably fabricated on a single gallium arsenide chip. The only electrical connections are bias voltage and ground terminals. Increasing the bias from 6V to 15V increases the contrast ratio (signal power) of the output, but at the expense of optical switching energy required at the input. In more detail, each S-SEED cell comprises a pair of p-i-n diodes in which the middle layer consists of a multiple quantum well structure. This, when subject to an external electric field, can modulate the light absorption by red-shifting the peak of the optical passband. When such a diode is reverse biased, it forms an optical bistable device that is switchable by optical signals alone. The AT&T device as described [*OTA Proceedings on Photonic Switching 3,3* (1989) Chirovsky *et al*] can switch in sub-nanosecond times and can hold its state indefinitely if supplied with 200nW of optical input per half-cell.

AT&T Bell Laboratories new S-SEED (symmetric self-electro-optic effect device) array. Devices are fabricated as 32×64-element arrays, as shown here.



But why go to all these lengths to do with light what can easily be done electrically? The answer, as hinted earlier, lies in the massive parallelism made possible by what Chirovsky describes as "free-space" optics. Because light can reach the input of a device with the minimum of obstruc-

Continued on page 270 ▶



Leo Chirovsky, of AT&T Bell Laboratories, uses a microscope and prober to test the photonic array. The monitor, top centre, displays what he sees.

tion, it means that in theory any cell in a machine can communicate directly with any other cell. No longer should systems designers be restricted to chips with 40 pins or to serial data buses. This of course opens up the possibility of new system architecture of a sort that simply hasn't been possible using electronics. In practice the new AT&T S-SEED chip is ideally suited to large experimental systems since, being a reflective device, the inputs and outputs are co-sited. This in turn allows for easy heat-sinking from the rear of the package.

AT&T Bell admit that such whole photonic systems are a long way off, but given the availability of experimental devices, they are confident that development will now press ahead. I certainly look forward to the intriguing prospect of a computer consisting of nothing but an empty space bounded by walls papered with ICs flashing at each other.

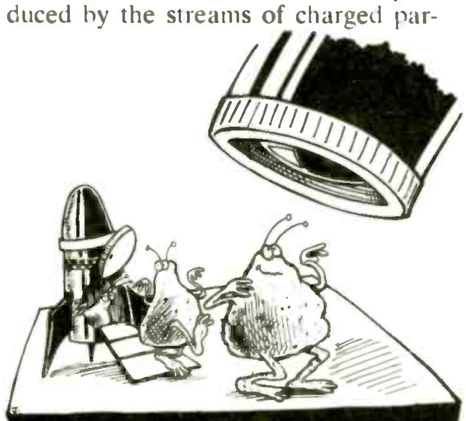
What flu in on the (solar) wind

Over the last few decades there have been attempts to correlate the sunspot cycle with a wide variety of seemingly disparate phenomena. These include the population of polar bears, the length of women's skirts, the quality of vintage and even the number of Republicans in the US Senate. The latest addition, though with much more scientific credibility, is influenza.

Professor Sir Fred Hoyle and his colleague Professor Chandra Wickramasinge of the University of Wales, famous for their earlier claims that viruses may emanate from space, have now found new evidence (*Nature* Vol. 343 No 6256) that 'flu pandemics coincide with the peak of solar activity.

This idea isn't entirely new, having originally been proposed 12 years ago (Hope-Simpson, RE. *Nature* Vol. 275, 86). What Hoyle and Wickramasinge have done is to extend the study back into the 19th century to cover a total of 17 sunspot cycles. They note, moreover, that since Hope-Simpson's original work there have been two further sunspot cycles, the 1979 one coinciding fairly well with the infamous worldwide outbreak of "Red flu".

On the face of it the evidence is impressive. Indeed, if it weren't so zany an idea it would probably pass unnoticed in the scientific literature. As it is, influenza experts around the world have expressed considerable scepticism, claiming that 'flu can spread quite well without any help from the Sun. On the other hand, no theory apart from that of Hoyle and Wickramasinge seems to explain the fact that a 'flu epidemic can spread around the globe in a matter of weeks or months at the most. Sir Fred believes that 'flu viruses hang about in the upper atmosphere, rather like volcanic dust. This is because they are extremely light particles. When the Sun is on the boil the electrical fields produced by the streams of charged particles drive the viruses downwards on to the heads of us unfortunate mortals. When asked (in an interview on the BBC World Service programme *Science in Action*) why we don't all succumb to the 'flu, Sir Fred explained that other factors also come into play. Not only does the virus come down to earth in little patches, but its descent may be modulated by meteorological factors such as heavy rain or fog. Sir Fred believes that a combination of foggy weather and a sunspot maximum is the worst possible 'flu risk. Next time, therefore, you see the aurora draped with a veil of mist, get indoors quick! And (as with Met. Office gale warnings) don't say you haven't been warned.



Sun on the boil

As you read this, the Sun will have reached what is generally expected to be the peak of solar cycle number 22. So far it's been the most active cycle ever recorded and there's clearly much more to come.

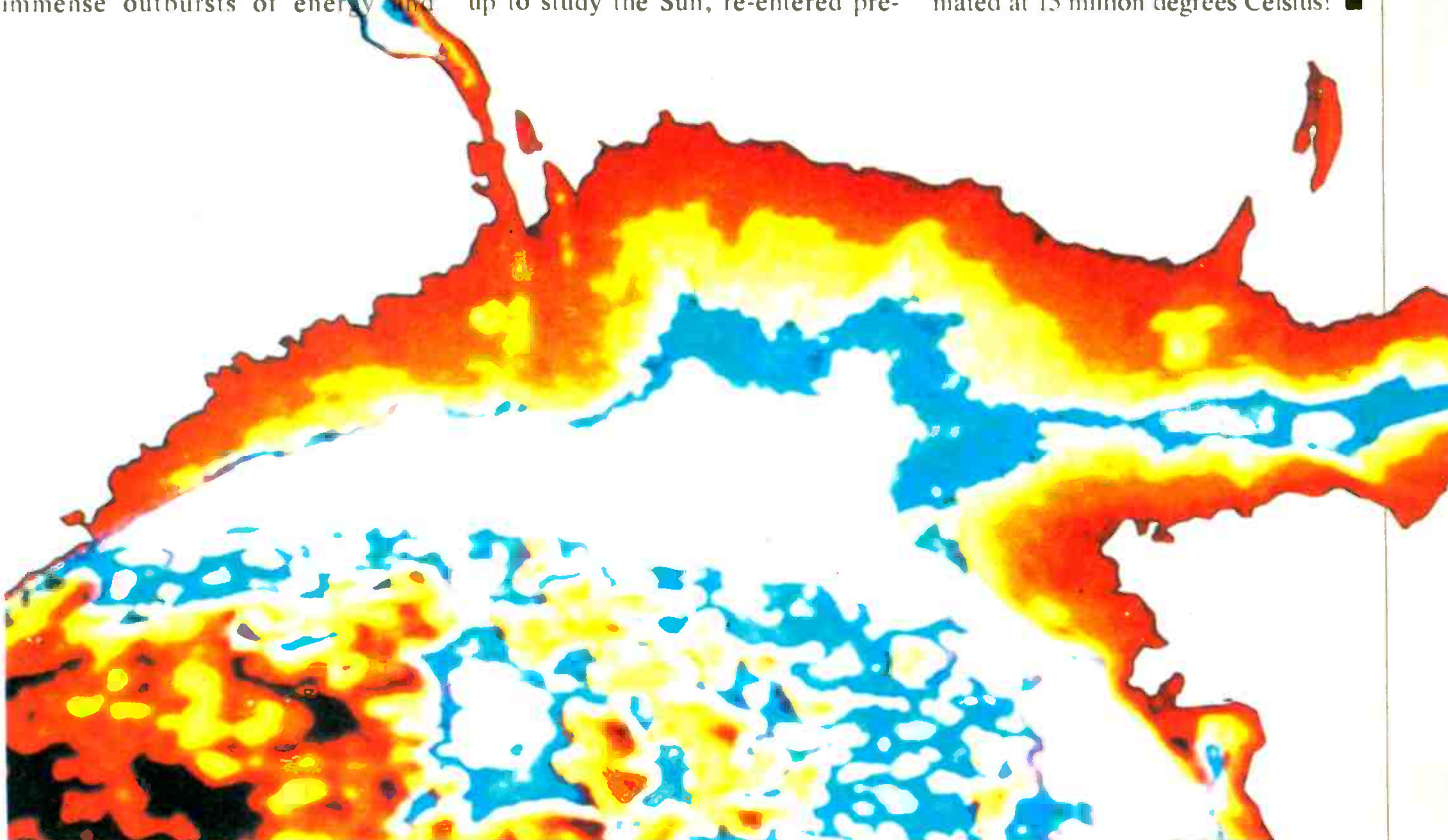
Traditionally the sun has been regarded as a somewhat placid, run-of-the-mill G-type star, with a fixed energy output described as the solar constant (1.35kW/m² at the Earth's surface). Recent observations by the ill-fated Solar Max satellite suggest however that the solar constant is not constant but steadily varying by as much as 0.1%. Other studies indicate that the whole of the Sun may be ringing like a gigantic bell with seismic waves that distort the magnetic field and which may give rise to the 11-year solar cycle.

Be that as it may, the cycle is characterized by a periodicity in the number of sunspots visible on the surface. These blemishes, often as big as a hundred earths, are areas of intense magnetic activity that interfere with the way charged particles conduct heat from the Sun's interior. That's why sunspots are cooler than the surrounding areas. Far from being inactive parts of the Sun however, these spots drive the processes that lead to solar flares: immense outbursts of energy and charged particles. Billions of tons of plasma shoot out into space at speeds in excess of three million km/hr. Here on Earth the effects can be dramatic. A year ago on March 10th a powerful flare despatched a blast of X-rays which, eight minutes later, ionised the D-layer of the ionosphere, causing massive disruption to HF communications. Over the following few days this was followed by a bombardment of protons and electrons which led to spectacular auroral displays. But solar particle bombardment and the million-ampere currents induced in the ionosphere have other effects much less benign, scarcely surprising when you consider that a big solar flare emits enough energy to supply a big city for an estimated 200 million years.

Already in this solar cycle, powerful transient magnetic fields and particle showers have been blamed for blacking out Montreal, for sounding radiation alarms in Concorde and the space shuttle and for causing considerable damage to solar cells powering the Venus-bound Magellan spacecraft. Worse still, this unexpectedly large outpouring of solar energy has heated up the Earth's atmosphere, causing it to expand. This, ironically, is why Solar Max, the satellite put up to study the Sun, re-entered prematurely. Friction from the expanding atmosphere was also why NASA had to get its skates on to recover LDEF—the Long Duration Exposure Facility. What has disturbed the space industry in a somewhat less spectacular way has been the high incidence of data errors caused to orbiting electronics. A single outpouring of solar protons last October led to hundreds of soft and hard faults. Radiation exposure to astronauts is another question that is bound to be raised as solar cycle number 22 coughs and splutters its way ahead.

Now may be the theoretical maximum but there's good reason to expect problems for a good few years to come. BBC research has, for example, shown that geomagnetic disturbances, with their consequent effects on ionospheric radio propagation, tend to occur most frequently a few years after the sunspot maximum.

Prepare for the worst, then, but remember that even the most violent disturbances reflect only the merest ripple on the surface of our amazing universal power supply. The odd hiccup on the Sun is perhaps scarcely surprising when you consider that it gobbles up 600 million tons of hydrogen every second and runs at a core temperature estimated at 15 million degrees Celsius! ■



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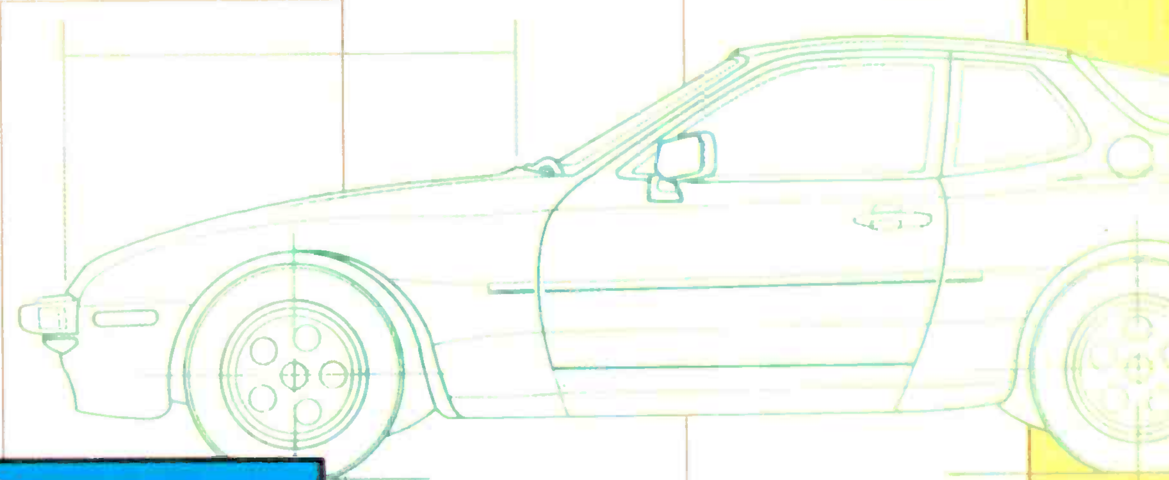

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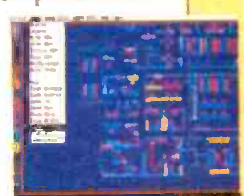

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Motorola in processor bloodbath

US chip maker Motorola has unveiled its latest 32-bit general purpose microprocessor, the 68040.

Motorola's 1.2 million transistor monster weighs in with around 20 million instructions per second of raw processing power, is clocked at 25MHz and uses 0.8-micron c-mos chip-making technology.

However, these statistics are no guarantee of success nor even survival. The 32-bit market is fast turning into a bloodbath with Motorola facing stiff competition from arch-rival Intel as well as from a clutch of companies with fast risc chips.

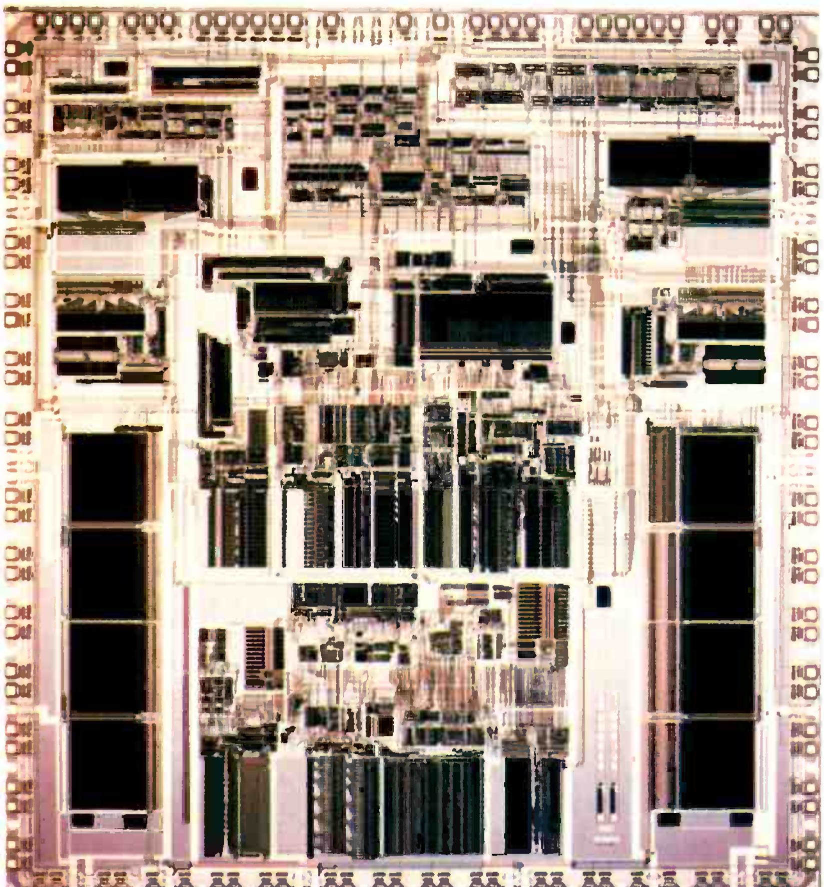
The risc merchants are eating into Motorola's traditional workstation business while Intel has the personal computer market sewn-up. So Motorola is positioning the 68040 as an up-market workhorse for multi-user minicomputers. Which pitches it head-to-head with Intel's 80486.

Motorola engineers have used the enormous transistor count to cram circuitry into the 68040. The device includes an arithmetic processor, a floating point co-processor, separate data and instruction caches and memory management all on the same piece of silicon.

The arithmetic processor is optimized to deliver between 19–21mips. Risc design features and parallel processing have been used to bring the execution time down from around the 3.4 clock cycles per instruction required in the 68030 to around 1.3 cycles per instruction in the 68040.

This major redesign of the processor core manifests itself in the integer unit which is object-code compatible with other members of the 68000 family rather than binary-code compatible. But the chip can still run all the 32-bit software written for its earlier cousins.

The floating point unit is basically a redesign of the company's 68881 and 68882 maths co-processor chips which have been placed onto the same piece of silicon as the main processor. Frequently-used instructions have been implemented in chip hardware and the rest executed in software. It includes a dedicated hardware multiplier (64×8). The floating point unit is object-code compatible with both the 68881 and the 68882, although it executes the code five to ten times faster than the 68882.



The floating point unit can deliver 3.5 million floating point operations per second (MFLOPS) in sustained performance in double precision Linpack. The unit chews maths at 8MFLOPS when pushed to peak performance, according to Motorola.

The 68040 includes two 4Kbyte cache memories: one for data and one for instructions. They help the chip to run fast by feeding information to the execution units as fast as they can use it. They work simultaneously to shift information at a rate of 200 bytes per second.

The organization of the caches is four-way set-associative and allows four long words per cache line. This means write operations can be buffered or copied back and allows cache reads and writes to be bursted efficiently. The claimed instruction hit rate is 93 per cent, the data read hit rate 92 per cent and the data write hit rate 93 per cent.

The data cache also supports bus snooping, which is a fancy way of saying that it makes sure the data cache is consistent with the external memory without software intervention. The caches also alleviate the load on external d-ram memory chips and so helps to cut system costs.

The 68040 also has two separate paged memory management units operating concurrently with the caches to provide simultaneous instruction and operand address translation.

The 25MHz version of the 68040 is currently being sampled at around $795 each and will be available in volume in the summer. Motorola is promising faster versions clocking at 33MHz and 50MHz in the future.

It is also working on the next generation chip: the 68050. Motorola sources say its device will probably incorporate 0.5-micron or even 0.25-micron triple-level metal c-mos, support 15 million transistors and be clocked at more than 300MHz.

It should be here by the mid-1990s; which gives us a few years to figure out what we could do with it.

Leon Clifford

Computing by light

The first ever digital optical processor has been developed by scientists working for the Bell Laboratories of US communications giant AT&T.

The device, comprising four separate optical chips, is clocked at around 1MHz and breaks no speed records but it does hold out the prospect of extremely fast optical chips in the future. Such chips could revolutionize computing and electronics because they could process faster than conventional circuitry.

Not only does light travel faster than electrons, but it can be split up into many beams which can each do a different job. So optical chips have applications in fast parallel processing computers, high-capacity links between electronic components and signal processing in optical-fibre communications systems.

The Bell Labs' digital optical microprocessor uses four monolithic gallium arsenide chips. Each incorporates 128 basic opto-electronic elements called symmetric self electro-optic effect devices (S-SEEDs); these are the fundamental building blocks of optical chips, just as transistors are the fundamental building blocks of conventional electronic devices.

Like logic gates, S-SEEDs are binary in their nature; they are either 'on' or 'off'. According to AT&T's Anthony Lentine, the S-SEED is versatile and can function as either a dynamic or a static memory. It can also act as a Nor logic gate or a basic optical switch.

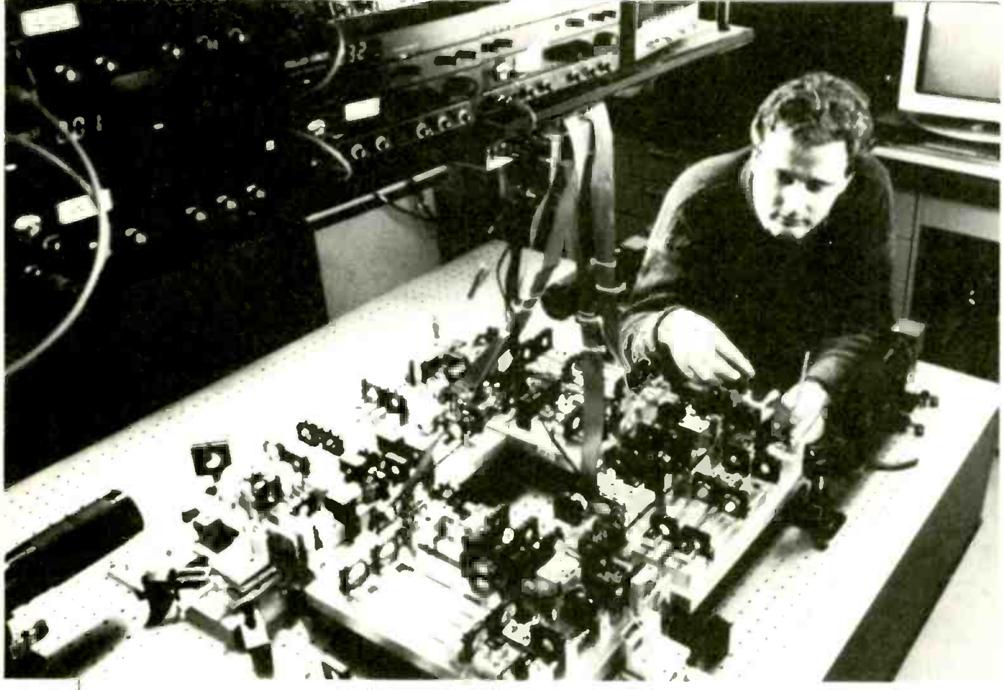
AT&T reckons that an S-SEED can switch on or off in less than a billionth of a second when it is illuminated by a low power beam of light. And very little optical energy is needed to keep information stored in an array of S-SEEDs.

At the end of the last year, Bell Labs unveiled a single gallium arsenide chip sporting some 2048 S-SEED elements. The device could process 2Kbits of optical information in parallel, twice that of any other optical device on the market. AT&T is selling samples of the device to interested parties.

Essentially, S-SEEDs are reverse biased p-n junction diodes with some fancy solid state physics between the p-contact and the n-contact. The fancy bit consists of alternating layers of gallium arsenide (GaAs) and gallium aluminium arsenide (GaAlAs). Each layer is only a few atoms thick and is laid down by molecular beam epitaxy.

This GaAs/GaAlAs sandwich forms what is called a multi-quantum well structure and is a region where quantum physics dominates over conventional electrical theory. It acts as an optically bistable device when it is electrically biased through a load.

Making an adjustment to the world's first optical processor: Michael Prise of AT&T.



When a small bias voltage is applied between the p and the n contacts, the structure can regulate the intensity of a light beam passing through it. This bias voltage is the only electrical input needed for Bell Labs' processor chip, which in all other aspects is totally optical.

The difference between an S-SEED and a SEED (a predecessor of 1984 vintage) is that an S-SEED uses two modulators per element biased in series, each acting as the other's load (and hence the 'S' for symmetrical), whereas a SEED uses one modulator per element. In simple terms, S-SEEDs are better suited for packing into large arrays.

There are four arrays of 32 S-SEEDs in the Bell Labs' microprocessor. Each array measures some 1.3mm on a side and also includes two 10mW semiconductor laser diodes which generate the many beams of light needed to make the chip work.

The output from one array serves as the input for the next; so the logic state of the S-SEEDs in an array is determined by the state of the S-SEEDs in the input array. The optical processor carries out calculations by changing the on-off status of the switches of S-SEEDs on successive arrays.

The four arrays of S-SEEDs are separated by lenses and masks that are analogous to interconnection between logic gates in electronic devices. The masks are essentially glass panes with regular patterns of transparent and opaque spots that can either block light or allow it to pass. The pattern determines the connectivity – the logic – of the machine.

S-SEEDs measuring some 40-microns by 20-microns are bigger than transistors but they are getting smaller all the time, according to Bell Labs' optical chip researcher Dr Mike Prise.

S-SEEDs can be switched much faster than 1MHz, according to Prise. "These S-SEEDs have worked at a 1GHz and similar devices have worked at 20–30GHz," he said.

"What we've got is a really simple system operating at MHz

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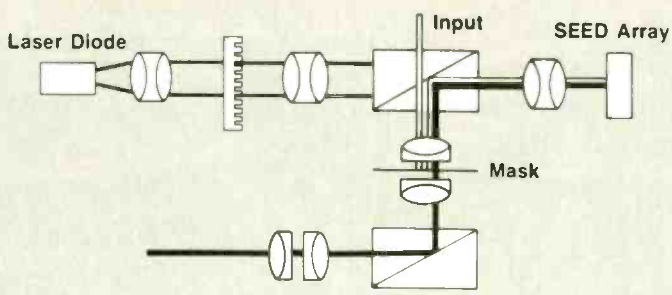
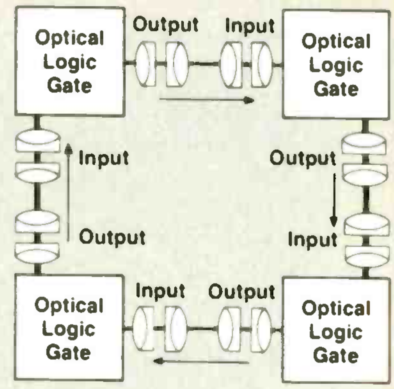
CIRCLE NO. 125 ON REPLY CARD





Light doesn't have capacitance: the system looks clumsy compared to silicon chip but it could work much faster.

frequencies," said Prise. "In four or five years we may have something real to show people. Right now we can design things on paper that look like plans for useful systems that we can think about building."

Prise points out that S-SEEDs are a low energy technology. "And you can make small ones with about the same energy density as c-mos chips," he added.

Bell Labs' breakthrough is undeniably impressive; but don't let stories about 1000-Cray equivalent computers go to your head. There's a lot of steam left in conventional electronics, and at much lower prices.

"Compared to what has gone before, this is a big step forward," said optics expert Professor John Midwinter of University College London. "But its not unreasonable to say that in the region of computing, this won't have a big impact."

He agrees that optical chips hold out the prospect of very fast highly parallel computers. "But in the cold light of day its hard to see what you can do with optical computers that you can't do with silicon." said Midwinter.

However, there are two very special areas where the Bell Labs technology may have applications: electronic interconnection and communications systems.

One of the problems with getting chips to talk to each other is that as clock speeds creep higher, capacitance gets to be a bigger headache for electronic engineers. "We could integrate these optical devices with silicon and use them for silicon gate interconnection," explained Prise.

He points out that optical pin-outs don't charge-up. The trick will be to embed optical circuitry on the same chip as electronic circuitry.

Professor Midwinter reckons there are two ways to do this: either take the silicon and grow the GaAs optic on top, which is very difficult; or grow optical devices on the same silicon substrate as conventional circuitry.

"It removes the pin-out bottleneck that limits the speed of integrated circuits," said Midwinter. "At the moment we design our circuitry around this bottleneck, but once it is gone we will be able to design our circuitry to run faster."

The other important applications area is in telecommunications where high-capacity optical-fibres mean that gigabit data rates must be processed in real-time; and these data rates are growing.

Conventional systems translate the optical signals into electronic ones, process them and then retranslate them back into light. Bell Labs' technology would allow this signal processing to be done optically.

"10Gbits is about the maximum that we can deal with at the moment," said Midwinter. "Optical technology will allow us to take that data rate up to terabits."

This is the one area where AT&T will be focusing a lot of research effort; after all it is a telecommunications company.

So although enormously powerful supercomputers may sound sexy, it's the terribly dull and mundane practicalities of coping with optical-fibre data rates and getting chips to talk to each other that will really benefit from Bell Labs' breakthrough.

Leon Clifford

High speed action defeats rogue disks

Between 8 and 12 December 1989, somewhere in excess of 15,000 floppy disks were mailed to computer users across the UK, Europe, Scandinavia, Southern Africa and Australia.

The disks, from a company called PC Cyborg Corporation, contained a program written to evaluate a user's risk of contracting the HIV virus according to answers given to a series of questions about the user's life-style.

The disks were very cheap 5.25in floppy disks with professionally-printed labels and were mailed in white envelopes to names taken from various mailing lists. Each envelope contained the disk and a small sheet of paper which gave details of how to run the program.

On the reverse of this sheet, in almost impossibly tiny print, were details of "Limited Warranty" and a "Licence Agreement". Buried within the print were such phrases as "There is a mandatory leasing fee for the use of these programs; they are not provided to you free of charge" and "If you install these programs on a microcomputer- . . . you thereby agree to pay PC Cyborg Corporation in full for the cost of leasing these programs."

The reader was further informed that in the event of a breach of the licence agreement, PC Cyborg Corporation reserved the right to use what it called "program mechanisms" to ensure "termination of your use of the programs". There followed a warning that these program mechanisms would adversely affect other program applications on microcomputers. Whether or not this licence "agreement" or any of its conditions are legal is still being debated, particularly since this disk comes under the heading of unsolicited material.

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INTERFACING WITH C

Fed up with whimsical microprocessor code but need its speed? The C language may provide an answer. This series of articles, directed towards electronics engineers, demonstrates the role of the language in connecting microcomputers to the real world. By Howard Hutchings.

C is a medium-level programming language developed by Dennis Ritchie of Bell Laboratories and implemented there on a PDP-11 in 1972. Historically, C was preceded by B, a language written by Ken Thompson in 1970 for the first UNIX system run on the PDP-7. B, in turn evolved from the Basic Cambridge Programming Language BCPL. Developed by Martin Richards at Cambridge in 1967 as a systems programming language.

The C Programming Language: Prentice Hall 1978, by Brian Kernighan and Dennis Ritchie is the definitive text. Although it is not adopted as an international standard, it is generally accepted as standard C. This original and enigmatic text is not an introductory programming manual; it assumes familiarity with basic programming concepts such as variables, assignment statements, loops and functions – and is probably best read once you have mastered C. The increasing popularity of the language has encouraged numerous less esoteric works, many attempting to simplify the original Kernighan and Ritchie text. Each of these introductions has its relative merits; no doubt you will make your own choice and find what suits you best. I have included a short bibliography of texts which I found particularly useful.

Properties and background

The versatility of C allows it to be run on personal 8-bit computers or the Cray-1, one of the worlds fastest computers. Designed to make programs fast and compact, this portable assembly language was used to program the remarkable computer-animated sequences in Return of the Jedi and Startrek II. In many cases programs written in assembly language for "efficiency" have been outperformed by comparable programs written in C. Despite being a medium-level language it still embodies advanced structural programming features normally associated with high-level languages such as Pascal. C is a concise language and small can be beautiful when programming. It has a particularly rich set of operators, ideal for configuring programmable input-output devices and flag testing.

The purpose of these articles is to teach those aspects of the C language

Allen's axiom: "When all else fails read the instructions" you will require to interface effectively. Our strategy is to teach C program constructions as we go along, presenting the information in "byte" sized packets in an attempt to make it more attractive and digestible. We have tried to organize the programs in a progression of complexity, so that each program presents a new feature of C or an alternative program construction. Where possible the construction is illustrated with a flowchart and the program liberally littered with comments to aid comprehension.

All the program examples presented have been tried and tested on an IBM PC clone using a Microsoft C compiler version 5.1. The emphasis is on effective interfacing rather than elegant programming. Where possible I have included alternative program constructions in an attempt to demonstrate the flexibility of this remarkable language. The text encourages you to run the programs and experiment with C. Inevitably some of the programs become lengthy, which tends to discourage even experienced programmers! To maintain interest the fundamental construction is presented separately. Most programs exist to be rewritten; and if after working through the examples you cannot do better, I'll be disappointed.

Rather than design and build our own interface circuits we chose to use the Blue Chip Technology data acquisition and control cards. These plug in cards are port mapped and may be driven by any language, simplifying the task of interfacing – allowing us to concentrate more effort and attention on the programming aspect of the problem.

Fundamental interfacing

The primitive concept of sending bit patterns to the outside world can produce remarkably sophisticated electronic projects with the minimum of hardware, principally because much of the problem is solved using creative software. Imagine an Exocet missile skimming low over the waves as it homes in on its target. On board, the computer receives data from the missile's transducers through the input port. The data is processed in real-time and the result used to control the trajectory in anticipation of a successful strike. Despite the complexity of the task the fundamental problem can be reduced to that of reading ones and zeros from a peripheral connected to an input port—processing the data and finally writing the re-ordered data to the outside world through an output port.

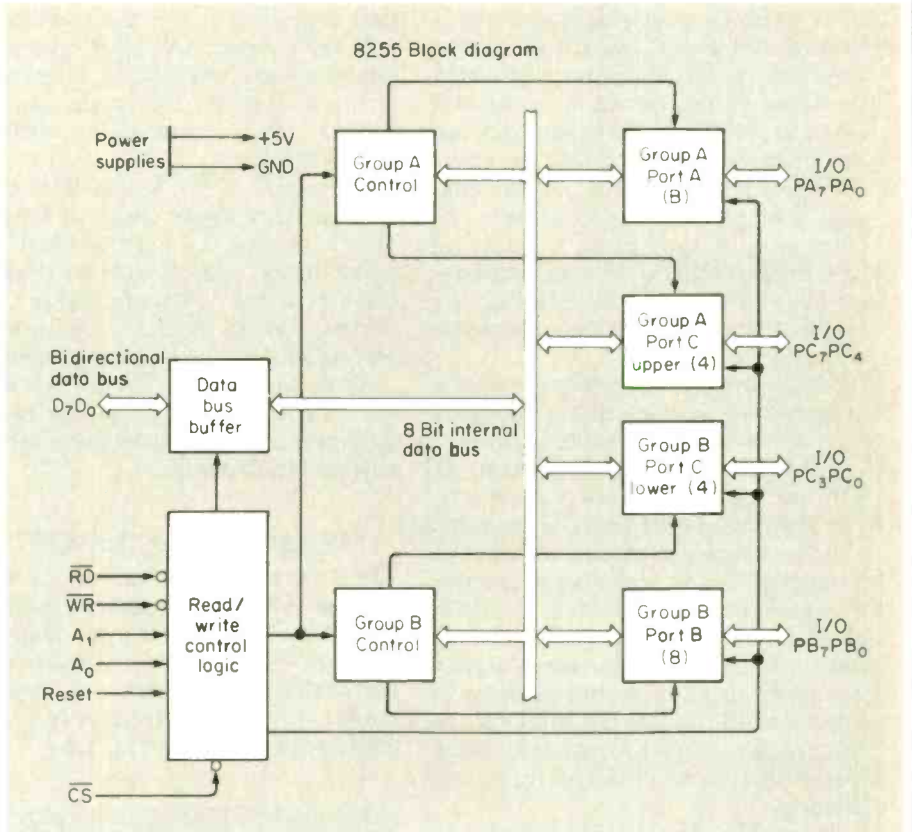
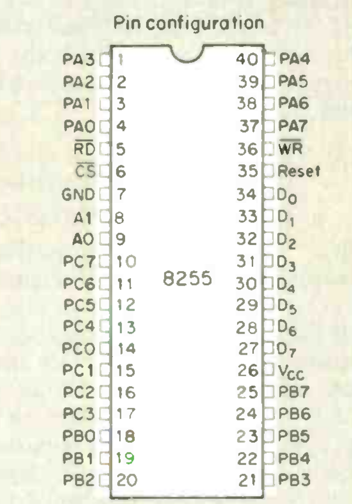


Fig. 1.1. Intel 8255 programmable port used as a programming model in the early stages of this series.



Pin names

D_7–D_0	Data bus (Bi directional)
Reset	Reset input
$\overline{CS}$	Chip select
$\overline{RD}$	Read input
$\overline{WR}$	Write input
A0, A1	Port address
PA7-PA0	Port A (bit)
PB7-PB0	Port B (bit)
PC7-PC0	Port C (bit)
V_{CC}	+5 Volts
GND	0 Volts

Here's the catch: how do you find the available I/O space; format the control word; control the I/O card; process the data? Unfortunately, unless you are an experienced assembly language programmer these objectives represent formidable assignments. Instead of aiming for "the best possible design", we will be content with the "best design possible" and use C to get very close to the target machine.

Programmable input-output devices

Communication between the real world and a personal computer is through the ports of the peripheral interface adapter (PIA) or versatile interface adapter (VIA). These relatively complex and specialized chips can be programmed to behave as input-output devices and effectively buffer the data bus from the controlled peripheral, thereby protecting the system. Employing memory mapped input-output ensures that the

CPU "sees" the ports simply as a collection of addresses, indistinguishable from any address in memory. Provided the input-output device is configured carefully, bi-directional communication can be made almost routine. In effect the operation of these devices are analogous to constructing electronic circuits without ever using a soldering iron, simply because the necessary connections are made by placing the required bit patterns in the appropriate control registers.

Unfortunately each microprocessor manufacturer appears to have adopted a particular programmable input-output device to suit their own system. As with microprocessor instruction sets, familiarity with a particular device tends to make the user patriotic and reluctant to change. Despite the unique features of many of these devices, certain characteristics remain common, making the transition from the comparatively primitive programmable peripheral interface PPI, such as the Intel 8522 to the complex and complicated MOS Technologies 6522 VIA relatively painless.

To explain the adopted interfacing protocols with any clarity it was necessary to be chip specific. Unfortunately this dates the text, although the fundamental concepts will remain current for some time to come.

8255 programmable peripheral interface

The Intel 8255 programmable peripheral interface PPI in **Figure 1.1** is a fairly simple parallel port chip. This rather venerable design was one of the earliest interface adapters on the market, originally intended for use in the 8008 and 8080A systems, but now enjoying a resurgence of popularity on account of the ease with which it interfaces to the IBM PC bus, which is effectively the bus for the 8088 processor operated in the "maximum mode". Large scale integration ensures that parallel input-output operation can be concentrated into a single 40-pin package. Making the chip software configurable offers the flexibility of deferred design – the values placed in the control register determine which groups of lines are inputs and outputs.

Communication between the microcomputer and the real world is through the 24 input-output lines. These are divided into two groups of eight lines, data ports A and B, together with two groups of four lines – forming port C. Port C can either be a data port or a control port depending on the mode selected.

In mode 0 ports A and B operate as two 8-bit ports, whilst port C is operated as two 4-bit ports. This mode supports simple data transfers without handshaking.

In mode 1 ports A and B may be configured as either input or output. They cannot be defined individually on a line by line basis as with the ports of certain other programmable I/O devices. Six bits of port C are set aside for handshaking and interrupt control.

Mode 2 uses the eight lines of port A for bi-directional data transfer. Handshaking is provided by the five most significant bits of port C.

Programming the 8255

The programming model of the 8255 consists of four 8-bit registers, ports A, B and C and a control register. Depending upon where you locate the device in the available I/O space, the register model appears as four contiguous addresses as shown in **Fig. 1.2**.

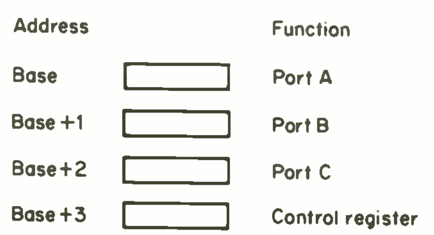


Fig. 1.2. 8255 programming model.

The operation of the I/O ports is controlled by the format of the 8-bit word written to the control register, located at address (Base + 3). The control word format is shown in **Fig. 1.3.** Simple input-output operations, without handshaking, require the control word to be configured in mode 0. **Table 1.1** represents the mode 0 – port definition chart; which should be an effective source of reference when consulting the example programs.

The Blue Chip data acquisition system, used as a teaching example in this series of articles, provides 48 I/O lines by port mapping two 8255s on the same plug-in card. The ports are terminated in a single 50 way connector at the rear of the IBM PC. Bus contention is avoided by making the base address selectable in the range 300H to 3FFH, the prototyping region.

IBM PC bus

As shown in **Fig. 1.4** the PC-XT bus is an 8-bit data bus implemented in a 62-pin edge connector. Many of the bus signals are used for direct memory access and interrupt handling and may be ignored at first reading.

The address bus lines A0—A19 can address up to 1Mbyte of address space. Although the 8088 processor can use all 16 lines A0 – A15 to access 64Kbyte of I/O space, only 10 lines A0 – A9 are actually decoded restricting the number of available ports to 1024. Many of the available I/O locations have been

Table 1.1. Mode 0 port definition chart.

In this mode, simple input and output operations for each of the three ports are provided. No "handshaking" is required; data is simply written to or read from a specified port.

No.	Control Word Bits								Group A		Group B	
	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Port A	Port C (Upper)	Port B	Port C (Lower)
0	1	0	0	0	0	0	0	0	OUTPUT	OUTPUT	OUTPUT	OUTPUT
1	1	0	0	0	0	0	0	1	OUTPUT	OUTPUT	OUTPUT	INPUT
2	1	0	0	0	0	0	1	0	OUTPUT	OUTPUT	INPUT	OUTPUT
3	1	0	0	0	0	0	1	1	OUTPUT	OUTPUT	INPUT	INPUT
4	1	0	0	0	1	0	0	0	OUTPUT	INPUT	OUTPUT	OUTPUT
5	1	0	0	0	1	0	0	1	OUTPUT	INPUT	OUTPUT	INPUT
6	1	0	0	0	1	0	1	0	OUTPUT	INPUT	INPUT	OUTPUT
7	1	0	0	0	1	0	1	1	OUTPUT	INPUT	INPUT	INPUT
8	1	0	0	1	0	0	0	0	INPUT	OUTPUT	OUTPUT	OUTPUT
9	1	0	0	1	0	0	0	1	INPUT	OUTPUT	OUTPUT	INPUT
10	1	0	0	1	0	0	1	0	INPUT	OUTPUT	INPUT	OUTPUT
11	1	0	0	1	0	0	1	1	INPUT	OUTPUT	INPUT	INPUT
12	1	0	0	1	1	0	0	0	INPUT	INPUT	OUTPUT	OUTPUT
13	1	0	0	1	1	0	0	1	INPUT	INPUT	OUTPUT	INPUT
14	1	0	0	1	1	0	1	0	INPUT	INPUT	INPUT	OUTPUT
15	1	0	0	1	1	0	1	1	INPUT	INPUT	INPUT	INPUT

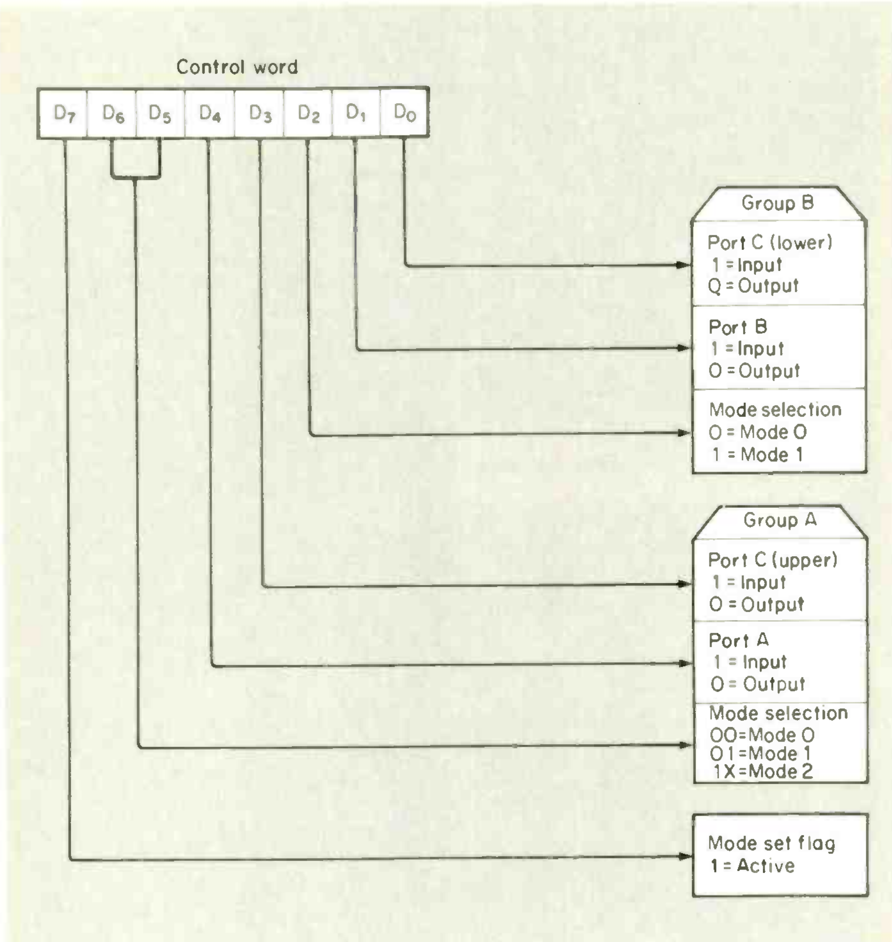


Fig. 1.3. Control word bit function for 8255.

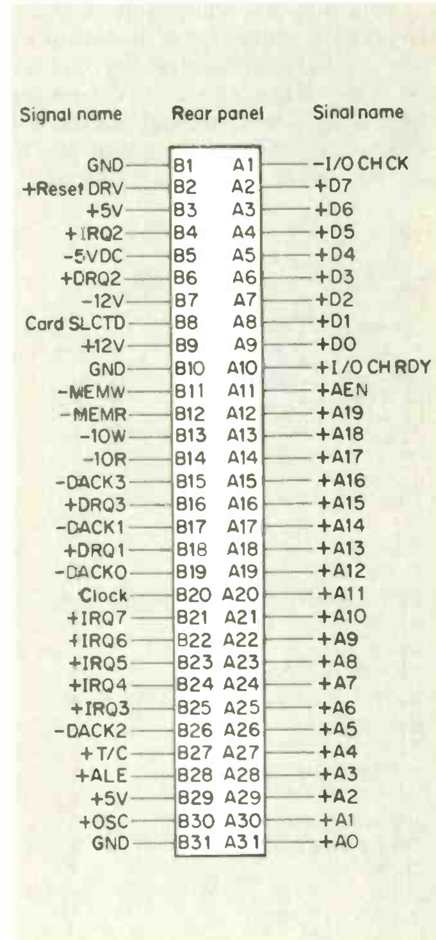


Fig. 1.4. IBM PC bus structure.

adopted by IBM for their own purposes, these assigned locations being shown in Table 1.2. Despite the crowded nature of the I/O space there are several ports available, particularly in the prototype region 300H—31FH. However, certain peripheral board manufacturers have monopolized some of these addresses for their own products, which means you must look elsewhere for I/O space. Clearly one simple solution is to use unoccupied assigned I/O locations.

Accessing specific memory locations with Basic and C

Before you can interface successfully with C, it is first necessary to access data from specific memory addresses. Rather than ruthlessly present the required C constructions, we prefer to reiterate the familiar Basic commands and program structures for the purpose of comparison.

GW-Basic run on the IBM PC supports both memory-mapped I/O using Peek and Poke, together with port-mapped I/O using the Inp and Out commands. C provides a similar construction, the former requiring the use of pointers—which are tricky until you get used to them. However, pointers cannot be used to access I/O devices in computer systems such as the IBM PC which have a separate address space for I/O devices. IBM has allocated addresses in the range 768 to 799 (denary) specifically for I/O prototyping. See **Table 1.2**.

C compilers for machines with this type of I/O system usually include library functions, which allow direct access to the port-mapped I/O space. For example, the Microsoft C compiler version 5.1 provides the functions inp( ) and outp( ) defined in the header file conio.h. By incorporating the additional compiler directive #include<conio.h> these functions can be made part of the program as it is compiled.

Accessing data from specific memory locations is central to the task of interfacing, no matter which language is employed. For this reason we feel it is appropriate to include extracts from the GW-Basic and Microsoft C programmers manuals, for the purpose of comparison.

Table 1.2. Address space for IBM I/O devices.

Hex address range	Use
000–00F	DMA chip 8237A-5
020–021	Interrupt 8259A
040–043	Timer 8253-5
060–063	PPI 8255A-5
080–083	DMA page registers
0AX	NMI mask register
0CX	Reserved
0EX	Reserved
200–20F	Game control
210–217	Expansion unit
220–24F	Reserved
278–27F	Reserved
2F0–2F7	Reserved
2F8–2FF	Asynchronous communications (secondary)
300–31F	Prototype card
320–32F	Fixed disk
378–37F	Printer
380–38C*	SDLC communications
380–389*	Binary synchronous communications (secondary)
3A0–3A9	Binary synchronous communications (primary)
3B0–3BF	IBM monochrome display/printer
3C0–3CF	Reserved
3D0–3DF	Color/graphics
3E0–3E7	Reserved
3F0–3F7	Disk
3F8–3FF	Asynchronous communications (primary)

*Since addresses overlap, you cannot use both communications options at once.

Believing that one picture is worth a thousand words we intentionally include the lighthearted **Fig. 1.5** as a reminder of how to access port-mapped data using GW-Basic and Microsoft C. These illustrative programs do not include any initialization protocols.

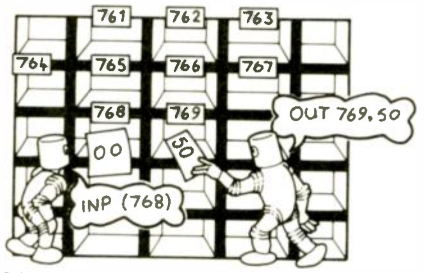


Fig. 1.5. Peeking and poking.

Example 1
```
10 REM PEEKING I/O
20 P = INP(768):REM READ PORT A
30 PRINT P
```
Example 2
```
10 REM POKING I/O
20 OUT 769,50:REM WRITE PORT B
```
Example 3
```
/**********************
* PEEKING I/O WITH C *
**********************/
#include<stdio.h>
#include<conio.h>
main()
{
unsigned char p;
p = inp(768);
/*----------
READ PORT A
-----------*/
printf("%d\n",p);
}
```
Example 4
```
/****************
* POKING WITH C *
****************/
#include<stdio.h>
#include<conio.h>
main()
{
outp(769,50)
/*------------
WRITE TO PORT B
---------------*/
}
```

Reading the contents of I/O space using pointers

My initial objective was to demonstrate how to write a C program to read and display the contents of the I/O address space shown in Table 1.2. Two options were available: either I pedantically advertise the necessary C constructions before presenting the program; or I present the program and encourage you to run it and then demonstrate the appropriate constructions. I chose the latter approach in the belief that evidence of a successful program will provide a sense of direction and encourage you to read the subsequent text more critically. Beware, listing 1.1 is not an elementary program, it contains many advanced features. Examine the fine detail after reading Chapter 1—then improve upon it!

Extract from GW-Basic and Microsoft C programmers manuals.

POKE Statement

Syntax **POKE** *address, byte*

Action Writes a byte into a memory location

Remarks The arguments *address* and *byte* are integer expressions.
The expression *address* represents the address of the memory location and *byte* is the data byte. The *byte* must be in the range 0 to 255.

The *address* must be in the range – 32768 to 65535. The *address* is the offset from the current segment, which was set by the last **DEF SEG** statement. For interpretation of negative values of *address* see "VARPTR Function."

The complementary function to **POKE** is **PEEK.**

Warning
Use **POKE** carefully. If it is used incorrectly, it can cause the system to crash.

See Also DEF SEG, PEEK, VARPTR

Example 10 POKE &H5A00, &HFF

PEEK Function

Syntax **PEEK**(*n*)

Action Returns the byte from the indicated memory location *n*

Remarks The returned value is an integer in the range 0 to 255. The integer *n* must be in the range – 32768 to 65535. The *n* argument is the offset from the current segment, which was defined by the last **DEF SEG** statement. For the interpretation of a negative value of *n*, see the "VARPTR Function."

PEEK is the complementary function of the **POKE** statement.

Example A=PEEK (&H5A00)

In this example, the value at the location with the hexadecimal address 5A00 is loaded into the variable A.

OUT Statement

Syntax **OUT** *port, data*

Action Sends a byte to a machine output port

Remarks The *port* is the port number. It must be an integer expression in the range 0 to 65535.

The *data* argument is the data to be transmitted. It must be an integer expression in the range 0 to 255.

Example 100 OUT 12345, 255

In 8086 assembly language, this is equivalent to:

```
MOV DX 12345
MOV AL, 255
OUT DX, AL
```

INP Function

Syntax **INP** (*port*)

Action Returns the byte read from *port*. The *port* must be an integer in the range 0 to 65535

Remarks **INP** is the complementary function to the **OUT** statement.

See Also OUT

Example This instruction reads a byte from port 54321 and assigns it to the variable A:

100 A=INP(54321)

In 8086 assembly language, this is equivalent to:

```
MOV DX, 54321
IN   AL, DX
```

Listing 1.1
```
/************************
* READING I/O ADDRESSES *
* USING POINTERS *
************************/
#include<stdio.h>
main()
{
int *port_x;
unsigned char contents;
int i,j,x;
/*------------------------------
*port_x IS A POINTER DECLARED AS
AN INTEGER. THE VARIABLE contents
IS AN UNSIGNED CHARACTER. THE
VARIABLES i,j AND x ARE INTEGERS
-------------------------------*/
start:printf("Input base address");
scanf("%d",&i);
/*--------------------------------
ENTER A DENARY INTEGER i FROM THE
KEYBOARD
---------------------------------*/
for(j = i;j <= 16 + i;j++)
{
x = j;
port_x = (int*)j;
/*-------------------------------
THIS CONSTRUCTION ESTABLISHES THE
ADDRESS OF THE POINTER
----------------------------------*/
contents = *port_x;
/*-------------------------------
WHEN * IS USED AS A PREFIX TO AN
INTEGER VARIABLE NAME WE RECOVER
THE VALUE AT THAT ADDRESS
--------------------------------*/
printf("%d\n",contents);
/*------------------------------
PRINT THE DENARY CONTENTS OF THE
I/O ADDRESSES ON THE SCREEN
--------------------------------*/
}
goto start;
}
```

Run listing 1.1 after first linking and compiling. The program responds by asking you to input the denary base address from the keyboard. Consult Table 1.2 for suitable values of I/O addresses. The result will be the contents of 16 contiguous addresses starting with the Base, displayed on the monitor. Now enter a new Base address and watch the program repeat the procedure. Unoccupied I/O locations may be identified by the contents being set to zero.

C program development

The C language is compiled. Program

Continued over page

statements, i.e. the source code, are not executed directly as with interpreted languages. Instead they are written to a file called the source program, using a text editor or word processor. The source program is then processed by the C compiler. The output from the compiler is the machine code equivalent of the source program: the object program. Incorporating certain external modules using the link program results in an executable program. The flowchart for the compilation/link process is shown in **Fig. 1.6**.

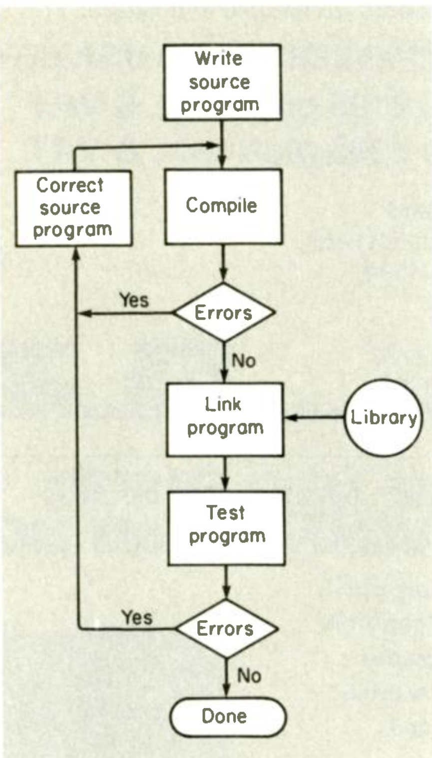


Fig. 1.6. C program development.

It is rewarding to examine the general structure of all C programs before becoming involved in the fine detail of interfacing.

Listing 1.2

```
/***********************
* GENERAL STRUCTURE OF *
* ALL C PROGRAMS *
***********************/
#include<stdio.h>
main()
{
/*---------------------
CODE TO BE EXECUTED
GOES HERE
----------------------*/
}
```

The anatomy of the program is made up as follows: #include<stdio.h> is the compiler directive and header file. This file is provided with each C compiler and should always be included to guarantee successful compilation. Check the C compiler manual for the precise syntax for your particular system. Some compilers require #include"stdio.h" or #include<h.stdio>. Stdio is a contraction of "standard input-output". This particular header file provides the necessary system information to input data from the keyboard and display it on the monitor. Some programs require additional header files, the names in these header files containing system related-information that is made part of the program as it is compiled – ref inp( ) and outp( ).

All C programs are functions, usually made up of the principal function main() together with any nested functions. The example in listing 1.2 is probably the most primitive C program imaginable, where the code located inside the braces is simply a non-executable comment, analogous to the Basic REM statement. Notice that the non-executable comment is preceded by a slash star /* and terminated by a star slash */. These comment delimiters ensure that any remark placed inside the structure will be ignored by the compiler. It's good programming practice to include a generous number of such comments, to improve readability. Modifying this elementary example to print a message on

Outp, outpw

■ Summary

# include <conio.h>	Required only for function declarations
int outp (*port, byte*);	Outputs a byte
unsigned outpw (*port, word*);	Outputs a word
unsigned *port*;	Port number
int *byte*;	Output value
unsigned *word*;	Output value

■ Description

The **outp** and **outpw** functions write a byte and a word, respectively, to the specified output port. The *port* argument can be any unsigned integer in the range 0–65,535; *byte* can be any integer in the range 0–255; and *word* can be any value in the range 0–65,535.

■ Example

```
# include <conio.h>
# include <stdio.h>

int port, byte_val;

main()
 {
 port = 1;
 byte_val = 3;
 outp (port, byte_val);
 printf ("The value %d has been output to port %d",
         byte_val, port);
 }
```

This program uses **outp** to write the value 3 to output port 1.

inp, inpw

■ Summary

# include <conio.h>	Required only for function declarations
int inp (*port*);	Reads a byte
unsigned inpw (*port*);	Reads a word
unsigned *port*;	Port number

■ Description

The **inp** and **inpw** functions read a byte and a word, respectively, from the specified input port. The input value can be any unsigned integer in the range 0–65,535.

■ Example

```
#include <conio.h>
#include <stdio.h>

/* Read will be done on port #0: */
unsigned int port = 0;
 char result;

main ()
{
 /* Input a byte from the port: */
 result = inp (port);
 printf ("The value from port #%d is %d n", port, result);
}
```

This program reads a character from input port 0.

the monitor is straightforward, as shown in **listing 1.3**.

Listing 1.3

```
/**********************
* DISPLAYING A MESSAGE *
* USING C *
**********************/
#include<stdio.h>
main()
{
printf("Interfacing with C");
/*---------------------
EXECUTABLE CODE
-----------------------*/
}
```

The result will be the message:
Interfacing with C

Everything inside the inverted commas has been displayed on the screen. Don't fail to notice that the printf() statement was terminated with a semicolon (;). All C statements end this way.

Variables

Data objects manipulated by the program are called variables. Any name can be given to a variable, provided that it starts with a letter and does not include any white space or punctuation. Variable names should be meaningful; ranging from the cryptic i, j, k often used as names in loops—to the more explicit port_A associated with I/O data transfer. Depending upon your compiler, the first six or eight characters should be unique. Variable names may be upper and/or lower case letters, or include numbers after the first character. Certain keywords (Table 1.3) are not permitted in isolation, although they may be contained within a variable name. For example, the contraction "ifr" meaning interrupt flag register is a valid name, despite containing the keyword "if". Keywords are composed of lower case letters only, hence "IF" is a valid name.

Table 1.3. Keywords in C.

auto	break	case
char	continue	default
do	double	else
entry	extern	float
for	goto	if
int	long	register
return	short	sizeof
static	struct	switch
typedef	union	unsigned
while	void	enum

Data type

When a variable is declared it is also given a data type. C requires the programmer to decide the declared variable's data type in advance. Certain data types, for example int and char are processed more quickly as the program executes and it is good practice to maintain only sufficient precision as is necessary, when declaring variables. Computers do not store floating-point numbers with infinite precision; they hold an approximation, depending upon the number of bytes employed.

Using C the following data types are available.

(1) char—can hold one byte and represent integers in the range −128 to 127.
(2) short—usually occupies two bytes and is used to store integers in the range −32,768 to 32,767.
(3) int—depending upon the characteristic word length of the computer, integers are stored in the range −32,768 to 32767 using two bytes, or −1,073,741,824 to 1,073,741,823 using four bytes.
(4) long—is used to store an integer in the range −1,073,741,824 to 1,073,741,823 and usually occupies four bytes.
(5) float—occupies four bytes and is used to store decimals with up to six digits of precision.
(6) double—usually occupies eight bytes and is used to represent floating point numbers with 14 digits precision.

Qualifiers

The data types char, short, int, long and float can be modified by the use of a qualifier. For example, the unsigned char declaration has the effect of restricting the representation of the variable to the positive integers in the range 0 to 255. Which is often a useful precondition when interfacing to an 8-bit port. Declaring the data types short, int and long as unsigned; has the effect of doubling the range of the positive integers. Making the declaration long float gives the same precision as double.

Reading the status of an input port

The operation of each port is determined by the format of an 8-bit word in the control register of the 8255 PPI shown in **Fig. 1.3**. When power is first applied, the reset signal going high on pin 35 clears all the internal registers and sets ports A, B and C to the high impedance state and automatically protects any connected peripheral. Initializing the control register by loading with 155 (denary), defines the control word as active and configures all the ports as input (mode 0). Data is to be read from eight logic switches connected to port A, the other ports remaining unconnected. The logic status will be displayed in denary on the monitor. One possible construction is shown in listing 1.4.

Listing 1.4

```
/********************
* READING THE STATUS *
* OF I.P PORT A *
********************/
#include<stdio.h>
#include<conio.h>
main()
{
int port_A,control_reg,word;
unsigned int contents;
/*------------------
DECLARE DATA TYPES
------------------*/
port_A = 768;
control_reg = 771;
/*------------------
ADDRESSES OF 8255
------------------*/
word = 155;
outp(control_reg,word);
/*-------------------------
INITIALISE CONTROL REGISTER
-------------------------*/
contents = inp(port_A);
/*-----------
READ PORT A
------- -----*/
printf("Port A contains %d\n",contents);
}
```

Controlling printf()

Much of the program structure has already been discussed and should be self explanatory. We take this opportunity to describe the printf() function in greater detail and show how to specify the type of output.

In this example the function is formatted to print the numerical value of the variable name "contents". The format of printf() is somewhat unusual and for that reason presented in excruciating detail.

```
printf("%d\n",contents);
```

(1) %d specifies the argument will be formatted in signed decimal.
(2) \n combination of the backslash \ and n is called "newline". It means take a new line.
(3) Items (1) and (2) are called the formatting string and must be contained in double quotes. The comma must be included to separate the formatted string from the argument.
(4) contents—in this case the argument: contents will be matched to the formatting string %d, and printed in signed decimal notation.

Changing the letter of the formatted string allows other data types to be displayed as shown in **Table 1.4**.

Table 1.4. Displaying other data types.

d decimal notation
o unsigned octal notation
x unsigned hexadecimal notation
u unsigned decimal notation
c single character
s string
e double or floating number in decimal and exponential notation
f double or floating number in decimal notation
g the shorter in length of characters, of %e or %f representation

When interfacing, the more primitive data types are often useful: x meaning unsigned hexadecimal is of particular interest. The way to learn a language is to use it, rather than simply read about it. If you have time, try modifying the format of printf() to display the decimal and hexadecimal contents of the input port. A crude but effective approach would be:

```
printf("Decimal No. = %d\n",contents);
printf("Hex No. = %x\n",contents);
```

which will print the contents of the input port (for example 128)
Decimal No. = 128
Hex No. = 80
Alternatively, the construction:

```
printf("Decimal No. = %d\n Hex No. =
%x\n",contents,contents);
```

Will produce an identical result and illustrates the format: \n meaning newline. To display the decimal and hexadecimal values horizontally on the monitor, simply replace newline: \n with the tab character: \t as shown.

```
printf("Decimal No. = %d\t Hex No. =
%x\n",contents,contents);
```

This will print:
Decimal No. = 128 Hex No. = 80

The coercion operator: cast

To illustrate how C deals with data types consider listing 1.4 again. Suppose, in our haste to program, we had inadvertently declared int contents. C interprets the variable "contents" as a signed binary integer, with potentially disastrous consequences when reading the contents of the input port. Fortunately C includes a construction called a cast or a coercion, which persuades the compiler that an object of one data type should be treated as if it had a different type. A cast gives the language flexibility, permitting eleventh hour fixes. The modification is:

```
printf("%d\n,(unsigned int)contents);
```

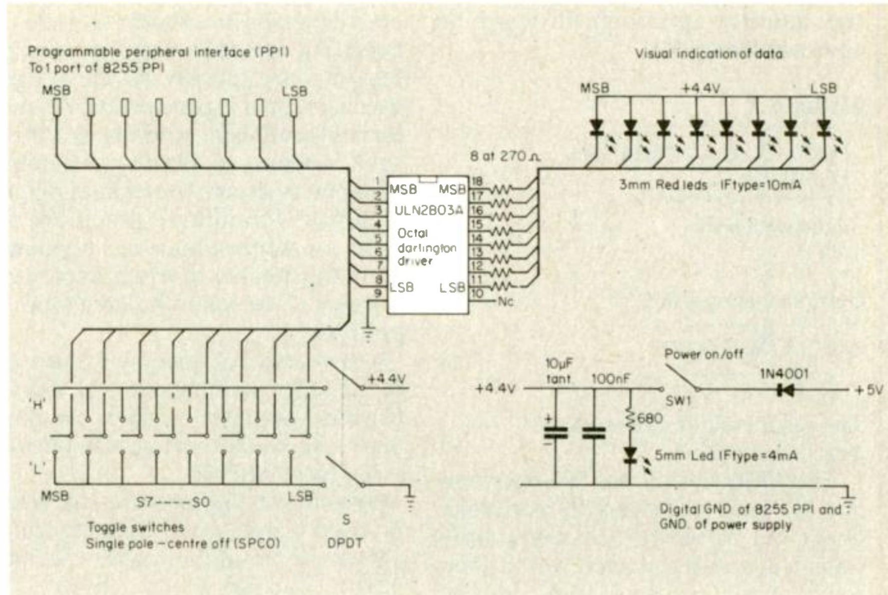


Fig. 1.7. I/O port demonstration circuit.

Writing from keyboard to output port

Using the keyboard to enter data, **listing 1.5** is a useful extension of the previous program. Conceptually the only new function to learn is scanf(), which complements printf() examined earlier. Although the characteristics are similar, scanf() is presented in some detail as an aid to comprehension.

Listing 1.5

```
/************************
* WRITING TO O/P PORT A *
* USING THE KEYBOARD *
************************/
#include<stdio.h>
#include<conio.h>
main()
{
int port_A = 768;
int control_reg = 771;
/*----------------
DECLARE DATA TYPES
AND ADDRESSES
-----------------*/
int x;
int word = 139;
outp(control_reg,word);
/*---------------------
INITIALIZE CONTROL REG
PORT A O/P:PORTS B & C
INPUTS
---------------------*/
printf("Input a No. 0-255");
scanf("%d",&x);
/*------------------
INPUT A NUMBER FROM
THE KEYBOARD
------------------*/
outp(port_A,x);
/*-----------------
WRITE X INTO PORTA A
--------------------*/
}
```

Entering data using scanf()

The function scanf() is used to collect data from the keyboard, the data type to be processed being determined by the conversion character in the control string. In this example the format %d causes scanf() to interpret the input characters as a denary integer, and store the value at the address of x, symbolised by &x (pronounced ampersand x).

Changing the conversion character of the control string modifies the input stream as shown in **Table 1.5**.

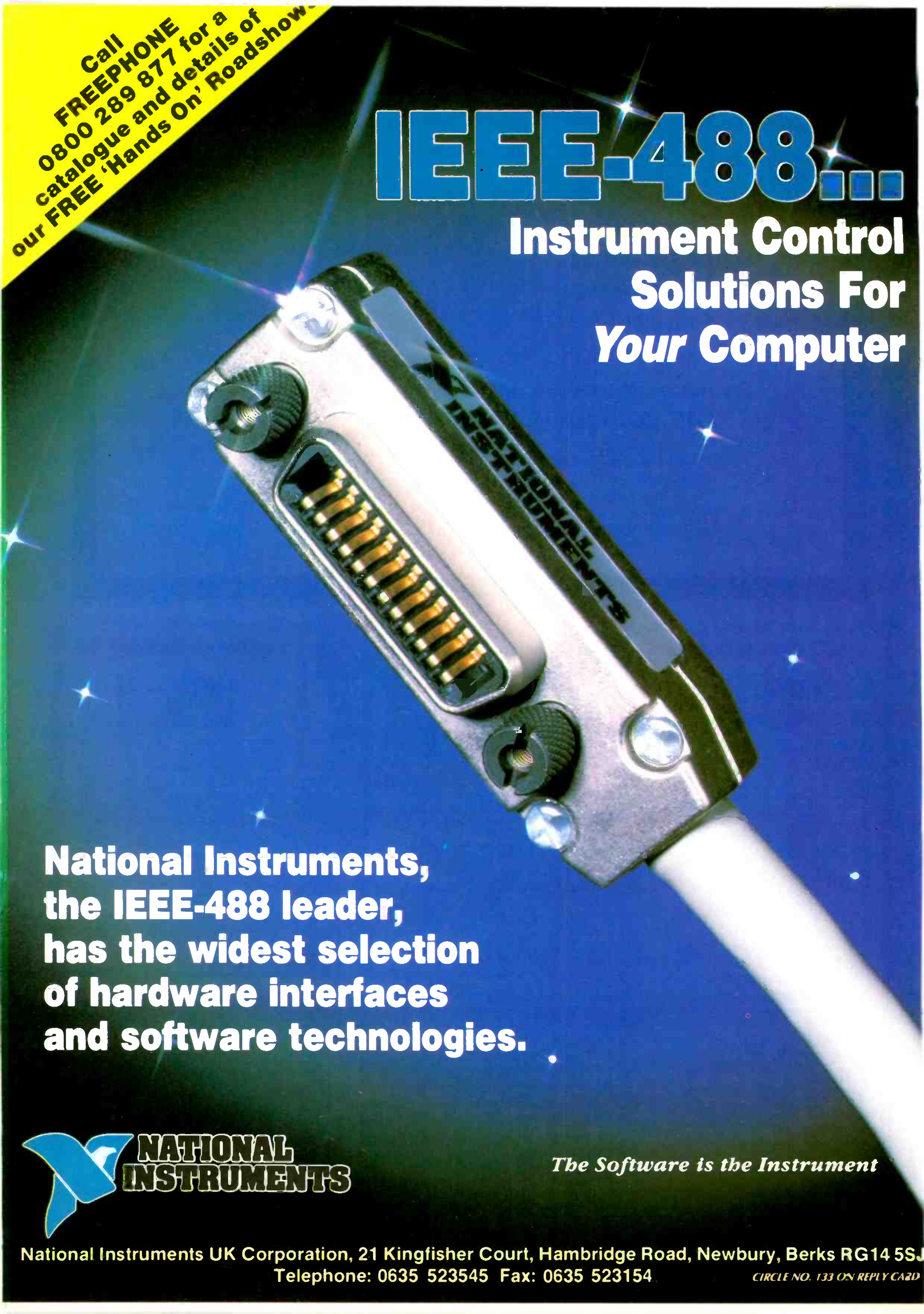
Table 1.5. Input data types.

d decimal notation
o unsigned octal notation
x unsigned hexadecimal notation
c single character
f double or floating number in decimal notation
s string

An effective visual indication of the data written to the output port is obtained using the circuit shown in **Fig. 1.7**. With the switches floating, the voltage levels (logic states) of the output port are displayed on the eight leds. Alternatively, configuring the port as an input and using the circuit as a source of logic levels (by enabling S), produces a visual reminder of the selected switch status.

Next month: Binary counters in software; using C for data acquisition.

Dr Howard Hutchings is Senior Lecturer in Electronics Control at Humberside College of Higher Education, and a part-time lecturer at the Open University.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CIRCLE NO. 133 ON REPLY CARD

Continued from page 278

It should be mentioned that the program could not be run on machines without a hard disk and its first operation was to print out an invoice for payment (for the software lease) to be made to a PO Box in Panama. A choice of leasing terms was provided at a cost of either US$189 or US$378.

Within a matter of hours, many users had discovered that the installation routine necessary to run the AIDS program had created a series of hidden files and directories on their hard disks. These were undoubtedly the "program mechanisms" referred to in the documentation.

At this stage no harm had come to other data and programs already on the hard disk. One of the computer magazines, who had sold a copy of its mailing list in good faith, began to receive calls from subscribers about the disk. It immediately started an investigation into the source and operation of the disk and its contents.

Within hours, it was found that installation of the AIDS program put users' machines at risk by operating a particularly vicious form of software protection. This "protection" allowed the machine to be switched on a specific number of times (usually 90) before an encryption scheme was invoked which altered information on the disk in such a way that the machine's hard disk (drive C:) was locked up and could not be used.

Once locked in this way, the machine would only respond to commands by displaying a warning that "The lease for a key software package has expired". It went on to insist that users should pay the leasing fee for the AIDS software to receive a renewal disk to regain the use of their machine.

The investigation into the actual software was immediately intensified in an attempt to discover how deeply into the operating system this "protection" scheme was penetrating. The programs had been written in a high-level language which meant that the files were quite large (172K and 146K respectively) and, although this did increase the amount of work involved in disassembling them, it actually simplified the task of identifying particular areas where malignant code might be found.

Preliminary investigations indicated that the program did nothing more than has already been described. Arrangements were made to produce a clean-up program which would remove the hidden files and directories set up by the installation routine. Removal of these installation files was a relatively simple process for knowledgeable individuals with the requisite software utilities.

However, it was felt that non-technical users would be at risk unless a special clean-up program was freely available. Such a program was written, tested and distributed free of charge and worldwide on various computer networks by lunchtime on Wednesday 13 December.

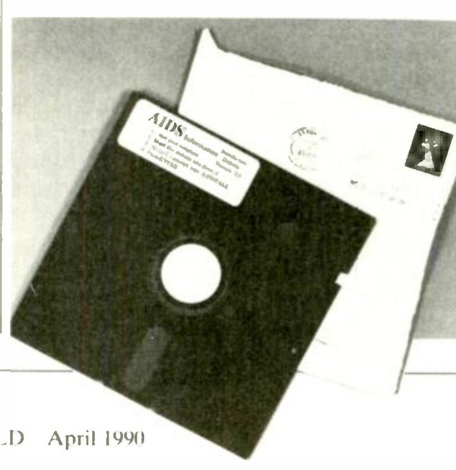
The next priority was to identify the encryption algorithms used during the disk "locking up" process so that a program could be produced which reversed the effects of this and was able to recover the use of the disk on a machine where the program had "triggered".

After further testing of the original program, a decryption program was eventually written which completely reversed the encryption and restored the machine to its state before the AIDS program was installed. As before, this program was immediately made freely available on a worldwide basis so that anyone who had a machine where this had triggered could recover its use with the minimum disruption.

This second program incorporated the functions of the first and was capable of recognising what state the machine was in and then taking appropriate action.

Meanwhile, genuine researchers were finding that disassembly was hampered by a feature within the INSTALL program.

One of the characteristics of the high level language used (QuickBASIC 3.0) is that all the printed output of a program is usually visible within the program file. This printed output is often an excellent guide to just what the program functions may be. Such output was certainly visible within the AIDS program itself, but the output



Utah born Dr Joseph Lewis Popp, 39, a medical computer specialist working in AIS research, is currently under arrest in the US following information provided by the UK police.

associated with the INSTALL program had been encrypted to prevent such visual inspection.

The solving of this encryption algorithm became of paramount importance. It was eventually broken early on the morning of Monday 18 December.

The urgency has now receded, but there is no doubt that many users will have been worried by this episode. Many will re-examine their departmental security arrangements.

The lessons to be learned are still the old ones – make regular backups of valuable data and view unsolicited software with suspicion.

One large company who received several of these disks has a system whereby all in-coming computer software is checked and verified before being allowed into the company.

One or two individuals and companies with commercial interests in marketing anti-virus software went way over the top in promoting rumours of viruses and other dire effects of this package. These rumour mongers succeeded once again in muddying the water for the genuine researchers.

Probably the most positive result of the whole incident was the way in which the computer magazines reacted. Unconditional support was immediately offered to the original magazine regardless of professional rivalry. The speed with which the clean-up programs and information reports were circulated worldwide must surely qualify for an entry in the *Guinness Book of Records* as the fastest and most widespread publication of any piece of computer software.

Within 24 hours of receipt of the software, the original clean-up program had been written, tested, packaged and made available to users globally.

Jim Bates

First reported in the February issue of our sister publication, *Practical Computing*. ■

His master's voice

We've been around a couple of million years. Computers are still pretty stupid in evolutionary terms. The prospect of holding an interesting conversation with your tumble dryer remains a nightmare but, as a pilot of a military aircraft, you can tell your war-horse to kill. By Rob Causey

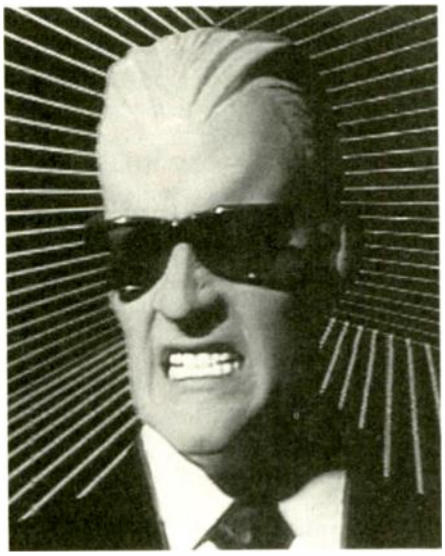
When a drunk staggers up to you in the street and says "Yavapricer-cuppateeguv?", how do you know what he wants? How many times have you stood on a railway station listening to an announcement when a train pulls in half way through and drowns it out? Do you really know what the accountant means when he says "The payment to dividend differential has migrated over the fiscal period from the projection in such a way as to minimize the return"?

If you think that you've got problems, how can you expect a computer to understand what you're saying. We all merge our words together. The shapes of our mouths vary, producing a disparate range of sounds. We use different words to mean the same thing and the same words to mean different things.

For a computer to hold a conversation, it has not only to solve these problems but be able to take sentences in context. We know what we expect people to say in certain circumstances, having been listening to speech for years. The most intelligent of systems will never have the chance to build up the same experience of speech as its users.

Programmers develop recognition systems using rules of speech which we never think about as we speak. Through all the variations, accents and tones, there are only forty distinct sounds, called phonemes, which form the basis of words in the English language. Picking out these phonemes and deciding what they mean is the essence of speech recognition.

The computer's problems have multiplied even before the words have left the speaker's mouth. The shape of the



mouth will determine the pitch and distribution of energy across the range of frequencies of the words. The same person will also talk at a different pitch depending on stress and emotion level.

The duration of the sound patterns varies from person to person. An English gent's speech will be "clipped", a Texan will "drawl". Although the English language is richer for the variety, it prevents the machine using techniques which assume that phonemes are the same length for everyone.

On its way to the computer, the speech will be contaminated by noise. Given the substantial differences between individuals, the system has to try to decide how much energy at a particular frequency is speech and how much is noise without information. This problem will be familiar to engineers working with digital signals; if you don't believe its importance in speech recognition try playing Chinese Whispers.

A typical human vocabulary will consist of about five thousand words, some of which are certain to arrive merged together. Called co-articulation or concatenation, this is what the drunk does when he asks for the price of a cup of tea.

Storing a full set of five thousand word combinations on a computer would be prohibitive in every sense. In practice it is easier to tell the human which words the processor will understand and restrict the machine's vocabulary.

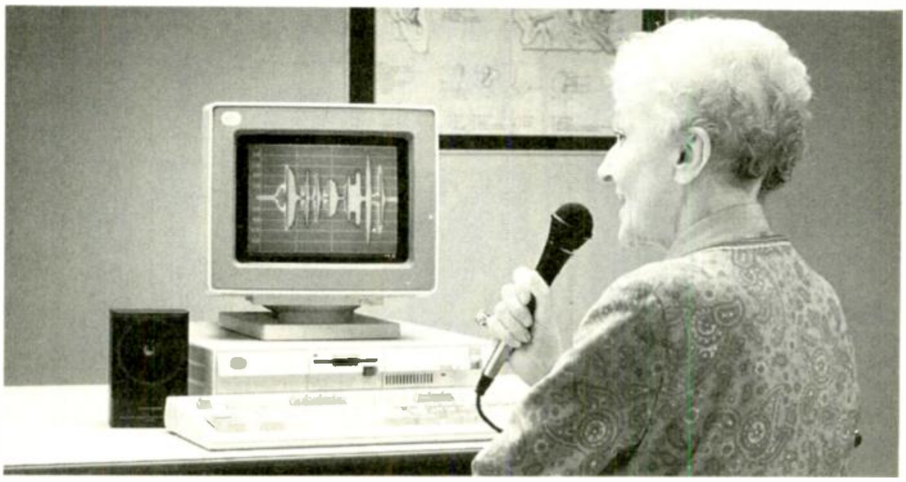
As a processing problem, speech recognition is complicated enough. But for a machine to hold a conversation, everything thus far must be dealt with in real time. Users will also expect the computer to realise when it has misunderstood and issue the digital equivalent of "Pardon me".

It also needs to be aware of the speech context. "Watch that tree' could be a life-saver to a driver in peril or an invitation to a very boring afternoon's viewing.

If the context is limited the user does not necessarily have to utter a complete phrase to make the computer understand. Not everyone who needs to talk to a system wants to start a long conversation.

Listening algorithm

Noise can mostly be dealt with through pre-processing and microphone technology before the speech analysis begins. The system then passes these signals through digital filters to split the speech up into short bursts called tokens or packages.



Self-training for the deaf: recognition equipment provides a visual indication of speech patterns. The picture shows the IBM Speech Viewer system in action.

The tokens are compared to a set of rules representing the behaviour of ideal speech. When the tokens correspond to conditions in part of the rule set, or algorithm, the computer knows that it has identified a phoneme. Comparing a string of phonemes to word patterns produces sense from the spoken statement.

Different makes use different algorithms. One of the most common, the Hidden Markov Modelling (HMM), involves comparison of energy in a particular token to a series of models, typically five. When the token matches one model, the machine tries to pass it to others in the line. The order of successful transactions between models identifies the speech element to the computer.

Another common algorithm is spectral peak picking (SPP). This represents the package as two values corresponding to the highest peaks in a particular frequency range. The system passes the discerned string of peaks through a filter bank and makes a note of which ones get through. A probability function then decides what the speech means.

Having identified the spoken words, the system must then decide the meaning and what, if anything, it ought to do about it.

Applications for speech recognition fall into two broad groups: systems which prompt, listen and log and those which prompt, listen and act.

Various tricks are available to the system designer which reduce the complexity of speech recognition equipment. A common device is to train the system to hear a particular voice. The operator speaks a number of predefined words into the microphone to allow the computer to build up a model of the operator speech patterns. The computer then adapts its voice models to match the user's. This greatly increases the chances of correctly identifying a word without producing a corresponding increase in the cost of the equipment. Its drawbacks are obvious.

A primitive world

Equipment based on the prompt, listen and log principle has found use in industrial inspection and data logging. Logica's *Logos* and the Marconi *Talkman* are designed to free the user's hands during a Q&A session. Both require user training.

Talkman, shown in the photograph, is a belt-worn portable data collection terminal. A headset carries the microphone. Data is passed from the terminal over an optical communications link to an IBM PC when the inspection is complete. The unit has a vocabulary of about 250 words. Although it can store models from more than one user, *Talkman* needs its operators to place every word in store before use.

Logos, designed for similar environments, also requires training by each new user. Various configurations, with different levels of complexity, provide between 20 and 240 active words from a total vocabulary of up to 1000. The lowest cost version performs its processing on an Intel 80286-based board, having first passed the speech through a filter circuit with a TMS32020 at its heart. *Logos* includes a speech buffer allowing between five and 20 seconds of message to be stored before processing.

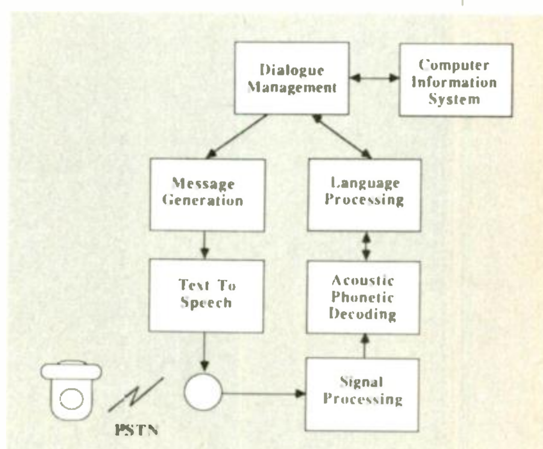
IBM has produced a voice typewriter, *Tangora*, which can recognise up to 20 000 words although the user has to pause between each one. Again, it requires training to recognise individual voice patterns. IBM's equipment produces a set of spectral patterns every 10ms which are compared to 20 spectral features generated during training. The system runs on an IBM PC with add-in boards filled with custom chips.

Away from the factory floor, Marconi's *Macrospeak* can transfer data at rates up to 125kbit/s between the host computer and the system. This should allow the equipment to be used in bank dealing rooms where the pace of work cannot wait for the computer to catch up. It can also be used for industrial inspection if necessary.

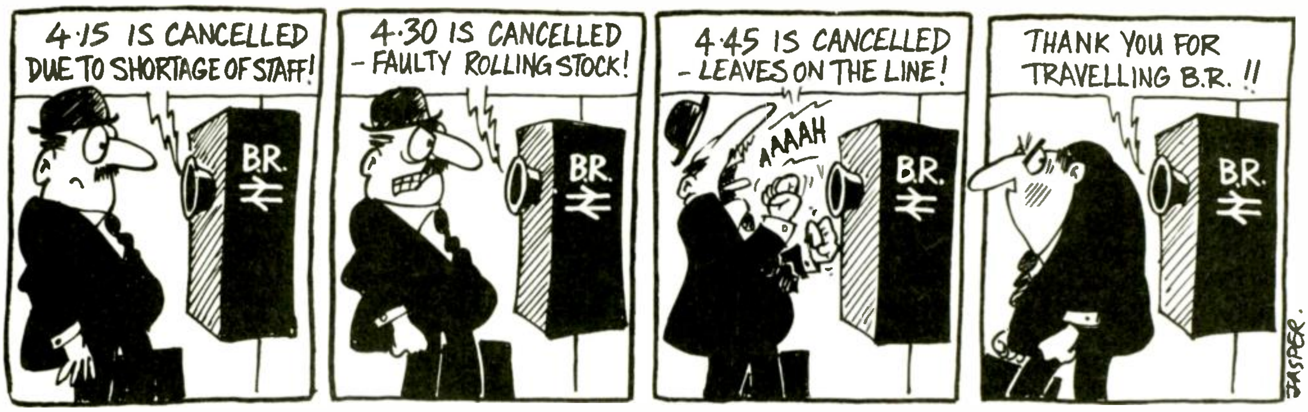
Macrospeak has a vocabulary of 640 words and can store up to 205 seconds of recorded speech. Dual RS232C ports connected the system to a host computer. Up to 800 macros, commands set in action by a single word, with 8000 characters can be stored.

The front line

Most applications for prompt, listen and act systems have been in military equipment. For instance, Marconi is developing a system intended for the European Fighter Aircraft (EFA). The company



Esprit's speech understanding and dialogue (SUNDIAL) programme is designed to progress the state-of-the-art across the field of recognition. Signal processing is based on transputer array passing data for decoding with hidden Markov modelling. Language processing includes a vocabulary of 10 000 words with decisions taking the context into account. A series of frames control dialogue management, identifying relevant information for comparison with data stored in the computer. The result should be a system which can interrogate its users to speed up telephone enquiry processing.



has already produced a speech-based control system for aircraft which has been tested at the Royal Aircraft Establishment and by the US Navy.

Marconi's *Airborne Speech Recogniser* ARS1000 provides 1000 word vocabularies for two users. The device has to be trained to recognise its operators but contains other features such as automatic gain control. This copes with the tendency of people to speak louder when background noise level increases. ARS1000 enables the user to interact verbally with the head up display, reducing the number of hand controls operated by the pilot.

Armada is another project for EFA; a system developed at the Royal Signals and Radar Establishment. Running on an array of six transputers, Armada uses HMM and advanced statistical techniques to develop context-sensitive models of the pilot's speech. It is still in the development stages, but early tests showed an 82% success rate using a 500 word vocabulary without grammar rules. Recognition was 99% successful when rules of grammar were used.

Away from the military field, IBM has developed an adaptor card for its PC range to help speech therapists and teachers dealing with deaf people. *SpeechViewer* converts elements of speech acoustics into graphics displays, which can be synchronized with audio playback. The system has been designed to motivate patients. It also analyses elements of speech without relying on language context. The software takes up the full dos 640Kbyte of memory.

A talking timetable for public interrogation has been developed by a group comprising Logica, British Telecom and Cambridge University. The group set itself the task of producing a telephone railway timetable which asks the user about the train they require. It has a series of frames to fill before coming up with the final answer, but these may be filled in any order. It doesn't matter whether the caller gives the departure time, destination or stops first, as long as all the information is provided at some point. The answer is probably "cancelled" in any case.

Called voice-operated database-inquiry system (VODIS), the equipment should be able to pick out relevant information which arrives as the answer to a different question. So if it asks the user for the final destination and the caller says "I need to arrive no later than 9.30", VODIS will store the destination time and come back to the station's name later. This should avoid the need to listen to long lists of trains currently given out from telephone services, which will increase the number of callers who can use the system in a given day.

Based on its VODIS work, Logica was asked to take part in an Esprit project on speech recognition. The speech understanding and dialogue (SUNDIAL) programme involves partners in France, Germany and Italy as well as the UK and will run for five years. It is intended to extend the scope of projects such as VODIS into telephone banking and hotel and travel booking. The diagram shows the project's base architecture.

Sundial's processing will be based on HHM methods, eventually using vocabularies of up to 10000 words. Obviously the system cannot be trained for a particular voice, which further complicates the analysis. The final aim is to demonstrate equipment speaking in all four languages.

Other work in the field includes the examination of better methods of dealing with the results of algorithm processing. Papers from Southampton University have suggested advantages in using a number of different matching models. If each analyses different characteristics of the speech and the results can be combined, there is a greater chance of correctly identifying the word.

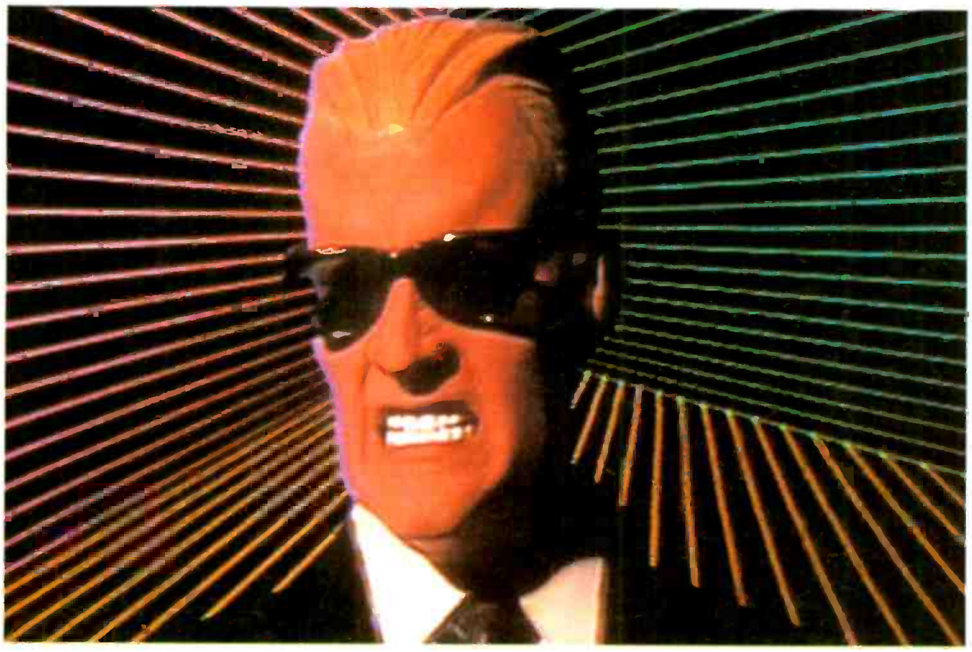
Although the current generation of systems cannot hold conversations with their users, it seems likely that machines will be soon talking freely. Beyond that, personality prototypes are the last obstacles to Sci-Fi speaking computers. ■

Rob Causey is a journalist with Electronics Weekly.

Personal stocktaking: this belt worn data logger from Marconi provides both prompt questions and analysis of the spoken answer.

10 TMS 3477 speech development boards to be won

COMPETITION



"WIN A TMS 3477 SPEECH DEVELOPMENT SYSTEM"

Using no more than 50 words, simply describe two applications for silicon speech synthesis. One should involve mass market, high volume usage; the other should indicate a specialised, low volume application.

The mass market, high volume application must take system cost into account. The specialised application should demonstrate the usefulness of speech synthesis; system cost is a secondary factor.

One application must involve the TMS 3477. The other may be implemented in any Texas Instruments digital speech technology. Entries will be judged on originality, taking into account technical and commercial viability.

Entries will be judged by representatives from Electronics World and Texas Instruments. The competition is open to everyone except employees of these organisations. Closing date for the competition is Monday, April 30, 1990.

Entries, which must include your name, address, company and job title should be addressed to:

Lindsey Gardner, Speech Competition, Electronics World, Room L301, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS.

Entries may also be faxed to us on 01-661 8939. No correspondence or communication can be entered into concerning the competition. Winners will be notified in writing.

continued over page ▶▶▶▶▶▶

SPEECH COMPETITION: ABOUT THE TMS 3477

Recording methods based on miniature tape recorders are being supplanted by all electronic systems where the speech is converted to digital signals, stored in solid-state memory, and replayed using a D-to-A converter.

All the main functions of a digital recording system have been incorporated on a single chip, the TMS 3477. Any sound or voice can be recorded – there is no need for advanced speech synthesis algorithms. This enables rapid system development with the minimum of resources. Although the TMS 3477 has full microprocessor compatibility, it can provide a simple recording system with just a couple of 1Mbit d-rams: an on-board refresh counter takes care of d-ram housekeeping. Two megabits of ram provides up to 30s of recording at the highest sampling rate.

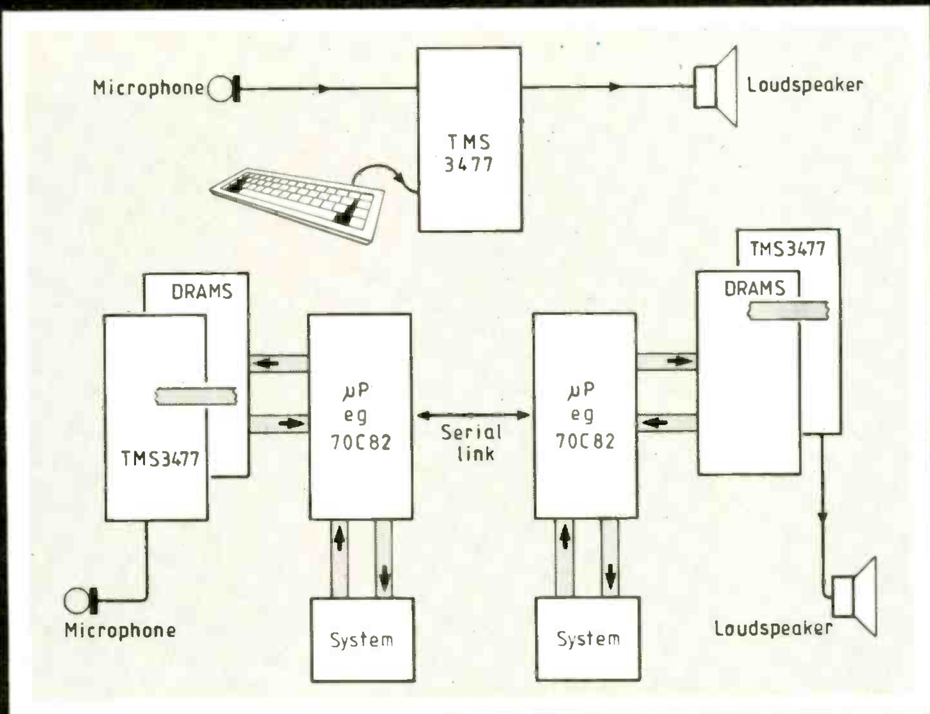
The device uses a continuously variable slope delta modulation (CVSD) codec with a choice of sampling rate between 16kHz and 64kHz. In the record mode, analogue signals are fed into the chip via the MIC pin. At each sampling period, the input is compared with the output from a 10-bit D-to-A working on data from the previous sample. Difference data is then sent to external d-rams.

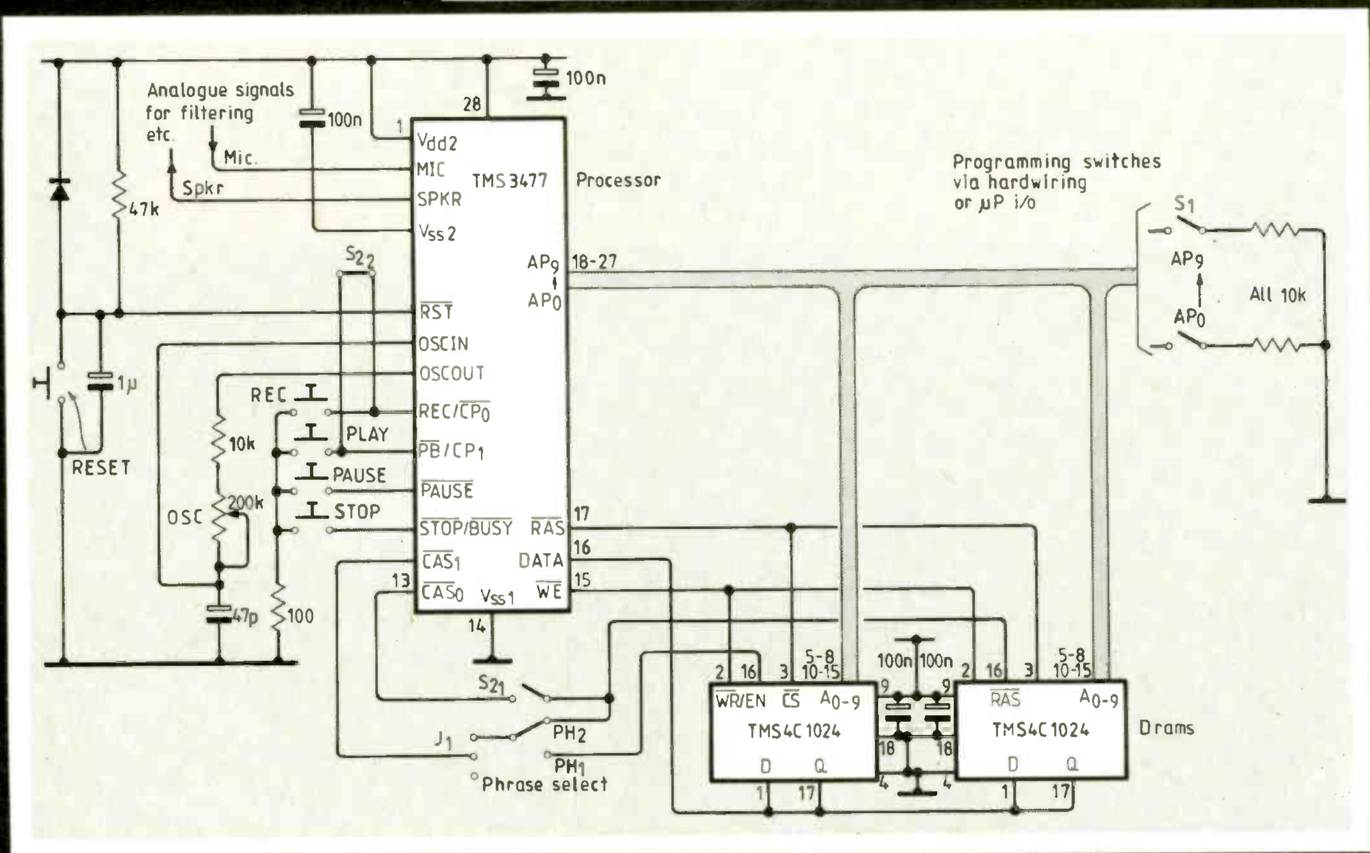
In playback, the encoded bit stream from the d-ram bank feeds the 10-bit D-to-A converter, the output of which is delivered to the SPKR pin on the TMS 3477.

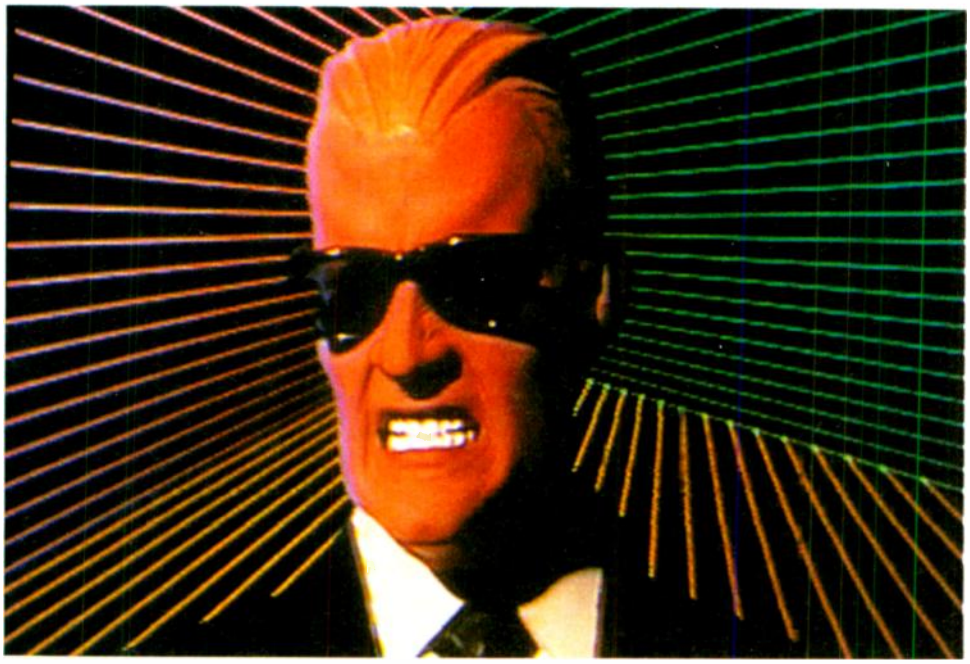
There are some useful variations on this basic operating procedure. First it is possible to store two different recordings in external memory with fixed or variable lengths to allow, for example, for an answering machine to be provided with a short recorded message and a longer recording of incoming calls.

A cyclical recording mode can be set to make sure that latest speech data is recorded in external d-ram. There is also a speech quality monitoring facility which plays back the encoded data in real time while recording.

A full description of the TMS 3477 appeared in *Electronics World,* November 1989.







Technology isn't a problem. Semiconductor companies have long since mastered the art of giving voice to silicon chips. Consumer resistance to talking appliances may be harder to deal with. By Steve Rogerson.

SILICON CONVERSATION PIECE

Speech synthesis has come a long way since 1978 when the *Speak 'n' Spell* toys were launched. But the general public still perceives it as little more than a gimmick, partly because of an unjustified perception of the poor quality, and secondly because of inappropriate applications, such as the Maestro talking car.

In fairness, the Maestro was a marketing mistake rather than a technological one. The public's attitude had been whetted by the popular TV series *Knight Rider* where a garrulous car was a positive oracle of useful information and had regular intelligent conversations with its driver. The advertisements for the Leyland Lemon played on this.

It should therefore have been of little surprise that the owners of talking Maestros quickly turned off the voice box, only to initiate it when they wanted to show how bad it was to their friends. There is a big difference between spoken intelligence and a car that tells you to fasten your seat belt or warns you that the car is ready for a service the day after it has had one. The latter happened because many of the garages that serviced the car did not know how to reset the computer.

Products such as talking coffee machines did little to improve the perception. *The Hitchhiker's Guide to the Galaxy* with its futuristic image of talking machines with in-built, inflexible personalities didn't help. Speech synthesis has a lot of ground to make up.

Two tasks had to be tackled to do this. The first was to improve the quality: leaps and bounds have been made in this direction, more of which later. The second is to find applications which offer real benefits. The bottom line is that most drivers setting off for work in the morning would prefer a red light on the dashboard to warn them of problems than a nagging voice, however good the quality. With the exception of toys, the same principle can be applied to every speech synthesis application so far developed. Even with telephone operators there is a preference for a warm human voice telling you the phone number rather than a dehumanised, synthesised alternative.

Sadly, if a recent brochure from Toshiba is anything to go by, the application problem has not really been tackled. Its list of possible uses for speech synthesis include mostly home and business machines for which led readouts and red warning lights are adequate and arguably better.

In fairness, it is unquestionably useful for the handicapped, either as a reading machine for people with poor or no sight, or as a voice box for those with speech problems. The Toshiba brochure does not mention this at all and a similar brochure from NEC lists it as the last of seven applications.

Meanwhile, as mentioned, the problems of quality seem all but solved.

Silicon larynx

The routes to speech synthesis can be grouped into three types – synthesis by rules, synthesis by analysis, and waveform synthesis. Synthesis by rules gives the poorest quality for the highest cost and is basically the technique used in the *Speak 'n' Spell* toys.

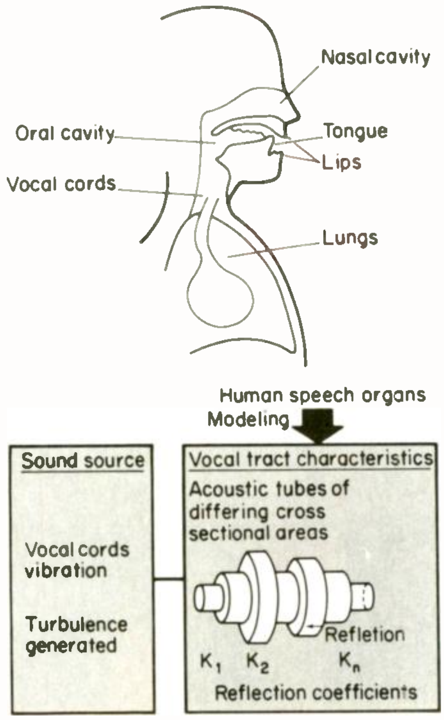
This procedure can generate an unlimited number of spoken words and strings of words using a relatively small memory. The technique stores basic phonetic elements such as phonemes, allophones and diphones. Intonation, stress and rhythm can also be added. Phonetic synthesisers add bits of phonemes together. It makes for poor quality and sounds robotic. *Speak 'n' Spell* used three chips to achieve this: the TMS1000 for control; the TMS5100 for synthesis; and the TMS6100 for rom.

TI quickly moved on to synthesis by analysis: linear predictive coding or LPC. The NTT and Toshiba partial correlation or Parcor method, though developed separately, uses the same basic principle.

These methods use the way people speak as a model. The voice is generated by air being forced out of the lungs and past the vocal cords. This produces a base band frequency spectrum ranging from 70 to 150Hz for men and roughly double for women. The frequency is altered by a cartilage which flexes and unflexes the vocal cords.

This frequency spectrum is further modified by harmonic excitation through variable filter characteristics in the vocal tract such as the tongue, lips and nasal cavity. Complex sounds are made by changing the characteristics of these filters from one split second to the next.

The lungs expelling air can generate two basic types of sound. One is a weighted white noise (or pink noise) spectrum generated when the vocal cords are relaxed. These are the so-called unvoiced sounds such as "sh".



Modelling the speech tract.

When the vocal cords are made to vibrate, the vocal tract acts as a more complex filter to produce voiced sounds such as "t". Amplitude peaks are also produced called formants, of which there can be five or six in any 20ms period. One fiftieth of a second is the fastest step change in spectral frequency content which the mouth can produce.

It is also possible to speak without using the vocal cords at all, as happens when you whisper.

Raj Gunawardana, European speech boss at TI in Bedford, explained: "A good percentage of speech is voiced. Your vocal cords are in play most of the time, but it does depend on the language. There are some sounds that are a combination of voiced and unvoiced called mixed excitation. But in modelling the human voice you can get away without mixed excitation because its use is so small."

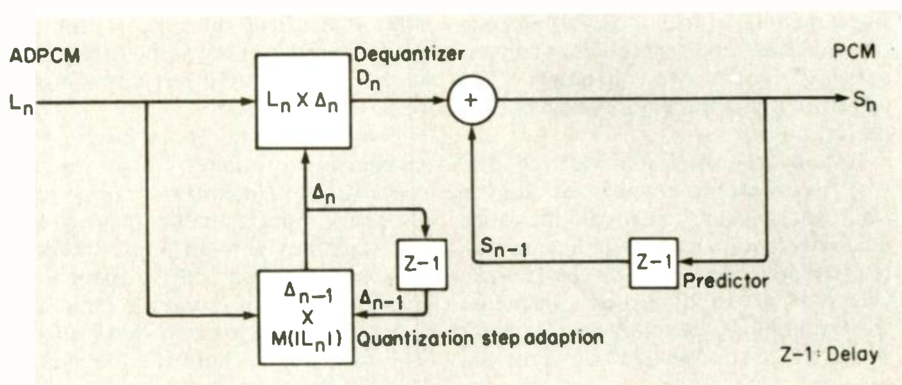
In the synthesis model, voiced sounds can be produced with a periodic waveform generator and unvoiced sounds with a random signal generator. These are connected by a switch which is controlled by the pitch. When the pitch is zero it switches to the random generator; when it is greater than zero, to the periodic generator. The vocal tract is modelled with a digital filter.

The procedure can be reversed – inversed synthesis – to analyse real speech for silicon encoding. This produces the raw data to drive the speech synthesiser.

The filtering stage (mouth) is modelled by low and high-pass filters to define the formants. For five formants, ten filters are needed. In practice, though, the fifth formant is rarely present so, in reality, only eight filters are needed. However, another two filters are needed for the macro of the whole 20ms period. In a real system five band-pass filters are needed rather than five low and five high pass filters.

The predictive part of LPC is a method where you predict the number of samples of a waveform based on a weighted linear combination of past samples. In creating this vocal tract model you need to be more accurate at lower frequencies than at high ones. In other words less bits are needed to describe the higher frequencies.

The ten filters mentioned earlier are given K numbers, K1, K2 and so on. For the lower frequencies K1 and K2, six bits are needed to control the centre frequency of each. K3 and K4 require five bits each, K5 and K6 take four bits and K6 to K10, three bits. This totals 42 bits for the filter section. The pitch uses between five and seven bits, though at five bits the sound is a little robotic. The gain stage uses four bits. This gives a total of slightly more than 50 bits. As this is based on a 20ms period, this data is applied at 50 times a second, giving a data rate of 2.5kbit/s.



Functional block diagram of ADPCM decoder with first order predictor.

This rate can be reduced because some sounds are held for longer than 20ms. By assigning a single bit to indicate whether a filter is to be repeated or not the data rate can be brought down to 800 bit/s.

Ironically, the bandwidth of communications from the ear to the brain is restricted. There is also some preprocessing that happens in the ear's cochlea. The ear acts as a spectrum analyser and the rate of information that is passed to the brain is believed to be only about 70 bit/s.

There are two commonly used methods of generating the baseband waveform which models the function of the vocal cords. One is to play the waveform out at a variable rate depending on the pitch. This is called pitch excited LPC and depersonalizes the voice somewhat. The preferred method is code excited LPC where a number of different waveforms are stored on rom, which acts as a look-up code book. This produces much more natural speech.

Method	Examples	Bit rate	Ease of data compilation	Quality
Synthesis by rules		20 to 300bit/s	Extremely difficult	Poor
Synthesis by analysis	LPC, Parcor	0.5 to 8kbit/s	Difficult	Good
Waveform synthesis	ADM, ADPCM	8 to 32kbit/s	Easy (real time processing possible)	Very good

Comparison of different speech synthesis methods.

Silicon recording

The third method of producing speech uses waveform synthesis. The two main types are adaptive differential pulse code modulation (ADPCM) used by NEC, and by TI for some applications, and adaptive delta modulation (ADM) favoured by Toshiba.

With ADPCM, a PCM recording is made of the waveform. This is a step digitization describing the waveform of a sound. The software predicts what the next step will be in a sequence of samples, the hardware reading in the real value and storing the difference between the real and predicted value. The difference value is further weighted to make the predicted wave more accurate. ADM works similarly but without the extra weighting.

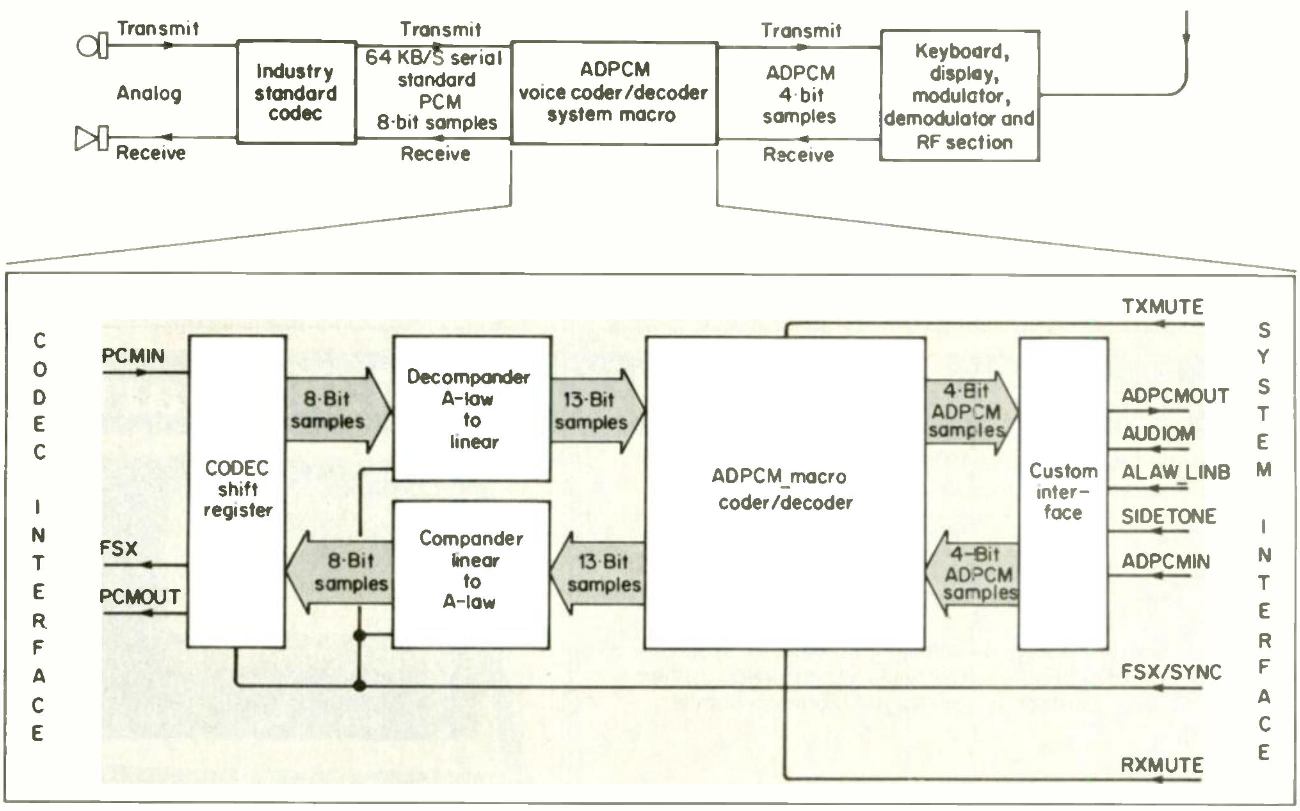
Repeated phoneme provides an enhancement of the process. This is similar to the repeat function in LPC and can be used to reduce the bit rate. The individual frames or phonemes of the coded waveform are compared with each other, and against a programmable similarity threshold. If several consecutive frames fall below this threshold only one frame is stored plus a repeat factor.

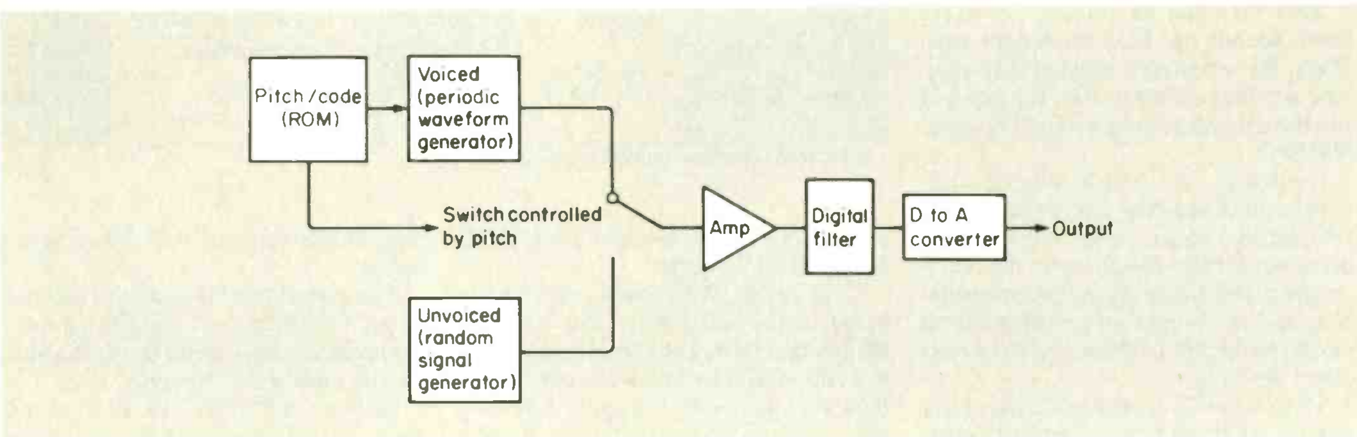
The repeat function can also be used to produce tones and melodies by storing musical content with count functions for the number of repeats.

Because ADPCM can work in real time, it finds applications outside the normal speech synthesis field. For example the CT2 cordless telephone system (Telepoint) uses ADPCM 32kB/s code. TI and NEC will supply this market. Toshiba is using the ADM system for record and playback use such as in telephone answering machines. There is no need for tape with such a system.

The disadvantage with waveform synthesis is that it is memory intensive. The amount of memory needed to store the waveform is so high that the practical duration is limited to about 16s. NEC's Stuart said: "You use more memory but memory techniques have improved. And as most applications are for a limited vocabulary, you don't therefore need lots of memory."

Block diagram of CT-2 handset showing the role of ADPCM.





LPC method speech synthesiser schematic.

As LPC methods have a lower bit rate, 800 bit/s compared with 8kbit/s and above for ADPCM, the amount of memory needed is smaller. ADPCM, though, produces a more natural sound and as said can be used in real time. The clarity of LPC is good but the sound is still slightly synthetic. An applications engineer at Toshiba said: "It depends on who the initial speaker is. Some speakers come out better than others."

Standard LPC is restricted to the human voice, although TI has managed to produce the sound of a barking dog. ADPCM is unlimited in the range of sounds and tones it can produce.

It comes down to a matter of horses for courses. Short duration and high quality lends itself to waveform synthesis. Real time has to be waveform synthesis. Longer duration with slightly inferior sound quality implies use of an LPC or Parcor type system. Both are miles better than *Speak 'n' Spell*.

Scientists have found ways to create high-quality talking machines. All they have to do now is convince people that they want them. ■

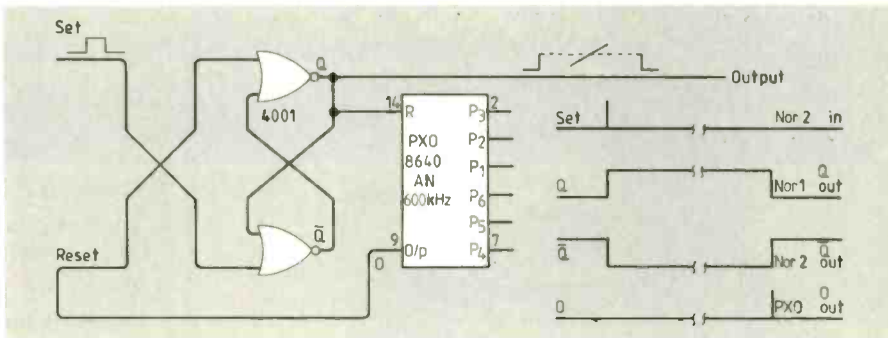
Accurate programmable one shot

Two Nor gates configured as an RS flip-flop and a programmable crystal oscillator comprise a programmable flip-flop which gives TTL-compatible pulses of up to 100s period. Its accuracy could not be achieved with a monostable multivibrator and it is simpler than other timing circuits.

On receiving a trigger pulse at the set input of Nor gate 2, the output of Nor gate 1 will go high and the oscillator will be turned on. The output of the oscillator immediately after the reset goes high is low for half the period of oscillation. This frequency is set by the programming pins P1 to P6 which can be driven from a TTL signal or hard wired using a mechanical switch.

With all programming pins taken high, the frequency will be 0.005Hz and after 100s the output will go high, resetting the flip-flop and taking the output of Nor gate 1 low. The reset of the oscillator will only be high for this 100s and it is from the reset that the circuit output is taken.

T. G. Barnett
Whitechapel
London



Frequency multiplier

The circuit shown gives an output frequency 600 times the input frequency for low-frequency inputs, the factor being set by three divide-by-n counters.

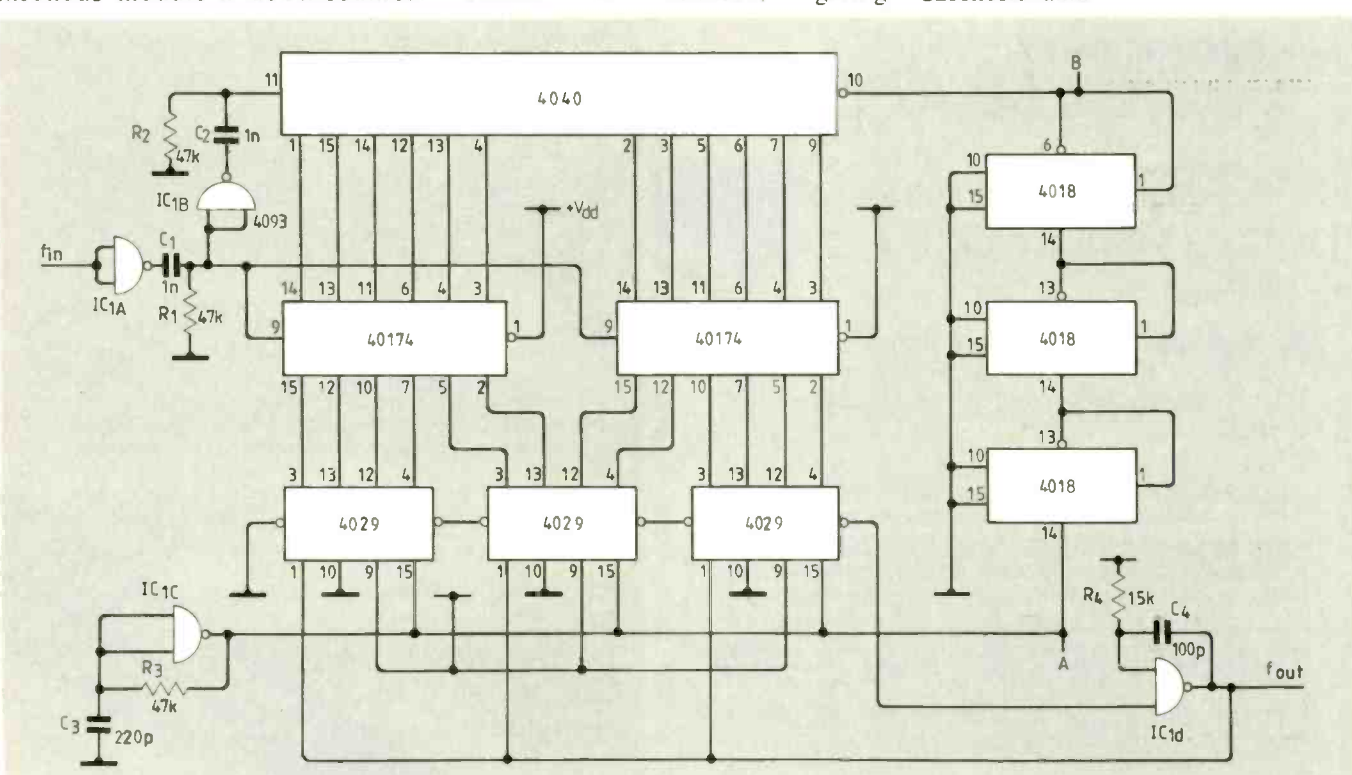
A free-running oscillator IC_{1C} feeds this counter chain with a signal of about 250kHz. Meanwhile, the 4040 binary counter is reset once per cycle of the input frequency, measuring input period in terms of output counts from B. The input period, a 12bit binary word, is latched by two 40174 buffers and fed to the three 4029s, which constitute a synchronous modulo-n down-counter. Each output from this counter generates one frequency output pulse, which feeds back to reset the 4029s for a countdown of the next period.

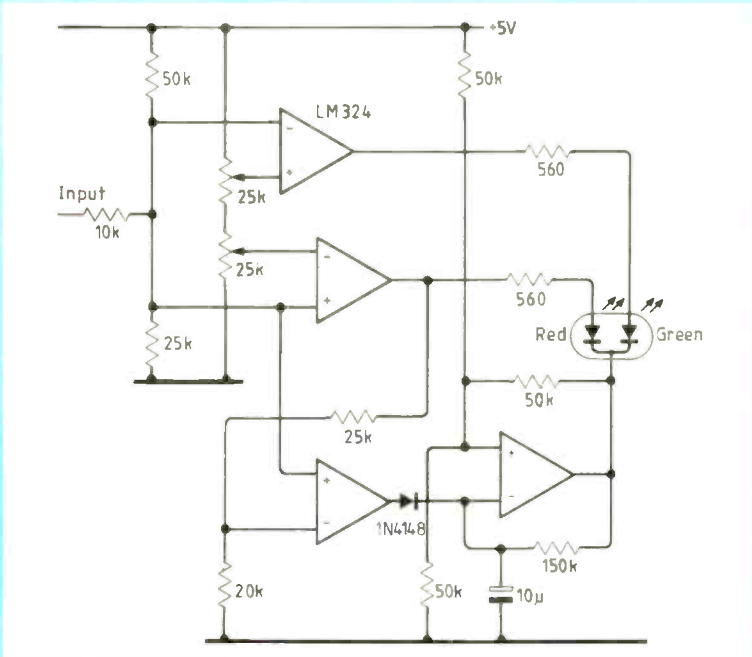
For example, at an input frequency of 1Hz, the 4018s divide 250kHz by 600 to produce 416.667Hz, and the 4040 counts to 416 before it resets. IC_{1A} and IC_{1B} each generate a positive pulse for each cycle of the input frequency to strobe the 40174 storage registers and then reset the 4040 counter. The 4029s countdown with a modulus of 416, clocked at 250kHz, giving 4μs × 414 = 1664μs, the period of 600Hz.

The input frequency can be multiplied by any available integer from 8 to 1000, the division factor between A and B. Connections to each 4018 can be altered to give a division between 2 and 10. Odd integers need an extra inverter and Nand gate.

The input frequency cannot be below about 0.06Hz for multiplication by 1000 because of the 4040's capacity of 4096.

Frantisek Michele
Czechoslovakia





Four-state logic tester

Using a single IC, the circuit shown can indicate four logic states. When the input is at high impedance or open-circuit, the led will emit a yellow flickering light. When the input voltage is high, the led will produce a red light and when low, the led will be green. An alternating voltage applied to the input will produce a yellow light and, if the frequency of the voltage is lowered, the led will switch red and green alternately.

The thresholds can be set for various logic types by adjusting the potentiometers.

Hong Yu Qing
TongLing
China

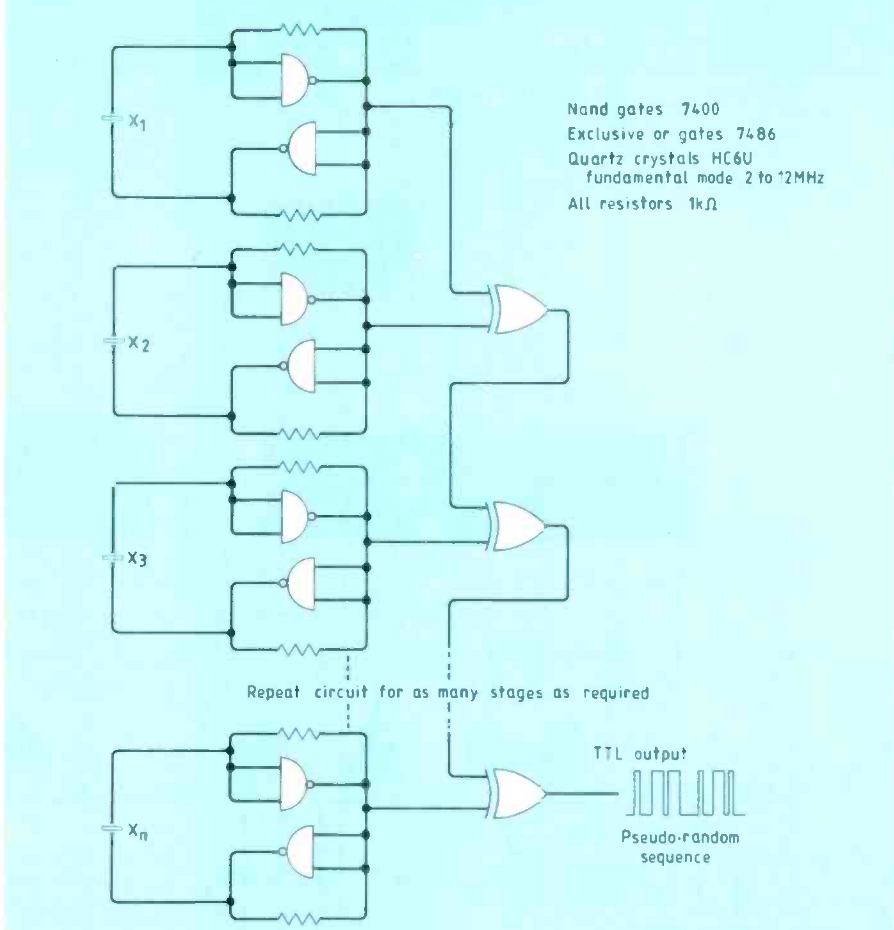
Pseudo-random bit-sequence generator

The standard way to produce a pseudo-random bit sequence is to use a shift register with feedback. By suitable choice of the feedback function, maximum sequence lengths and hence randomness can be obtained. But the output spectrum of such a circuit comprises a fundamental component at the sequence period and its harmonics.

A better way is to make a circuit comprising a number of quartz crystal oscillators whose outputs are mixed together using exclusive-Or gates to produce the pseudo-random output. The larger the number of oscillators, the whiter the resulting output spectrum; even a four-stage circuit will produce a spectrum surprisingly rich in intermodulation products.

The crystals should be chosen so that their frequencies are unrelated. It is not recommended that LC oscillators be used, because they may phase lock due to stray coupling.

Terry W. Spencer
Shanklin
Isle of Wight

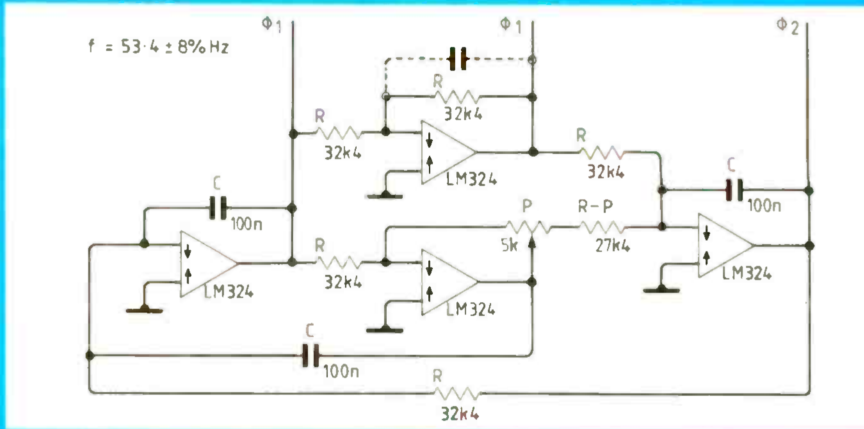


Oscillator for driving motors

This circuit is an oscillator that can be used for driving two-phase synchronous motors; frequency can be varied over a fairly wide range with a single potentiometer.

The $\phi1$ and $\overline{\phi1}$ outputs are 180° out of phase and the $\phi2$ output lags the $\phi1$ output by 90°. This means it can be used in two ways.

In some applications, one winding is connected from $\phi2$ to ground and the other from ground to either $\phi1$ or $\overline{\phi1}$ to reverse. It is also possible to connect one winding from $\phi1$ to $\phi2$ and the other from $\overline{\phi1}$ to $\phi2$. This allows operation from a single supply voltage if the non-inverting amplifier terminals are connected to E/2.



The minimum frequency is given by $f_{min}=1/(2\pi RC)$ and the maximum $f_{max}=f_{min}R/(R–P)$. Adjust the capacitor connected by a dotted line for reasonably fast starting without excessive clipping; it is typically about 0·2C.

Stepper motors can be used with two-phase sine-wave drive and run almost as smoothly as synchronous motors. Because of the availability of small angle motors, this fact can sometimes be used to avoid a gear train in high-torque, low-speed applications.

McKenny W. Egerton Jnr
Owings Mills
Maryland, USA

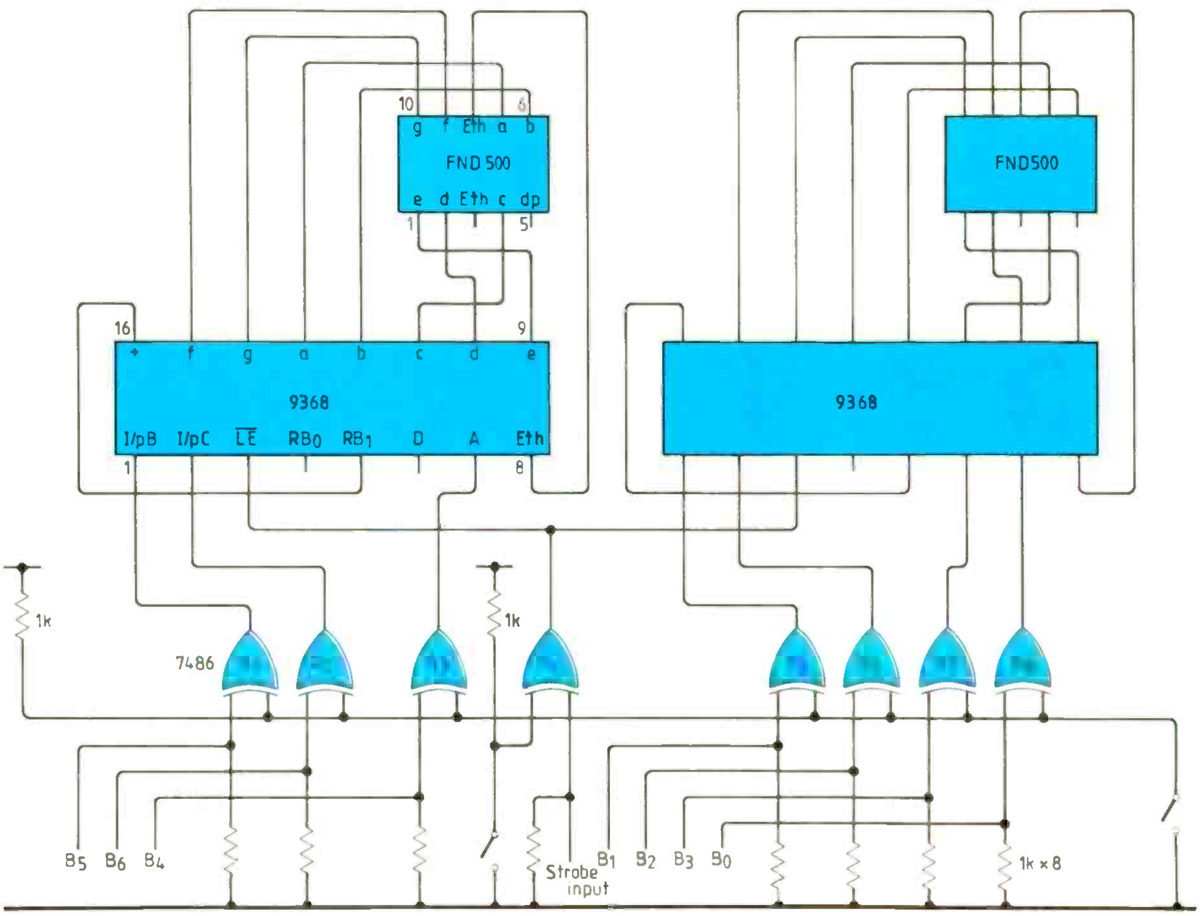
Keyboard tester

This circuit allows the output of an ASCII-encoded keyboard to be decoded into a hexadecimal representation of the key that has been pressed. For example, pressing "a" would produce 61 on the display.

Data bits 0 to 6 of the keyboard's output and the strobe are passed through exclusive-Or gates, configured as conditional inverters. With the switches open, the input is inverted and with the switches closed it passes unchanged.

The latch input is active low and, for a positive-logic keyboard, the latch switch would be open and the data switch closed. Therefore, the exclusive-Or gates with the switches allow any normal combination of latch and data logic levels to be accommodated.

John D. Ritchie
Doncaster
South Yorkshire



PPL lock indicator

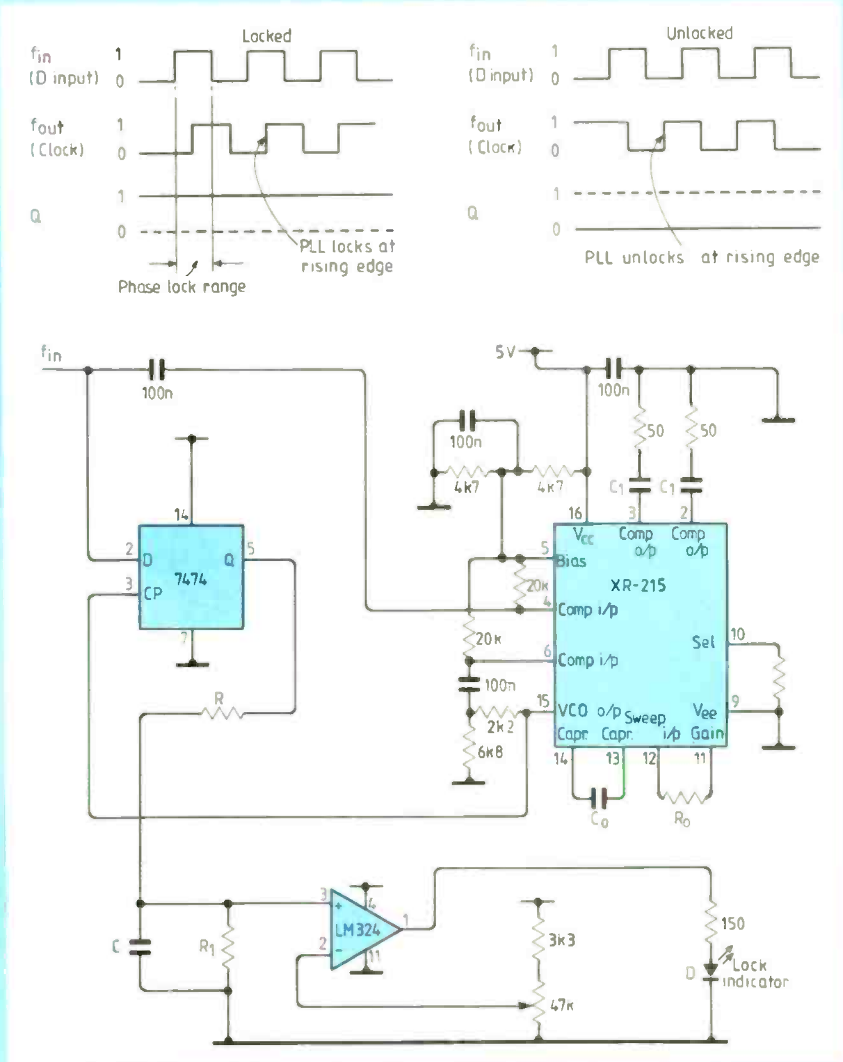
A D-type flip-flop and an op-amp can be used to detect the lock condition of a PLL, such as the XR-215 shown in the diagram. This PLL consists of a balanced phase comparator, a highly stable VCO and a high-speed op-amp. It can operate with supplies from 5 to 26V and frequencies from 0.5Hz to 35MHz. Analogue signals can be accommodated from 300μV to 3V and it can interface with DTL, ECL and TTL circuits. Tracking range is adjustable from ±1 to ±50% and the SNR is 65dB.

Consider quadrature detection. In this condition, lock can be obtained within 90° phase difference between the input and output. A D-type flip-flop acts as a phase comparator by clocking the state of the input frequency at the rising edge of the output waveform.

A steady state of 1 at the flip-flop indicates a lock condition, which will cause the integrator (R, C and R_1) to make the op-amp output rise towards 5V supply voltage, illuminating the led.

If there is more than a quadrature phase difference between the input and output frequencies, the output of the flip-flop will be a train of pulses of different widths, indicating out-of-lock condition. Here, the output of the op-amp switches low and the led is off.

V. Lakshminarayanan
Bangalore
India

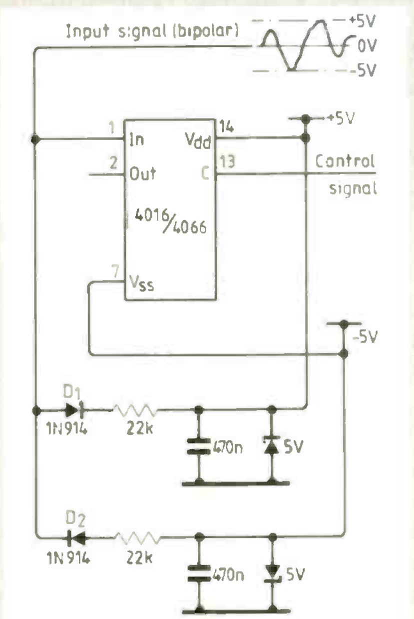


Analogue switch needs no supply

An analogue switch IC, such as 4016 or 4066, can draw its power requirements from the signal applied at its input without significantly loading the source of the input signal. The diagram shows the scheme for deriving +5V for V_{DD} and −5V for V_{SS} supplies needed for the analogue switch to handle bipolar input signals without signal clipping.

These quad packages of analogue switches need only 1.5μA under conditions of $V_{in} = V_{SS}$ or V_{DD}. The scheme works well for switching frequencies down to 100Hz. Since the on resistance of the switch is typically 200Ω, loading of the source does not occur.

V. Lakshminarayanan and
V. Gopalakrishnan,
Bangalore



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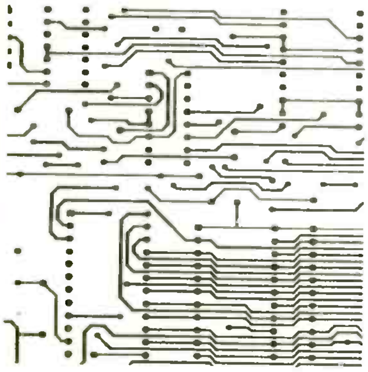

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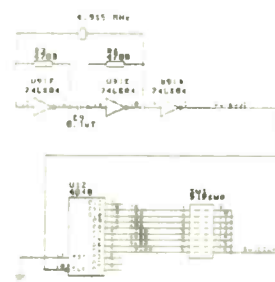

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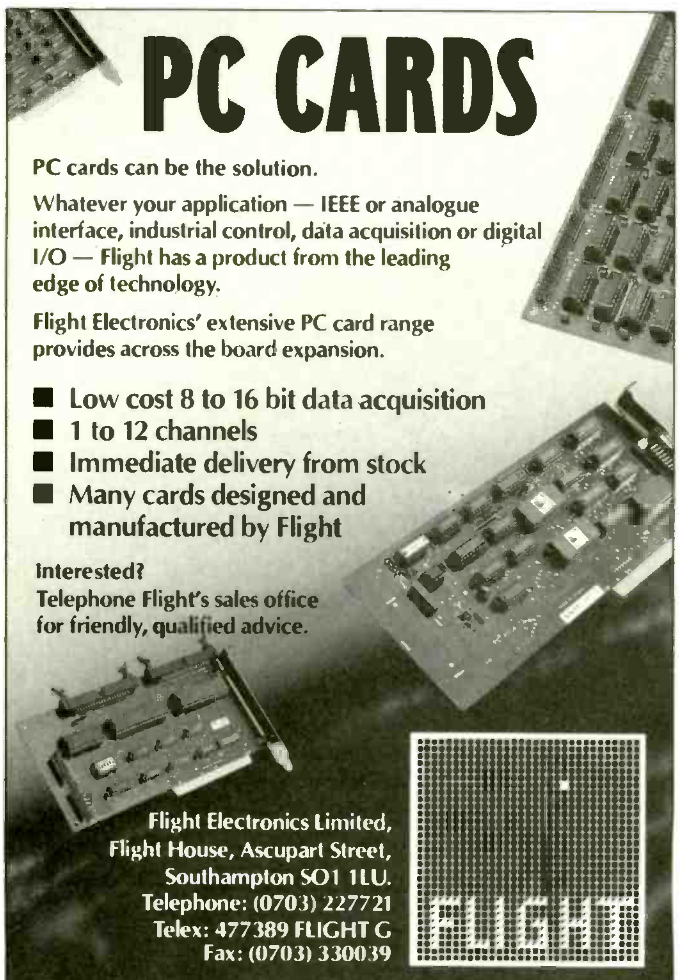

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THE PC INSTRUMENT BUS

The IEE488 bus crosses every application boundary. It means as much to small companies as large ones and is used by both the scientific community and industry. The advent of cheap personal computers makes it first choice for small to medium sized data acquisition and automatic test systems.

An idea developed back in 1965 is starting to bring the benefits of automatic test systems to small and medium sized companies. The idea was a forerunner of the IEEE488 bus. The catalyst which smashed open the market is the IBM PC and its plethora of clones.

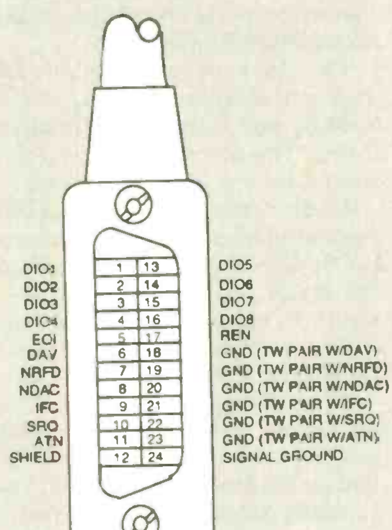
Hewlett-Packard initially developed what it called the HP interface bus (HP-IB) to connect a range of programmable instruments to its computers. Because of what was, at the time, a high data transfer rate (up to 1Mbyte/s) the bus gained popularity in other uses such as communication between computers and peripheral control. Such an increase in use led to its adoption as IEEE standard 488 in 1975 and the nickname "general purpose interface bus" (GPIB). There were some minor differences between IEEE488 and the HP-IB standard which have now been resolved.

As the bus gained popularity companies such as National Instruments pioneered its use on other computers. National is still the market leader today but its position looks far more assailable than it did in the early days. One of the first personal computers to be used in this field was the Commodore Pet but it was not until the advent of the IBM PC that life started to change, and for a number of reasons including cost, versatility, availability and an ever growing range of software.

Nick Challacombe, director of Keithley Instruments, highlights the difference in cost: "In 1978 computer based systems used minicomputers which left little change from £100000 whatever you did. It was cheaper to hire more engineers at annual salaries of £3500 each. A few years later as computer prices fell and salaries rose it reached parity. Today a PC is a fifth the cost of an engineer and lets one engineer do many different jobs".

In the early 1980s Hewlett-Packard still controlled the market, but since then, the market has grown and business has shifted from HP to the PC. HP acknowledged this change by bringing out its own PC look-alike called *Vectra*. HP computers still control a large chunk of the market, mainly because many engineers grew up using the HP user-friendly software and want to remain with it. In response to this there are software products available such as *HTBasic* which effectively converts an IBM PC/AT/386 into an *HP9000* series 200/300 workstation look-alike.

GPIB connector showing how each line is assigned.



When used with, say, an IOtech GP488 IEEE board, *HTBasic* makes the PC closely emulate the HP workstation. It operates under DOS and has nearly all the instructions presently supported by HP Basic. Full screen editing and debugging are included and the editor has been enhanced to include find, substitute, move and copy capabilities. Many existing programs written for HP computers can be executed with *HTBasic* without alteration.

Geoff Dyson, a sales and marketing manager at Keithley, also noted the PC's versatility: "The PC has made a tremendous difference because of the added software available from word processing to engineering packages. PCs have become more popular for multi-use. You can switch off your test system and start using the PC for word processing. This has made automation accessible to a lot more people and reduced the cost of automatic test equipment. These days, in most cases, manufacturers of test equipment incorporate IEEE488 as standard".

Farnell Instruments, though, only offers the bus as an option on its *AP* and *MP* series power supplies, but it is available as standard on some of its other products.

Standardization

The link between IEEE488 and the PC is important because more people are looking for an automated rather than manual solution to their problems. Before the advent of the IEEE488 bus the answer was a binary coded decimal system. This led to a rat's nest of wires. The IEEE488 bus allows the use of equipment from any vendor with a reasonable chance that the system will work. The instruments simply plug in the back of a PC and communicate with each other. Challacombe added a note of warning: "But there is a but: and that but is not the protocol, which is carefully controlled, but the command language which is not."

He pointed out that the "F" character is used to change the functions on Keithley instruments (F1, F2 and so on), but the IEEE standard does not specify F. So if you have a Keithley DMM and replace it with an HP DMM you may have to rewrite some of the software. Software cost is such that people occasionally buy old instruments rather than update the software for use with new ones.

Keithley has tried to overcome this problem by a firmware routine built into its instruments called *Translate*. With *Translate* you can emulate an old instrument on the PC. For example, one can quickly change the function key from an F to an A or vice versa, although this may soon be irrelevant.

In the various IEEE488 committees there is a move for a compatible command structure which, on the face of it, will make emulations redundant. A new command structure, 488.2, is already available on some instruments. The industry hopes that the new language will standardize functions from manufacturer to manufacturer.

Asystant-GPIB software to let a PC control instruments on the IEEE488 bus

One of the disadvantages of the bus is its speed. At just over 1Mbyte/s it sounds fast but the system involves a lot of handshaking which slows it down. There are two developments which aim to overcome this.

The first is a new bus system called VXI which many predict will eventually replace IEEE488. It is very strong in the military and aerospace sectors and Nick Challacombe described it as "the bus structure of the future".

Even so IEEE488 will be around for a long time. VXI is more expensive and it will be at least five years before its price becomes competitive. In the meantime the second solution of making the instruments more intelligent will probably have overcome the speed problems.

For example, two-channel DMM can make one million readings a second on each channel. Theoretically, at this speed, it could not be used on the bus. But the instrument has a microprocessor and a chunk of memory in which the data can be dumped until there is free time on the computer.

Coombs said: "VXI attempts to resolve the paradox about fast new computer systems and an old 8-bit bus. Why can't we take the computer architecture and use it in instruments. What the VXI consortium did was develop an architecture that takes the VME bus and adds to it. We are developing a card that plugs into a VXI chassis and lets a GPIB instrument run an VXI".

He said that VXI is growing faster than any other bus ever did and believes that in ten years time it will have overtaken the IEEE488 bus.

The first programmable DMMs appeared about ten years ago. Current, voltage and switching equipment followed. This was a major step because it moved the bus into test systems.

Under control from the IEEE bus voltage and current could be sourced to the device under test, switched around the device and results sent to the measurement unit. The bus had become the base of a simple instrument-based ATE system run from a cheap PC.

A recurring problem of the early equipment was that it came either big and expensive or cheap and simple. Philips challenged this with the *system 21* which comprised 15 stackable, intelligent modules that let the user start small and build up as needs dictated. All could be tied to a single IEEE488 address under computer control.

Siemens, too, has a range of instruments that can be operated from a PC across the bus. These include multimeters, scanners, counters, function and pulse generators, digital I/O, transient recorders and voltage and current calibrators.

More complexity

Typical of the more complex instruments now emerging is the Clarke-Hess *6000* digital phase meter available from Lyons Instruments. This unit has an optically isolated IEEE488 interface and can be used for the precise measurement of phase angle at frequencies from 5Hz to 500kHz. It costs around £3000.

Keithley's latest, the source measurement unit (SMU), will simultaneously source current and voltage and measure current and voltage. So, for example, you can source a voltage to a device under test and measure the current. It is effectively four instruments in one – current source, voltage source, current meter and voltage meter. Three or four SMUs may be stacked together for multiple source and measurement. This is particularly applicable to the semiconductor industry.

Keithley has also started to make a switching matrix which can program 576 individual relays in a full cross-point matrix. There are up to six cards in the mainframe, each card possessing 8 by 12 cross-points. This gives 8 by 72 ways on the cross point. Combining these with the SMUs creates a test system which can do very complex tasks. This is about as much as anybody will want to do on the bus.

Most of Keithley's instruments can be connected together and built up to an advanced test system. Its most recent success is an automated Hall profiling system which allows the carrier concentration and mobility profiles of semiconductor layers to be obtained at room and liquid-nitrogen temperatures. Once set up, the programming for a full series of cycles is as easy as using a modern washing machine. The cursor moving across the screen pointing to the operation in progress bears a resemblance to the wash, dry, spin routines at the launderette. The gurgling and burbling of the chemicals completes the illusion.

To change a PC into an IEEE488 instrument controller, an interface card has to be plugged into the PC. There are a large number of cards available from many manufacturers.

Keithley's Stephen Blight inspects the automated Hall profiling system.

IOtech has a range of products that relate to the IEEE bus. National Instruments is the market leader, however. National created the market and everybody else has followed with compatibles. National, for example, has the AT-GPIB for the PC and AT and the MC-GPIB for the PS/2. Both will run under OS/2.

The AT-GPIB works with computers equipped with 16-bit plug-in slots. It is a direct memory access (DMA) interface which can control IEEE488-compatible instruments via the PC or AT. An NEC microprocessor provides the basic talker, listener and controller functions. The MC-GPIB is for PS/2s equipped with Micro Channel plug-in slots. It uses the same NEC processor.

Nearly all IEEE488 boards for the PC use either this NEC μPD7210 chip or the alternative Texas Instruments TMS9914A. Newer designs often use the NEC unit because it can detect the receipt of a specific character automatically. This allows the system to set up a high-speed DMA transfer and get on with other tasks until it detects the terminating character. It will then interrupt to indicate the transfer's completion. To do this with the TI chip needs extra circuitry which is not always available.

IOtech by comparison offers the *Personal 488* series with versions for the PC, AT, 286, 386, MC-PS/2 and compatibles. These again use the NEC chip.

While Philips recognises the need to be in the market with its *PM2202*, identical to National's MC-GPIB, it also produces a card that will turn its *PM3655* logic analyser into an IEEE488 development system and instrument controller. This card fits into one of the PC-compatible expansion slots of the analyser's built-in IBM-compatible computer.

ICS Electronics also makes two interface cards which are available from Amplicon Liveline and again use the NEC chip. These are for the PC, XT, AT and PS/2 model 30.

An interesting variation found in National's AT-GPIB is the Mostek *Turbo488*. This asic c-mos IC increases both the performance of programmed I/O data transfer software and the data transfer rates obtainable with the high-speed DMA controller on the PC motherboard. It works by using fifo memory to buffer data, allowing instru-

Listening, talking or just sitting

The IEEE488 bus is the most widely used method of connecting a number of instruments to the I/O port of a computer. Ability to make use of the bus is a built-in feature on many instruments.

Communication between devices on the bus is done by passing one of two types of message through the system. Device-dependent messages have information such as programming instructions, measurement results, machine status, and data files. Interface messages are command type messages for, say, addressing and unaddressing devices.

Devices on the bus can be listeners, talkers and/or controllers. A DMM for example is a talker but it can also be a listener. A talker basically sends messages to one or more listeners with the controller managing the flow of information by sending commands to all the devices. It is possible to have a talk-only device connected to a listen-only device. Such a system does not need a controller.

Using a plug-in interface card and associated software, an IBM PC or compatible can be converted to a controller in charge of a wide range of test equipment.

The interface system itself consists of 16 signal lines and eight ground return or shield drain lines. The signal lines comprise eight data lines, three handshake lines and five interface management lines. The data lines carry data and command messages and use the 7-bit ASCII or ISO code set. The eighth bit can be used for parity.

Handshake lines asynchronously control the transfer of message bytes between devices. The three lines are NRFD (not ready for data), NDAC (not data accepted), and DAV (data valid). NDAC shows when a device has or has not accepted a message.

The five interface management lines manage the flow of information across the interface. They are: ATN (attention) issued by the controller to differentiate a byte between command, address and data; IFC (interface clear) issued by the controller to initialise instruments to their known state; REN (remote enable) issued by the controller when it wants remote control over all the instruments on the bus; SRQ (service request) issued by any device needing service from the controller; and EOI (end or identify) sent by the talker with the last byte of a data stream to show the end of the message or issued by the controller to tell devices to identify their response in a parallel poll.

Negative logic is used with standard TTL logic levels. When DAV is true for example it has a TTL low level less than or equal to 0.8V. When DAV is false it is a high level of more than 2V.

The PM3635 logic analyser can be used as an IEEE488 controller by adding an interface card to its internal PC.

ments to operate at top speed without having to wait for the PC to handshake every transferred byte.

Andrew Penney, an application engineer at National, said: "The *Turbo* chip lets us run at the full recommended speed of the bus. It lets us get the most out of the bus. Computers have 16 and 32-bit buses but the GPIB has an 8-bit bus. The *Turbo* lets us take a 16-bit word off the bus. It can be important when moving large amounts of data such as when transferring a waveform."

In theory, there is a number of restrictions when using the bus. The distance between any two devices can be no more than 4m with an average separation of only 2m across the entire bus. The total cable length cannot exceed 20m. And there is a limit of 15 devices that can be connected to the bus. This remains theory because there are products which break these limits.

Bus expanders are a typical example. These can double the number of instruments that may be connected to the bus to 28 devices, and double the 20m cable limit.

Extenders burst through the 20m limit allowing instrument remote control up to 2km away. Smaller units are available for 300m extensions. They work by switching the signal from IEEE488 to RS232 or RS422 and then switching it back at the other end. For example, National's *GPIB100A* turns the 16 IEEE488 signals into 24 parallel RS422 signals for transfer over 300m. Its larger *GPIB110* for 2km operation uses a serial communication link to the distant extender. Since serial communication is more prone to transmission errors, a 4-bit cyclical redundancy check is also included.

Converters permit non-IEEE488 devices to be used on the bus. Products include RS232, RS422, Centronics and SCSI interfaces. They enable a computer fitted with an IEEE488 port to control non-GPIB devices or, conversely, let GPIB devices be controlled by a computer with a different port.

Times of trouble

The greater use of the bus has created a need for troubleshooting. In response, Keithley has developed a bus analyser.

Keithley's Nick Challacombe commented: "Over the years we have come across all types of problem where the customer says the bus does not work. If you have a lot of instruments from a lot of companies and something goes wrong you don't always know who to shout at. What the analyser does is to isolate the faulty bit of kit."

Setting up application programs for the bus can be a tricky task for a software specialist, never mind an engineer. But there are a number of PC based software packages available that make programming and debugging easier by providing high-level programming commands, on-line help, instrument and function libraries, and powerful editing and debugging facilities.

Jean-Louis Steevensz of Philips said: "Writing and debugging IEEE488 application programs for GPIB instrumentation systems has traditionally been a tedious task for the specialist . . . PC-based programming tools have changed all this, and there is now a range of software packages which help the first time and the experienced user alike".

Challacombe said it was his intention "to deskill the software side because the industry is full of engineers who are not software engineers. The idea is to make their job easier. There are a lot of packages available that do this".

"You need software that lets you use the hardware without being a PhD in software engineering."

Philips' *Test Team* and National's *LabWindows* let application programs be compiled with an off-the-shelf compiler so the computer does not have to store the complete development program suite.

Keithley puts its faith in the *Asyst* software package. This is a programming language with a long learning curve. *Asystant-GPIB*, a menu-driven interface written in *Asyst*, gets around this; with little programming knowledge, an engineer can perform FFT analysis and various statistical functions.

It works in two modes – interactive and program. In interactive mode, commands can be sent to the instrument and information received back. In program mode it enables user programmed macros to reduce the number of key strokes.

Shane Naish of Keithley said: "An engineer will easily be able to use it in a couple of hours".

His colleague Stephen Blight added: "You can create new command words to improve user friendliness. This means you can also easily translate it to German, for example. Or you can configure the language to match exactly what you are doing".

Coombs is critical of menu-driven software, understandably since *LabWindows* uses icons: "There are always limitations with a menu-driven program because if it isn't in the menu, then you can't do it. *LabWindows* lets you control the GPIB instrument, acquire data, format data and then do analysis. It has more than 100 analysis routines on the library".

He added: "We want to do for the engineer what spreadsheet programs did for the accountant."

The next step with *LabWindows* will be to develop software which makes use of the higher power available to newer machines. ■

Cache memory for faster VMEbus systems

Cache memory can be a cost-effective alternative to large blocks of high-speed system memory. Frantisek Michele describes the use of cache with the VMEbus

Cache memory techniques are well known in the mini-computer and mainframe worlds, but not yet in the 32-bit microcomputer community. Yet the system performance of today's bus-based 32-bit computer boards can be improved by applying cache memory techniques, originally developed for minis and mainframes, which can increase a microprocessor unit's working speed and throughput, despite a performance degradation in other system elements.

The microprocessor unit in most systems operates at a higher speed than the system elements to which it is connected. By closely coupling a small block of high-speed memory to the processor, the memory is accessed without delays and system throughput is increased. If this high-speed memory cache is designed to be loaded continuously as the processor executes programs, the cache becomes a buffer between slower system resources and the higher-speed processor.

In early systems such PDP-11s and IBM 360s, speeds were orders of magnitude slower than present microprocessor-based systems, but the problems were similar. For example, CPU speed and throughput were limited by the need continually to access slower system elements such as core memory. The principles that made cache memory techniques attractive to DEC and IBM can be applied to bus-based architectures. While VMEbus-based systems are used as examples in this article, the concepts apply to most bus-based designs.

VMEbus hosts a diversity of applications, many of which push the bus data bandwidth to the limit. This DSP development system, a PC-AT on a VME card communicating with a Motorola DSP56001 in an adjacent slot, uses a high speed local sub-bus which allows the large quantities of data involved in a typical DSP system to be transferred without congesting the system bus. The sub-bus carries a data burst rate of 18Mbit/s. The addition of a cacheing system to the main bus may offer considerable advantage with this data-intensive type of application.

The PC board runs a 12MHz 286, incorporates 1Mbyte of ram, VGA graphics and controls both the 3½in floppy and a 40Mbyte SCSI hard drive. The system comes from Data Beta.

Principles of cache memory

Cache effectiveness is based on the idea of locality of memory, which has three characteristics. First, over short periods of time, most MPU memory accesses are made to adjacent small groups of memory locations (as in program loops). Therefore, a cache memory coupled to the MPU – storing carefully selected data – will generally have the data the MPU needs. Second, data stored in the cache and recently used by the MPU will probably be re-used quickly. And third, data adjacent to data that has been recently used by the MPU will probably be used next. In other words, since most of the MPU's accesses to memory are performed sequentially, a well designed cache memory scheme closely couples the processor to the data most likely needed. This design allows the processor to function at its maximum performance level (**Fig. 1**).

When the MPU is initialised, it must load program code from system memory – often a combination of dram and bulk media, such as floppy or hard disk. As the MPU takes individual blocks of information into its registers from system memory, it also tags the information in a unique manner and deposits it into the cache. Since the tagged information in the cache has a direct association with information in main memory, the tagged data can be checked and retrieved from cache at very high speed.

Before each fetch from main memory, cache logic checks to determine whether the specific information being requested by the processor resides in the cache. If so, the MPU can access it quickly. If it is not in the cache, an access to main memory is required.

When the MPU writes information into memory, it also writes the same information into cache. As the MPU executes a block of program code, the cache fills and becomes a window containing a mirror image of the same information contained in main memory for this program block. Given the principles of locality and the looping nature of many programs, the probability of finding information in the cache is very high.

When information required by the MPU is found in cache, the event is called a cache hit, which allows the MPU to run with little or no delay in executing the program step. If the information is not found in the cache, the event is called a miss and the MPU is forced to wait until the information can be retrieved from main memory. A well designed cache architecture will have hit rates of 80–95%.

There are many maximizing strategies for keeping relevant data in cache memory. When the MPU begins to execute a new program, the information probably will not be relevant any longer and a series of misses will occur while relevant information is retrieved from main memory.

Any method by which new information is deposited into the cache, displacing older information, involves several trade-offs. For example, various algorithms have been developed selectively to replace the oldest or least-used data in the cache as new data is brought from main memory.

Each of these algorithms involves a certain level of complexity in its hardware implementation. Random replacement of old cache data with new data is a very effective compromise between maximized performance and such hardware complexity.

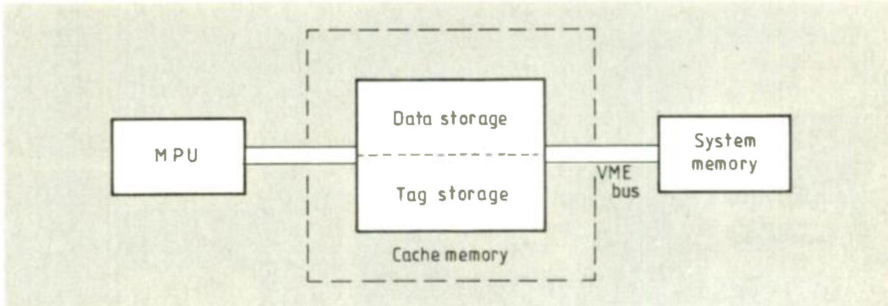


Fig. 1. Tagged information in cache memory is directly associated with information in system memory and can be accessed at high speed by a microprocessor.

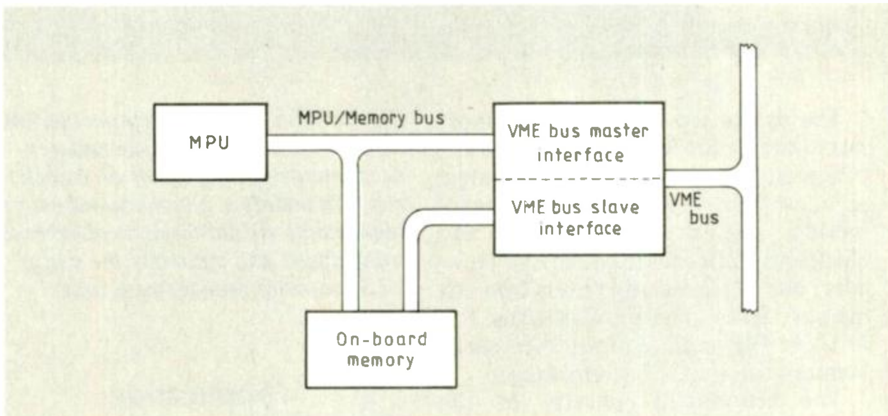


Fig. 2. For additional global system memory, the designer can provide dual-ported memory access to both CPU and VMEbus. MPU memory accesses are made over the VMEbus or a dedicated memory bus (VMX). Cache memory reduces the overhead for both buses.

Cache memory and VMEbus

One of the most important issues affecting performance is the speed with which the processor can access system memory. With the dramatic improvement in both the speed and density of d-rams, many VMEbus applications use processors with large blocks of memory resident on the VMEbus processor board.

Because the memory is physically and electrically close to the MPU, no waiting is required to access it. If a second port, or an extension of the CPU-memory bus to the VMEbus, is provided, the memory also serves as global system memory. The configuration shown in **Fig. 2** is desirable from a performance and cost standpoint if the memory on the VMEbus processor module is sufficient for the system application. When system applications require large blocks of memory – for example, in large databases and imaging applications – there is insufficient board space on a VMEbus processor module to keep the memory closely coupled to the MPU.

Under these circumstances, MPU accesses to memory must be made over the VMEbus or over a dedicated memory bus, such as VMX. Accessing memory over the VMEbus involves bus overhead delays as well as bus arbitration between other system elements that need to use this common resource.

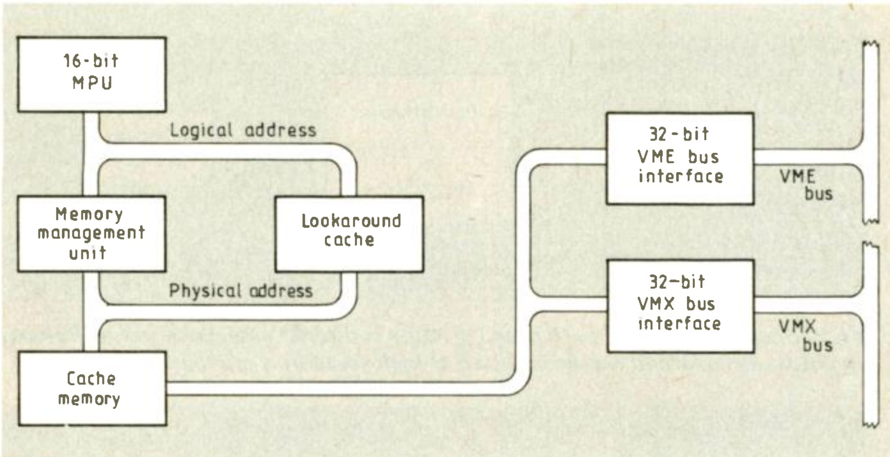


Fig. 3. With 16-bit microprocessor and 32-bit data transfers, cache memory accommodates long words on a cache miss. In addition, a lookaround cache implements virtual-to-physical address translations and optimizes the use of VLSI memory-management units.

The use of the local VMX memory bus to couple the MPU and large blocks of system memory, moves the system architecture a step closer to the ideal of having memory physically and electrically adjacent to the MPU. However, bus overhead still enters into any memory access over the VMX bus. It is in these bus architectures that cache memory can improve performance.

The cost/speed penalty of the memory devices is an added consideration – one that becomes increasingly important as the system memory is expanded. With relatively small blocks of memory (for example the 512Kbyte that might be found on a VMEbus processor), high speed d-ram can be used to provide no-wait-state performance.

However, large blocks of very high speed memory become uneconomical as system memory requirements grow. Cache memory becomes an attractive buffer between the high-speed MPU and large blocks of slower memory accessed over the VME or VMX buses.

Application

Cache memory architecture can be applied in many ways to improve system performance. For example, disk-drive controllers and memory boards have been designed with on-board cache memories. The operation and the value of cache memory on these system components is similar to designs in which cache is used to optimize MPU throughput.

Variations of the cache principle can be applied to reduce the translation overhead of VLSI-based memory-management units. For example, by providing a look-around cache, virtual-to-physical address translations can be implemented at high speed. In this application, the cache limits the lengthy translation time associated with VLSI memory management units, while providing the security and flexibility of the MM unit.

16-bit processor unit. Cache memory's effectiveness lies in its ability to provide a mirror image of selected system memory that can be accessed by the MPU at high speeds. In other words, to ensure system integrity, the system software must always be assured that cache memory data is a copy of the data in system memory. This is not a problem in single-master VMEbus systems, but in systems with multiple masters, such as a processor and a disk with independent DMA capability, there must be a way to keep track of memory changes not performed by the MPU.

A memory change can occur, for example when a specific program is loaded via the DMA disk controller. Any cache data that references system memory locations overwritten by the DMA device must be purged from the cache. This is accomplished by implementing the cache with memory elements like high-speed resettable static ram.

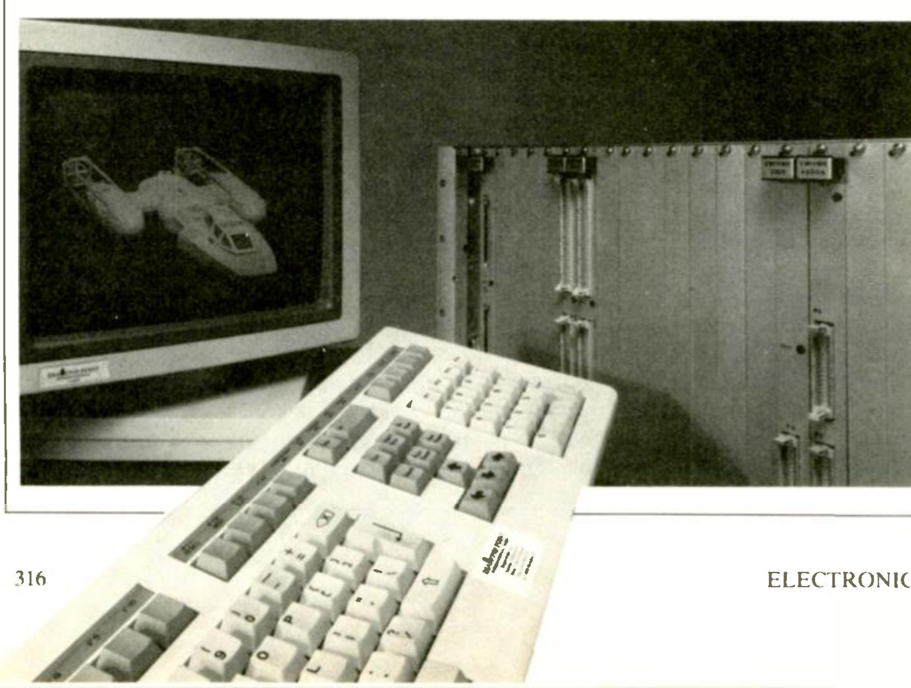
To help reduce the need to purge questionable data, the cache memory can be closely coupled to the memory management scheme. This design allows for specific addresses of system memory to be deemed non-cacheable, so that data from these areas must always be fetched from system memory. Thus, fresh data is always available to the MPU for memory location that may be changed by other system masters.

There are other cache options that assist in tuning the system to maximize cache hits. These include operating the cache for instructions only (instead of data) or dividing the cache space to segment data and instruction activity.

The cache can be configured to use the 32-bit VMEbus bandwidth while using 16-bit processors. Since programs generally access sequential memory locations, if word X is fetched from the system memory on an MPU access, it is highly probable that the sequential word Y will be needed in the next step of the program.

System performance can be optimised further by configuring the cache logic to fetch more than one word of data from memory when a cache miss occurs. This pipelining is referred to as the cache blocking factor. Using a 16-bit MPU, coupled with the ability of the

Ripe for cacheing in the chips? Intelligent I/O controller from Diamond Point. Configuration includes a 68K processor and 68880 series floating point unit and system controller in a 20-slot chassis.



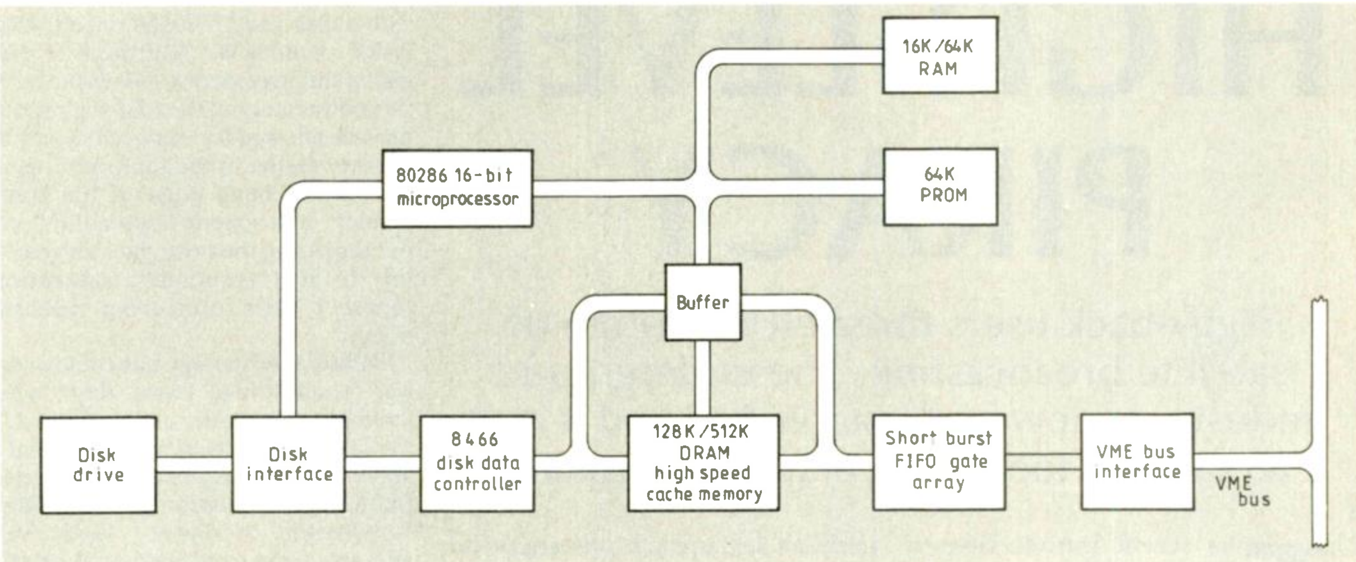


Fig. 4. Multiple data paths on this intelligent cacheing disk controller provide the disk interface, system interface and on-board 80286 microprocessor with access to the high-speed cache memory.

VMEbus to support 32-bit data transfers, cache memory can be configured to retrieve a VMEbus long word on a cache miss (**Fig. 3**).

Disk-drive controller. An intelligent cacheing disk-controller is a device based on a high-performance MPU and uses a sector buffering technique to improve a system's disk I/O performance by reducing the access times associated with rotational delays and seeks. The cache controller is able to reduce access times by responding to system data requests directly from its cache memory.

The MPU manages the contents of the cache and the physical disk operations. The cache's random-access capability allows data at various disk locations to be transferred into, out of, and retained in the controller under MPU control without restriction.

The sequence of events for the most common cache function, a read operation, begins when the controller receives the read request from the operating system. Instead of immediately initiating a disk seek, the controller searches its cache memory for the desired sector or sectors. If the search results in a cache hit, the data is transferred directly from the cache to system memory. If the desired sector is not located in the cache, the controller performs a normal disk read operation.

Once the data has been transferred into the cache memory from the disk, it will be transferred to system memory. In either case, when the system has received the data, the controller will issue the command complete interrupt to inform the system that the operation is complete.

Dual-porting of the cache memory allows the controller to perform parallel cache operations transparent to the system. Unlike traditional controllers, an intelligent cacheing controller will not terminate a disk read operation as soon as the requested data is on-board. Instead, it will transfer the requested sectors to the system while disk data is 'read-ahead' into the cache. It is possible that this background cache-fill operation will continue past the time when the command complete interrupt was issued for the original request.

A cache on a disk controller could support write cacheing, another parallel activity. The controller reads data to be written on the disk into its cache memory, posting completion status to the system before the disk write occurs. Conceptually, write cacheing is just the reverse of read cacheing, but has the distinction of having a cache hit rate of nearly 100%, because the disk latency time always occurs as a parallel or background activity.

The functionality of a cacheing disk controller requires a hardware design capable of supporting advanced operations such as parallel data transfers, real-time activity, queue management and data-structure management including searching and sorting.

The hardware architecture (**Fig. 4**) has many significant characteristics. A primary characteristic is the insertion of the cache memory on the local data bus. The memory is not monolithic – memory pages can be allocated to perform functions independent of the balance of the memory pool. The optimal size of a cache memory depends on system variables, such as operating system application, number of disk drives, and system load.

A cache size equal to the disk drive's capacity would result in a cache hit on every operation, but the cost and space required for such a cache eliminates this as a viable choice. The optimum cache size is the point at which additional cache yields little gain in hit rate. This value will vary from system to system and may range from several dozen Kbyte to more than 0.5Mbyte.

The intelligent cacheing architecture uses a FIFO device to interface to the system, the main function of which is to allow high-speed burst transfers across the system bus. It does not have to act as the speed matching device – the cache memory performs that function. As a result, the FIFO only needs to be equal to the largest required data burst. Since this controller is closely tied to the system bus, additional functions can be incorporated into a cacheing controller's FIFO. For example, the short burst FIFO gate array performs byte and word swapping for compatibility across MPU types.

The availability of 16- and 20-MHz 32-bit microprocessors with 4-Gbyte address ranges opens new VMEbus-based system architectures. While there will continue to be improvements in memory density and speeds, along with a lower cost bit of stored data, there will still be a need to match the high speed processor's capability with slower memory and subsystem components. Cache techniques can do the job. ■

HIGH-LEVEL PIRACY

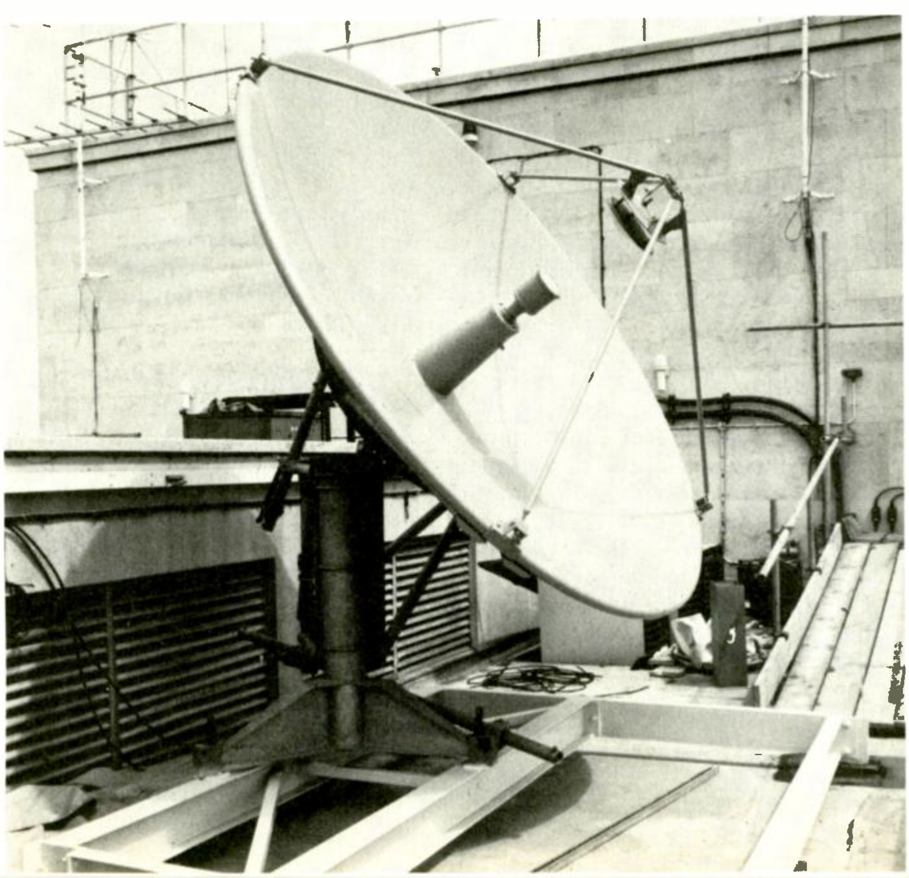
Piggy-back users threaten the future of satellite broadcasting. The underground industry is now well established and it may already be too late to eradicate it totally.

The recent introduction to Europe of high-power television direct-broadcast satellites has resulted in an alarming increase in a previously little-known phenomenon. This is observed as the accumulation of additional, or parasitic, energy at the band edges of orbital transponders.

These Additional Low-output Obscure Flux, or ALOOF, signals appear on the output of satellite transponders as the result of narrow-band uplinks from equipment being supplied under the counter to businesses and other parties requiring periods of communication over long distances who are not willing to run up huge bills on the international telephone networks. Once established, these links can carry voice, data or fax and usually go completely unnoticed because of their relatively low field strength compared to the main, or host, signal.

The principle of operation is well established. A TV transponder has a bandwidth in excess of 30MHz and, below saturation, provides an output power proportional to the input power received from the ground. A ground station commonly radiates an EIRP (equivalent isotropic radiated power) of around 100 MW, a combination of some hundreds of watts RF and a very high-gain dish antenna. Sufficient signal is received by a viewer's dish to give good quieting of the FM carrier in a bandwidth of 26MHz. However, to achieve a comparable carrier-to-noise ratio in a receiver of 26kHz bandwidth, an EIRP of only 100kW would be needed.

Most parasitic tranceivers use narrowband FM with receiver bandwidths of 12kHz. A typical transmitter provides 20W of RF which, together with a dish gain of 46dBi, results in an EIRP of 800kW. Although at first glance this may seem a somewhat excessive power margin, the following factors must be allowed for: service beyond the primary region of the footprint; operation at the band edge of the transponder; atmospheric attenuation; and, not forgetting the host, gain loss resulting from transponder saturation, together with interfering sideband noise.



Parasitic technology has come a long way since those early days when attempts were made, mainly in the US, to shake it off by the simple expedient of applying a low-frequency quasi-random frequency modulation to the satellite conversion oscillator. Such vain attempts were soon countered by two-way frequency-control systems which rendered aloof virtually immune to such measures. Later attempts deliberately to position interfering energy at the band edges were quickly abandoned because of their adverse effect on picture quality. The odd aloof may go unnoticed by the viewer, but deliberate great chunks of energy do not!

Modern parasitic units are very easily installed and require little adjustment once the dish has been aligned and the operating channels set. A thriving underground industry produces and instals the devices, and at around £20k sterling for a pair of transceivers, many businesses have seen this as an excellent investment for a link which can be available 24 hours a day. The dishes are indistinguishable from those already familiar on the skyline.

Since it is usual for official ground stations to monitor return signals themselves, a spectrum analyser forming part of their operational armoury, aloof has adopted some low-profiling measures. One thing an engineer expects to observe when examining an FM-TV signal is a reasonably symmetrical display. Aloof therefore places the full-duplex 'go' and 'return' carriers symmetrically about the host with a total separation of about 28 MHz. In order to diffuse these carriers when displayed, aloof gives them their own energy dispersal, similar to that of the host. In the event of loss of carrier or modulation of the host, aloof will hop to an adjacent transponder, making it impossible for parasitic transmissions to be located in a quiet band.

The TV industry is very worried indeed. Such is the unease among European satellite operators that international talks have already been held to discuss means by which this problem might be eliminated. ■

CIRCLE NO. 113 ON REPLY CARD

CIRCLE NO. 114 ON REPLY CARD

CIRCLE NO. 115 ON REPLY CARD

PROTEL SCHEMATIC AND AUTOTRAX REVIEW

B. Anderson reviews two packages from Protel Technology: a circuit-drawing aid and a PCB layout system.

Protel Schematic is a 2-D drafting package optimized for quick and efficient rendition of electronic circuit diagrams. It is written by Protel Technology, a Tasmanian company.

WHAT YOU GET

The complete product is supplied in one IBM-style book-box and comprises a well produced manual, five floppy disks and the dongle. It is worth saying that, in the business software arena, dongles and other copy protection devices are no longer the norm and we are now seeing the copy protection schemes being removed from other schematic-capture products.

INSTALLATION

This I like. Instead of a special executable or batch file which creates its own directories and fiddles around with the PC system files (CONFIG.SYS and AUTOEXEC.BAT), Protel provides simple instructions for generating the required code and data directories; all files are then simply copied into the code directory. Installing the display and hardcopy device is a simple matter of running the batch file which copies the appropriate device driver to the file accessed by the program.

The programs, drivers and library take about 1.5Mbyte of hard disk, but the data files appear to be reasonably compressed, so that your hard disk will not be overloaded with storage-intensive bit-image files.

Once in the program, there is a set-up facility which allows the user to configure for any desired colour scheme, data file path and other operational attributes.

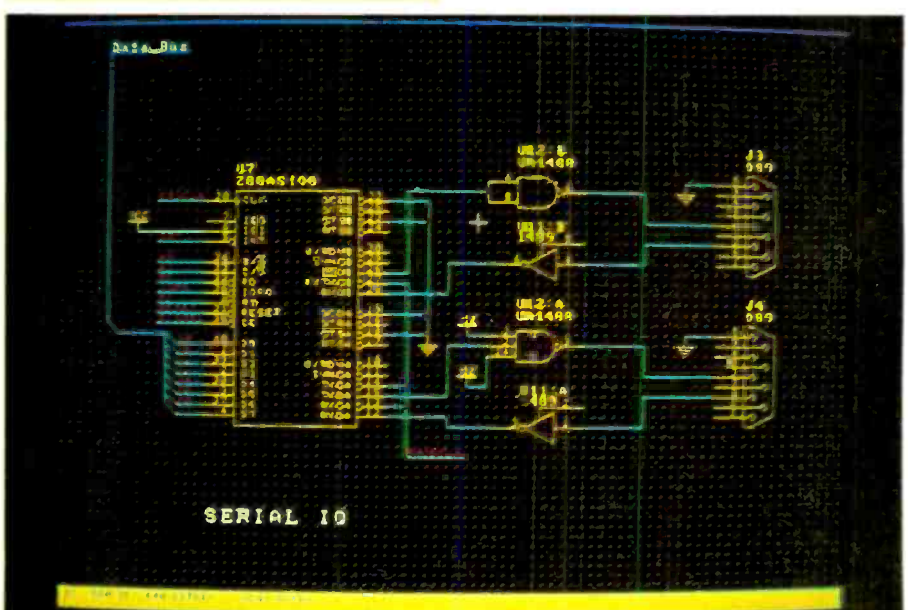
RUNNING THE SOFTWARE

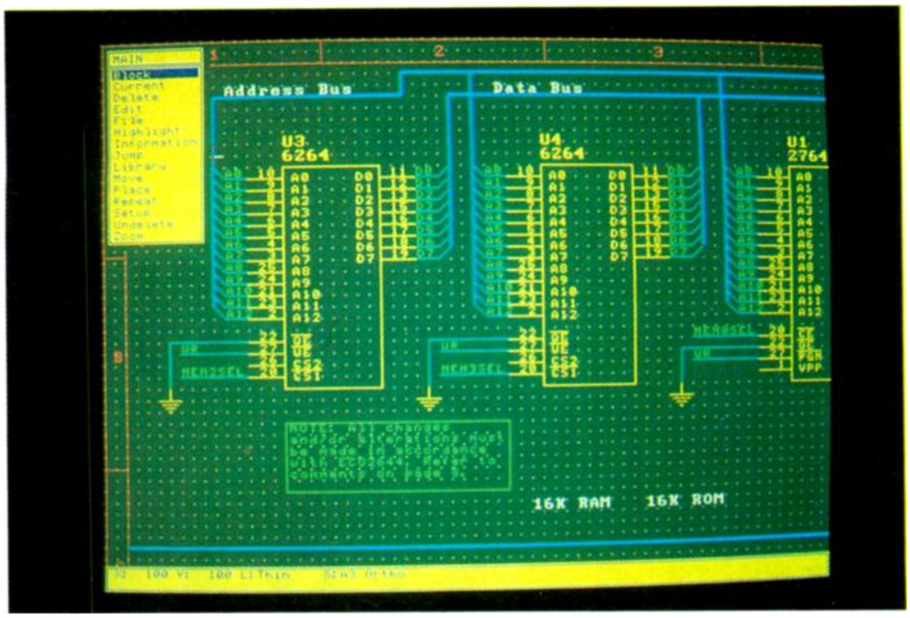
The first time I tried to run the software I got the message "Copy protection device not in place", which was found to be due to a bad connection at the dongle. When this was screwed home, the software started without problem.

As might be expected for a cad package, the whole interface is in a graphics environment and much of the user interface is remarkably intuitive, allowing one to use the product, in a simplistic way, immediately without reading the manual.

Action is initiated through the left mouse button or the return key, and exit from action initiated through the right mouse button or the escape key. Actions are thus effected by pressing the left mouse button, which pulls down the main menu at the left of the screen, selecting an item from that menu which may in turn effect another pull-down menu with further selections.

Circuit connections using the Schematic package are made using either signal lines or netlabels.





Line-type buses are drawn by attaching the same net name to lines at opposite ends of the bus.

Most of the options bring about a mode of operation. An example of this is the component placement mode which allows the user to select items from a library and bring them into the schematic. However, once in component placement mode, it is not possible to do anything else but place components, which can be irritating if you wish to alternate between component import and line drawing. A double escape keystroke returns to menu mode.

Once you are familiar with the various commands, then instead of the point-and-shoot mouse environment, the rather faster first-letter-select technique is probably better. For example, to PLACE A LINE, then type only "PL" and the line placement mode is selected. The alternative is to pull down the main menu, use the mouse to select the PLACE item, press the action button, and from the new menu then displayed to select the LINE option.

COMPONENT LIBRARIES

These are good; they are comprehensive and well designed, albeit with one or two quirks. Firstly, a maximum of only three libraries can be assigned as on line at any given time. Although this did not cause problems in the layout undertaken, it might be very irritating having to ditch and reload libraries. The second, more annoying, aspect is that the items in the library are not necessarily arranged in any logical (or alphabetical order). Hence if you cannot remember the exact component nomenclature even if the component you want is in the currently accessed library, then it is necessary to search through the library visually, looking through hundreds of items to locate the one required.

A separate library manager may be used to modify the supplied libraries or indeed build your own.

IN USE

Components may be selected from the library, at which point they appear on the screen highlighted. They may be moved around to any point on the screen and rotated through multiples of 90 degrees. The component may then be placed by pressing return.

Line-type bus is available to allow you to achieve tidy processor diagrams, as in the circuit diagram shown. The technique employed is to run normal lines into the bus line, and then attach a net name to that line. That particular line can then be picked up at a remote point by placing a line from the bus to a new node and attaching to it the same net name.

All the usual editing facilities are available, including block move, copy, save and delete, as well as an undelete facility to reinstate deleted items.

AUXILIARY FILES

Once the circuit has been drawn and saved, the post processor may be invoked. This is an excellent piece of software, which generates net list, connection list, bill of materials and a design rule report; the net list appears to be of the Schema type of format. The bill of materials is a completely resolved list by type, rather than a parts list. The advantage of this is quick generation of quantity order lists.

A weakness of having a separate post processor is that, if the design rule report shows that a node remains unconnected, then the program must be re-run to carry out the changes. It would have been helpful if this facility could have been run from within the editing environment and, for example, position the cursor at the offending node.

A very nice aspect of the report is the list of which nodes are left unconnected, together with warnings of unconnected inputs.

SPEED

Panning across the screen is by complete re-draw, rather than copy and part-update. This places great emphasis on the speed of the re-draw algorithms and makes movement across a complex drawing particularly tedious. However, this aspect of the package is well written and even on a PC AT, the re-draw speed is reasonably fast.

On the whole, the speed of any operation is acceptable, although loading of some libraries took a few seconds.

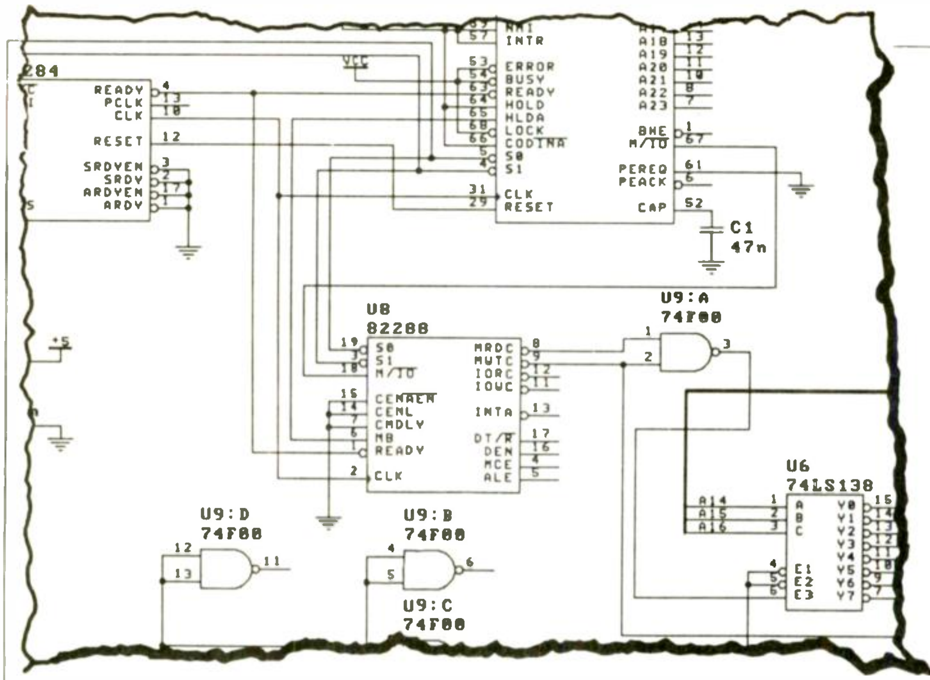
PLOTTING

Plotting of the circuit diagram is accomplished with a separate program, which allows good control over the final output, including rotation and scaling. Although the speed of output was rather slow, the quality of the final result was excellent.

The overall result was tidy and professional, though some component sizes were rather large, which in conjunction with the rather coarse placement grid resulted in poorly packed diagrams.

CONCLUSIONS

I particularly like the library facilities, which are comprehensive and simple to use. The intuitive user interface, similar to many business and scientific software packages, is a simple to use. My only grumbles are the dongle and the rather limited zoom range. Although the facilities are very limited compared with standard 2D drafting aids, those provided are attuned to the circuit schematic problem and, within that context, provide an excellent solution. The latest version (3.3) of this software is now supplied without the dongle, and within the context of the UK market should be considered to be reasonable value for money at £525.



Circuit diagram of a single-board computer produced by Protel Schematic.

AUTOTRAX

Protel Autotrax is the PCB layout companion to Protel Schematic. It is immediately clear that the two come from the same source, since the user interface of replacable pull-down menus and action keys is the same for both.

The package supplied is the same as that for Protel Schematic, with a well laid out manual, files totalling 1.2Mbyte and another dongle. At one stage, when running this software, my machine had three different dongles daisy-chained out of the parallel port of my machine, one for each of the Protel products and a third for another cad package!

Installation again followed the same course with the user in total control of the name of subdirectory and the copying process itself. Selection of particular screen and output device drivers was accomplished by running appropriately named batch files, e.g. EGA.BAT to install an EGA screen.

FACILITIES

The software can be used for PCBs up to 32 by 32in with position resolution of 1mil (0.001in). It supports up to six signal layers with two overlays and two resist masks. As evidence of its good support for surface-mount devices, it also supports two paste masks. The number of nets per file is limited to 1000 and, although this may seem generous, if you have a 32 by 32in square PCB, you could easily exceed this limit.

Moving around the PCB can be effected with either the mouse or cursor keys, zoom level being controlled with PAGE UP/PAGE DOWN keys. One nice feature is that the software is always looking for user input, so if you press PAGE UP twice, then having accepted the first zoom up request (and started the re-draw), Autotrax then spots the next ZOOM UP command, stops the previous re-draw and draws at the next zoom level. Hence the program is very responsive and little time is wasted.

A facility which provides for a very fast operation of common key-stroke sequences is the keyboard macro. These macros may be nested and are based on the simple one-letter command sequences (the first letter of the command) which allow keyboard access through the menus. Macros may be recorded to disk and automatically reloaded each time the software is run.

Ground planes are well handled by Autotrax. Simply define a polygon on the layer of interest and it is then filled in intelligently, missing other tracks, vias and pads.

When the program is run and the last edited PCB is selected then not only is the PCB loaded but so is much of the state of the the system at the time the editing was last halted, including highlighted nets and the set-up values.

LIBRARY

The component-outline library provides data on pad size and placement for a wide variety of components. There are options available to generate your own library components, or indeed modify those provided. This is all achieved within the program by generating what you wish on the PCB, highlighting this as a block and then saving the block to the library. The "component" may then be loaded to the PCB in the same way as any other.

PLACEMENT

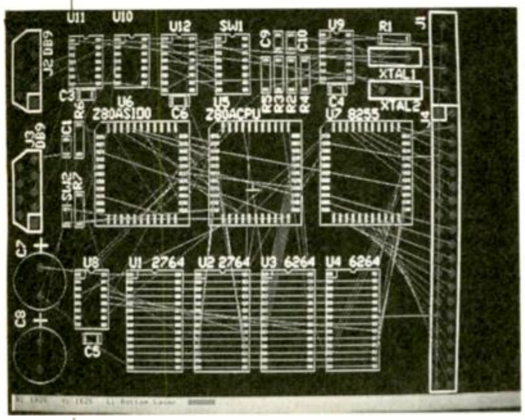
Before routeing is carried out, the components must be placed –manually, or automatically based on minimizing the rats-nest route lengths. However, this is only a first attempt and the manual suggests that you should pre-place as many of the critical components as possible. Further, when components are placed on the basis of the shortest rats-nest length, that does not mean that it will be the most efficient once the card is routed. Consequently, it is advisable to move components with the rats nest showing and make a (human) judgement on how, in general, the card should be routed.

ROUTEING

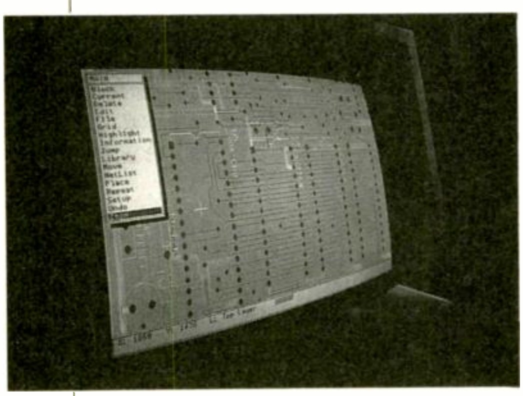
Import of the net list allows display of the rats nest of connectivity data, a simple point-to-point net. These nets can then be routed either manually or automatically.

The automatic router seemed to be very comprehensive with strategies based on simple point-to-point, one via L routes, two via Z and C routes and others. However, although the package was able to accomplish a reasonable job on the demonstration PCB files supplied, when presented with a simple 80286 SBC circuit, the routeing was unintelligent (missing obviously more direct routes) and generally slow. This problem was traced to the poor placement of devices, which limited the facility for routeing. After moving the components to achieve a more logical flow, the autorouter completed the job to 87% after about 49 minutes on an 8MHz PC AT. For those requiring more comprehensive autorouteing, there is an add-on product called Traxstar which provides rip up and retry routeing strategies for a further £850.

A point to note here is that the system gave an error when the net was being loaded from the schematic capture, and the report file generated indicated that the 80286 had not been loaded. The



A rat's-nest of unrouted connections, which "rubber-band" when components are moved.



Zoomed display of a PCB on the Auto trax screen

cause of this was traced to incorrect lead outline nomenclature in the net list, fed through from the schematic capture library. So beware– the libraries are not necessarily correct. Note that the software only registered the fact that one component had not been loaded, but did not explain why. This is an indication of a general failing, in that there were limited messages when things went wrong and no on-line help to supplement them.

To aid manual routeing, particular nets may be high-lighted, making it a simple matter manually to route each net.

The results of the routeing are available in two forms: firstly the displayed traces; and secondly a report file. Although it is annoying to have to leave the package to get the report, the data contained therein is a mix of the useful and the never to be used. The report lists the wide range of routeing and polishing strategies available and the relatively quick time for each pass. The really useful data is the list of unrouted connections, which may be used to route the board manually.

The smoothing passes were interesting, offering an opportunity to clean up the routeing automatically. Facilities include the diagonal remover, which removes short diagonals which the autorouter has duplicated, the loop remover, the double back remover, the dual stub remover and the two-via remover.

I encountered what could potentially be a serious problem, in that there appeared to be no direct way of highlighting unrouted nets for manual intervention. This had to be done one by one, tediously checking whether they had already been routed from the report file. This called for a chance to test the on-line support offered by JAV, which turned out to be helpful and well informed. The answer to targeting the unrouted nets was simply to command all nets to be high-lighted which, after routeing, highlights only the remaining unrouted nets.

Supplier
Protel Schematic and Autotrax are obtainable from:
JAV Electronics Ltd
Unit 12A Heaton Street
Denton
Manchester M34 3RG
Telephone 061 320 7210

Prices of the packages from JAV are:

Schematic	**£525+VAT**
Autotrax	**£999+VAT**

Operating environment
System requirements are a PC or PC AT-compatible computer running MS-DOS, with a hard disk or two floppy disk drives; CGA, EGA or VGA graphics or Hercules; a colour monitor; and a parallel printer port. It is recommended that a Microsoft-compatible mouse and a draft printer be used and access is needed to a pen-and-ink plotter, a Gerber-compatible photoplotter and an Excellon-format NC drill.

DESIGN RULE CHECK

After manual routeing, the program will check that the PCB is routed to the set of design rules, for example track spacing and via-to-track clearance.

NETCHECKING

An option is available to generate a netlist from the PCB. This file can, in principle, be checked against the netlist generated from the schematic. The program to do this is called "NETCHECK", but no data on its operation was available in the manual.

STRINGS

The program allows the placement of text strings on any layer, the strings being set to be of one of a variety of sizes and stroke widths. Since the PCB is viewed from the top with all layers transparent, the strings placed on the solder side and the lower screen should appear mirrored, but did not. It requires a separate operation (TEXT MOVE)) to correctly orientate the solder side strings.

SURFACE MOUNT

Surface mount components (SMD) can be handled perfectly well, even when pin lead devices and SMDs are mixed on both sides of the board. All necessary reverses of the SMD pattern are effected.

HARD COPY

Plot facilities are provided through a separate program, Traxplot; this supports a wide range of peripherals, including popular devices such as Gerber photoplot, HPGL, Epson and Laserjet.

AUXILIARY FILES

A post processor may be used to generate a bill of materials from the PCB data. Although reasonably effective, it of course cannot provide the same level of information as the bill of materials generated from the schematic capture.

Conversion utilities are provided for earlier versions of the software.

THE MANUAL

The manual is reasonably well produced and includes tutorial and reference sections, although the package is very straightforward to pick up and use and the manual is only of importance when you get stuck. The information is all there, though some items were difficult to find because of a rather limited index. ■

CONCLUSIONS

Protel Autotrax is simple to learn and use, especially if used with Protel Schematic to generate the circuit diagram. The facilities are there, but some need to be used with care, particularly auto placement and autorouteing. Once the ground rules have been set for these facilities, they perform well, although the autorouteing is rather slow. The program has no on-line help and has annoying quirks, such as the need to exit to DOS in order to view the routeing report log. Priced at just under £1000, the package is quite good value for money in the UK market.

Single-chip signal conditioner

The FX506 single-chip audio processor will replace all the components associated with Rx/Tx audio and squelch signal processing in a cellular radio. It counts total elimination of manual adjustments as its principal design feature.

FX506 is in three sections. The pre-process path will set incoming Rx or Tx audio to levels and frequencies for amalgamation with auxiliary systems such as scramblers and sub or in-band signalling schemes. The post-process path further adjusts the signal's level and frequency characteristic for input to a loudspeaker amplifier or transmitter modulation inputs. The squelch-signal processing path filters and monitors noise or RSSI signals against a predetermined threshold.

In Tx mode, the chip accounts for two microphone inputs and modulates the VCO and reference oscillator (two-point modulation).

In Rx mode the chip takes recovered audio and the RSSI signal from the IF circuit. Internally, the audio signal is separately applied to speech and carrier squelch circuitry. Audio is passed to the loudspeaker power amplifier and a logic signal, indicating noise squelch or RSSI validity, to the microprocessor. Signalling and voice scrambling (analogue or digital), may be added externally. The remaining inputs are a serial data bus interface to the radio's host microprocessor and usual power supply and clock interfaces.

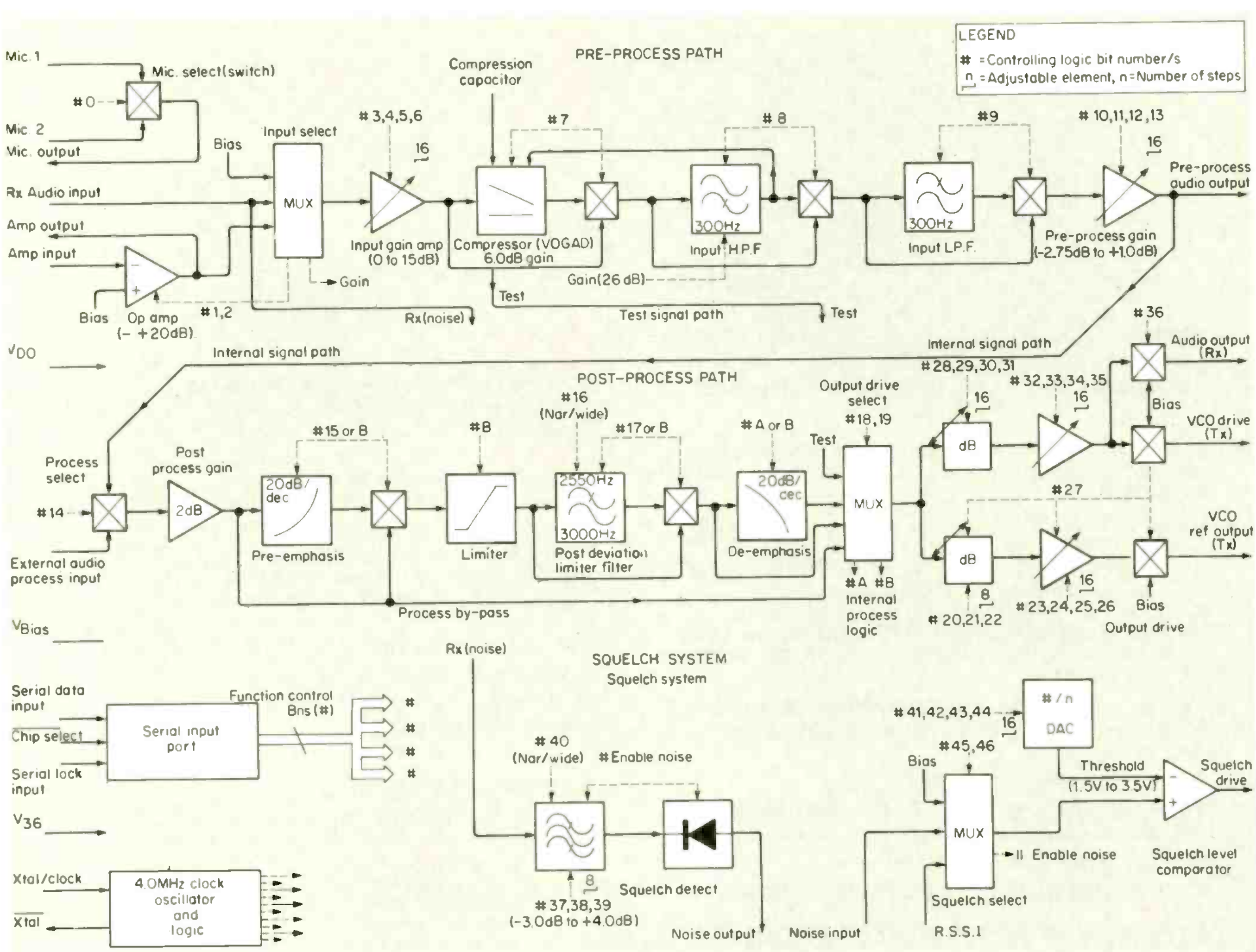
Programmable trimming

The absence of gain setting, volume or squelch adjusting components relies on digitally programmable on-chip trimmers. These are typically adjusted by the host microprocessor through the serial bus. Squelch and volume controls operate in the same way.

In Tx mode, Mic 1 (or Mic 2) is selected, and audio brought out at the microphone output pin. The microphone signal may be pre-processed prior to amplification. But, as the microphone signal is low level, low-noise external filters should be used.

The Tx voice signal is amplified by the on-chip amplifier, giving up to 20dB of gain. Microphone audio is selected via the input select switch which applies the signal to a 16-step digitally controlled trimmer, giving a further 15dB of gain in 1dB steps.

After amplification, the Tx voice signal is applied to the voice-operated gain adjusting device (vogad) which acts as a low-distortion limiter. Attack and decay times are adjusted by choosing a suitable value for the external compression capacitor. The vogad is a true AGC device rather than the 2:1 dynamic compander often found in cellular systems.



Bandpass (300–3000Hz) filters to CEPT follow the vogad stage with pre-process gain set by a digitally controlled trimmer, giving 4dB range in 0.25dB steps.

The signal may take one of two paths: an internal route to the rest of the Tx processing cells via the process select switch; and an output to external audio processor options. The signal, having been externally processed or internally routed, is applied to the process select switch and amplified by the post-process gain cell.

A hard deviation limiter is followed by an anti-splatter filter/limiter with a cut-off frequency adjustable for 12.5kHz or 25/30kHz channel spacing.

Next in the Tx line-up is the output drive selector, which selects one of four possible inputs. The test input derives from the Tx audio path prior to the vogad circuitry, which lets the test engineer apply tones directly to the modulator input, making test and set-up of deviation easier.

The final Tx process path stage consists of two drive outputs which couple the modulating signal to the VCO and reference oscillator of a synthesized radio (two-point modulation). Fine and coarse adjustment, with balancing of the two drive levels, is achieved using all four digitally controlled trimmers. The overall range of adjustments per drive output is 28dB in 0.25dB steps.

Received audio from the demodulator would be applied directly to the input select mux and the noise squelch bandpass filter. The received audio, having been selected through the input select mux, is applied to the input gain amp. The digitally adjustable trimmer, with other circuit elements, is re-used in Rx and Tx to reduce the size and complexity of the chip.

Received audio is externally or internally routed to the process select switch and gain adjusted. Rx signals then pass through the limiter, which doubles as an ignition noise suppressor. The low-pass filter smoothes any harmonics which result from the ignition noise-suppression process and also reduces high-frequency radio noise.

After pre-emphasis, the audio signal is passed, via the output drive select mux, to both sets of digitally controlled trimmers. The top set of trimmers acts as the volume control in Rx mode and would be adjusted by the user via the host microprocessor. The squelch circuit can be operated by channel noise or an RSSI level, from the local IF chip. Noise from the Rx audio input is applied to an on-chip programmable filter, the output of which is rectified to produce a signal on the noise output pin. Having filtered and rectified noise, the signal is externally integrated and applied to a comparator via the squelch select mux. Chip functions, excluding the squelch system, may be powered down during standby to reduce current consumption.

Automated testing

Automatic test equipment and the radio's host microprocessor can communicate on a data bus, iteratively measuring and adjusting levels without manual intervention. Once the radio is fully aligned, the information on the settings of the digitally controlled trimmers would be blown into the radio's prom.

Synthesized radios suffer from a non-linear conversion gain characteristic, depending on which channel is selected. By characterizing this effect, software would be written adaptively to adjust the deviation level depending on the channel number selected.

Consumer Microcircuits Ltd
1 Wheaton Road
Witham
Essex CM8 3TD
Phone: 0376-513833

Wideband GaAs amplifier

Receivers for radar beacons, missile guidance, fuse activation and contermeasures are among the wide range of applications for National Semiconductor's LH4200 general-purpose GaAs fet amplifier. It operates from 500kHz to 1GHz.

It has a GaAs input stage to give the high-frequency performance and bipolar second and third stages for low output impedance. Feedback can be included for gain stabilization and input impedance improvement. A control input can vary the open loop gain of the amplifier for automatic gain control and mixer applications.

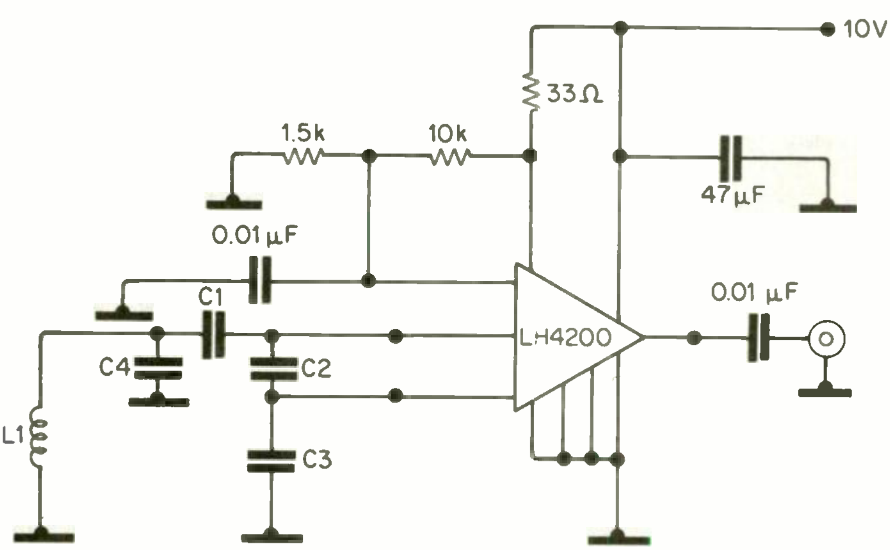
The amplifier is internally by-passed to improve high-frequency performance but it should be by-passed externally with a 10μF aluminium electrolytic capacitor to prevent low-frequency stability or oscillation problems.

There are three inputs, two high

Description	f(MHz)	Typical (dB)[1]
Power gain[2] with V_{in1}=0V and V_{in2}=+1.5V	10 100 500 1000	50 37 18 3
Power output at 1dB compression	10 100 500 1000	15 14 6 1
AGC range with V_{G2}=−2V	100	60
Noise R_S=50	10,500	3
Noise R_S=800	10,500	2

1. For power output, this column reads in dBm.
2. Power gain measurements are taken with the LH4200 open loop.

Fig. 1. The basic test circuit and results (see table, left)



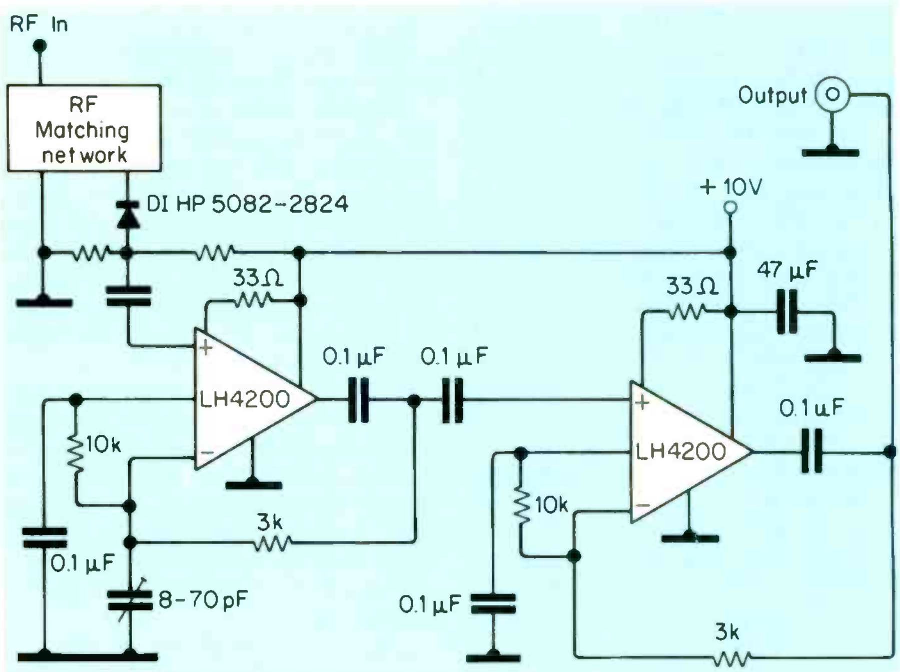


Fig. 2. This type of amplifier configuration can provide 60dB gain at up to 100MHz bandwidth.

impedance gates for signal input and a low-impedance source for series mode feedback. Normally the first input is used as the signal input, while the second controls the gain of the amplifier for AGC applications.

Gain control ranges of more than 60dB are possible to 100MHz. The second input is biased at +1.5V for maximum gain and −2V for minimum gain. The second input and the feedback input (pin 3) are normally by-passed with 0.01μF capacitors for maximum gain.

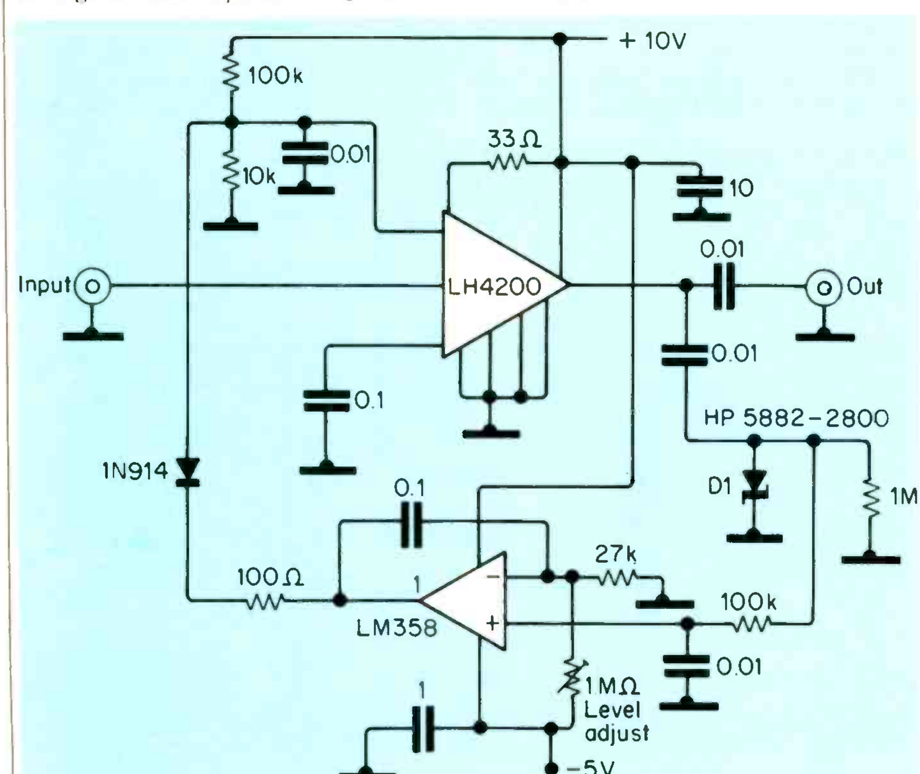
The second input can be used for isolated small-signal operation. The open loop gain at this point is about 60dB less than for the first input.

When used as a feedback amplifier, the third input is connected to the output with a suitable resistor to set the overall power gain. In this way, voltage series feedback establishes the power gain and increases input impedance.

The unit's performance degrades from the ideal above 250MHz. Input impedance decreases and is capacitive while the output impedance increases and is inductive. For maximum performance from 250 to 900MHz, some performance improvement can be obtained through suitable matching networks.

The LH4200 can be used as a Colpitts oscillator above 500MHz. It is stable, has load isolation, and will provide +15dBm to a 500Ω load. This is shown in **Fig. 1** with capacitors C_2 and C_3 providing feedback from source to gate of the input GaAs fet. The resonator network L_1 to C_4 is coupled to the active device through C_1. Typically at 75 to 150MHz, approximate values for beginning design are 5pF for C_1, 30pF for C_2, 60pF for C_3 and 150nH for L_1. For 150 to 300MHz these go up to 3, 6 and 10pF and 100nH respectively and, for 300 to 500MHz, 1.5, 3 and 6pF and 50nH.

Fig. 3. The fet input structure allows circuit configurations with AGC provided by the envelope detector, D_1, and amplified by the LM358



Video diode receivers are another possible application (see **Fig. 2**). These are much less sensitive than their superheterodyne counterparts, but they are simpler. Typical applications include radar beacon receivers, missile guidance systems as well as signal monitoring and power levelling detectors. This circuit has two LH4200s cascaded to give a gain of 60dB with a bandwidth greater than 100MHz.

Series-mode feedback provides high input impedance over the operating frequency range and low noise figures from high source impedances. Measured noise figure is 7dB from a 50Ω source and less than 4dB from a 1kΩ source.

Figure 3 shows an AGC application. This circuit provides a constant RF output signal level over a broad range of input signal levels. Diode D_1 provides a DC signal proportional to the RF output level. This signal is compared to a reference voltage at the input to the LM358, which in turn controls the voltage at the amplifier's second input, controlling its gain. ■

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In a spin

As a longtime, 40 years, reader of your magazine, I am pleasantly surprised to find that you are giving space to gyroscopic phenomena: "Harrison Gyroscopes", December 1989 *EW+WW*.

I have beens studying this for 20 years. The quaint armchair observations of Leonhard Euler which have been codified as Euler's Equations of Gyroscopic Motion are of historical interest but for a mankind which sets its eyes on the stars, totally obsolete.

There are many mistakes in Euler's observations but so not to be prolix I suggest there is an assumption in his work which is unjustified and incorrect. Encoded in Einstein's general theory of relativity is the assumption that inertial mass is an invariant except at light speed velocities. This is wrong.

Harrison should experiment to determine whether the inertial mass of a gyroscope remains constant under precession. The standard observation is rotation does not affect the properties of objects. This is incorrect. If an apparatus is constructed which consists of two identical gyroscopes rotating in opposite directions, co-planar and with axles parallel, experiments can be performed on rotating objects without the interference of gyroscopic forces. Thus he can determine that the inertial mass of the precessing gyroscope *increases*.

The substantial increase in the inertial mass of a precessing gyroscope, 18–21% in measurements made at precessional angular velocities consistent with the precessional angular velocity of the same gyroscopes under the influence of gravity, renders invalid the Newtonian interpretation of the balance of forces necessary to maintain the gyroscope precessing on the end of a string.

This confusion is because experiments are constructed in which the forces of gyroscopic precession are not cancelled and interfere with and confuse the interpretations of the experiments.

Before Harrison *assumes* the inertial mass of a mechanical object remains constant while undergoing rotation, he should make a measurement and confirm or disprove his findings.

The fact that the inertial mass of a rotating gyroscope is variable and anisotropic invalidates general relativity as well as opening the door to exploring outer space using antigravity machines and space drives based on the principle of variable inertia.

What is tragic about Harrison and his dynamicist friends is they forget physics is an experimental science where progress is made in the laboratory not in the armchair. The basic assumption is that rotation *does not* affect the properties of mechanical objects. Unless this assumption is tested there is no reason to accept the "standard interpretation" of gyroscopic phenomena.

I suggest some additional experiments which may be performed in a short demonstration at The City University, London:

- Measure the period of a swinging pendulum with a rotating bob;
- Measure the momentum transfer in the elastic collision of a rotating object with a nonrotating object;
- Measure the momentum transfer in the elastic collision of a precessing gyroscope with a non-rotating control; and
- Drop the rotating gyroscope completely enclosed in a case and see if it falls at the same acceleration it would if the internal gyro were not rotating.

All of these experiements show deviations from the classical results obtained with non-rotating masses.

There is more, but the basic point is the unstated assumption that the mechanical properties of rotating and non-rotating mechanical objects are identical. This assumption is incorrect.

Bruce DePalma
President
DEC

Asic angst

It was with great interest that I read "In depth – asic" in the May 1989 issue, articles which dealt with the designers' and industry aspects of using asics. Two other groups of users are worth remembering: the customer and the maintenance engineer.

By definition, the asic is an "application-specific integrated circuit"; it is, in effect, a very limited-application chip. The production batch size will therefore be very small in comparison with consumer ICs and there will be no second-sourcing.

The size of production runs will most certainly be reflected in the cost per chip; the asic might be the most expensive part in the equipment being manufactured. This will be offset by the use of fewer components and a smaller PCB size.

As most equipment has a limited production life – due to advances in technology and the need for change to boost sales – new products are developed, requiring new asics.

As an electronic maintenance engineer, I have two questions for the asic – related manufacturing industry. Firstly, is the manufacturer willing to stock expensive chips for maintenance purposes, knowing that he can't liquidate them through component retailers? And secondly, will the customer not be compelled to buy new equipment, once the old breaks down, due to unavailability of spare asics (say after five or ten years).

In effect: will manufacturing industry be holding the consumer to ransom?

Marc Cornelius
Jette
Belgium

Mac is tosh

I agree with Mr Spyker's comments on the Apple Macintosh in his letter in December's *EW+WW*. Designed around the excellent 68000 CPU, with its 32bit internal architecture and symmetrical instruction set, the Mac should have been streets ahead of the PC, handicapped by the peculiar architecture and strange instruction set of its 8086 processor. But no – lumbered with that horrible mouse/icon user interface and an overweight operating system that gobbles up memory and CPU time – it crawls along at a pace that makes even a bottom-of-the-range PC seem like a supercomputer.

Three years ago I designed a 68000-based single-board system. I needed to write software to test the system and, not having a 68000-based computer, I obtained a 68000 cross-assembler and used my home-made Z80-based S-100 bus CP/M system. The resulting binary files were downloaded to an eprom programmer and the test eproms programmed.

A programmer wrote the eprom-based digital signal processing software to let it be used as a spectrum analyser/digital storage oscilloscope. As he had no resources, an Apple Macintosh with a set of programmer's development software tools was loaned to him.

Eventually the suite of software was completed – all 51Kbyte of source code – and it was ready to be assembled and tested on the recently completed prototype of the new computer. The disk was put into the Mac. Its disk drive ground and grated away for 56 minutes before the assembler completed its task. The software did not work the first time and, each time the poor programmer made some alterations, we had to wait an hour as the Mac assembled it. To make matters worse, the output files produced were intended to be run on a Macintosh and not exported to an eprom programmer; additional programs had to be

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U192	1.00
U193	1.00
U251	2.50
U801	3.50
UABC80	1.00
UAF42	1.95
UBC41	3.95
UBC81	1.50
UBF80	0.95
UBF89	1.00
UBL21	2.95
UC92	2.50
UCC84	0.70
UCC85	1.00
UCF80	1.00
UCH21	2.50
UCH41	2.50
UCH42	3.95
UCH81	1.95
UCL82	1.75
UCL83	2.95
UF41	2.25
UF42	2.25
UF80	1.75
UF85	1.20
UF89	2.00
UL44	3.50
UL84	1.95
UL85	0.85
UU5	3.50
UU6	6.00
UU7	8.00
UU8	9.00
UY41	3.50
UY85	0.70
V235A/1K	250.00
V238A/1K	295.00
V246A/1K	250.00
V24[illegible]/1K	315.00
V241C/1K	195.00
V453	12.00
VLS631	10.95
VP4B	9.50
VP41	4.95
VR101	2.50
VR105/30	2.50
VR150/30	2.50
VU39	2.50
W21	4.50
W61	4.50
W77	5.00
W81M	4.50
W739	1.50
X24	4.50
X41	4.50
X66/X65	3.50
XB1	6.80
XC24	1.50
XC25	0.50
XFW47	1.50
XFW50	1.50
XG1-2500	75.00
XL628FT	7.50

XNP12	2.50
XR1/1600A	25.00
XR1/3200A	79.50
XR1-6400A	149.50
Y65	6.95
YD1100	75.00
YJ1060	265.00
YL1020	42.50
YL1060	195.00
YL1070	195.00
YL1071	195.00
YL1290	65.00
Z77	1.20
Z3001	6.00
Z302C	12.00
Z359	9.00
Z700U	9.50
Z759	15.00
Z803U	18.95
ZM1020	8.50
ZM1021	8.00
ZM1023	7.95
ZM1082	9.00
ZM1084	10.00
ZM1162	9.00
ZM1175	6.50
ZM1177	9.00
1A3	4.50
1AE4	3.50
1AX2	3.50
1B22	10.00
1B27	55.00
1B3GT	1.95
1B35A	45.00
1K3	2.50
1L4	2.50
1N5GT	2.50
1P28	25.00
1R5	1.50
1S5	1.50
1T4	1.50
1U4	1.75
1U5	1.50
1X25	2.50
2A3	12.15
2AS15A	11.50
2B7	4.50
2B22	69.50
2C36	70.00
2C39A	25.00
3C39A	32.50
2C39BA	39.50
2C40	37.00
2C42	29.50
2C43	60.00
2C51	2.50
2CY5	1.50
2D21	2.25
2D21W	3.15
2E22	49.00
2E26	7.95
2J55	295.00
2K25	59.00
2K26	95.00
2K59	250.00
2K48	140.00
2K56	250.00
2X2A	5.00
3A/107B	12.00
3A/108A	9.00
3A/109B	11.00
3A/110B	12.00
3A/141K	11.50
3A/146J	7.50
3A/147J	7.50
3A/167M	10.00
3A3A	3.95
3A4	1.50
3A5	4.50
3AT2	3.35
3B22	25.00
3B26	24.00
3B28	15.00
3BZ6	1.50
3C45	39.50
3CX3000A7	650.00
3CY5	1.50
3D21A	29.50
3E22	49.50
3E29	39.50
3EJ7	1.95
3H	0.40
3J/170E	1450.00
3L	0.40
3Q4	2.50
3V4	3.50
4-65A	85.00
4-250A	105.00
4-400C	95.00
4-1000A	495.00
4B32	35.00
4BQ7A	1.75
4BZ6	1.95
4C28	25.00
4C35	95.00
4CS250R	115.00
4CV35,000	1650.00
4CV100,000	2950.00
4XC125C EIMAC	150.00
4CX250B	45.00
4CX250BM	65.00
4CX250K EIMAC	115.00
4CX250R AMPEREX	125.00
4CX350A	100.00

4CX1000A	425.00
4CX1500B	475.00
4CX5000A	1000.00
4D21/4-125A	85.00
4D32	125.00
4E27A	125.00
4G57	2.25
4GV7	2.25
4J6A	2.95
4KT6	1.50
4T85P	150.00
4X150A	35.00
4X150D	55.00
4X500A	350.00
5A/102D	9.50
5A152M	9.00
5A163K	10.00
5A170K	6.25
5A-180M	9.00
5A-206K	10.00
5B-110M	10.00
5B-254M	11.50
5B-255M	14.50
5B-256M	15.00
5B-257M	15.00
5B258M	14.50
5C22	125.00
5CL8A	2.50
5J180E	1250.00
5JL8	2.95
5R4GY	4.95
5R4WGY	5.95
5T4	5.95
5T8A	1.95
5U4G	2.95
5U4GB	4.50
5V4G	2.50
5W4	4.95
5X4	4.95
5Y3GT	3.50
5Z3	4.50
5Z4G	2.50
6/30L2	0.70
6A/203K	9.00
6A7	4.95
6A8	2.50
6AB7	4.50
6AC7WA	2.00
6AG5	2.50
6AG7	2.50
6AH6	3.50
6AJ4	3.50
6AJ7	2.00
6AK5	1.95
6AK6	2.50
6AL5	0.85
6AM4	3.25
6AM5	4.50
6AM6	1.95
6AN5	4.50
6AN8A	4.50
6AQ5	1.75
6AQ8	1.50
6AS5	1.50
6AS6	2.50
6AS7G	4.50
6AT6	1.95
6AT8	1.75
6AU4GT	2.95
6AU5GT	4.50
6AU6	1.50
6AV6	1.95
6AW8A	3.50
6AX4GT	1.95
6AY3B	1.95
6AZ8	4.50
6B49	10.50
6B8G	2.50
6B10	1.95
6BA6	1.50
6BA7	4.50
6BA8A	3.50
6BC8	1.50
6BR3	2.95
6BE6	1.50
6BG6G	3.00
6BH6	1.95
6BH8	1.50
6BJ6	1.50
6BK4	6.50
6BL6	85.00
6BL8	1.15
6BM6	115.00
6BN6	1.65
6BN8	3.95
6BQ5	1.50
6BQ7A	1.50
6BR7	4.95
6BS7	5.50
6BW6	3.95
6BW7	1.50
6BZ6	2.50
6BZ7	2.95
6C4	1.95
6C5	2.50
6C6	3.50
6C8G	2.50
6C9	4.95
6CA4	4.95
6CA7	3.50
6CB5	3.95
6CB6	2.50
6CD6GA	4.50
6CF6	1.95
6CG7	3.50
6CG7 GE	5.25
6CH6	6.95
6CL6	3.25

6CL8A	2.95
6CM7	2.95
6CS6	0.75
6CS7	0.95
6CW4	8.00
6CX8	3.95
6CD6	2.35
6DJ8	1.50
6DJ8 SPECIAL	3.50
6DK6	1.50
6DQ5 GE	11.95
6DQ6B	2.50
6DT6A	1.50
6DW4B	3.50
6E5	3.95
6EA7 GE	4.50
6EA8	2.50
6EB8	3.50
6EJ7	0.85
6EM5	2.50
6EM7	2.50
6EU8	1.75
6EV7	2.95
6EW6	1.50
6EW7	4.50
6F1	2.00
6F5	5.50
6F7	5.50
6F13	3.00
6F14	1.00
6F17	2.75
6F23	0.60
6F24	1.25
6F25	1.25
6F28	1.25
6F32	1.25
6F33	7.50
6FH5	8.50
6FH8	15.00
6FL2	4.50
6FQ7	3.50
6GE5	3.95
6GH8A	2.50
6GJ7	0.85
6GK6	3.95
6GM6	2.65
6GS7	21.5
6GV8	0.95
6GW8	2.50
6GY5	4.95
6GY6	2.50
6H1	9.50
6H6GT	2.50
6HB7	1.95
6HF5	12.50
6HF8	3.50
6HM5	2.50
6HQ5	3.50
6HS6	4.95
6HS8	2.95
6HZ6	3.50
6J4	2.15
6J5GT	2.50
6J6	2.00
6J7G	4.15
6JB6A GE	9.50
6JE6C GE	12.50
6JM6	10.95
6JU8A	2.50
6JS6C GE	10.95
6JZ8	5.95
6K7G	2.00
6K8G	3.00
6KD6 GE	11.95
6KG6A	6.95
6L1	2.50
6L6GC	3.50
6L6GC USA	9.50
6L6GT	3.50
6L7	3.50
6L15	3.15
6L19	3.95
6LJ8	2.50
6LD20	2.50
6LF6 GE	12.50
6LQ6 GE	12.50
6LU8	9.25
6P28	2.00
6Q7GT	2.50
6R7	3.15
6S4A	1.95
6SA7	1.95
6SC7	1.95
6SH7	1.95
6SJ7GT	1.95
6SK7	1.95
6SL7GT	2.50
6SN7GT	3.15
6SQ7GT	4.50
6SS7	1.95
6T8	1.50
6U6GT	3.50
6U7G	3.50
6U8A	1.50
6V6G	1.95
6V6GT	2.50
6W4GT	1.95
6Y6G	3.95
6X2N	1.00
6X4	1.50
6X5GT	1.00
6X8A	2.25
6Y6G	4.50
7AU7	1.50
7B6	3.50
7B7	2.50
7D8	4.50
7J7	5.50
7K7	7.50
7L7	1.50
7Q7	4.50

7Y4	2.50
8B8	2.50
8B10	2.50
8BQ5	1.95
8CW5	1.50
8EB8B	1.50
8FQ7	1.95
10D2	1.25
10DE7	2.50
10DX8	2.50
10EB8	1.95
10EW7	2.95
10F1	1.95
10GK6	1.95
10P14	2.50
11E3	55.00
11R3	5.50
12A6	3.95
12AD6	2.50
12AE6	5.50
12AH7GT	4.95
12AL5	1.00
12AT6	1.75
12AT7	1.95
12AT7WA	3.50
12AU6	1.50
12AU7	0.95
12AV6	1.95
12AV7	2.50
12AX4GTB	2.50
12AX7	1.50
12AX7WA	2.50
12AX75	7.95
12AY7	3.95
12B4A	4.50
12BA6	2.50
12BE6	1.95
12BH7A GE	6.50
12BL6	1.75
12BR3	1.95
12BY7A GE	6.95
12C8	2.50
12CA5	1.95
12CX6	1.95
12DQ6B	3.50
12DW4A	3.50
12DZ6	3.95
12E1	19.50
12E14	38.00
12FX5	1.95
12GN7 GE	6.95
12J5GT	3.95
12J7GT	3.50
12JZ8	2.95
12KGT	1.50
12K8Y	1.95
12KU7	1.95
12S7GT	1.50
12SA7GT	1.95
12SG7	4.75
12SK7	1.95
12SJ7	1.50
12SN7GT	1.85
12SW7	3.50
12SY7	4.50
12X4	1.95
13D7	3.20
13DE7	2.50
13DR7	2.95
13E1	145.00
13EM7	3.50
14B6	4.50
14R7	3.50
15E	5.50
16AQ3	1.95
16GY5	2.95
16H	0.40
16L	0.40
17A8	3.50
17AX4GTA	1.95
17BE3	2.50
17DW4A	2.95
17EW8	1.50
17JZ8	8.50
18D3	6.00
18GB5	3.50
19AQ5	3.50
19AU4GT	2.50
19BG6	3.50
19G3	19.50
19G6	9.00
19H4	35.00
19H5	33.50
20CV	9.50
20D1	1.50
20LF6	7.95
20L1	0.95
20P1	0.55
20P4	1.95
20P5	1.15
21JZ6	10.50
21KQ6	4.95
21LU8	3.75
24B1	39.50
24B9	39.50
25BQ6	1.75
25DQ6B	2.95
25L6GT	1.75
29C1	19.50
29KQ6	6.50
30C15	0.50
30C17	0.40
30C18	1.48
30FL2	1.35
30FL12	0.95
30FL13	1.10
30FL14	1.25
30L1	0.45
30L15	0.60
30L17	0.60

30P4MR	1.00
30P12	1.00
30P18	0.60
30P19	1.00
30P1	2.50
30PL13	0.60
30PL14	1.75
31J26C	7.50
33A/158M	19.50
35A3	3.95
35A5	4.50
35C5	4.50
35L6GT	2.00
35Z3	1.95
35Z5GT	3.50
38HE7	10.95
40KD6	8.50
47	6.00
50A5	1.50
50B5	1.95
50C5	0.95
50CD6G	1.95
50EH5	1.50
50JY6	2.95
53KU	4.50
75B1	3.50
75C1	4.50
80	4.50
83	8.50
83A1	7.50
85A1	6.50
85A2	2.95
90AV	17.50
90C1	3.50
90CG	17.50
90CV	17.50
91AG	9.00
92AG	25.00
92AV	25.00
95A1	6.50
100E1	50.00
108C1	2.50
150B2	6.50
150C1K	9.00
150D2	2.50
150C4	2.50
185BT	1.50
211	14.95
230D	1500
231D	15.00
250TH	150.00
307	5.00
328A	15.00
572B	49.00
705A	12.50
713A	25.00
713A/B	75.00
724A	275.00
725A	275.00
726A	75.00
801A	15.00
803	14.95
805	16.95
807	5.50
807A	6.95
812A	12.50
813 PHILIPS	35.00
813	19.50
829B	22.50
833A	65.00
845	23.00
866A	8.50
872A	20.00
873	60.00
954	1.00
955	1.00
1802	1950.00
1849	315.00
1927	25.00
2040	25.00
2050A GE	9.95
4212H	250.00
4471	35.00
4687A	9.50
5544	79.50
5559	55.00

5636	5.50
5642	9.50
5643	9.50
5651	2.50
5654	1.95
5670	3.25
5672	4.50
5675	28.00
5678	7.50
5687	4.50
5696	4.50
5702	3.50
5704	3.50
5718	3.50
5725	2.50
5726	2.50
5727	2.50
5749	2.50
5750	1.85
5751	2.95
5763	6.50
5814A	3.25
5823	9.50
5829WA	6.50
5840	3.50
5842	11.00
5847	10.95
5863	95.00
5879	9.50
5886	13.95
5894	39.50
5899	4.50
5963	1.75
5965	2.15
6057	3.75
6058	2.50
6060	2.25
6072	6.95
6080	8.50
6080WA	9.50
6132	10.50
6136	2.50
6146B	9.50
6146B GE	15.00
6146W	12.50
6155	72.00
6156	125.00
6157	2.50
6158	3.20
6166	650.00
6189	4.50
6201	6.45
6350	3.50
6360	4.50
6386	14.50
6442	75.00
6463	7.50
6550A	9.95
6550A GE	13.95
6870	11.50
6883B GE	14.95
6973	10.50
7025	2.50
70255	6.95
7027A GE	12.50
7092	125.00
7119	9.00
7189	5.50
7199	10.50
7247	8.50
7475	5.00
7486	155.00
7527	125.00
7551	8.50
7581A	11.95
7586	15.00
7587	19.50
7591A	10.50
7815	59.50
7868	8.50
7895	17.50
8156	9.95
8417	10.95
8950	10.50
18042	10.50
9002	6.50
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LETTERS

run after each assembly to convert the files to a standard format compatible with an eprom programmer.

Using my system at home, which had been dismissed by the programmer as "ancient, a totally obsolete pile of junk", I assembled the program to produce a file that could be fed directly to the eprom programmer – in just 6 minutes.

The very next day, the Mac was relegated to the receptionist and its place was taken by an elderly S-100 bus CP/M system complete with 8in disk drives and a separate terminal. To this day, this system is still in use for developing 68000 software.

I work for the microcomputer side of a university computing service. Unfortunately, orders from above are that we must only encourage and actively support the use of those microcomputers from the two main families of currently popular machines that are "officially approved and recommended" by the college's computer centre; there are no prizes for guessing which currently fashionable model range this includes.

Andy Thomas
Hornsey
London

Gyroscopes and contradictions

In your December 1989 issue Dr Harrison restates the fallacy which constitutes one side of the Newtonian contradiction. The fact that there is a contradiction was revealed by my initial experimental observation some 20 years ago.

On the one hand we have the statement "all observed gyroscopic phenomena are quite adequately explained by Newtonian mechanics."

On the other hand we are told, with equal certainty, that "The centre of mass of a closed system of components cannot alter its condition of rest or uniform right line motion unless a force be *impressed* upon the system. It is impossible for the internal motions of the components to affect the motional condition of their common centre of mass." It is to be noted that any alteration of motion will be in the direction of the right line along which the force is impressed.

The second statement is a direct consequence of the three laws of motion and their attendant notes.

The initial experiment (*circa* 1970), details of which are appended, clearly falsifies the second statement above.

We have, therefore, a situation in which classical mechanics, as is presently interpreted, contradicts itself, the first statement claiming to explain the experiment which falsified the second as a general case.

It is now for Dr Harrison to tell us how, when using a faultless chain of logic, a set of three mutually consistent axioms may be used to derive contradictory conclusions.

When considering this matter it should be remembered that the analogue between the conservation of angular and linear momenta is mere assumption and does not constitute a formal logical step. Perhaps this particular assumption lies at the roots of our failure to unify the forces of nature.

Alex Jones
Swanage
Dorset

An experiment to demonstrate that motion can be caused without the need for a reaction in an equal and opposite direction.

A flywheel was suspended with its axis of rotation at right angles to a shaft by means of a universal ball joint. The shaft was carried within a frame supported upon a near frictionless surface comprising two level glass plates separated initially by steel rollers and subsequently by three steel ball bearings. Fig.1. The flywheel comprised an electrically driven gyroscope weighing 7 pounds including its cage. The weight of the support frame and shaft was about 3 pounds.

When the flywheel was spinning it was raised so that its shaft had an an aligment O-Y within plane X-X and then released to allow it to orbit about O in the direction of arrow A.

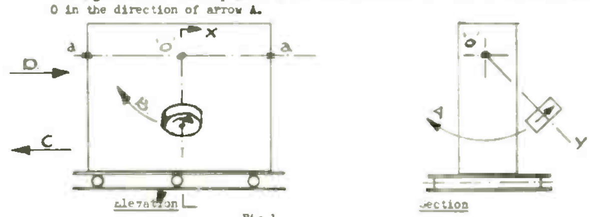

Fig.1.

It was observed that when on rollers:-
a) The flywheel moved in direction B, restrained to centre O.
b) There was no movement of the frame upon the rollers in direction D.

First conclusion.
Considering the unit as a whole, there was a nett mass movement in direction C without a reaction in direction D.

Music for pleasure

I read with interest and amusement the letter from M. Peacock in *EW+WW* December 1989 issue. Like him, I can remember the time when *Wireless World* was one of the most sought after magazines by constructors in building high quality amplifiers or just reading about how to do it.

I note his phrase "The use of electronics to further the quality of sound reproduction is all about getting sheer enjoyment from life." I trust that he includes the enjoyment gained from listening to music in the home, as well as the pleasure from construction. One of the greatest pleasures is to gain a greater appreciation and insight into a piece of music through improving a hi-fi system oneself.

The reason for the lack of audio articles in *EW+WW* is first that there have been very few articles of real interest in recent years. Writers want their articles to be read by people who appreciate their efforts and those who design amplifiers know that people with an interest in audio engineering read *Audio Amateur* (an American magazine), *Audio Conversions* (available by subscription only), *ETI, Hifi News and Hifi Answers* because those magazines publish material which relates directly to factors (engineering and other) which affect quality of sound. Readers who used to read *EW+WW* are discouraged by the lack of any real audio engineering articles.

Secondly the apparent very low quality of readership of *EW+WW* as depicted by the letters published on audio topics hardly inspires the confidence to advertise high quality components which improve the sound quality through engineering factors related to their quality of manufacture. Out of more than £10 000 spent on advertising audio amplifier kits and components in electronics and hi-fi magazines by my firm in the last three years, none has been spent in *EW+WW*.

When I advertise, I want the message to get across to people who have the intelligence and education to understand that temperature coefficient of resistors, the dielectric properties of insulating materials in capacitors and cables, the chemical purity and crystalline structure of conductors all directly relate to sound quality, as much as, and perhaps more than, power supply ripple rejection, slew rate limiting, output damping factor and other aspects of circuit design.

I want to reach people with the scientific integrity to test all theories which claim to improve sound quality and to use their judgement to apply those which work. Those who hang on to past ideas when knowledge has moved forward, and who seem to be well represented in these letters pages, offer me little.

The "subjectivists v objectivists" debate is one which digresses from the importance of applying all known engineering knowledge to the furtherance of enjoyment of music through hi-fi equipment.

I do not think that this is the place to explain some of the engineering factors which I have observed to improve the sound quality of hifi equipment. I would simply recommend that all interested readers see that excellent film "Dead poets society" and decide for themselves whether the quality of poetry can be measured by the area under the square in the graph!

Graham Nalty
Borrowash
Derby

I trust this letter on an audio topic reinforces your view on the quality of the readership – Ed.

Riddle of a riddle

Could Peter Graneau, author of the article The Riddle of Inertia published in the January 1990 issue, please explain why it is necessary to introduce the concept of the force of inertia at all?

Classical mechanics can be formulated without referring to the concept, as for example in the standard treatments by Goldstein[1] and Lindsay[2], which do not mention force of inertia. If then the concept is redundant, wherein lies the riddle?

David Salt
Saffron Walden
Essex

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2. R.B. Lindsay, Physical Mechanics, Van Nostrand, 1957.

$E=mc^2$

J. Ferguson (*EW+WW*, December 1989, p. 1208) gives a mistaken interpretation of the article by L. B. Okun in *Physics Today* (June 1989, p. 31f). The problem under discussion is how to write, correctly, the famous Einstein relation between mass and energy, $E=mc^2$; with or without an index o under E and/or m. There are four possibilities and $E_o=mc^2$ seems to be the right answer. "The purpose of this article is to promote the rational terminology" (L.B.O.). But not at all to call into question the theory of special relativity.

J. J. Bleeker
CERN
Geneva

Killing fields

The recent articles in the February issue of *EW+WW* question the reason for differences between the proposed guidelines for restricting exposure to electromagnetic fields in the 1986 NRPB consultative document[1] and those in the final document[2] issued in 1989. Germane to this question is the issue as to whether the guidelines should have been based on risks other than those of electric shock, radiofrequency burns and overheating of the body.

The scheme put forward in the 1986 consultative document was based on the concept of "dose" represented by the integral over exposure time of the intensity of the electromagnetic field. When, as required by its statute, NRPB consulted with the Medical Research Council on the biological basis for its proposals, it was advised that there was no such basis for the concept of "dose". Other replies to the consultation document strongly questioned whether there was a biological basis for any form of restriction. In addition, it emerged that the scheme was often not understood and when it was understood it was regarded as impossible to administer.

Our conclusion from the replies to the consultation therefore was that the urgent need was for a simple scheme with a firm recognisable biological basis, which would be acceptable to industry and the Health and Safety Executive.

A reasonably firm basis for restricting the level of heating of the body at frequencies above 30MHz can be established from animal experiments, considerations of human metabolism and the rather primitive dosimetry of electromagnetic fields. At frequencies below 30MHz, a firm biological basis rests on the responses of people to electric currents at different frequencies. An anchor point is the allowable leakage currents from electrical appliances at 50–60Hz. It would be inconsistent to restrict allowable induced currents from electromagnetic fields to levels below or above these values. The 1989 NRPB guidelines, as stated in the document, are designed solely to protect against overheating, electric shock and radiofrequency burns.

There is a growing literature indicating that there may be long-term health risks from exposure to electromagnetic fields and that in particular there may be risks of inducing cancer or promoting cancers induced by other agents. Those who believe the risk is real tend to favour the latter possibility; which requires the presence of some cancer inducing agent for the manifestation of the risk. The sources of the data which has raised these possibilities are studies of electrical and electronics workers and studies of populations exposed to magnetic fields in the home environment.

The occupational studies yield a weighted average relative risk to electrical and electronic workers from all forms of leukaemia of 1.2 (95% confidence limits 1.1–1.3)[3,4] and from brain tumours of 1.3 (95% confidence limits 1.2–1.5)[5]. Because of the way these risks are derived they are likely to be overestimates due to the confounding factor of occupational class. Taken at their face value they imply an additional average annual risk to workers in the age range 15–64 of 1×10^{-5} from leukaemia and 2×10^{-5} of from brain tumours. The total risk of 3×10^{-5} is within the range regarded as tolerable for occupational risks.

Population studies are not easily interpreted, but from the data of Savitz[7], the relative risks of childhood cancer appear to increase at a rate of between 0.2% and 1% per nanotesla, depending upon which of several sets of data are used[5]. However, the confidence limits on these estimates embrace negative increases with exposure, i.e. a beneficial effect. The tolerable levels of exposure implied by these highly unreliable estimates lie in the range 10 to 50 nanotesla for members of the public and prolonged exposure. These levels of exposure will be exceeded in most British homes. Over the past fifty years the use of electric power has increased twenty-fold, while the incidence of childhood cancer does not seem to have increased and childhood cancer mortality has decreased. It seems unlikely therefore that these risk estimates are realistic. If the risk is real, we are still lacking the basic understanding of the biological mechanisms, so that it would be impossible to deduce equivalent risk estimates for electric fields.

One particular source of uncertainty is the implication of some of the scientific literature that risks might be higher at specific frequencies and in windows of intensity, so that merely reducing exposures below a certain level may not necessarily reduce the risk. Given the uncertainty about the reality of the risk and the considerable uncertainties in its quantification, it would be premature to specify limits based on the possibilities for long-term effects on health. Nevertheless, there is obviously a case for avoiding unnecessary exposures and reducing exposure levels where this can be done easily; and a strong case for research to determine whether the indicated risks are real and their underlying scientific cause.

NRPB is currently carrying out and supporting research on aspects of fundamental mechanisms, on the possibilities of inducing birth defects by exposure to magnetic fields, on theoretical dosimetric aspects and on methods for reducing exposures in industry. Support for epidemiological studies related to cot deaths and birth outcome is planned and for some time NRPB, together with the Department of Health, has been supporting the construction of a data bank on the geographical distribution of childhood cancers in England and Wales which will provide a basis for further studies. This scientific programme is in addition to that of the CEGB and has been in progress for some years.

J. A. Dennis
Assistant Director (Physical Sciences)
National Radiological Protection Board
Didcot
Oxfordshire

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One fundamental factor makes it particularly difficult to establish whether non-ionizing radiation causes illness. Artificial electromagnetic fields are pervasive throughout the developed world and if, as many believe, these fields do constitute a hazard to health, there is no control population available for study in a pollution-free environment. Thus, in any epidemiological investigation, one may be comparing the state of of the bad with that of the worse.

Your February issue contained a trilogy of articles on this subject in which reference was made to papers[1,2] to which I contributed and also to the supply of electricity by pole-mounted cables to domestic premises in rural areas. In 1979 measurements were made of the 50Hz magnetic field at 590 suicide addresses and 594 control addresses in part of the West Midlands of England. A significant correlation was found between the suicide addresses and higher magnetic field. In one Shropshire village, which had a population of 2488, eight suicides had occurred between January 1969 and October 1976. This incidence of suicide was five times the annual rate for Shropshire and eight times the annual rate for the whole area studied. Two of the suicides had lived at the same address where the front door of the house gave directly onto the pavement bordering the main road through the village. Here the maximum 50Hz magnetic field reading was 800nT and this was thought to be due to a 33kV underground cable close to the front of the house. The remaining six suicides had all lived in one council estate where the first 40 houses were supplied through overhead feeders mounted on poles and the remainder by underground services. All but one of the six suicide addresses had magnetic-field readings exceeding the median value for the 1184 addresses in the whole study area. Moreover the measurements were found to decrease steadily in intensity along the line of supply.

In your article 'Killing Fields' it is stated that, in a study of the distribution of illness in multi-storey blocks in Wolverhampton[2], it had been found that in blocks where there was underfloor or storage electric heating the proportion of cases of depression living in flats near to the rising cable rose *by* 82%. In fact, the proportion rose *to* 82% of the total number of cases of depressive illness admitted to hospital from such blocks, which was highly significant. (P=0.013).

In a third paper[3], which was not cited, was described the investigation of all the admissions to hospital in 1985 of patients suffering from myocardial infarct (600) and from depressive illness (359) from addresses in the whole Metropolitan Borough of Wolverhampton. Measurements at the addresses of these patients and their corresponding controls showed no correlation between 50Hz magnetic field intensity and myocardial infarct, but a significant correlation was found between the higher field measurements and the addresses of patients admitted with depressive illness. (P=0.033).

Certainly, the electrical industry is unlikely to promote any truly independent investigation. Indeed, they deserve some sympathy because the implication of the British findings and those of American and Swedish scientists must be that variations in the intensity of power-frequency magnetic fields of small magnitude may be affecting the health of the whole population. Even if they were to concede that this was the case, the best remedy that electrical engineers could hope to achieve would be some balancing of the risks – and that at great cost.

F. Stephen Perry
Wolverhampton

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VDU's and X-rays

In the February edition, J. A. Corbyn's letter claims to equate the X-ray dosage and risk received from six months occupational use of a VDU, to that received from a typical chest X-ray.

However, the exposure rate he uses for his typical VDU is too large, and he ignores fundamental differences in the physical characteristics of the two X-ray sources.

Taking the maximum exposure rate allowed by BS6204 "Safety of data processing equipment" of 0.5 mR/hr *at 5cm*, the exposure rate at a typical VDU to abdomen distance of 60cm will be approximately 0.01 mR/hr. This will give a total skin dose after 25 weeks of 40 hrs per week of 10 millirem, not the 30 millirem he calculated. Furthermore, the X-rays emitted from a VDU have very little penetrating power and at least 90% will be absorbed within the first few centimetres of tissue, unlike those used in a chest X-ray.

It is worth noting that during the same six months, the VDU operator will have received about 100 millirem from natural radiation. Thus, the dose received from a VDU operating at the maximum allowed levels is a very small fraction (less than 1%) of the dose received from other sources.

Cleveland Medical Physics Unit
Middlesbrough
Cleveland

Correction

Quintin Davis, who wrote the letter on laser vibration measurement in our January issue, points out a misprint at the end of the second paragraph. The Decca instrument was able to measure movement down to 10^{-10}cm, not 10^{-20}cm. Apologies to Mr Davis. ■

ACTIVE

A-to-D and D-to-A converters

8-bit A/D converters. Two high-speed microprocessor-compatible 8-bit analogue-to-digital converters operate with a single +5V supply, a +1.23V external voltage reference, and accept input voltages ranging from 0V to 2V ref. Both c-mos devices use successive-approximation technique to achieve 15mW dissipation and operate down to 5μs conversion time. The AD7575 and AD7576 offer a data access time of 100ns and easily interface to all 8-bit microprocessors. Kudos Thame Ltd, 0734 351010.

Linear integrated circuits

Isolation amp. Burr-Brown's ISO212P is a two-port isolation amplifier with 12-bit accuracy and an internal isolated DC-DC converter, all powered from a single +15V supply. Its plastic SIL package has a 2.2 × 0.3in footprint and is 0.43in high, permitting card-to-card spacings of 0.5in without mechanical interference. Rated isolation voltage is 750VRMS. The external power capability is +5mA (at 8V), and power dissipation is 75mW. The internal op-amp can provide gains from 1 to 100 using a few external components. Burr-Brown International Ltd, 44 0923 33837.

Audio op-amp. The Linear Technology Lt1115 op-amp features 0·9nV/√Hz noise at 1kHz and less than 120nV/√Hz noise over the 20 to 20kHz audio spectrum. Referred to the professional audio standard, wideband noise exhibited by the LT1115 is -136dB. Driving a typical 600ohm load, the total harmonic distortion is less than 0.002% at 10kHz; typical CCIF intermodulation distortion is less than 0.0002%. Micro Call Ltd, 0844 261939.

Monolithic amp. Raytheon has announced the RC4277, a monolithic bipolar dual op-amp which comprises two amplifiers in an eight lead package. It is claimed to have the lowest input offset voltage available in a dual op-amp, only 30μV maximum with offset drift of 0.5μV/°C maximum. Open-loop gain is 2 000 000 minimum into a 2kΩ load, while input bias current is +3nA maximum and power consumption a low 100mW maximum (both channels). CMRR and PSRR is 120dB minimum. Raytheon, 0494 450327.

Memory chips

Programmable fifo. The Am4601 c-mos first-in first-out buffer memory circuit features programmable status flags and is compatible with the Am720X-series fifo family. The Am4601 is 512 words deep. Each word is nine bits wide. The circuit has two fixed flags—full and empty—and two programmable flags. Both 25ns access-time versions of the part are available.

64K-bit s-rams. Byte-wide s-ram, FCB61C65, is an 8K device which features power consumption of 1μA, both on the 5V standby and in the battery back-up mode. Normal and low power versions are also available and speeds range from 55ns to 70ns. It operates from a single 5V supply; inputs and outputs are TTL and c-mos compatible. Two chip-enable pins are provided. Philips Components Ltd, 01-580 6633.

Microprocessors and controllers

Risc microprocessors. Samples of the 33MHz Am29000 (29K), AMD's 32-bit risc microprocessor are available. The 33MHz 29K brings 22 mips performance to applications such as networking control and high-end graphics, which require high speed data throughput capability. The 33MHz 29K is pin compatible with AMD's current 29K family which includes 16, 20 and 25MHz versions of the risc microprocessor. Advanced Micro Devices 0483 740440.

Transverse filter. Hawke Components now offers the Inmos IMSA100, a high-speed 32-stage digital transverse filter with a flexible architecture that lets it be used as a building block in many discrete Fourier transform (DFT) applications. It can perform convolution and correlation, as well as many filtering functions. The input data word length is 16-bit and coefficients can be selected as 4, 8, 12 or 16-bit wide. Two's complement numerical formats are used for data and coefficients. It can throughput data up to 15MHz. Hawke Components Distribution, 01-979 7799.

LD/MF dialler. The AMS S2570 is an integrated c-mos device for push-button telephones, which converts data from the keyboard in either correctly timed line disconnects (LD) or generates tone pairs for multi-frequency (MF) signalling in accordance to CCITT recommendations. Mode switching form LD to MF and back is implemented via the keyboard. Austria Mikro Systeme Int Ltd, 0793 537852.

TV controller. Designated the Z86C27, the Zilog device provides the usual picture/audio controls and also offers a greater choice of screen display information formats than similar devices. Using a Z8 microcontroller, the DTC is more powerful and easier to program than similar 4-bit products and offers a 2-colour on-screen bar graph for visual displays of other inputs (e.g. volume and contrast). Displays can be faded out or in. Other on-chip capabilities are a front panel led display drive and keyboard scanning. Celdis 0734 585171.

Maths processor. MicroCall Solutions has available the Cyrix fully 80387 compatible numerics processor. Called the Fastmath, the device offers up to ten times the performance of standard processors, very low power dissipation, and 100% software and pin compatibility with the standard 80387 PC maths coprocessor. MicroCall Solutions, 0844 261500.

Optical devices

Optocouplers. The 20 000 3A series of optocoupler, compact rail-mounting units, 100mm × 12.7mm wide, have the Entrelec universal mounting foot to fit DIN 1, DIN 3 and Cenelec rails. Input voltages may be 24V, 48V, 110V AC/DC and 220V AC, whilst output voltages may be either 3-60VDC or 24-280V AC. Entrelec (UK) Ltd, 0273 570730.

Optocouplers. A 11kV (peak) breakdown isolation is provided by the Isocom IS1000 range. The coupler comprises a coupled IR pair with a 4mm internal gap to give the high isolation figure. Housed in a 4-pin plastic package, it has an I_{ceo} of 100nA max and BV_{ceo} of 30V min. Milgray Distribution Ltd, 0788 543550.

PASSIVE

Microwave terminations. A series of KDI topless and coverless high-power film terminations and resistors is impervious to moisture penetration. The open construction is suitable for use in microwave stripline and microstrip circuits, where the moisture resistance eliminates the need for special moisture protection. The devices handle up to 20W average and 2kW peak power. Operating frequency range is from DC to 3GHz. Anglia Microwaves Ltd, 0277 630000.

One of the accelerometers from Entran's EGCS-240D range.

Ceramic trimmer. The Tusonix VARI-Thin series 513 ultra-miniature trimmer capacitors has a 100V DC working voltage range and is 0.196 in × 0.080in claimed to be the smallest of its type currently available. The 513 is available in capacitance ranges from 1 – 5pF up to 7 – 40pF. STC Mercator, 0493 844911.

Miniature electrolytic capacitors. Two series of Rubicon miniature aluminium electrolytic capacitors exhibit high levels of stability and reliability at elevated temperature up to 105°C. The PS2 series is intended for smoothing circuit applications in switching regulated power supplies and other high-frequency equipment. It has enhanced temperature, frequency and high-temperature load (2000 hours at 105°C) characteristics and reduced high-frequency impedance. Offered in seven voltage ratings of 6.23V to 63V, the PS2 series covers a capacitance range of 22 to 2200μF. The MHA series is in seven voltage ratings from 10 to 100V and covers a capacitance range of 0.47 to 6800μF. HB Electronics, 0204 386361.

Bidirectional transient suppressor. Silicon transient suppressor 60KS200C is a bidirectional device for use in shipboard equipment and other power servicing equipment where large voltage transients endanger voltage sensitive equipment. Features of the 60KS200C include peak pulse power dissipation of 90000W, a 200V bidirectional capability and the ability to exceed MIL-STD-1399 requirements. Steady state power dissipation is 10W. Weighing approximately 50g, the new device

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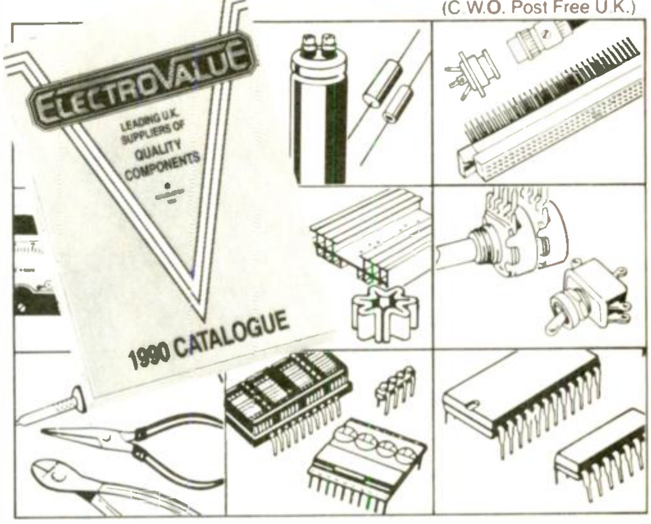

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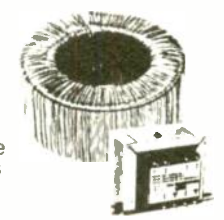

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1000	53.54	48.19	35.34	33.46	30.25	28.11	26.77
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Z759	19.90
Z800U	3.45
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Z803U	21.15

Z9001	9.50
1A3	1.90
1L4	0.95
1R5	1.20
1S4	1.20
1S5	0.85
1T4	0.75
1U4	1.25
2X2A	3.80
3A4	1.30
3AT2	3.40
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3B28*	19.50
3D6	1.15
3E29	21.85
3S4	1.70
4B32	35.00
5R4GY	4.85
5U4G	1.85
5V4G	1.90
5Y3GT	2.20
5Z3	4.85
5Z4G	2.20
5Z4GT	2.20
6/30L2	0.80
6AB7	1.85
6AC7	1.80
6AG5	0.60
6AK5	1.90
6AK6	2.85
6AL5	0.60
6AL5W	1.50
6AM5	6.50
6AM6	1.60
6AN8A	3.80
6AQ5	1.75
6AQ5W	2.90
6AS6	1.15
6AS7G	4.95
6AU6	0.90
6AX4GT	1.30
6AX5GT	1.30
6BA6	1.75
6BA6*	2.20
6BE6	1.75
6BE6*	2.20
6BG6G	2.65
6BJ6	1.75
6BQ7A	3.95
6BR7	4.80
6BW6	6.10
6BW7	1.50
6C4	1.20
6CH6	7.50

6CL6	2.75
6CW4	7.40
6CX8	4.60
6CY5	1.15
6D6	2.50
6F6G	2.90
6F6GB	2.90
6F7	2.80
6F8G	1.75
6F12	1.60
6F14	1.15
6F15	3.40
6F17	3.10
6F23	0.75
6F24	1.15
6F33	10.50
6FH8	18.80
6GA8	0.65
6GH8A	0.90
6H6	1.60
6J4	1.95
6J4WA	3.10
6J5	2.30
6J5GT	1.80
6J6	2.20
6J6W	2.80
6JE6C	9.15
6JS6C	9.15
6JU6	6.35
6K7	2.20
6KD6	12.90
6L6	7.10
6L6GC	9.60
6L6GT/C	2.80
6L18	0.70
6LD20	0.70
6LQ6	9.15
6Q7G	1.50
6SA7*	1.80
6SG7	1.80
6SJ7	2.50
6SK7	1.85
6SL7GT	4.35
6SN7GT	4.35
6SQ7	0.95
6SR7	4.60
6V6G	1.50
6X4	1.50
6X5GT	0.75
6Y6G	2.80
6Z4	1.75
7Z4	1.90
9D6	2.15
11E2	19.50

12A6*	3.50
12AT6	1.95
12AT7	1.25
12AU7	0.95
12AX7	1.10
12BA6	3.50
12BE6	2.40
12BH7A	4.80
12E1	19.95
12J5GT	0.55
12K7GT	1.15
12K8GT	1.25
12Q7GT	1.15
12SC7	0.80
12SH7	1.25
12SJ7	1.40
12SK7	1.45
12SQ7GT	2.20
12Y4	0.70
13D3	2.80
13D6	0.90
19AQ5	1.85
19G3	11.50
19G6	10.35
19H5	38.00
20D1	0.80
20E1	1.30
20P1	0.60
25L6GT	1.90
25Z4G	1.80
85A2	1.40
85A2*	2.55
572B	61.90
807	3.45
807*	4.30
811A	13.50
812A	32.00
813	28.50
813*	44.00
829B	16.00
829B*	24.00
866E	14.95
931A	18.95
931A*	26.80
954	1.10
955	1.10
956	1.20
5763	5.75
6060	1.95
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operates in the range of -65 to +150°C. Hunter Electronic Components, 0628 75911

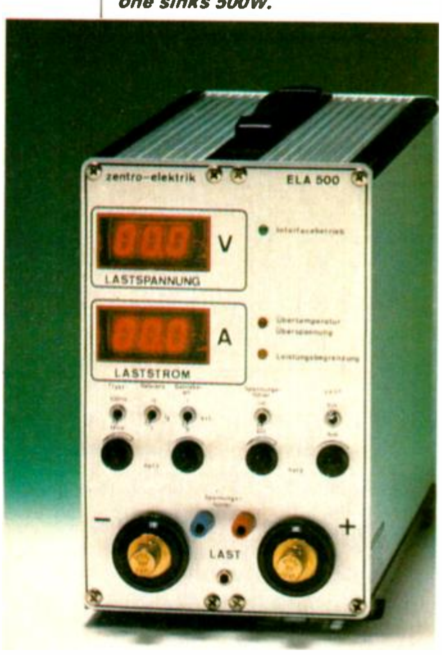
Bridge rectifier. A series of miniature 1A single-phase rectifier bridges with ratings from 100 to 800V is known as the 1B series and uses 6-pin dil packages with pins on 0.2 × 0.3in centres to fit with the 0.1in pitch PCB design matrix. The devices are end stackable in standard IC sockets. Surge capacity is 30A and temperature range -40°C to +150°C. International Rectifier Co, 0883 713215.

Toroidal transformers. The first products from the Swedish company Lintron's new UK factory are toroidal transformers ranging in size from 5VA to 10000VA. The design ensures low magnetic field disturbance, combined with low weight and profile. Lintron Electronics Ltd, 0670 717595.

Metal foil resistor networks. Hermetically-sealed, ceramic DIP versions of the Alpha high-precision metal-film resistor networks in 8, 14 and 18-pin types are now available, with a wide choice of configuration, including resistor arrays, independently connected elements, voltage dividers and ladder networks. The TCR tracking of ±1, ±2 or ±3ppm/°C. Best tolerance is ±0.02% absolute and ±0.01% matching. Resistance value range is from 5Ω to 60kΩ. Rhopoint components, 0883 717988.

Connectors and cabling

D connectors. A range of D-type connectors combines the shielding properties of metallised connectors with the low cost and light weight of ABS housings. The range is based on metal plated shells and units are available for use with both flat and round cable. Junction shells with cable entry at 50° and 180° are also available. The range covers the full range of commonly used D type connector sizes, including 9, 15, 25 and 37-way. Jermyn Distribution, 0732 450144



Zentro Elektrik electronic load from Gresham Powerdyne. This one sinks 500W.

CS 1041 portable diagnostic instrument for process control, from Status Instruments.

Hardware

Wire strippers. Hand wire and tubing cutter, Model AB10, is a hand-crank unit which will cut equipment wire of up to 14AWG into lengths between 2.54mm and 216mm, and sleeving and tubing of up to 6.35mm diameter into lengths between 2.54mm and 51mm. The unit is being offered with a free bench-top free-running de-reeler. Rush Wire Strippers, 0264 51347

Instrumentation

Generators. There are 21 models, covering the 10MHz to 18GHz frequency range in the NC7000 series of programmable, broadband noise generating instruments. Each instrument contains a broadband noise generating unit and RF amplifier. Noise output, which can be up to +30dBm, is Gaussian in amplitude distribution and is varied by an attenuator of up to 127dB in 1dB steps. The instruments are fully micro-processor controlled and information on operation is given on a led display. IEEE-488 bus is standard. Atlantic Microwave Ltd, 0376 550220

Electronic loads. The Zentro Elektrik ELA200 and ELA500 electronic loads, which sink 200W and 500W, are now on the UK market. For use as test loads for PSUs and batteries, they can be used in either constant-I or constant-R modes. Two ELA200 versions cover 1-40V at 0-40A and 1-75V at 0-20A, while the 500W type handles 1-75V at 0-99A. The constant resistance is adjustable at the front panel from 0.1Ω to 30kΩ and 0.04Ω to 10kΩ respectively. Gresham Powerdyne, 0722 413080

100MHz oscilloscope. A compact four-channel, 100MHz oscilloscope, the V-1085' features sweep-time autoranging, trigger lock, CRT readout, frequency counter; auto trigger level and selectable signal output. The V-1085 provides four independent 100MHz channels, each possessing position control, +3% accuracy, selectable input coupling (AC and DC), and sensitivity (0.1V div and 0.5V div). All the oscilloscopes possess trigger lock for the observation of pulse trains, enabling the sum of the holdoff and sweep time to be held constant, a push button automatically selects the optimum sweep time (with approx 1.6 to 4 cycles of signal displayed). Hitachi Denshi (UK) Ltd, 01 202 4311

Clip-on Hall-effect meter. The HEME 600 AC DC clip-meter, offering a 1% accuracy, employing the Hall-effect to enable fast measurement of volts, amps and resistance without the need for direct contact into a circuit. The meter will handle conductor sizes up to 30mm. STC Instrument Services, 0279 641641

Circuit analyser. The National Microsystems Model 2600 continuity analyser is a high-speed low-cost system which combines a high testing capability with ease of use. Up to 1024 test points can be accommodated in one chassis and the system may be expanded to provide more than 65 000 test points. Whilst the system features the ability to program and test without the aid of another computer, test programs can be created off-line using an IBM PC AT or compatible computer. Smith & Jones, 0491 410700

Data logger. CS 1041, a portable diagnostic tool for process control systems, is based on MEDACS process control technology and is compatible with systems running Lotus 1 2 3, IBM PS2, AT OS2 or MS-DOS. It will accept either analogue or digital input from the host system, logging and time-stamping events at 100ms resolution. Data acquisition is controlled by pre-set parameters. Status Instruments Ltd, 0684 296818

Literature

Data, power instruments catalogue. Amplicon Liveline's catalogue contains a wide range of data acquisition, instrumentation and power supply products. Over 100 new products include a range of boxed products; analogue signal conditioning modules, a PC diagnostic system; and digital panel meters. Amplicon Liveline, 0273 570220

Linear application note. An application note on using switching regulators in power supply and other kinds of circuit design is available free from Linear Technology (UK) Ltd. The applications note contains schematics for more than 80 designs of battery-based switching power supplies. The application note is entitled "AN30 Switching Regulator Circuit Collection". Linear Technology 0932 765688

Power supplies

EHT DC-to-DC converter. Direct-current output ranging from 20V to 10kV is provided by the Model 2590 DC-to-DC converter module. Load current rating is 1mA and, at this level, the module draws around 700mA from the input supply of between 19V and 30V, quiescent current is about 120mA. Increasing output current from zero to maximum causes output voltage to vary by 0.3% and for a 22V to 30V input swing, output voltage varies by 0.1%. Flashover and overload protection is provided. Brandenburg, 0483 756066

DC/DC converters. BP50000 is a series of DC-DC converters which deliver a fixed output voltage from a wide range of input voltages (8-30V). Housed and epoxy encapsulated in compact 7 or 9 pin single-in-line packages, the series is suitable for supplementary on-board voltage regulators, telecom equipment and PC expansion boards. Rohm Electronics (UK) Ltd, 0908 271311

Programmers

PC-based eprom programmers. A range of PC-based eprom programmers offers the PC user versatile, easy to use products at low cost. Pals (20 and 24-pin), all 27 series eproms including c-mos and 87XX series CPUs are catered for by a variety of models. In all cases, complete software is provided and the programmers are driven by easy to use menu-style software. Flight Electronics Ltd, 0703 227721

Switches and relays

Miniature latching relays. Since no coil power is consumed when the relays are in a steady state, operating temperatures are low. During switching, the single coil version needs 150mW for 6ms and the double-coil version twice that power, also for 6ms. Coil voltage can be from 3 to 48V, and contacts, in a two-pole changeover format, are rated at 30V/1A and 125V 0.5A. ECC Electronics (UK) Ltd, 0628 810807

Flowswitches. Watermill flowswitches are primarily developed for the automatic operation of water pressure boost pumps, but are suitable for a wide range of other applications. They are designed for direct in-line connection and include a built-in solid-state power-control circuit. Switching sensitivity of 3 or 4in head of water, or a flow rate of 0.2 to 0.6 litres per minute, is a factory pre-set to customers requirements. The switches are rated up for flow rates up to 1200 litres/hour, and can be used with a wide range of fluids with temperatures up to 110°C dependent upon chemical composition and pressure. Watermill Products Ltd, 0883 715425.

Transducers and sensors

Pressure sensors/transmitters. A range of piezoresistive pressure sensors and transmitters been designed for severe environmental applications. Featuring an all-welded stainless-steel construction, the SenSym PS.GA/GC series are sensors and the BT/PT2000G1A series transmitters. Gauge pressure ranges are available from +15P to 300PSI or, as an option, from 1 to 25Bar. Output signals are in the 100mV FSD range. Celdis, 0734 585171.

Accelerometers. The EGCS-240D series of miniature accelerometers has fluid damping and mechanical overange stops making it robust and able to withstand shocks up to ±10 000g. Various measuring ranges are available from 15 to ±5000g; the units are fully temperature compensated and, being piezo-resistive, will operate in either static (DC) or dynamic modes. Entran Ltd, 0344 778848.

Vision systems

Image analysis. OFA-Master is a PC-based product designed primarily for the integration of image analysis with external systems such as motorised stages, positioning equipment, alarm circuitry etc. Software applications modules are available for automated image archive, particle sizing, low light level imaging, object tracking, DNA sequencing, instrument read-out, and laser beam analysis. Hardware includes either an erasable or write-once optical disc drive, full colour or 3-channel monochrome video input, real-time video rate averaging and differencing,and hardware-based histogram, convolution, thinning and connectivity operations. Oxford Framestone Applications, 02357 66078.

Computer board level products

DSP board. VASP-16, the VMEbus board from FDS is now available with enhanced speed processors giving benchmarks 30% faster. 30MHz Zoran Vector processors make the VASP-16 the fastest integer DSP board on the world market, claims FDS. It combines a TMS320C25 scalar processor running at 40MHz with four 30MHz Zoran Vector co-processors, along with fast VMEbus and multiple MAXbus 8 and 16-bit I/O ports. All I/O runs concurrently with processing for maximum throughput. The MAXbus interface standard is used. C source software is available for PC, OS/9 and Sun platforms and includes a 980 function library that makes the board easy to use. Future Digital Systems Ltd, 0256 882760.

I/O board. MetraByte's MacAdios II JR provides high-speed high-performance data acquisition and control for the Macintosh II. This unit consists of a multifunction, NuBus compatible analogue and digital I/O board with support software. It provides 16 single-ended or eight differential analogue input channels, jumper-programmable gain instrumentation amplifier, a high speed 12-bit A-to-D converter, two 12-bit D-to-A outputs, 16 digital I/O channels and 3 counter/timer channels. The 12 bit A-D converter is accurate to within 0.02% with a conversion time of 12.5ns. With 12-bit resolution, the least-significant-bit value is 4.88mV in the +10V range. Keithley Instruments Ltd, 0734 575666.

32kHz real time clock. The EM Microelectronic-Marin M3001 is a monolithic low-power c-mos device intended for use as a 32kHz real time clock for processor system applications. Time information is stored in a 16 × 8-bit ram and an 8-bit status word in the ram stores the user programmed mode of operation. Automatic leap year correction is provided. MCP, 0734 772345.

COMPUTER

Data communications products

Secure networking system. VSLAN secure system will link both mainframe and workstations operating at different security levels. VSLAN operates at the physical and data link protocol layers of the OSI (802.3) reference model. The VSLAN consists of a single Network Security Centre (NSC) and up to 64 network security devices connected by a LAN facility. The NSC provides a centralised management facility to control the operation of the VSLAN and also to collect and export audit data. Marconi Security Systems, 0245 267111.

Development and evaluation

VIC/VXI prototyping board. Supporting the VXIbus is a "C" size (6U × 340mm) 8-layer fully loaded high-density wire-wrap prototyping board, fitted with socketed pins to aid device insertion and complete with an on-board full VMEbus interface based on the VTC-068 chip. The board allows the use of 7.62mm, 10.16mm, 12.70mm and 15.24mm pitch devices in the wire wrap area and PGA devices up to 17 × 17 pins; +5V, -2V, -5.2V and ground are taken from the appropriate pins on the P1 and P2 connectors and distributed evenly across the board via dedicated layers. BICC-Vero Electronics Ltd, 0703 266300.

Emulator. The Multi-Prom eprom emulator supports 32-pin 1Mbyte eprom devices, enabling software developers to download information from PCs to target systems within seconds. The emulator is loaded via the Centronics printer port at the back of the PC. CMS Software Ltd, 0865 748875.

Modem design package. The PC-AT compatible modem design package/EB-V29 modem, includes a plug-in modem board and communication software. The board provides data-pump and source code level control software for the V25 16-bit microprocessor and the μPD77P230 digital signal processor operating in 24-bit fixed-point format. The software is modular in structure, allowing modifications and additional features to be incorporated and the hardware includes analogue front end, line telephone interface and two DTE interfaces for either PC data or V.24 (RS.232C) communication. NEC Electronics (UK) Ltd, 0908 691133.

Computer peripherals

Digitiser tablets. Wacom digitiser cordless tablets come with either a puck or a stylus, are totally passive, requiring no battery and are light in weight. The buttons on the puck have a positive action. The stylus comes in two types: the standard "press to select" mode or a pressure sensitive mode designed for graphics packages such as the Artisan software dependent on pressure. The full range spans A5 up to A0 and comes with Summagraphics and Microsoft mouse emulation software. Source Two Ltd, 089582 4944.

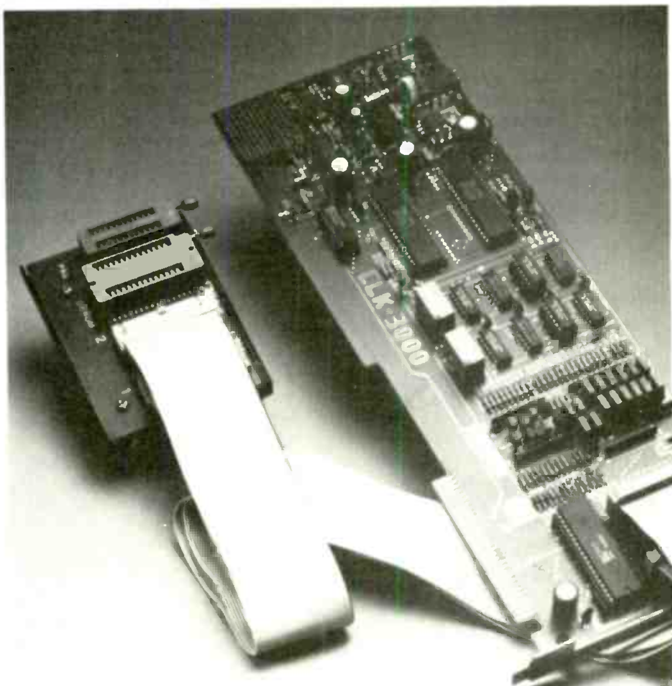
Programming hardware

Memory and logic programmer. Pronto Electronic Systems offers the SMS Sprint Expert, a combined memory and logic programmer. It supports pals and memories up to 5000-gate EPLDs, PGAs and 4Mb eproms in eight to 84-pin packages. It uses the IBM PC/XT/AT as its host. Pronto Electronic Systems, 01 554 6222.

Software

Ansi standard C compiler. These C compilers are fully transportable from one processor to another with no more than a single re-compilation being required. Programs written for previous systems can be used as a base for new development. Four modes of compilation are selectable, tiny, small, standard and large. Large provides a complete C implementation, including long integers and floating-point numbers, while Tiny squeezes code into the smallest possible space. Tiny is most useful for single-chip microcomputers such as 68HC11, 8051 and 1802 where data space is limited. The compilers can separate the data and code areas of the program to produce true rom-able code. American Automation UK Oxford, 0993 778991.

PC-based eprom programmer – one of the Flight Electronics range.



PIONEERS

40, Jean Maurice Emile Baudot (1845–1903)
The farmer who became famous


Emile Baudot (IEE)

Some days a stressed employee might feel he could shoot the boss. One day, one did.

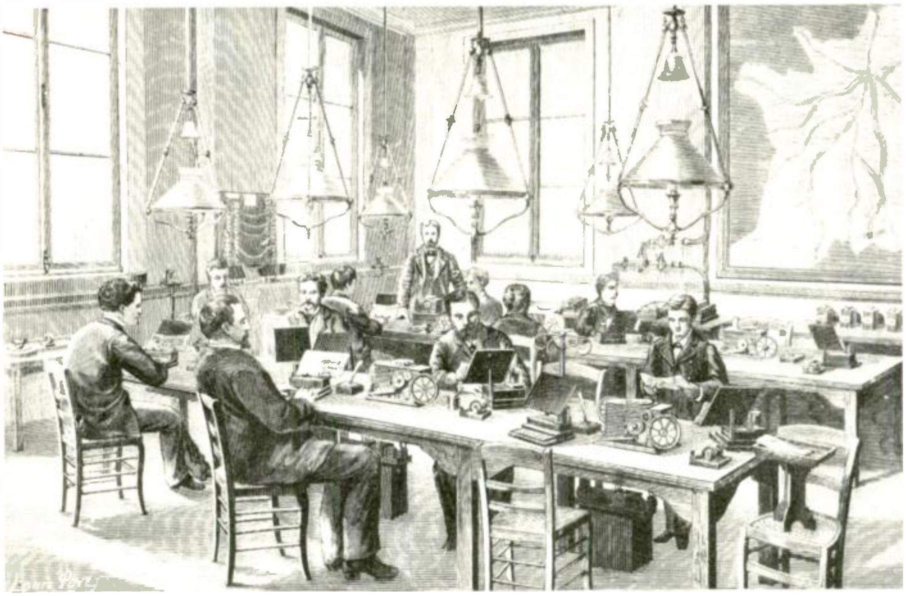
On the 4th January 1888, J. M. Raynaud, the Chief Engineer of the French Administration of Posts and Telegraphs and Director of the Telegraph College, left his office in the Rue de Grenelle in Paris at 11.45am to walk home. As he walked, a man approached him and fired six shots from a Bull 9mm revolver. Raynaud collapsed. After receiving first aid he was carried home on a stretcher.

The assailant was one Louis-Victor Mimault, a telegraph engineer who also worked for the French telegraph service and who claimed to be the true inventor of the multiple printing telegraph named after Emile Baudot. Holding Raynaud responsible for crediting Baudot with the invention, Mimault took the law into his own hands. For Raynaud, deciding between rival technical systems proved to be a matter of life or death . . . he died in agony eight hours after the attack.

Whatever Mimault may have dreamed, it was Baudot's name that went into the history books. Baudot's invention that established time-division multiplexing in practice, and Baudot we remember in the name of the unit for the speed of signalling: the baud. The baud was proposed as the unit of telegraph signalling speed at the International Telegraph Conference in Berlin in 1927.

Emile Baudot was born at Magneux, in Marne, France, on the 11th September 1845, very early in the era of the electric telegraph. His father was a farmer (though one reference has him a shoemaker; perhaps he was both) and his mother a dressmaker. His formal education was limited to that provided by the local primary school; there was not even a dream of a university place for him. His vocation was to follow in his father's footsteps and he trained as a farmer.

He has been described as being devoted to agricultural work and it is said that throughout his life he jealously guarded the simplicity of his upbringing. One contemporary, Montoriol, recorded that Baudot loved to speak of the rural life of his youth and the contrast he met when he joined the telegraph service. He "did not blush at his



Baudot's multiple printing telegraph, installed at the Administration des Telegraphes in Paris.

modest origins", wrote Montoriol, and enjoyed his ultimate fame and success without vanity.

At the age of 24 Baudot left agricultural work and joined the telegraph service where he was to become famous as the inventor of a new telegraph system. The crux of his system was the combination of an output printed on paper in plain language and the use of time-division multiplexing to send more than one message at a time down a line. Printing telegraphs, as they were known, were already in service and others had experimented with embryo time-division multiplexing. But it was Baudot who combined them into a successful working system.

At the time he joined the Telegraph Administration he was, in his own words, "completely ignorant about the existence of printing telegraph equipment". His knowledge was limited to a superficial understanding of the Morse and the dial telegraphs. To anyone meeting him, an agricultural worker with only a basic education, he would have seemed an unlikely candidate for fame which would last over a century. Nevertheless, his aptitude for inventing soon came to the fore. Before long he was developing his own ideas for a new dial telegraph which, however, was never built. As a paper invention, it was no better than many implemented years before by dozens of inventors of whose work he was totally ignorant.

In September 1869, the year he joined the Telegraph Administration, he was sent to Paris for a course on the famous Hughes telegraph, which automatically printed its message at the receiver in Roman type. This superb machine, invented by the American David Edward Hughes and patented in 1855, deserved its long and outstanding success in America and on the Continent. It "was magnificent printing apparatus," wrote Baudot, "whose ingeniousness and perfection caused me to abandon the idea of following in its track." His own ideas evaporated in the face of the Rolls-Royce of printing telegraphs and he studied the Hughes equipment until the following Spring.

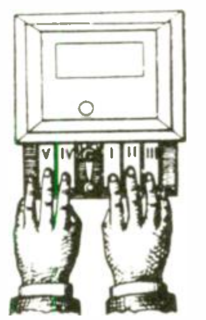
After completing his course Baudot joined the Central Paris telegraph station in July 1870 before moving to Bordeaux at the end of August as an employee 5th class. By then the Franco-Prussian War had broken out and by the end of the year he had been commissioned with the rank of Lieutenant and was serving with the military telegraph service of the Second Army. After the war ended, Lieutenant Baudot once again became a civilian and returned to duty in Paris in February 1872.

It was about this time that he began to speculate on how the two quite different telegraph systems then in use in Paris could be combined. One was the Morse system which needed a specialist operator to decode and write down the incoming messages. Its capacity had been increased by the Frenchman Bernard Meyer who had adapted it to allow four simultaneous signals to be sent along one wire. The other was, of course, the Hughes printing telegraph which sent only one message at a time.

Baudot had already started to acquire a reputation as an inventor for improvements he had suggested to existing equipment. He was now encouraged by the Chief Inspector of the exchange, M. Héquet, to design a "multiple Hughes". In itself the encouragement was something of a reward for his desire to search out improvements, but it did not extend to allowing him 'firm's time' in which to work out his idea. He was still expected to fulfil his normal duties and so it was his own free time in the evenings which was spent designing his multiple printing telegraph.

As work progressed, his own meagre resources became insufficient for him to construct his machine and so he turned to the Telegraph Administration, which

Keyboard and coding system of the printing telegraph transmitter.



Main Gauche V	Main Gauche IV			Main Droite I	Main Droite II	Main Droite III
		A	1	●		
	●	B	8			●
	●	C	9	●		●
	●	D	0	●	●	●
		E	2		●	
		É	&	●	●	
	●	F	f:		●	●
	●	G	7		●	
	●	H	h	●	●	
		I	º		●	●
	●	J	6	●		
●	●	K	(	●		
●	●	L	=	●	●	
●	●	M	)		●	
●	●	N	Nº		●	●
		O	5	●	●	●

Main Gauche V	Main Gauche IV			Main Droite I	Main Droite II	Main Droite III
●	●	P	%	●	●	●
●	●	Q	/	●		●
●	●	R	–			●
●		S	;			●
●		T	!	●		●
		U	4	●		●
●		V	'	●	●	●
●		W	?		●	●
●		X	,		●	
		Y	3			●
●		Z	:	●	●	
●		t	.			
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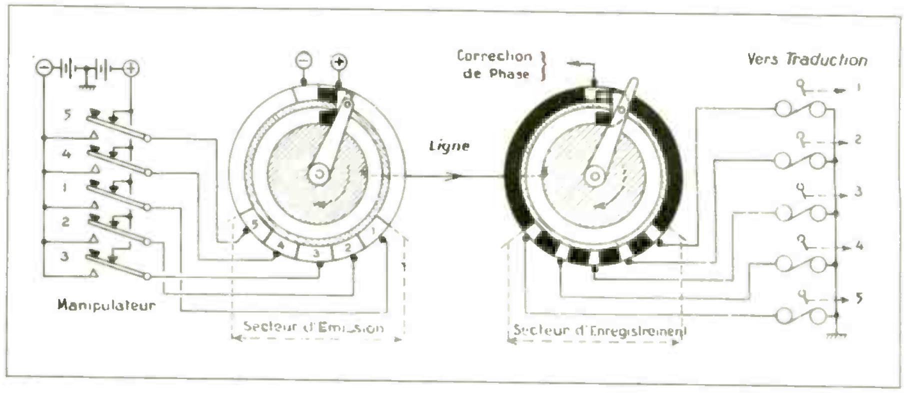
	●	BLANC de CHIFFRES				
●		BLANC de LETTRES				

at that time did not have a research laboratory. To persuade them to back the project with cash and materials he needed drawings produced to a professional standard. Others with the necessary skills were enlisted to help, they too giving up some of their evenings. At last, on the 17th June 1874, Baudot obtained his first patent for his "Système de télégraphie rapide". It came, incidentally, six months after Mimault received his patent for his own invention. Three weeks later Baudot offered his patent to the Telegraph Administration in exchange for the funds to build it.

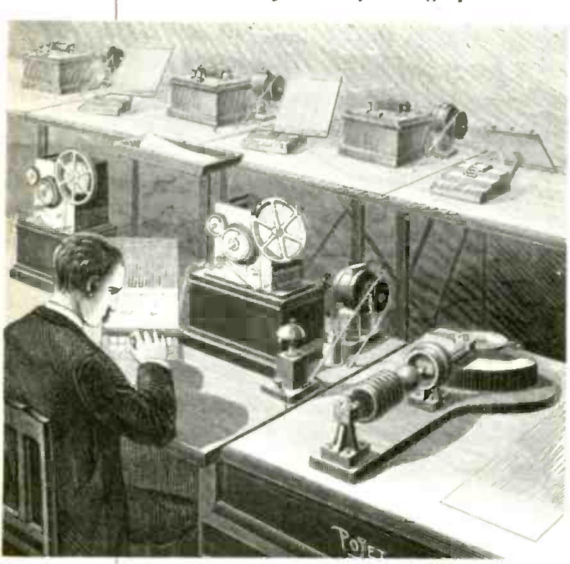
On the 25th July Baudot sent a letter to the authorities describing his proposed equipment. A five-man commission (including M. Raynaud) was set up to examine the proposals. They recommended a budget of 2000 francs for the construction of a prototype. In December the following year (1875) tests began which led to a quintuple telegraph being made for regular service.[1]

In his telegraph Baudot took advantage of the fact that the pulses comprising the signal were present on the line for only brief moments, leaving the line idle for much of the time. Several machines could use the line if their signal pulses could be so arranged, as it were, to fit in between each other. To do this he made a segmented distributor for each end of the line and this assigned the line to one message at a time. Six operators could share the line in this way. The distributor arrangement had been used earlier in France by Bernard Meyer, also of the Telegraph Administration.

The revolving arms of the distributors were connected to the line. As they swept round they connected the six individual telegraph equipments to the line in series. Each telegraph contact was further subdivided into five segments representing the five units of the Baudot code. The arms were synchronized by driving the one at the receiver slightly faster than that at the transmitter and using a sixth contact to apply a brake once every revolution. Both the transmitter's and receiver's arms were driven by clockwork.



Transmitter (left) and receiver. Sixth contact at top of receiver distributor synchronized the two arms, which were driven by clockwork.


One terminal of a multiple telegraph.

For time-division multiplexing (a term not then used) Baudot needed each character to occupy the same length of time. Each, therefore, used five pulses which could be positive or negative. In modern parlance, it was a five-bit code of ones and zeros. At the printer this code gave a geometric progression such that the first pulse could move a type wheel one position, the next moved it two positions, the next four positions, then eight and then 16, giving 32 positions in all. In this way the required letter could be brought into position at the right time and the message printed in plain language. It appears that, initially, Baudot used a sixth pulse to extend the progression to 32. In his description of the Baudot telegraph published in 1921, Fleming described it as "certainly one of the most ingenious telegraphic instruments ever invented".[2]

Writing 46 years after the initial invention Fleming could point to only one defect, the "nervous strain it puts on the sending operator". The transmitter operator had to synchronize his pressing of the transmitter's five piano keys to the arrival of the distributor arm at his set of segmented contacts, being neither too early nor too late. It was like playing to the strictest of tempos. The correct time was signalled to him by a "cadence tapper" which made a sound to tell him to press his keys. An electromagnet then held them down the required length of time, about one fourteenth of a second. About 140 letters could be sent in a minute, per operator, though a typical speed was around 20 words per minute.[2] Later, machines were designed to handle 60 words per minute.

Mimault, meanwhile, had progressed along his own path of invention. Also based in Paris, he had met and become friendly with Baudot when both were young men and their acquaintance had continued. His inventions did not, however, find the favour of the Administration in the way that Baudot's did and, as we have seen, he took his revenge. At his trial he was found guilty of murder, but not of premeditation, and was sentenced to 10 years forced labour and 20 years imprisonment.

Baudot died in 1903 at the early age of 58. Montoriol described him as prematurely worn out by a life of labour without rest but, unlike many inventive geniuses, he was privileged to have seen his genius "radiate around the world". His telegraph met with rapid success when it was introduced in France and was soon in use throughout Europe, India and South America. An early British use was on the Anglo-French cable and it was used extensively by the British Telegraph Service. Fleming ranked it with the Wheatstone Automatic and the Hughes Printing Telegraph as one of only three systems to have had extensive general use throughout the world. ■

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The author gratefully acknowledges the information provided by France Telecom on which much of this article is based.

AUDIO POWER, FETS AND FEEDBACK

Ivor Brown builds on his approach, described in an earlier article, to the careful application of negative feedback in fet audio power amplifiers

In a previous article published in the February 1989 issue of *Electronics & Wireless World* I described an approach to audio power amplifier design that goes against most current thinking, in that it incorporates a considerable amount of negative feedback. Its use of fets is the key to the design, as they introduce less cross-over distortion than bipolars and, when driven sensibly, are capable of a better high-frequency performance. This paper describes an amplifier following that approach.

The common-mode problem

In the first article I stated, without offering proof, that negative feedback did nothing to improve errors in the differencing process that occurs at the input of an amplifier between the applied and feed-back signals.

Figure 1 shows a simple feedback system built around a differential amplifier. It is normally assumed that the amplifier only responds to the difference between its input voltages, that is

$$V_0 = A_v[V(+) - V(-)]$$

where A_v is the voltage gain of the amplifier. In this case normal feedback theory applies and the overall gain of the system (A_{vf}) with a feedback fraction of β is

$$A_{vf} = \frac{V_0}{V_s} = \frac{A_v}{(1 + A_v \cdot \beta)}$$

and if $A_v \cdot B \gg 1$

$$A_{vf} \rightarrow \frac{1}{\beta}$$

Since B is determined by passive components, the gain of the feedback system can be accurately defined and made very linear.

Now suppose that the amplifier also responds to the sum of the input voltages so that

$$V_0 = A_{vd}[V(+) - V(-)] + A_{vc}[V(+) + V(-)]$$

where A_{vd} and A_{vc} are the gains for differential and common-mode signals respectively. A_{vc} can be considered as the error in the differencing process, not the usual definition of common-mode gain. Let $A_{vc} = k \cdot A_{vd}$, expecting k to be small. It will not, however, be constant over the signal cycle, since it contains the non-linearities of both A_{vc} and A_{vd}. The non-linear terms in k will extend to higher orders than those present either in A_{vc} or A_{vd}.

First, suppose there is no feedback, so that $V(+) = V_s$ and $V(-) = 0$. The amplifier's gain is given by

$$A_v = \frac{V_0}{V_s} = A_{vd}(1 + k)$$

Now with feedback, $V(+) = V_s$ and $V(-) = \beta \cdot V_0$, and

$$A_{vf} = \frac{V_0}{V_s} = \frac{A_{vd}(1 + k)}{[1 + A_{vd} \cdot \beta(1 - k)]}$$

If $A_{vd} \gg 1$ and k is small,

$$A_{vf} \rightarrow \frac{(1 + k)}{\beta(1 - k)}$$

Using the binomial expansion on the denominator and neglecting the k squared term, we finally have

$$A_{vf} \rightarrow \frac{(1 + 2k)}{\beta}$$

The effect of feedback is to make this source of distortion approximately twice as bad as it is in the basic amplifier. Feedback does not improve matters, it makes them worse!

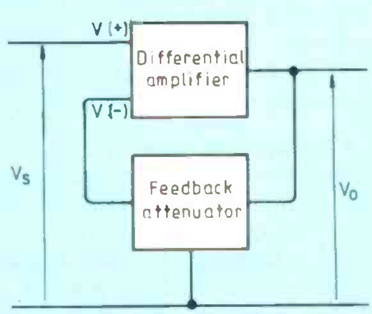


Fig. 1. Simple feedback amplifier using a differential amplifier. The input signal is the difference and also the sum of the input voltages.

The prototype circuit

Figure 2 shows the complete circuit diagram. On the right there is the four-fet output stage; all the devices are operated in the common-source mode and in class AB. The output power fets are Hitachi types 2SK346 N-channel and 2SJ102 P-channel. The driver pair are ZVN0106A and ZVP0106A, N- and P-channel respectively.

The basic two-stage output amplifier has a voltage gain of about 40 when loaded by an 8-ohm resistor, reduced to just below nine by the 220Ω and 22Ω feedback resistors. Some degree of quiescent current stabilization is obtained by the use of two separate feedback attenuators and the two 0.47Ω wire-wound resistors. For safety under test conditions, the 220Ω resistors (not wire-wound) need to be rated at 2W. The bandwidth of the complete output circuit is 3MHz.

The fuse has a resistor across it to preserve overall feedback when the short is removed. The 10Ω and 100nF Zobel network prevents the effective load ever becoming too inductive. The 1µH inductor to maintain stability with a capacitive load is made from 20 turns of 22SWG wire, close-wound on a 6mm diameter former.

Quiescent current through the output fets is larger than that required in bipolar designs but is not critical; around 80mA is usually chosen. However, the output circuit is temperature sensitive and some compensation is necessary. The four diodes and the driver fets are all mounted in a small isolated heat sink. Adjustment of the 5kΩ potentiometer that sets the quiescent current is critical and a multi-turn component should be used. A slightly negative temperature coefficient to the quiescent current results when the power devices are bolted to a substantial heat-sinking chassis. The arrangement has proved satisfactory over many hours of use and testing.

The fets used are not fitted with protection zener diodes on their gates, but none should be necessary, since the gate voltage rating cannot be exceeded. However, as one early amplifier was approaching overload, both its power devices went into conduction, putting an effective short circuit across the power rails. As overload is neared, the overall feedback tries to keep the output a faithful copy of the input, causing large spikes to appear in the earlier stages. The inclusion of the back-to-back zeners on the emitter-follower outputs zeners limits the spikes applied to the output circuit and removes the problem.

The rest of the amplifier consists of two emitter-coupled stages with current sources in their emitter circuits to give good common-mode rejection. The difference between the input signal and the fed-back signal is only about one two-hundredth of either signal and, as shown later, one emitter-coupled stage does not give adequate common-mode rejection. To minimize the output offset voltage, the input emitter-coupled pair should have their DC current gains matched at a collector current of 100µA and then fixed together with epoxy adhesive. The choice of transistors was made simply because they were available; I see no reason why other types should not be used with equal success.

Frequency response of the stages is tailored by the RC networks between the collectors to provide stability. If the types of fet in the output stages are changed, then it is likely that these values will have to be changed as well. The values were calculated using a computer model of the open-loop amplifier to give adequate stability margins when connected to a load of 8Ω and 2.2µF in parallel. Under normal loading the margins are about 14dB and 45° and the 10kΩ and 2.2pF phase-advance network in the main feedback attenuator was the only modification necessary;

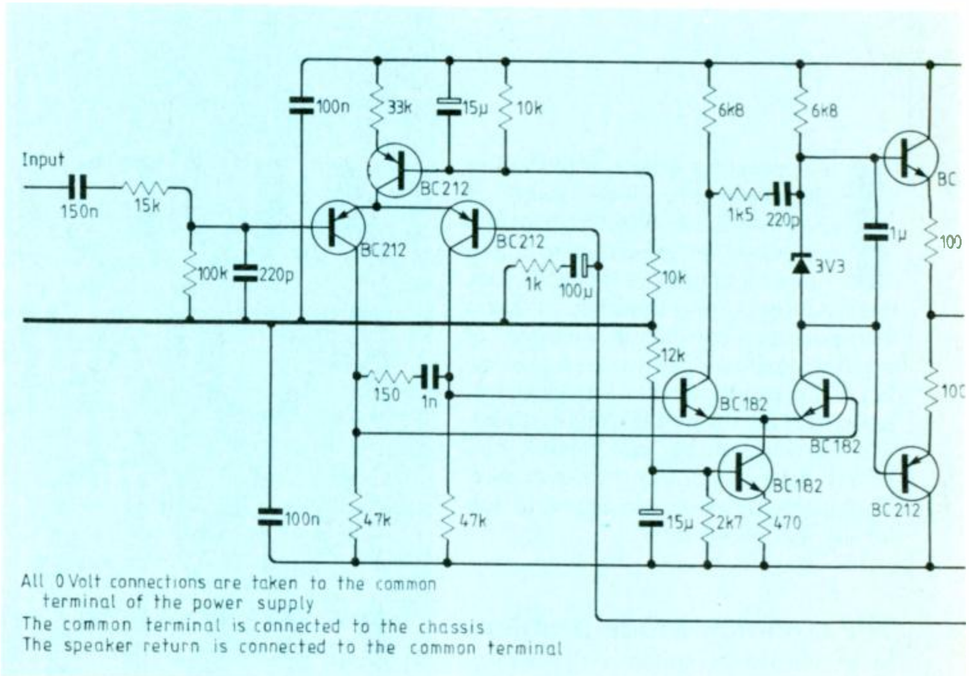


Fig. 2. Complete circuit diagram of the power amplifier using four fets in the output.

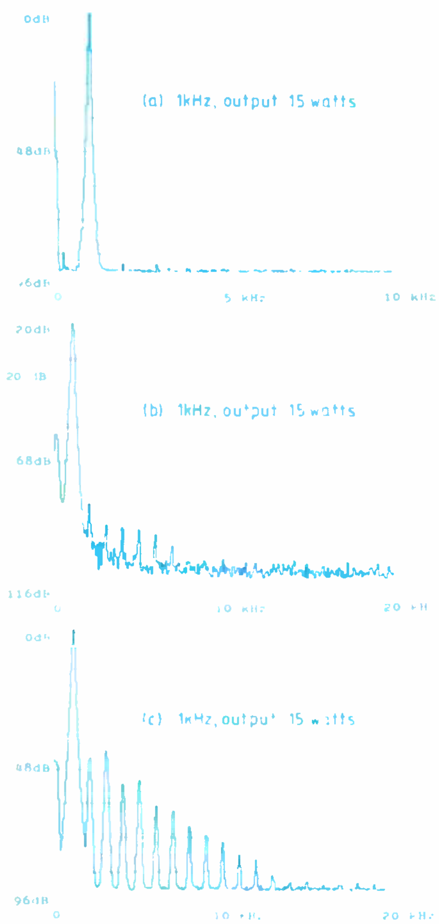
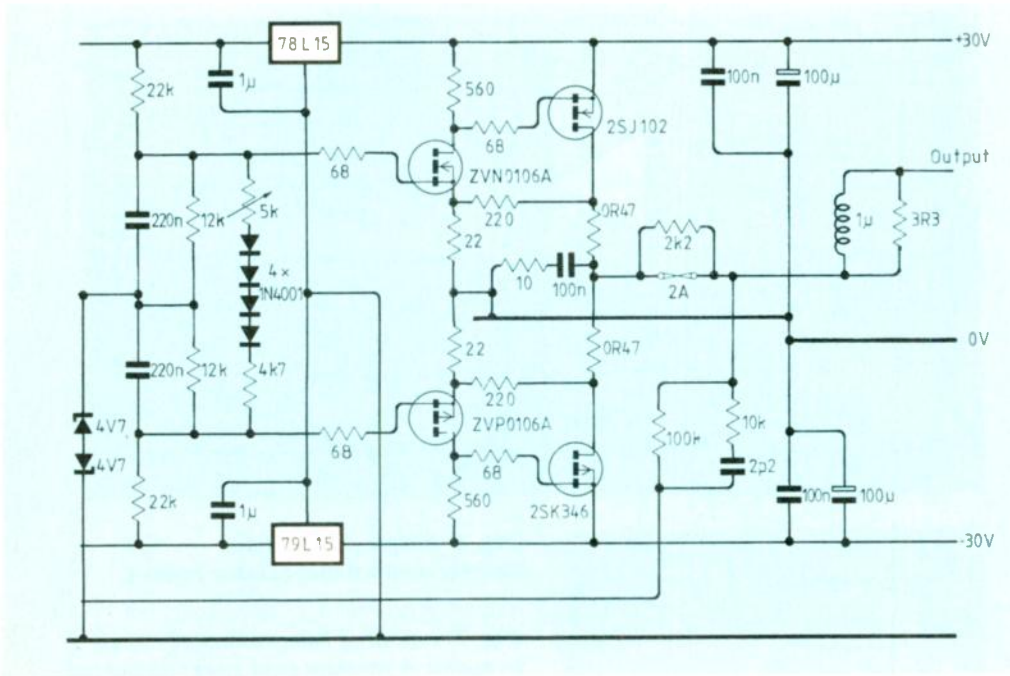


Fig. 3. At (a) is the output at 1kHz, second and third harmonics being barely visible; higher-order harmonics are not present. The spectrum at (b) was obtained by reducing the fundamental to show harmonics, which are at a low level. The spectrum of the small-signal amplifier is at (c) and shows the harmonics that cancel those in the output stage.



this comes into operation over 700kHz.

Overall gain is set by the 100kΩ and 1kΩ feedback attenuator from the output to the base of the right hand transistor of the input pair; DC gain is reduced to unity by the 100μF tantalum capacitor. Tests have not detected any alteration in performance when other types of capacitor are used.

The bandwidth of the basic amplifier circuit extends from around 1Hz to nearly 1MHz, the passive input filter limiting the system bandwidth to roughly 10Hz–40kHz. The amount of feedback present varies little for all audio frequencies.

Measured performance

To limit the number of diagrams in this paper, I am only including spectra for an output level of half the nominal maximum, 15W, which corresponds to about 30V peak-to-peak into a 8Ω load. At all lower levels there is less distortion evident in the output spectra. A band-pass filter was connected between the signal generator and the amplifier to reduce harmonics present in the input waveform.

Problems of making distortion measurements more than 80dB below the fundamental must be borne in mind when considering the results that follow. Variations of over 10dB in the indicated harmonic levels can be obtained merely by slightly altering the arrangements of the 0V line or the earth leads and poor contacts can also cause similar changes. At low frequencies, the magnetic leakage field from the mains transformers in test equipment can cause spurious signals.

Figure 3a shows the 1kHz output spectrum, in which second and third harmonics can just be seen above the noise. The size of these components depends largely on the degree of non-linearity present in the fets and on the matching of upper and lower halves of the output circuit. There is some variation between samples of the amplifier on this point and some do not quite meet the figure I gave in the February paper. The absence of any fourth or higher-order components above the noise level is typical of all samples.

The spectrum in **Fig. 3b** is for the same output passed through a simple band-reject filter that reduces the fundamental by 20dB and the second harmonic by less than 1dB. Higher-order, cross-over, components are present but at very low levels, all above the seventh being below −100dB. It is likely that the harmonic levels have been modified by distortion generated in the filter circuit, but the result suggests that minimal crossover distortion is present in the output waveform.

A spectrum of the small-signal amplifier output is shown in **Fig. 3c**, which illustrates the harmonic components fed to the fet output stages virtually to cancel the distortion that is generated therein; total harmonic distortion in the output stage is about 1%. The amplitudes fall rapidly with increasing frequency, so demonstrating the good cross-over performance obtainable with fets. Comparing this spectrum with the previous one, and considering the 46dB or so of loop gain, it appears likely that, at the final output, all the harmonics above the fourth are below −100dB. At this low level of distortion one cannot expect much correlation between the relative amplitudes in Figs 3b and 3c since there must be some distortion generated in the small-signal stages.

Figure 4 is the 10kHz output spectrum, in which higher-order components are not evident, the second and third harmonics being slightly increased from the 1kHz spectrum. This is to be expected as the compensating networks do introduce some phase shift in the open-loop response at this frequency.

High-frequency intermodulation was assessed using the 11 and 12kHz signals from the *Hi-Fi News and Record Review* test CD. Again, no intermodulation components appeared above the noise level.

Figure 5c shows the output for a 10kHz square-wave input. The upper trace was obtained with an 8Ω resistive load; the lower with a load of 8Ω and 2.2μF in parallel. The reactive load causes some ringing, but is well damped, illustrating the satisfactory stability margins obtained.

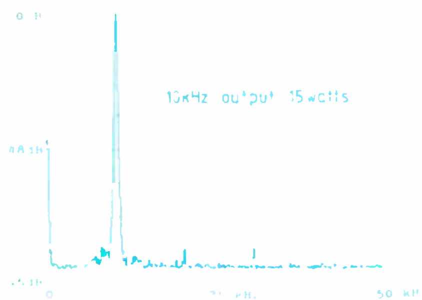


Fig. 4. At 10kHz, the spectrum shows slightly increased low harmonics due to phase shift, but nothing at higher orders.

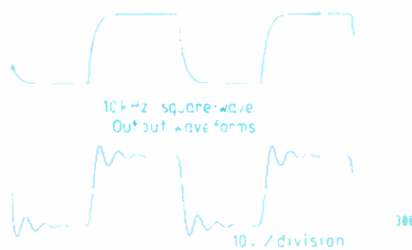


Fig. 5. A 10kHz square wave with an 8Ω resistive load (a) and an 8Ω plus 2.2 μF load at (b).

Input circuits

The fet power amplifier has a nominal maximum sinusoidal output power of 30W into 8Ω, with a voltage gain of 101 defined by the feedback loop. However, at its input there are passive filters which reduce the overall gain to 88, so for 30W output an input of about 175mV is needed. The input impedance is 115kΩ. When the filters are driven from a low impedance, the −3dB frequencies are 55kHz and 9Hz. A source impedance of 10kΩ mainly affects the upper frequency and lowers it to 31kHz.

Controls

The only essentials are an input selector and a volume control; the inclusion of a balance control is a matter of personal preference. Today, few recordings are made with a channel balance that requires correction, but an imbalance caused by poorly positioned loudspeakers is not unusual. The inclusion of a balance control need not require extra active devices in the system. Tone controls and steep-slope filters are now omitted from many designs since, for many designers, the additional active devices needed rule against their inclusion. In this paper they will not be considered further.

Inputs

Taking the inputs in a descending order of level, we have first the CD player. The nominal maximum output is 2V but, with the abrupt overload characteristic of digital sources, this figure is unlikely to be found in practice. I suggest that 1V is a reasonable figure to take as the input needed for maximum amplifier output.

The output levels of radio tuners, tape decks and similar sources are not defined and so reasonable estimates of the requirements are all that can be made. From experience, a sensitivity of around 400mV for maximum output seems suitable.

A moving-magnet pickup cartridge requires amplification and equalization. The output of cartridges is specified in terms of mV/cm/s of stylus velocity at 1kHz and is usually between 0.5 and 1. Maximum recorded velocity at this frequency should be 22cm/s, so a sensitivity of about 10mV at 1kHz is reasonable. Moving-coil pick-ups need a low-noise preamplifier or transformer before the equalizing circuit. These specialized components are beyond the scope of this article.

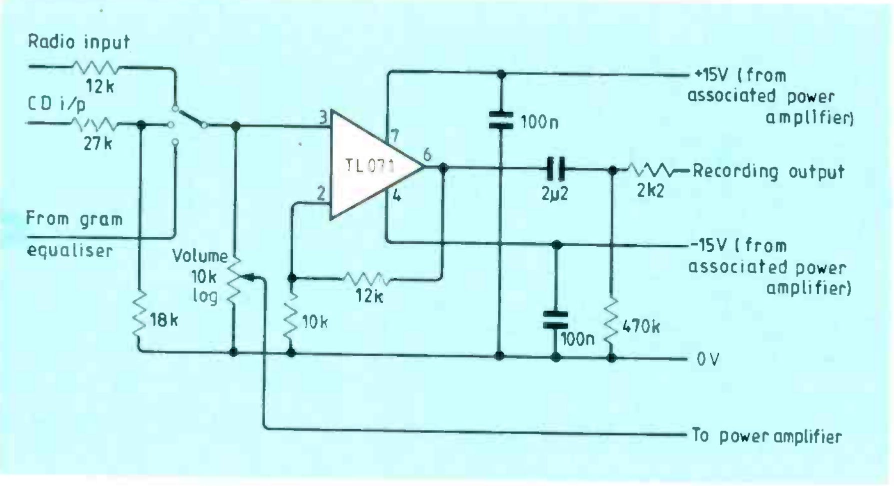


Fig. 6. Simple pre-amplifier arrangement without balance control.

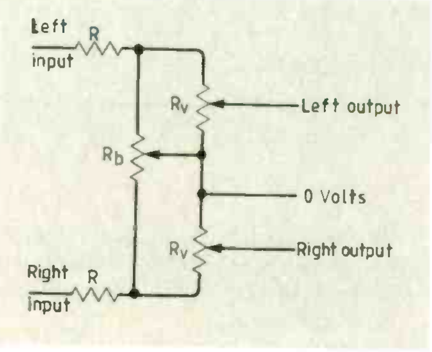
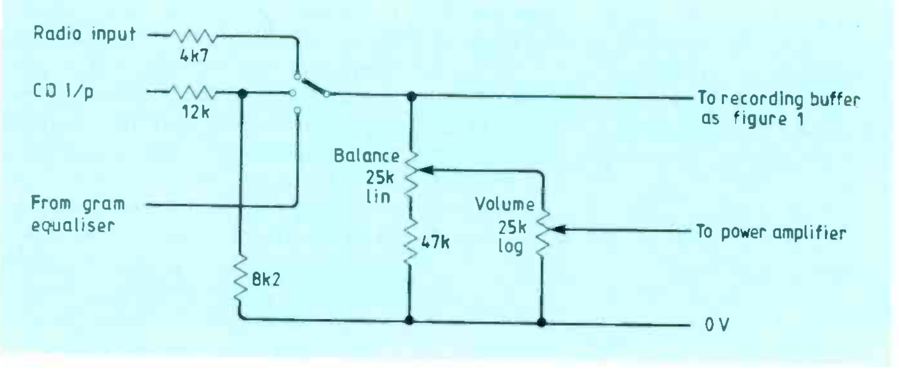


Fig. 7. Layout of balance control circuit to maintain constant total power output.

Fig. 8. Practical balance control to provide 7dB difference between channels – enough to move mono sound between speakers for a central listener.



Balance

Figure 6 illustrates a simple arrangement without a balance control, only three inputs being shown for simplicity; the radio input can be duplicated for the tape recorder and auxiliary inputs. For this input the 12kΩ resistor gives an input sensitivity of 385mV, the maximum output resistance presented to the power amplifier being 5.5kΩ.

For CD the 12kΩ resistor is replaced with a 2.5:1 attenuator that has an output impedance of around 12kΩ. The input impedance for this input is about 33kΩ.

The equalizer amplifier for the pickup input is described later.

Since the input from a tape recorder has been attenuated before reaching the selector switch, a simple non-inverting amplifier is incorporated to restore it to its original level. This amplifier also serves to isolate the amplifier signal from any low-impedance load that may be connected to the socket.

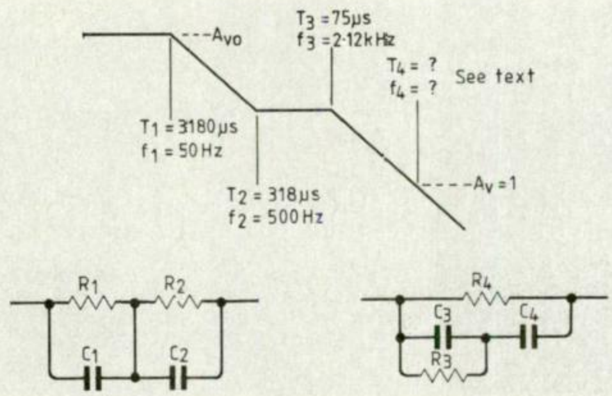
A simple balance control that maintains the total output power output

The essence of the design is that the use of fets, with their good high-frequency performance, in the output stage of a power amplifier allows a higher-frequency roll-off in the earlier stages and larger amounts of negative feedback than is currently considered normal, while still maintaining stability. The beneficial effects of feedback, when carefully used, are then seen throughout the audio range of frequencies nearly constant for all positions of the control is shown in **Fig. 7**. If R_v, the volume-control potentiometer, has a much greater value than the balance control R_b, then making $R = 0.7R_b$ satisfies the above condition. For lower values of R_v, the parallel combination of R and R_v must equal this figure. A linear wire-wound potentiometer should be used for R_b as the wiper provides a good short on the wire element to ground; a composition potentiometer's wiper may not make contact all the way across the track and give rise to some crosstalk. Complete isolation can be obtained by using a ganged pair of potentiometers with their wipers grounded, but with $R_b = 10k\Omega$ and $R_v = 25k\Omega$ the loss in the network is too great for the fet amplifier.

Subjective tests suggest that a difference of about 7dB will place the mono sound image close to the louder speaker for a central listener. **Figure 8** shows a circuit that provides this degree of balance control.

Pickup equalizer

Figure 9 shows the Bode straight-line approximation to the standard RIAA response defined by the three time constants T_1, T_2 and T_3. The diagram shows two networks whose impedance follows this response, and their design equations. The resistance of the network (R_t) has to be considered with the three time constants to define the four component values. The performances of the two are obviously identical, but it may be that the components for one or the other are closer to preferred values.



The resistance between the terminals of a network = Rt

$$C_1 = \frac{T_1(T_1-T_3)}{R_t(T_1-T_2)} \qquad C_3 = \frac{T_1 T_3(T_1+T_3-T_2)}{R_t(T_1-T_2)(T_2-T_3)}$$

$$C_2 = \frac{T_3(T_1-T_3)}{R_t(T_2-T_3)} \qquad C_4 = \frac{T_1+T_3-T_2}{R_t}$$

$$R_1 = \frac{R_t(T_1-T_2)}{(T_1-T_3)} \qquad R_3 = \frac{R_t(T_1-T_2)(T_2-T_3)}{(T_1+T_3-T_2)^2}$$

$$R_2 = R_t - R_1 \qquad R_4 = R_t$$

Fig. 9. Straight-line Bode plot of RIAA response, showing the three time constants T_1, T_2 and T_3; T_4 is due to the amplifier running out of gain at high frequencies. The two networks are similar in performance.

The RIAA network may be connected as part of an attenuator in cascade with a flat-response amplifier, to make a system with passive equalization. Noise considerations necessitate the amplifier preceding the network and so it must be able to handle relatively large high-frequency signals, which are severely attenuated by the network. More usually the network is used to define the voltage gain of a feedback stage.

In the prototype system, a feedback equalizer built round a single IC is used. TLO71 amplifiers have been used in the Brunel University laboratories for audio signals at about the 1V level with distortion products not greater than 100dB below the fundamental.

A feedback equalizer can use either voltage-shunt or voltage-series feedback. In the former case, **Fig. 10a**, the stage will have a very low input impedance, so that the standard 50kΩ input resistance required by the cartridge will have to be obtained by adding a series resistor, which may degrade the noise performance unacceptably. The advantage of this approach is that, provided the amplifier has sufficient gain, the frequency response accurately follows the impedance of the network.

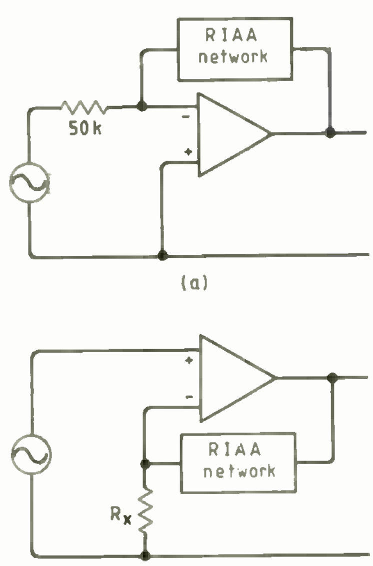
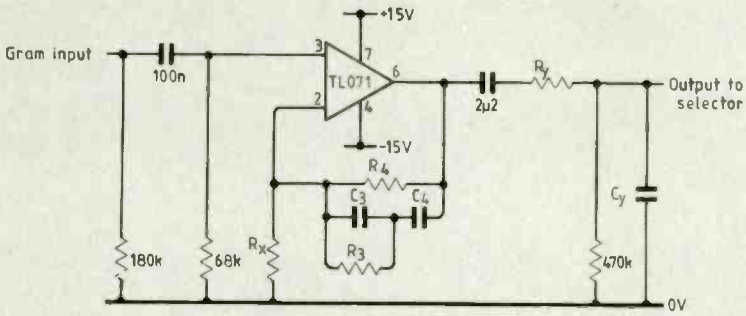


Fig. 10. Two methods of connecting feedback equaliser: (a) in voltage shunt and (b) in voltage series.

The voltage-series circuit in **Fig. 10b** does not suffer the noise problem and does provide a high input impedance. The 50kΩ can be obtained by means of a shunt resistor that does not compromise the noise performance. The complication with this system is that the gain is not simply proportional to the impedance of the network. The algebra given in the appendix, which assumes a very high-gain amplifier, shows that the denominator of the gain expression contains the correct two time constants, T_1 and T_3. However, the numerator also contains two, one more than is wanted. One of these we require to be at T_2, and the other, T_4, is due to stage gain tending to unity at high frequencies instead of continuing to fall as required by the RIAA response. This problem can be solved by adding a simple cancelling resistor-capacitor filter after the feedback stage.

The second problem is that the lower rising break in the amplifier's response does not occur at T_2. The network will have to be designed for another time constant, T_{2x}, so that when included in the feedback amplifier, the overall response does exhibit the correct T_2. The appendix shows expressions for T_{2x} and T_4, both depending on the low-frequency gain of the stage (A_{vo}).



Circuit		A1	A2	B
C3	=	3n6	3n3//220p	3n3
C4	=	10n	10n	10n
R3	=	22k	24k//560k	24k
R4	=	300k	300k	300k
Rx	=	1k5	1k5	680
Cy	=	2n2	2n2	390p
Ry	=	2k	2k	4k7

Fig. 11. Circuit of pickup equaliser. RC network at right avoids the problem of T_4.

Low-frequency gain in the RIAA response is some 20dB above the gain at 1kHz, so a low-frequency input sensitivity of about 1mV is needed. The gain of the equalizer depends on whether a balance control is included. Suitable low-frequency gains for the amplifier are about 200 for use without a balance control, and about 450 for use with the control; the two circuits will be referred to as A and B respectively. Their overall gains are lower than these figures due to the loading of the passive filters after the amplifier stages.

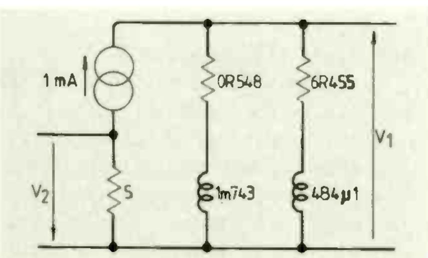


Fig. 12. Ideal model of moving-magnet cartridge.

Looking at component catalogues, it appears that close tolerance capacitors can readily be obtained only up to 10nF. To avoid capacitors in the network exceeding this value, R_4 must not be less than 300kΩ. The low-frequency stage gains and theoretical numerator time constants, in microseconds, for the two versions shown in **Fig. 6** are:

circuit A: $A_{vo} = 201$ or 46.1dB:
$T_{2x} = 307.1 : T_4 = 3.731$
circuit B: $A_{vo} = 442$ or 52.9dB:
$T_{2x} = 313.0 : T_4 = 1.70$

Complete equalizer circuits were analysed with a simple computer package. The circuit in **Fig. 12** models an ideal pick-up cartridge with an output of 5mV at 1kHz (V_1) and also a frequency-independent output of 5mV (V_2). Frequency responses obtained by feeding the equalizer from V_1 and comparing it to V_2 shows the voltage gain at 1kHz and

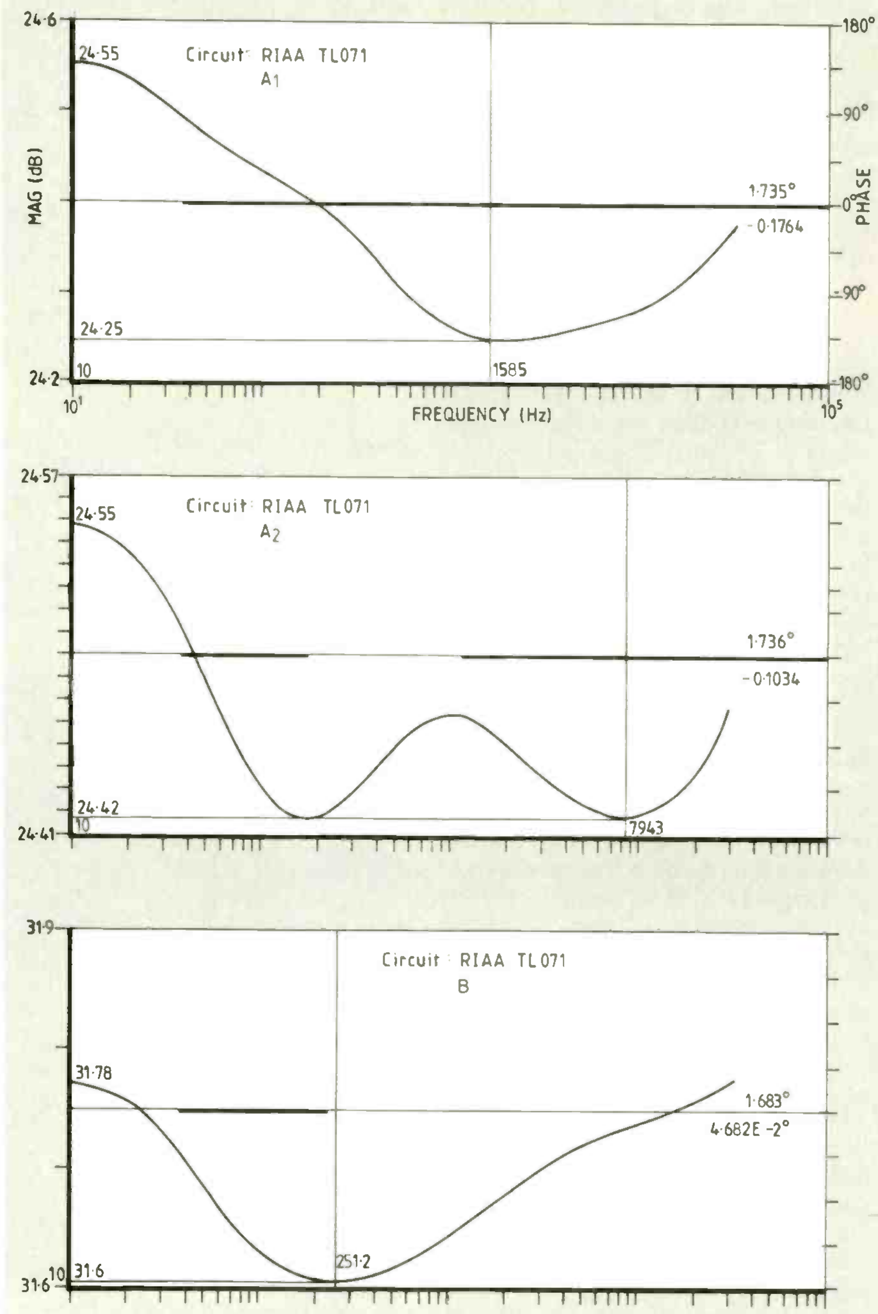


Fig. 13. Results obtained from the equaliser circuit using the three sets of values shown in Fig. 11.

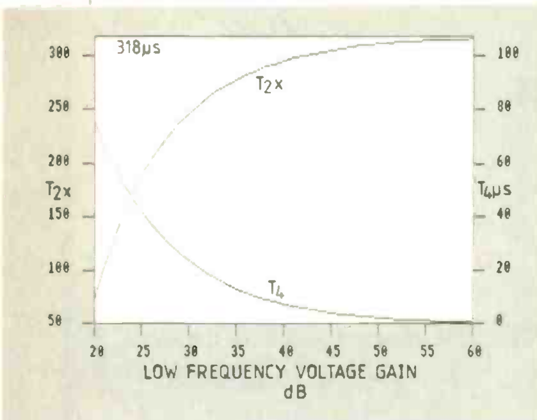


Fig. 14. Variation of T_{2x} and T_4 with A_{vc}. Equaliser network must be designed to use T_{2x} to take account of amplifier's frequency response not corresponding to T_2.

the accuracy of the circuit. Initial analysis included a very high-gain, wideband amplifier model, with the theoretical values accurate to four figures, for the passive components. Responses were both correct to within ±0.01dB over the range 10Hz to 100kHz. Changing to a TL071 model with a DC gain of 200 000, and unity-gain frequency of 3MHz increased the dB errors by about ten times.

Figure 11 includes three sets of practical component values. Set A_1 is the best that can be done for the lower-gain equalizer with single components from the 5% range of values. Set A_2 is an improved version with two sets of parallel components and set B gives the higher-gain system and has a response within 0.1dB over the range 10Hz to 20kHz with no components in parallel. The results of analysing these circuits are in **Fig. 13**; the phase responses do not deviate far from zero degrees.

Using 1% tolerance components to build these circuits, the responses are unlikely to deviate from the computed curves by more than 0.2dB. All the circuits that have been constructed fall well within this figure.

The 100nF input capacitor provides the additional bass-cut at about 20Hz as required by IEC specifications, while the 180kΩ and 68kΩ resistors provide the required 50kΩ input resistance, the former also serving to keep the input at DC ground potential if left open circuit.

Appendix

Let the impedance of the RIAA network be Z.

In Fig. 9,

$$Z = \frac{R_1(1+sT_2)}{(1+sT_1)(1+sT_3)}$$

Assuming a very high gain amplifier the gain (A_v) of the voltage-series circuit is

$$A_v = \frac{R_x + Z}{R_x}$$

At very low frequencies

$$A_v = A_{vo} = \frac{R_x + R_1}{R_x}$$

Substituting and rearranging terms we find

$$A_v = A_{vo}\frac{1 + s[\{T_1 + T_3 + (A_{vo} - 1)T_2\}/A_{vo}] + s^2[T_1T_3/A_{vo}]}{(1+sT_1)(1+sT_3)}$$

The denominator is as required, but the numerator contains two time constants. There will be a high-frequency break (T_4) because the gain of the stage tends to unity as Z falls to zero at high frequencies. The equation will not, in general, give the wanted value for T_2, so replace T_2 by T_{2x}; a value for T_{2x} will be found to give the correct overall response.

We require the numerator to be of the form $(1+sT_2)(1+sT_4)$, so the 's' squared term must be $(T_1 \cdot T_4)$, and the 's' term $(T_2 + T_4)$. Comparing these terms with those in the last equation for A_v with T_2 replaced by T_{2x}, we have

from the squared term

$$T_4 = \frac{T_1T_3}{A_{vo}T_2}$$

from the linear term

$$T_{2x} = \frac{A_{vo}T^2 + T_1T_3 - T_2(T_1 + T_3)}{(A_{vo} - 1)T_2}$$

The variation of T_{2x} and T_4 with A_{vo} is plotted in **Fig. 14**. As expected, when the gain is large, T_{2x} approaches T_2. The graph shows how much alteration to the basic network is necessary for low-gain equalizers. In designs where only two or three discrete transistors stages form the amplifier, a low-gain equalizer is unavoidable if the limited amplifier gain is not to affect the overall response. ■

Mobile Radio Servicing Handbook, by R. Belcher, M. Fitch, D. Ogley and G. Varnell. As its title indicates, this is an essentially practical book on the choice, installation and maintenance of systems and equipment.

It is not intended as a specific guide to particular equipment, but rather covers the subject in a wider sense, thereby allowing the engineer to gain sufficient knowledge of the subject to develop his own methods and to apply it to any hardware he might encounter.

The first few chapters discuss the principles of the subject and are followed by four on principles and practice of communications and RF measurements. There is a section on EMC and a comprehensive chapter on aerial selection, installation and maintenance. Finally, three chapters are included on cellular systems, digital techniques and data communications. Heinemann Professional Publishing, hardback, 281 pages, £25.

Telecommunications Primer, by G. Langley. With the implications of the buzz words "information technology" well in mind, the author presents in this third edition a large number of sections on theory and practice.

It is not written for the communications engineer, but is intended for relatively non-technical managers who need an understandable guide to what is happening in the field and need to be able to talk intelligently on the subject; and also for those students who are not primarily concerned with telecomms and IT but who nevertheless must be familiar with its fundamentals.

The book is written simply and concisely and is well suited to its professed task of informing the uninitiated. Pitman Publishing, card covers, 182 pages, £9.99.

Newnes Microprocessor Pocket Book, by Steve Money. This is one of a series of extremely useful little books which function as *aides-mémoires* for the practising engineer and avoid the need to sort through a collection of sources.

Microprocessor operation is described and a general discussion of typical instruction sets is provided, leading to a number of sections which describe in detail the common 8bit, 16/32bit and risc processors.

Sections on displays and development systems complete the book, except for lists of abbreviations and some useful manufacturers' addresses. Heinemann Profession Publishing, hard back, 252 pages, **£9.95**.

Diagnosing board faults

Ian Fletcher describes an instrument for testing boards in low-volume production, which needs no programming or expensive test fixtures

The performance and capability needed by modern automatic test equipment has a tendency to put it beyond the reach of smaller-volume equipment producers who do not have the throughput to justify the capital investment and running costs.

Many smaller companies use little or no bought-in ATE. Often, their boards pass from the production line to a final "hot bed" or functional system test. With a little effort and ingenuity, this approach can offer effective quality control – without recourse to ATE.

Repair or discard

There still remains the problem of what to do with boards that fail the final test. Since it is usually impractical to build extensive diagnostics into the final test, the smaller company is faced with a simple choice – either throw the bad boards away or undertake a separate procedure to locate the fault and repair it.

The first option may appear attractive when the product is relatively simple and cheap to discard but, even if yields are high, it is generally not to be recommended. By disposing of faulty boards, the manufacturer gains very little knowledge of why they failed – information which is vitally important if the production process is to be improved and quality maintained. If the failure rate on high-value boards suddenly increases due to a recurring fault, discarding them becomes too expensive to contemplate and rework becomes necessary.

The automated approach

In recent years, manufacturing defects analysers (MDAs) have become a popular way to track down board faults. Although these machines are less expensive than full-blown in-circuit testers, they must still be fed by considerable numbers of boards to justify their cost.

The lower-volume producer who does not even employ a bought-in machine for final test is even less likely to be able to justify an MDA for fault diagnosis. Apart from the significant initial cost, an MDA usually requires expensive custom bed-of-nails fixtures and considerable programming effort for each type of board tested.

In a diagnostic role, an MDA will only receive boards that fail the final test, so even if production volumes are high, the MDA may only be justified if quality is poor. As quality improves and more boards pass final test first time, the MDA becomes less economic to run.

Manual test

If the automated approach is beyond their reach, many companies entrust the diagnosis of board faults to engineers with general-purpose instruments such as oscilloscopes, logic probes and multimeters.

But this method also has its drawbacks: manual testing is time consuming and requires qualified, experienced staff. Also, it is often difficult to exercise a board's logic whilst performing the tests; if a board is suspected to have a fault in its floppy-disk controller section, for example, the engineer would somehow need to make the board perform continuous reads and writes to disk. It is not feasible to exercise all the possible logic states, so faults can be missed.

Manufacturers having a relatively low number of boards to rework need something between the fully automated MDA and the manual troubleshooting approaches: a method that provides a well-defined test procedure with some form of automation, that does not tie up highly paid engineers and that offers low initial and running costs.

In-circuit testing

A solution to these conflicting requirements has emerged with the in-circuit digital IC tester, intended primarily for service and repair departments, whereby the operator simply attaches a test clip to each device in turn. The functionality of each IC is automatically checked by the equipment and any faulty devices reported.

It may seem unlikely that this type of machine would be appropriate for the testing of newly manufactured boards, since the nature of faults found in them differs from that of faults in boards that have spent time in the field, which usually suffer from failed ICs and other component faults. If goods-inward tests have been performed, less than 5% of faults on new boards are due to defective components; most faults are manufacturing defects such as wrongly inserted components, solder bridges, dry joints, broken tracks and holes which have not been plated through properly.

Simply checking a board's ICs will not detect these major sources of board failure. Fortunately, however, it is possible to extend the in-circuit IC test approach, since the clip which fits around each IC can be made to look outwards at the board as well as inwards at the device itself.

By examining the connections to each component in turn, the tester can build up a complete view of the board's interconnection and show discrepancies between the observed and expected connections, giving a good indication of where manufacturing defects lie.

ABI Electronics produces the DDS-40XP IC tester with this added capability, which can locate faults on a range of board types and is low enough in cost to bring it within reach of lower-volume board makers.

Dividing the test into smaller tasks means that only a small number of channels is required, which makes the instrument relatively inexpensive. A test clip that fastens onto standard dual-in-line packages is often all that is needed to connect to the board – no costly fixtures are required. The DDS-40XP can functionally test the components on the board, a capability beyond the conventional MDA. This facility, which can be run whilst performing a manufacturing defects test with very little speed penalty, will pick up the odd faulty component that has found its way into production and is also useful for locating faults such as the insertion of a wrong component which an MDA might miss. Tests for a comprehensive range of SSI, MSI, memory and peripheral devices are held in a library within the tester and called up as required.

Semi-automated test

When diagnosing faults with this tester, the operator first connects the board under test to the machine's 5V supply. He then attaches a test clip to each device, in any sequence; the tester automatically positions the clip, so that any size of clip can be placed over the IC in any position, provided all the pins are covered. This allows one clip size to be used for ICs with various numbers of pins, wherever the operator happens to fasten it on, even if it is reversed. Often, a single clip can be used to test a whole board.

The clip is connected to tri-state digital output drivers within the tester, which are capable of sinking and sourcing sufficient current momentarily to back-drive the inputs to the device under test and effectively isolate it from the circuit. Minimum currents and times are used to do this, to prevent any possibility of damage to other devices through overheating.

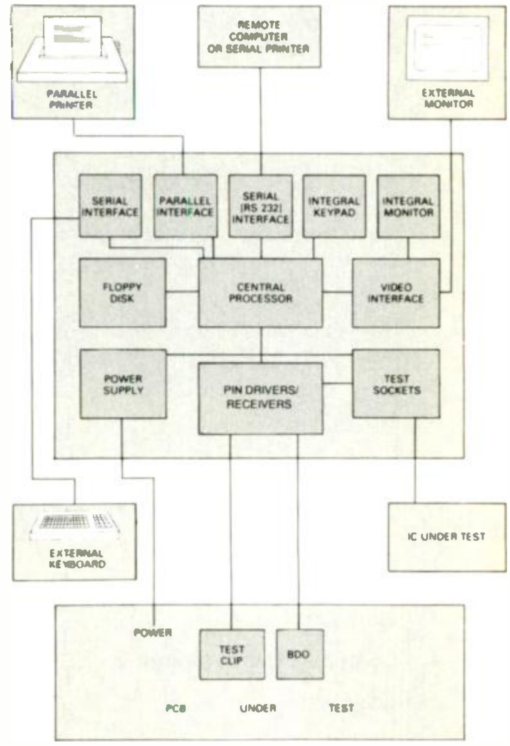
Once the tester has determined the position of the device in the test clip, it checks that both the supply and ground rails are present and within specification. If not, the test is aborted and an appropriate message displayed.

The tester continues to analyse the IC's connection in the circuit, checking whether any of the device inputs are not being driven or any test-clip pins are open-circuit. Pins shorted to the supply rail or linked to another pin on the device are detected.

Automatic circuit compensation

Such connections pose problems for traditional ATE, since they prohibit the application of certain test patterns to the device. For example, a two-input Nand gate connected as an inverter with both inputs tied together cannot have different logic levels applied to its inputs. Conventional testers need such information programmed into them, but the DDS-40XP automatically compensates for links and shorts. It does, however, also have the intelligence to recognise when the configuration does not make sense – an IC output connected to ground, for example – and will indicate the fact. This automatic compensation removes the need for any form of circuit configuration programming, greatly reducing the skill and time demanded of the operator to set up the test.

Finally, devices are functionally tested. Combinational ICs such as gates, buffers and decoders can simply be checked against their truth tables. Sequential parts such as flip-flops, counters and registers are subjected to tests which exercise them through all their possible states, the tester issuing such pulses as clock, clear and preset as appropriate. The instrument will handle 40-pin devices such as the 6800, Z80 and 8085 microprocessors. As well as being displayed on the screen, test results can be sent via built-in RS232 or Centronics ports to a printer or to a computer for storage and analysis.



System diagram of ABI's DDS-40 series, which tests ICs or complete boards.

Power-off testing

To meet the special needs of manufacturing defects testing on small to medium volume assembly lines, the tester can make tests which identify shorts, links and floating pins without the board being powered, thereby finding faults without risking further damage if the board has previously shown signs of overheating.

Testing with no power on the board also checks on any type of dual in-line device, not just ICs: op-amps, comparators, linear ICs and even relays and opto-isolators can all be probed in the same way as digital components.

To keep the operator's tasks to a minimum, the DDS-40XP has "save and compare" facilities, which allow details of a known good board to be stored on a floppy disk, using the tester's disk drive. The system compares the results with the stored data and highlights any differences.

To sum up, the instrument offers a cheaper alternative to the MDA, with the advantage that it is equally useful in a service department. ■

The DDS-40XP is obtainable at £4950 (exc. VAT) from
ABI Electronics Ltd,
Mason Way,
Platts Common Industrial Park,
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