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FEBRUARY 1989 £1.95

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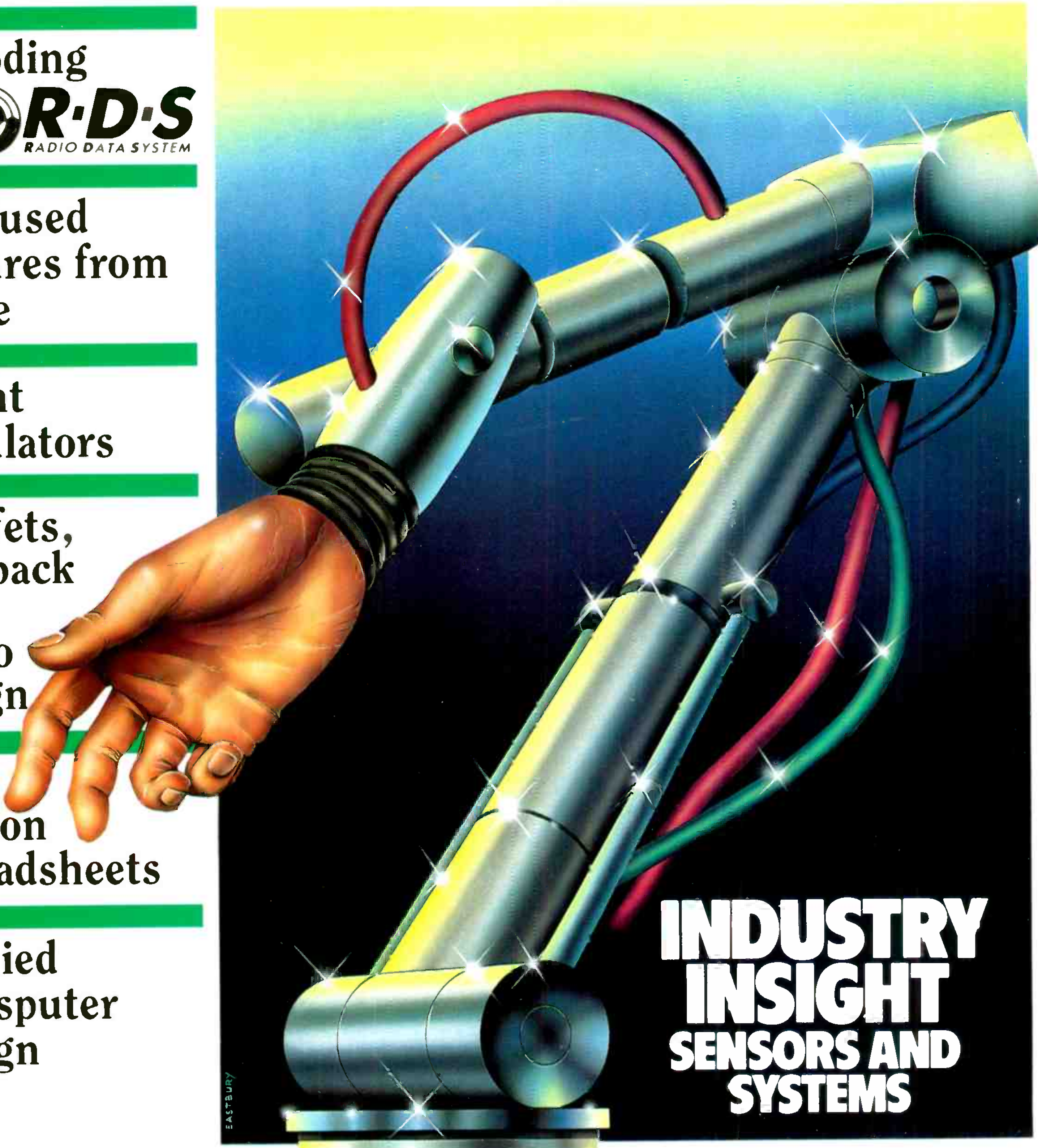

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TAYLOR RF/VIDEO MEASUREMENT INSTRUMENTS

MEASUREMENTS MADE EASY

UNAOHM EP741FMS FIELD STRENGTH METER/SPECTRUM ANALYZER

Frequency Range: Continuously adjustable via a geared-down vernier as follows:

IF	38.9MHz
Band I	46 to 106MHz
FM Band	88 to 108MHz
Band III	106 to 290MHz
Band H	290 to 460MHz
Band U	460 to 860MHz

Frequency Reading: TV Bands — 4 digit counter with 100KHz resolution
FM Band — 5 digit counter with 10KHz resolution
Reading Accuracy: reference Xtal +/−1 digit.

Function: TV Monitor NORMAL: picture only
ZOOM : 2 to 1 horizontal magnification of picture
: picture + line sync pulse (with chromaburst if TV signal is coded for colour)

Panorama: panoramic display of the frequency spectrum within the selected band and of tuning marker.

Panorama Expansion: Adjustable expansion of a portion of the spectrum around the tuned frequency.

Analogue Measurement: 20 to 40dB. Static measurement of received signal. Scale calibrated in dBuV (at top of picture tube) to rms value of signal level.

DC/AC Voltmeter: 5 to 50V.

Measurement Range: 20 to 130dBuV in ten 10dB attenuation steps for all bands; −60 to 130dBuV in nine 10dB steps for IF.

Measurement Indication: ANALOGUE: brightness stripe against calibrated scale superimposed on picture tube. The stripe length is proportional to the sync peak of the video signal.

Video Output: BNC connector. 1Vpp max on 75 ohm.

DC Output: +12V/50mA max. Power supply source for boosters & converter.

TV Receiver: tunes in and displays CCIR system I TV signals. Other standards upon request.

Additional Features: (1) Video input 75 Ohm. (2) 12V input for external car battery. (3) Output connector for stereo earphones.

Price: **£1344.00** exc. VAT and Carriage.

UNAOHM FSM5987 T.V. FIELD STRENGTH METER

INPUT

Sensitivity: from 20dBuV to 110dBuV (−40dBmV to 50dBmV) or 10uV to 0.3V, in eight 10dB steps.

Reading: dB reading proportional to peak value for video signals; proportional to mean value for AM or FM sound signals. For both signals scale calibrated to rms value and expressed in dBuV. Two more scales are available: volt from 0 to 50, and ohm from 0 to 2000 ohm. Battery status is also provided.

Accuracy: +/− 3dB for bands I & III +/− 6dB for bands H & IV/V

Impedance: 75 ohm unbalanced; DC component blocked up to 100V.

FREQUENCY

Range: 46 to 860 MHz as follows:

Band	
I	46 to 106MHz
III	106 to 206MHz
H	206 to 460MHz
IV/V	460 to 860 MHz

Reading: 4 digit LCD readout. 100KHz resolution.

Price: **£378.00** exc. VAT and Carriage.

UNAOHM EH 1000 TELETEXT AND VIDEO ANALYZER

Function: Eye Pattern: display of RF and video-frequency teletext signals by means of eye pattern diagrams both in linear representation and lissajous figures (0 and X). Line selection: display of video signals and line by line selection. Measurement of modulation depth. Teletext: monitoring of teletext pages.

RF Input: Freq. Range: 45 to 860MHz. Frequency synthesis, 99 channel recall facility, 50KHz resolution, 30 channel digital memory. Level: 40 to 120dBuV; attenuator continuously adjustable. Indication of the minimum level for a correct operation of the instrument. Impedance: 75 ohm. Connector type: BNC.

Video Frequency Input: Minimum Voltage: 1Vpp. Impedance: 75 ohm or 10K ohm in case of a through-signal. Connector type: BNC.

Teletext Input: Voltage: 1Vpp/75 ohm.

Teletext Clock Input: Voltage: 1Vpp/75 ohm. Measurement: Aperture of eye pattern: linear or Lissajous figures, selectable. Indication: directly on the picture tube. A calibrated scale shows percentage of eye pattern aperture. Error: the instrument introduces an error of ≤5% with video input and 20% with RF input. Jitter on regen'd clock: ≤25ns. Line selector: Selection of any TV line between the 2nd and the 625th scanning cycle by means of a 3 digit thumbwheel switch.

Oscilloscope: VERTICAL CHANNEL: Sensitivity: 0.5 to 2Vpp/cm. Frequency Response: DC to 10MHz. Rise time: pre & overshoot ≤2%. Input Coupling: AC. Input Impedance: 75 ohm/50pF. TIME BASE: Sweep Range: 20 to 10ms (1.1/2 frames); 32; 64/192us (1/2; 1; 3 lines). Linearity: +/−3%. Horizontal Width: 10 divisions; x5 magnification.

Price: **£1670.20** exc. VAT and Carriage.

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Against the national interest

You don't have to be on the left wing of anything to appreciate the inadequacies of the defence industry. One look at the Nimrod affair – a cost (with profits) of some £600 million to the tax payer with nothing at the end to show for it – confirms the statement in the minds of reasonable people. Failure in the Nimrod project can reasonably be attributed to GEC companies failing to deliver the necessary computing hardware. But it yields yet further cause for concern. The UK electronics industry has become so grossly distorted by padded defence contracts that it can no longer compete in the real world. The Government to its credit now insists on fixed price contracts. The legacy however will probably last until Sir Arnold Weinstock either dies or goes into retirement.

The UK didn't actually invent the transistor but then neither did Japan. The subsequent history speaks for itself. Japan built computers and transistor radios to follow the mass market demand from the Western world; the Western world built military systems against costs plus contracts for a military establishment which was happy to order whatever its supply industry said that it could deliver. The Japanese built functional components and equipment that people and businesses really needed while the defence industry built mostly non-functional equipment for an easily beguiled, criminally uncritical military establishment.

The semiconductor industry is a perfect example of defence stifling. One published estimate suggests that 50 per cent of the electrical giant GEC's earnings are related to military sales. Yet it is a fact that the same company has never managed to achieve success as a large scale commercial vendor of semiconductor components. It has had plenty of opportunities – AEI Semiconductors at Lincoln, the Fairchild partnership, GEC Semiconductors, the Hirst Research facilities but its merchant delivery never amounted to more than a drop in the commercial ocean. Never once did it attempt manufacture of mainstream mos devices such as microprocessors and memories.

Then one might consider GEC's premature departure from the Alvey project. Lord Weinstock considered it quite appropriate to take the money associated with what should have been the UK's prime semiconductor technology programme before leaving at the first contractual opportunity. GEC has shown absolutely no commitment to accepting a role as a mainstream semiconductor supplier. The only allegiance it has ever shown is to its shareholders and the bottom line.

This same company now has the gall to make a public accommodation with the powerful Siemens group to buy the reasonably independent Plessey Semiconductors operation. A reasonable man could say that a union of GEC and Siemens itself represents an unhealthy monopoly. Plessey has its own distortions due to a history of padded defence and telecomms contracts but it represents the UK's last free enterprise semiconductor venture. The message to Lord Young must be: tell Weinstock to get stuffed.

Frank Ogden

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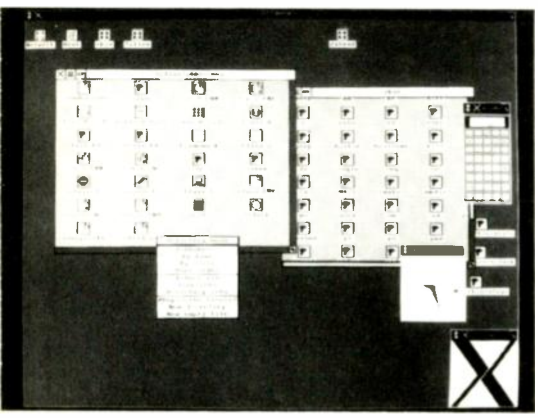
Desktop unix for under £4000

The announcement of an under £4000 unix desktop machine from Acorn Computers will lend weight to the considerable body of opinion that OS/2 just isn't going to make it in the way that dos has.

Unix began its breakout from the VAX and AT&T based minicomputer world a couple of years ago when it started to become clear that OS/2 couldn't deliver the multitasking, multiuser applications which have always been at the heart of the AT&T operating system. When major companies such as DEC, Hewlett-Packard, ICL and others got together with AT&T to lay down new standards for unix, it put the wind up IBM who responded with its own unix look-alike, aix. It also made the software houses act. Microsoft of dos fame produced a unix version called xenix. It should be noted that while all of the unix versions were similar, application software had to be written specific to a particular version of unix.

The £4000 desktop unix computer from Acorn will use the X.desktop user interface developed by Cambridge software house IXI.



Sun, AT&T and other vendors brought out software compatible unix machines for the top end of the business microcomputer market, an encroachment which displeased IBM greatly. IBM had already played the OS/2 card with its Intel based 80286 and 80386 machines and hoped to mirror the success enjoyed by its PC models. It certainly didn't wish to see the business threatened by a completely aligned unix consortium, a position made more likely when Sun brought out a unix workstation based on the 80386 processor chip.

Big Blue did a couple of things. It made a version of aix available for its PS/2 desktop PC. It also joined the Open Systems Foundation, a unix dominated organisation comprising itself, Hewlett-Packard (again), DEC (again), Nixdorf, Honeywell Bull, etc.

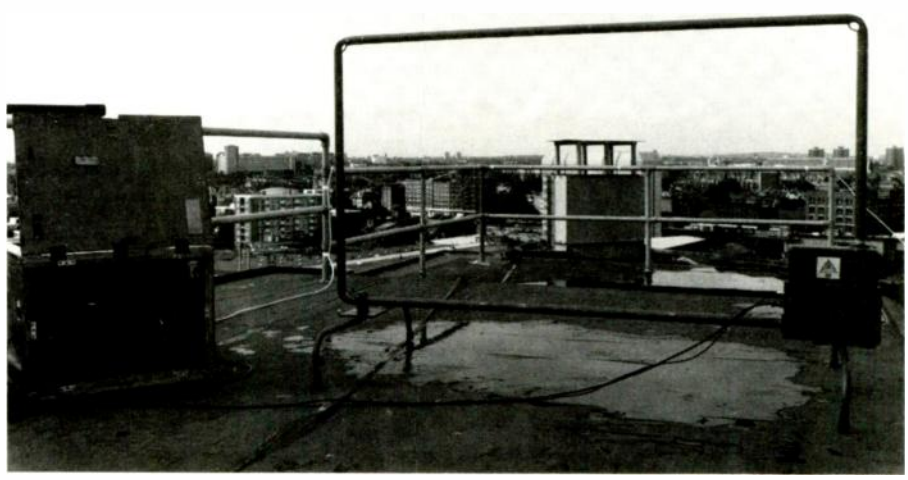
While all this was going on, the technology was also moving. MIPS Computers, a Californian venture capital company, came out with its first risc based high performance micro dedicated to unix. It performed so well that the big players had to take note.

DEC for instance responded by engineering its own machine based on the same R3000 risc processor engineered by MIPS Computers, capable of running at the 20 to 30mips mark. An 80386 will do around 5mips flat out by comparison.

All this underlines the importance of the Acorn announcement, a risc based product using the Archimedes chip set. The machine, which offers 4MB of ram and 50MB of SCSI hard disk together with thick and thin Ethernet interface, goes right to the heart of the networked personal computer business earmarked by IBM for its own machines running under OS/2. Acorn expects to deliver its first machines during January.

New HF loop system

British Aerospace has spent three years developing this HF loop antenna system, which has been on trial with H.M. Forces on NATO exercises in Norway and on a small launch in the south Atlantic. It passed all tests with flying colours and is now to be made available commercially.



Minimal size HF transmitting aerial developed by British Aerospace. This collapsible loop of extruded aluminium will handle 400W and comes complete with automatic tuning unit.

Essentially a collapsible loop of specially extruded aluminium tubing, the system has an automatic antenna tuning unit which can handle up to 400 watts — although it needs only the merest whiff of RF to tune.

It easily outperforms any of the wire antennas even a specialist could erect; and anyone who has witnessed what squaddies will throw up as an excuse for an antenna will quickly appreciate what a difference the system is making to forces communications in the field.

The system is designed to optimize high-angle radiation properties by nearly vertical incidence skywave (NVIS) which has proved particularly useful at sites low down in Norway's fjords. Short-wave radio still plays a vital role in short range communications, since satellite links cannot be relied upon wholly.

Of particular importance is the uniquely low visual profile the loop offers. It can be configured in various sizes, down to 2m × 1m, with tubes of only 40mm diameter. It is capable of being mounted (and operated) on a vehicle or being carried by just one man, and has also been found to make an excellent tent-frame.

Some protection from local interference is offered by the nulling properties of the loop, as was demonstrated during the recent BBC Radio Show when army cadet forces tried to use their wire dipole on the roof of Olympia — they got nothing but computer hash which corrupted their data traffic. But the loop could be oriented to ignore the noise from below.

The system will handle power down into the AM broadcast band, and looks ideal for use as a 'quick and easy on the air' solution to many emergency broadcasting needs.

Paul Rusling.

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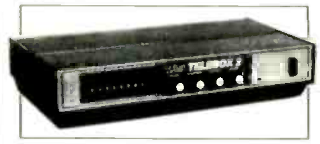

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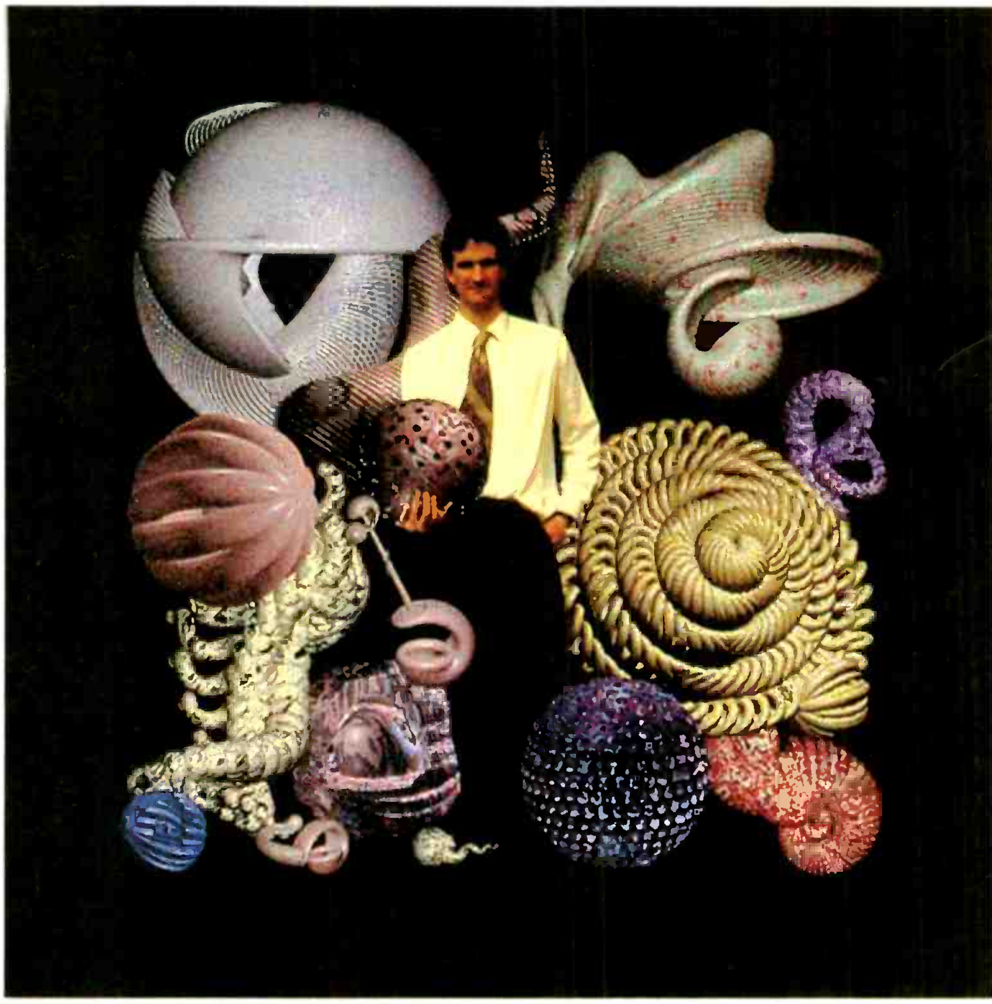
Ghosts in the machine

Artist William Latham has put 3D computer modelling to work to create a series of computer "sculptures" from a stack of digital data.

He says that the sculptures, produced at IBM's Scientific Centre, Winchester, "are in some ways like ghosts of physical sculptures in that they exist only in the form of data and not in a solid material form."

Latham adds that the visual characteristics such as texture, lighting and surface qualities can be simulated, as can be second stereo view. Public presentation is made by stereoscopically projecting the image pair to create the illusion of a solid sculpture. "I am attempting to create sculptures which are beyond the human imagination" he states.



Computer sculptures from artist William Latham generated in a computer using 3D graphics modelling techniques.

Linear motor runs on air

An interesting combination of air bearing and linear motor technology has resulted in a new way of building linear stepper drivers.

The Dorset company Digiplan has produced a system which is near frictionless yet can exert static forces up to the 8kg mark at resolutions of 12 500 steps/inch. The acceleration can be programmed within the range 0.01 to 10G, giving a maximum speed of 100in/s.

The motor system can be used in two modes: operating standalone from its own program memory and activated by switches, or under control of a computer through an RS232 link. The built in eeprom memory is large enough to store up to 40 motion control routines for individual or sequential execution.

The company says that the motor system suits applications which require X-Y motion and can also drive more than one motor unit on a platen with overlapping trajectories. This allows multiple motion tasks without cumulative errors.

Large, flat TV in big hang up

A prototype flat screen TV measuring 12in across the diagonal has been developed by the Finnish company Lohja in conjunction with Matra and SGS Thomson.

The apparatus, designed for wall hanging, uses monochrome electro-luminescent LCD grayscale levels. The company reports some success in making a colour version but admits that "relative colour hues and intensities need further research". The receiver includes teletext with remote control and can also be used as a VDU.

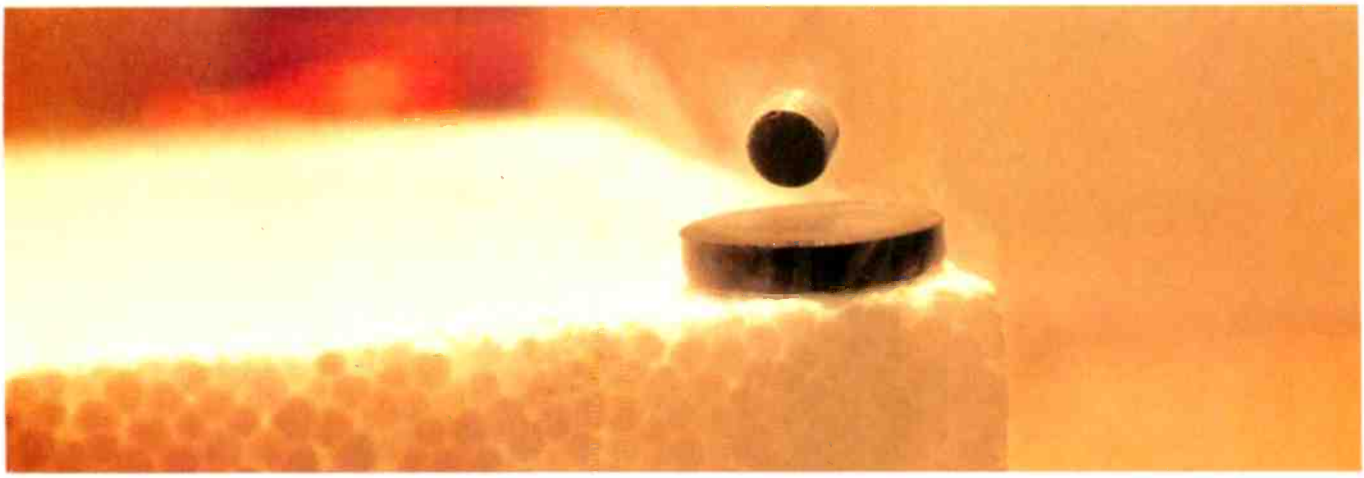
Finlux flat screen TV based on the technology are expected to become commercially available in the second half of the 1990s.

Hitachi demonstrated a 6in 384 000 pixel flat screen colour TV display at this year's Electronica exhibition. The perceived picture quality was directly comparable in all aspects except viewing angle with a conventional CRT.

Hitachi's 6in flat-screen colour display. The picture is genuine.

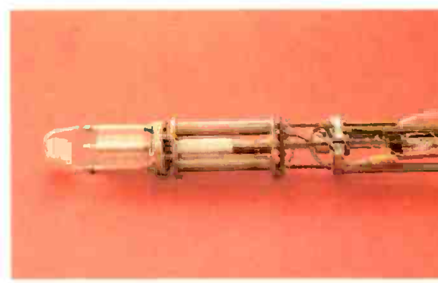
Super fast op-amp

A bipolar op-amp from Harris Semiconductor features a 1GHz gain bandwidth with 150V/µs slew rate. Applications include video amplifiers, radar, medical imaging and in RF circuitry. The device, the HFA-0002, claims an offset of 0.7mV and an open loop gain of 96dB. Two further devices in the series offer other tradeoffs between slew rate and gain/bandwidth.



Clarendon Laboratory research profile

Martin Eccles



During November, photographer Graham Richardson and I visited Dr Gregg and his colleagues at Oxford's Clarendon Laboratory to talk about their research into ultra-cold GaAs fets. If all goes well, we will be presenting a report of that work in the March issue. In the mean time, this collage representing just a small portion of the work done there should whet your appetite.

An inch diameter disc of a new high-temperature superconductor, top, which is cooled to below its superconducting transition temperature by liquid nitrogen. A small cylindrical samarium-cobalt magnet is able to float freely above the disc by virtue of the Meissner effect: this effect is a characteristic of superconducting materials and involves the exclusion of magnetic flux from the body of the material when in the superconducting state.

In the centre is a cryogenic radio-frequency magnetic resonance spectrometer with sample in-situ ready for insertion into the cryostat (seen in the background having its liquid nitrogen radiation shield filled).

The bottom end of the spectrometer including the sample (far right, top) is cooled to temperatures of order 1K during operation using liquid helium. The spectrometer uses cooled GaAs MESFETs which perform well at these low temperatures.

Liquid helium boils at 4.2K and costs about the same price as whiskey. The liquid helium transport vessel containing up to 50 litres of refrigerant can be seen to the left of the picture. It is connected to the cryostat via a vacuum-insulated transfer line which enables the very cold liquid to be transferred to the apparatus without appreciable boil-off. The helium gas is recovered as it boils off during the course of the experiment and is reliquified.

Magnetic resonance is a versatile tool in solid-state physics and is used to probe the fundamental magnetic properties of materials at an atomic level.

An ultra-pure crystal of a rare-earth garnet (DyA1G) onto which has been grown an array of high-frequency ultrasonic transducers. The transducers on this crystal inject longitudinal and transverse acoustic waves at frequencies between 200MHz and 2GHz with low insertion loss. This assembly is used in the study of some very unusual magnetic properties which the material exhibits at liquid helium temperatures of below 4K.

The electronic equipment and techniques used are broadly similar to those of modern radar technology and are capable of measuring acoustic path-length changes in the material to parts in 10^{10}.

The Clarendon Laboratory: one of the physics laboratories in the University of Oxford.

Making waves with electrons

One of the most remarkable tools developed in recent years is the scanning tunnelling microscope (STM). It relies on the fact that electrons can 'tunnel' their way through very thin layers of insulation, whether solid, gas or vacuum.

Tunnelling is essentially a quantum effect used to practical effect in tunnel diodes. Because the tunnelling current is critically dependent on the thickness of the insulating layer, it is possible to use it as a measure of this thickness. Or, if the current is used to control a mechanical servo loop, it becomes possible to maintain two conductors in air at precisely controlled separations of 10^{-9}m or less.

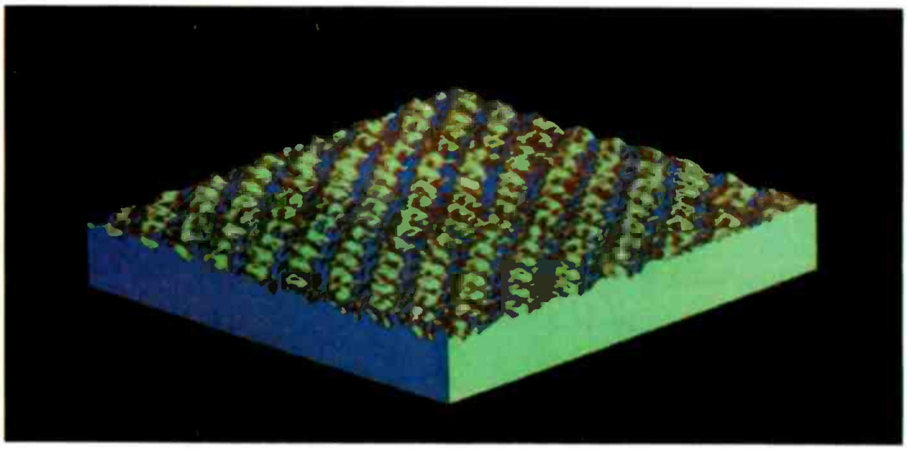
If one such conductor is a moving needle and the other a fixed substrate, it follows that the needle can be made to follow faithfully every nook and cranny in the substrate, right down to atomic dimensions. Using the loop control voltage to drive a computer, an operator can, at the same time, build up a three-dimensional map of the substrate or even reveal a single molecule – as has previously been shown in these pages (May 1988, p.452).

So far, so good. But, as pointed out (*Nature*, Vol.335 No 6185) by a team at Columbia University, the technique is not only sensitive to the topography of the substrate; it can also respond to electronic phenomena not directly related to the arrangement of the atoms. In simple terms the STM may well reveal more than just what you'd see down some unimaginable perfect microscope.

Xian-Liang Wu *et al* were studying a material called tantalum disulphide (TaS_2) which behaves as a metal at high temperatures. As the temperature is lowered TaS_2 undergoes a phase transition to a new electronic state called a charge density wave (CDW). This wave has a periodicity much greater than that of the rows of TaS_2 molecules in the crystal lattice and can be seen superimposed on STM pictures of the lattice.

Wu and his colleagues performed a neat second experiment in which they suppressed the CDWs by replacing 10% of the tantalum atoms by titanium. The resulting STM images showed only the molecular lattice without any CDWs.

Studying electronic phase transitions of this sort may seem something of an arcane activity, but such transitions are now being seen as central to many of the problems of solid-state physics. Transitions to ferromagnetism and superconductivity are other examples which might eventually yield some of their secrets to techniques such as scanning tunnelling microscopy. They might also become the basis of new practical devices far more esoteric and useful than the tunnel diode.



WIMPs may determine the future

Deep inside a disused railway tunnel in Northern Spain, scientists are looking for tiny particles known as WIMPS, which may determine the future of the Universe.

WIMPs — short for Weakly Interacting Massive Particles — are tiny sub-atomic particles predicted by some theories of cosmology. As their name implies, they are not expected to interact much with other matter andd are therefore likely to be very hard to detect. Indeed, no-one has yet identified any particle corresponding to the theoreticians' predictions.

Nevertheless, WIMPs could be important, for though they are likely to be only ten times the mass of a proton, they could exist in huge quantities, scattered throughout the universe. And because of their total mass they may have a significant bearing on whether the Universe goes on expanding, as at present, or whether it begins to contract again, ending up in a sort of 'Big Crunch'.

Calculations based on the known mass of stars and gaseous material would suggest eternal expansion, but if there were a lot of mass in the form of so-called 'dark' matter — that is to say, particles such as WIMPs — then the forces of gravity might well have a dramatic effect on what happens billions of years into the future. Looking for WIMPs is therefore more-than-usually fascinating.

The tunnel in Spain is a good place to look for such particles because it is under about 200 metres of solid rock. Professor Angel Morales from Zaragoza University and his colleagues from the University of South Carolina and Pacific National Laboratory in the USA have had to take their equipment as far away as possible from natural radioactivity and cosmic rays from space. These could confuse the detectors and lead to spurious results. To be doubly sure that no background radiation can spoil the experiment, the physicists are shrouding the detector in a 2cm thick layer of lead, surrounded by a 20cm thickness of paraffin wax bricks and other radiation barriers.

The detector itself consists of a lump of the element Germanium-76. Professor Morales says that if it is hit by a WIMP, an atom will be nudged very slightly, causing its nucleus to recoil. Measuring this recoil through its magnetic effects could then provide evidence for the WIMP's existence.

If the theories are correct, the WIMPs will pass through the rocks, the lead and the paraffin wax as easily as a ray of light passes through the glass of a window. Other forms of radiation will, it's hoped, be kept outside.

The idea behind this experiment is not just to detect WIMPs but, it is hoped, to discover something of their characteristics. By measuring the precise effects of such particles on the nuclei of the germanium atoms, Morales hopes to discover just how big these still hypothetical particles are. If they are as heavy as some theoreticians believe, then they could account for 90% of the total mass of the Universe. In other words there could be much more dark matter out there than everything else put together. If so, then we are definitely heading for a Big Crunch in which all matter collapses back on itself in a fireball not unlike the Big Bang that started it all.

On the other hand if the dark matter comprises lighter particles such as the axions required by unified field theories, the expansion from the primaeval Big Bang could go on until its energy is exhausted and all motion eventually ceases.

RESEARCH NOTES

Great balls of fire

Of all natural electrical phenomena, ball lightning is possibly the most intriguing. Eyewitness reports, some substantiated with photographs, describe glowing balls around 25cms diameter, variously coloured — white, red, blue or yellow. Some hover almost stationary; others drift at speeds of up to 4 or 5 ms^{-1} though they rarely last more than a minute before disappearing, sometimes explosively.

As with any unpredictable and transient phenomenon, scientists can do little more than advance plausible theories. And although ball lightning has been consistently reported for more than 150 years, some meteorologists still doubt its existence.

Not so a group at the Soviet Institute of Thermal physics led by Boris Smirnoff. Smirnoff believes that the 'fuel' consists of an aerosol of ozone adsorbed onto charged dust particles on the atmosphere. These particles then coalesce and, as they do, the oxidation process causes the temperature at the centre to rise to as much as 2000°C. Eventually, according to this theory, the charged particles are neutralized and the ball breaks up or disappears.

How accurate this explanation is must remain a matter of speculation. If the centre of a ball of 'lightning' is at 2000°C, it's hard to explain, for example, why it hovers and doesn't rise. It's also hard to explain why in some cases the ball floats in close proximity to combustible material without setting it on fire.

It may of course be that not all such phenomena have the same explanation. Some meteorologists are convinced that at least 80% of ball lightning events can be explained by more conventional means. Of the remaining 20%, who knows? Smirnoff has certainly fired the imagination.

Zapped by microwaves

A little knowledge of RF can be a dangerous thing, at least to judge from a nationwide survey conducted by Cambridge University safety adviser, John Williams. Following informed rumours about accidents involving microwave ovens in laboratories, Williams decided to find out for himself. A questionnaire sent to members of the University Safety Association has now been analysed and the results published in *Laboratory News*, 31.10.88.

The microwave oven, it appears, is now being used indiscriminately as a sort of up-market bunsen burner. But no-one is reading the instructions — at least not many. 14% of those returning questionnaires said that they could recall a damaging incident of some kind. Worse still, thirteen universities had experienced explosions or accidents that were actual or potential causes of serious injury. In two such incidents microwave ovens had their doors blown clean off.

Of some wry satisfaction to well-educated engineers is the fact that all thirteen of the serious accidents took place in biology (sorry, life sciences) laboratories. They involved heating closed containers of liquids, leaving metal clips on glassware and failing to allow time for superheated liquids to cool down.

I can only surmise that either they've changed the 'O' level physics syllabus since my day or else that they've resurrected the old lady who warmed up a cold bath with the aid of a suitably immersed one-bar electric fire.

Quantum well heat detectors

AT&T Bell Laboratories in New Jersey report a simple gallium arsenide/gallium aluminium arsenide heat detector that is potentially simpler, cheaper and more sensitive than anything in use today.

Existing infra-red detectors used by the military in heat-seeking missiles and remote sensing satellites rely on mercury cadmium telluride which, while extremely sensitive, is not the easiest material from which to fabricate devices of reproduceable performance. AT&T decided therefore to develop an entirely new infra-red detector based on more complex principles, but using readily available materials that are relatively easy to work.

Their new experimental pyroelectric detector consists of a crystalline lattice of GaAs containing 4mm-wide quantum wells bounded by barriers of gallium aluminium arsenide. As infra-red photons enter each well they excite electrons which leave the wells and flow through the lattice as a whole.

Varying the dimensions of the quantum well and its barrier enable the device to be optimized for detecting infra-red radiation over a whole range of wavelengths. So far the AT&T team, led by Federico Capasso, has experimented with devices capable of responding to wavelengths between 5 and 10×10^{-6}m.

Work on a practical device has now been under way for about a year and a half and already its sensitivity is equal to that of existing commercial mercury cadmium telluride detectors. Better still, because it uses gallium arsenide technology, its inventors hope to be able to integrate it with the amplification and processing circuitry that normally has to be built separately. That promises to yield infra-red detectors of unparalleled performance.

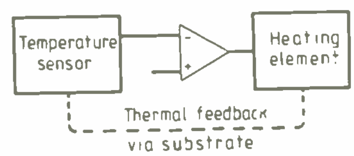
Rarified atmosphere in China

Evidence that technological progress is alive and well in the People's Republic of China comes in a recent description of a novel integrated vacuum sensor developed at the Nanjing Institute of Technology. J. B. Huang and Q. Y. Tong point out (*Electronics Letters* Vol. 24, No 23) that a fully integrated unit would offer considerable benefits over existing vacuum sensors based on pressure chambers and strain gauges. Not only could it be batch fabricated, it could also be integrated with some of the processing circuitry.

The idea of an integrated vacuum sensor isn't in itself new, but most efforts so far have suffered from poor linearity, poor sensitivity or the inability to work at pressures much above atmospheric.

The design of an integrated sensor is based on the fact that the thermal conductivity and the convective heat transfer coefficient of a gas vary with its pressure. In other words a hot object will lose heat faster when the pressure of gas around it is higher.

Huang and Tong have got round the problem of many earlier integrated sensors by designing a system that works at a constant temperature. The schematic is shown below:-



Regardless of how much heat is lost from the unit, its temperature is kept constant by means of the negative-feedback loop. All that varies as the ambient gas pressure varies is the total amount of power consumed by the heating element. Measurements of the current consumed by the device are then simply translated into pressure readings.

The situation is actually a bit more complicated in practice because the thermal conductivity of a gas isn't directly proportional to pressure at very low pressures. Under these conditions convection comes to the rescue, though only if the temperature of the sensor remains constant. Huang's and Tong's elegant demonstration of this forms the theoretical basis for what promises to become a useful commercial device.

Fabricated using conventional c-mos technology, their prototype sensor measures 1.62×2.02mm and is mounted with an insulating layer between the chip itself and the package to reduce thermal response time.

Results appear entirely satisfactory in practice, with none of the defects noted in earlier experimental integrated vacuum sensors.

Single-chip engine for document compression

As the paperless office becomes a reality, the time taken to store and retrieve documents containing both text and images becomes more critical. AMD has developed a single-chip compression and expansion engine capable of processing an A4 size document in human reaction times. This allows the storage of information on disc in compressed form and almost instant display of the document on demand.

NICK WILSON

Probably the first major application of document compression and expansion occurred as a result of the need to transmit documents as rapidly as possible using the limited bandwidth available on conventional telephone lines. Fax transmission uses a data compression ratio of as much as 50 to 1. Since the compression and expansion algorithms employed are a well defined global standard, it seems sensible to consider them for other applications.

A document for faxing is first scanned and digitised; each pixel converted to a binary one to represent a black dot or binary zero to represent a white dot. The resultant "bit mapped" image is then compressed and subsequently transmitted over the dial up telephone line using a modem (usually V29 at 9600b/s). At the receiver the data is then expanded to reproduce the original document which is then printed out.

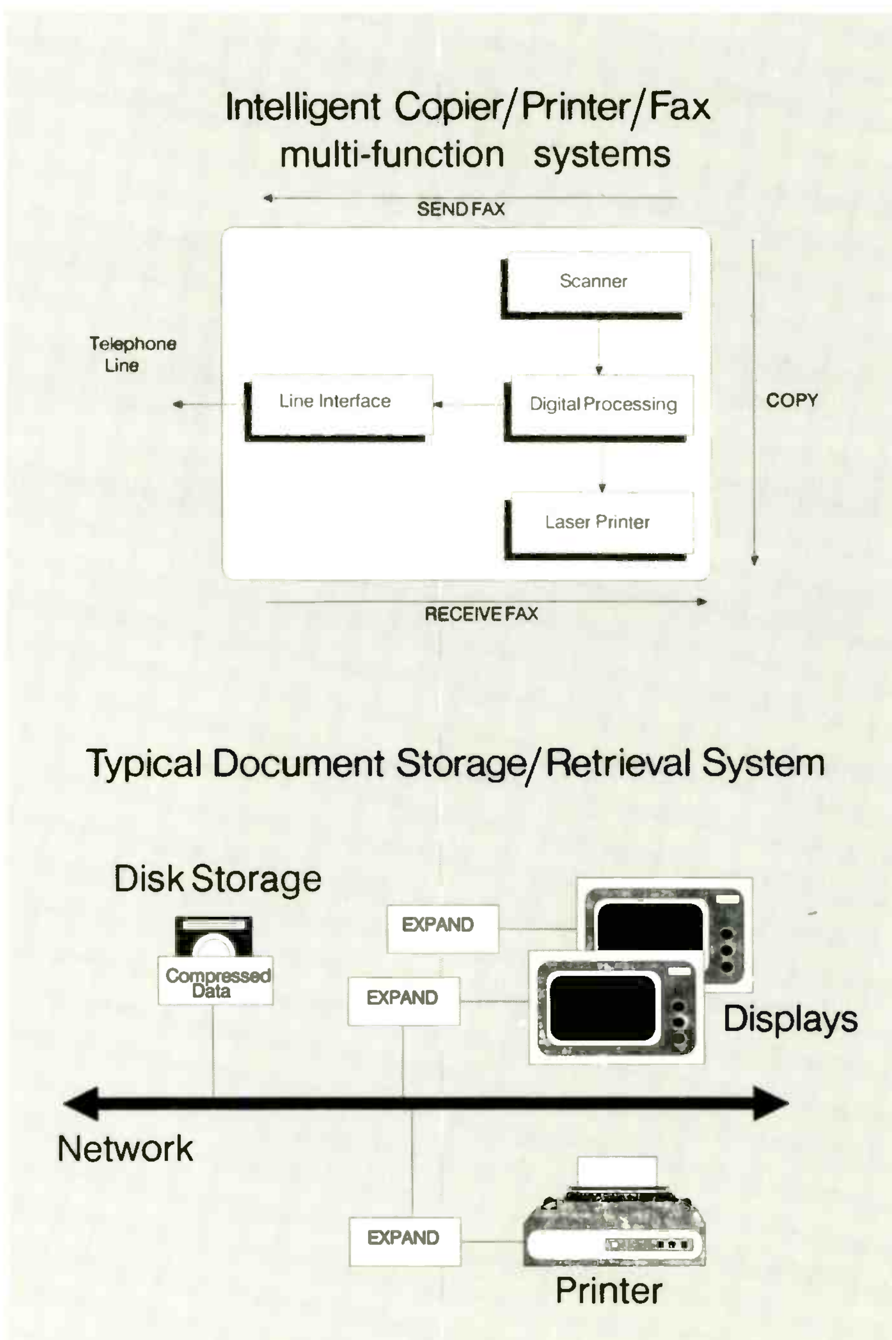
TOO MUCH DATA!

The need for compression becomes clear when a simple calculation is performed to determine the amount of data needed to represent a single A4 page of text and/or images at a resolution of 400DPI (dots per inch). If a single binary bit is used to represent each pixel then the total amount of data needed to define the whole page would be $400 \times 400 \times 8.25 \times 11.25$, about 1.8MB or five floppy disks worth! This is clearly not a practical proposition for either facsimile transmission or document storage and retrieval systems.

THE NEED FOR SPEED

In a simple facsimile application, the maximum rate at which a document can be transmitted is limited by the actual speed of the transmission system rather than the time it takes to compress or expand a document. The V29 standard used for fax modems operates at 9600b/s so there is little point in having a much faster compression and expansion engine in this simple application.

The need for very high speed comes about in more complex document storage and



retrieval systems or multi-function copier/fax/electronic document processing systems. The ability to access a document stored on disk in compressed form, reproducing it on a display unit (in expanded form) in normal human reaction times, requires a very high throughput from the expansion processor. Such a facility would allow document browsing without the need for large, expensive buffer memory and make the resulting system more useful.

BETTER, FASTER, CHEAPER, MORE RELIABLE

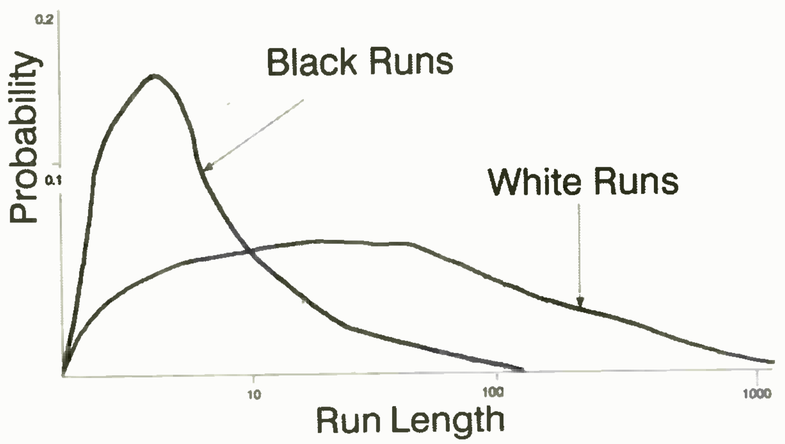
In a photocopier application, a high speed compression and expansion engine would give rise to a number of substantial benefits. Firstly it minimises the buffer memory between the scanner input reader and the laser printre output device. Secondly it offers the ability to accept input from the scanner and compress the data in real time without the need for a large, bit mapped buffer memory between scanner and system.

The same benefit and system cost reduction results from the ability to expand stored images directly to the printer in real time, thus eliminating large image buffer memory normally required between printer and system.

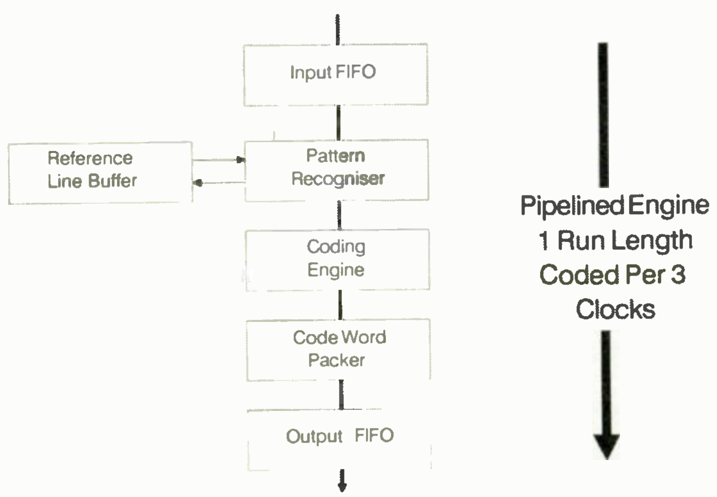
A further major benefit in the copier application occurs when multiple copies of a document are required. A conventional machine has to re-scan the input document for each copy that is required. This itself is slow but when a document consisting of a number of pages needs to be copied the problem becomes more complex.

In a conventional system the automatic collating facility utilises intricate and expensive mechanical systems that are both bulky and unreliable. With a VCEP (video compression/expansion processor) incorporated into the copier, multiple documents can be scanned and stored in compressed form within the copier. They may then be printed out many times in a predetermined order without mechanical sorting and with only a single input scan of each page for reproduction.

Run Length Histograms



Am95C71 VCEP Compressor



DOCUMENT BROWSING

In a document storage and retrieval system where many documents are compressed onto a mass storage device such as an optical disc, the need to be able to access quickly and display documents to screen for selection purposes is a necessary requirement. Display of a document on screen at the touch of a key requires significant system performance; throughput of the expansion engine to display a 300DPI A4 document in 200ms requires around 45Mb/s.

COMPRESSION AND EXPANSION ALGORITHMS

Compression is achieved by recognising that most typical documents contain long runs of white pixels then a short burst of black pixels. Quite often the difference between adjacent lines is also minimal. The two basic coding schemes in wide usage today make use of one or both of these observations to compress the amount of information needed to represent a typical document.

1D Encoding. The first method of compression, known as 1D since it operates on each single scan line independently, is based on modified Huffman run length encoding. Here, instead of transmitting each pixel on a line as a logical 1 or 0, a code is transmitted describing the number of black or white pixels in each group on that line. Hence a completely blank line of an A4 page consisting of 3300 pixels would be transmitted as a number saying that there are 3300 white pixels on this particular scan line, a considerable saving in data.

The actual code transmitted is not a direct number representing the number of pixels in each run length. Instead the codes are designed such that the most common run length of black dots or white dots are given the shortest codes to represent them. This technique makes the compression algorithm even more efficient.

The codes are chosen based on the run length histogram shown. Here it can be seen that on a typical "average" document there are a lot of short runs of black pixels and not many long runs. White runs are more evenly distributed. There tend to be more long white runs than long black runs. Hence the codes chosen to represent short black runs should be small and those chosen to represent long white runs should be small. We can afford to allow long black runs to have longer codes because they do not occur very often.

This predictive approach works very well as long as documents are "typical". The actual compression ratio achieved will depend upon the content of the document. A check ensures that the compressed form is never actually longer than the raw data. This could happen if one tried to compress a pixel checker board pattern. The CCITT publishes eight test documents based on typical types of letters, images and drawings. These are used to evaluate the efficiency of the compression algorithm and its throughput.

2D Encoding: This method transmits the difference between the current scan line and the previous scan line on a line by line basis. It assumes an imaginary first line comprising of all white pixels and compares the first scan line to this. The difference between the two lines is transmitted. Although efficient, any errors made in the document will corrupt the entire page from the point at which the error was made.

In traditional analogue transmission over conventional telephone lines this would be unacceptable. Pure 2D encoding is only used in error free environments such as is offered by digital transmission systems (CCITT Group 4).

Current fax machines use a combination of 1D and 2D encoding over the existing telephone network. CCITT Group 3 encoding defines that the first line is encoded using modified Huffman run length techniques and that the next n-1 lines are transmitted using the 2D encoding method. The value n-1 is known as the k parameter and effectively determines the maximum number of scan lines that can be corrupted if an error occurs. For digital transmission systems k can be infinity.

The VCEP supports the Modified Huffman (MH), Modified Read (MR) and Modified-Modified Read (MMR) coding schemes used by the CCITT Group 3 and Group 4 standards. The MMR is pure 2D encoding and offers the highest compression ratio. The extent of data compression provided by Group 3 or Group 4 compression techniques depends on the specific data patterns contained in the image. A typical black and white document will yield a compression ratio between 5:1 and 50:1.

The multi-function desktop system allows document copying, storage, retrieval, document manipulation, FAX, and printing. The VCEP uses the standard CCITT group 3 or group 4 compression/expansion standards used in every ordinary FAX machine allowing communication with existing equipment.

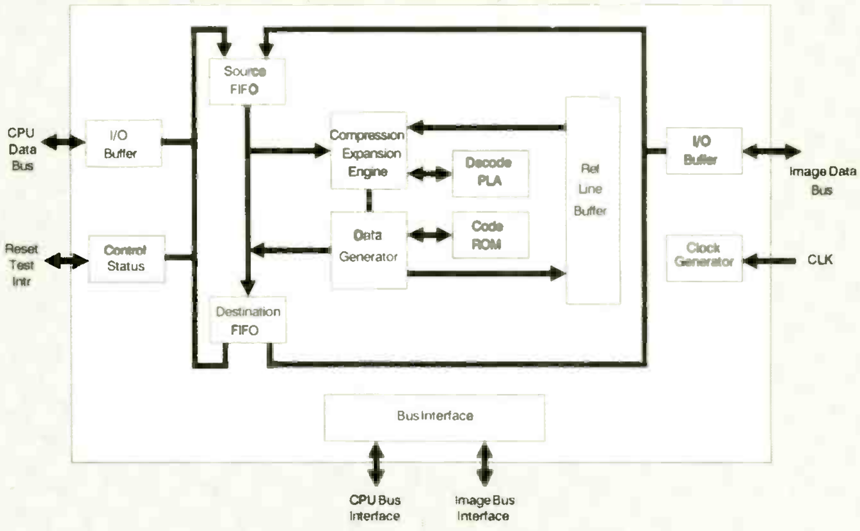
THE VCEP

The VCEP from AMD does its jobs quickly; using the standard set of eight documents defined by the CCITT to quantify throughput, it processes a data stream of 60Mb/s. The performance is achieved by exploiting similar techniques to the earlier processing engine, the Am7971. This part is still available for the less demanding application of the simple FAX machine. The VCEP is fabricated in c-mos and particular attention has been paid to hand tuning the actual layout of the silicon.

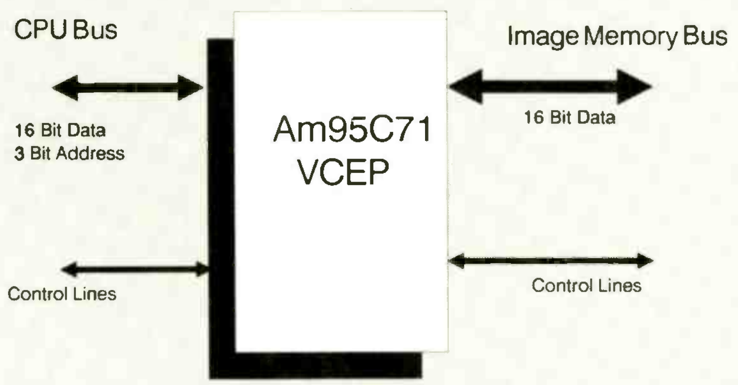
PATTERN RECOGNITION IS THE KEY

The device works by recognising patterns rather than operating on a bit by bit basis. The pipelined internal architecture and the use of an on chip reference line buffer allows the 2D encoding process to operate on a word at a time basis. The current line and stored previous (reference) line are compared on a 16 bit word basis in a single clock cycle; this allows a bit throughput rate effectively higher than the clock rate.

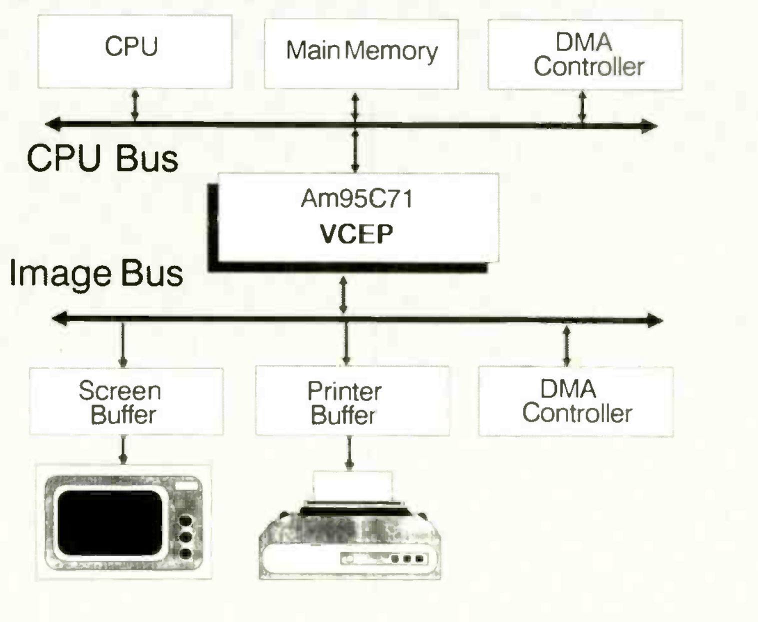
Am95C71 VCEP Block Diagram

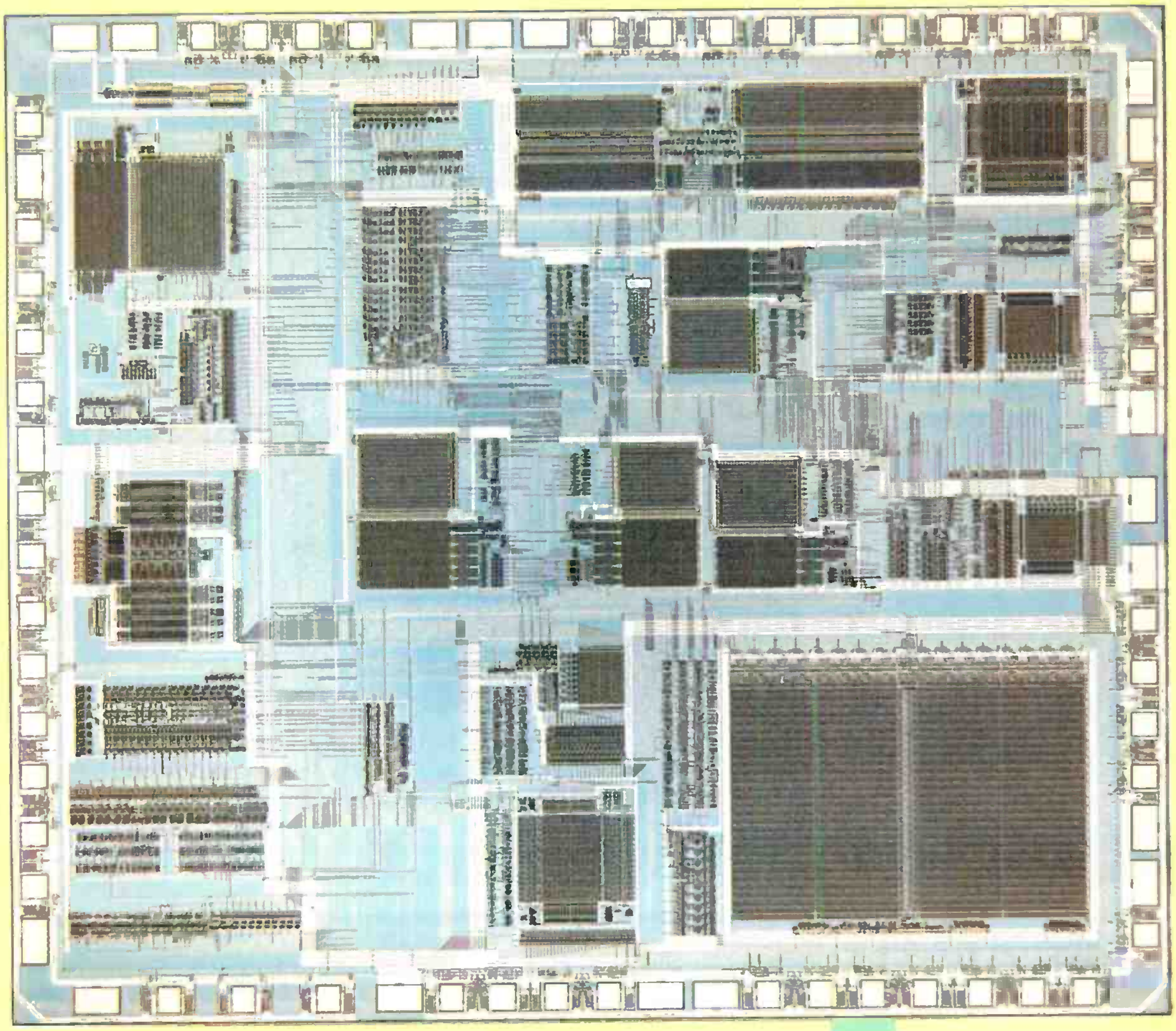


VCEP Has Dual 16-bit Busses



Typical Full Performance VCEP Based System





The reference line buffer is 6911 bits in length, more than enough to store a complete line of a normal size document even if scanned with a resolution of 400DPI.

For large drawings the standardised technique of tiling is exploited. Here the drawing is processed in smaller "tiles" of 512 × 512 pixels to make the information more manageable. Each "tile" is simply treated as if it were a separate document.

DUAL PORTS

In a typical system the VCEP allows data to be expanded from the CPU bus port and output to the image bus port. Data to be compressed is taken from the image bus port and output to the CPU bus port. Internal design flexibility even allows data to be compressed or expanded with the source and destination port being the same, ie compressed or expanded data can be output to the CPU port.

The use of on chip 16 word fifo and a dual 16-bit port structure minimises the overhead on the CPU and even allows a "transparent mode" removing the need for extra bus control logic and buffers if a straight through path is required. For maximum throughput a dual bus system should be employed with expanded image data appearing only on the image bus side of the VCEP and compressed data only on the CPU side.

The VCEP performs the expansion and compression process using dedicated digital processing techniques. This means that the system software does not have to implement the algorithm, a process that is slow even when run on the fastest processors available. A typical software expander running on a desk top PC-AT takes well over 90s to retrieve a screen full of information during which time no other tasks may be performed. The VCEP unburdens the system processor from this time consuming task as well as drastically reducing the overall task run time.

Nick Wilson is an AMD application engineer

The same benefit and system cost reduction results from the ability to expand stored images directly to the printer in real time,

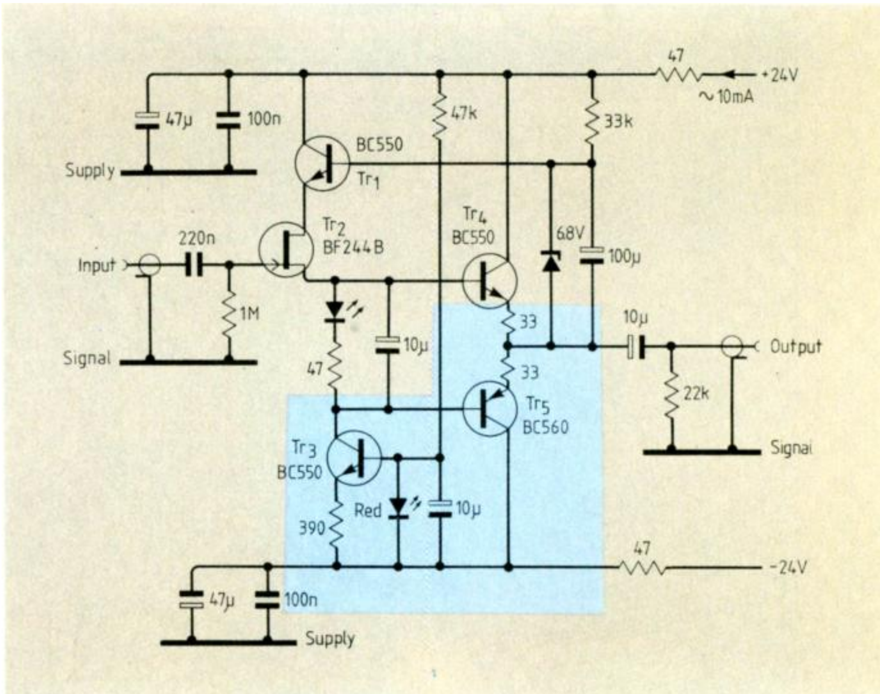
CIRCUIT IDEAS

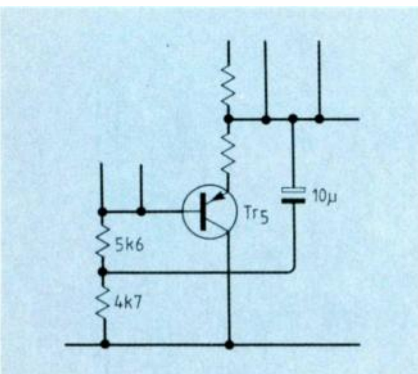
High-quality unity-gain buffer

Measurements on this unity-gain buffer show a 300V/μs slew rate, 60Ω output impedance and 0.02% distortion at 1kHz with a 10V pk-pk signal and 1kΩ load. It is suitable for driving capacitive loads like long cables and tone controls.

In performance terms, the circuit is similar to an op-amp connected as a voltage follower, but having no overall feedback it is less affected by instability and transient intermodulation distortion.

Operation of the circuit is simple. The input stage is a cascode built around $Tr_{1,2}$ which, loaded by current source Tr_3, drives a complementary output stage, Tr_{1-5}. Two leds form 1.6V references. In low-cost applications, current source Tr_3 can be replaced by the simpler inset circuit.





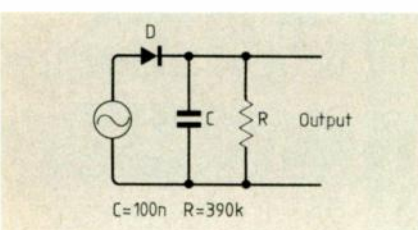
Compared with an op-amp design, the only real trade-off is d.c. offset at the output, which results in the requirement of an output decoupling capacitor; the input capacitor can be omitted.

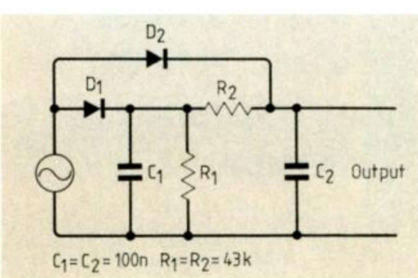
Paolo Palazzi
Cervignano
Italy

Improved peak detector

Conventional peak detectors provide a simple means of measuring the level of a.c. signals and have the advantage of very wide bandwidth. There are however occasions when there is an uneasy compromize between output ripple and discharge time.

This idea improves the situation. The first detector, D_1,R_1,D_1, develops a voltage that opposes the discharge of the main detector, D_2,R_2,C_2, allowing time constants to be shortened. Component values shown are for detectors working at 1kHz, having an output ripple equal to one per cent of the input signal amplitude. Discharge times of simple and improved detectors were 39 and 13ms respectively (measured as a time-constant).





Further stages could be added, and it may be convenient to model the circuit as an RC filter in which the diodes set the initial conditions, i.e. the capacitor voltages. More generally there may be useful configurations based on filters with complex poles in their transfer functions, be they realised with inductors or gain blocks. The diodes would still charge the capacitive elements.

J.N. Wells
St Albans
Hertfordshire

VMEbus i/o

Readily available 1MHz peripheral i.cs make an economical VMEbus i/o interface providing two serial ports and 20 parallel lines.

Decoding of the upper 16 address bits, carried out by $IC_{1,2}$, produces master select signal MASEL which locates the board on any convenient 256byte boundary via dil switches $S_{1,2}$.

Initially, JK bistable devices $IC_{9a,b}$ are cleared, causing the Q output of IC_{9b} to go high. This sets latches IC_{1-5} to their transparent mode. At the start of a peripheral access, latch IC_4 will be enabled if the access is a VMEbus write. If the access is a read, IC_4 goes to its high-impedance state and IC_5 is enabled. On the first falling edge of E, bistable device IC_{9a} is clocked high provided that MASEL and DS_1 are asserted.

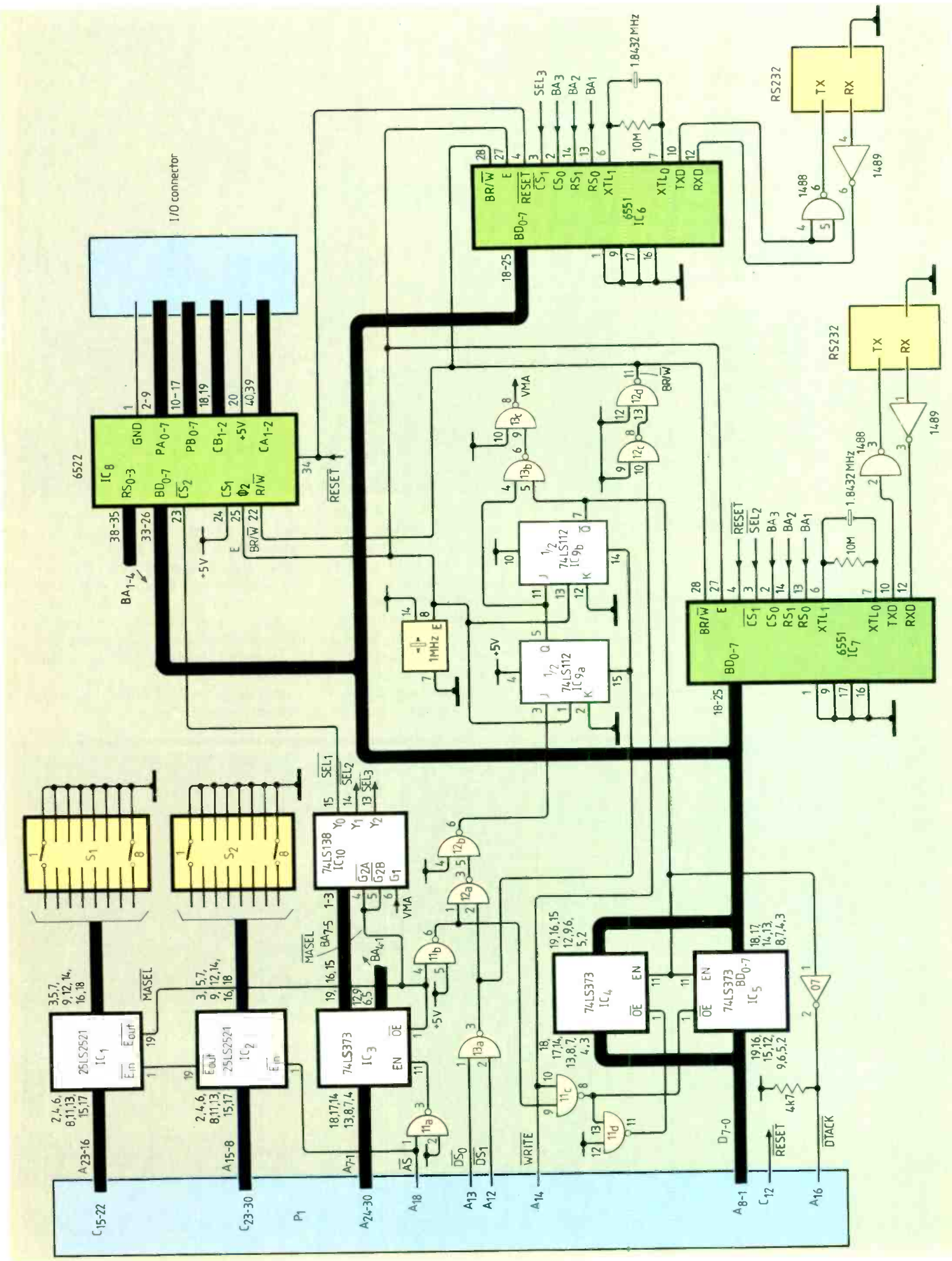
Output Q of IC_{9a} is gated with the Q output of IC_{9b} and then inverted to produce valid memory address signal VMA for 3-to-8-line decoder IC_{10}. Selecting the peripherals at this point ensures adequate address set-up time.

On the next falling edge of E, the Q output of IC_{9b} is clocked low, asserting DTACK and holding data in the enabled latch. Output Q of IC_{9b} also serves to deselect the peripherals by causing the VMA signal to go low. Bistable device IC_{9a} is also cleared when the access terminates and the interface circuit is initialized for the next access.

Expansion for other peripherals is easily accomplished by using the spare select signals available at the 3-to-8-line decoder IC_{10}. To expand the circuit to 16 bits is possible by replicating latches IC_{1-5} although if only eight-bit accesses are required, it may be advisable to disconnect DS_0 from IC_{13a} and tie pin 1 high.

L. Smith and F. Kelly
Computing Science Department
University of Stirling

CIRCUIT IDEAS



CIRCUIT IDEAS

More convenience for hard of hearing

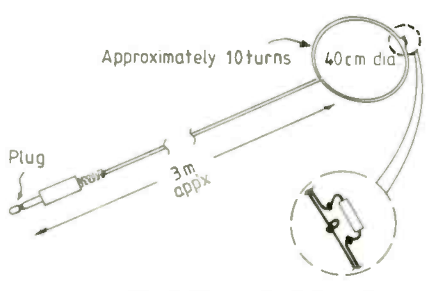
Many hearing aids are now fitted with an inductive coupler selected by moving the aid's switch to its 'T' position. Such couplers are intended for adapted telephones and loop systems fitted in public buildings.

A personal loop, which is very easy to make, enables people with impaired hearing to listen to television programmes without disturbing other members of the household. The television needs a headphone socket; the personal loop either plugs directly into the socket or is connected via a small matching amplifier.

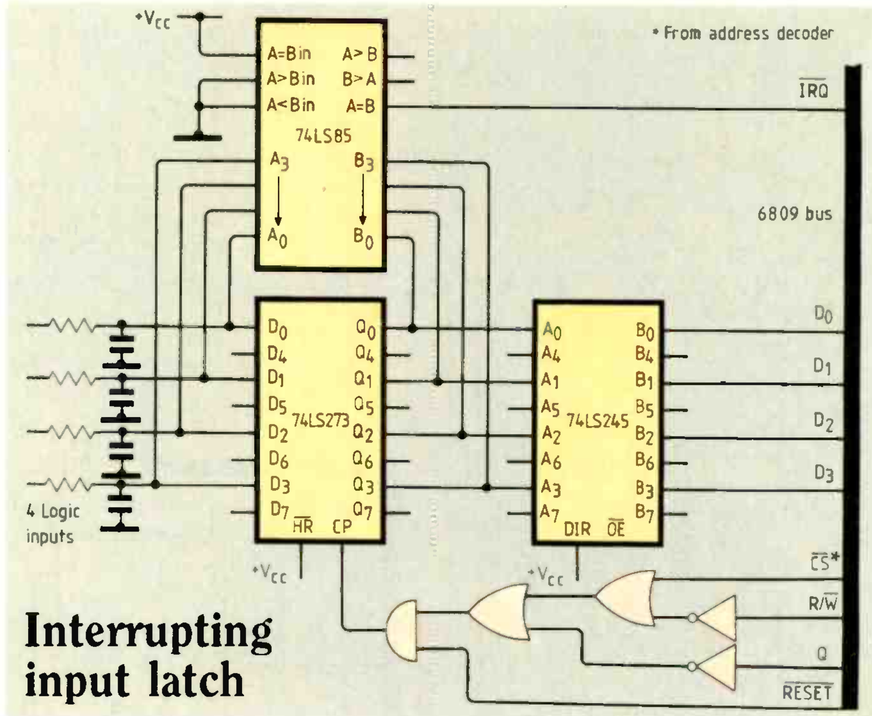
Lighting flex or speaker wire can be used for the loop which, being worn around the neck, should be large enough to be comfortable; a cloth covering increases comfort. Sadly, low-frequency response is often poor due to limitations of the hearing aids.

David Taylor
Sheffield
Yorkshire

Check that the tv's output is suitable for low-impedance loads – Ed.



3Ω resistor, ends of flex tied and resistor soldered between



Interrupting input latch

Where processing time is at a premium, replacing an i/o polling system with interrupt-driven ports can give a great saving. I made this interrupt latch for my 6809-based robot-arm controller, but it should be suitable for many 6800-systems.

On reset, the comparator's A=B output goes high, causing disabling of $\overline{IRQ}$ and transparency of the latch. When input data changes, the comparator's A=B output goes low, interrupting the processor and transferring input data to the data bus. Since the latch input and output lines are now the same, $\overline{IRQ}$ returns high. The processor resumes its task once the data has been read.

Input signals must remain in the same state long enough to allow time for the microprocessor to execute the interrupt routine and read valid data. I found that opto-isolators at the inputs provided not only galvanic isolation, but also efficient low-pass filtering.

Dominic Bergogne, CUST Genie Electrique, Clermont-Ferrand, France

NEXT MONTH

Miniature HF TX aerial. The search for a truly compact yet efficient HF transmitting aerial has become something of a Holy Grail among the RF fraternity. We present a genuinely new design arrived at through a reverse look at the original Maxwell wave equations. Imagine this: an aerial structure (it doesn't look like one) with dimensions of λ/200 with an effective bandwidth of 30 per cent of operating frequency but with efficiency comparable to high current loops.

Developing an industrial imaging system. Area scan imaging enables a computer to keep a cold, calculating eye on an external situation using little more than a monochrome TV camera, PC computer plus interface board and software. This is how it's done.

Low temperature GaAs. Gallium Arsenide has an inherent electron mobility of around six times that of silicon. It works well at room temperature but cryogenic cooled micro structures are showing some startling characteristics.

Working with the PC: A special feature on the computer architecture used by more than 60 per cent of professional engineers covers hard disk development, local area networks and hooking up to the outside world.

In depth: Data communications. Packet switching for static data links, RS232 explained, computers and the public switched network and training for the new boom time in data comms.

Feedback and fets in audio power amplifiers

Negative feedback and power mosfets alike represent steps forward in audio amplifier design but neither, nor indeed both of them together, provide all the answers. Ivor Brown takes a sober look at the current state and outlines a design resulting from his research.

IVOR J. A. BROWN

In recent years the regard of negative feedback as a technique used in the design of audio power amplifiers has undergone a radical change. Twenty years ago it was common to see advertisements for amplifiers that proudly proclaimed the large amounts of negative feedback incorporated in the design. Today it is generally accepted that feedback can cause some very undesirable effects in an amplifier and it must be applied with care and caution.

Bandwidth restriction of the basic amplifier, necessary to ensure that the system is stable when feedback is applied, causes most of the problems. In most current designs the amount of negative feedback applied is strictly limited to avoid too great a bandwidth restriction.

Power mosfets are capable of better high-frequency performance than bipolar devices, and their use enables a fresh evaluation of negative feedback techniques to be made. Some device manufacturers seem to regard the mosfet as the solution to most of the difficulties encountered in audio amplifier design. However, this is not the case and they need to be used so as to maximize their advantages and minimize their disadvantages. Providing this is done, high-performance designs that use substantial amounts of feedback are possible.

POWER MOSFETS

Features of mosfets as they affect audio power amplifier design are as follows.

Power mosfets exhibit a more gradual turn-on characteristic than bipolar devices. This is their most important advantage. In class-B designs the circuit is split into two halves with one half handling the positive part of the waveform, and the other the negative. Transfer of the signal from one half of the circuit to the other has to be very well controlled; otherwise, there will be significant cross-over distortion.

Cross-over distortion generates many odd harmonics of the input signal. To smooth out the transfer and minimize this distortion, the output devices pass a small quiescent current and so operate in class AB — even so, the abrupt turn-on characteristic of bipolars makes them pretty good harmonic generators.

Displaying the output from some designs on a spectrum analyser, with an input sinusoid of say 200Hz, reveals that all the odd harmonics are present to frequencies above the audible limit. The display shows the near-equal-amplitude odd-harmonic components standing like a row of soldiers. Each component may be much less than 0.1% of the fundamental but there is a lot of them. Field-effect transistors handle the cross-over region more gently and the amplitudes of the harmonics that are generated fall more rapidly with increasing frequency.

Field-effect transistors are unipolar devices, that is the conduction process involves only one kind of charge carrier, and so they have the potential for a better high-frequency performance than bipolar devices. This is their second most important advantage which should be exploited when using them in amplifer designs. There are, however, appreciable capacitances between the terminals of power fets, as relatively large areas of silicon have to be used to obtain a high power rating. The various patented manufacturing techniques are mainly concerned with reducing the capacitances while keeping a satisfactory power handling capability. To obtain the improved high-frequency performance, fets must be driven from low-impedance sources.

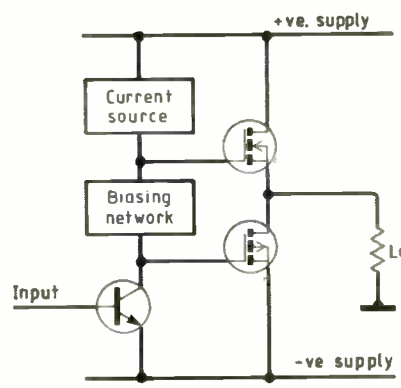


Fig. 1. With this configuration, maximum output power is severely restricted due to the fet's high gate-to-source voltage.

At the same collector or drain current the mutual conductance of a bipolar is much higher than that of a fet. **Figure 1** shows in outline the type of circuit in which fets are frequently employed, with a class-A driver feeding complementary source followers. Mutual conductance of the output devices determines the output impedance of the amplifier in the absence of overall negative feedback.

In bipolar devices and fets the mutual conductance rises with increasing current and the output impedance falls. It is desirable that the output stage itself has a low output impedance so that the circuit does not have to rely on overall negative feedback, or some other technique, to provide damping for the loudspeaker. In general, fet power stages operate at higher quiescent currents than bipolar designs, but even then the output impedance will be appreciably greater.

Field-effect transistors require a larger driving voltage than bipolars which can lead to design complexity. Base-emitter voltage of a bipolar when the collector current is an ampère or so will be about one volt, while the gate-source voltage of a fet may approach ten volts. In the circuit outlined in Fig. 1, this can severely restrict the maximum power output that can be obtained from given DC supply rails, and so make the design less efficient than an equivalent bipolar one. Some circuits in the fet manufacturer's application notes include additional higher voltage rails for the driver stages to overcome this disadvantage.

Because field-effect transistors have a negative temperature coefficient, they do not exhibit thermal runaway. This statement is true but needs qualifying. The desirable negative coefficient is present only at high drain currents; say over a few hundred milliamps. Under quiescent conditions, when an appreciably lower drain current is likely, the coefficient is positive and thermal stability can be a problem just as in bipolar designs.

Input current of fets is zero so they have infinite power gain. This is correct, but of limited significance. As Fig. 1 shows, fets can be driven directly by a low-level class-A stage, but as already mentioned this simple approach incurs some penalties. Note that the fets are not driven from a low-impedance source. Bipolar devices have to be cascaded to make output circuits with sufficient gain so that they can be driven from a low-level stage.

Unlike bipolar devices, field-effect transistors do not suffer from secondary breakdown. This undesirable feature has been successfully overcome in the design of millions of bipolar amplifiers, so it is hardly a significant advantage for the fet.

Field-effect transistors may be considered to be more expensive than bipolar equivalents. If you are comparing the cheapest of each type this is correct, but not correct if the bipolar devices are high-frequency types. The extra cost of using fets will hardly be significant in the context of the total cost of an amplifier.

As you see, fets are indeed a mixed bag of advantages and disadvantages. Circuits of the type so far considered hardly make the most of the former while not minimizing the effects of the latter. Later I will describe a circuit arrangement that makes better use of fets, but first I will consider some of the features of negative feedback and other linearizing techniques.

FEEDBACK AND OTHER TECHNIQUES

Electronic devices are not perfect and for high-quality audio applications some method has to be employed to make an amplifier work in a highly linear manner. Discovery of negative feedback before the last war could be said to have initiated the interest in, and made possible the construction of, high-quality audio systems.

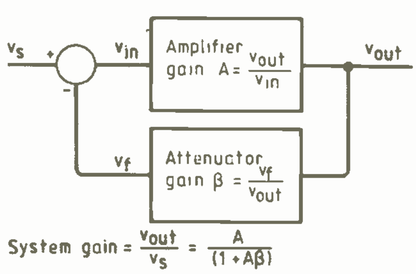


Fig. 2. Negative feedback reduces distortion by 1+A, and it has many other advantages, but it is not a cure-all. It does not reduce distortion produced in the subtraction process, and it can decrease stability.

In **Fig. 2**, a fraction of the output signal is fed back and substracted from the source signal. It can be shown that the gain and the non-linearity of the system will be reduced by the same amount. A low-distortion preamplifier can be used to make up the loss in gain, leaving the overall benefit of improved linearity. Feedback will not reduce distortion generated in the subtraction process, so this must be done very accurately. When correctly applied, negative feedback will lower the output impedance of the system, making it more suitable for driving loudspeakers.

Due to phase shifts occurring at high frequencies, returning some of the output of an amplifier to its input can make it oscillate. To ensure stability, the bandwidth of the basic amplifier has to be restricted so that the gain within the feedback loop falls gradually with increasing frequency. If appreciable feedback is applied the fall-off may have to start from a frequency well below the upper audio limit. (The loop gain has to fall to below unity before the active device frequency limitations, with their attendant phase shifts, become significant.) This decreasing gain is accompanied by a phase lag of the output signal compared to the input.

When there is sufficient feedback to achieve large reductions in gain and distortion the source and feedback signals should be virtually the same, leaving only a small difference signal when they are subtracted. This condition will not be obtained with signals which include high-frequency components, such as fast transients, due to the reduction in amplitude and the delay of the feedback signal. A large momentary signal will result which may cause transient distortion in the amplifier.

Current designs tend to incorporate the minimal amount of overall feedback consistent with obtaining acceptable benefit from the feedback without causing serious transient problems. Feedback can be applied round individual stages without these difficulties. The amount of gain inside the feedback loop is limited so there may be no need to restrict the frequency response, but the linearizing benefit of the feedback will also be limited.

To obtain good results, a careful optimization of the basic amplifier design will be necessary and perhaps fairly complex circuits will have to be used. For more details on feedback and its associated stability problems, refer to standard electronics text books such as those mentioned in Refs 1–3.

There are other techniques that can be employed to linearize amplifiers, such as feedforward, **Fig. 3**. Here a fraction of the output is compared to the input. The fraction is set to equal the inverse of the forward gain of the main amplifier, so that if there is no distortion the two signals that are compared will be identical.

In practice the difference between the signals is an attenuated and inverted representation of the distortion produced in the main amplifier and should be small. This signal is then passed to an accurate secondary amplifier whose gain is equal to that of the main amplifier. As this amplifier has only to handle small signals it is assumed that it introduces negligible distortion. Its output is added to the main amplifier's, output, thereby cancelling all the distortion products from the final output waveform. As there is no feedback in this system it cannot oscillate and hence no limitation of bandwidth is necessary. However, addition of the inverted error signal to the output of the main amplifier is not that easy to arrange.

Current dumping is another approach. It is a mixture of feedforward and feedback with the output transistors included in a balanced bridge arrangement. Linearity of the whole circuit is controlled by a small class-A amplifier in the bridge, leaving the output transistors to just dump a large current into the load[1,5]

These alternative techniques may seem attractive, but do not overlook that they depend on the accurate balancing of gains in different parts of the circuit. This balance must hold for the whole range of audio frequencies and beyond if it is to cancel the effects of all the distortion mechanisms. While these alternative circuits are capable of good performance and appear to solve many of the problems encountered with feedback they do create some of their own. As far as I know, they are not found in 'economical' designs.

I will look again at negative feedback to see how it compares with the other techniques. It does not completely remove the effects of non-linearities; it can however reduce them to negligible proportions. It does not rely on parts of the circuit being in balance, but only on there being sufficient forward gain in the basic amplifier to obtain the desired reduction of distortion.

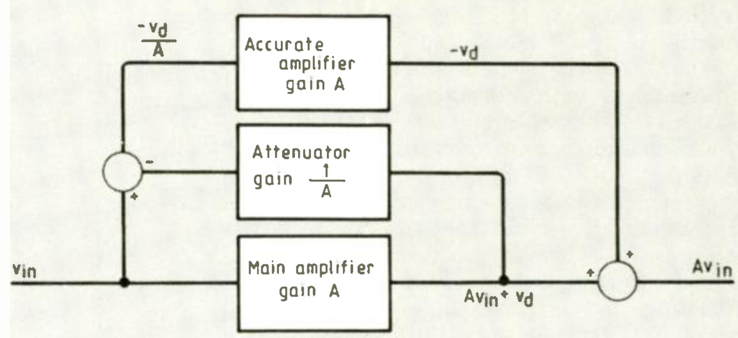


Fig. 3. Feed-forward amplifiers are inherently stable, so they do not need bandwidth limiting. But addition of the inverted error signal to the output of the main amplifier is not easy to arrange.

If a distortion mechanism, such as crossover mismatch, causes the forward gain to momentarily fall to a low figure, negative feedback can do little to improve matters; so the use of feedback does not remove the need for good circuit design. In general, feedback will reduce the amplitude of small low-order harmonic products quite successfully, but as mentioned earlier, if an amplifier produces high-order components the application of feedback can result in most of the remaining distortion energy being in even higher-order components.

Most problems encountered with feedback are due to the restricted bandwidth of bipolar output stages requiring an earlier

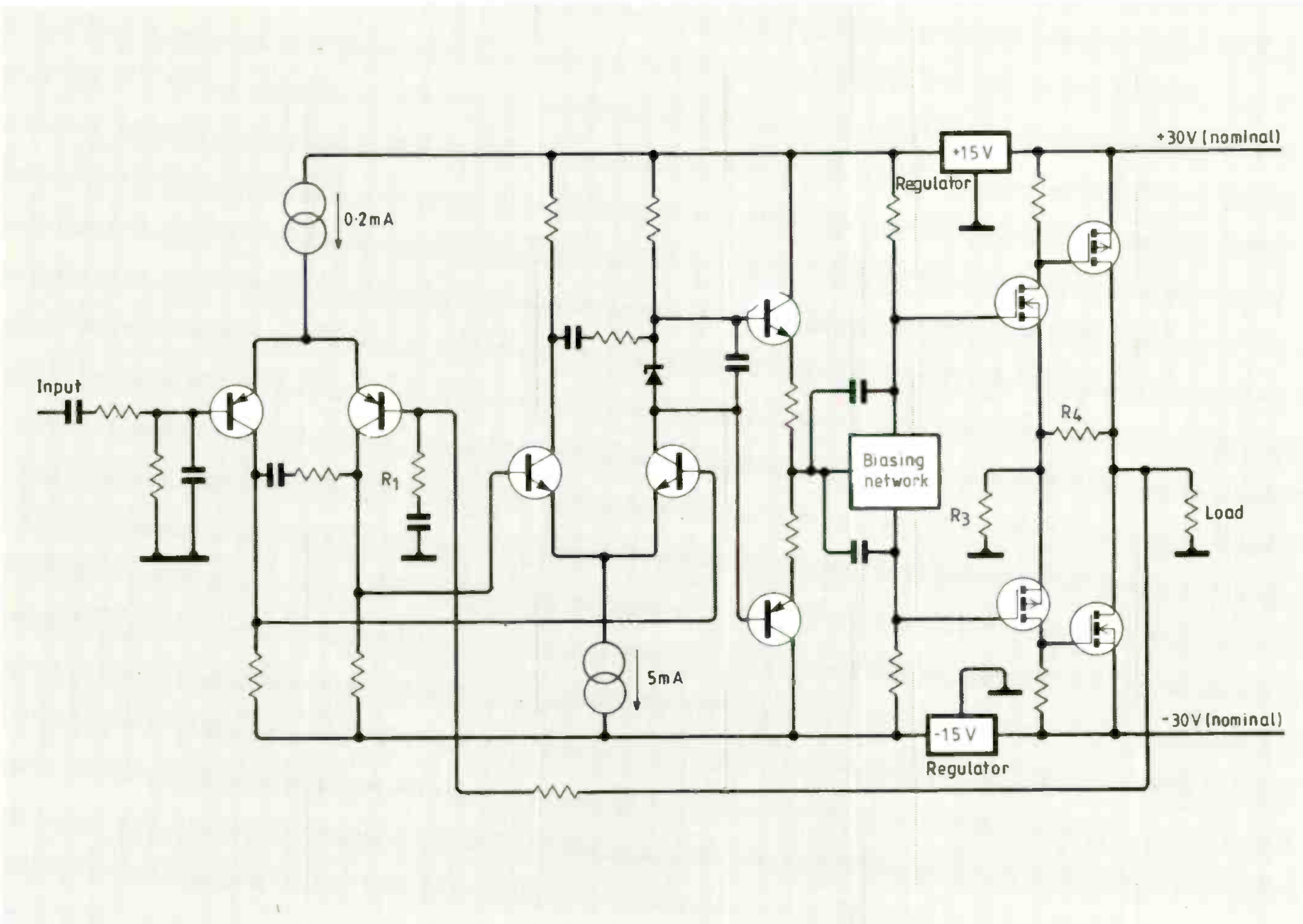


Fig. 4. Prototype audio power amplifier. Driving the fet output stage is an op-amp. It is built using emitter-coupled bipolar devices to provide good signal-differencing performance.

stage to have an even more restricted bandwidth to keep the system stable. Output circuits incorporating fets can have wider bandwidths so that the roll-off of the earlier stage can be above the audio range, and the benefits of feedback will now be present for all audio frequencies. The other advantage is that fets produce few high-order harmonic components. Provided that the input signal is limited to the audio range, there will be no problems with transient signals, since there will be negligible high-frequency attenuation and delay of the feedback signal.

PROTOTYPE DESIGN

A neat design, which formed the basis of a number of amplifier kits, was published in 1970 by Texas Instruments[6]. In essence the circuit is a bipolar class-AB output arrangement. It has voltage as well as current gain and is driven by an operational-amplifier integrated circuit with stabilized low voltage supply rails.

As the gain of the op-amp has to be rolled-off from a low audio frequency to maintain stability, the design does not accord with present-day thinking. However, the extension of the idea to a small-signal, very linear, wideband amplifier taking control, via an overall negative feedback loop, of an even wider bandwidth output arrangement, is attractive and acceptable.

Provided the output stages do not introduce too much distortion, sufficient overall feedback can be employed to effectively linearize the complete system without encountering transient problems. With fets in the output stage and the small-signal amplifier constructed from discrete components this can be achieved, very much along the lines of the Texas circuit. This arrangement exploits the advantages of using fets in audio power amplifiers.

Figure 4 is an outline of the circuit. The four-fet output circuit is operated from positive and negative rails of about 30V. Local negative feedback is applied by R_3 and R_4. Approximate performance figures for the output circuit alone, loaded by an 8Ω resistor but with no overall feedback, are:

Maximum output power	— 30W
Voltage gain	— 18dB
Distortion components	— less than 1% (mainly low-order harmonics)
Bandwidth	— 3MHz
Output impedance	— 1Ω from 0 to over 100kHz
Total quiescent current	— 80mA

The fact that the power devices require a few volts to drive them means that the low-power fets operate at a direct drain current of about 8mA with 500Ω drain resistors, and that they work in class A over most of the output range of the amplifier. At such currents, fets have a square-law relationship between their drain current and gate-source voltage.

This non-linearity gives rise to only the second harmonic, so from the distortion point of view it is not serious. It does mean, however, that dissipation in these devices goes up with the level of drive. The trouble is

"Power mosfets are capable of better high-frequency performance than bipolar devices, and their use enables a fresh evaluation of negative-feedback techniques to be made"

not that they are in danger of being destroyed but, having a positive temperature coefficient at low currents, their drain current will increase. This change will be amplified by the power fets, resulting in a large increase in the quiescent current of the whole output circuit.

The solution is to attach the driver fets and the temperature compensating network between their gates to a small heat sink. Only a very small amount of heat is generated, so thermal tracking of the devices is not very important; the sink effectively serves to keep them all at ambient temperature. Use of two cascaded stages with local negative feedback solves the problem of obtaining a low output impedance from devices with low mutual conductances. Maximum output swing is limited only by the drain-source saturation voltage of the high power fets.

Discrete transistors are used for the small signal amplifier, which is in effect an op-amp. It is composed of emitter-coupled stages, which are necessary to obtain a good signal-differencing performance, with a complementary class-A output stage. The output stage provides the low impedance necessary for driving the fets to obtain a wide bandwidth. Its DC supplies are fully stabilized by integrated-circuit regulators. Low frequency voltage gain is approximately 2000.

Two networks are included in the differential stages to gradually roll-off the response of the amplifier from about 20kHz. These compensating networks cause the high-frequency response to "ripple" down at an average slope of about 9dB/octave[7]. This is half way between the first-order slope of 6dB/octave, as used in compensated op-amp integrated circuits, and the second-order slope of 12dB/octave which would cause peaks in the overall response. Using this technique the open-loop response is kept sensibly flat throughout the audio range while maintaining a good margin of stability.

Bandwidth of the input signal is restricted by a passive input filter. Voltage gain of the complete circuit at audio frequencies is set to 100 by the overall feedback resistors $R_{1,2}$. The capacitor in series with R_1 decreases the gain at DC to unity, thereby accurately defining the quiescent output voltage to be very close to zero.

At all output levels up to overload, the complete amplifier has a total harmonic distortion less than 0.005%. This figure does not rise at higher audio frequencies. Transient signals do not cause large error signals to be present so transient distortions are not a problem and the circuit is unconditionally stable. The only adjustment necessary after construction is to set the quiescent current of the output circuit. Provided tone controls are not required, all signal sources, except for gramophone pick-ups, can be simply connected to the amplifier via volume and balance controls.

PROTOTYPE PERFORMANCE

My prototypes have been used as replacements for some well reviewed economical amplifiers in a number of audio systems. In all cases a difference in the sound was immediately apparent to all listeners without any need for A/B comparisons.

The impression is one of greater clarity with individual instruments standing out more clearly separated from each other. Transient sounds are sharper with a faster attack. The location of sources in the stereo sound stage is more precise, with each source appearing to be smaller. Drums and other bass instruments have more "punch", weight, and reality. All these effects can be simply described as an improvement in definition, with more "silence" between the instruments.

If an amplifier produces many harmonics, albeit all of small amplitude, from a simple sinusoidal signal, imagine what will it do to the complex waveforms found in a recording of music involving perhaps symphony orchestra, choir, and organ. There must be thousands of spurious signals produced due to the harmonic, intermodulation, and transient distortion mechanisms.

There cannot be too much correlation between these spurious signals in the two stereo channels, so there will be a "carpet" of low-level sound, not directly related to the main sounds in frequency or amplitude, stretching between the loudspeakers. The images of individual instruments are formed above this "carpet", which is likely to be thicker near the real sound sources, so forming a diffuse halo of sound round each instrument. The amplifier described in this article generates very few high-order distortion and intermodulation products; hence the enhanced clarity and localization of sounds.

Transient non-linearities can be caused in the output stages of amplifiers when large low-frequency components in the signal cause the unstabilized supply rail voltages to vary. In the prototype design the signal delivered to the output stages is tightly controlled by the small-signal amplifier throughout the audio range. Distortion components generated in the output circuit are effectively cancelled by the small-signal amplifier supplying a waveform which includes matching inverted distortion components.

I have checked this experimentally by comparing the distortion products introduced by the output stages on their own, with those in the waveform appearing at the output of the discrete op-amp. In the complete amplifier the harmonic components, as observed with a spectrum analyser, were virtually identical in both cases.

SUGGESTION FOR DEVELOPMENT

It may be possible to devise better output circuits that have lower inherent output impedances and distortion figures and a higher output-power capability. Setting-up and thermal stability of the quiescent current is an aspect that warrants attention; perhaps a scheme can be found that removes the need for any adjustments to be made after construction. Use of a discrete component op-amp as the low-level part of the circuit does involve rather a lot of components, albeit inexpensive ones, so another avenue for research is to investigate simpler circuits with the aim of achieving similar results.

How far up the performance ladder this design approach can be taken I do not know, but it appears likely that some of the techniques used in expensive designs, for example very-high-current power supplies, may prove unnecessary. With fets used to their advantage, the performance-to-cost ratio of quality power amplifiers may see a significant improvement.

BEHIND THE DESIGN

I am a lecturer in the Electrical and Electronic Engineering Department at Brunel university, Uxbridge, and I am responsible for the final year Audio Systems Engineering course which includes power-amplifier design. When power fets arrived on the scene I wanted some experience of designing with them. Another reason for starting this work was to assess, in a real design situation, an easy-to-use computer circuit-analysis package that we have in the undergraduate laboratories at Brunel. It saved many hours of work, and I doubt whether the project would have been so successful, or successful at all, without it. The early parts of this article are a summary of the theoretical work undertaken before starting the design exercise.

My decision to write this article stems from the favourable comments of those who have heard the prototypes. With regard to audio systems; beauty is in the ear of the listener, and not in the eye of the engineer looking at instruments in his laboratory. I am not implying that measurements are not important; a system that measures well may audition well, but I doubt that good sound will be obtained from one that produces poor figures in the laboratory.

Bearing in mind this history, I make no claims for my amplifier's giving state-of-the-art performance. It has not gone through an optimization process to find the best type and value for each critical component, nor does it contain any special high-quality items. In its present form it is relatively cheap, and I believe that the favourable comparisons that have been made with other amplifiers are realistic, in that they were between systems that should involve similar manufacturing costs.

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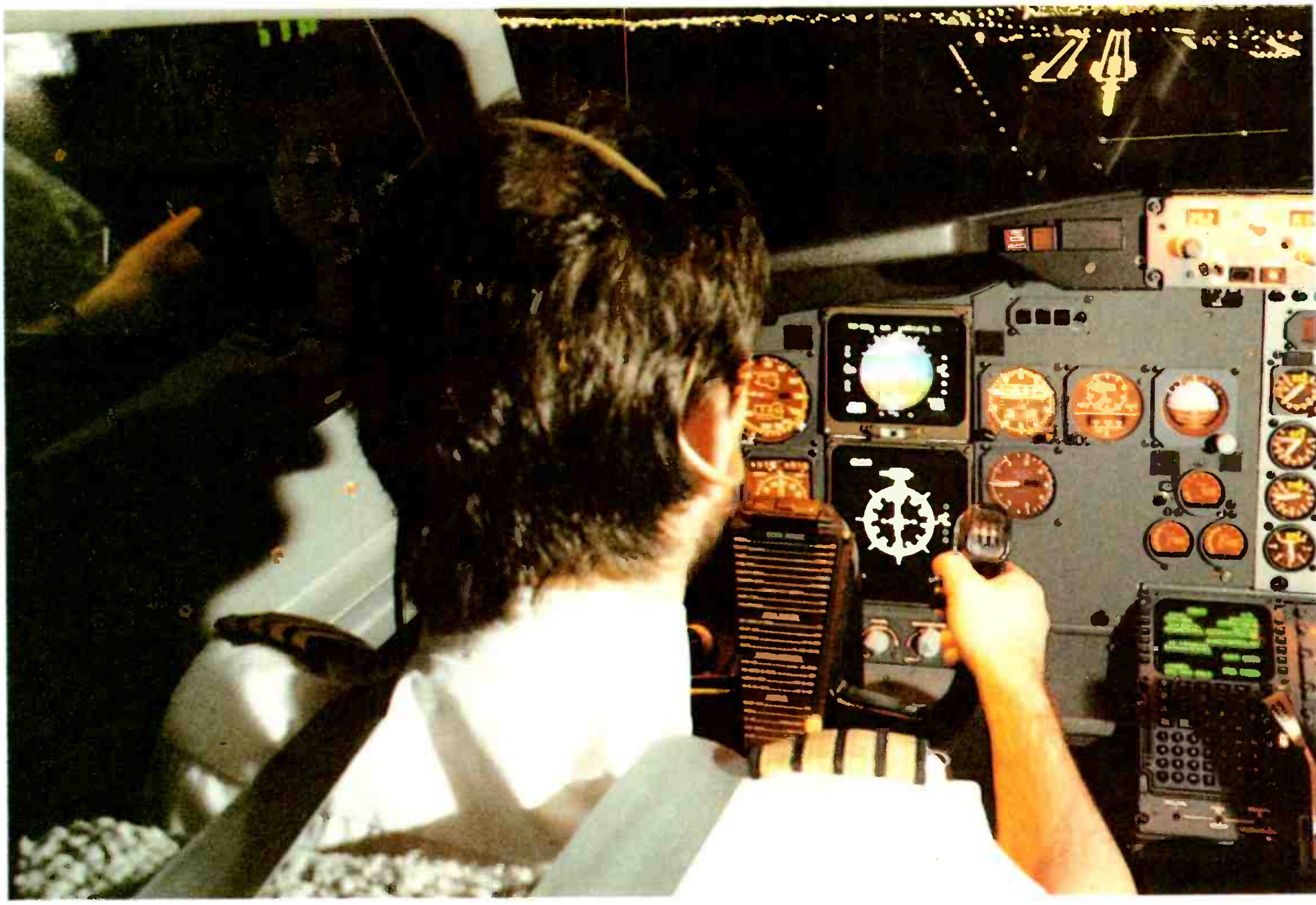


The flight simulator is a device for the instruction and training of aircraft crews. It allows them to carry out operations which might, in a real aeroplane, be dangerous to the aircraft and the crew. The financial aspect is important, in that there are considerable savings in flying time, fuel and wear and tear: the use of revenue-earning aircraft for training is also reduced. It has been estimated that the cost of training using aircraft can be up to ten times that of simulator training.

Modern simulators are already able to satisfy the UK CAA's CAP453 requirements and those of the US FAA Phase II and III "zero flight-time" specifications, which means that *all* pilot conversion and regular training can be carried out by simulator, no real aircraft being involved at all.

Military aircraft crews are possibly in greater need of specialized simulator training, since the assortment of systems at their disposal, particularly the lethal variety, can be difficult to deploy in peacetime. Full mission training, tailored to fit specific needs, is now in use.

THE BEGINNING

At the start of World War II, a large number of civilians who were formerly totally innocent of any involvement with flying were suddenly required to take full responsibility for expensive aeroplanes. The direct ancestors of modern simulator techniques can be seen in a number of electronic devices of that period, which used analogue methods of computation. The Link Trainer was one such.

In 1950, Redifon (now Rediffusion Simulation) built the first, fully electronic flight simulator for commercial crews, basing it on the Boeing 377 Stratocruiser and following it quickly with a Comet 1 machine – the first simulator for a jet airliner in the world.

As civilian jets came into use, more data was produced by the manufacturers which could be used to improve the accuracy of simulator performance. To use the data, more powerful computers were needed and real-time digital computing came into being, improving the fidelity of simulation in motion modelling, control feedback and, after a time, full visual simulation of the view from the "office". The computer makes provision for an instructor to create flight plans before the "flight" begins, including malfunctions and adverse weather, the specified events and conditions occurring automatically.

Until recently, the Gould Concept 32, 32-bit mainframe was used for flight simulation, but the provision of larger amounts of performance data and the requirements of more demanding legislation have pushed mainframe computing to the limit, so far as simulation is concerned. The need to specify simulators for many different requirements and the need to provide for future expansion have dictated the use of distributed, dedicated processors. Gould's SCI-Clone/32 distributed computer, which is used in the Rediffusion Novoview system, employs the architecture shown in Fig.1. As many computing nodes as may be needed are linked by a reflective memory (the outer ring) and a low-speed housekeeping link as the inner ring. A dedicated node is used to operate the system. Further nodes to provide more channels of simulation may be added and the simulator can be as simple or as complex as required, from the type needed to simulate small feeder-line types to that for 747s. A maximum of 40 nodes is possible to provide 40 channels of simulation, nine being the most used to date.

THE INSTRUCTOR

A recent facility, the touch-activated simulator control (TASC), has the effect of making the simulator transparent to the instructor, so that he can devote his time to instructing, rather than operating the computer. Touch-screen controls avoid the use of keyboards, for example allowing the instructor to "move" weather conditions around at a touch without searching for the relevant keys to press.

REALISM

Utmost fidelity to the experience of flying is the aim in all simulators. Flight-induced sensations involving sight, hearing and motion are synthesized to the extent that there is virtually no discernible difference between flying the aeroplane and going absolutely nowhere in a simulator, except that the results of running out of airspace are a great deal less dire.

FLIGHT SIMULATORS

The next time you climb aboard a 747, the pilot might not have flown one before. This article explains why.

The flight deck exactly duplicates that of the aircraft type being simulated and is fitted with all controls and instruments. Forces fed back to the controls from the control surfaces are simulated and the pilot receives sounds relevant to that part of the flight envelope. The visual system reproduces the outside view and the whole thing is mounted on a system of jacks to provide motion cues to the pilot. All these processes are controlled by computer.

The flight dynamics software, which determines the reaction of the "aeroplane" to the pilot's demands, is based on aerodynamic data obtained by the aircraft manufacturer from wind-tunnel results and flight testing. Other systems such as power plant, autopilot, fuel management, electrics, hydraulics, pneumatics, warning systems, radio systems and navigation are all simulated.

Sound. Sounds from the engines and other systems are generated digitally and fed, via a

Heading picture shows a Boeing 737-300 simulator by Rediffusion, showing an SP1T night/dusk display. Middle picture is a ground scene at Seychelle Airport, shown by a Novoview LCV low-cost display. Far left is a dusk shot of Frankfurt Airport, displayed by an SP-X computer-generated image system and left, an LCV image of a landing at Bogotá in fog.

number of channels, to many loudspeakers around the flight deck, so that the effect is that of external sound.

Feel. Apart from the seat of his pants, the pilot's only contact with the aeroplane are his flying controls. The "feel" of the controls conveys information and is computed from static and dynamic forces on and movement of the controls and control surfaces 500 times in a second. Outputs from the control surfaces resulting from the pilot's demands are used to compute the ensuing motion and scene changes.

Motion. To provide a realistic sensation of motion, the control-surface outputs give information from which to calculate the accelerations which would be experienced by the crew. The motion system receives its data from the flight dynamics software and calculates a new platform position every 2ms. The effect of all this is that the crew receive the correct sensation of motion for any manoeuvre being carried out – even that of continuous, long-term acceleration as experienced on a take-off run. In such a case, the authentic "shove in the back" is brought about by tipping the whole machine backwards while maintaining the view from the flight deck in the normal condition – all under computer control.

The speed of computation means that the system will respond accurately to the two extremes of high onset acceleration and low-speed washout. In other words, the acceleration produced by the start of a manoeuvre is reproduced, as is the gradual reduction of the acceleration to correspond with the aircraft's approaching the attitude demanded by the flying controls.

Visuals. Computer-generated image systems provide realistic visual simulation of the outside scene under night and dusk conditions, or full daylight VFR (visual flight rules) conditions. The image presented to the crew includes geometric transformations, changing perspective, picture clipping, shading due to ambient light and differing aerial perspective and colour changes with varying weather. "Fog" is reproduced at pixel level, rather than the older method of lowering a "curtain" of fog over the scene. To impart a sensation of speed when close to the ground, surfaces carry texture (it is even possible to depict bricks in walls, with their changing apparent sizes and perspective). It has been possible for some time to produce texture on two-dimensional objects, but the most recent simulators are able to apply texture patterns to any polygon, regardless of its orientation. Databases, covering a volume of 400 nautical miles up to 90 000 feet, represent real airports of the world, cities and topographical features under a range of weather conditions. The databases provide for the simulation of contaminated runways and docking.

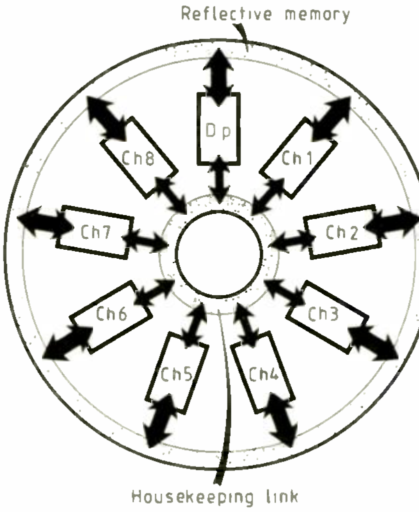
The computer-generated image is displayed to the crew by either a monitor-based system or by projector. A monitor display uses a CRT with collimating optics to make the display appear to be at infinity, as in real life. To create the necessary wide field of view, up to six monitors are disposed around the simulator, with adjacent views overlapped to eliminate gaps and joins: an angular coverage of 120° horizontally and 33° vertically is thereby possible.

Simulator by Rediffusion Simulation for JAL, showing the curved, wrap-around screen for the WIDE image display. The jacks impart the motion sensation.

One disadvantage of the monitor-based system is that different crew members see a different view of the display, which becomes distorted. For this reason, Rediffusion produced a visual system called WIDE, which is short for "Wide-angle Infinity Display Equipment". It provides an uninterrupted field of view of 150° and 40° and, because the system is based on a wrap-around back projection, the distortions which are associated with monitors are eliminated. The whole flight deck sees the same view.

WIDE uses three vector-type projectors, mounted above the simulator, to throw the image on to a parabolic back-projection screen which the pilots view via a large-diameter collimating mirror round the outside of the flight deck. A later version of WIDE – WIDE II – uses five sealed Schmitt projection tubes instead of three, an improved design of tube with a larger phosphor and a corrector lens providing the increased resolution and angular coverage needed for helicopter training. WIDE II covers a horizontal angle of 200° degrees to give a view out of the side windows and over the shoulder.

The Rediffusion-Gould computer architecture, which allows a modular approach to the expansion of facilities. Up to 40 nodes can be used.



Particularly in military training, where high speeds are involved, a very large field of view and very high resolution are needed to allow target identification at a distance. Using a larger display surface with more computing power would be one solution to the problem, but might not be the most cost-effective. Instead, the "area-of-interest" (AOI) type of display, where a small, high-resolution sector is inserted into the lower-resolution, wide-angle field, has been adopted. The smaller area corresponds to the pilot's field of view, which is controlled by the pilot's head and eye movements, so that the scene displayed tracks with the direction in which the pilot is looking.

The earliest method of obtaining an AOI display was to build a model of the terrain on a large board and to point a CCTV camera at it. A helmet-mounted projector had its field of view centred on the pilot's head direction. A light-valve projector, fitted in the cockpit behind the pilot, projected an image via a jointed optical relay assembly, which allowed motion in the three axes. It was fitted with angle sensors to provide head-orientation angle information to drive the camera over the model.

In the more recent designs, laser optics allow the use of small-aperture optical systems necessary to produce high-density head and eye-tracked scenes.

TRAINERS

Although simulation training can cost a tenth of that using aircraft, it is still expensive. In some circumstances, such as systems training, where the trainee must gain familiarization with navigational, engine-management and emergency procedures, a great deal of time at a fairly low level of complexity has to be spent and it is found that full simulators with visuals and all the other exotica cannot be justified. Instead, it is common practice to use a small, desk-top computer, loaded with simulation programs for the relevant system, called a trainer. One recent Rediffusion trainer for systems familiarization on a 747 uses two screens, one of which depicts the control panels and the other a schematic of the system, which changes in response to the trainee's operation of the controls. A trainer of this type can cut the costs of simulation by up to 30°.

This article is based on material supplied by Rediffusion Simulation Limited

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FEEDBACK

Reeves in equilibrium

In your series *Pioneers* in your September issue you covered the life and works of A.H. Reeves. I feel that his work in the "Equilibrium Principle" deserves a mention, because it may well be yet another topic well ahead of its time. The picture actually showed a four digit companding vibration equilibrium coder made using tunnel diodes, and behind it a mechanical model thereof, but there was no mention of it in the text.

The best description of equilibrium process as against the more normal serial processes we all know is as follows. If you have a beaker of sand and you have to level the sand in the beaker, you can use a pair of tweezers and move each grain until the surface is level. That is the serial method. Alternatively you can merely shake the beaker until it is level. That is the equilibrium process. It relies on the fact that the force of gravity causes the particles to level in the manner you want by the application of energy in the form of shaking.

When Mr Reeves developed the equilibrium method of coding or analogue to digital conversion, (as it is now known) transistors were just ceasing to be a novelty and integrated circuits unheard of. Therefore methods of doing anything that minimised the number of components and got high speed results using low speed components were at a premium. He sought to invent a circuit whose *equilibrium condition* gave the required number or code for the given input. Not content with a straight digital to analogue conversion, he also set out to make it compand, i.e. give a log law. This improves the fidelity when sound is encoded using only a few digits.

The circuit whose photograph you show used four tunnel diodes. These were diodes that change conductance depending on the current flowing through them. They were supplied with different currents at which they "triggered." Four of them with different triggering currents were arranged in this circuit so that they were triggered by an input pulse whose amplitude was modulated by the speech to be encoded. If a particular diode triggered feedback would reduce the amplitude of this pulse, and it was therefore a feature of the circuit that there would be only one equilibrium state with a given input pulse and a specific pattern of the four diodes that could be triggered. A damped sinewave was superimposed on

Maxwell was half right

A basic dogma in twentieth century physics dictates that for an observer in the universe there is nothing faster than the velocity of light in vacuum, that light or anything else can never overtake light. These statements are fundamental assumptions of the theory of relativity. Obviously, they are unproved statements for such a universal application. However, any disbeliever could never dare to express his doubts and will immediately be considered a heretic or a science ignorant person, perhaps a charlatan. The theory of relativity is more than a religion in the twentieth century. Religions in the twentieth century are diverted in heresies. However, for the theory of relativity there is no room for any heresy, no matter whether it is based on unproved or totalized statements. It is hard to believe this fact, but it is true.

It comes without surprise to find that the experiments of Alexis Guy Obolensky and Harold go unreported even though they were conducted over 11 years. Recently the Pappas-Obolensky experiments demonstrated electrical signal propagating in the range of 2C and over 100C under special conditions.

No theory is in hand to explain these velocities. However, we may suggest that the Maxwell theory for the propagation of electric alternating to magnetic disturbance, ie for the propagation of electromagnetic waves correctly predicts a velocity C relating to the ratio of electric and magnetic parameters of the medium. However, one can enter a doubt that an electric signal should always alternate with a magnetic signal 100 per cent and vice versa. It seems reasonable that under certain conditions, part of an electric signal or part of a magnetic signal may propagate by its own disturbance without alternating 100 per cent with a complementary electric or magnetic disturbance. In a such a case the velocity of a such disturbance may not be based on C and not limited by C.

The weakness of the observed superluminal signals and the special conditions for their propagation supports the above ideas. Therefore, research is needed to investigate techniques for effective transmission of unitary signals, to investigate optimum media for their propagation.

If unitary waves exist, they are certainly used by advanced civilizations. Most likely, the development of unitary waves by a civilization is the minimum qualification to join the next to the human group of civilizations.

Recently, the Advanced Energy Research Institute, UK, announced its decision to investigate and develope unitary interactions with the contribution of the pioneer investigator of Unitary interactions, Technithion Laboratories, USA and its director Alexis Guy Obolensky, as well as with the recently joined member Professor Dr Panos T. Pappas. Let us celebrate and hope for such initiatives.

Professor P.T. Pappas
Joint author "36ns faster than light"

If the Pappas-Obolensky observations result from singular electrostatic or electromagnetic components separated from a standard Maxwell E-M wave, then it should be relatively easy to prove this. An electrostatic (or magnetic) screen separating a pulse excited aerial system from its corresponding receiver will always cause an echo detectable at the receiver. This would presumably be caused by the faster than light separated magnetic (or electrostatic) component arriving ahead of the main E-M wave. The bulk of replies will be published next month. – Editor.

FEEDBACK

the top of the pulse to "shake" the circuit into its stable state.

A detailed mathematical working of the equilibrium method of coding is given in *Principles of Pulse Code Modulation* by K.W. Cattermole, Iliffe 1969, ISBN 592 023834 8, chapter 4 section 6.

Mr Reeves' futuristic ideas were sometimes tinged with an "otherworldliness", though. In the early 1960s I suggested (whilst a student doing summer industry experience) that PCM could be used to improve the fidelity of tape recordings. He replied that it would certainly work, but there would be no demand for it. One wonders what sort of technology would have emerged if he had taken it up, and whether he could have solved the problems of digital audio using 1960s tape decks and technology. I would suspect that if he had, we would have now got something far simpler than the expensive spinning head equipment now on offer.

However the equilibrium principle may well be applied to other problems, and if it does appear again in the fields of artificial intelligence, pattern recognition or neural networks then due recognicance should be given for Mr Reeves' work with it in the 1960s.

John de Rivaz
Truro
Cornwall

3HP television

Mr. Atherton's articles on *Pioneers* are always of great interest to me, particularly the piece on Walter Bruch who, incidentally, was born one year after me!

In the early 50's when I was Vice-President of research and development in the Freed Radio Corporation, USA, I was a member of the National Televisions Systems Committee (NTSC) which was based in Washington. The advantage was that we could visit most of the major companies doing research on compatible colour television, and naturally we were impressed with the work done by RCA on the shadow mask tube, although the picture quality in those early days was not very good but we realised it needed development. The initial decision didn't go in favour of the RCA system however.

The picture shown by Dr Goldmark at CBS which used, I believe, a 14in tube with a colour disk in front which was synchronous with the colour signal. Naturally the quality was very good, as we knew only too well because all those experiments were carried out by my former company, Scophony Limited, in England many years before the war, and probably by many others. But is was an incredible surprise when the Federal Communications Commission decided on the CBS system for compatible colour television. The set manufacturers then launched a campaign against the CBS system.

I believe that the reason for the change was an anti-CBS demonstration given by Dr Dumont of Dumont Television. Unfortunately I was not present on that day but he demonstrated a 30in cathode ray tube which, I am told, was about 5ft long and in front was an enormous disc driven by a large synchronous motor in the order of 2 or 3hp. I believe the disc containing the various colour filters was 9ft diameter. By pre-arrangement with the maintenance staff of his factory Dr Dumont organised it so that when the FCC viewed his large screen picture all the lights in the building went out and everything shut down after just two minutes viewing. He apologised and said that he thought the future would be a larger picture for the home but that unfortunately the big disc would require an awful lot of power. He claimed the main circuit breakers operated when the load of the disc was switched on.

Not long after that the FCC changed their minds and the RCA system, approved by the NTSC, was given official approval.

Joshua Sieger
Poole
Dorset

Direct broadcast pollution

Once again the news is full of satellite broadcast announcements.

I have never seen any reporting of the adverse effect that all this RF "pollution" will have on the work of radio astronomers, who have to work at very low signal levels.

It seems a great shame to sacrifice research into the cosmos for the sake of ever-increasing numbers of pulp TV channels, from abroad.

Given an equal amount of investment, how much would it cost for fibre-optic nerworks to distribute data to houses. Apart from the absence of RF pollution, optical networks would also have the benefit of being two-way, and able to support computer data transmission too.

Mike Whittaker
Appleby
Cumbria

Not NAND

I am sorry to have to turn down Mr Medes' kinds invitation (Letters, November) to start getting my hands dirty. As I have been successfully designing and building electronic equipment for 30 years or more, his invitation has arrived too late.

Some of his other points fall into the broad category of: "I have had little success in doing so-and-so; if someone else claims to have done better than me he must be a #!§*."

I did not say what he claims that I said about SN7400's. But I have never come across a 7400 which does what his diagram, shows, namely, always maintains its two outputs different at Q and not Q, without any qualifications or exceptions. But at least in that particular instance my scrap of code is less out of touch, and represents real 7400's more accurately, than his diagram does. Diagrams can represent hardware inadequately just as surely as a computer program can.

J.G.D. Pratt
Leatherhead
Surrey

NiCad whiskers

I am surprised your correspondent R S Ratcliffe does not seem to know that "whiskers" in NiCad cells can be cleared, quite safely in my view, by discharging a capacitor across the cell. I use 5000 μF charged to 16V, and discharge positive to positive. Tests with an Ohmeter show whether the fault is cleared. A good cell gives an effect rather like that of a large capacitor.

R.A.W. Hill
West Kilbride
Ayrshire

ACTIVE

ASIC

Asic verification. The XL2 from Instrumatic provides 896 individual pattern generation and acquisition channels, or up to 448 bidirectional I/O channels, to verify devices with over 600 pins. It also delivers 100 MHz clock rates and 80-MHz data rates across all 896 channels. Instrumatic UK Ltd. Phone 06284 76741

Fast c-mos gate array family. Cmos-5 gate arrays operate with an output frequency of 100 MHz. The family offers gate counts from 2000 to 45000. From 71 to 318 TTL or cmos logic level I/Os are available, according to gate count, and output drive capability is up to 17.5mA. NEC. Phone 0908 691133

Transistor array for 2.4GHz. For use with digital or analogue circuits up to 2.4GHz, a array includes integral 236 bipolar NPN transistors, 320 resistors, 8 capacitors, 19 protective elements against electrostatic discharge and one bias driver. Siemens. Phone 0932 752323

A to D and D to A Converters

A-to-D converter. The ADS 111 sampling A-to-D converter, which combines a 12-bit converter and a fast sample-and-hold amplifier in a 24-pin dip. The ADS 111 digitizes sinusoidal-input signals at minimum rates of 500ksamples per second with 12-bit binary performance. Datel. Phone 0256 469085

Discrete active devices

Small-signal transistor. The MRF0211, a low-noise, high-gain, small-signal RF transistor, packaged in an SOT143 four-lead surface-mount package. Important features include gain bandwidth of typically 5.6GHz, a collector-base capacitance of typically 0.7pF and a collector-emitter breakdown voltage of 15V minimum. Motorola. Phone 0628 39121

General microprocessors

Microcontroller. Two application-specific devices to its range of 4-bit single chip c-mos microcomputers. The HD404302 and HD4074308 allow features such as multi-channel A-to-D conversion and direct drive of fluorescent displays and led annunciators to be implemented with a single chip solution. The HD404302 contains a 2048 × 10-bit masked rom, while the HD4074308 is a ZTAT version containing an 8192 × 10-bit one time programmable eprom. Hitachi. Phone 0932 246488

Microcomputer with eeprom. The MC68HC05B6 combines a c-mos 6805 core with peripheral features, which include 256 bytes of byte-erasable eeprom, an 8-channel A-to-D converter, a serial communications interface and two pulse-length modulation systems. Motorola Ltd. Phone 0908 614614

32-bit microprocessor. Toshiba's first 32-bit microprocessor is based on tron architecture. Main features of TX1 include an average operating speed of 5mips and 12.5mips under the clock cycle of 25MHz. Toshiba. Phone 0276 694600

Tram modules and motherboards. Each module comprises a small daughter board with a transputer and between 32KByte to 8MByte of memory. All the trams use transputers running at 20MHz with all the T414 variants upgradable to T800 floating point transputers. Transtech Devices Ltd. Phone 0494 464303

Interfaces

Analogue interface chip. TLC 32040 analogue interface circuit is a complete analogue-to-digital and digital-to-analogue input/output system held on a single monolithic chip. Hi-Tek Electronics. Phone 0223 213333

PC into system controller. The 70618 RS232/IEEE 488 converter enables a PC to become an IEEE 488 controller without sacrificing any PC slots. The converter is a length of cable with an enlarged 25-way D connector shroud housing the interface. Schlumberger Technologies. Phone 0252 544433

Linear integrated circuits

BiMOS dual op-amps. GE Solid State offer a pair of operational amplifiers for 5V power supply operation in microprocessor based systems. The CA5260 and CA5250A are dual op-amps with a mosfet input stage and c-mos output stage. GE Solid State. Phone 0276 685911

Voltage regulator. Voltage regulator IC provides 5V regulation. The STA 2931 is a 5V positive regulator in TO-92 plastic package. It has a low quiescent current (typically 0.4mA at 10mA output), and maintains regulation with input-output differential typically down to 0.05V. ITT Semiconductors. Phone 0932 336116

Wideband operational amplifier. The Elantec EL2040 is a high slew rate amplifier designed for closed loop gains of more than 10, which provides 400 volts per microsecond slew rate, an open loop gain of 83dB, a 400MHz gain-bandwidth product and 6.3MHz high power bandwidth. Microelectronics Technology Ltd. Phone 08446 8781

Dual monolithic power op-amp. The PA21 combines two isolated power amplifiers in an 8-pin hermetic TO-3 package. Manufactured by APEX Microtech, each amplifier is rated at 2.5A output and will operate with supply voltages of 5 to 40V or ± 20V. Microelectronics Technology Ltd. Phone 08446 8781

Bipolar arrays. The QuickChip 2 family from Tektronix is a series of uncommitted arrays of bipolar NPN (6.5GHz) C and R Schottky diodes enable the design of TTL drivers, fast recovery amplifiers, clamping circuits, etc. Tektronix. Phone 06284 6000

Memory chips

High density c-mos fifo. 17 c-mos fifos with densities of 256B to 2K and speeds from 25ns to 80ns are now available from AMD. Advanced Micro Devices. Phone 04862 22121

256k eproms with 70ns access. The TC57H256D family of 256kbit UV erasable eproms. With a 32768 × 8-bit architecture these devices offer access time for read operations as low as 70ns. Toshiba. Phone 0276 694600

Optical devices

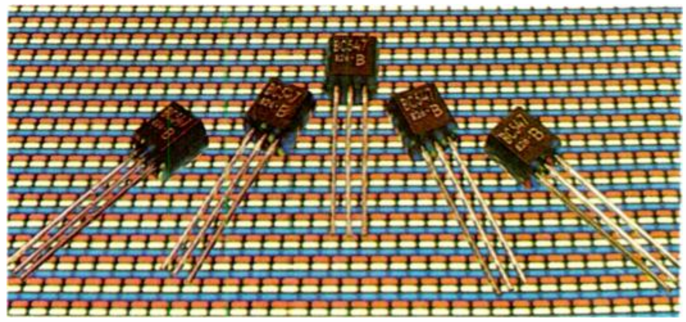
3000 mcd leds. The SLA 590 series of leds which have typical luminous intensities from 700 mcd up to 3000 mcd at 20mA. Hero Electronics Ltd. Phone 0525 405015

GaAs chip set for optical fibres. A set of GaAs ICs provide a complete transmit receive interface for optical fibre communications at data rates of 2.4 Gb/s. The set consists of the HS6902 multiplexer and PHS6901 laser diode driver for the data transmission functions and five devices that provide signal conditioning and demultiplexing at the receiver end of the fibre. Hitachi Europe Ltd. Phone 0923 246488

Optical fibre connector. Plug versions are available to suit both single and multi mode fibres and typical mean insertion losses of less than 0.1dB are achieved with either fibre type. Leetec. Phone 01 852 2203

Avalanche photo diode. The Hitachi HR1201. Major performance parameters include a typical sensitivity of 0.9mA/mW at 1550nm and a typical dark current of only 2nA. Micro Call Ltd. Phone 084 421 5405

Red semiconductor laser. NEC claims the first visible semiconductor laser for commercial applications. The NDL3200 is an AlInP diode delivering 3mW recommended maximum at 670nm. NEC Electronics (UK). Phone 0908 691133



Small-signal semiconductors from Toshiba.

Laser diode. Toshiba's TOLD321 and TOLD323 laser diodes exhibit variation better than 0.01 mW between −20°C to +60°C (typical). Output power is 0.1mW for a threshold current of 20mA (typical). Toshiba (UK) Ltd. Phone 0276 694600

Power semiconductors

Smart power ICs for brushless DC motors. With pulse width modulated current control, communication logic, and protected power outputs on a single chip, the UDN-2936W and UDN-2937W provide three 45V push pull outputs, each rated at 3A continuous (4A at startup) and protected by ground clamp, flyback power diodes and thermal shutdown. Sprague. Phone 0932 253355

Standard logic circuits

20-BIT encoder/decoder. Fabricated in c-mos, the AS2787 encoder/AS2788 decoder provide over one million different conversions in the single channel mode. Four different output channels with 262 144 combinations each are also available. Both the encoder and decoder are clocked by an on chip oscillator and amplifier. Austria Mikro Systems International Ltd. Phone 0793 37852

Integrating A-to-D converters. For 3.75 digit DMMs. The Maxim MAX133 and 134 feature an internal resolution of plus or minus 40 000 counts and provide an extra digit for use as a guard digit to allow autozero. Dialogue. Phone 0276 68200

LCD graphics/character module. The TLX 1301 is complete with driver chip and 64K of ram and offers a viewing angle of 50. Toshiba. Phone 0276 694600

PASSIVE EQUIPMENT

Passive components

Multiturn potentiometer. The Model 64 from Beckman is a ¼in square 15 turn cermet trimmer, an industrially priced unit meeting MIL specifications. Beckman Industrial Ltd. Phone 021-643 3399

Flat electrolytics. The FLK series of flat aluminium electrolytic capacitors from ECC Electronics features a maximum operating temperature of 105°C. The capacitors are 7mm thick. ECC Electronics (UK) Ltd. Phone 0494 36113

Cermet trimmer. The Spectrol Reliance Model 64 ¼in multi-turn trimmer comes in five pin styles and top or side adjust. Spectrol Reliance. Phone 0793 21351

Chip inductors for automatic mounting from Stettner have been specially coated with a high mechanical strength material for use with automatic mounting machines employing suction nozzles. The coating also protects the coils against damage during handling. Steatite Insulation Ltd. Phone 021 6436999

Connectors and cabling

Phase-adjustable SMA connector. This connector from March Microwave is a combination of connector and phase shifter that allow phase adjustments and trimming to be performed during and after installation. March Microwave Ltd. Phone 0376 44277

D connectors with integral suppression. From Murata is the CUBL range of D type connectors which feature integral RFI-suppression capacitors connected between the metal casing and user selected pins. Murata. Phone 0252 522111

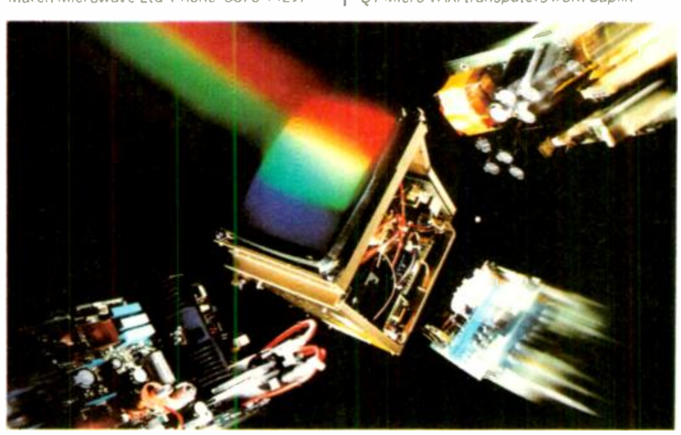
Optical-fibre connectors. Sumitomo Electric has developed a duplex optical-fibre connector designed to meet the requirements of the ANSI X3T9.5 subcommittee which is establishing standards for the FDDI 100 Mbit/s local area network. Sumitomo Electric Europe S.A. Phone 01-723 4003

Displays

Membrane with leds. Diamond H Controls has introduced a range of membrane switch panels featuring surface mounted light-emitting diodes implanted within the membrane sandwich layers. Diamond H Controls Ltd. Phone 0603 45291

Low-cost displays. The Siemens HDSP 2000 series of stackable dot matrix displays is available from RR Electronics. These 0.15 in 4 character 5 × 7 devices offer a reduction in power consumption, being in c-mos, and come in red, high efficiency red, yellow and bright green. RR Electronics Ltd. Phone 0234 270272

Intelligent video I/O board adn software for QT Micro VAX/transputers from Caplin



Instrumentation

Oscilloscope amplifier. The SA100 amplifier from AWR Technology is attachable to any oscilloscope to extend its sensitivity by a factor of 100. A differential input and switchable high-cut and low-cut filters eliminate the noise that usually accompanies low level signals. AWR Technology. Phone 0304 365918

Multimeter. An "audible bargraph" in Beckman Industrial's HD153 digital hand-held multimeter converts the reading into an audible signal in addition to displaying the values, allowing hands off operation. Beckman Industrial Phone 021 643 8899

Instrumentation tape recorder. Earth Data Ltd has introduced the EDR128 instrumentation tape recorder which provides mixed-bandwidth digital recording on a standard VHS cassette. It will digitize up to 128 analogue signals using 12 or 16 bit conversion, at a bandwidth of up to 40kHz. Earth Data Limited. Phone 0703 869922

Pressure transducers. The EPNM transducers from Entran have a threaded body for high stability. Metallic-foil strain gauges bonded to a stainless-steel diaphragm provide a typical output of 9mV f.s. for 5V excitation, an optional internal amplifier giving 5V full scale. Pressure range is from 0-150psi up to 0-7500 psi. Entran. Phone 0344 778848

Digital storage oscilloscope. The Hameg HM205-2 can operate as a digital-storage or real-time oscilloscope. In analogue mode, it provides two 20MHz channels. As a digital storage oscilloscope, 1042 × 8 bit memory is available per channel and maximum sampling rate is 5MHz per channel. Feedback Test and Measurement. Phone 0892 653322

1GHz service monitor. The SM 1000 Service Monitor from Helper Instruments features continuous frequency coverage from 100kHz to 1,000MHz. It is a digitally synthesized generator/receiver measuring frequency, RF power, frequency deviation, SINAD, modulation peak deviation and modulation density. As an AM/FM generator, output is adjustable from 0.1 to 10,000 µV. Lyons Instruments. Helper Instruments. Phone 0992 457161

Portable instrumentation recorder. Instrument Rentals offer the Racal V-Store instrumentation tape recorder available on a variety of rental and/or leasing arrangements. The V-Store, using VHS cassettes, comes in either 8, 16 or 24 channel version. Signal monitoring and display are provided. Instrument Rentals. Phone: 0753 44878

Direct digital synthesizers. Lyons Instruments have introduced two phase-continuous, fast, high-resolution, direct digital frequency synthesizers from Sciteq Electronics Inc. The VDS-8 is an "ultraclean" module with 8 MHz bandwidth. Model VDS-15 is a 16 MHz DDS and phase generator in a chassis construction. Resolution is 0.1 Hz for the VDS-8 and VDS-15 anywhere in their ranges. Switching speed of VDS-8 is less than 750ns between any two frequencies and phase noise less than -140 dBc/Hz at 1KHz offset. Lyons Instruments. Phone 0992 467161

Midata 510 option. Marconi Instruments have a plug in option for the MIDATA 510, the digital test system for entire boards or individual asics. The DTS is a digital test sub system featuring 10 megapatterns per second application/sense rates. Marconi Instruments. Phone 0727 59292

200 MHz logic analyser. Performance Solutions Ltd announce a PC-based, 32-channel logic analyser. Features include memory depth of 8Kbytes per channel, internal clock rates of 5ns to 5ms, store, retrieve, compare and search facilities, together with screen printing to an IBM-compatible printer. Performance Solutions Ltd. Phone: 0494 791606

LCR component bridge. The 6421 automatic bridge from Prism Electronics offers 0.2% measurement accuracy of L, C, R, D and Q at three test frequencies of 100Hz, 1kHz and 10kHz. Four-digit resolution is provided and full IEEE-488/RS232 talk/listen facilities are available with an optional interface. Prism Electronics Ltd. Phone 0480 62225

Function generator. The AFG from Rohde and Schwarz is a pulse generator producing single pulses or pulse trains with adjustable rise and fall times. The unit provides linear or logarithmic sweep with phase-continuous steps and AM, FM, VCO, pulse modulation and frequency shift keying. Feedback Test and Measurement. Tel 0892 653322. Rohde and Schwarz. Phone

Signal generation for D-MAC and D2-MAC. Schlumberger Instruments announces a D-MAC and D2-MAC packet test signal generator designed to provide test patterns and signals to EBU specifications. The generator simply replaces the program for testing a transmission channel, receiver or code converter. Schlumberger Instruments. Phone 0252 544433

Low-cost oscilloscopes. Tandem Technology Limited offer six oscilloscopes with bandwidths of 20 and 40MHz, with two or three channels, delay sweep and 1mV/div sensitivity. X/Y operation, line and TV sync separator circuit and variable hold off. Prices start from £270. Tandem Technology Ltd. Phone 0243 788703

Multiplex simulator and analyser. Tekelec Communications have introduced their TE880 primary multiplex simulator and analyser for testing of PCM and TDM multiplexers. The unit will simulate a PCM link at frame and channel levels and, as well as TSO and TS16 displays, it will measure A-A, A-D, D-A and D-D. Tekelec Communications. Phone 0734 771020

Measuring oscilloscope. Tektronix announce the 2247A portable oscilloscope, which features a counter timer, automatic rise/fall time measurements, and extended measurement capabilities. The 2247A is a 100MHz, 4-channel oscilloscope, providing auto setup, on-screen cursors and up to 20 pre-programmed measurements. Tektronix. Phone 06284 6000

Low-cost DSO. The Tektronix 2201 is a lightweight digital storage oscilloscope. Its features include a 10MS/s sampling rate, pre trigger, 8-bit resolution, 1MHz useful storage bandwidth and a 2K record length. The instrument possesses 20MHz bandwidth, a dual channel capability and sensitivity ranging from 5mV to 5V per division. Tektronix UK Ltd. Phone 06284 6000

Thermocouple temperature meters. The TM-35 and TM35X range of thermocouple meters from Texmate are suitable for use with either 'J' or 'K' type thermocouples. They feature thermocouple break detection and indication, display hold, display test and auto polarity indication. The meters have a differential input. Texmate. Phone 0481 53131

Eight-channel logic analyser. The TA100 is a hand-held logic analyser that can often be substituted for more complex logic analysers. It has eight data inputs an external clock input, a trigger output, and a trigger chaining capability. Maximum clock frequency is 25MHz and data pulses less that 10ns wide can be captured. Thandar Electronics Ltd. Phone 0480 412451

Power supplies

High-current power supply. The TS1541S from Thandar is a laboratory linear power supply with remote sensing, able to provide 0 to 4A at 0 to 15V, with liquid-crystal displays. The power supply operates in constant-current or constant-voltage modes with automatic crossover. Current limit control is logarithmic. Thandar. Phone 0480 412451

Printers and controllers

Rack-mounting printer. An improved version of the RM-80 rack mounting printer has been announced by Blue Chip Technology. This is an 80-column type with integral paper feed and collection, designed for use in areas where dirt, dust or water may damage the printer or printout. Blue Chip Technology. Phone. 0244 520222

COMPUTER

Fax card for IBMs and clones from Communicate.

Computer board level products

PC comms expansion. Altek announces the DigiBoard PS-COM/16, a multichannel communications expansion board designed for the IBM PS/2 models 50, 60 and 80, offering 16 asynchronous serial communications ports on the one PCB. Altek Microcomponents Ltd. Phone 0734 772345/791579

Image processing for the MicroVAX. Caplin Cybernetics Corporation (C3) has added the QTV10 intelligent video I/O board and image processing and graphics software to its QT series of MicroVAX/transputer products. The board allows VAX users to capture and store monochrome or colour images, process them at high speed, and display the results, without passing image data through the Q-bus or MicroVAX CPU. Caplin Cybernetics Corporation. Phone. 01-538 1716

Analogue and digital I/O boards. The Datel DVME range of compatible data acquisition and control boards for the VMEbus system, available from Crellon, comprises A to D, D to A, digital I/O and analogue multiplexer boards and their associated software packages. Gothic Crellon Ltd. Phone 0734 788878

VME analogue input coprocessor board. A high-speed, intelligent, analogue input board for the VMEbus is available from Crellon Microsystems. Using an on-board 68010 microprocessor, the Datel DVME-601 A/D coprocessor will automatically collect multiple A-to-D scans for transfer to host memory through a 64 Kbyte dual ported RAM. Gothic Crellon Ltd. Phone 0734 788878

VME backplanes. Fabri-VME backplanes are available from Onboard Electronics, Basingstoke. Five, nine and twenty slot J1 and J2 versions of these devices are available, built to conform with the VMEbus specification and easily mounted on standard Eurocard racks. Onboard Electronics Ltd. Phone. 0256 843346

Adapters for IBM PS/2. Roalan International have a range of Adapter Cards for their PS/2 Microchannel Architecture Computers. The range includes a parallel, serial, four channel serial, combined parallel and serial and a GPIB interface (IEEE-488). Roalan International. Phone. 0202 86 1512

68020 and 68030 single-board computers. A range of single-board computers from Stuart James Systems is based on Motorola's 68020 and 68030 processors, running at 16, 20 or 26 MHz. Each board in the range can provide support for up to four floppy and eight SCSI hard discs, 2 or 8Mb of DRAM, a real-time, battery-backed clock, eight serial ports and 2 parallel ports. Stuart James Systems. Phone: 0543 256979

VXI-based "Instruments on a card". Tektronix UK Limited has launched the first VXI "instruments on a card". These include a waveform digitizer and an arbitrary waveform generator for D size mainframes. There is also a scanner controller card that links VXI systems to the Tektronix line of switching products for manufacturing ate. Tektronix U.K. Ltd. Phone 06284 6000

Data encryption development board. Texas Instruments has introduced a low-cost IBM PC board to assist in developing data encryption systems, or systems for authorising electronic funds transfer transactions. The board is based on TI's TMS32010 digital signal processor. Texas Instruments Ltd. Phone 0234 63211

Computer systems

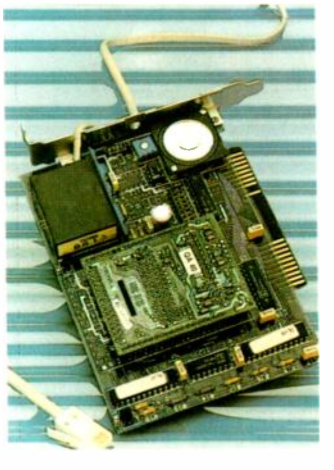
Network workstation. Com (UK) Ltd has announced 3Station/2E, an enhanced version of its 3Station dedicated network workstation, or "netstation". The new product is designed for users requiring more sophisticated graphics and computation-intensive applications such as desk top publishing. 3Com (UK). Phone. 0628 890670

Image computers. Kontron Electronics announces the IMCO 10 Image Computer, which is based upon the Intel 80386 microprocessor. The workstation is an image processing system for those who need to gain a low-cost entry to image computers. It will accept a variety of sensor input devices including RGB cameras, slow-scan devices, videotape and optical disc. Kontron Electronics. Phone

Data communications products

Group 3 fax for under £200. A plug-in half card that will provide an IBM PC or compatible with full facsimile transmission facilities to Group 3 CCITT standards for under £200 has been announced by Communicate. The basic C-Fax S half card is a send only text device, but an upgrade provides send and receive capability (C-Fax SR). Communicate Distribution. Phone 01-390 6802

OEM colour CRT drive package from Kent Modular Electronics.



Global positioning by satellite

Transputer decoding lowers the cost of accessing the modern Global Positioning System to that of earlier Loran and Decca systems.

PHILIP G. MATTOS

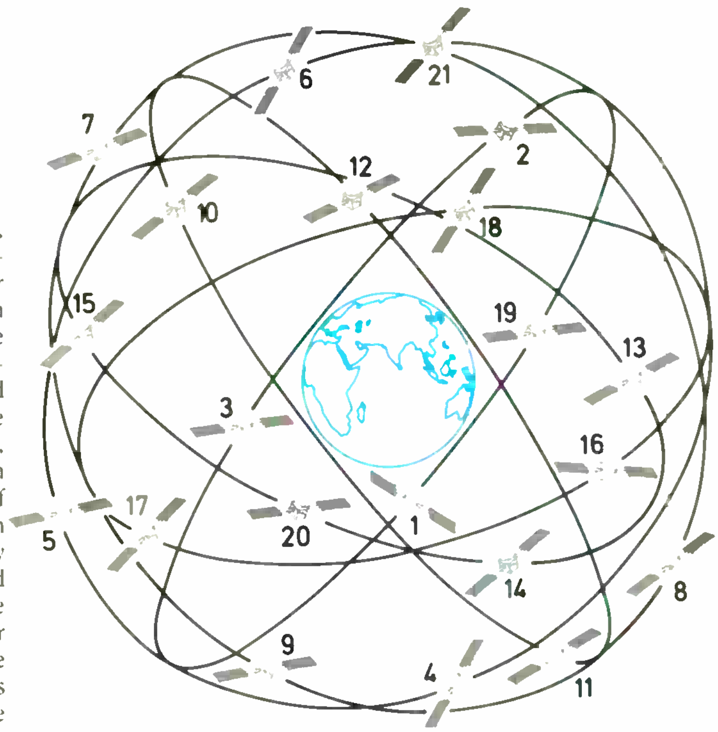


Fig. 1. GPS satellites are not geostationary — they have inclined orbits that take them over any point on their ground track once every 12 hours. (Diagram from Ref. 1.)

Global positioning system, GPS, is based on the concept that if you know your exact range from three known positions, you can calculate your position in three dimensions. The range is determined by the propagation delay of the signals from the satellites, which assumes you knew when they were transmitted. Short of carrying an atomic clock in every receiver, this is solved by using a fourth satellite, and using the redundancy in the position equations to solve for time also. While earlier satellite navigation systems such as Transit used Doppler shift as the measuring domain, GPS uses propagation delay.

Contrary to popular belief, the satellites are not geostationary. They are in an inclined orbit that takes them over any point in their ground track approximately every 12 hours, **Fig. 1**. Geostationary satellites cannot provide three-dimensional positions, nor latitude accuracy near the equator, nor any coverage of the polar regions.

There are currently six operational satellites, so coverage is severely limited. This is largely due to delays with the NASA shuttle. It is anticipated that the full constellation will be in service by 1995, with useful coverage of the UK by mid 1990.

SPACE SEGMENT

The system consists of eighteen operational satellites in six orbits, with a spare satellite also available in each of the six orbits. This is a relatively recent change from the original specification, which had the satellites divided over only three orbits. The specification may change again, as the current orbits, being almost synchronous with the earth's rotation, albeit at twice the frequency, suffer cumulative orbit disturbance due to the sun and solar flux. Desynchronising them would give a more stable orbit with less need for firing the jets.

All of the satellites transmit on the same frequency using a spread-spectrum technique. To spread the spectrum of the signal, inherently only 100Hz wide, it is multiplied by a code-sequence known as a Gold code after its inventor. As the chip-rate of the code is 1.023MHz, this results in the transmitted signal having a bandwidth of around 2MHz, with a very low power density (−163dBW). This is far below atmospheric and front-end noise.

Each satellite has a unique code, so when the signal is descrambled, the energy from a particular satellite only can be extracted.

Global Positioning System, GPS, arose from early experimental American military programmes interested in clock stability and relativity, such as the "Timation" programme in the 1970s. Specifications of the prototype system became public in 1978, with a full issue of the (American) *Institute of Navigation Journal* being dedicated to the subject.

COMMAND SEGMENT

Carriers transmitted by the satellites are modulated by the Gold code and also by useful data needed in the receiver to work out both the satellite position and the user position. Coefficients are transmitted that allow the exact position of the satellite to be calculated, and also measured values of the ionospheric propagation characteristics. This data is uplinked to the satellites by the ground stations around the world, after considerable computation to perform curve fitting such that the new parameters can remain valid for at least four hours, even through they are uploaded every two hours.

Ground stations, at Ascension Island, Diego Garcia, Kwagale and Hawaii, are controlled from the master station at Falcon Air Force Base, Colorado. These give global coverage, so satellites are never out of sight of a control station for more than the two hour uplink interval.

Data sent by each satellite consists of detailed information about its own orbit and transmission parameters, and at a slower rate, less detailed information about all the other satellites. This latter data, known as the almanac, is useful as it allows acquisition of satellites after the first to be directed at the correct code, and also the correct Doppler offset.

USER SEGMENT

In order to determine both the timing information and the downloaded data, the user has to receive the off-air signal, from at least four satellites, and descramble it. To receive the signal, an aerial that can see almost an entire hemisphere has to be used. The specification asks for down to 5 degrees above the horizon.

To descramble the signal, the user must generate a copy of the satellite code. The copy is then multiplied by the incoming

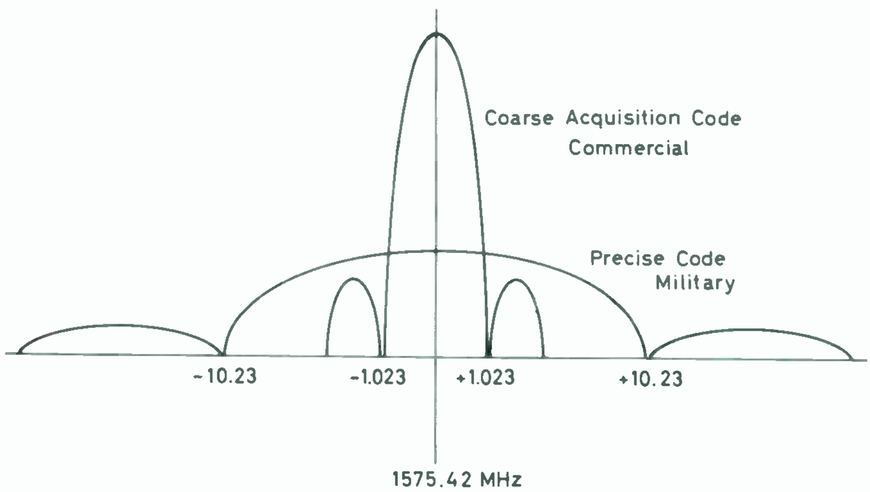


Fig. 2. In this GPS signal spectrum, the central peak is of interest; data contained in the wider curve is for military use and its code is secret.

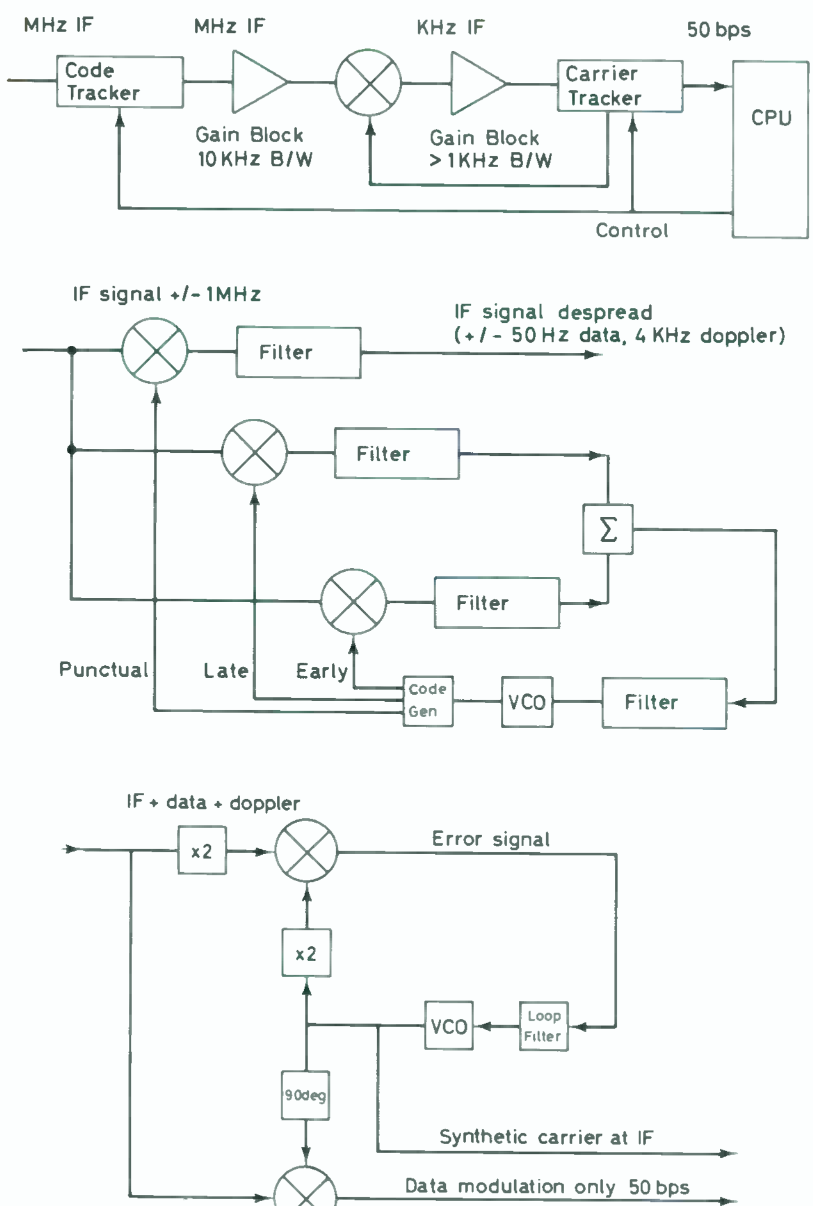


Fig. 3. Traditional GPS receivers require one of these hardware tracking channels per satellite (a). Sections (b) and (c) are a traditional code tracking loop and a hardware carrier tracking loop respectively.

signal at the correct offset to allow for propagation delay, which must be found empirically. This gathers the energy from the required satellite while spreading out the noise, and the other satellites, even further.

Finally the offset and data are used to calculate first the satellite's position and then the position of the receiver. For the satellites, this is largely a case of plugging the downloaded coefficients into given equations, but there is one small calculation that must be performed iteratively. For the user position, a matrix of four simultaneous equations must be solved, and it is most convenient to handle this iteratively.

THE TRADITIONAL APPROACH

The traditional approach consists of a dual-conversion superheterodyne front-end using a coherent local oscillator and intermediate frequencies, then four or five hardware signal-processing paths that each deal with one satellite, feeding their output to a processor which performs the calculations and handles the user interface.

Radio-frequency front end. The RF front end takes the incoming 2MHz-wide signal at 1575.42MHz with a received power of −163dB, and amplifies it. It then down converts it to a convenient frequency. The spectrum is shown in **Fig. 2.**; the wider curve is the military signal whose code is secret so we cannot unscramble it. Our desired signal is the coarse acquisition (C/A) code, which forms the central peak.

It is usual to use a first IF of 100-200MHz, in order that the front-end image frequency is easily eliminated. Some systems only use the single IF, but running phased-locked loops at these frequencies is inconvenient, so most use a second down conversion stage, to a frequency of 5–20MHz.

All frequencies used in the satellite are a multiple of the 1.023MHz basic chipping rate, so it is convenient to use other multiples for IFs and local oscillators. Thus the carrier is 1540×1.023MHz. If the first IF is to be 120×1.023MHz, i.e. 122.76MHz, then the local oscillator is 1420×1.023MHz. Another favourite is 160×1.023, i.e. 163.68MHz.

Choosing such multiples means that all local signals can be generated synchronously from the same chain, and thus be completely free of undesired beat frequencies. The actual incoming carrier is of course not exactly on frequency, due to Doppler shift from the fast moving satellite.

Hardware signal-processing loops. The signal tracking hardware is the most expensive section of the receiver. In early sets, it consisted of a satellite code generator, a very narrow filter, and a phase-locked loop, with the offset of the code generator and the frequency of the PLL being swept empirically until the signal was found.

The signal processing consisted of two-mixing (or multiplying) stages, the first of which multiplied the incoming signal by the locally-generated satellite code. This does not alter the centre frequency, but it does, when synchronised, pull all the satellite energy from the 2MHz wide signal into a single narrow carrier.

Output of the PLL was used in a down conversion mixer to make the carrier, now only 100Hz wide, hit the passband of the filter. The filter had to be very narrow in order to achieve the required noise performance, but due to Doppler shift, it would then miss the carrier without such tracking.

In order that the hardware can detect such a signal, the PLL normally runs at twice the final carrier frequency, so that the BPSK modulation on the carrier does not affect it. A divide-by-two circuit and an exclusive-OR gate can then extract the download data stream from the satellite.

Traditional hardware is shown in **Fig. 3**, taken from Ref. 4.

Such hardware could, in 1980, use a card per satellite. Soon after, the use of higher levels of integration, and even custom chips, allowed it to be reduced, but it still remained the major section of the hardware.

Processor. In the earliest systems, the satellite tracking was almost entirely autonomous, with the processor interested only in the code-generator offset and the download data from each of the four or five channels. As faster micros became available, the micro was used inside the hardware loop to command the code generator, and command the PLL frequency.

The main task, however, was to perform the mathematics to calculate the position, and to monitor the keyboard and drive the display.

As the hardware tracking loops became more integrated, they ceased to be autonomous, so the micro workload grew, especially on receivers designed for 'high-dynamics' vehicles, where predicting the Doppler shift becomes a problem.

Despite the rapid increase in microprocessor performance, all the signal processing was still done in the hardware tracking channels, as the micro could not historically keep up with the speed demands.

WHY CHANGE?

I set out to design a hand held receiver. That means low chip count for small size and for low power consumption. It also means rapid satellite acquisition time, both for convenience (one's arm starts to ache after a very few seconds of holding something at arm's length), and to save battery life.

Thus the main problem to be tackled was the hardware signal processing. This used a large number of chips, since the custom asic approach was not open to me, and thus also space and power. It is also the section that determines the acquisition time — and the traditional approach takes an average of 44s to acquire a satellite, with a worst case of double that. The reason for this long time is that it must search through a large number of frequency domains (say 10), and a large number of code offsets (2046), resulting in 20 000 trials, each requiring the lock up time of the PLL.

WHAT THE TRANSPUTER OFFERS

The transputer is a very high-speed general purpose processor with on chip serial communications that can transfer up to 1.8Mbyte/s on each of eight links (four in, four out). Communications is autonomous from the processor, which only authorises the communication at a cost of about 1μs per message, no matter what the message length.

So the transputer can perform i/o operations concurrently with the main processing. Even more significant is the speed of the processing — the simple maths operations such as ADD or XOR needed for this type of signal processing take 50 or 100ns.

In order to allow such speeds of i/o and computation, the transputer provides 4Kbyte of static ram on chip, **Fig. 4.** Being on chip this ram cycles in 50ns on the 20MHz parts, avoiding the problems of driving pins and printed circuit tracks to external memory.

If more than 4Kbyte is needed, it can be added externally. Additional memory need not be fast since the time critical programs done in the fast internal ram.

Availability of a 10MIPs machine rather than the 0.5MIP microprocessor conventionally used makes a significant difference to how the problem can be approached. Suddenly it becomes possible to handle the signal directly with the microprocessor and in the case of GPS, this means five separate signals.

Another major feature of the transputer is the hardware scheduler. Even a single transputer can handle multiple tasks at the same time. Conventional processors doing this take a large percentage of the CPU time managing the interaction between the tasks, but in the transputer, this is performed entirely in hardware at negligible time penalty. As a result the input task performed by the serial communciations hardware, the signal

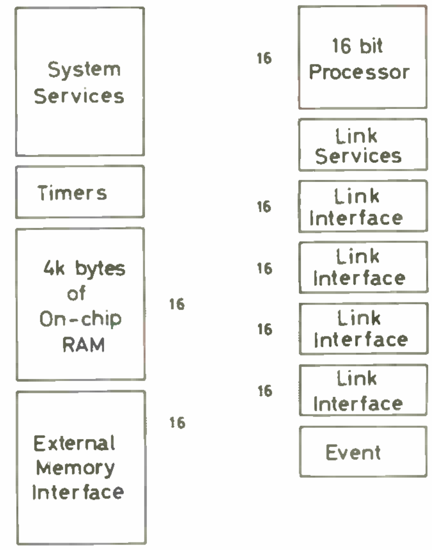


Fig. 4. Because the transputer has internal memory, accessing is very fast since the problems of driving i/o pins and printed circuit tracks do not arise.

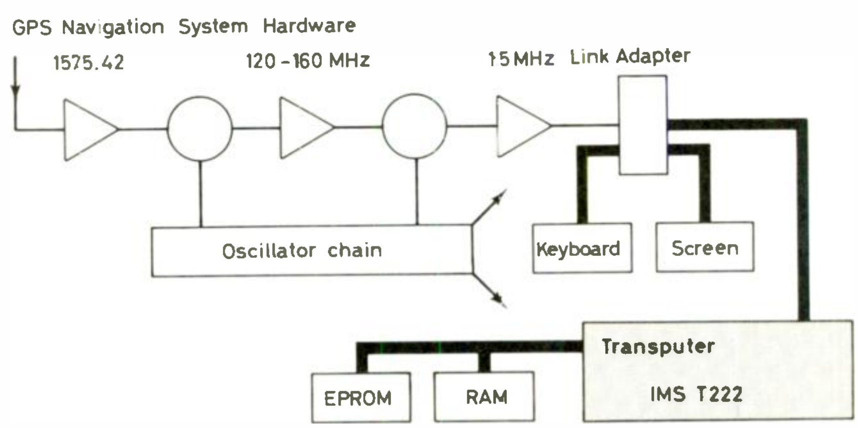


Fig. 5. GPS navigation system hardware. This new system uses the same r.f. section as a traditional system, but conversion is to a lower frequency of 1.5MHz — the lowest frequency that can handle the bandwidth.

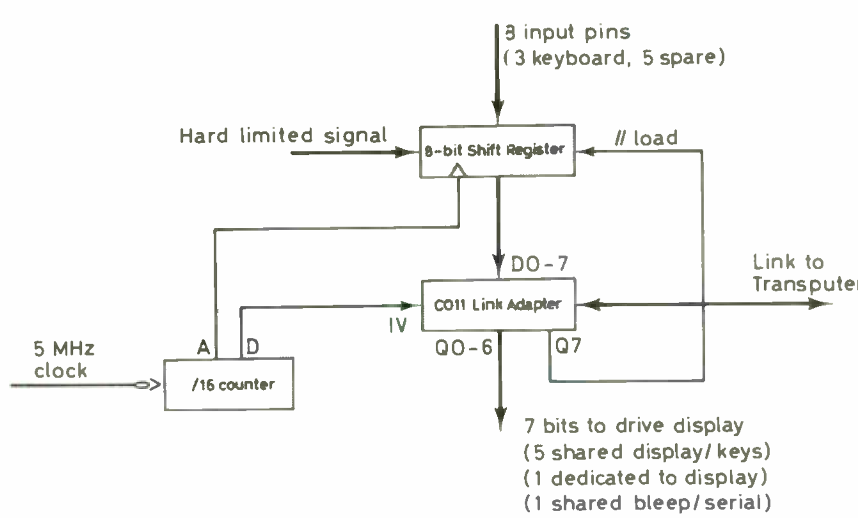


Fig. 6. Interface for 2.5MHz hard-limited samples with keyboard and screen interface.

processing task, and the computation/user interface task can all run simultaneously; the CPU switches between them transparently.

THE NEW APPROACH — SOFTWARE SIGNAL PROCESSING

The new approach is to perform all the signal tracking in software. Essentially the same radio-frequency front end is used, but conversion is to a lower frequency of around 1.5MHz, the lowest frequency that can conveniently handle the bandwidth. This is then fed into the transputer for processing, **Fig. 5**.

The signal has to be read in to the processor, multiplied by the locally generated code, filtered and detected. The easiest way of achieving the last two operations is to down convert to a low frequency and apply a low pass filter, then perform an FFT if the frequency is unknown, or a synchronous down conversion to DC if the frequency has already been determined. In the following sections, I will cover the approach taken for a single satellite, then later demonstrate how vast economies can be achieved when performing the work for multiple signals.

INPUT

To input the signal I have tried two methods — an analogue-to-digital converter, or hard-limited one bit signals. An a-to-d converter severely limits i/o bandwidth, and a 100 per cent duty cycle is not achieved. A few milliseconds of off-air signal are taken and processed inside 20ms, resulting in a 10–20% utilisation of the incoming signal.

With the hard-limited approach, a faster sampling rate can be used without hitting i/o limits, and by devious tricks that process a word's worth of samples (16 or 32) in a single instruction, a vast saving in processing can be achieved. Additionally no AGC circuits are needed in the front-end.

Thus the chosen design clocks a hard-limited signal into a shift register, and when a byte has been collected, feeds it down a transputer link using a link adaptor. This uses a link adaptor plus two TTL chips, **Fig. 6**. Because the link is attached to an autonomous direct-memory-access controller in the transputer, no CPU time is involved in input.

CODE CORRELATION, DOWN CONVERSION

Once a buffer has been filled in the processor, the hardware scheduler wakes the cpu, which switches buffers so that the next message will go into another buffer while this one is processed. Thus the data is never copied, it is processed in situ.

The code correlation function consists of multiplying the incoming samples by a code stream which is held in memory. It is a binary stream, so is packed one sample per bit.

Down conversion consists of multiplying by a locally generated set of samples that represent a synthetic local oscillator. These are generated once only, at start-up, or even kept in the ROM, and are also hard limited one-bit samples. The result is then at around 4kHz, plus or minus the Doppler shift.

Because these two multiplies represent the equation,

```
y := signal[i] * code[i+offset] * local.oscillator[i]
```

you can see that once the correct code offset is achieved, code*local.oscillator can be calculated once and saved, thus reducing the repetitive work in the loop. Even before the offset is found, this is valid, as an offset applied to the local oscillator only represents a phase shift, which is acceptable at this stage. Note that while it is imperative in the analogue world to perform code correlation before the down conversion, to prevent the lower edge of the bandwidth going negative, there is no such restriction in the mathematical world, and hence I have used no parentheses in the above equation. (Occam would require them.)

So the equation becomes,

```
y := signal[i] * code.LO[i+offset]
```

which by redefining the base of code. LO becomes

```
y := signal[i] * code.LO.offset[i]
```

As I have said, the signal is only one bit wide, and is packed 16 to a word on the T222 transputer. A one bit multiply is an exclusive-OR operation so assuming a group of input samples in a buffer, one could use the following code:

```
SEQ i = 0 FOR samples/16
  y[i] := signal[i] >< code.LO.offset[i]
```

Note that 16 two-microsecond multiplies have been reduced to a single 100ns XOR operation — a speed up of 320 times! Now the loop is dominated by the loop-control code, taking around a microsecond, and the array indexing. Both of these are solved by opening the loop out/in line. This removes the loop control, and allows the transputer's efficient constant-index instruction to be used. Assuming a buffer of 128 samples, i.e. eight 16bit words, this becomes,

```
SEQ
  y[0] := signal[0] >< code.LO.offset[0]
  "
  "
  "
  y[7] := signal[7] >< code.LO.offset [7]
```

This code generates the same number of output samples as there were input samples, so although it has performed a huge amount of work, it has not reduced the size of the data. This can be done in the filtering operation.

FILTERING

Now, the sample stream represents a 4kHz carrier sampled at 2.5 or 5MHz. For 32bit transputers, the higher rate is used, giving improved noise performance. Either rate is far higher than required, so the samples are decimated. Additionally, in order to filter the signal, a large number of samples need to be averaged.

These two tasks can be combined, and the transputer has a very effective instruction that will perform the task for a word's worth of samples at a time. This instruction is available directly in OCCAM as the BITCNT predefine. By careful choice of sample rates and buffer sizes, the filter bandwidth comes out correctly in the wash; this one averages 128 samples, which represent 50μs sampled at 2.5MHz, giving a filter that has a deep null at 20kHz, but passes 0–8kHz.

Thus the following code will filter and decimate, counting the number of bits set in each word cumulatively

```
SEQ
  accumulate := 0
   accumulate := BITCNT(y[i],
                        accumulate)
```

The same rules can be applied to speed this up as before, i.e. opening the loop, but in fact the best approach is to integrate the active line into the same open loop with the correlate/convert operation, yielding,

```
SEQ
  accumulate := 0
  accumulate := BITCNT(signal[0] ><
```

```
LDL     signal.b.i    --   address of signal        2
LDNJ    j             --   constant index           2
LDL     LO.code.i     --   address                  2
LDNJ    j             --   constant index again     2
XOR                   --   (inc. prefix)            2
BITCNT                --   (worst case)            34
                                                   ——
                      --   no of 50ns cycles       44
```

On a T425-20, execution time is 2.2μs per 32 samples.With overheads, this becomes 327μs per 5000 samples.

Fig. 7. Assembly code for main signal processing calculation.

```
                code.LO.offset[0].accumulate)
   .
   .
   .
accumulate := BITCNT(signal[7] ><
                code.LO.offset[7].accumulate)
```

This code compiles into extremely efficient instructions: it can be improved by less than 5% by hand coding in assembler. The improvement comes from eliminating the intermediate stores to the variable "accumulate", and can also be achieved in OCCAM by combining all eight lines into one, with appropriate brackets. I do not propose to demonstrate on the printed page since it is too narrow.

Assembly code instructions for the main expression are shown in Fig. 7. For an explanation of the mnemonics, see Refs 2, 3.

This combined code has now achieved a single sample representing 50µs of off-air signal, and it has less than 20µs of CPU time to do it. All future work will be done on these slow samples: since the routine runs only 1/128th as often, it will absorb very little CPU time.

DETECTION — COARSE FFT

In acquisition mode, we need to look at the output of processing using a particular code offset to determine whether a signal has been found. If the code offset is incorrect, we will be unable to find a signal.

Thus we continue in the fashion described above until sufficient slow samples have been built up, at this stage, 16. We then perform an FFT on these samples, which will show the energy in each 1.25kHz band from zero to 20kHz. We scan the output in the lowest eight bands, and if it exceeds a predetermined threshold, we have found the satellite code offset and can stop searching. Otherwise, the processing repeats at a different code offset.

The coarse 16 point FFT takes around 2ms and only represents 1ms of input data, so is not feasible for a 100% duty cycle system after acquisition. Having determined the code offset, we now concentrate on determining the Doppler frequency accurately.

DETECTION — FINE FFT

The input and processing system is then allowed to run for a longer period at the offset thus found. When 1024 low-frequency samples have been accumulated, an FFT is run on these, giving a frequency resolution of about 20Hz. Thus a new low-frequency local-oscillator stream can be generated, which when multiplied by future incoming LF samples, will convert them directly down to base-band DC.

DETECTION — CONVOLUTION

Future incoming low-frequency sample streams are multiplied by the new synthetic stream, yielding down-loaded data from the satellite. This new final down conversion needs to be performed in phase and quadrature, in order that gradual phase drift caused by slight errors in the synthetic carrier frequency can be monitored, and thus not interpreted as data; it also allows detection of the need to correct the synthetic carrier.

The maximum rate of change is about 2kHz per hour, or 33Hz per minute, so a new carrier is needed every 40s or so — this event is too rare to have a significant effect on CPU utilisation.

The sample stream on which the convolution is performed can be analogue, i.e. numbers in the range 0–127, or it can be hard limited and packed as it is created. This latter case costs some noise performance, but works well for the single satellite case, and takes negligible CPU time as the synthetic stream can also be limited and the operations performed a word at a time as before. However for ultimate performance, it can be done explicitly with full-word values, since there will only be around twenty points per millisecond to be handled. In this case it takes about 2% of the CPU.

MORE SATELLITES?

Thus I have shown how one satellite is acquired, taking some 36% of the CPU in the high-speed signal processing and some 2% in the low-frequency processing. We need to track four satellites, and ideally a fifth to allow a clean handover when one goes below the horizon, so either we accept a less than 100% duty cycle, we add more processors, or we think up some tricks.

Reducing the duty cycle makes synchronous operation difficult, makes carrier phase tracking difficult, and degrades noise performance. Adding processors is easy with the transputer — they simply bolt together with no additional hardware or software. For high-performance military systems, this is the approach to take, but the cost will be too high for more modest budgets.

The clever tricks approach seems to be most appropriate. The most productive of these is to avoid having to perform the high-speed signal processing separately for each satellite, and rather to do it once for them all.

There are two approaches to this. One is to square the incoming signal. This automatically multiplies the code and signal by themselves, resulting in a term that is signal squared, with the code removed. However this removes all code timing information, and tracking must be done from the carrier phase.

Such systems are very hard to initialise, and could not use the hard-limited approach, as squaring a hard limited signal has no meaningful effect.

The second approach is to use a composite-code method, where a synthetic code is created that is the best approximation to all four or five codes required on a pre-bit basis. Initially this code is created with no offset between the codes, and is run through the sample stream to find all the satellites. Knowing their offsets, a new composite code is created so that the codes are correctly offset, and a single pass over the data will pull out the signal for all four satellites. Thus the same 36% of the CPU time will do the work for all the satellites, and the same acquisition effort likewise.

Low-frequency work must still be done separately, but this means that the 2% becomes 8/10 for 4 to 5 satellites, or still negligible if one performs it on a single-bit basis.

Just as the synthetic carrier frequency will drift due to changes in the Doppler shift, the code offsets will change due to the satellites' movements. They will reduce for ascending (approaching) satellites, and increase for descending ones. The maximum rate of change, however, is about one chip every 1.5s (Ref. 4), so the creation of a new stream every half second would suffice, again absorbing negligible CPU time.

Once the first position fix has been obtained, all these changes can be predicted, and additionally they can be monitored. This is done by dithering the offset by one incoming sample and establishing whether the advanced or retarded signal is stronger for each satellite, allowing fine tuning of the prediction.

POSITION CALCULATIONS

We now have a system that can acquire and track the signal from five satellites continuously with a 100% duty cycle, with 3 to 5MIPs of CPU resource still available for position calculation, the remainder having been used by the signal processing.

Satellite position determination requires simple calculations involving plugging in the coefficients down loaded from the satellite, and this takes less than 2ms of CPU time. Equations are given in the GPS specification, Ref. 1.

The user position calculation is a solution to the four equations

$$(Range.i - ct)^2 = (X - Xi)^2 + (Y - Yi)^2 + (Z - Zi)^2$$

for i=i to 4, where Range is the distance from satellite to receiver, calculated from the propagation delay assuming a perfect receiver clock, c is the speed of light, t is the user clock error (unknown), XYZ is the user position (unknown) and XYZi is the position of satellite i.

The user clock error becomes the fourth unknown, with XYZ, to be solved for. Note that the first result will not be perfect, as the satellite positions were calculated with respect to time, and the time used was "wrong". However successive calculations will yield progressively more accurate results for t, and thus for XYZi, and thus for XYZ.

The user does not need a position update more frequently than once every five or ten seconds, so it is usual to put a filter on the data that averages over such a period before running the position calculation. Such a filter can also allow for short outages of a satellite signal caused by local obstructions such as tall buildings. However on a portable set, a repetitive display is probably unnecessary: the above equations could be solved iteratively until the results stabilised, and then the complete set turned off except for the display, in order to conserve power.

A marine (yacht) receiver would have an additional suite of software to provide data such as average course and speed, to give distance, bearing and estimated time of arrival at the next waypoint, to follow a route or sailplan through a pre-selected group of waypoints, and to raise various alarms when off course.

It would also provide outputs to control an autopilot. All this software has been written for the transputer based navigation system: it is a lot of code, but since it executes relatively rarely it does not severely affect CPU time.

DISPLAY AND KEYBOARD

The display of a handheld version need only show a position, either in latitude and longitude or in local coordinates such as a national-grid reference. However my implementation allows for the handheld to be used on boat, so includes the larger display and a keyboard for mode selection and waypoint entry.

My prototype has a display with two lines of forty characters, and is organised such that it can be exchanged for a 4×20 character version. These have compatible interfaces, and the latter allows the face of the unit to be 100mm wide by 170mm high, suitable for a hand-held pocket set.

The link adaptor described above for inputting the off-air signal also provides eight output pins. These are used to drive the display module, to strobe the keyboard and to operate a bleeper for acknowledging key depressions. The shift register used to capture input samples also has a parallel input, and this is activated to read the keyboard as necessary. Thus no additional hardware is needed.

This lack of hardware entails some slightly complex software to share the transputer link, but is worthwhile on a portable unit. On the marine version, I have used a second link adaptor for the user functions. This allows a clean separation of the software, and also makes a separate control head for the charthouse, the cockpit and the flying bridge very economical extensions.

The simple handheld version would have the transputer, three 28-pin chips and four TTL packages. If the navigating functions are included, it would use more memory, expanding to five 28-pin chips. The processor board is the same size as the keyboard, about 90×70mm, and lies beneath it, allowing a very thin lower case, except in the bottom 30mm, where it thickens up to contain the batteries.

All radio-frequency sections are built on a board 90×120mm in the folding cover of the set, with a patch aerial with the same size ground plane. Thus the combined unit is about 25mm thick, that being dictated by the battery dimensions, and opens into two hinged units about 13mm thick, with a convenient thicker grip point around the base.

These sizes are using conventional packaging. Using surface-mount components would not gain anything on the full facilities model, since the size is dictated by the keyboard, battery and display.

On the position-only handheld, the size could be reduced to 80×125×25 by removing the keyboard and using a smaller display, but could still use conventional packaging. Any smaller than this would suffer badly from the reduced ground plane under the antenna.

CONCLUSIONS

Use of a high-speed general-purpose microprocessor such as the transputer allows the implementation of functions previously restricted to hardware, with appropriate benefits in flexibility, space and assembly costs.

Off-the-shelf components rather than custom silicon signal processing allows the smaller company access to the technology, rather than limiting it to the vertically integrated companies that either have vast funds or in-house semiconductor operations.

The transputer card takes up no more space than the microcontroller it replaces, but an entire suite of signal processing hardware has been removed, allowing an implementation that is suitable for portable use or panel mounting in terms of both size and power consumption. It brings the accuracy of the GPS system to the level of cost of the old Decca and LORAN systems that have been running since the war.

References

1. MOD/NATO STANAG 4294 Draft H, Feb 1987, Navstar Global Positioning System (GPS).
2. Transputer Reference Manual, Inmos.
3. The Transputer Instruction Set, A Compiler Writer's Guide, Inmos.
4. GPS Signal Structure and Characteristics, J J Spilker, *Journal of the Institute of Navigation (USA)*, Vol. 25 No 2, Summer 1978.

RF path evaluation with a PC

A personal computer can take care of much of the routine work in analysing RF paths. This article describes a method of using standard integrated spreadsheet and graphics software to plot path profiles on the computer screen and to calculate path loss.

H. JURKE

Although a great deal of information is available on predicting the loss of point-to-point radio links at v.h.f./u.h.f., little is published on how a personal computer can take the tedium out of the many repetitive calculations which are involved.

At least one proprietary computer program is available which will do an exhaustive analysis, but this may not be economically justifiable if only occasional use is to be made of it. Reference 1 covers the basic theory behind the calculations and contains a listing of a program which will plot a path profile using a dot matrix printer, but does not deal with using the computer for loss calculations.

If integrated spreadsheet and graphics facilities are available either on a multi-user system or a stand-alone personal computer, the traditional method of plotting path profiles on special path profile graph paper can be completely dispensed with. Once the data for the whole path has been entered into the spreadsheet, it is possible to select parts of the path interactively and to plot these in greater detail. The resolution obtainable is limited only by the data entered.

The advantages of this approach are as follows:

- A first "rough" plot of the basic path together with the main high points can be obtained quickly on the screen and an immediate decision can be made whether there is clear line of sight, or whether the ground profile needs to be obtained in more detail to evaluate the likely performance.
- For any given path, profiles for different values of K factor can be quickly produced.
- If the Fresnel zone is drawn in, then the effect of changing the working frequency is easily evaluated.
- Assuming that path information is available in sufficient detail, it is a simple matter to produce an overall path plot, together with selected parts in greater detail.
- The basic path data is stored in a convenient form which can be easily updated and new plots drawn.

FACILITIES REQUIRED

The basic facility needed for this procedure is an integrated spreadsheet/graphics package with appropriate hardware for graphical output (if this is required). The essential characteristic required of the graphics is the ability to plot true XY plots. Many packages are able to plot line graphs only, where the points on the X axis are simply evenly spaced instead of being scaled in the same way as the Y axis points. If the software can only plot line graphs, then it can still be used but the distance points along the X axis must be evenly spaced along the path. For plots covering the whole path this is feasible, but it will be difficult to examine individual sections in more detail to any great resolution.

The ability to enter a logical If-Then-Else cause into spreadsheet cells is also necessary. To be able to plot smooth profiles for the Fresnel zone and the Earth's bulge, a reasonable number of distance points must be included (e.g. at 1km intervals minimum). Height data may not be needed for all these if, for example, it is obvious that there is only one obstruction. Only the height data for that obstruction need then be entered. Use is made of the If-Then-Else clause to calculate profile points only where height data is included. The end result is much tidier plot.

A third desirable feature is the ability to write macro instruction sets. This will allow the process of adjusting the graph settings defining which section of the path is to be plotted to be automated. On invoking the macro, the user is simply prompted to enter the start and finish points of the section to be plotted and the macro does the rest.

PLOTTING PATH PROFILES

Path profiles are plotted so that the radio path is represented as a straight line. The line of the first Fresnel zone is drawn below the radio path. The Earth's bulge is shown and the ground profile is plotted above this. It is then immediately obvious whether the radio ray clears high points along the path or is obstructed by them. The amount of the obstruction is also apparent.

The basic path profile data comprising ground height against distance along the path is derived either from topographic maps or by purchasing a path profile dataset.

Parameters required for a path plot are calculated from this basic data and are shown in **Fig.1**.

The formulae used for the calculations are as follows:

1. **Path height** (PHT). This calculates the values needed to darw the radio ray as a

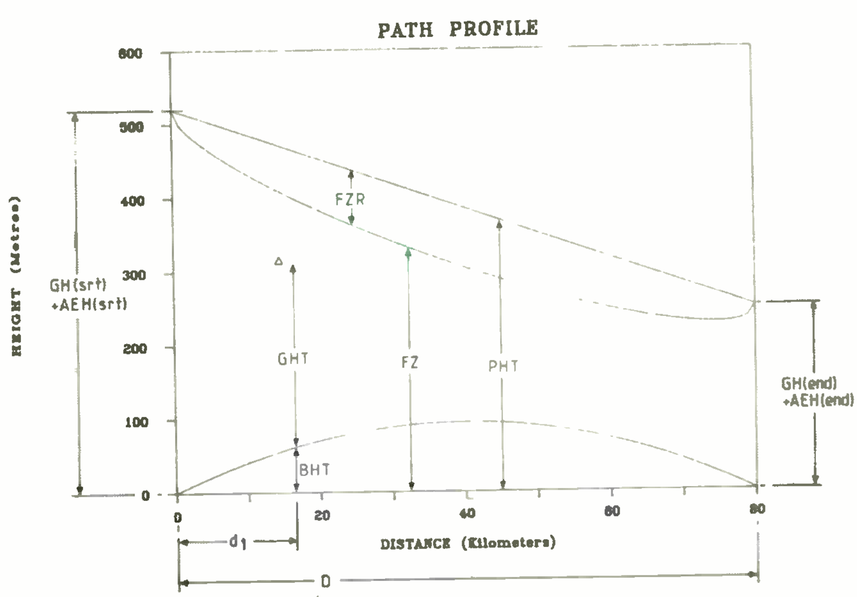


Fig.1. Parameters needed for path profiles.

straight line above the imaginary straight X axis joining the two ends of the path.

$$PHT = G(srt)+AEH(srt)] + [d_1/D] \times \{[GH(end)+AEH(end)] - GH(srt)+AEH(srt)]\} \text{ metres}$$

2. **Earth's bulge height** (BHT). This calculates the height of the Earth's bulge above the imaginary straight X axis for any point between the start and end points of the path.

$$BHT = 0.0784 \times d_1 \times (D-d_1)/K \text{ metres}$$

3. **Fresnel zone radius** (FZR). The formula calculates the radius of the first Freznel zone for any point along the path.

$$FZR = 31.6 \times [300 \times d_1 \times (D-d_1)/(F \times D)]^{0.5} \text{ metres}$$

4. **Distance of Fresnel zone** above imaginary X axis (DFZ). This simply calculates the equivalent XY points so that the first Fresnel zone can be plotted on a path profile as a curve below the direct radio ray.

$$DFZ = PHT - FZR \text{ metres}$$

5. **Ground profile** (GHT+BHT). The Y values for the XY points of the ground profile on the path plot are simply the sum of the corresponding values for GHT and BHT.

6. **Distance from start** (d_1), kilometres. This is entered manually or parsed from a path profile dataset. Distance points should be at less than 1km intervals for the whole of the path so that sufficient points are available to plot the ray, Earth's bulge and Fresnel zones as smooth curves. Height data may not be available for all distance points, in which case the cells are left blank.

7. **Ground height** above sea level (GHT), metres. This is entered manually or parsed from the path profile dataset. With data entered manually and distances entered at 1km intervals as recommended above, there will be gaps in the GHT column. This does not normally matter as an If-Then-Else condition on the calculation of the ground profile points (GHT+BHT) can usually be applied which will then only produce an entry in that column if there is an entry in the GHT column.

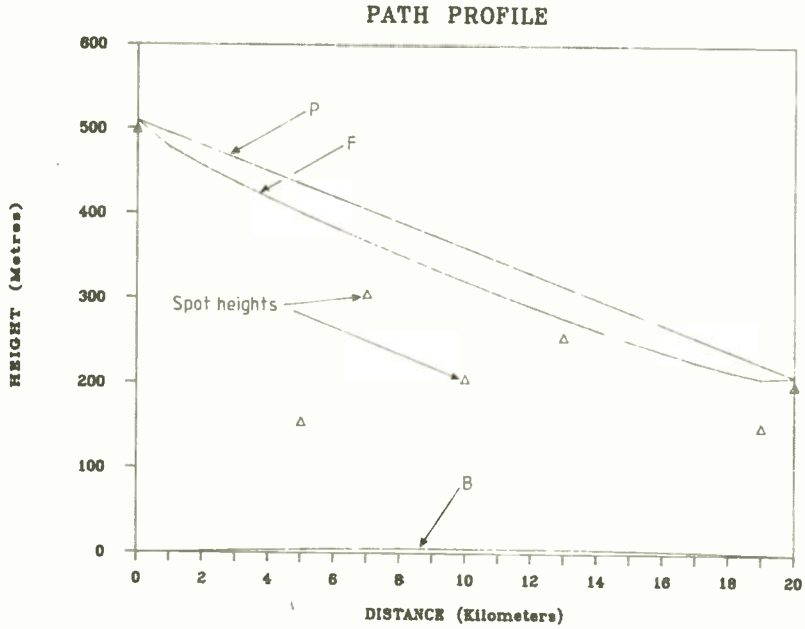


Fig.2. Typical "rough" path profile for a 20km path. This profile is drawn using a K factor of 4/3 and a radio frequency of 950MHz.

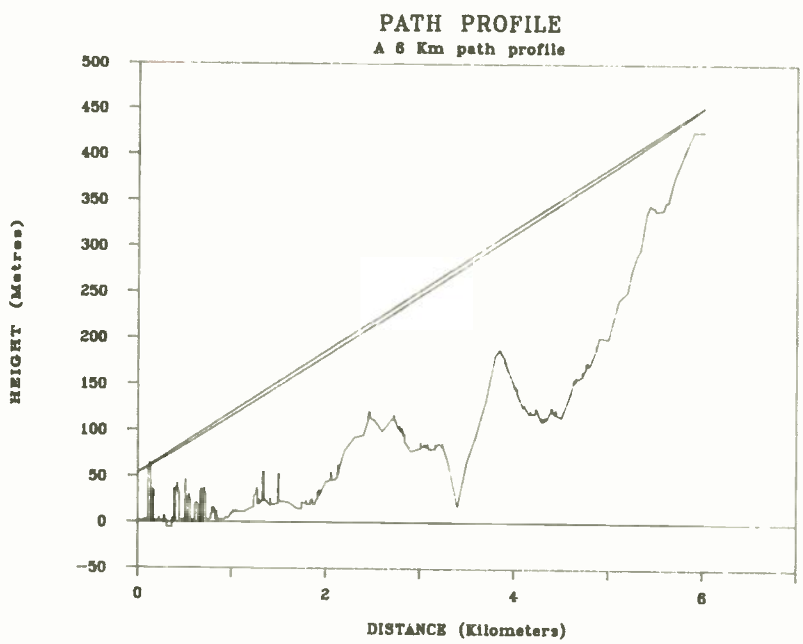


Fig.3. Full profile for a 6km path.

SETTING UP

A standard spreadsheet is set up with cells for the following path parameters:

■ K factor	K
■ End-to-end path distance	D kilometres
■ Frequency of operation	F megahertz
■ Ground height at start	GH(srt) metres
■ Ground height at end	GH(end) metres
■ Antenna height at start	AEH(srt) metres (above ground)
■ Antenna height at end	AEH(end) metres (above ground)

The ground height (in metres) versus distance (in kilometres) data is entered into two columns. The remaining columns for the radio ray, Earth's bulge, Fresnel zone and ground profile are calculated using formulae 1 to 7 together with the data from the above table.

The path profile is drawn from this spreadsheet by simply graphing the calculated data on to the screen. Whether the whole path is drawn or just a portion of it is determined by altering the range of values to be graphed, either manually or by invoking a macro routine.

A typical "rough" path profile for a 20km path would appear as in **Fig.2**.

The profile shows the radio path (P), the first Fresnel zone (F), the Earth's bulge (B) and a number of points of high ground along the path denoted by triangles.

This path exhibits clear line of sight along its whole length and apart from checking the foreground clearance at each end, can be assumed to be a free-space path.

PATH PROFILE DATASETS

Instead of deriving path height versus distance data manually from topographic maps, this may be available on disc or tape at reasonable rates. It may be supplied in a variety of formats, but for parsing into a spreadsheet, the most useful is a text file.

Each line of text should be to a fixed format and represent one point on the path. The distance of that point from the start of the path and its ground height above sea level as well as its grid coordinates are usually given. The line of text can then be regarded as a number of fields of a set of data and readily parsed into a dataset structure on a spreadsheet. Grid coordinates are not required and are ignored.

The advantage of these datasets is that a large number of points along the path are included. This means that the ground profile can be drawn accurately and sections of the path can be examined in detail with a high degree of confidence. This is particularly useful where marginal paths over urban areas are involved.

The profiles shown in **Fig.3**, 4 illustrate this. The first is for a complete path from a central city site to the top of a nearby hill, drawn for a radio frequency of 13GHz. Except at the city end, where buildings intrude, the path is clear line of sight. The second profile is drawn from the same set of data with the X coordinates restricted to the first 500 metres. The problem building is clearly highlighted. Such detail could not be obtained from topographic maps.

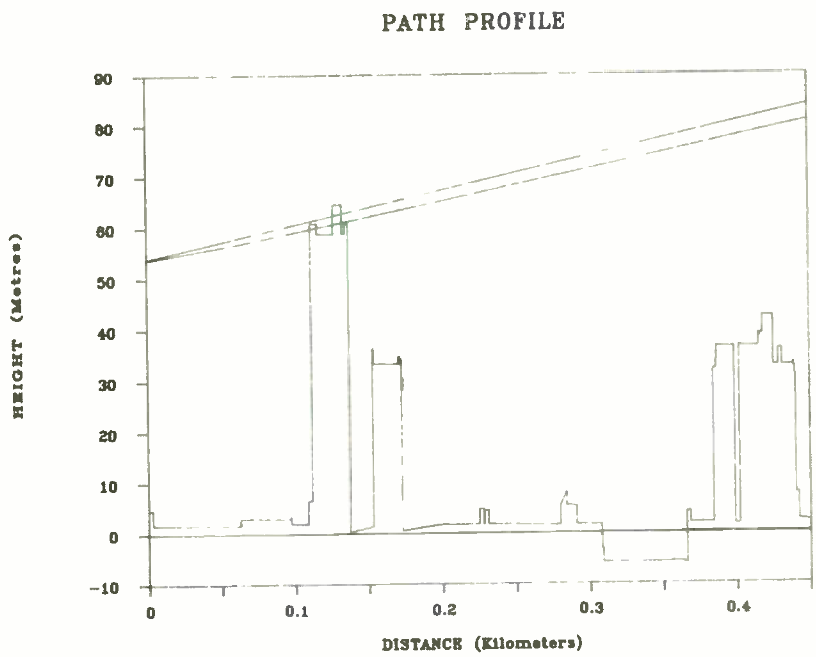


Fig.4. First 500 metres of the profile in Fig.3.

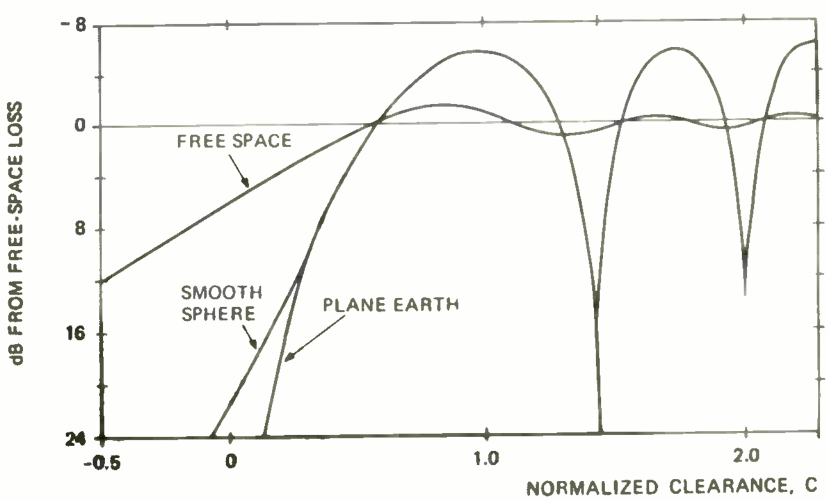


Fig.5. Loss versus normalized clearance.

CALCULATION OF PATH LOSS

Theorectical path loss is most easily estimated using the classical formula for the free space loss and adding any further losses due to obstructions to the line of sight path.

To decide whether an obstruction will contribute a significant loss, use is made of the fact that little power is transmitted outside the first Fresnel zone. The theoretical diffraction loss curves for isolated obstacles extending into the first Fresnel zone are shown in **Fig.5** as a set of curves of loss versus the normalized clearance H/FZR (clearance H divided by Fresnel zone radius FZR) of the path over the obstacle[3]. The curves cover the range of obstacles from knife-edge to smooth earth. A typical mountain ridge would be somewhere in between as determined by the "radius" of its top as seen in cross section.

These curves indicate that where the normalized clearance within the first Fresnel zone is greater than or equal to 0.6, the obstruction does not introduce any loss, but may introduce a gain.

The loss due to an obstruction with a normalized clearance of less than 0.6 is markedly dependent on its radius of curvature and clearance with respect to the path. The simplest method of estimating the loss due to obstacles[2,3] is to calculate two factors characterizing the obstacle, the normalized clearance H/FZR and a factor α where α is calculated by the formula

$$\alpha = (\lambda^{2/3} \times r^{1/3})/R$$

where λ is the wavelength, r the radius of the top of the obstacle and R the Earth's radius.

The curves used to estimate the loss from the obstacle characteristics H/FZR and α are given in reference 3 and reproduced in **Fig. 6**[3].

On the spreadsheet used to plot the path profile, additional columns are included to allow the loss due to multiple obstructions to be estimated. These are

Column d_1. The values are calculated and are the manually entered distances, less a startpoint offset (the need for an offset is explained below). Column d_1 contains the actual values to be used for path profile calculations. Initially, the offset is set to zero and the contents of d_1 will equal the distances entered.

A column for the ratio H/(FZR). The values are calculated according to the formula ((GH+BHT)−PHT)/FZR.

A column for α. The values are calculated according to the formula $\alpha = (\lambda^{2/3} \times r^{1/3})/R$.

In addition, some extra cells are required for the following values:

- **Start point offset.** The value will be entered manually.
- **Wavelength (λ).** The value is calculated from the cell containing the working frequency in MHz using the formula λ=300/F.
- **Effective radius** (r) of the obstruction to the radio path. The value will be assessed from the path profile and entered manually.
- **Free space attenuation** (A_f) for the path. The value is calculated from the operating frequency and overall path length data, entered elsewhere on the spreadsheet, using the formula $A_f = 32.5 + 20\log(D \times F)$.

PATH LOSS

Estimation of path loss is carried out as follows. Enter all path profile data, set the offset to zero and recalculate spreadsheet.

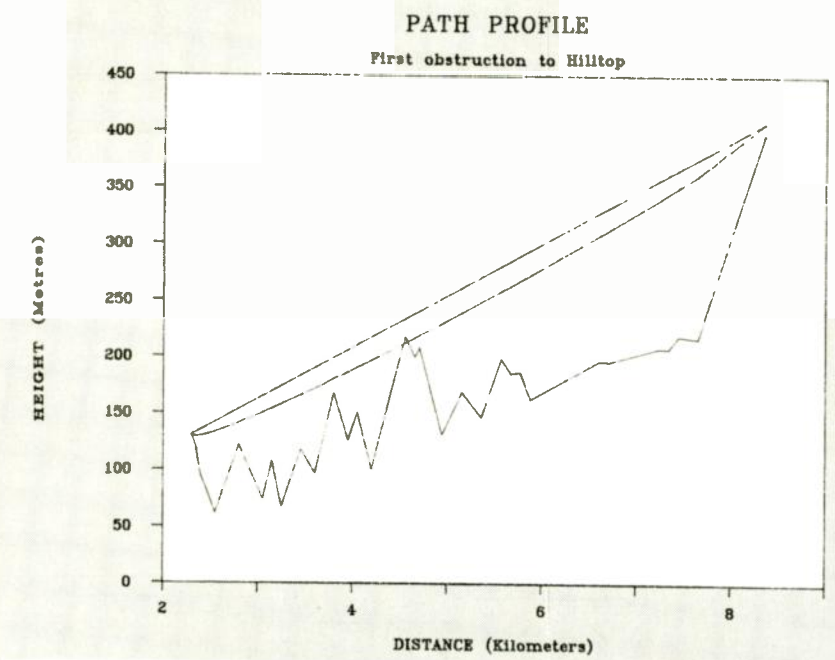


Fig.7. Full path profile, city building to hilltop.

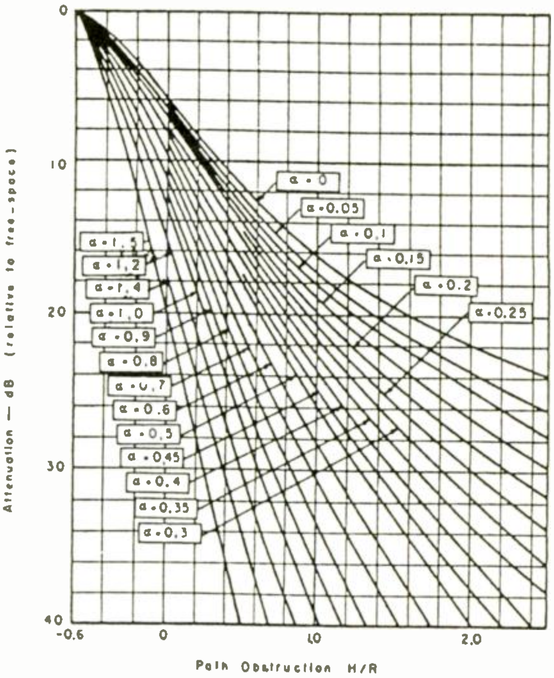


Fig.6. Diffraction over rounded obstacles.

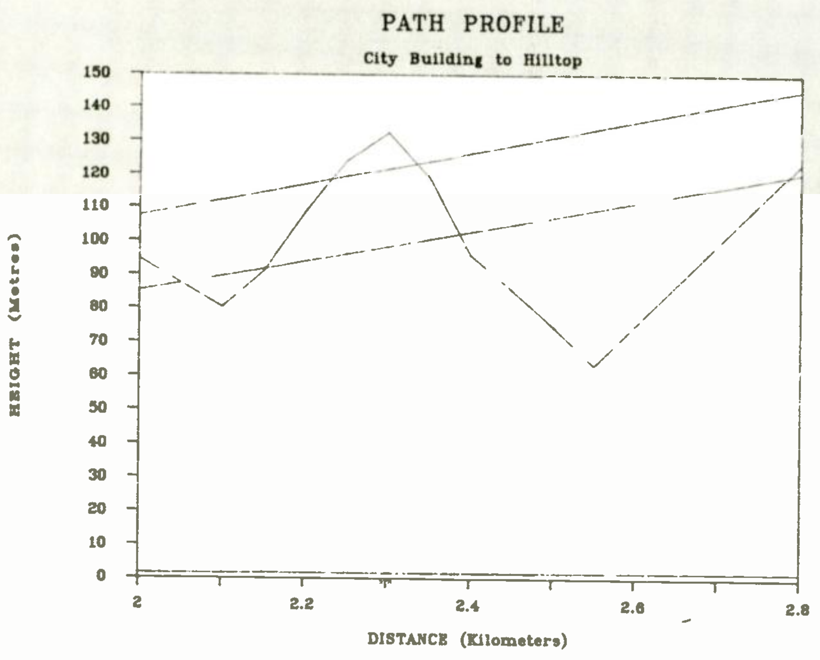


Fig.8. Major obstruction 2.3km from city building.

The free space loss is read off directly from the cell (A_f).

The cell in the H/R column which contains the maximum value for that column defines the most prominent obstacle. Note that H (the obstacle height over the path height) is numerically the same but directionally opposite to the clearance discussed above. Hence any obstacle contributing a loss will have an H/R value greater than −0.6. Draw this obstacle on the screen and estimate the radius of its top. Enter this value in the appropriate cell and recalculate the spreadsheet. The values of α and H/FZR can now be read off and the loss due to this obstacle determined from the loss curves in Fig.6.

The next most prominent obstacles are identified by considering the two sections of path on either side of the main obstacle as separate paths. They are considered individually. At this stage the whole path data must be saved since copies will be required for modification.

To consider the first section, delete all path points after the main obstacle. Adjust D, GH (end) and set AEH (end) to zero. Recalculate the spreadsheet. Inspection of the H/R column as before will identify the most prominent obstacle in this part of the path. The values H/FZR and α for this obstacle are determined as before and the loss it contributes determined. Check the H/R values to see if there is likely to be another obstacle in this part of the path. If there is, then save the spreadsheet for later use.

The second section is assessed by taking a fresh copy of the whole path and deleting all points before the main obstacle. Set the offset equal to the distance value of the first point in the d_1 column, adjust D, adjust GH(srt), set AEH(srt) to zero and recalculate the spreadsheet. Inspection of the H/FZR column as before will identify the most prominent obstacle in this section. Determine the values for H/FZR and α as before to estimate the loss it contributes. Check for other likely obstacles and proceed as before.

Repeat the above procedure until all obstacles have been dealt with. Note that not all obstacles protruding into the first Fresnel zone will necessarily contribute to the loss. If the most prominent obstacle protrudes above the radio path, then once this is dealt with and the sections on either side are considered individually, the lesser obstructions may not return a value for H/FZR greater than −0.6.

The total loss introduced by the obstacles is then the sum of the individual losses introduced by each one. This is added to the free space loss for the whole path to give a total path loss.

For maximum path reliability, calculations should be done at the minimum recommended value for K for the path (2/3 for temperate zones).

An example will make this clear. The path profile used is typical of those from a city building to a nearby hilltop radio station (**Fig.7**).

From the spreadsheet, the major path obstructions were determined using the criterion H/FZR>−0.6. Two possible obstructions exist: the major one, 130.94m high, with (H/R=+0.46) at a distance of 2.3km from the origin and a second potential one (H/R=−0.35) at a distance of 4.55km from the origin.

To find the effective radius of curvature for the major peak, the plot range is restricted to include only this peak and its immediately adjacent ground (Fig.8). By inspection, the effective radius of the top of this peak was estimated to be 75m.

To assess the effect of the second peak 4.55km from the origin, the path data up to the first peak is deleted. The start point offset is set to 2.3km. D is set to (8.36−2.3). GHT(srt) is set to 130.94. AEH(srt) is set to 0 and the spreadsheet recalculated. The effective value of H/R for this secondary obstruction turned out to be −0.75; and because this is less than −0.6 it can be ignored. **Fig 9** confirms this.

There is, therefore, only one significant obstruction with the parameters H/R=0.47 and α = 0.09; and the loss it contributes, determined from the loss curves in Fig.6, is 13dB.

The total path loss is therefore the free space loss from Sheet 1 (110dB) plus the obstruction loss of 13dB; i.e.

total path loss = 110+13 = 123dB

GROUND REFLECTION POINT

Significant interference from reflected signals is likely if large bodies of water or wetlands are on the line of the path at the point of reflection and if the angle between the direct and reflected rays is within the beamwidth of the antennas.

The point of reflection is defined[4] as point P on **Fig.10**, where T and R are the antennas at each end, R_0 is the Earth's normal radius (6370km), K is the usual Earth radius factor and APB is a tangent to the Earth's surface at P.

For a real path, it can be assumed that the angle of reflection and hence θ_1 and θ_2 are all small. It can also be assumed that r_0, r_1 and r_2 are approximately equal to D, d_1 and d_2 respectively. The point of reflection P and angles θ_1, θ_2 between the direct and reflected rays at each end are calculated from the path geometry.

Using the above approximations, the following equation can be derived:

$$m(Y-Y^3)+Y-c=0$$

where $Y=(2\times d_1/D)-1=1-(2\times d_2/D)$

$c=(h_1-h_2)/(h_1+h_2)$

$m=(1000\times D^2)/(4\times K\times R_0\times(h_1+h_2))$

D, d_1, d_2 are all in kilometres; h_1, h_2 are in metres; c and m are constants.

Solving this equation for Y will give the value for d_1 which determines the reflection point.

Because the factor m contains K (which is dependent on the atmospheric refractivity) a range of values for d_1 needs to be calculated for the expected range of K.

Once the position of P is known, θ_1 and θ_2 can be also be calculated, since it can be shown that

$h_1'=h_1-(1000\times(d_1^2)/(2\times K\times R_0)$

$h_2'=h_2-(1000\times(d_2^2)/(2\times K\times R_0)$

angle of reflection (TPA)$=h_1'/d_1=h_2'/d_2$

$\sin\theta=d_2 x \sin(\pi-2\times TPA)/D$

$\sin\theta_2=d_1 x \sin(\pi-2\times TPA)/D$

The solution of the equation for d_1 (X) and the calculation of the angles, at each end, between the direct and reflected rays can be done on the spreadsheet set up for path profile plotting.

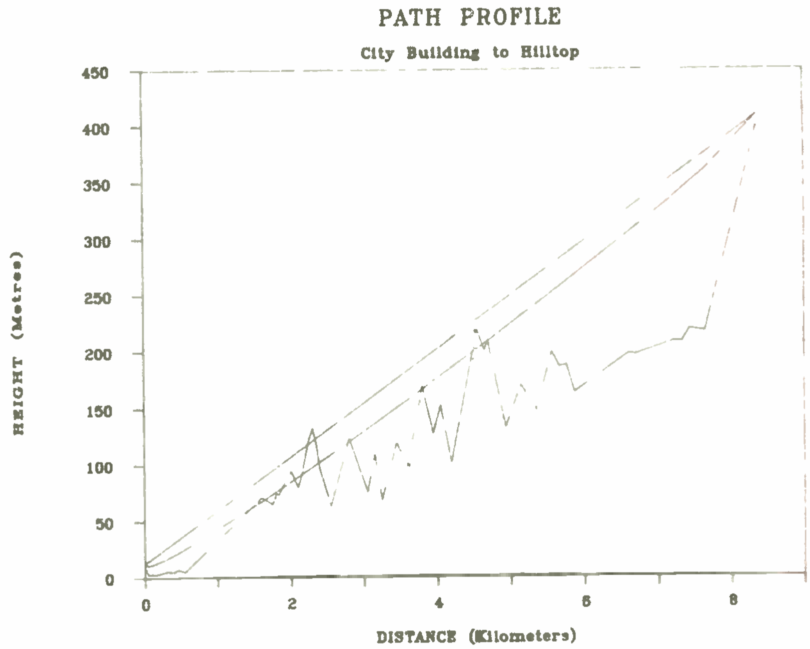


Fig.9. Path from first obstruction to hilltop.

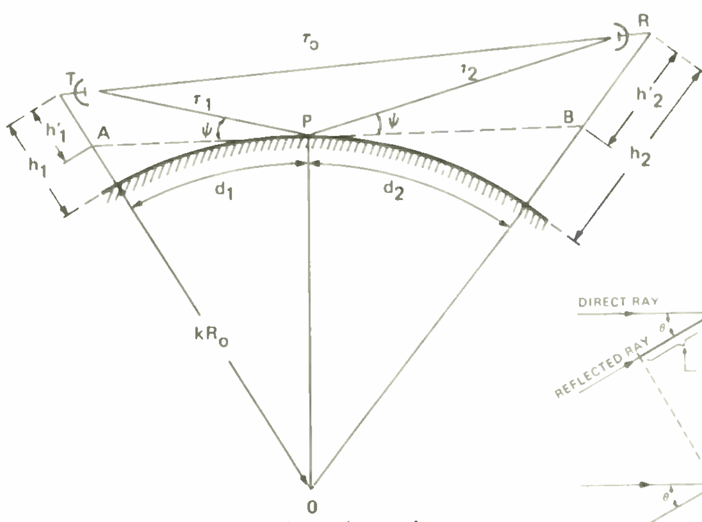


Fig.10. Geometry of a path to determine the point of reflection and angle between direct and reflected rays.

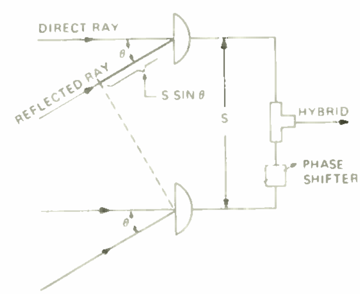


Fig.11. Reception of direct and reflected rays.

ANTENNA SPACING

If the reflection point falls on water or wetland, then a possible solution is to install two antennas at each end mounted vertically above each other and to combine their signals (**Fig.11**).[5]

Assuming that the plane of the two antennas is normal to the direct ray, the two outputs from the antennas due to this will be in phase and will add. However, there will be a difference in phase between the outputs due to the reflected ray because of the different distances this ray has to travel to reach the two antennas.

For the signals due to the reflected ray to cancel, the phase difference should be radians. The antenna spacing S to achieve this is given by S=150/(Fsin0), where F is the working frequency in MHz and S is in metres.

• The author adds that, provided the simple criteria described in his article are met, these procedures can be implemented on any reasonably professional integrated spreadsheet/business software package. He developed the ideas and the basic spreadsheet under PFS First Choice on his Exzel IBM compatible and used it at work under Lotus Symphony on a Sperry IBM compatible.

Hagen Jurke is a chartered engineer.

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Decoding RDS

To complement November's survey of the BBC's progress with RDS, this article provides a technical description of the signal. Next month the author presents a practical RDS display module which can be used to enhance conventional FM receivers.

SIMON J. PARNALL

A large percentage of the population now understands something of what is meant by the letters RDS – the Radio Data System. The eye-catching logo is destined to become as familiar on radio receivers as Dolby's double-D symbol is upon cassette machines today.

RDS signals are carried by all BBC FM transmitters in England, and also by many independent local radio stations operating under franchise from the IBA. Several European countries are carrying these signals too, and within the next year or two most of western Europe will be included.*

RDS has a number of distinct "features" (see panel). A feature may be described as a reserved data channel within one or more RDS group types. The subject of group types will be covered later, but suffice it to say that by altering the mixture and balance rate of group types used a broadcaster can control the mixture and balance of the RDS features he transmits.

The two- and three-letter acronyms (e.g. PI, PS, PTY) are an essential part of RDS-speak, and will be used throughout this article.

*What is happening to RDS? Bev Marks (BBC), *Electronics & Wireless World*, November 1988, 1096-1100.

RDS FEATURES

What does RDS offer the listener? People naturally think of teletext, a familiar broadcast data system. Parallels between the two should stop here, however, because unlike teletext, RDS is primarily radiated to assist the listener in reception and to give additional information about the programme being received. Subsidiary channels are included within the specification, but the recommended proportion of overall RDS capacity to be given to these applications is very small.

A list of RDS features[1] is as follows:

Programme identification	PI
Programme service name	PS
Programme type	PTY
Alternative frequencies	AF
Traffic programme identification	TP
Traffic announcement flag	TA
Decoder identification	DI
Music/speech switch	MS
Programme item number	PIN
Radiotext message	RT
Clock time and date	CT
Other networks	ON
Transparent data channel	TDC
In-house data	IH

Programme identification: the PI code is a 16-bit binary number which labels a station's transmissions. If a receiver finds two transmitters carrying the same code it may assume that the two transmissions are identical. The receiver may then use relative signal strength and quality to determine which transmission to use.

Programme service name: the PS name is an eight-character string, used to identify the station being received. Whereas the PI code is 'machine readable', the PS name is designed to be seen by the listener. Examples are "BBC R4" and "Cambrdge".

Programme type: the PTY code defines the current programme as being in one of 32 categories. Examples are: news, current affairs, pop music.

Alternative frequencies: a list of alternative frequencies is built up from two-byte AF code elements. A single FM frequency on the 100kHz lattice may be expressed in one byte by declaring the offset (in 100kHz units) from the base of Band 2 (87.5MHz). MF and LF band frequencies, and FM frequencies offset from 100kHz lattice points require two bytes.

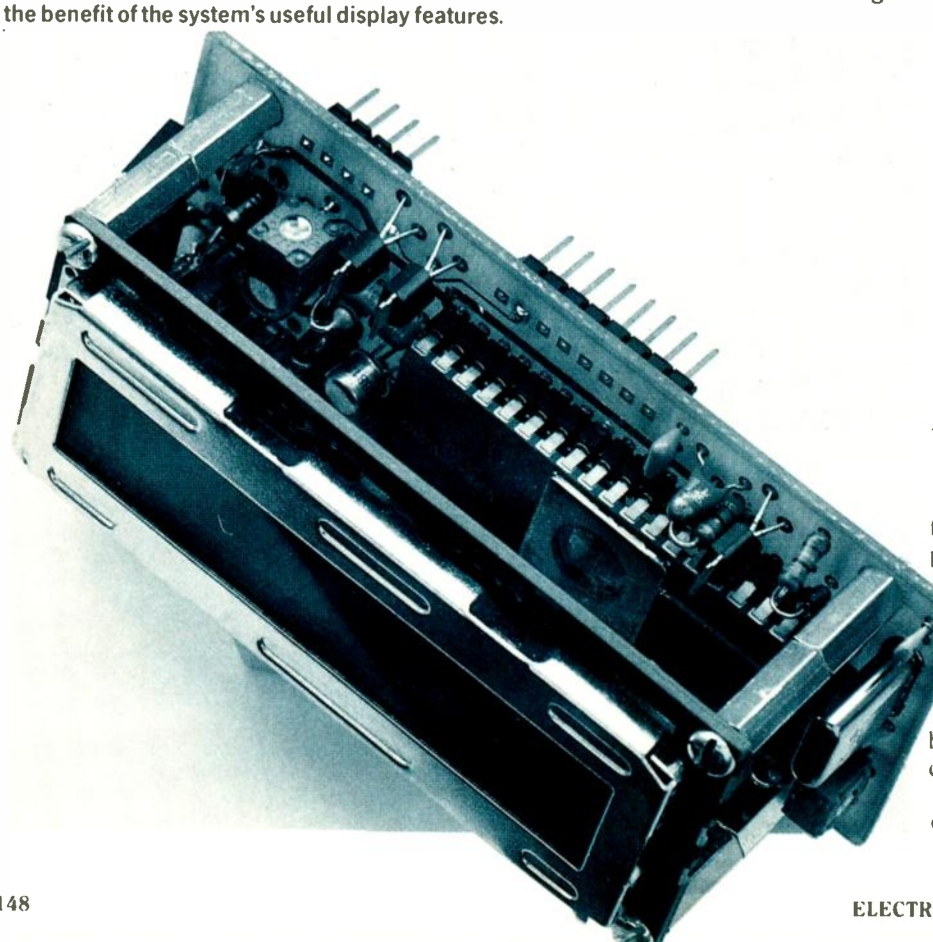
The AF list is used by a mobile receiver, which checks the signal strength, quality and PI code of each of the listed frequencies. If one of these offers superior reception the receiver should retune and use this new frequency instead.

Checks need to be repeated frequently, since signal strengths from FM transmitters can vary quite widely over short geographical distances. To do this the receiver must employ a second front-end, dedicated to the task of testing frequencies contained in the AF list; or else use gaps in programme material to retune to listed frequencies and make the necessary tests.

The AF list is essential to efficient operation of either type of receiver. Without this provision the receiver would need to test the PI code of every receivable frequency in the band. However, the PI code acquisition time is inherently of the order of 100ms, making this process very slow. By defining a subset of the band, indeed a subset of the band in which the PI code may be presumed to be correct, the AF list considerably shortens this task.

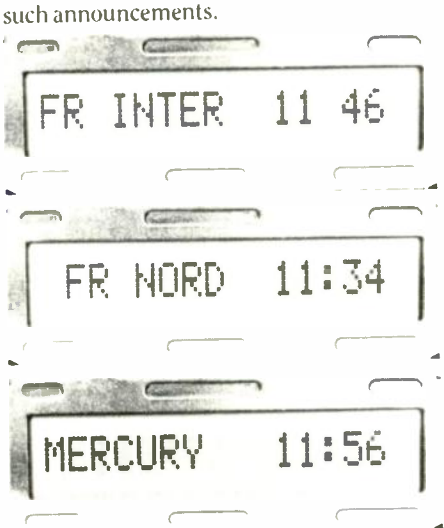
A receiver operating with a single front-end cannot make a PI code test on frequen-

Although it does not implement the important auto-tuning features of RDS, this compact module, to be described next month, can be added to a conventional FM tuner to bring it the benefit of the system's useful display features.



cies that it samples because the length of time required, and the consequent audible drop-out that would be produced. Instead, the receiver will make a check of the PI code when it has retuned to the new frequency as a programme source. Invalid frequencies included in an AF list will cause such receivers to give a short burst of an unwanted programme whilst the PI code is being read, before the frequency is rejected.

Traffic programme: TP is a single bit. It identifies that the station being listened to, indeed the programme being listened to, is likely to carry travel announcements. Motorists can use this as a means of seeking travel news in an unfamiliar area. Normally the TP flag would be set on the transmissions from a BBC local radio station; provided, of course, that the station does indeed carry such announcements.



RDS is now being implemented by broadcasters all over Europe. These PS displays were received from the France-Inter and Fréquence-Nord services of Radio France, and from Radio Mercury, the ILR station for Reigate and Crawley.

Traffic announcement: TA is also a single bit, and is used in conjunction with TP. If TA is set then the station being listened to is broadcasting a travel announcement at this moment. The receiver can use this bit to increase the volume, stop a cassette, or some similar action.

Decoder information: DI is formed from four bits, and identifies the decoder operating mode required. One bit indicates mono/stereo, another indicates whether an artificial head has been used for recording, and the third indicates whether compression is applied to the signal. The fourth bit is undefined.

Music/speech: Ms is a single bit. It may be used by receivers to switch between two volume settings.

Programme item number: the PIN is a composite number, expressed in 16 bits, formed from the day of month, hour and minute of the published start of the current programme. The programme may start late, or early, but the PIN remains the same. It may be thought of as similar to a railway timetable reference: the 1612 train is *still* the 1612 even though it actually leaves at 1615 today.

Receivers may use this number to switch on automatically at the start of a particular programme, or to start recording (copyright law permitting).

Radiotext: the radiotext message is a string of either 64 or 32 characters. Two transmitted variants are specified. RT is intended to give information about the programme being received.

Clock time and date: CT information defines the year, month, day, week number, day of week, hour and minute. Seconds and fractions of a second are implied by the timing of transmission of this information: the end of transmission defines the minute described precisely.

Other network: ON data is a collection of RDS features relating to other stations. The features are: PI, PIN, PTY, TP, TA and AF. Thus, although listening to a particular station, the receiver can be informed of the frequencies on which to find other services in the area, the state of their travel broadcasts and what type of programme they are carrying.

This feature provides the means by which a listener may find Radio 2 (say) having driven 300 miles listening to Radio 4. At every stage on the journey the receiver may determine, from ON data on Radio 4, the frequency on which to find Radio 2.

ON holds the key to the operation of a comprehensive travel service whereby, whatever station your receiver is tuned to, it has ready and immediate access to all travel announcements in the area. Such data, if transmitted, is likely only to be consistent between the services offered by a given broadcaster.

Transparent data channel: TDC provides up to 32 sub-channels for communication with data-consuming devices, e.g. home computers.

In-house data: IH is similar to TDC, but reserved for use by the broadcaster.

This is a comprehensive list of RDS features defined in the EBU specification[1]. Some features are basic to the system and cannot be omitted, others are optional. In any case, even basic features may be left in a default state by the broadcaster or changed in accordance with the programme. The BBC uses the words "static" and "dynamic" to describe this operational disparity.

The BBC has declared that it is radiating PI, PS, AF, ON, and CT from its transmitters. It exercises dynamic control over PI, PS and ON from its Radio 2, 3 and 4 transmissions, changing station names when appropriate throughout the day. Normally Radio 2 transmissions carry the PS name "BBC R2/1"; the 2/1 reminds listeners that the service changes to Radio 1 at certain times. At these times the PS name will change, to "BBC R1/2". Other changes are made to re-label educational broadcasts and indicate when the FM and LF networks are split, and therefore carrying different programmes. At present, the IBA is not radiating ON or CT.

In addition to the declared features, both the BBC and IBA are radiating default RT (radiotext), PTY (programme type), TP and TA flags from all transmitters. The BBC exercises dynamic control of these features

R·D·S
RADIO DATA SYSTEM

on an experimental basis from all Radio 2, 3 and 4 transmitters, and their content may be expected to change on a regular basis. The changes are scheduled to occur at published programme boundaries, and are executed by the BBC's central RDS computer at Broadcasting House, London. Changes are communicated to RDS encoders at transmitter sites by the use of spare capacity in the BBC's Nicam programme distribution system[2]. It must be stressed, however, that this information is transmitted on an experimental basis and the BBC has not undertaken to offer these features as a public service.

Summary of the BBC's current RDS features.

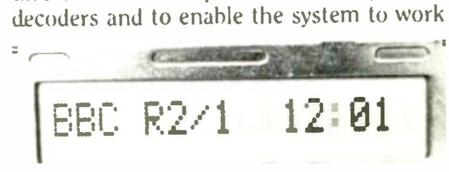
	Static	Dynamic	Experimentally Dynamic
Local radio and Radio 1	PI,PS,PTY AF,TP,TA, DI,MS,PIN RT,ON	CT	
Radios 2,3,4	AF,DI,MS	PI,PS,CT	PTY,TP,TA,PIN, RT,ON

Note that CT (clock time) transmissions must be dynamic to be of any use! BBC clock time transmissions are synchronized to MSF transmissions from Rugby and are traceable to the NPL standard. Automatic changeover from GMT to BST is provided in this service and thus BBC CT transmissions will make the same changes.

HOW IS THIS DATA TRANSMITTED?

RDS uses an additional subcarrier of 57kHz. This frequency is three times that of the stereo pilot tone and is phase-locked to the pilot tone when this is present. The injection level of the 57kHz subcarrier is expressed in terms of the deviation of the main FM carrier due to the (unmodulated) subcarrier. The BBC uses injection levels of 2.0kHz for local radio and Radio 1, 2 and 4 transmissions, and a reduced level of 1.2kHz on Radio 3.

The subcarrier is amplitude modulated by a shaped bi-phase coded signal. The subcarrier itself is suppressed to avoid data modulated cross-talk in phase-locked loop stereo decoders and to enable the system to work



All BBC national and local stations in England now carry RDS signals. Coverage is being rapidly extended to Scotland, Wales and Northern Ireland.

alongside the German ARI system (Autofahrer Rundfunk Information)[3].

The basic data rate is 1187.5 baud. This rate is obtained by dividing the subcarrier frequency by 48.

Data is differentially encoded at the transmitter according to the expression

$$\text{Output}[t] = \text{Input}[t] \oplus \text{Output}[t - t_d]$$

$$\text{where } t_d = \text{one bit period} = \frac{1}{1187.5}\text{s}$$

At the receiver the reverse process is applied by the expression

$$\text{Output}[t] = \text{Input}[t - t_d] \oplus \text{Input}[t]$$

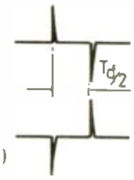
This combined process ensures that the data will be decoded correctly if the demodulated signal is inverted.

The bi-phase symbol generator produces two impulses for each input bit. A logic 1 input gives

$$e(t) = \delta(t) - \delta(t + t_d/2)$$

and a logic 0 gives

$$e(t) = -\delta(t) + \delta(t + t_d/2)$$



An example of the resultant impulse train is shown at (4) in **Fig.1**. This is then shaped by a filter whose response is ideally

$$\frac{\cos \pi fd}{4} \text{ for } 0 \leq f \leq \frac{2}{t_d}$$

$$0 \text{ for } f > \frac{2}{t_d}.$$

The resultant shaped impulse train then modulates the 57kHz subcarrier.

In the receiver, the above processes need to be reversed. The stereo multiplex signal is band-filtered and a synchronous demodulator used to recover the shaped bi-phase

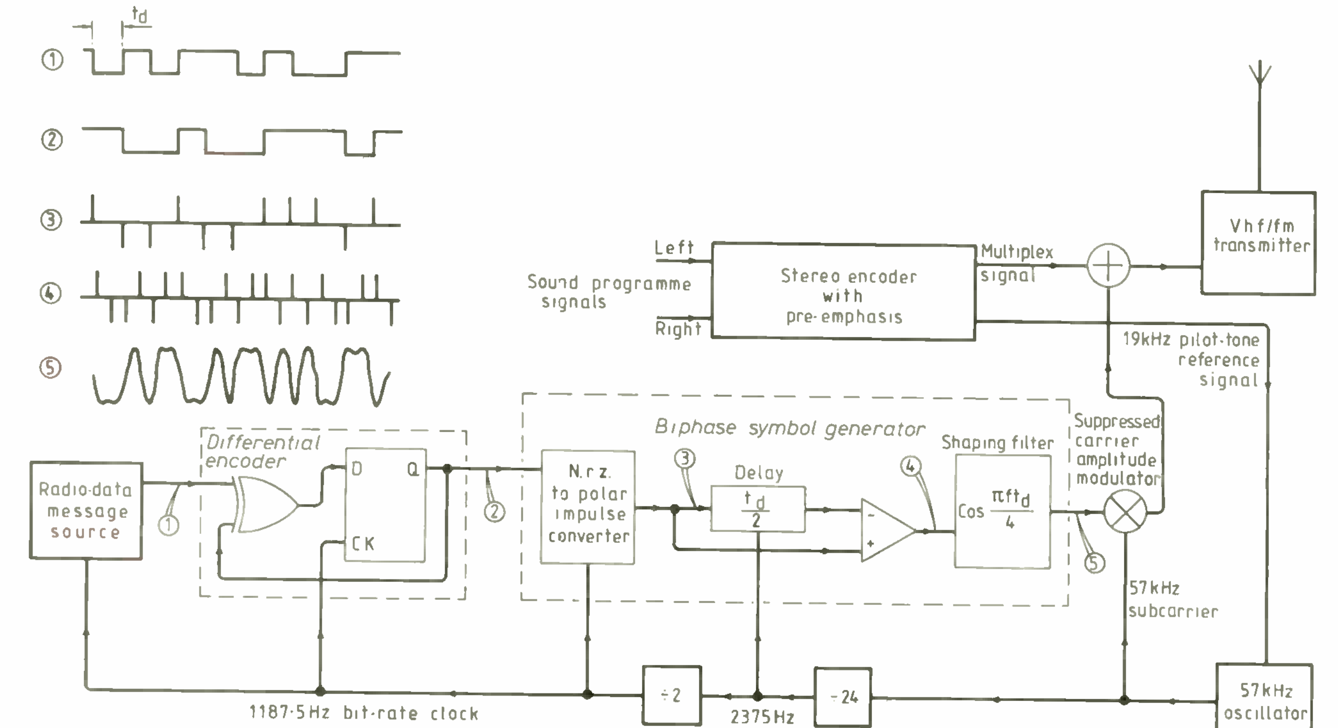


Fig.1. RDS transmission chain. The 57kHz subcarrier is locked to the stereo pilot tone, if present.

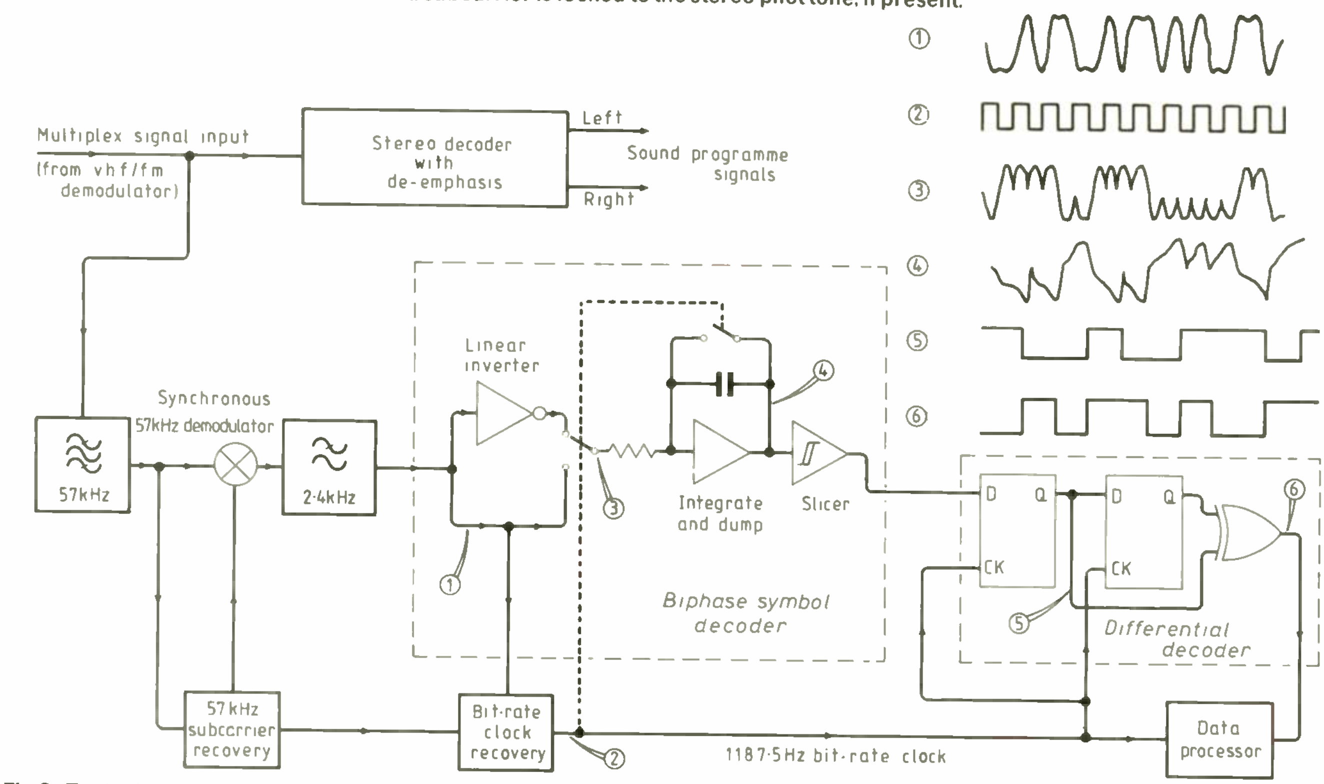


Fig.2. Typical receiver decoding system for RDS. The rather complex modulation scheme was chosen to minimize the risk of inteference to the audio programme.

symbols. One form of bi-phase symbol decoder is shown in **Fig.2**. It is important to note that, for optimum noise rejection, the combined filter response of the shaping filter and bi-phase decoder should have the same characteristic as the transmitter's filter, shown above.

BASEBAND CODING

RDS uses a continually repeated data structure known as a *block*. A block comprises a total of 26 bits. Sixteen bits carry data: the ten extra bits are used for error detection/correction and synchronization.

Four such blocks are transmitted sequentially to form a *group*. The first block is known as Block 1, the second as Block 2 and so on. When transmission of the group is complete, transmission of the next begins. There are no gaps between blocks or groups. The group repetition period may be calculated as follows:

$$t_g = t_d \times 104 = \frac{104}{1187.5} s = 87.5ms.$$

RDS is designed to carry information to that most difficult of destinations, the moving motor car. Reception conditions can vary on a second by second basis, multipath distortion sometimes rendering the datastream useless. For this reason RDS employs a high degree of redundancy, both in terms of the check bits appended to each block and the repeated transmission of group types. The structure and length of an RDS group were chosen to optimize the data-carrying capacity in the presence of random and periodic reception errors.

A 26-bit block may be generated from 16 data bits by multiplying the data bits by the following matrix:

```
        10000000000000000001110111
        01000000000000001011100111
        00100000000000001110101111
        00010000000000001100001011
        00001000000000001101011001
        00000100000000001101110000
        00000010000000000110111000
G=      00000001000000000011011100
        00000000100000000001101110
        00000000010000000000110111
        00000000001000001011000111
        00000000000100001110111111
        00000000000010001100000011
        00000000000001001101011101
        00000000000000101101110010
        00000000000000010110111001
```

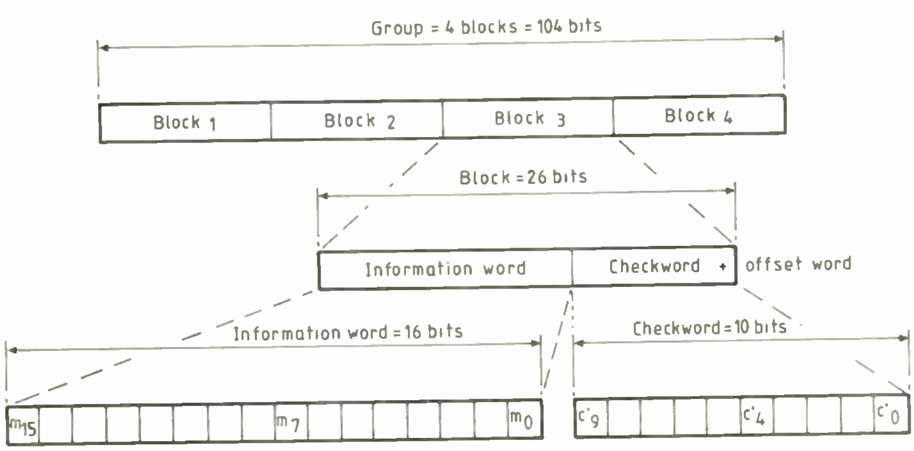


Fig.3. Basic data structure of RDS is a 26-bit sequence known as a block.

This is the matrix equivalent of the generator polynomial

$$g(x) = x^{10} + x^8 + x^7 + x^5 + x^4 + x^3 + 1$$

The result of multiplying this matrix by the data word D=0100010000100011 may be shown by writing the data bits vertically beside the matrix and then exclusively or-ing together all lines of the matrix where D[bit n] = 1.

```
0 10000000000000000001110111
1 01000000000000001011100111 Line Used
0 00100000000000001110101111
0 00010000000000001100001011
0 00001000000000001101011001
1 00000100000000001101110000 Line Used
0 00000010000000000110111000
0 00000001000000000011011100
0 00000000100000000001101110
0 00000000010000000000110111
1 00000000001000001011000111 Line Used
0 00000000000100001110111111
0 00000000000010001100000011
0 00000000000001001101011101
1 00000000000000101101110010 Line Used
1 00000000000000010110111001 Line Used
```

Result is given by

```
        01000000000000001011100111
XOR     00000100000000001101110000
XOR     00000000001000001011000111
XOR     00000000000000101101110010
XOR     00000000000000010110111001

=       01000100001000110110011011
```

The matrix leaves the data bits untouched (they are multiplied by the unity matrix), and generates a 10-bit check word. The check word is akin to the CRC (cyclic redundancy check) well known in data storage systems. The resultant word is modified by exclusively or-ing the result with a 10-bit word known as an *offset word*. This offset word is different for each of the constituent blocks of a group. Offset words applicable to each of the group elements are shown below:

Block	Offset	Offset word
1	A	0011111100
2	B	0110011000
3	C	0101101000
"	C'	1101010000
4	D	0110110100

Note: block 3 has an alternative offset word to aid identification of a special set of group types.

SYNCHRONIZATION

In the decoder a parity check matrix (shown below) is used to generate a 10-bit number from an accumulated 26-bit data sequence. The matrix multiplication is performed in the same way as the generation shown earlier except, of course, that there are 26 input bits and 10 output bits.

```
        1000000000
        0100000000
        0010000000
        0001000000
        0000100000
        0000010000
        0000001000
        0000000100
        0000000010
        0000000001
        1011011100
        0101101110
H=      0010110111
        1010000111
        1110011111
        1100010011
        1101010101
        1101110110
        0110111011
        1000000001
        1111011100
        0111101110
        0011110111
        1010100111
        1110001111
        1100011011
```

The result of this matrix calculation is known as a *syndrome*. Each offset word produces a characteristic syndrome when the matrix is multiplied by the 26 bits forming the respective block. If the decoder is in sync the syndrome for offset A will be found 26 bits ahead of the syndrome for offset B, which will be found 26 bits ahead of the syndrome for offset C or C', and so on.

To lock to an incoming data stream a decoder must apply the parity check matrix to the contents of a 26-bit shift register of incoming data bits at each and every bit period until a valid syndrome is detected. Confidence is increased if another valid syndrome is found 26 bits later, and so on. The offset words, effectively being deliberate errors introduced at known intervals, thus form the basis of the synchronization mechanism.

Offset	Offset Word	Syndrome
A	0011111100	1111011000
B	0110011000	1111010100
C	0101101000	1001011100
C'	1101010000	1111001100
D	0110110100	1001011000

Once a sequence of four blocks with offsets A, B, C or C', and D has been formed, the decoder has acquired one RDS group; this may now be processed.

GROUP TYPES

The four most significant bits of Block 2 of any group label the group and define the RDS features to which the group's data relates. In addition, the next most significant bit further divides the group type into one of two variants: A or B. Thus a group is known by its four bit number (0-15) and its variant letter (A or B).

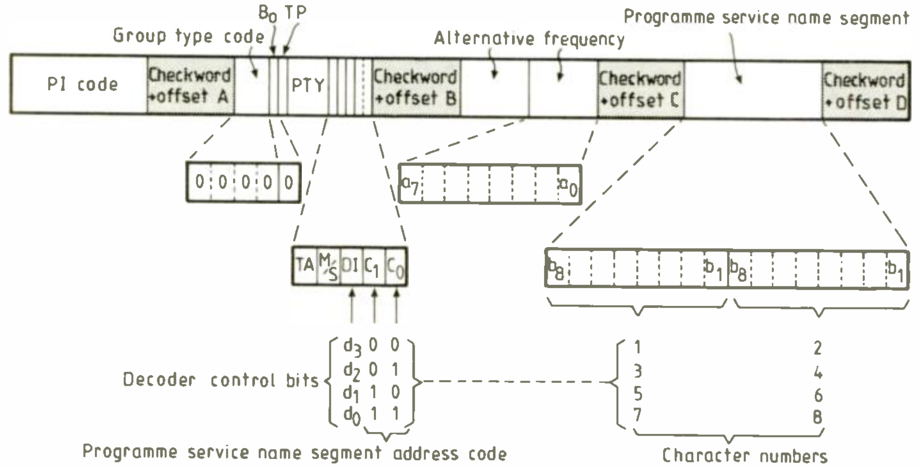


Fig.4. This RDS group is of type 0A: it carries basic tuning information.

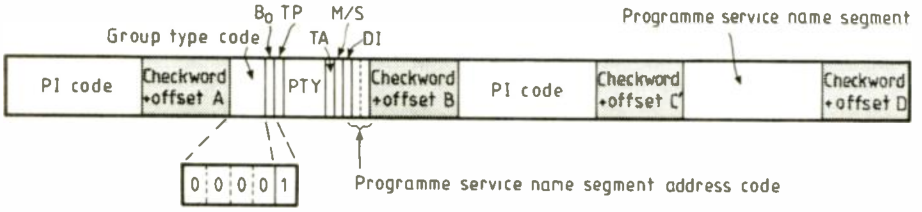


Fig.5. Type 0B group. PI is the single most important code carried by RDS and is repeated frequently.

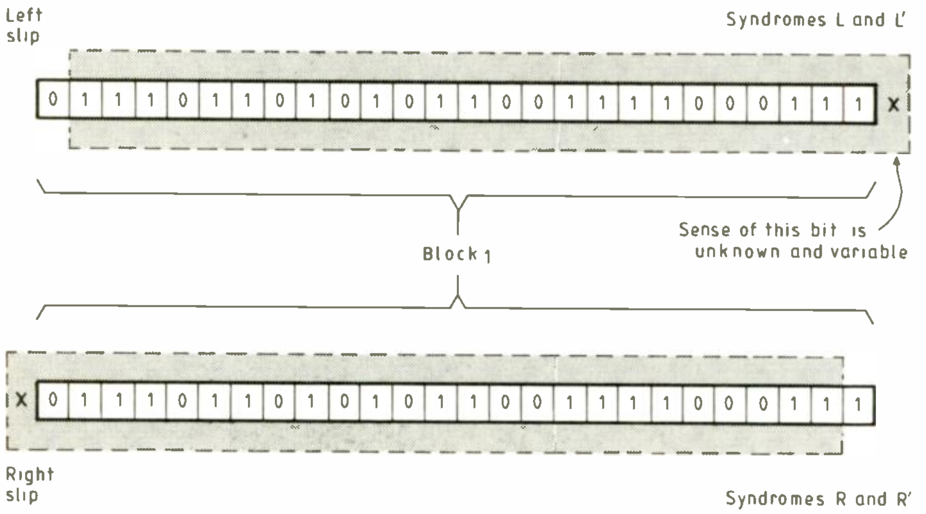


Fig.6. Locking to the RDS bit-stream: block 1 bit-slip syndromes.

An example of a group is shown in **Fig.4**. This is an 0A group which carries basic tuning and switching information.

Block 1 is occupied by the PI code. Block 2 carries the group type identification (0A) and a mixture of RDS features: TP, TA, PTY and one of the four DI bits. Exactly which of the four DI bits is defined is set by the last two bits of Block 2. These two bits form a number in the range 0-3, pointing to one of the DI bits. The same number also determines which two characters of the eight-character PS name are to be updated by the two new characters in Block 4. Block 3 contains two AF codes.

The effective data rate of RDS can be calculated, knowing that only 64 out of every 104 bits (i.e. one group) carry data, and that five of these carry group labelling information. This gives an effective data rate of

$$59\times\frac{1187.5}{104}=637.67 \text{ baud}$$

Every group type has the PI code in Block 1. The PI code is the single most important piece of information that RDS carries, since it is the key to all the automatic tuning features. Because of this importance and the need to keep the PI repetition rate as high as possible, variant B of all group types includes the PI in Block 3 *as well*. In this case the offset word C' is used instead of C for Block 3. This enables a receiver to determine the PI code of a transmission by looking for offset A or C'. There is no need to accumulate a whole group, with the consequent time penalty, in order to extract this information.

At the present the following group types have been defined:

Group type	RDS features carried
0A	PI, PTY, TP, TA, DI, MS, PS, AF
0B	PI, PTY, TP, TA, DI, MS, PS
1A/B	PI, PTY, TP, PIN
2A/B	PI, PTY, TP, RT
3A/B	PI, PTY, TP, ON
4A	PI, PTY, TP, CT
5A/B	PI, PTY, TP, TDC
6A/B	PI, PTY, TP, INH
15B	PI, PTY, TP, TA, DI, MS

By regulation of the group types radiated and their repetition rates the broadcaster can exercise some control of the range of RDS features included in his services. He certainly cannot avoid transmitting PI, PTY and TP, which are the main features which might be used by a receiver performing a station-by-station search along the band. Such a search, whatever the group type mix, will always find the desired feature repeated every group. Other features can be acquired more slowly once a station has been selected.

BBC transmitters currently radiate the cyclic group sequence: 0A, 1B, 0A, 2A, 15B, 0A, 3A, 15B, 0A, 2A, 0A, 1B, 15B, 0A, 3A, 2A, 0A, 15B, 0A, 15B, with the addition of a group 4A included automatically at each minute's edge. This group sequence achieves the minimum repetition rates for each feature recommended by the EBU, and explains why certain RDS features are not apparent in BBC transmissions.

The PI code for a station is not necessarily constant, indeed the BBC actively switches PI codes to reflect changes in its networks in the same way as the PS name. However, these changes are, in RDS group terms, very infrequent. Once the decoder has locked to the bit stream and has read the PI code, it may calculate the four possible syndromes that will occur with Block 1 if a bit is slipped in either direction. Four possibilities exist because the sense of the gained bit is unknown and indeed variable. If syndromes A, B, C/C' or D are lost but a pair of these new syndromes (L/L' or R/R') is detected at 104-bit intervals (one group length), the decoder can make a rapid adjustment to its bit count to re-synchronize to the stream.

(To be continued)

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1. EBU Tech. Doc. 3244. Specifications of the radio data system RDS for VHF/FM sound broadcasting.

2. NICAM-3: Near Instantaneously Companded digital transmission system for high-quality sound programmes. R. Caine, A. R. English and J. W. H. O'Clarey. *The Radio and Electronic Engineer*, Vol. 50, No 10, October 1980.

3. ARI – Autofahrer Rundfunk Information. H. G. Duckeck. Proc. SAE Conference on Audio Systems. Detroit, February-March 1984.

Specialized components and completed modules are available for the decoder design. For details, send a stamped, addressed envelope (or two IRCs) to the *E&WW* editorial office, marking your covering envelope "RDS". A copy of the author's object code for the 68701 is available from the same source, as a Motorola S-format hex listing.

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DBS COUNTDOWN TO CHAOS

By BARRY FOX

The sad story began in 1982, when the British Government allocated two of Britain's five satellite channels to the BBC for providing a DBS service in Britain. It added the proviso that the BBC must buy or lease its satellite from Unisat, a consortium of British Telecom, British Aerospace and GEC-Marconi. Bill "son of Wakey Wakey" Cotton was in charge. There was much grand talk.

But after finding that Unisat was asking up £80M a year, the BBC ducked out and later paid £10M in compensation (Unisat wanted nearly £60M) rather than risk bankruptcy trying to provide a service.

The BBC had also been worried by the Government's edict, made after channel allocation, that the BBC must use a completely new television transmission system. This was Multiplexed Analogue Components, or MAC, developed by the rival Independent Broadcasting Authority, instead of PAL.

The BBC had developed its own system called extended PAL, which took advantage of the wider bandwidth available for DBS while retaining compatibility with existing PAL sets. The extended PAL signal had extra high-frequency information on top of the ordinary signal band. Ordinary PAL sets would ignore this extra signal; an extended PAL receiver would use it to display a clearer picture, without Moiré effects.

MAC separates the chroma and luma information in time rather than frequency. Bursts of digital code for text and sound are interleaved with the picture bursts.

In July 1982 the Government set up a committee under Sir Anthony Part to decide between the two rival systems. In November that year Part came down firmly in favour of MAC. Union and International Telecommunications Union followed suit, recommending MAC as a standard for direct broadcasting by satellite throughout Western Europe.

Time would later prove that ex-PAL might have been a better solution, politically if not technically.

After the BBC got cold feet on MAC DBS, the IBA took on the job of finding a replacement. In December 1986 the IBA awarded the DBS franchise to BSB, a consortium of the Granada and Anglia TV groups, Pearson Publishing, Virgin and – at the time – Amstrad. BSB had impressed the IBA with promises of a £200 dish system, ten million subscribers after ten years and 25 000 new jobs. Poor Lord Thomson seemed quaintly oblivious of the fact that Amstrad buys-in boxes from the Far East.

The Government's concession was to drop its previous demand that anyone running a British DBS service must buy a British satellite. BSB bought from Hughes Aircraft in the US, with a guaranteed launch on a McDonnell Douglas Delta rocket from Cape Kennedy in Florida scheduled for August, 1989.

But the IBA franchise still required BSB to use MAC. This ties in with the decision by all European states to adopt the MAC system. It had the intention of helping the European consumer electronics industry, dominated by Philips and Thomson, compete with Japan on future high-definition TV technology.

Europe's Eureka HDTV system builds on MAC. The HD picture is formed from 1250 lines, but retains compatability with 625 line MAC receivers. Patents on MAC could also protect the West from the East, just as EMI's clever exploitation of Telefunken's patents on PAL made it possible for inefficient factories in Europe to survive until the legal cover ran out.

The original MAC system was called C-MAC, and it incorporated a digital data stream running at 20.25Mbit/s. This data stream can carry eight separate digital audio channels, either as four stereo pairs, eight different language soundtracks or any combination of the alternatives. Alternatively some of the data could be used for text or business communication.

France and West Germany objected to this standard because the data stream is of such high frequency that it cannot travel down the existing network of TV cables on the Continent. Their engineers developed a variant of MAC, called D2-MAC which halves the data rate to 10.125Mbit/s by the simple expedient of halving the number of digital channels.

Britain said no to D2-MAC, and developed a clever half-way system called D-MAC. This maintains the full data rate but halves signal frequency through duobinary coding, where two bits are transmitted in the time normally taken to transmit one.

In July 1987 the Home Office confirmed that BSB would use the D-MAC system, hoping that the Continent would follow. Unfortunately this has not happened, largely because ITT in Germany has invested in the production of microchips for D2-MAC receivers.

Hoping to capitalize on the standards split, a consortum of Philips, Plessey and Nordic VLSI (of Norway) has been developing a multi-MAC chip set, which can cope with all varieties of signal: C-MAC, D-MAC and D2-MAC.

Foreseeing the risk of starting to broadcast a D-MAC service which no one can receive, BSB is paying ITT £50 million to modify its D2-MAC design for D-MAC, and produce four million chip sets for TV manufacturers.

BSB decided early on that it would broadcast all three channels in scrambled format, using "hard" computer encryption. Viewers will only be able to see pictures and hear sound if they have paid a subscription, or one-off fee for a special programme such as a championship boxing match, or been given a free decoding key. This technology, called conditional access, relies on the transmission of digital codes along with the signal broadcast from the satellite. These codes interact with digital codes burned into the microchips inside the receiver. The signal is unscrambled only where the codes match. Non-payers get non-matching codes unless the programme provider wants everyone to watch on a free basis. Two of BSB's channels will be free and supported by advertising. UK viewers will get free codes. Encryption reduces copyright fees because only British viewers will be sent the correct codes.

BSB is paying General Instrument £100 million to modify its *VideoCypher* system as used in the US, and make *EuroCypher* hardware modules available for manufacturers next summer.

In June 1988, Rupert Murdoch, News International managing director, re-wrote the rules of the game. He announced that his Sky Channel had taken four channels on Luxembourg's private venture Astra satellite and would use PAL without encryption. Amstrad, no longer a member of the BSB consortium, would sell reception equipment for under £200. Murdoch subsequently took a fifth channel on Astra in a deal with Disney. Around 80 manufacturers have now said they will sell two million dish/receiver systems in 1989.

In a desperate effort to re-establish confidence in MAC and BSB, the Home Office and Department of Trade and Industry said they were considering the transmission of BBC2 and Channel 4 TV from the same satellite as BSB. Immediately, and predictably, there was outcry. Soon after the ill-advised announcement, the Government tempered its proposal by promising to continue simulcasting terrestrial transmission for an interim period. Then the whole daft idea was dropped.

In October 1988, W. H. Smith took two channels on Astra and confused things even further. WHS decided against using PAL, and will use D-MAC instead like BSB. But WHS hardware suppliers will use the multi-standard MAC chip set being made by the consortium of Nordic VLSI, Plessey and Philips, thereby making receivers compatible

The sad history of consumer electronics

Twenty years ago the hi-fi industry went through a painful learning process. Manufacturers found out the hard way about the perils of incompatibility.

There were at least four different quadraphonic surround-sound systems, each supposedly better than the rest. People who bought one system found that the records they wanted were available only for a competing system. Magazines endlessly debated the relative merits of different coding technologies. This sold magazines, and kept journalists in business, but did nothing to resolve the standards debate.

In the end, all the four systems on offer (SQ, QS, CD4 and UD4) – plus a BBC system and a neat compromise from David Hafler – fell by the wayside, spoiling the chances of the much better Ambisonics system. Now surround-sound has made a come-back, in the guise of the Dolby system used by the cinema industry. Home decoders can reproduce surround-sound tracks on video releases.

Success of the Dolby system has nothing to do with technical superiority. The Dolby surround system is designed to help sell films in cinemas, not provide subtle ambience in a domestic environment. But the availability of software has broken the traditional "no hardware, no software" vicious circle.

In the mid 1970s, sales of home hi-fi declined. The public started to spend money on home video instead. And an even worse muddle over standards arose: in all there were four different European systems, variously offered by Philips and Grundig. Then came the battle between VHS and Beta from Japan. Slowly and painfully, VHS emerged as the de facto standard for time-shifting and library rental.

Technical superiority had nothing to do with the emergence of VHS as a home standard. Although the format now offers very good pictures and sound and every imaginable feature, VHS often trailed its rivals in the early days. The format won through because it was backed by the largest number of manufacturers with commercial clout.

In the meantime, the consumer electronics trade was busy creating the biggest muddle of all, this time in home computing. There were systems from Sinclair, Commodore, Apple, Acorn, Atari, Apricot, Tandy – and many more – all incompatible with each other. Often several different incompatible systems were on offer from the same manufacturer. There was also a chaos of non-standardization for communication protocols and disc storage.

IBM stepped into the vacuum, with its own hierarchy of PC standards based on the MS DOS operating system. The success of the PC with DOS had nothing to do with technical merit and everything to do with the old industry adage "no-one ever got fired for buying IBM".

The one lesson that comes over loud and clear is that the consumer electronics industry never learns from past mistakes. This is partly because the manufacturers play a Mac Hatter's tea party game with personnel and partly because the industry is split into water-tight compartments which never communicate.

The people making and selling video learned nothing from the audio experience, and the computer industry learned nothing from either audio or video. Now exactly the same thing is happening with satellite television. A whole new generation of salespeople are fighting a standards battle in public that could cripple what looked for a while like a promising new market for consumer electronics.

with both PAL and D-2 MAC as favoured by France and West Germany.

WHS will fund its programmes with a mix of advertising and subscription, so must encrypt its broadcasts. For this WHS will use the *Eurocrypt* system backed by the same chip consortium. But because multi-MAC and *Eurocrypt* chips will not be ready until mid-1989, decoders will not be available until the end of 1989 and so WHS will start broadcasting from Astra in February using PAL without encryption.

Thus, for at least six months people who buy simple receivers to watch Rupert Murdoch's channels will also be able to view programmes free. But after that they will either have to modify their satellite tuner or buy another one. The snag is that upgrading for MAC and even some forms of PAL decryption will be possible only if the tuner can handle a signal of around 10MHz bandwidth. Cheap PAL decoders may handle only around 6MHz and thus not be upgradeable.

There is a further problem. Astra will broadcast from 19 degrees East but the BSB satellite will sit at 31 degrees West and thus need a separate dish aerial or dish steerer. Although BSB will use D-MAC for all its three channels, it is already committed to using the *EuroCypher* encryption system like WHS. There is no compatibility between *Eurocrypt* and *EuroCypher*, so anyone wanting to watch WHS programmes and BSB programmes will need two decryption units, even though both programmes use D-MAC. Is this the way to sell a new entertainment service? It gets worse.

Although Rupert Murdoch's original plan, as announced in June, was to broadcast all his Sky channels in clear PAL, he soon found himself in trouble with the film companies who insisted on encryption. Satellite broadcasts into Britain can be picked up elsewhere in Europe, where separate rights deals are being struck. Only encryption can restrict viewing to the country for which rights have been sold. So Murdoch had to promise to encrypt his Sky Movie Channel.

Then came the deal with Disney, and the birth of a plan to encrypt both the Disney and Sky Movie channels and charge a bundle subscription of £12 a month.

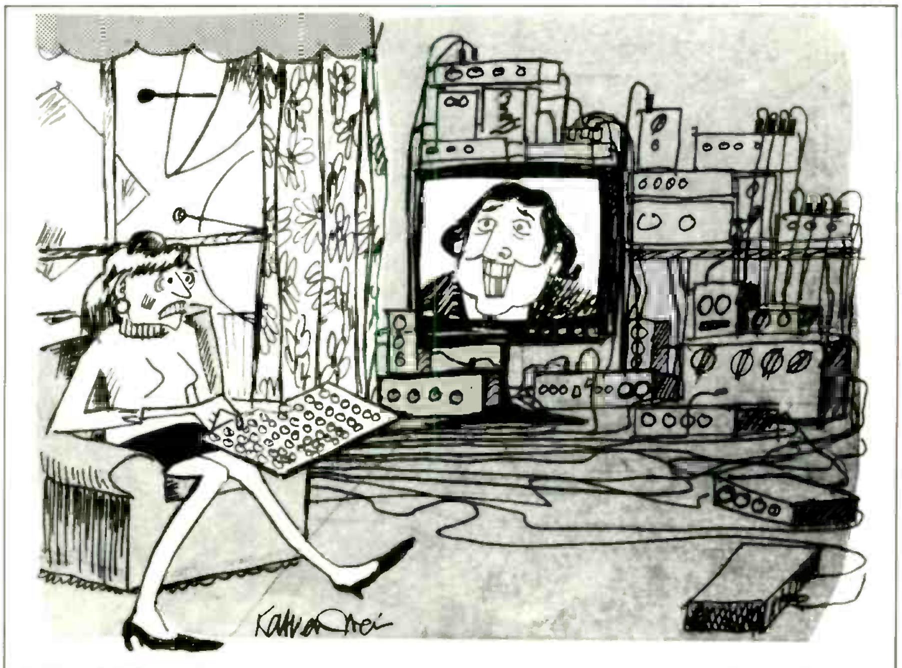
Sky soon realised it would be impossible to get a foolproof encryption system up and running by February 1, so set August 1 as the deadline for encryption. Sky then toyed with the idea of using a compromise system as an interim solution between February 1 and August 1 but recognised it would cause chaos. It now looks as if Sky will broadcast in clear PAL from February 1 to August 1 and then switch to hard encryption, but still use PAL; at least that is what Sky has promised the film companies. And in this business, the situation can change with the wind.

It seems inevitable that dates will be missed all round, and the trade and public will be faced with a bewildering array of different and incompatible reception systems. Some viewers will switch off mentally and never switch on to the new technology.

Trade experience in audio, video and home computing teaches that a lot of people will lose a great deal of money learning the same old lessons, all over again.

Ignorance is an expensive luxury.

● The Astra satellite lifted off from Kourou in the early hours of December 10. Start of programmes is scheduled for midday on January 20.



"D-MAC, D2-MAC, PAL, enhanced PAL, Eurocypher, Eurocrypt and all I can get is flaming Wogan!"

EPLD programmer design

To illustrate the design of programmers for UV-eraseable PLDs, this unit and a PC will program Cypress C20 devices

JOHN CROMIE

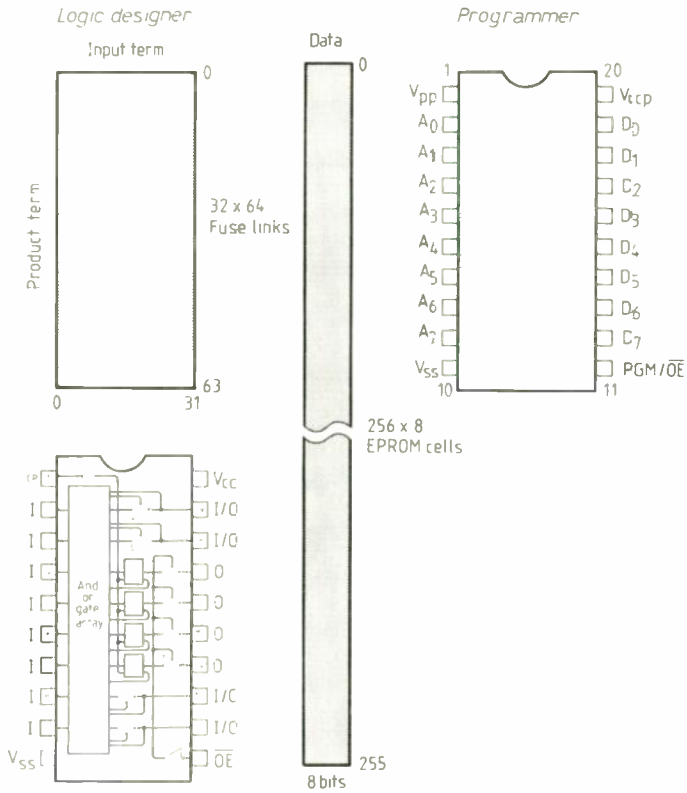


Fig.1. A PLD as seen from two different perspectives.

Commercial PLD programmers can be costly, principally because they must support a plethora of exotic devices from different manufacturers with widely varying programming and testing requirements. The usual approach is to provide software-configurable pin drivers which may be specifically tailored to the voltage, current and slew-rate requirements of virtually any device. For many users, though, this respresents vast overkill, since they may only be interested in programming the common or garden 16L8, 16R4, 16R6 ad 16R8 architectures. In fact, the majority of combinational and sequential logic functions may be implemented using these four industry-standard architectures.

This simple, low-cost programmer is designed to program the popular and readily available Cypress C20 Series UV-eraseable PLDs: PALC 16L8, 16R4, 16R6 and 16R8. The programmer is connected to the serial port of any PC. A communications package, such as Procomm, running on the PC, can then provide the VT100 terminal emulation, and ASCII file transfer capabilities required to use the programmer.

FEATURES

The programmer offers the following facilities.

- Device programming from a JEDEC file generated by a logic assembler, such as PALASM or CUPL. Alternatively, the JEDEC file may be generated manually from a fuse map using any text editor.
- Automatic test vector application from a JEDEC file.
- A novel means of quickly and easily testing a programmed logic function during the development process, by manually applying inputs and examining the output states.
- Blank check to verify unprogrammed devices.
- Checksum on the fuse states is automatically verified after programming against that in the JEDEC file.
- Full implementation of CYPRESS intelligent quick-programming algorithm.

PROGRAMMING AND TEST COMMANDS

The programmer will accept the following commands.

BLANK carries out a blank check on the device.

CSUM returns the device checksum, in Hex: 0000 if device is unprogrammed.

JEDEC downloads a standard JEDEC file from the host, as created by a logic assembler such as PALASM or CUPL. The device is programmed and the checksum is verified. Any test vectors are then applied to the device. May be exited at any time by typing <ESC>. Only the Design Specification, Link, Checksum and Test Vector fields are handled; others are ignored.

PLINE n displays fuse state of Product Line n: (0=<n=<64)

0: fuse unprogrammed

1: fuse programmed

RESTART has same effect as pressing reset button.

TEST enters manual test mode. An input vector can be edited and applied to the device inputs; the subsequent state of the outputs is then displayed.

Inputs

1: Drive input HIGH

0: Drive input LOW

X: Don't care (actually driven LOW)

–: Treat this pin as an output (pins 12-19 only)

Output states

H: Output is HIGH

L: Output is LOW

Z: Output is high-impedance.

The inputs may be edited in conjunction with ← and → cursor keys. When the desired input vector has been set up, it may be applied to the device by hitting either **<Return>** or **<Cursor Up>**. Hitting **<Cursor Up>** differs in that the application of the input vector is followed by a clock pulse (rising edge) being applied to the device's CLK input. Note that the device pins remain unaffected by any editing prior to hitting either of the above two keys.

Outputs A	B	I	Pin state
0	0	I	LOW (not allowed)
0	1	I	V_{pp}
1	0	I	LOW
1	1	I	HIGH (pulled up to 5V)

PROGRAMMER TEST COMMANDS

CALL aaaa calls subroutine at location aaaaH and then returns to prompt.

PULSES applies a continuous stream of 0.1ms programming pulses at V_{pp} and short verify pulses at 0V to pin 11 of the device for testing timing and voltages, using an oscilloscope. It is an infinite loop, and the programmer must be reset to exit.

READ aaaa displays the contents of memory

location **aaaa**H in the microcontroller.
WRITE aaaa dd writes byte **dd**H to memory location **aaaa**H in the microcontroller.

OPERATION

The HD63701 single-chip microcontroller, with software embedded, enables a reduction in programmer hardware. In addition to the microcontroller, only three other ICs and a few passive components are needed, as shown in the circuit diagram of **Fig.5** The HD63701 was selected because it had all the necessary on-chip features such as 4K eprom, 256 bytes of ram, timers and a serial port, but also because it was available in an economical one-time-programmable (o.p.t.) version.

There are two pin drivers for device pins 1 and 11, allowing the pins to be driven to V_{pp} (13.5V), logic HIGH (5V) or logic LOW (ground). Each pin driver is controlled by two outputs from the microcontroller, shown in the table.

Output A controls the switching of V_{pp} through to the pin via an o.c. buffer (7407) and a power op-amp (L272). Whenever B is HIGH, the non-inverting input of the op-amp will be held around 4.5V; so long as A is HIGH the voltage at the inverting input will be pulled up to 15V and thus the op-amp output will be around 0V, disconnecting V_{pp} from the pin. The pin state can then be toggled between logic HIGH and LOW by B, via another o.c. buffer and pull-up resistor. Whenever A goes LOW and B is HIGH, the inverting input voltage will drop to around 2.5V, which is now less than the 4.5V on the non-inverting input, causing the op-amp output to swing to V_{pp}. This then drives the pin through the diode. Due to the voltage drop across the op-amp and diode, the 15V supply is dropped to the required 13.5V (±0.5V) for V_{pp}. Resistors R_9 and R_{10} allow B to control the voltage at the non-inverting input. Hence, if B is LOW, V_{pp} cannot be switched through to the pin since the voltage at the inverting input will never fall below that at the non-inverting input. This interlock protects against the pin being driven low at the same time as V_{pp} is applied, causing the op-amp output to be shorted to ground through the buffer. Diodes D_3 and D_4 protect the op-amp inputs in the absence of the 15V supply. Note the low value of R_{11}; this is necessary to ensure a sufficient rise time on the clock pulse since, in the absence of an active pull-up, the pin input capacitance can only be charged up through the pull-up resistor. The L272 power op-amp was chosen because of its limited slew rate of typically 1V/μs, allowing the pin driver comfortably to meet the minimum 1μs V_{pp} rise and fall time specifications of the PAL C20 Series.

The pull-up/pull-down switch, controlled by microcontroller output P35, allows pins 12-19 of the device to be pulled either HIGH or LOW via the 47kΩ resistor pack RP_2. This facility is used in testing these outputs for a possible high-Z state. If the pin is in the high-Z state it can be freely pulled HIGH or LOW using this switch, whereas this would not be possible if the pin was being actively driven by the device as an output. Transistor Tr_3 switches the common pin of RP_2 to 5V if P35 is driven low.

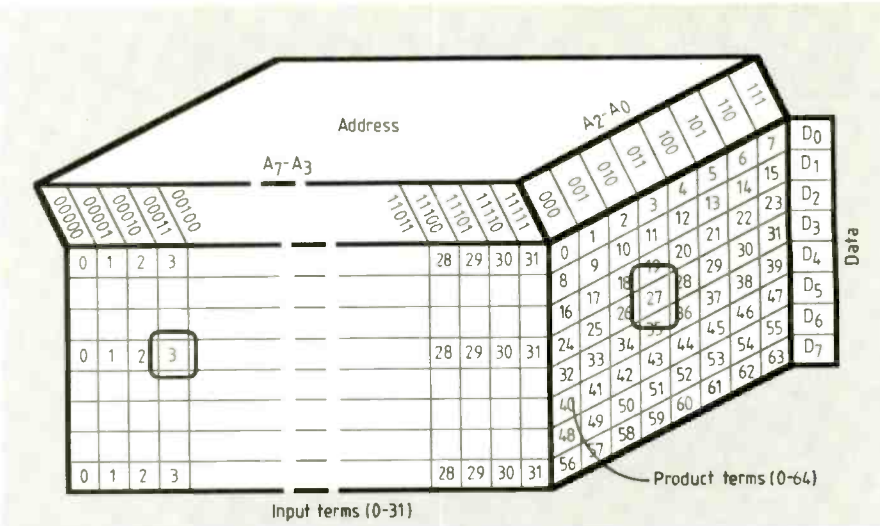


Fig.2. PLD address mapping. For example, (Product Term 27, Input Term 3) (Address 00011011, Data 00001000).

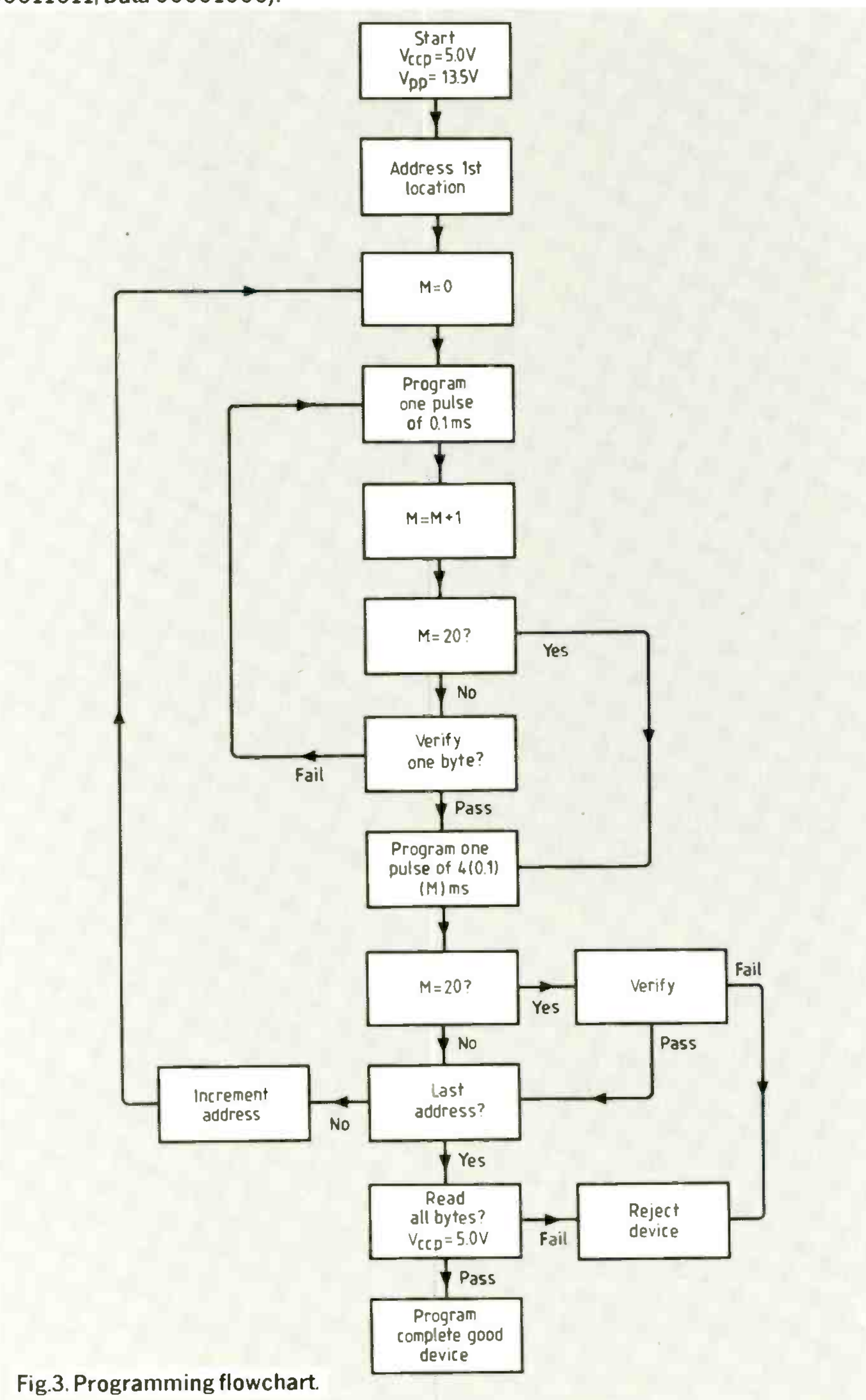


Fig.3. Programming flowchart.

Ports 1 and 4 of the microcontroller are connected directly to the rest of the device pins which do not require high-voltage pin drivers. Port 4 is always an output port, since pins 2-9 of the device will invariably be inputs. Port 1, however, is bi-directional, since pins 12-19 can serve as either inputs or outputs. To afford protection in the event of contention between a device output and a Port 1 output, series resistors (RP_3) are inserted to limit the current. Pull-up resistor packs RP_1 and RP_2 ensure that V_{IH} to the device meets the specified 3V minimum.

Mode-control inputs PC0-PC2 are held HIGH, so that the controller will start up in its single-chip mode (mode 7).

IC_5 (ICL232) provides a complete RS232 interface, with both positive (+10V) and negative (−10V) supplies being generated on-chip: capacitors C_9-C_{12} smooth these supplies. Only the TXD RXD and GND lines of the RS232 interface are used, with no facility for a hardware handshake. Leds indicate line activity: green for RXD and red for TXD.

A spare input to IC_5 (pin 8) is used for a rudimentary check on the presence of the 15V supply. Pin 9 goes to input P37, and will be low if a voltage greater than 3V is present.

EPLD PROGRAMMING

As viewed by the logic designer, the PLD is represented by a 32 × 64 fuse matrix, with a particular fuse being addressed by its Product Term (0-63) and Input Term (0-31) co-ordinates. So far as the programmer is concerned, all four PLDs appear identical as a 256 × 8 bit eprom array with eight address inputs and eight data lines (Fig.1.). It is the task of the programmer to map this logical 32 × 64 representation on to the actual physical 256 × 8 array of eprom cells (Fig.2.):

(Product Term, Input Term) → (Address, Data)

Because of the eight-bit data bus, eight cells may be programmed or verified simultaneously. The 64 Product Terms are split into eight groups, with one data line assigned to each group as in Fig.2. The address is in fact made up of two fields: A7-A3 select the Input Term and A2-A0 select the particular Product Term within each group of eight to be connected to the data line.

A7-A3 => Input Term number

A2-A0 => remainder of (Product Term number/8)

Since the programmer will be programming one Product Line at a time as the Link fields of the JEDEC file arrive, the fuse data will not arrive in an order permitting us to program eight fuses at the one time. Hence, only one data line at a time can be set to '1' in order to program a cell.

Data mask D7-D0 => quotient of (Product Term number/8)

Once the Address and Data inputs have been set up, the Cypress programming algorithm can be entered (Fig.3.). The V_{pp} input must be raised to 13.5V to place the device in programming mode. Programming consists of applying brief 100μs pulses at V_{pp} to the PGM input, reading back the fuse state after each pulse by dropping the PGM input briefly to GND. Once a '0' is returned in the appropriate bit location, indicating that the fuse has been programmed, a knock-out pulse of 4 × 100μs × (the number of short pulses required) is applied to boost a few extra electrons into the floating gate of the cell. A maximum of 20 short pulses are allowed to program a cell, although generally 1 to 3 will suffice.

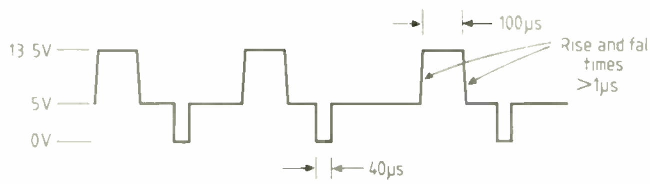


Fig.4. Pin 11 of device under control of pulser test routine.

SOFTWARE

The microcontroller software is structured around a generalized command interpreter CMD INTP, whose job is to accept a command as a character string from the user (via the serial port), compare this command with a table of possible commands and call the appropriate subroutine if a match is found. Naturally, if no match is found, it beeps and sends out the prompt again. Other functions of CMD INTP include sending out the prompt, echoing the characters typed in by the user, handling the Backspace and Delete functions and ensuring that the receive buffer is not overrun. This command interpreter loop was developed and thoroughly tested first of all, since it forms the backbone of the interactive software structure. The rest of the software is then developed as subroutine modules, which may be called by the interpreter once an entry is made in the Command Table. Each entry in the table has three fields:

1. Number of characters in name (n) 1 byte
2. Name n ASCII chars
3. Address of subroutine 2 bytes

The end of the table is marked by an entry with 0 in the Number of Characters field.

This approach facilitates development work, particularly if no development system is being used, since new modules or test routines may be easily linked in and tested. In fact, two of the first commands entered were READ and WRITE to read from and write to specific memory locations: invaluable in testing the rest of the code! Some of the major subroutines are detailed below.

PJEDEC receives a JEDEC file line by the line from the host. Once a line has been received, the field identifier is checked and one of three actions follows:

'L' field: MAKE PREC is called to calculate the Product Line number and pack the fuse data in binary format into four sequential bytes in memory. ZAP PLINE then programs the Product Line: if no errors occur PJEDEC loops again to receive the next line.

'V' field: TEST VECTOR is called to apply the inputs and test the subsequent outputs. If the test vector passes, the next line is received.

'C' field: the received checksum is compared to the one totted up in CHECKSUM as the device was programmed. An error is reported if there is no match.

The XON XOFF protocol is used to control data arriving. Once a line is received, XOFF is sent to the host while that line is being processed; XON is then sent to request the next line. PJEDEC terminates on receiving either <ETX> denoting the end of a JEDEC file, or <ESC> typed by the operator to abort.

MAKE PREC takes a Link field in the receive buffer and scans the fuse data, packing it bitwise into four sequential bytes in memory. This simplifies programming, since simple logical shift instructions may now be used to access the fuse data. The Product Line number is also calculated and stored in variable P LINE.

ZAP PLINE takes this binary fuse data and proceeds to program the Product Line fuse by fuse, setting up the appropriate addresses as it goes. Error codes are returned by ZAP PLINE if a fuse refuses to program or is already blown when it shouldn't be.

ZAP FUSE is called by ZAP PLINE to program each individual fuse according to the Cypress algorithm. It is supplied with the necessary data mask (8 bits with only one set).

VFY FUSE is called by ZAP FUSE following each programming pulse, in order to ascertain whether or not the fuse programmed successfully. This may be achieved very simply by ANDing the mask with the data read back from the PLD:

Cell programmed
0001 0000 mask
xxx0 xxxx data read

0000 0000 all zeroes

Cell not programmed
0001 0000 mask
xxx1 xxxx data read

0001 0000 not all zeroes

PULSE PGM is called by ZAP FUSE to apply a programming pulse to the device. The Output Compare feature of the 68701 is used in conjunction with the 16-bit free-running counter to achieve accurate timing.

PIN EDITOR is the module implementing the Manual Test feature of the programmer.

BLANKCHECK checks if all the fuses are unprogrammed.

DISP PLINE takes a Product Line number and displays the state of that line.

CSUM calculates and displays the checksum of the device.

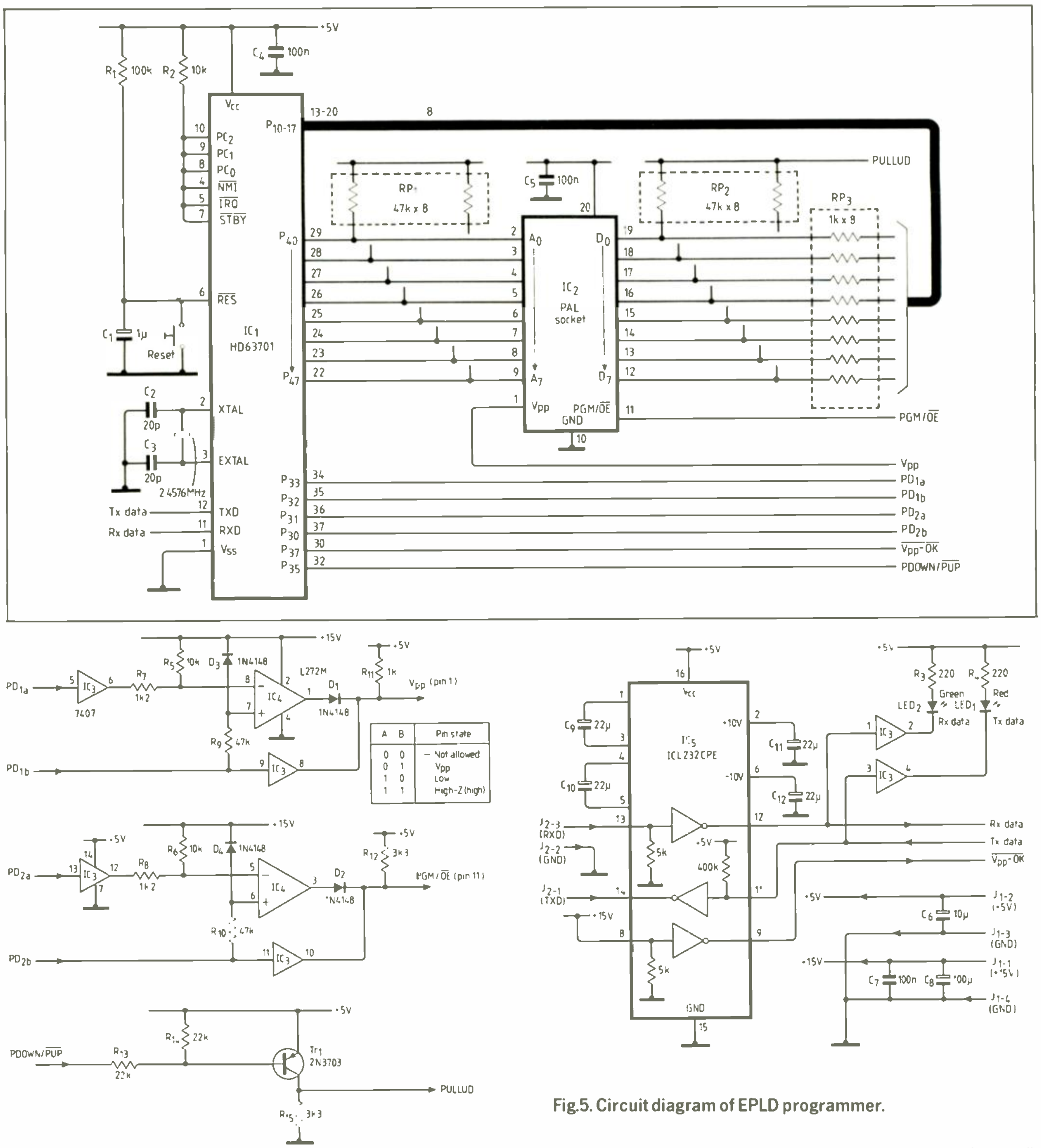


Fig.5. Circuit diagram of EPLD programmer.

OPERATION

Connect the programmer to the PC serial port.

PC	**PROGRAMMER**
Pin 2 TXD	Pin 3 RXD
Pin 3 RXD	Pin 1 TXD
Pin 7 Ground	Pin 2 Ground

The PC should be running a communications package set to the following:

VT100 emulation
XON/XOFF enabled
Echo Off
Full Duplex
4800 baud
8 bits
No Parity

If all is well, the Reset button should clear the screen and the power-up message will appear, along with a prompt. <Return> should cause another prompt to appear. Line activity may be seen on the TXD and RXD leds. Type BL <Return> and make sure you get a *'Device Blank'* message back. Switch off the 15V supply and type BL again. You should now get a *'V_{pp} not present'* message.

Connect an oscilloscope to IC_2 pin 1 and enter command PUL. The signal should appear as in Fig.4. Verify that the rise and fall times of the V_{pp} pulses do exceed 1µs. Remove power and insert a blank device in IC_2. Check that BL returns *'Device blank'*, and CS returns a checksum of 0000.

The author invites readers to contact him for details of software and hardware for the programmer. Address: "Ratherbourne", Dunwiley, STRANORLAR, Lifford, Co. Donegal, IRELAND. (Tel: 010-353-74-31209).

Bibliography

Programmable Array Logic Handbook. Advanced Micro Devices. 1984

PAL Handbook (Third Edition). Monolithic Memories 1983

Systems Design Handbook (Second Edition). Monolithic Memories 1985

Programmable Hardware. *BYTE*, January 1987 issue

Programmable Logic Design Guide. National Semiconductor

Programmable Logic Handbook. G. Bostock. 1987 Collins

CMOS Databook. Cypress Semiconductor 1988

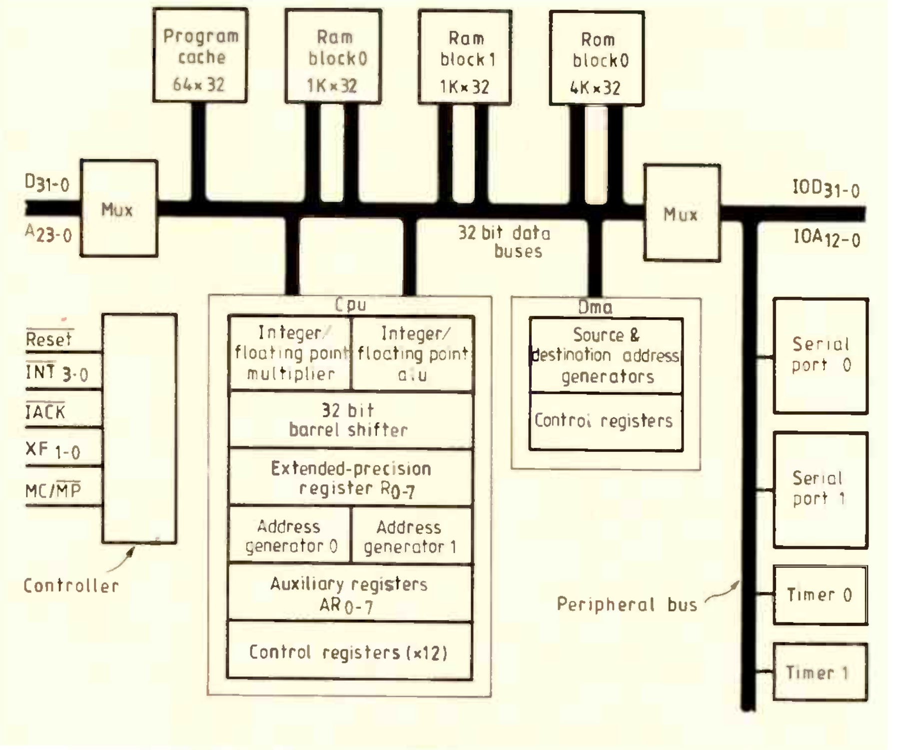
APPLICATIONS SUMMARY

DSP overview

Preliminary information concerning Texas' latest cmos signal-processing chip is given in brochure SPRT036. The eight-page TMS320C30 Preview Bulletin gives general specifications of the 32bit device and broaches its architecture.

With a 60ns cycle time, the device can execute more than 33 million floating-point operations per second. It has on-chip memory, a concurrent DMA controller and an instruction cache.

Texas Instruments, European Literature Centre, Manton Lane, Bedford MK41 7PA.

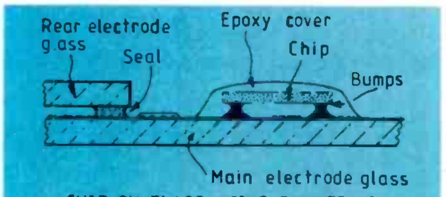


LCD for automotive applications

Reprints of a technical paper available through Philips describe how advances in liquid-crystal technology are gradually making mechanical and vacuum-fluorescent displays less attractive alternatives for automotive cockpit indications.

The paper, called 'LCD for Automotive Instrumentation', is published by The Engineering Sociey for Advancing Mobility Land Sea Air and Space. Within its six pages, the paper discusses the problems of mounting an LCD in the dashboard, and advances in technology such as 'chip-on-glass'.

Philips Components, Mullard House, Torrington House, London WC1E 7HD.



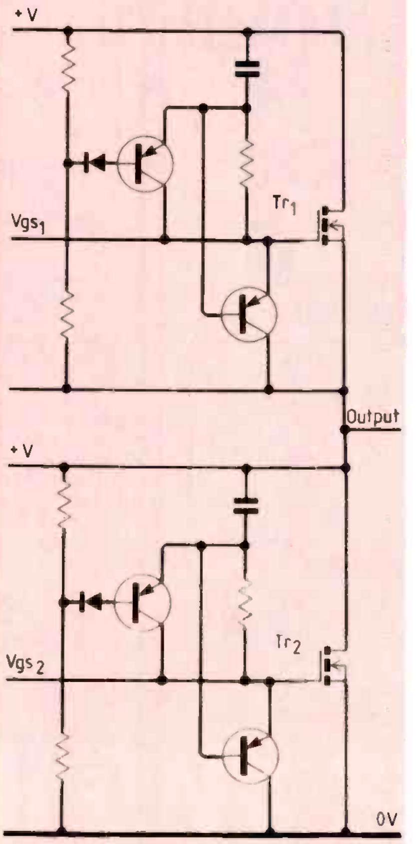
CHIP-ON-GLASS USING BUMPED IC

Using power-fet modules

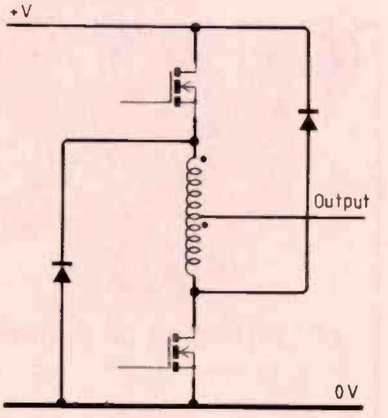
As far as electrical parameters are concerned, the statement that power fets are easily paralleled to increase current capability is true. At high currents however mechanical constraints relating to paralleling mosfets have to be considered.

Power Hexfet modules reduce the mechanical problems of paralleling devices, but other problems relating to the use of power mosfets, such as heat sinking, driving and e.m.i. still have to be considered. Application note GBAN-HEX-1 from International Rectifier covers these subjects and presents ratings of the company's Hexfet modules.

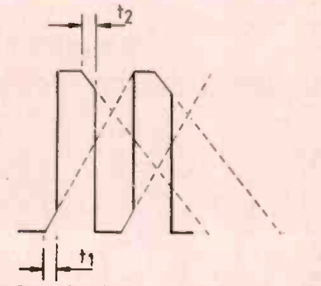
International Rectifier, Holland Road, Hurst Green, Oxted, Surrey RH8 9BB.



DV/DT STRESS RELIEF OF PARASITIC DIODE BY ACTIVE GATE CONTROL



DV/DT STRESS RELIEF OF THE PARASITIC DIODE WITH SERIES INDUCTORS/AUTOTRANSFORMERS



t_1 Is critical time to allow parasitic of Tr_2 to recover

t_2 Is critical time to allow parasitic of Tr_1 to recover

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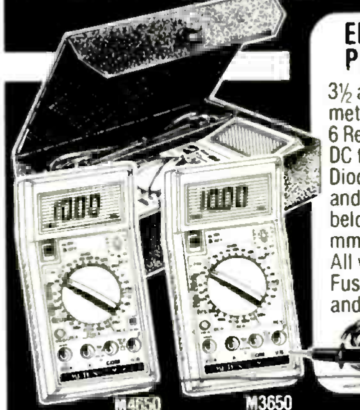

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INDUSTRY INSIGHT

Micromachined silicon into transducer technology • distributed temperature sensing could prevent underground fires • rival systems come to market • prosthetics and robotics shake hands • electronic nose learns vapour discrimination • fuel cell gas sensors respond to legislative push • prototype fibre optic gyroscope • optical sensor markets • who does what in optical sensors • guided wave sensor development for industry • fly by light • smart sensor markets • salmonella sensing

SENSORS AND INDUSTRY THE WAY FORWARD

The world market for sensors in industry is currently around £8 billion and growing at about 10% per year. It will all but double by 1995. In some industries, such as the motor industry and healthcare, the rate of growth is much greater. New techniques and applications are constantly in development as emerging technologies make the sensing of more variables accurate, reliable and cost-effective. The US, Japan and West Germany are leading in the demand for introducing sensors into products and processes. More industry sectors are realising the exciting potential offered by the new sensing technologies and are investing in the development and introduction of products which exploit these possibilities.

The US and Japan lead Europe in automotive sensing, but consumer, safety and environmental lobbies are pushing the European motor industry along avenues that will demand a rapid closing of the gap. This represents important opportunities for the motor manufacturers and for their component suppliers. The expertise to compete exists in the R&D laboratories within Europe.

This is an example of the UK position within but one sector of the world market. Similar situations exist in other areas of industry. Healthcare, machine tools, robots, security devices and household appliances are all areas in which sensing technology advances will need to be applied to maintain competitiveness and to make the most of the potential of modern microelectronics and automated assembly and inspection.

Having developed microprocessor systems to a level where they are cost-effective elements of many products, these industries must invest in sensing technology to cash in on the possibilities of intelligent control. The brains and hands exist today – in many cases the eyes do not.

And this affects not just the products a company offers. Sensing technology is a key component of the manufacturing process, and the most successful manufacturing and assembly operations of the future are likely to be improving their yield and efficiency by the innovative application of novel sensing techniques.

Alec MacAndrew, physics group, PA Technology.

INSIDE

Insight cover. Picture from the optical group at Schlumberger's transducer division highlights the major benefit of optical sensors – immunity from lighting strokes and electromagnetic interference.

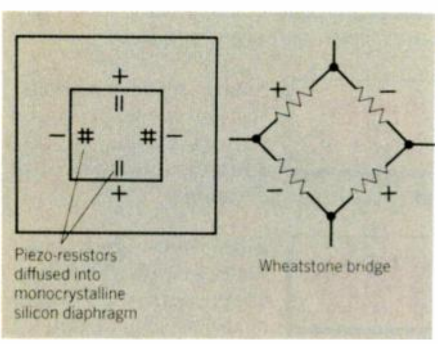
 Industry Insight is edited by Geoffrey Shorter and designed by Alan Kerr. Potential contributors should make immediate contact on 01 661 8639, send an outline by fax on 01 661 8913, or mail articles to Industry Insight, *Electronics & Wireless World*, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS. Potential advertisers contact Paul Kitchener 01 661 8640.

SILICON SENSORS IN TRANSDUCER TECHNOLOGY

Although inherently a brittle material, silicon has a tensile strength and hardness comparable with that of steel. For transducer manufacture, a remarkably robust silicon sensor can be achieved by making it very small, so that scratches and other surface imperfections which might instigate breakage are effectively eliminated. Silicon has the added advantages of a high stiffness: weight ratio and — if single crystal — virtually zero creep. It can operate at around 400-500°C so that other factors such as on-chip circuitry eventually set the temperature limit.

Semiconductor transducers using a silicon piezoresistive diaphragm are now so well-established for pressure sensing, especially in aerospace applications, as to warrant the label 'conventional'. Four piezoresistive strain gauges are diffused into the surface of the silicon connected in a Wheatstone bridge configuration. A constant current is fed to the bridge. The diaphragm distorts under the applied pressure, varying the conductivity of the strain gauges and unbalancing the bridge with an output voltage in direct proportion to the change in the applied pressure.

Two opposing resistors may be arranged perpendicular to the stress induced in the diaphragm when pressure is applied and will register say a positive change in resistance. The others may be parallel to the stress and produce a corresponding negative change. Because the bridge is configured with negative and positive components, it is possible to compensate for temperature variations and other common-mode effects occurring in the sensor diaphragm.



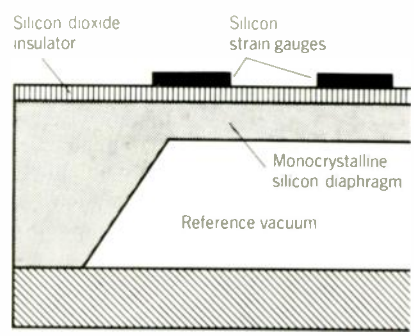
Conventional semiconductor silicon pressure sensor has four piezo resistive strain gauges diffused into the surface of the pressure diaphragm and connected in a Wheatstone bridge.

> Experience gained in machining and manipulating silicon has encouraged the transducer manufacturing industry to investigate ways of adapting silicon to its own technology.

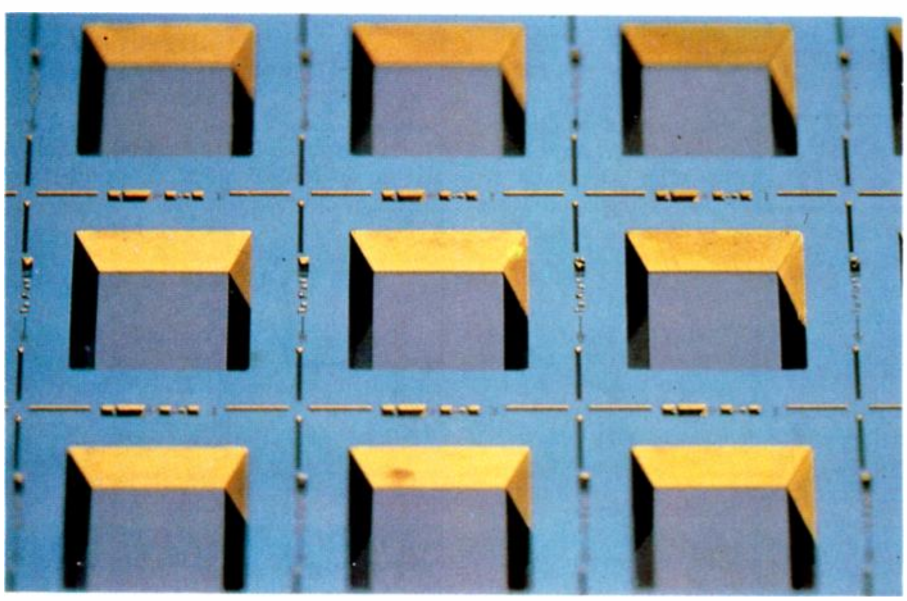
Accuracy of the electronic readout is dependent, however, upon the stability of the piezoresistors. These components have a maximum operating temperature of about 130°C for reasonable accuracy, because the current leakage between the strain gauges and the silicon diaphragm increases dramatically as the temperature rises above this level. The circuitry can also be adversely affected by electromagnetic interference. The application of this type of pressure transducer is severely restricted by these two factors.

To get around the problem of drift caused by a high operating temperature, a modified version of this transducer involves interposing a layer of silicon dioxide insulator between the strain gauges and the silicon diaphragm (see diagram). In this design, the strain gauges are also of silicon. Silicon-on-insulator chips improve the linearity, repeatability and stability of the transducers. Such pressure transducers will be able to operate at temperatures up to 250-260°C and are basically designed to be resistant to electromagnetic interference and lightning spike.

A third generation of silicon sensor operates on the same principle as the vibrating cylinder sensing technology, characterized by high accuracy and long-term stability of measurement, as used for example in aerospace absolute air pressure transducers. The



By interposing silicon dioxide between strain gauges and diaphragm, temperature limit is raised to 250°C.

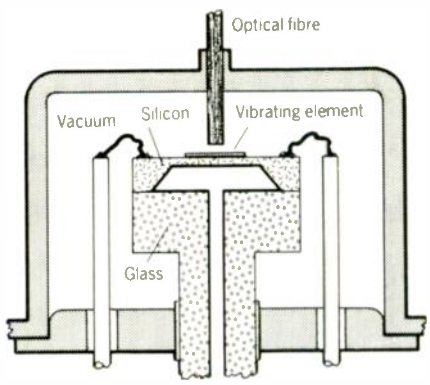


Diaphragms etched into silicon wafer will be cut into pressure sensors less than 4mm square (Novasensor).

silicon version of this resonant sensor (below) incorporates a resonant structure bonded at both ends to bridge supports formed in the surface of the diaphragm. The diaphragm encloses a reference vacuum maintained on the resonator side of the diaphragm while gas for pressure measurement is applied to the other side.

The resonator carries one electrode of a capacitor, the other electrode being mounted above it on the enclosure. An alternative voltage applied across the electrodes makes the structure resonate at its natural frequency.

Applied pressure causes the diaphragm to bow, stretching the resonator and changing



A bridge structure incorporated into the surface of the silicon diaphragm is made to resonate at its natural frequency with electro-static excitation. Pressure applied to the diaphragm bows and stretches the resonator, causing its frequency to change.

its resonant frequency. The system reads the change of frequency piezoelectrically and feeds it into a phase-locked loop to the electrostatic drive. This feedback signal is used to alter the excitation frequency in such a way that the beam continues to oscillate at its new natural frequency. A fraction of the feedback signal is picked off to provide a digital output proportional to pressure.

In a current development of this resonant sensor principle, the on-chip circuitry is eliminated, and fibre optics provide a frequency-related output for measurement. The allowable operating temperature determined by the fibre optics is conservatively estimated to be in excess of 350°C. The design benefits from the fact that fibre optics systems are intrinsically safe and consequently well suited to application in potentially explosive and otherwise hazardous environments.

In this design, the resonator is excited optically. The top of the resonator is chromium coated for reflection and the end of an optical fibre positioned a predetermined distance from this surface.

One laser diode generates a modulated light signal to provide excitation in the optical circuit; another produces a continuous signal to monitor the change in the gap between the resonator and the fibre end,

MICROMACHINING OF SILICON SENSORS

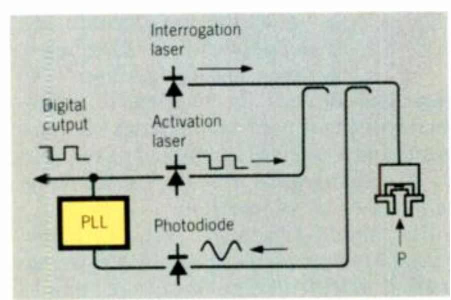
Micromachining allows silicon to be made into mechanical sensing devices that are almost as small as the microelectronic chip for which the technology was originally devised. It is also possible to manufacture many sensors simultaneously, thus spreading the cost of production and making individual sensors significantly cheaper. The micromachining process chemically etches silicon to form wells, holes, bridges, cantilevers and numerous other structural features in the base material. Virtually any mechanical shape of design of sensor can be made using combinations of these structural elements.

Monocrystalline silicon is normally used. Although brittle, this material is harder than most metals and extremely stiff. Furthermore, because of the single-crystal structure, the silicon exhibits no creep and hence no hysteresis. Micromachining involves heating the silicon wafer to between 800 and 1200°C in an atmosphere of steam to produce a thin layer of oxide on its surface. An organic polymer photoresist is then deposited over the oxide surface, a photomask is placed in contact with it, and the polymer exposed to ultraviolet light. Rinsing the wafer in a developing solution removes either the exposed or unexposed areas of polymer, depending on the photoresist type. Hydrochloric acid removes the exposed oxide but not the remaining photoresist or any of the underlying silicon. The remaining photoresist is removed by hot sulphuric acid to leave an oxide pattern on the silicon surface. This pattern is either a positive or negative version of the pattern on the photomask.

During subsequent chemical etching, the silicon surfaces not covered by the oxide are attacked to form deep, three-dimensional pits. Isotropic etchants excavate the silicon crystals at the same rate in all directions and form gently rounded edges. Anisotropic etchants – also known as crystallographic or orientation-dependent etchants – remove silicon at different rates in different directions and form well-defined shapes with sharp edges and corners.

which changes as the diaphragm distorts under applied pressure. The two transmitted ature measurements, it could be appropriate where high accuracy is requied — for instance for temperature compensation of the optical pressure sensor described earlier.

For vibration measurements, a large inertial mass could be formed on the end of a cantilever beam incorporating a resonant signals need to be of different wavelengths to minimize crosstalk. These two light signals are combined in an optical coupler and transmitted via another coupler to the resonator. The return signal comes back through the second coupler to a detection diode and, via a bandpass filter, back to the oscillator diode in a phase-locked loop. An output signal is taken from the loop for frequency measurement.



In the latest version of the resonant silicon pressure sensor, fibre optics excites the resonator and provides the frequency output for measurement. There is no on-chip circuitry and the allowable operating temperature determined by the fibre optics is estimated to be in excess of 350°C.

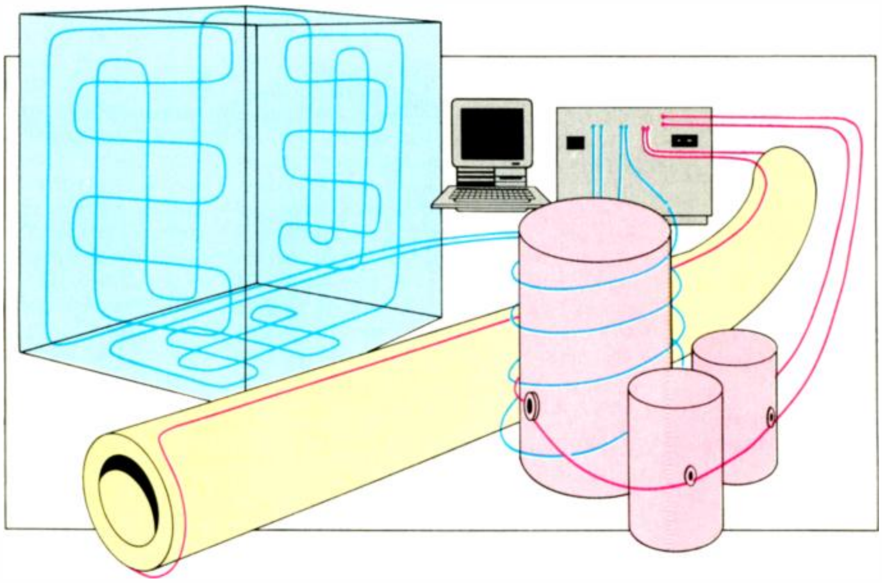
As the distance between the reflective surface and the fibre end changes, the intensity of the returning signal alters from dark to light to dark and so on. So the return signal is sinusoidally modulated on a phase scale of half a wavelength. A small change in the reflective gap as the diaphragm bends under applied pressure creates a corresponding change in the light intensity, which is what the optical system senses.

This optical sensor system has been demonstrated and work is now in hand to engineer a rugged interface unit which will withstand the difficult environmental conditions that this type of sensor is likely to experience. The next step is to apply the same principle to other measured parameters; there is no shortage of ideas in this direction.

In the case of temperature measurement, for example, the resonator could be a cantilever, free at one end. The stiffness of the silicon cantilever will change with temperature and can be measured. Although this would not be cost-effective for many temperstructure. All conventional accelerometers depend on such an inertial mass for measurement. As the sensor is accelerated, a movement of the mass relative to the sensor body occurs and a time-dependent stress is imposed on the resonator. This stress alters the resonant frequency which can be measured much as before.

It has been suggested that the design could be adapted for chemical sensing by coating the resonating structure with a chemically sensitive material. As the monitored chemical passes the sensor it will bond to the resonant structure and alter its mass and produce a change of resonant frequency.

Cost will be a major factor in determining how widely these silicon sensor systems will be applied. For the time being, their potential is seen mainly in those severe duty applications where high accuracy, reliability and long-term stability are the main criteria.



FIBRE LOOP THERMOMETRY

The driving force behind the development of distributed fibre sensors has been the need for inexpensive, compact equipment used in industrial environments and with sufficient projected reliability to allow regular monitoring for long periods without intervention.

Distributed fibre-optic sensors allow several hundred points (typically 400 in the case of DTS-II) to be measured simultaneously on a single optic fibre. This far exceeds the capacity of other schemes to multiplex many fibre-optic sensor outputs onto a single fibre. The equipment is thus shared between a large number of measured points and therefore the cost of the equipment per measured point can be very low. This is particularly the case with DTS II, where up to four fibres can be addressed by a single instrument, increasing the number of measurement points accessible by a single instrument to 1600. In many practical cases, then, the cost of the measurement is dominated by the cost of the fibre and its installation. Here again, the distributed approach provides an advantage since only one fibre needs to be installed to monitor the temperature of many places.

New instrument measures temperature at hundreds of points along a single fibre simultaneously, to avoid breakdown, improve efficiency and save lives

Instrumentation

The DTS-II system consists of one or more loops of optical fibre, possibly cabled, the DTS-II instrument itself and a desk-top computer for control – a colour version of the HP-300 series made by Hewlett-Packard. The fibre is in thermal contact with objects whose temperatures are to be measured, deployed in the DTS-II system, as a loop, both ends returning to the instrument.

The DTS-II contains all of the optics and electronics required to perform the measurement and a certain amount of data processing. Specifically, the source is a GaAs injection laser delivering pulses of 1 W peak power and 40 ns duration. Directional couplers allow the forward-travelling probe pulse to be separated from the backward-travelling backscatter signal, whilst fibre switches select the fibre loop to be measured and the fibre end. The returning signal is filtered by an interference filter, detected by a silicon avalanche photodiode, and to a transimpedance preamplifier followed by further stages of amplification. The signals are digitized by a high-speed converter circuit able to sample the entire backscatter return from each probe pulse at 50 ns intervals. Noise on the digitized waveform is reduced by digital averaging and the result sent to the controller for further processing.

Measurement of the fibre from both ends allows the effect of fibre loss to be determined and thus eliminated from the temperature information. As a result, the instrument is largely immune from errors caused by loss at bends in the fibre or connectors. Fibre can be added to, or removed from, a measurement loop and after a few minutes of re-programming the sensor system is ready to function.

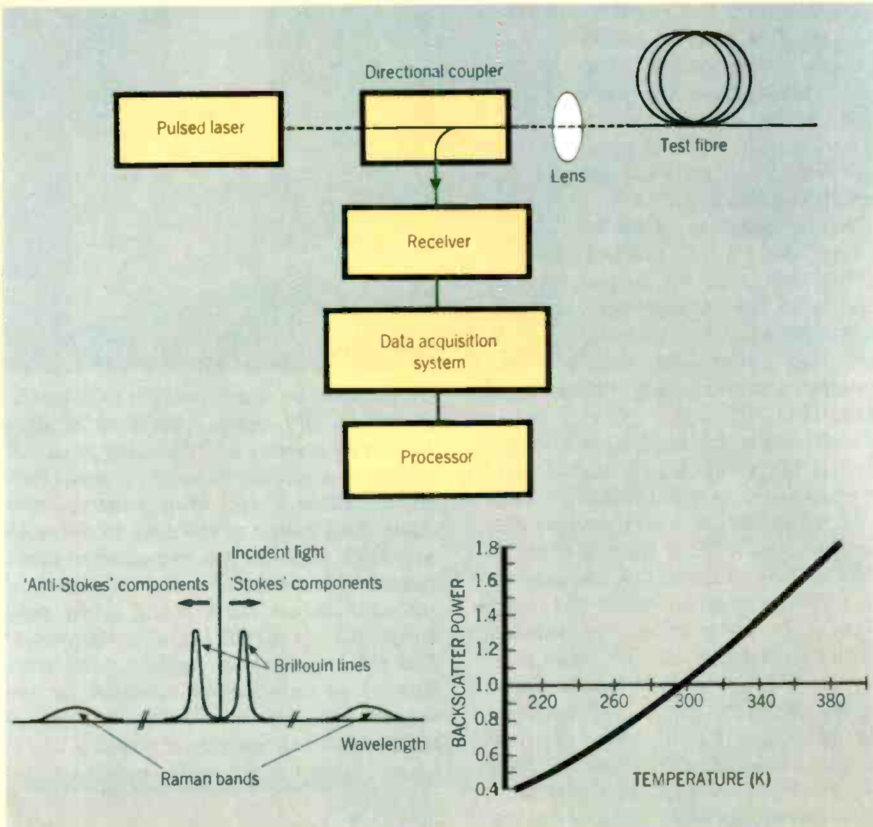
Performance criteria

The performance of distributed sensors is judged not only on their accuracy, measurement range and measurement time but also on the length of fibre they can cover and their spatial resolution. The maximum length of fibre is determined by the signal-to-noise ratio required to give a required temperature resolution after signal processing. Thus as the total loss in the measurement loop increases with increasing fibre length, so the quality of the measured signal is degraded and the uncertainty on the output increases.

Spatial resolution on the other hand describes the ability of the instrument to distinguish adjacent points in the fibre. Since DTS-II is the first commercial distributed sensor, no precedents exist and we have chosen, arbitrarily, to define the spatial resolution as the distance over which an abrupt temperature transition along the fibre appears to be spread, measured between 10% and 90% points. The spatial resolution should not be confused with the sampling interval: it is possible to sample the backscatter waveform at far higher frequencies than the bandwidth of the analogue electronics. However, according to sampling theory, no further information is obtained, once the sampling frequency has exceeded twice the bandwidth. DTS-II has a spatial resolution of 7.5 m and a sampling resolution of 5m.

In a system where the measurement accuracy is limited by the signal-to-noise ratio, the measurement or integration time will vary as the square of the accuracy required. However, criteria specific to distributed sensors also impact the measurement

PRINCIPLES OF OPERATION



An optical time domain reflectometer typically consists of a laser source, a directional coupler connected to the fibre under test, an optical receiver, followed by further electronic circuitry.

A short, high-intensity optical pulse is launched into the fibre and a measurement made of its backscatter as a function of time. The signal consists of light scattered during the progress of the pulse down the fibre and re-captured by the waveguide in the return direction: it takes the following form as a function of the position z of the scattering element dx:

$$P(z) = \tfrac{1}{2} P_0 W v_g \alpha_s S \exp \int_0^z -2\alpha \, dx$$

where P_0 is the power launched, W, the pulse width, v_g the group velocity. Here α_s and α are the scattering and total losses, respectively, and both can be functions of position along the fibre. S is the capture fraction i.e. that proportion of the scattered light collected by the optical system. Of course, the measurement position z is determined by the time for the optical pulse to travel the distance between the launching end and z and return.

To use optical reflectometry in a distributed sensor, the scattering loss[1] α_s, the local capture fraction S (which both affect the signal directly) or the local fibre attenuation[2] α must be functions of the quantity to be measured – and preferably of nothing else! Most of the results reported have involved the measurement of temperature although in principle other measurands can also be addressed and the detection of magnetic fields has been reported[3].

Modulation of scattering loss. The first distributed fibre-optic temperature sensor demonstrated[1] used a special fibre having a liquid core. In the core, increasing temperature results in greater molecular agitation and thus in a larger scattering coefficient, the sensitivity of the scattered signal being of order 0.5%/K. This resulted in a distributed temperature sensor able to resolve around 0.1K over a distance of 100m with a spatial resolution of 2.5m after averaging 1000 pulses. A resolution of 1K, with 1m spatial resolution over 100m of fibre, was achievable with 1000 pulses, a measurement time well below 1s. This performance is the best so far reported but the approach is out of favour since liquid-filled fibres are inconvenient to work with, have limited temperature range and unproved lifetimes. The sensitivity of the scattered signal to temperature in glasses is orders of magnitude lower and different means are thus required for solid fibres.

Inelastic scattering. The scattering coefficient in optical fibres is caused principally by Rayleigh scattering and is attributable to density and composition fluctuations frozen in to the material during the drawing process. This type of scattering is largely independent of ambient temperature provided that the thermo-optic coefficients of the fibre constituents are similar. However, as is shown schematically, the scattered light spectrum also contains a small contribution to the scattered power from Raman and Brillouin spectral lines which originate in thermally driven molecular and bulk vibrations, respectively. The intensity of these lines is temperature sensitive and the finite sensitivity of the total scattered signal in solid fibres is largely attributable to the contribution of Brillouin and Raman scattering. By selecting only one of these parts of the scattered light spectrum, the sensitivity of the measured signal to temperature can be greatly enhanced.

In practice, the Brillouin lines are shifted by only a few tens of GHz from the incident radiation frequency. This puts demands on the linewidth and frequency stability of the source and filter which are presently incompatible with the use of semiconductor lasers – preferred for their small size, low cost and good reliability. The Brillouin scattering approach is therefore not judged to be the most suitable at present.

In contrast, the Raman spectrum is well separated from the incident wavelength and can be readily separated by means of standard optical filters. Unlike that of free atoms and molecules, the Raman spectrum of high-silica glasses consists of very broad bands with a 200cm^{-1} wide band centred around 440cm^{-1}. Some of the details which can be used in conventional Raman spectroscopy are thus lost to us in glasses. However the information is sufficient to obtain the temperature distribution along the fibre[4] and to eliminate spurious effects caused, for example, by fibre attenuation.

In the York DTS-II, the shorter-wavelength Raman band (the anti-Stokes band) is used to obtain the temperature information since it has a far higher temperature sensitivity than the longer wavelength. Stokes. band.

The Raman approach provides a practical solution to a number of measurement problems and forms the basis for the York sensor. One of its main advantages is that it can be used with standard multimode telecommunication fibre, which is readily available and relatively inexpensive.

Two other approaches have also been proposed.

Modulation of the fibre loss. If the loss of the fibre varies with the measurand of interest, this should be detectable by reflectometry.[1] This has been demonstrated at Southampton University by inserting thin colour-glass filters at selected positions in the fibre and more recently in fibres doped with rare-earth ions,[2] providing a sensitivity of loss to temperature via the shift of absorption bands with temperature. In either case, the effect of the temperature on loss may be separated from other causes by referencing the measurement to another wavelength at which the loss insensitive to temperature.

The main drawback of the loss-modulation approach is that the number of sensing points is limited by attenuation induced directly by the measurand: if the fibre is sensitive, its loss will sometimes be high, which will then leave little power to probe the following point. In practice, about 10 hot-spots can be measured simultaneously, which could be sufficient in a number of applications. In other applications, it is desirable to use approaches which do not require the fibre loss to be high; this is the case when the scattering loss, the capture fraction or the polarization of the light is modulated.

Polarization effects. In single-mode fibres, the backscatter signal carries information on the evolution of the state of polarization to the scattering point and back[5]. This approach has been used at the Central Electricity Research Laboratory to detect magnetic fields[3] via the Faraday effect but never taken much beyond demonstration owing to difficulties in separating the information of interest from a number of spurious effects which mask the desired signal. Whilst it could undoubtedly be used for obtaining temperature distribution information, the practical difficulties associated with it have, to date, precluded its use.

1 A.H. Hartog. *J. Lightwave Technol.* 1983, vol. VT-1, pp498-509.

2 M.C. Farries et al., *Electronics Letters* 1986, vol. 22, pp418-9.

3 J.N. Ross, *Electronics Letters* 1981, vol. 17, pp596-597.

4 A.H. Hartog, et al. *Electronics Letters* 1985, vol. 21, pp.1061-3.

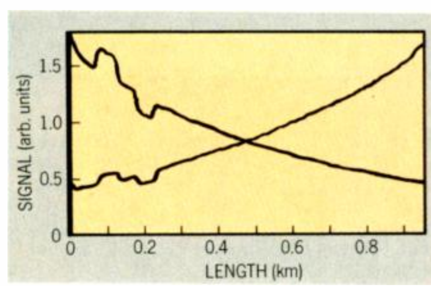
5 A.H. Hartog et al. Proc 6th European Conf. Optical Communication (post-deadline session) York, UK 1980.

time since, as the required fibre length increases, so too does the system loss and the signal-to-noise ratio is thus degraded. Similarly as the spatial resolution is made finer, the pulse width of the source must be reduced and the receiver bandwidth must be increased, which degrades the system noise.

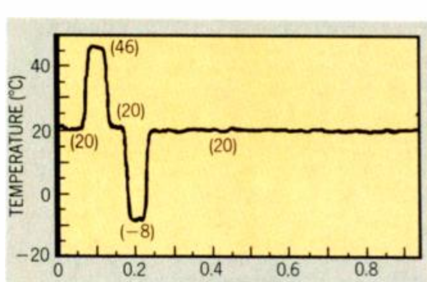
There is therefore a trade-off between the various performance criteria and, for a fixed accuracy in the measurement, the integration time increases rapidly with improving spatial resolution and increasing total loss of the sensing fibre.

The DTS-II is able to measure fibre loops of 2km in 12 seconds, with an uncertainty on the temperature of ±1°C (peak) and with a spatial resolution of 7.5 m. This represents a round trip loss of about 12dB. If more than one fibre loop is measured, measurement time increases in proportion to the number of loops. In many cases, the ability to measure several separate fibre loops gives a better overall system performance than increasing the fibre length and leads to a reduced measurement time per point addressed. In addition, a degree of redundancy can be introduced into the system so that all measurement capability is not lost if a fibre is broken.

DTS-2 software allows the user to programme up to 100 zones – sections of fibre defined by starting and finishing positions and given a specific name (e.g. 'main boiler', 'escalator X' etc) to help the operator relate the location of the zone to the readout. Each zone has pre-programmed alarm levels which are tested by the measurement software and an alarm raised if any zone temperature is outside is limits. Many users find this approach to displaying the large amount of information acquired by the instrument easier to use than a display of temperature as a function of position.



Raman backscatter waveforms measured from each end of a 1 km sensing fibre. The trace measured from the second end has been time-reversed so that positions on the horizontal axis correspond to the same point in the fibre in both cases. The effect of heating a length of fibre (100m from the first end) can be seen as an increase in the scatter return. Likewise, the second fibre about 200m from the origin has been cooled with respect to the rest of the fibre and shows a decrease in signal at that point.



The temperature distribution obtained from processing the curves shows the fibre loss has been eliminated and the temperature information is clearly visible. The temperature trace is flat in all regions where the fibre was held at uniform temperature.

Applications

The DTS system has a vast range of applications; almost certainly some of these will not become apparent until the technique is well known. For the sake of illustration, some of the applications follow:

Electricity supply industry. DTS is ideally suited to locating hot spots since it can provide continuous coverage of the whole of the transformer windings. The present performance is adequate in most respects although improvements in spatial resolution are desirable.

Another application in the same industry is the monitoring of large generators, where the risk is primarily from blocked cooling pipes. The very high spatial resolution required can be obtained by coiling the fibre into a number of separate sensing coils to monitor each cooling pipe.

In thermal power stations, DTS could monitor high pressure steam pipes for leaks which are extremely hazardous as well as disruptive.

Process industry. Monitoring of long thermal curing process, where temperature gradient along a curing oven is important. A major American company using DTS to monitor one of its production processes estimates to have saved many times its value in its first six months of operation from improvement to yields.

The technique can be used for monitoring machinery to detect over-heating before damage to the equipment has occurred.

Pipeline monitoring. Detecting leaks of fluid, by the cooling that results from the expansion of the gas leaving the pipeline.

Failure of a viscosity-reducing heating system or of the insulation can cause a pipeline to seize up, a situation which is costly to rectify, in addition to the cost of any loss of production incurred.

Buildings and tunnels. DTS has application inside buildings and tunnels as a fire-alarm system. Fires in railway tunnels frequently start in cable trays and can smolder for a long time undetected before a fire breaks out. A fibre installed along the tunnel could detect the outbreak of a fire very quickly, wherever it occurs, as well as the overheating before a fire actually occurs.

DTS can also measure the temperature in areas to provide inputs to heating and air conditioning systems.

The fire alarm and environment monitoring functions can be combined in a single system. A major advantage of the DTS in these applications is that the amount of wiring is reduced considerably. With dedicated software, it should also be possible to reduce the incidence of false alarms since an unusual condition can be rapidly qualified as a real emergency or as equipment malfunction. A break in the fibre, for example, can be identified by the processing software as a fibre break (and its location given) and not as a fire alarm.

Future prospects

The performance of existing distributed fibre-optic temperature sensors is already sufficient for many applications, but falls short of the requirements for many others. In particular, the spatial resolution will need to be improved for many industrial applications and work is progressing in this area. Eventually, this will involve the development or adaptation of more suitable sources, refinements of the electronics and possibly of the fibre itself. It is expected that a spatial resolution of 1m over 1km of fibre, with 1K accuracy and measurement times of a few seconds will be achieveable in the near future.

Pipeline monitoring will demand extreme range and systems spanning about 20km of fibre should be achievable without unduly sacrificing performance in other respects. Progress is also expected in the methods used for processing the signals; for example beyond a spatial resolution of 1m or so, measurement in the frequency domain may offer useful performance advantages.

In the longer term, attention will turn to the measurement of other physical parameters and almost certainly this will involve the development of special fibres with tailored sensitivity.

York is working closely with several large users and system houses for OEM applications of this technology and welcomes further relationships of this nature.

SINGLE-ENDED MULTI POINT THERMOMETER

Cossor readies single-ended distributed temperature sensor for marketing later this year

Distributed fibre temperature sensors rely on the measurement of a temperature-dependent anti-Stokes backscatter signal together with a calibrating signal (Stokes or Rayleigh backscatter) to cancel the effects of fibre attenuation and splice loss. Since these scattered signals are at different wavelengths they are subject to slightly different values of fibre attenuation and the cancellation is inexact, leading to significant measurement errors, particularly at long distances.

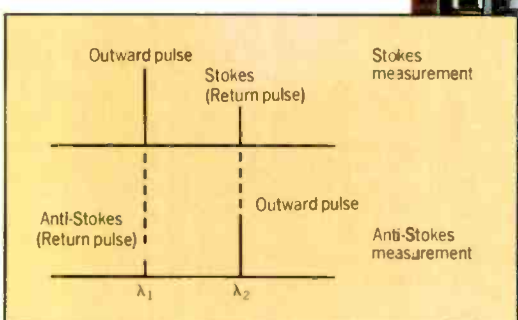
Cossor Electronics are currently developing a system under licence from CEGB to overcome this problem by using dual laser sources. The laser wavelengths λ_1 and λ_2 are chosen according to

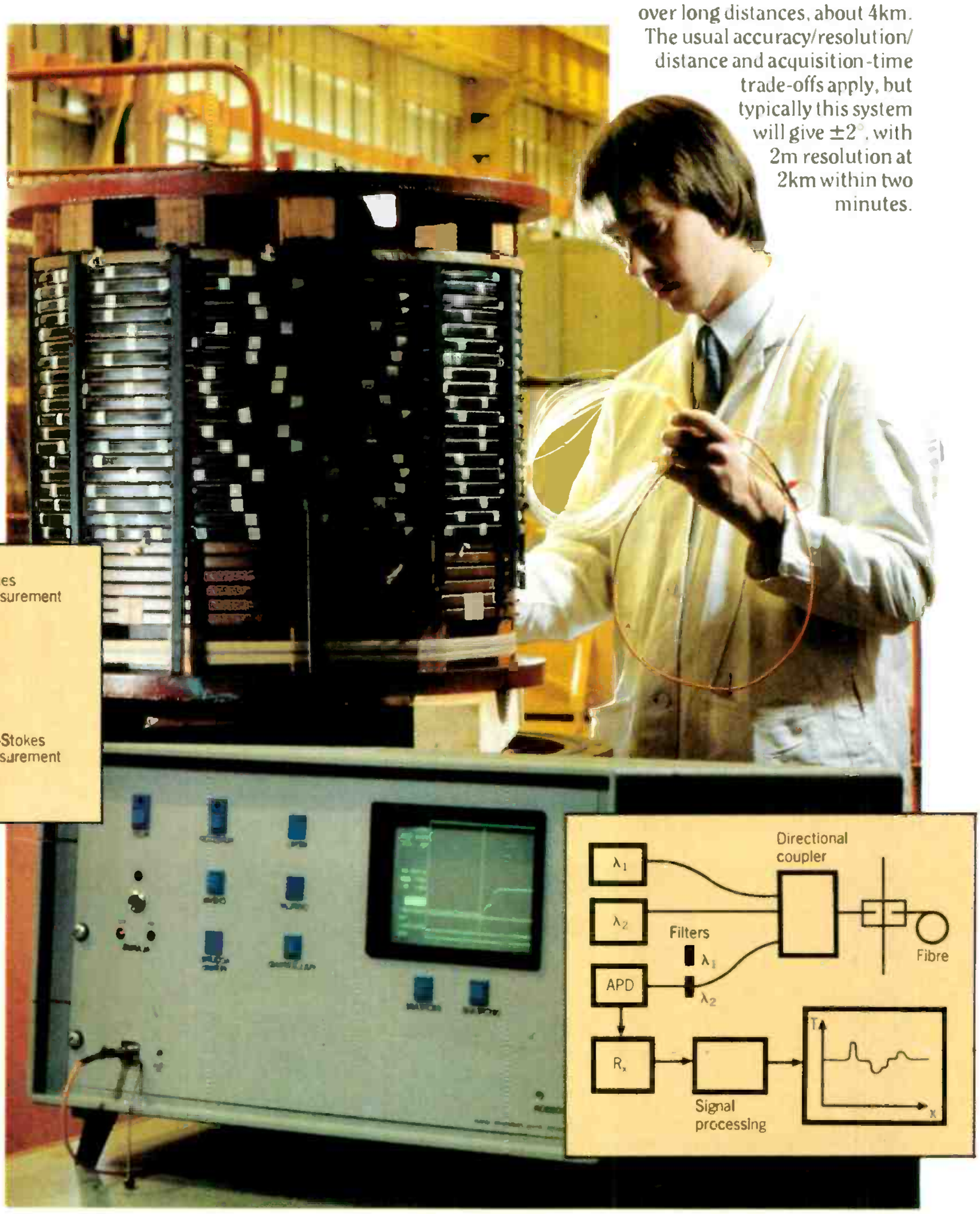
$$\frac{1}{\lambda_1}-\frac{1}{\lambda_2}=\nu$$

where ν is Raman wavenumber shift. Using the source at λ_1, the Stokes scattered light is measured at λ_2; and using the source at λ_2 the anti-Stokes scattered light is measured at λ_1. In both instances light passed an equal distance through the fibre at each wavelength: outward at one wavelength and returning at the other. The total attenuation is therefore the same for both measurements, irrespective of the spectral attenuation properties of the fibre. A major advantage that results from this is that the Cossor system requires access to only one end of the sensing fibre and will remain accurate irrespective of any changes in cable characteristics.

A second key feature of the system is that the receiver is based on the use of a photon-counting avalanche photodiode using techniques originally developed for the OFL119 optical fault locator. This offers considerable sensitivity advantages over conventional transimpedance receivers and allows the system to operate with superior spatial resolution (1m), and industry-standard multi-mode fibre (50/125) over long distances, about 4km.

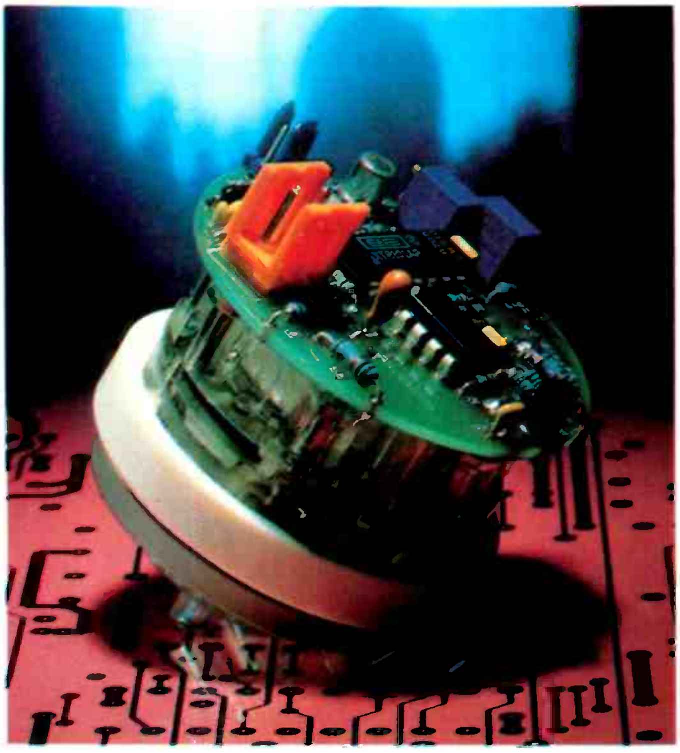
The usual accuracy/resolution/distance and acquisition-time trade-offs apply, but typically this system will give ±2°, with 2m resolution at 2km within two minutes.





FUEL CELL GAS SENSORS

Over the past 10 to 15 years there has been much government legislation throughout the world concerned with health and safety at work and atmospheric pollution control. This has caused a rapidly growing demand for a range of chemical gas sensors and associated control instrumentation. This demand for gas sensing equipment has been further reinforced over a similar period in the area of general industrial process control and in particular flue gas analysis for control of large combustion plant for energy conservation.



Electrochemical gas sensors have proved particularly successful in meeting the requirements of these various applications. Such sensors provide reliable, stable and accurate measurements over long maintenance cycle periods and can be manufactured in small, robust and relatively low-cost units, which are equally suitable for either portable and personal safety equipment or fixed monitoring installations.

Previous oxygen sensors of the diffusion barrier type (see panel) have used very thin plastics membranes, which not only have handling and stability problems, but inevitably result in very high temperature and pressure coefficients, which limit the usefulness of the device. CTL sensors take a radically different approach by using a gaseous diffusion barrier which can take the form of a simple capillary. This is not only extremely robust and stable, but entirely different diffusion laws apply, with the following practical consequences.

Low temperature coefficient: for many practical purposes temperature compensation is unnecessary (see curves)

Legislation around the world is the driving force behind the rapid growth in the electrochemical gas sensor market

Sensors measure volume percentage of gas directly.

Low pressure coefficients: typical values for standard oxygen sensors are about 4 to 5% signal change per atmosphere.

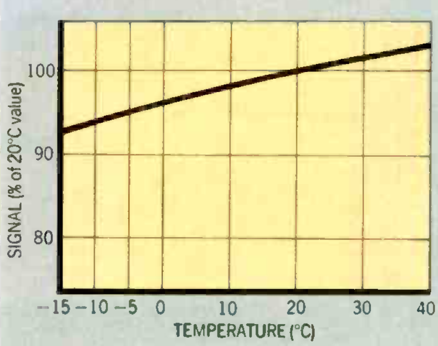
Signals vary non-linearly with gas concentration and follow the $S = K\ln(1-C)^{-1}$ law where S is the signal, C the fractional concentration (0.209 oxygen in air), and K a constant. For low concentrations, below a few percent, the signal is essentially linear. When oxygen sensors are calibrated in air, and the response assumed linear in the range 0 to 20.9%, the deviation from linearity is as illustrated. Above 25% oxygen the deviation becomes increasingly significant, and may be compensated electronically using a suitable linearizing circuit.

For many applications the gaseous diffusion barrier will comprise a nitrogen "carrier" gas. The diffusion coefficient of oxygen through the barrier varies, to a first approximation, inversely as the square root of the mean molecular weight of the carrier gas, and recalibration of the sensor may be required where the carrier gas molecular

MARKETS

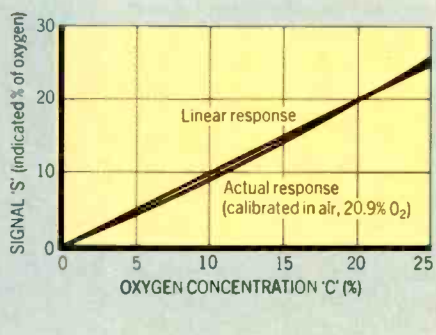
Electrochemical sensors are being widely adopted to satisfy a growing demand for reliable, low-cost gas-measuring devices in safety and process control applications. Four factors have contributed to this increasing demand for gas sensors.

- Health and Safety at Work Acts, requiring sensors for a wide range of gases.
- Energy conservation sector, requiring oxygen and carbon monoxide sensors for combustion efficiency monitoring.
- Offshore oil and gas exploitation, requiring hydrogen sulphide emission detection from "sour" wells.
- Pollution control, demanding sensors for monitoring emissions of carbon monoxide sulphur dioxide and oxides of nitrogen.



The oxygen sensor has a low temperature coefficient over the range −15 to +40°C Curve shows the signal as a percentage of the 20°C value.

Output signal of an oxygen sensor over the range 0 – 25% oxygen is non-linear, following the law $S = K\ln(1-C)^{-1}$. The curve is the oxygen sensor signal as a function of concentration in the range 0-25% oxygen.



SENSOR OPERATION

The principle of operation can be illustrated using an oxygen metal-air sensor as an example. The sensor comprises a metal anode, electrolyte and an air cathode, to which the diffusion of oxygen is severely restricted by a diffusion barrier.

At the air cathode oxygen is reduced to hydroxyl ions which is matched by an equivalent amount of metal oxidation at the anode and flow of electrons from anode to cathode via the external circuit. The diffusion barrier restricts oxygen access to the cathode such that all oxygen reacts as it arrives at the cathode where its concentration is essentially zero. In this condition:

oxygen diffusion flux ∝ oxygen concentration gradient

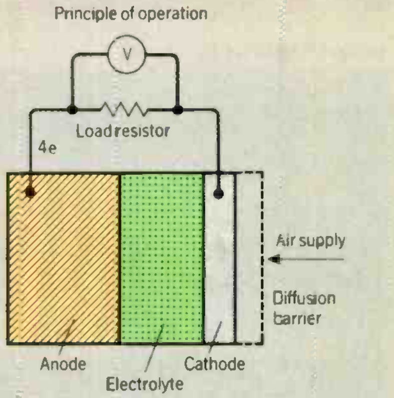
" ∝ partial pressure oxygen

The sensor will be operating in the limiting current' region of the current-voltage curve, when:

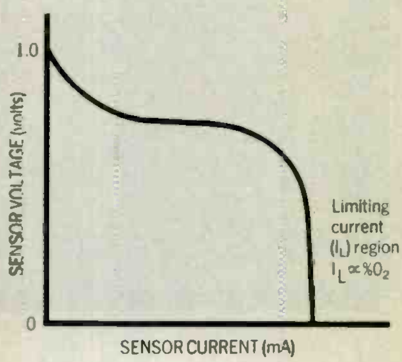
sensor current, i ∝ flux (O_2)

therefore i ∝ partial pressure (O_2)

There is then, a direct link between oxygen concentration and the sensor limiting current, which constitutes the signal from the sensor. With a known value of resistor across the sensor this can be read off as a voltage signal.



Anode reaction $2Pb + 4OH^- \rightarrow 2PbO + 2H_2O + 4e$
Cathode reaction $O_2 + 2H_2O + 4e^- \rightarrow 4OH$
Cell reaction $2Pb + O_2 \rightarrow 2PbO$



weight alters significantly.

The use of oxygen electrode technology as developed for fuel cells and metal/air batteries gives a cathode with a very high reserve of electrochemical activity. This ensures a high sensor stability over long periods of time. Typical sensor drift rates are less than 2% signal over six months.

The anode has been chosen to provide sufficient voltage for the sensor to be self-powered and to prolong storage life and ensure freedom from self-corrosion and gassing.

The operational life of the sensor is determined by the anode capacity and standard sensors are designed to achieve a minimum of 10^5 'oxygen % hours' – this amounts to at least six months continuous discharge in air at 20.9% oxygen, with typical lifetimes being nearer nine or ten months in practice. The active life is unaffected by six months storage off load, under cool, clean conditions.

All known failure modes result in loss of signal and for oxygen deficiency applications the sensor is therefore fail-safe.

The principle of sensor operation may be used to measure any gaseous substance that can be made to react electrochemically at a suitable electrode. In addition to oxygen sensors, CTL have been developed cells to measure carbon monoxide, hydrogen sulphide, sulphur dioxide, oxides of nitrogen and chlorine. Unlike oxygen sensors, most of these gases undergo anodic oxidation at the sensing electrode and are accompanied by oxygen reduction at the counter electrode. Such fuel-cell sensors have no directly consumable – and therefore life limiting – components: life is determined more by factors such as seal and electrode degradation, not as easily quantified as for the oxygen sensor. Field experience has indicated a life expectancy of several years, provided that the ambient conditions are not excessively aggressive.

A key feature of any chemical sensor development is the minimization of cross interferences when operating with multiple gas mixtures. This is largely managed in electrochemical sensors by

– development of specific sensing electrode catalysts and electrolyte systems

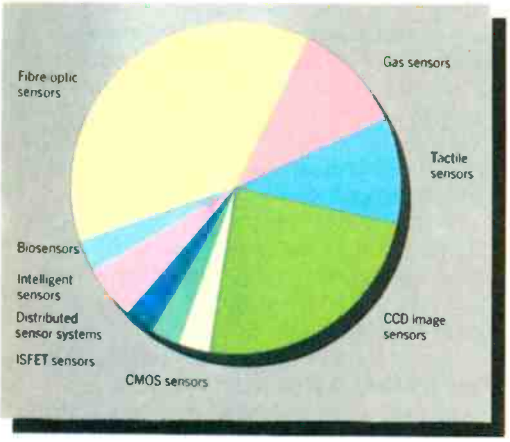
– control of the operating potential of the sensing electrode, and

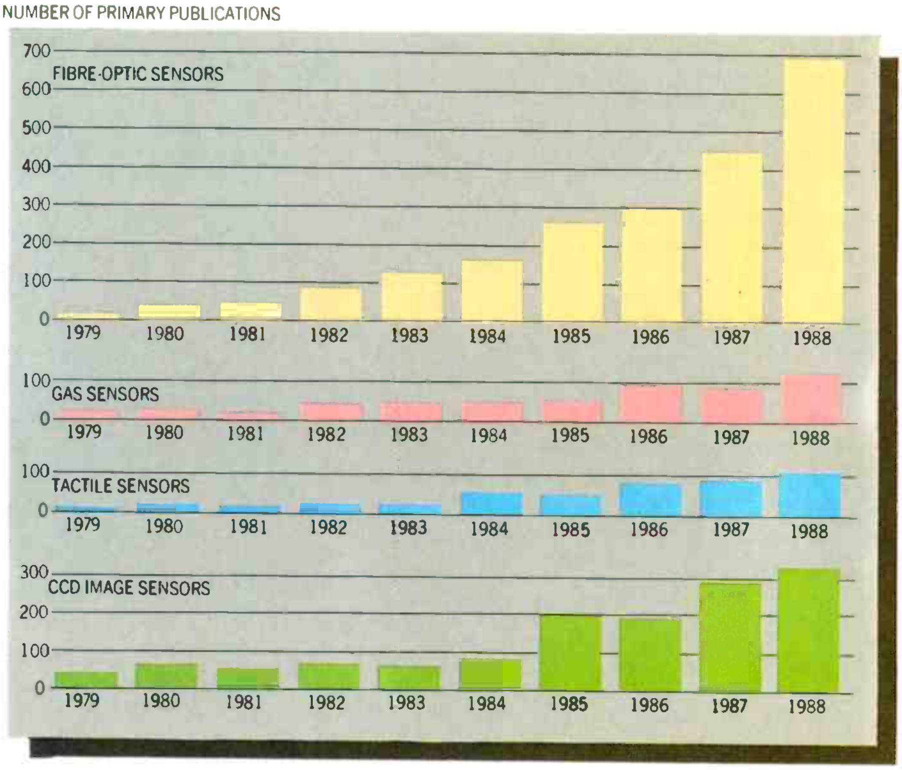
– use of chemical filters to selectively remove interfering gases.

A disadvantage of the last is limited life. A patented in-board gas filter concept, introduced for CTL sensor designs, can overcome this objection. Here the filter material is located between the sensor diffusion barrier and the sensor electrode where it only has to cope with the very low gas diffusion flux into the sensor, rather than exposure to the full, in-line gas stream of the sampling system.

Thanks to Dr Brian Hobbs of City Technology for help with the preparation of this article.

SENSING THE SENSORS





An analysis of the IEE's information services database on sensors confirms the rapid growth in primary publications on fibre optic sensing devices. Published work in this area now almost matches that of all other types of sensor added together, with an estimated 700 references in 1988.

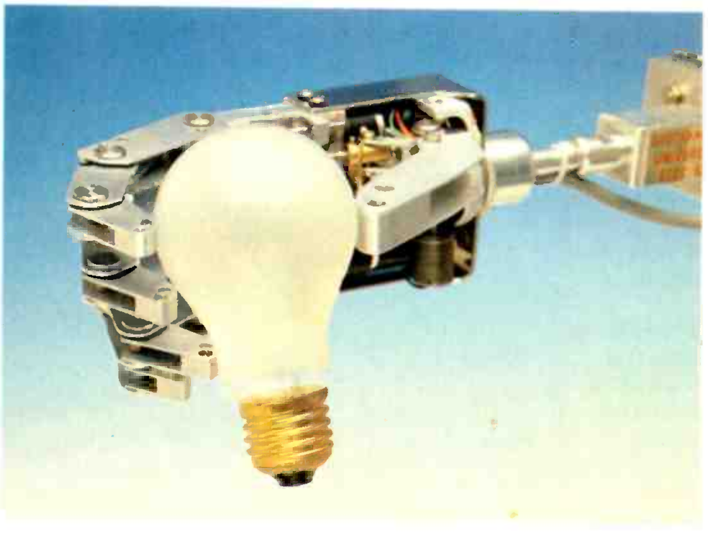
The database can be reached at Inspec Marketing, Station House, Nightingale Road, Hitchin, Herts, tel 0462 53331.

PROSTHETICS LEAD THE WAY

Early robots were dumb, mute, stupid devices that operated in highly structured environments. Everything they encountered had to be in the correct place and orientation. All the robot had to do was to reach out and pick up the object. The only difference between the robot and the machines they served was that a robot's actions could be modified more easily than those of a steel roller.

The latest generation of robots are smart. They have arrays of sensors that allow decisions to be made about what to pick up, what to do with the object and where to put it. Over 20 years ago, it became clear from research into artificial hands for limb replacement, that for a more sophisticated and life-like prosthetic hand, sensors are an important part of a system. The user, a person who has lost a hand in an accident or was born without one, will wish to use the prosthesis in an everyday environment, which seldom has structure built into it, so the hand must be able to grasp a wide range of objects of differing shapes, sizes and orientations.

Southampton's University has a family of anthropomorphic robots under development



The artificial hands available two decades ago were crude devices. They had one degree of freedom, that is, the thumb and fingers opened together. Many hands were, and still are, operated by a cable attached to the wearer by a harness across his shoulders. Flexing his shoulders opens the hand, a spring closes it. These systems are very versatile and allow for a delicate touch as the wearer can feel the object through the cable much like a driver feels the road through the steering wheel of a car. Although objects can be manipulated with ease and often skill using the harness, it is disliked by some users as the action is unnatural and uncomfortable. In addition some tasks are impossible to perform (such as changing a light bulb), as overhead movement opens the hand prematurely.

Electrically powered hands are compact and lifelike in appearance. They are not controlled by a cable but by amplifying the small voltages generated when a muscle contracts. An opposing pair is used: one muscle opens the hand the other side closes it. The disadvantage of this is that the mechanical feedback is lost. The operator has to rely on visual feedback to tell him when the hand is touching an object and when to stop closing the hand. If the object is obscured then grasping a delicate object becomes difficult.

A person without a hand is faced with the choice of a functional hand which has cables and is unsightly, or one that resembles a natural hand more closely but is limited in use. It was the gap that the Electrical Engineering department at Southampton decided to explore.

A four-degree-of-freedom hand is being developed. It is easy to use; the wearer supervises the hand and instructs it to open, close, hold, squeeze or release an object by the same type of muscle-contraction techniques as conventional electrical hands. The hand then adopts the correct posture and gripping forces to hold the object. For example, to pick up a kettle, the hand is opened and brought into contact with the handle. Sensors on the palm touch first so the fingers close in a fist. As the handle is quite narrow the fingers close a long way before the finger tips touch it. Once the fingers close beyond a minimum size the controller instructs the thumb to swing round to steady the kettle. The initial gripping force is low but if the kettle slips then sensors on the hand detect the vibrations and the grip tightens until the sliding stops.

The wide range of grips possible is due to the four motors giving the hand four degrees of freedom. Although the natural hand uses muscles in the forearm, so that a wide range of people can be accommodated, the prosthesis is made compact, with all the motors housed in the palm, inside the outline of a natural hand. The index finger moves on its own, thumb moves side to side and in and out, and the other three fingers move together. If one finger is stopped the others can continue to close so that they wrap round the edge of a curved object.

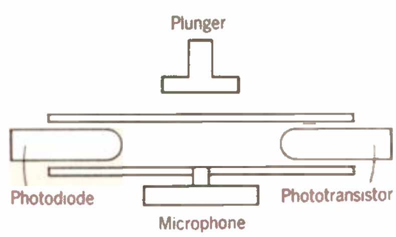
You can appreciate that the control relies heavily on the tactile sensors spread across the surface of the hand. These sensors can detect grip-force, touch-contact or object-slip. Over the two decades many designs of transducers have been tried but sensors have particularly strict specifications. Not only must they be compact, robust, easily fitted with low drift, but like all ideal transducers they must have low power consumption, must need little post-processing, and above all be very cheap.

The controller's design has progressed from a relay-drive fixed-logic processor to the adoption of the latest generation of microcontroller integrated circuits. The early designs for the hands were also bulky. They were cable driven from motors and the drives extended up to the elbow. The most recent has fixed links that don't stretch or break.

As the controller technology has become more advanced, more information can be gained and used for the sensors. The early devices gave simple on/off data about contacts on the hands; newer devices have an analogue output which is then digitized by the microcontroller. Even so, each sensor has its limitations and two of the more recent types are described to show some of the problems that prosthetics research produces.

The first sensor to combine both touch and slip transduction at a single site was developed at the University. The sensor uses an infrared beam 'shining' down a rubber tube, see diagram. When an external force on the leaf spring compresses the tube, the light received at the far end is reduced in proportion to the force. The basic principle has been employed elsewhere in commercial transducers. The crucial difference for prosthetics is that the tube connects to a microphone. An object sliding across the leaf sets up vibrations which are detected by the microphone and is interpreted as slipping of the object.

Earlier slip transducers had the microphone directly in contact with the surface of the finger. External noises also tended to be picked up by this arrangement. By placing the detector inside the tube the outside interference is attenuated to an acceptable level. A version of this sensor has been added to a commercial single-degree-of-freedom hand to test its performance.



A second sensor is based on a linear Hall-effect detector/amplifier integrated circuit. A magnetic field near the chip generates a differential voltage proportional to the field at the outputs. If a small plastics magnet is placed on a block of foam on top of the chip, compressing the foam causes the local field to the detector to increase and so the output voltage changes in response to the field.

This device not only detects the forces on it, but it also directly picks up the vibrations of an object sliding across its surface. So the force and slip information come from a single output. The mass of the magnet and the foam compliance tend to damp out the external vibrations as well as the high frequencies, leaving only those frequencies associated with slip. Stray magnetic fields are removed by common-mode rejection methods, and as the latest devices available are only a few millimeters long arrays of many devices are possible.

"There is a lot of work to be done before we see the likes of The Six Million Dollar Man and Robocop on the streets"

The project is a collaboration between many parts of the University. The mechanical design of the hand was principally the responsibility of the University's own central design service and it was constructed by the University's workshops.

Expertise in human touch was drawn on to see what could be learned from millenia of evolution. Other work includes software and finally trying it out on the prosthesis. So in common with much of modern research, the project does not lie exclusively in one department or even one faculty. A large campus with a wide mixture of disciplines allows for the best and most productive cross-fertilization of ideas.

Many publications on smart industrial robots suggest that the techniques developed for robots could be used for medical applications such as prosthetics. Although the two disciplines have a lot in common, solution in prosthetics are arguably harder to realise. Only some solutions are applicable to both. The prosthetics research at Southampton is now being applied to robotics and the information flow is in the opposite direction. A family of anthropomorphic robots for different applications is being developed. In addition the ideas for control are being used in the electrical stimulation of paralysed limbs for people with spinal injuries. However it is probably safe to say that there is a lot of work to be done before we see the likes of the "The Six Million dollar man" and "Robocop" on our streets.

by Peter Kyberd MSc, supervisor Dr PH Chappell, of the University of Southampton's electrical engineering department.

INTELLIGENT ODOUR DISCRIMINATING NOSE

It is the ultimate aim of research into odour characterization to develop a small portable instrument which can identify and quantify the constituents in a low-concentration gas mixture. The detection head would ideally comprise a large array of integrated sensing devices, with digitized outputs feeding via a microcomputer via a multiplexer, followed by a visual display unit giving results of the gas analysis. Progress toward this ideal is well advanced, according to Warwick University's Dr Julian Gardner.

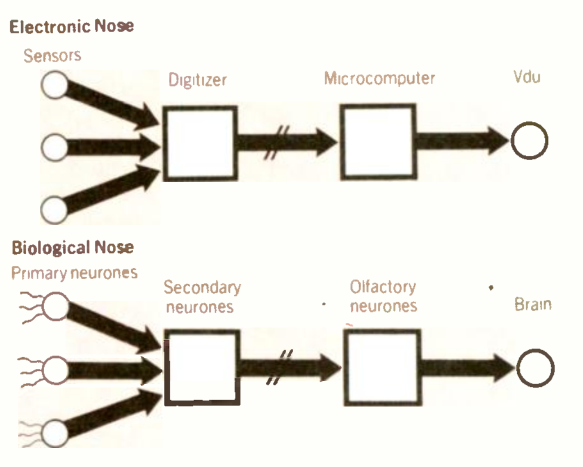
General principles

The electronic instrument is based on the same general principles that have been identified in a biological nose and the two are compared in the top diagram. The mammalian olfactory systems, which is able to detect as little as one part of odourous substance in 10^{12} parts of air, has primary receptors which are neurones terminating in mucus. Some ten thousand of these will synapse into a secondary neurone which feeds into the olfactory cordex of the brain and this vast number of neurones helps to explain why the mammalian nose can be so sensitive and discriminating[1]. Through this facility a complex odour can stimulate elecrical signals to the brain, which may be interpreted as a unitary stimulus.

The target for a man-made nose must be modest by comparison and the number of individual elements is limited by present technology to perhaps a few hundreds, in an integrated array. These, however, are in an early stage of development and the largest number of elements so far reported for a practical electronic nose is no more than 12 discrete devices[2]. However, it was shown several years ago that remarkable success could be achieved in discriminating between complex gas mixtures for a system having only three discrete sensors[3]. The arrangement for an electronic nose corresponds to the biological situation in that the primary neurones are replaced by sensing devices that feed an amplifier with linearising properties, a microprocessor performing the type of analytical function provided by a biological brain[1].

Twelve-element chemosensor array identifies complex gas mixtures

Warwick University's intelligent odor-discriminating nose pictured below consists of a 12-element chemosensor array with 5-litre flask linked to Opus IV microcomputer via 12-bit intreface card. Display shows a typical output from a test vapour mixture used to generate a characteristic 'fingerprint' using associate vector space analysis or neural network techniques.



A biological nose may be schematically represented as an array of 50 million primary neurones connected to the brain via several thousand secondary and olfactory neurons. As shown, the Warwick electronic nose mimic's this network using sensors, a 12-bit data convertor and a microcomputer.

ARTIFICIAL NEURAL NETWORK

Several array processing techniques are being investigated at Warwick University in their application to integrated gas sensor arrays. One of the most promising relies on artificial neural networks, and may lead to exciting possibilities in odour or gas detection. The potential advantages offered by this technique are adaptability, fault-tolerance and distributive associative memory. Our effort has centred on a back propagation technique* on a multilayer perception model. Initial results from a commercial PC-based software package, Neuralworks, are encouraging, and will be announcing results shortly. The field is of enormous interest due to applications in many fields such as image analysis, speech, robotics, and control.

*Rymelhart and McClelland. Parallel distributed processing. MIT Press. 1986.

Need for linearity

If each sensing element can be made to provide a voltage output that varies in linear proportion to the concentration of each constituent gas in a mixutre, then a complete analysis can be made, assuming also that the principle of superposition holds and that the combined effect of a number of gases is equal to the sum of individual effects. This is expressed mathematically if the value of each sensor output, after digitization, is expressed by a linear equation of the form

$$V_n = a_nC_1 + b_nC_2 + c_nC_3 + \ldots$$

where V_n is the value yielded by a sensor n, C_1, C_2, etc. are the concentrations of first, second, etc. substances and a_n, b_n, etc. are constants characteristics of the sensor n. The microcomputer receives and stores a complete set of samples from the whole array of sensors and the resulting set of linear equations may be solved by elementary means for C_1, C_2, etc., assuming that the constants a_n, b_n, etc. have been evaluated by preliminary calibration in which known amounts of constituent gases are introduced individually.

If the responses are non-linear and the relationship between the output and a particular gas constituent depends on the presence and concentration level of other gases that may be present then no simple solution is possible. Fortunately, by using appropriate linearizing circuitry, linearity and superposition can be shown[5] to hold up to gas concentration levels of around 50 – 100 parts per million.

Linearizing circuitry

The detecting elements used in an electronic nose may depend for their action on changes in resistance or electronic charge as a result of gas adsorption. A commercially available sensing element operating by resistance change is the Taguchi type of sensor, which utilizes a film of doped tin oxide material as the gas-sensitive layer and this is headed to the normal operating temperature of some 350°C by means of a heading coil incorporated into the device[6]. In the form of construction illustrated, the coil passes down the middle of a ceramic tube and the tin oxide layer is deposited on the outer surface of the tube.

Such a device may be used to provide a voltage which depends on the gaseous environment by using the sensor tin oxide layer as an element in a potential divider. The tin oxide behaves as an n-type semiconductor in which the number of conduction electrons depends on the surface oxygen content. In the presence of oxidizing gases, the content increases and more electronic charge becomes trapped, hence raising the resistance. If the supply voltage V is maintained constant, the output V_o will be reduced. Whilst this arrangement gives a satisfactory indication of the presence of an

VAPOUR DISCRIMINATION USING A COMPOSITE 12-ELEMENT ARRAY

In a mammalian nose the intake of a gas mixture containing odorants results in the generation of electrical signals to the brain, which may be interpreted as a unitary stimulus. Work at Warwick University's department of engineering is based on mimicking the biological structure with regard to the sensing arrangement and information processing procedures. There, a multiple gas-sensing array generates electrical signals which, after digitization, are processed by microcomputer, resulting in identification of the vapour. In a mammalian nose, high discrimination and sensitivity is achieved through some ten million primary receptors, which are basal cells linked via supporting cells to olfactory neurones. Ten thousand of these may synapse into a single secondary neurone, the brain being fed from many such neurones[1].

An ultimate aim in mimicking the biological system is to produce an integrated array with thousands of minute sensing elements on a single chip. Work of this nature has, indeed, begun though it is in its infancy. To maximize information for discrimination, the elements should differ from each other and this poses major, though not insuperable, manufacturing difficulties. Hitherto, attempts to provide vapour discrimination via a composite sensing unit have been limited to models using no more than three or four discrete elements[2]. Whilst these have given interesting and perhaps even remarkable results, their power is naturally limited with so few elements.

Drs Shurmer and Gardner of Warwick's solid-state laboratory described a system using 12 discrete SnO_2 Taguchi-type sensors at an IEE colloquium[3] held recently in London. Each sensor possessed different individual characteristics whilst at the same time being sensitive to a broad spectrum of gases. Spurious effects of moisture and temperature fluctuations are reduced by the inclusion of ceramic humidity and temperature sensors. The power of discrimination available from this system is increased enormously compared with anything else so far reported and enables information processing techniques to be applied effectively.

There are basic limitations to the performance of the system to be discussed, and their influence on the development of the present system to be detailed, in a forthcoming conference paper[4], which will also outline steps taken to improve stability and repeatability – factors which need continuous checking, since they have a dominant effect on the power of discrimination.

The researchers will report on how different methods for processing the raw data are compared in terms of accuracy, efficiency and ease of implementation for a wide range of chemicals, beverages and foodstuffs.

1. Persand, K. and Dodd, G.H., Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose. *Nature*, vol 299 1982 pp 352-355.

2. Shurmer, H.V. et al, Development of an electronic nose, *Physics in Technology*, vol 18 1987 pp 170-176.

3. Gardner, G.W. and Hines, E.L., Integrated array processing in an electronic nose, IEE Colloquium on New Trends in Sensor Array Processing, London, 6 December 1988.

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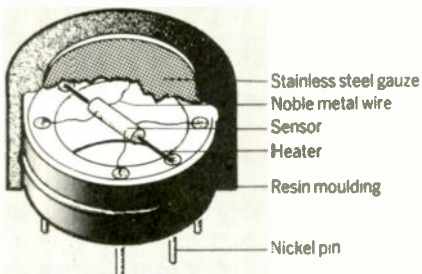
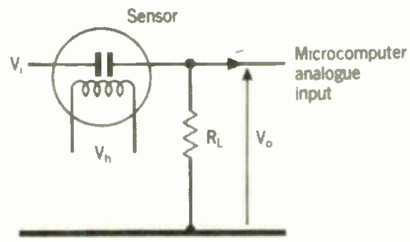
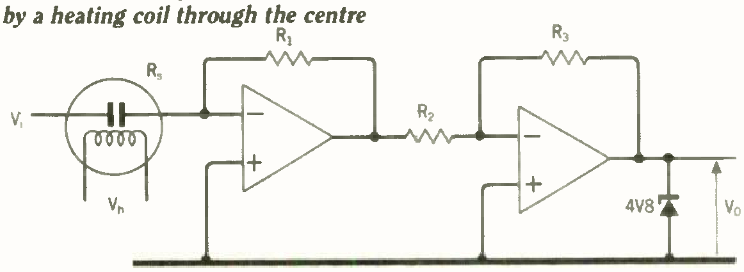


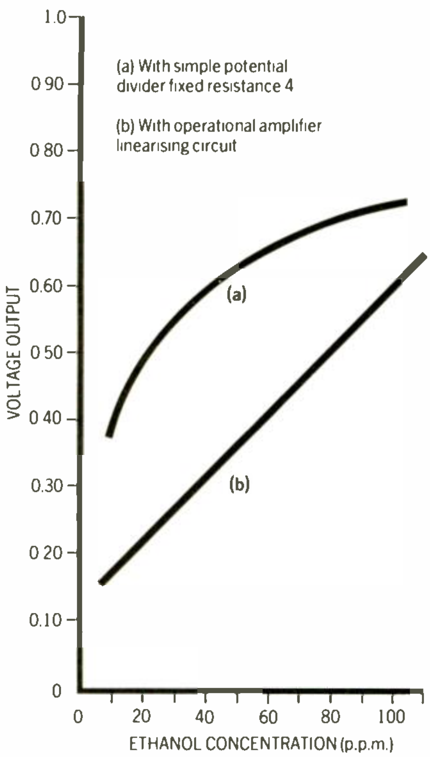
The Taguchi gas sensor consists of a ceramic tube on which an interdigital electrode structure lies, covered by a sintered tin-dioxide layer. Film conductance changes with the chemisorption of atmospheric vapours, while its temperature is maintained by a heating coil through the centre



Possible circuit arrangement for a Taguchi gas sensor where the output voltage V_o varies with device resistance for a fixed supply voltage V_s, and load resistor R_L.



In the improved circuit arrangement used at Warwick the gas sensors act as a current source in a virtual earth circuit feeding an inverting amplifier with fixed gain R_3/R_2 to give an output voltage V_o.



oxidizing gas (or of a reducing gas by converse effects), the output is very non-linear with concentration.

A much improved response from the linearity viewpoint may be obtained at the expense of circuit complexity. Consider the circuit shown, in which the potential divider of the previous arrangement now supplies two cascaded feedback amplifiers. If the voltage gains of the two amplifiers are G_1 and G_2 the output voltage V_o will be given by $G_1G_2V_i$ where $V_i=5V$, $G_1=R_1/R_3$, $G_2=R_2/R_3$. Thus

$$V_o = \frac{V_iR_1R_3}{R_sR_2}.$$

Denoting the conductance of the sensor tin-oxide layer by G_3, where $G_s = 1/R_s$ it follows that $V_o = kG_s$, where k is a constant. Provided that the conductance of the gas sensitive layer is proportional to the concentration of detected gas in the environment, the output voltage will be a linear function of gas concentration.

A comparison is given of the general form of output response for the potential divider arrangement and for the linearizing circuit, this providing an excellent linear relationship with gas concentration level. As preliminary investigations have indicated that superposition principles may also be applied at low concentration levels, a full analysis for a complex gas mixture is entirely feasible, provided the system is initially calibrated for all components present in the mixture.

References

1. Persand, K and Dodd, G.H. Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose. *Nature* vol. 299 1982 pp 352-355.
2. Shurmer, H.V. and Gardner, J.W. Intelligent vapour discrimination using a composite 12-element sensor array. Eurosensors III, Montreux 1989.
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4. Shurmer, H.V. Apparatus and method for identifying or measuring gas or liquid borne substances. UK Patent Application 8802385, 3rd Feb. 1988.
5. Shurmer, H.V., Gardner, J.W. and Chan H.T. Application of discrimination techniques to alcohols and tobaccos using tin oxide sensors. *Sensors and Actuators* (In press)
6. Taguchi N. UK Patent 1257155, 1971.

GUIDED WAVE SENSOR DEVELOPMENT FOR INDUSTRY

Optical sensors have existed for a long time and many of today's scientists and engineers will have encountered optical sensors for the first time at the Science Museum in London, where optically activated automatic doors were installed in the 'Childrens' Gallery' before 1932. During recent years there has been considerable interest in developing fibre-optic based sensors as alternatives to conventional sensors for a large range of measurands.

Fibre-optic based sensors may be grouped into two main classes. Fibre link – where some form of conventional optical sensing element or system is remotely deployed and illuminated via a fibre optic link and the optical encoded signal transferred via another fibre optic link for final demodulation – and fibre optic sensors – where the measurand directly modulates some physical property of the fibre.

This second class of sensors may be further sub-divided by transduction mechanism and classified as 'intensity' or 'interferometric'. Fibre optic intensity sensors tend to be based on multimode fibre whereas fibre optic interferometers are usually constructed from monomode fibre. In the 'tree' of optical sensors shown, the entries under the 'hybrid' label are all fibre link devices. There are a large range of transduction mechanisms that have been exploited to realise fibre-based sensors as indicated in the second chart, where you can see that there are many more transduction mechanisms to be exploited for the multimode and hybrid devices than for the interferometric systems. Measurands that have been addressed via fibre optic sensors are indicated in the third chart.

Kent has more fibre-optic sensors under development than any other research centre in Britain

An important aspect of any sensor is its range to resolution ratio (dynamic range); typically the dynamic range of an intensity-based sensor is $1:10^3$ to $1:10^4$ whereas it can exceed $1:10^6$ for interferometric devices.

The research work at the University of Kent at Canterbury has concentrated on interferometric sensors implemented as either hybrid or all-fibre systems and funded by SERC, the Royal Society's Paul Instrument Fund, MoD, OSCA*, the US Air Force and UK industry. Several examples of recent successful projects are outlined next.

BASIC TRANSDUCTION MECHANISMS

Multimode and hybrids	Interferometric
Intensity variations via: Microbending loss Breakage Fibre-to-fibre coupling Modified cladding Reflectance Absorption Attenuation Fluorescence Wavelength change Molecular scattering Molecular effects Evanescent fields Polarization Doppler shift Optical path change External to fibre	Optical phase via: Bulk dimensional change and variation in opto-elastic fibre constants Magnetic fields via: Changes in modal propagation constants

SENSOR GROUPING

Hybrids		Multimode (Intensity)	Monomode Interferometric (Phase)
Particle size Turbidity pH Distributed (temp)	intensity	Pressure Displacement Position Strain Flow Switch Force Temperature	Temperature Displacement Strain Magnetic field Acceleration Force Rotation Flow Vibration Extrinsic Magnetic field Electric field Chemical
Pressure Displacement Postion Magnetic field Temperature Gas Chemical Vibration Level Optical radar	intensity or phase		
Laser velocimetry Vibrometry Holography	phase		

Current measurement

The use of the Faraday effect, in which the plane of polarization is rotated in the presence of a magnetic field, within a monomode optical fibre is being used as the basis of an electric current sensor for use on high

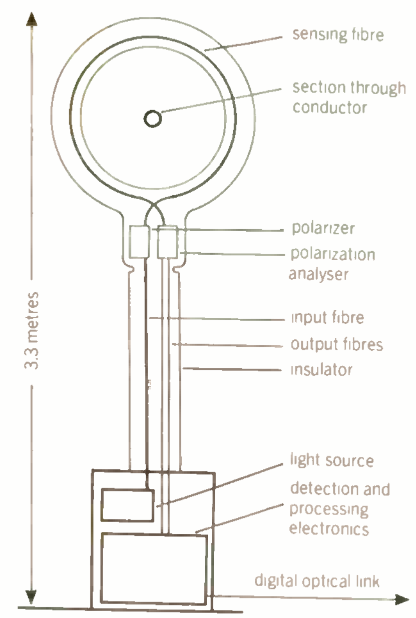
*See also article starting page 184.

voltage transmission and distribution lines. This has advantages in its substantial electric isolation (due to the dielectric nature of the sensing element), high bandwidth and immunity from electromagnetic interference. Light from a solid-state laser couples into an optical fibre which is looped several times around a current carrying busbar. At the output a polarization analyser converts the azimuth rotation to an intensity signal, transmitted via multimode optical fibres to detection and processing electronics. The system demonstrates excellent linearity up to currents in excess of 60,000 amps. This work has been carried out under an SERC/DTI Teaching Company Scheme with Sifam Ltd, of Torquay.

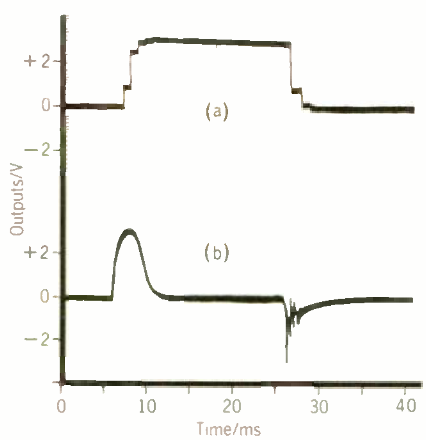
The current measurement system is relatively large and will remain permanently sited, but it is possible, by using optical materials with large Verdet constants, to construct miniature current probes. Typically the sensing probe will be deployed at the end of a monomode optical fibre link and interrogated using some form of heterodyne signal processing. An example of a prototype system is shown below where the multimode fibres are used to transfer the reference phase and signal phase change to remote detectors. Possible applications for these miniature probes could be for health monitoring of large electrical machines.

Very high bandwidth thermometry

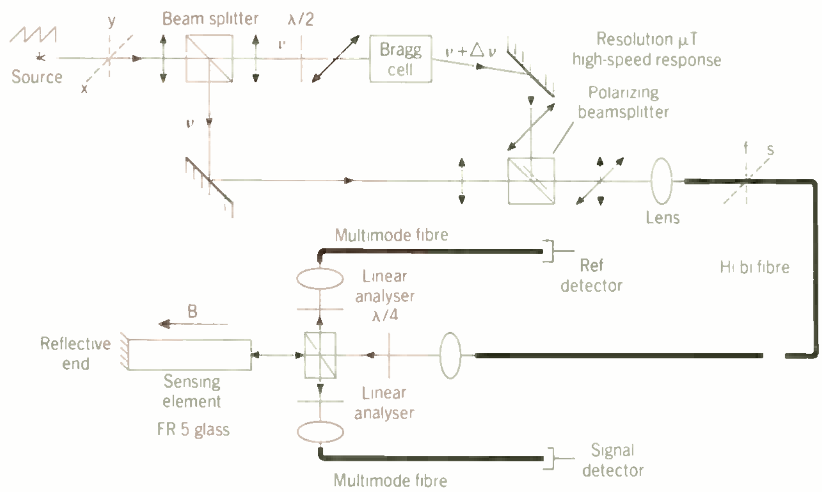
Miniature fibre Fabry-Perot interferometers can be used as very high bandwidth thermometers. In the experimental arrangement used to study the thermal diffusion of very short heat pulses generated optically of light from the argon laser is switched and focused on the fibre tip using the Bragg cell. The response time of the sensor is less than three microseconds. A similar experimental configuration can be used for conventional thermometry, in which case some form of autocalibration must be included if absolute measurements of temperature are to be made.



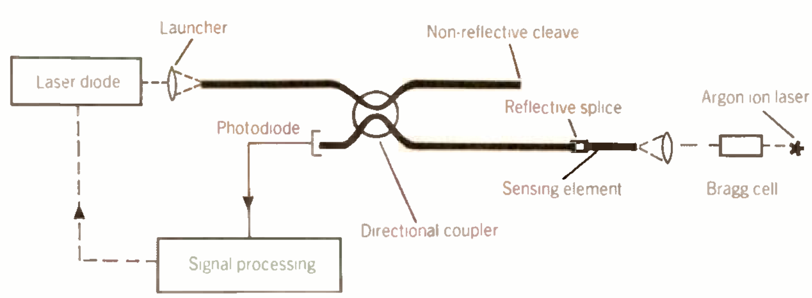
Prototypes of the Faraday current sensor developed in conjunction with Sifam will be undergoing field trials later this year. One of the unique features of this system is that the polarizer is made in situ on the fibre. The polarization analyser developed especially: it can determine both the ellipticity and the azimuth of the optical beam transmitted through the sensing fibre.



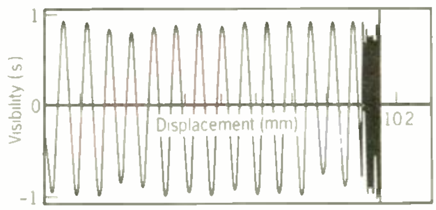
The conventional current transformer cannot be used for transient measurements because its output is proportional to the rate of change of current with time (Ldi/dt), whereas the output of the fibre optic system is linearly related to current, making it suitable for both direct and transient currents.



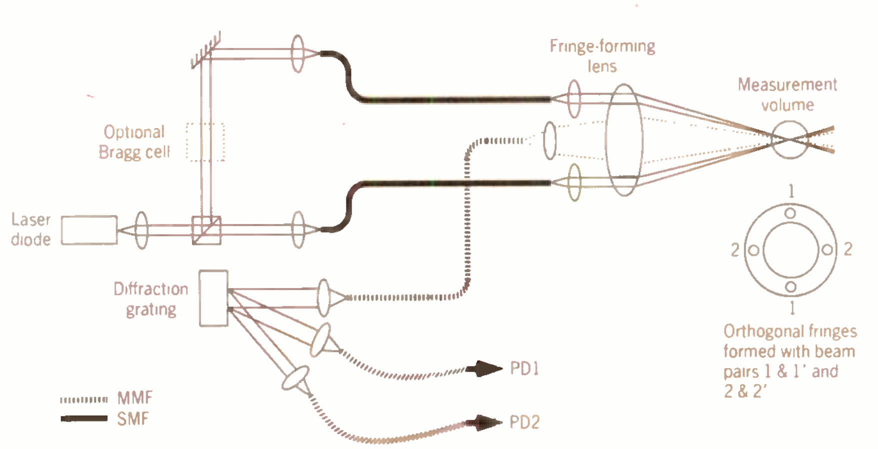
Miniature remote probe for current sensing: orthogonally-polarized beams from a linearly polarized solid-state laser with a difference frequency △ν are injected into the 'Hi-bi' optical fibre so that the propagate through the fibre in different eigenmodes. A quarter-wave plate effectively converts them to a linear state rotating at △ν, amplitude-division at the final beam splitter to produce a reference beam and probe beam, passing through the sensing element twice. It is the relative phase of these two beams that is directly related to the magnetic field (B).



The heat pulse measurement system is formed by fusion splicing a miniature fibre Fabry-Perot interferometer to one of the output ports of a single-mode directional coupler. A simple low-bandwidth servo controls the laser diode's injection current hence its absolute frequency such that the operating point of the interferometer is stable and not effected by low frequency environmental noise whilst remaining very sensitive to high frequency transients.



Variation of visibility of embedded differential interferometer as a function of displacement of the centre of graphite composite bar. Rapid cycling of the visibility indicates onset of bar failure.



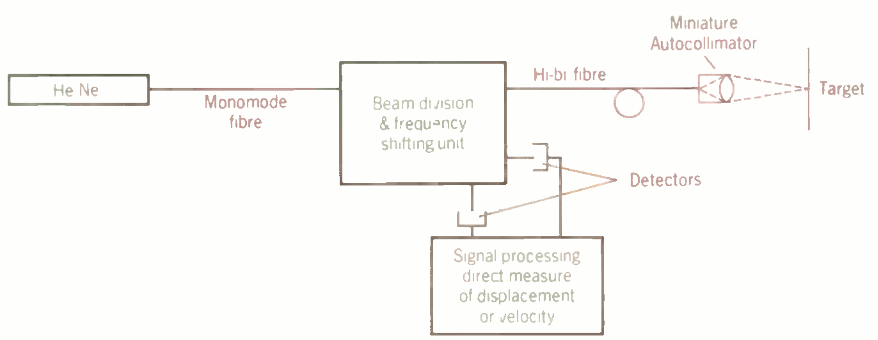
After amplitude division at the beamsplitter, light from the laser diode wavelength λ_1 is injected into the two single-mode fibre links, the output beams from fibres 1 and 1' are collimated and focused by the lens to produce Young's fringes in the measurement volume. The Bragg cell imparts a frequency difference between 1 and 1' if it is necessary to determine the direction of the flow. The second channel is formed in a similar fashion using a second laser diode of wavelength λ_2. The diffraction grating demultiplexes the two Doppler signals.

Structural analysis

Knowledge of the mechanical properties of carbon fibre composite materials is extremely important in order to assess the 'life-time' of structures and their vulnerability to impact damage. One approach to this problem is to embed optical fibre sensors in the structure at the time of manufacture. The photograph shows the results of an experiment where a carbon fibre beam has been loaded at its centre and the extension of the composite measured using an embedded differential interferometer. Each cycle of the visibility corresponds to a beam extension of 52 microns, corresponding to a strain of 0.1%; micro-strain resolutions are readily obtainable by this method. This work was performed in collaboration with City University.

Laser Doppler velocimetry

The use of laser light to measure the velocity of a fluid (laser velocimetry) is now well established. No material probe need be placed in the flow, which can be measured in the range of microns to kilometres per second. One such system, designed to measure internal flows, exploits the properties of both single and multimode fibres to enable a small probe to be constructed, and separated from the laser source and detectors, and their associated electronics. A laser diode (wavelength 780 nm) is the source and light is conveyed to the small instrument head by a pair of single-mode optical fibres. Optical elements in the head form a pair of beams which produce interference fringes thus defining the measurement volume of the instrument. Light scattered from particles entrained in the flow moving through the measurement volume is collected by a lens and relayed back to the detector by a multimode fibre. The fibre link in this case is 10 metres and the instrument head shown without its protective cover, contains only passive components and is intrinsically safe. In this instrument, a second laser diode of 830mm wavelength is used to form a second pair of beams which overlap in the same region of space as the first pair. This gives the instrument the ability to measure two orthogonal components of velocity simultaneously.



Non-contact vibration sensor using heterodyne signal processing will be marketed by Cogent Ltd of Ascot later this year.

The dimensions of the instrument head shown here are 100mm long × 25mm diameter. Measurement volume is 130mm in diameter and situated 85mm from the front face of the collecting lens, visible in the photograph. This work was performed under a research contract from MoD.

Vibration and displacement measurement

Laser Doppler techniques can also be used to determine the vibrational amplitude spectrum of a surface. In a system developed at Kent, a monomode optical fibre couples the light from the HeNe laser to a remote unit in which the input beam is divided, and one of the beams is frequency shifted with a Bragg cell. The unshifted beam is coupled into a fibre and transferred to the autocollimator. The back-reflected beam from the vibrating target is then coupled back into the fibre via the autocollimator lens and re-directed to the signal processing unit, where it mixes with the unshifted beam to produce a phase modulated carrier at the Bragg-cell frequency. This is subsequently demodulated with a phase-locked loop to produce a signal proportional to the instantaneous velocity of the surface.

The operational range of this device is up to 20m, the displacement resolution is 10^{-9}m and the velocity range 1μm/s to 10m/s for frequencies up to 100kHz. Systems of this type are finding application in the design of automobile suspensions. This project is currently supported by SERC/DTI Teaching Company scheme in association with Cogent Ltd.

The group is also involved in the development of many of the other sensors indicated on page 181.

By David Jackson, Professor of Applied Optics in the University of Kent, Canterbury.

OPTICAL SENSOR MARKET

Optical sensors development is being helped along by advances in optical fibre technology arising primarily through telecommunications requirements, information technology and consumer electronics. As with many developments in the sensors area, the application of the technology for measurement is a spin-off from its development to meet the much larger requirements of these primary markets. The technical benefits of fibre optics are not inconsiderable; however, except in special cases, cost-effectiveness is not, as yet, one of the frequently-claimed benefits. The technology is having difficulty in displacing conventional technologies which are already entrenched, and is now advancing by carving out new niche markets for itself. This is in fact the traditional pattern for the uptake of new technology in the measurement industries, and is rationalised by recognising that once a sensor is designed-in to a piece of equipment or system that has a far greater value than itself, there are only small potential economic benefits to changing the sensor, coupled with substantial technical risks.

Collaboration in new sensing techniques is needed if UK firms are to trade in this new area, as it develops.

In the case of fibre optic sensors the characteristics relevant to the new applications are size and weight, resistance to electromagnetic effects, inherent electrical isolation, and possibly a high intuitive degree of inherent safety. In addition, fibre optic cables are lighter, particularly when considering their high bandwidth capability, and can achieve very low levels of cross talk, making them highly attractive to the aircraft manufacturing community: fibre optic sensors benefit by default, and not by virtue of intrinsic characteristics. The almost unique capability of fibre optic sensors for distributed measurement has emerged in early products* but has yet to make a substantial commercial impact.

Diversity of solutions and applications

A device capable of generating information about its physical or chemical surroundings in a technologically useful (and ultimately electronic) form is going to be subtle, complex and require skills of a multi-disciplinary nature. The many different permutations ensure that there is technical fragmentation of the supply side of the 'sensors market'.

the user of a sensor or transducer generally requires it to protect or monitor expensive equipment, and is therefore concerned about many facets of the device performance, besides its primary capability to measure just one variable. Indeed, susceptibility to secondary variables is probably more important than accuracy for the primary variable, given viable performance/cost for the last-mentioned. This is one of the major factors influencing the proliferation of device types: each user has his own collection of 'small print' performance parameters which make nominally identical requirements (at the superficial level) in reality very different. For a given problem, only a few of the possible sensor solutions are relevant.

In practice, the combination of a set of demanding technologies and a set of demanding applications results in specialization by virtue of both technology and application. Users of sensors are often much larger organisations than their suppliers, and being technically sophisticated, demand technical sophistication from the suppliers. But, companies on the supply side of the industry are often not sufficiently large to sponsor basic research on new measurement principles; rather, practical engineers employ known principles or combinations of principles to produce cost-effective solutions, given both their drawbacks and the difficulties of the measuring environment. The new principles which are applied are often derived from research undertaken for other, more significant purposes. A perfect example is represented by optical sensors, the technological infrastructure of which is being developed primarily for telecommunications and consumer products.

It is interesting to observe the timescales involved in exploding research and development in sensors. Harmer documented a 10

*The first to market is described on page 170.

OPTICAL SENSORS COLLABORATIVE ASSOCIATION

The industrial members of OSCA now number over 30 with over 20 affiliated universities. A core of members have been involved since 1982-4, but the overall complexion has changed in broad line with commercial expectations of the technology. Thus, whilst the strong process industry interest is retained, the aerospace interests of old and a few newer members is also becoming evident. The initial bias toward physical variables has been replaced by a more balanced approach involving (dissolved) chemical and gaseous sensing. Whilst one recent member has strong medical interests, defence activities are not directly reflected in the programme.

For the period April 1987 – March 1990, the Department of Trade and Industry is providing a grant of £270k, representing about 40% of total expenditure, the balance being from membership fees. About 30% of the budget is spent on providing members with information on the activities of the Association, and awareness services covering the scientific and technological literature, including patents. The rest of the funding is used to sponsor research on a customer-contractor basis, principally in UK centres of expertise. The project work includes studies of the literature and the market, and laboratory work on pre-competitive aspects of systems, sensors and components. Contractors include members (academic, industrial and laboratories), other universities, technical consultancies and firms. Additionally, a continuing effort is devoted to establishing quantitative guidelines to support the much-claimed, but not demonstrated, 'inherent safety' of optical fibre sensor systems.

ABB Kent plc
AFRC Engineering
Bestobell Mobrey
BICC Research and Engineering
Biomedical Sensors
British Coal
British Gas
British Telecom
CEGB
Cogent
Department of Trade and Industry
Dowty Electronic Systems
Elf UK
ERA Technology
GEC
Health & Safety Executive
Laboratory of the Government Chemist
Lucas Automotive
Rosemount Engineering
Schlumberger Industries
Servomex
Shell
Sira
STC Technology
Thorn EMI
Transinstruments
UKAEA
Warren Spring Lab
Water Research Centre
Westland Helicopters

year cycle from initial laboratory work to product launch involved in three fibre optic sensors initiated at Battelle Geneva. The bulk of R&D on which the many successful silicon sensor companies are based was undertaken in the late sixties and early seventies (first publications were in the late fifties), but it is only in the eighties that the business made significant market impact. The previous generation of small strain gauge, the unbonded gauge, was discovered in the late thirties and did not make a market impact until the late fifties and early sixties.

Market situation

There is a substantial market that already exists for devices of the simple beam-interrupt type. From those using white light and macro-optics to the more sophisticated employing the latest opto-electronic components, these represent a market of around $500 million in the USA alone – probably more than twice this worldwide. They are used for counting objects or determining an object's presence; they are simple and effective when used on biscuits and bottles, nuts and bolts.

Much of current work on optical sensors is directed toward devices more sophisticated by virtue of the envisaged applications environment, the information requirements, and packaging considerations.

The UK's optical sensor collaborative (OSCA – see panel) concentrates on devices in which the optical path is either invasive – that is, penetrates the measured volume – or non-invasive in that in is confined within fibres or, if the device is an extrinsic sensor, within the housing of the packaged device. Light scattering instruments for determining the number, shape, size and velocity of particles are in the first category, as well as instruments for determining chemical information based on Raman spectroscopy. Optically non-invasive sensors include fibre optic versions of conventional pressure transducers, or temperature sensors for example which have wide market address from the process to aerospace industries. Distributed sensors fall within this class.

Just over a year ago OSCA commissioned ERA Technology to conduct a comprehensive world-wide product survey* of fibre optic sensors for process variables, covering analogue, switch and digital devices in development, with preliminary and product specifications. Over 200 suppliers were iden-

* *Results from this survey are summarized in the listings on page 185, 186.*

Commercial optical sensor activity overseas

This data has been abstracted from questionnaires completed by sensor manufacturers and UK suppliers and should not be regarded as exhaustive; about 70% of relevant manufacturers responded. The sensors investigated are intended for continuous monitoring only – process control in its widest sense. A number of sensors suitable for single-shot medical/chemical usage and fibre optic gyroscopes are not therefore included.

Company	Measurand: Temperature	Pressure	Flow	Liquid level	Turbidity	Force	Displacement	Gas concentration
Accufiber Inc	ac		c					
Acme Cleveland Inc	Sc						Sc	
American High							Ac	
Asea Research	A	a						
Aster	c	c						
Aurora Optics Inc	Aa	Aa	ADa	ADa		Aa	ADa	
Babcock & Wilcox	c	c	c	c	a			c
Balluf Inc							Sc	
Bertin Et Cie	Aa				Ac			
CSEM	ASab	Aab		Aa		Aab	ASab	Aa
Eltec Instruments	ASbc							
Eotec Corp	Sc	Sc				Ac	ASc	
Erwin Sick Optic							c	
Fiberdynamics	Ac	Ac	c	Ac			Sc	
Fiberoptic Sensor	Aa	Ac		Aa				
Focal Marine Inc			Dc	AaS		Aab		
Fuji Electric Ltd	AcS	AcS	AcS	AcS			Sa	
General Motors Inc		Aa				Aa	Aa	
Hitachi Cable Ltd	Sa							
Honeywell Inc				Sa				
Ingalls Shipbuilding	a					a	a	
Ionic Systems Inc						c		
Ircon Inc	Ac							
ITT Barton Inc	Ac	Ac	Ac	Ac				
Japan Radio Co							c	
Koden Industry Co							Sa	
Ladd Research Lab		Ab						
Leybold-Heraeus GmbH								Ac
Litton (VEAM) Inc	Sb			Sb				
Lockheed Aero	a							
Luxtron Corp		a	a			a		
McDonnell Douglas	a	a				a	a	
Mechanical Tech							Ac	
Metricor Inc	Ac	Ac					a	
Mikron Instrument Co	c							
Minerva Research								c
Mitsubishi Electric	A	A						
Mitsubishi Rayon							Sb	
Monitex Inc					Aa			
National Corp							Sc	
Optelecom		Aab						
Opticable NV	ASab	ASab	ASa	Sa		Aa	ASc	
Optical Engineering							a	
PCO Inc								a
Photenetics SA	Sa	Sa		Sc				Ac
Polytec GmbH							c	
Pulnix America Inc							ASb	
Showa Denko KK								a
Simmonds Precision	a	a		a			a	
Soundek Oy	Ab							
Sumitomo Electric	Ac							
Teledyne Ryan		Aa						
Toshiba Corp	Ab	Ab	b	Aa				
Totoku							Sa	
TSI Inc			a					
United Technologies	a							
Vanzetti Systems Inc	c							
Volpi AG							Ac	

Compiled by Sam Crossley, manager of ERA Technology's electro-optical programme, with acknowledgement to the Optical Sensors Collaborative Association, on whose behalf the original work was carried out. Reasonable efforts have been made to ensure the validity of the data presented, but ERA cannot be held liable for omissions and/or inaccuracies. KEY A – analogue, S – switch (two-valued 'set point' type output), D – digital, a – product in development, b – preliminary spec available, c – product spec available tified, of which over 100 supplied detailed data over the entire range of measurands. Of the 78 manufacturers who said they were considering the systems potential of their products, a little over half claimed to have it.

In terms of the global industrial market sectors greatest activity is in the aerospace and electricity generation and supply sectors. In the aerospace industry, the benefits of fibre optics as a gravimetrically-efficient and production-friendly means of communication in aircraft is imposing a requirement for compatible, passive, optical devices on the transducer and sensor manufacture. Displacement in the mm range to tens of centimetres is a particularly important measurand. Many of the measurements relevant to flight control are of a positional nature, and rotation is also an important variable. An attractive approach is to intensity-encode multiple channels derived from, say, the spectral width of a light-emitting diode through wavelength division demultiplexing. The resulting signal can be multiplexed down a single fibre and demultiplexed for extraction of the required information. Besides the control of flight, there is the additional need to control the propulsive gas turbines. Rolls Royce recently issued a statement of requirements for optical sensors to make measurements at 30 different locations in a typical power plant.

In the electricity industry, more efficient capital investment carries with it a requirement for more monitoring; in the typically noisy measurement locations, optical sensors score heavily. Measurement of electrical quantities can be achieved in a variety of ways, including the use of bulk or thick-film Pockels and Faraday cells. In the first case, lithium niobate and bismuth silicon or germanium oxide are the preferred materials; in the second, sophisticated garnets, zinc selenide, lismuth silicon oxide and flint glass have all been used successfully. These materials have relatively high rotary powers and Verdet constants respectively. Applications as diverse as gas-insulated switch gear and 'telegraph pole' transformers have been reported, at least one family of devices being elegantly compensated against temperature fluctuations. On the other hand, the emphasis of much UK work has been on the measurement of properties of fibres not necessarily optimized for the measurand of interest, but configured in long lengths to make up for lack of sensitivity.

The safety issue

Safety is crucial to the ultimate success of optical fibre sensors in many applications. There will be a safe level of transmitted power that, if by light from a fibre is accidentally projected into space, cannot trigger explosions by, say, the chance heating of a particle illuminated by the beam.

Commercial optical sensor activity in UK

This data has been abstracted from questionnaires completed by sensor manufacturers and UK suppliers and should not be regarded as exhaustive, at least outside the UK. The sensors investigated are intended for continuous monitoring only – process control in its widest sense. A number of sensors suitable for single-shot medical/chemical usage and fibre optic gyroscopes are not therefore included. UK data has been updated by telephone, first week December. Data for the rest of the world is approximately one year old.

Company	Temperature	Pressure	Flow	Liquid level	Turbidity	Force	Displacement	Gas concentration
Asea Brown Boveri Kent 0582 31255	Ac							Ac
British Gas Corp 091-268-4828				b				b
Cambridge Consultants 0223 358855							Aa	
Cossor Electronics 0279 26862	Dc							
Data Logic 01-486 7288							Sc	
Delta Controls 01-941 5166	S			S			Aa	
Era Technology 0372 374151		a	a			b	a	
Eurotec Optical Fibres 0302 61574				c				
Furnace Instruments 0742 731608	Ac							
GEC Research 01-904 1262	ab						a	
Haenni 0252 515151							ASc	
Herga Electric 0284 701422	ASa	ASa	ASa	ASa		ASa	ASc	
Huntleigh Technology 0222 485835							Sc	
IMI Opella 0432 57331			Ac					

Company	Temperature	Pressure	Flow	Liquid level	Turbidity	Force	Displacement	Gas concentration
MTE 0702 527111							S	
NMI 01 977 0933							A	
Oliver Engineering 0565 2636	Sab	Sab		Sab		Sab	Sab	
Oriel Scientific 0372 378822				A			c	
Orion Devices 0263 732345							ASc	
Pilkington Security 0745 714771								Sb
Scama 0284 64921							Sc	
SDS-Relais 0908 567725				Sa			Sa	
Sieger 0202 676161								Aa
Smiths Industries 0256 473191	c						Sa	
Schlumberger 0252 544433	Ab	Da					Db	
STC Techology 0279 29531				Ac	Ac			
York Group 04215 60411	Ac	Aa						

Compiled by Sam Crossley, manager of ERA Technology's electro-optical programme, with acknowledgement to the Optical Sensors Collaborative Association, on whose behalf the original work was carried out. Reasonable efforts have been made to ensure the validity of the data presented, but ERA cannot be held liable for omissions and/or inaccuracies. KEY A – analogue, S – switch (two-valued 'set point' type output), D – digital; a – product in development, b – preliminary spec. available, c – product spec. available

Given that sufficient power is available, the probability of such an occurrence is low, yet the versatility and cost effectiveness of the technology is directly linked to the level of power that can be transmitted down the fibre without an explosion hazard, if it were to break. It is therefore useful to establish the lowest power density at which explosions can be initiated; the safe level then becomes a matter of judgement.

Two phases of work in this area by Sira Safety Services has already produced some interesting findings.

- Ignitions of di-ethyl ether and carbon disulphide have been obtained by irradiating small inert solid objects with light from a laser.
- No ignitions were obtained at an incident energy of less than 80mW, or with objects less than 130μm diameter.
- For particles greater than about 800μm in size, power to cause ignition falls with size; at about this diameter there may be a minimum to the curve such that for smaller particles the power for ignition rises again, but the difficulty of doing experiments makes this uncertain.
- The power required to cause ignition appears not to be influenced greatly by the ignition energy or the ignition temperature of the flammable materials tested.

Optical fibres are capable of transmitting far more power than is required to cause ignition, and solid-state laser diodes are available that will provide more power in an optical fibre than the minimum required to cause ignition.

There is a strong case to continue with this work, and additional finance has come from the Health and Safety Executive with the further objectives of widening the range of flammable and illuminated materials and variation in the circumstances of illumination.

Chemical sensing

A key shift in the scope of OSCA's range of activity over the last few years has been the adoption of a programme on chemical measurements. One aspect of the work, undertaken in a collaboration between the Harwell Laboratory of the UKAEA and Strathclyde University, effectively a design study for sensors where the attenuation of a waveguide structure (planar or circular) is perturbed through the evanescent field being affected by the presence of a lossy medium. Ray optics, perturbation and matrix methods were used for different cases, and the results were interpreted for the presence of different analytes such as petrol, aqueous solutions and gases. Coupled waveguides and fluorescence spectroscopy were other aspects considered in work which did compare calculations with experimental data. The results were detailed and in some respects surprising, showing that optimal performance could be obtained by careful attention to the light propagation modes. The influence of 'surface contamination' and how it might be ameliorated was also determined. A patent application has arisen from this work.

In an ambitious attempt to make Raman spectroscopy more attractive to the process industry for potential on-line use, Southampton University undertook a one-year investigation into the possibility of using the sharp lines in flash-lamp emissions as the light source. The approach suffers from the relative lack of width of the lines and the background intensity, which it was hoped might allow spectrographic detection. But this has been overtaken by the exciting development of Fourier transform Raman spectroscopy which appears now to be very close to commercialisation.

In the case of the toxic gas, detection investigations to establish the detection limits and sensitivity of frequency modulation spectroscopy for nitrogen dioxide, will conclude with an assessment of instrument designs and their relative cost. From a safety perspective, detection of flammable gases such as methane and other hydrocarbons is important. Previous work on tunable diode laser spectroscopy using lead-salt diode lasers in the mid-infra-red range points to the possibility of remote gas sensors based on second harmonic detection of absorption using a scanned, multimode diode laser source. Alternative detection schemes will be evaluated in what promises to be an exciting project. Additionally, work on the application of comb filters for sensing gases is under active consideration. All this is directed toward cost-effective systems with improved selectivity and lifetime performance over pellistors and semiconductor gas sensors.

Hybrid sensors and actuators

For the process industry, a technically attractive alternative to the passive optical sensors required of the aerospace industry is the use of a hybrid configuration involving a conventional sensor – Wheatstone bridge, capactive gauge, thermocouple etc. Electrical energy is provided either electrochemically or by light through an optoelectronic converter. Communication of the magnitude of the sensed parameter is via an fibre link, which in the second case can also be the fibre that provides the powering illumination. The all-optical option is one which, with the wider availability of the lower power cmos devices, has been demonstrated in the literature, and battery powered products are already on the market. GEC (Marconi) Research Laboratories recently completed for OSCA a techno-economic comparison of systems options.

Members of OSCA have supported with SERC a Cooperative project at Brunel University which has demonstrated switched control of a pneumatic actuator via infra-red light transmitted down commercial optical fibres; 5mW average light powers into membrane-flapper optopneumatic converters operating in differential mode led to conversion efficiency of 60Pa/mJ. The work has also been extended to allow any output in the range 3-15 psi to be chosen for operation of standard actuators. Improved response time could be obtained by careful attention to the design.

Systems and components

Manchester Polytechnic has undertaken a comprehensive review of the current status of wavelength division multiplexing. This covered spectral effects in fibres and fibre components, sources and detectors; multiplexers and demultiplexers; and relevant publications on sensors, systems and networks.

Currently underway are three studies into specific aspects of optical fibre sensing. One covers the status, future prospects and role in sensing of polymer optical fibres. A second is reviewing comprehensively the technical and patent literature in relation to position sensing. And a third is examining the current status and prospects for fibre-bend sensors.

The availability of suitable components with the right combination of performance and cost is one of the areas where improvements are required. A general trend in the market has been toward the development of passive integrated optic devices in glass. A thermally stable, mode-insensitive coupler technology is required for the implementation of the balanced sensor approach to compensation of intensity-based sensors, which OSCA has been progressing for some time. University College has been evaluating prototype glass integrated optic components against this particular sensor philosophy, with very interesting results.

As an emerging sub-technology, silicon micromachining probably has no contemporary equals, other than perhaps the deposition of coatings of diamond by chemical vapour disposition. The UK has considerable technical expertise that might be applied not just to sensors, but to pumps, actuators, nano-filters and the like. Birmingham and Strathclyde Universities are co-operating on a project aimed at disciplining the temperature sensitivity of structures for strain measurement so that strain effects can be discriminated alone for pressure measurement. The micromachined structures are set into vibration and monitored optically giving an attractive output, an intensity of variable frequency.

Dr Peter McGeehin, who compiled this report, is director and chairman of OSCA, at Compton Consultants, School Road, Compton, Newbury, Berks RG16 0QU.

FLY-BY-LIGHT

"Fly-by-wire" is the current buzz word in the aviation arena. Used properly, it can be taken to mean the assisted control of aircraft, including automatic control, by computer rather than by means of mechanical linkages. Such systems are able not only to enhance manoeuvrability and stability (some aircraft are deliberately made unstable without the computer control to increase agility), but will also ensure that engines are controlled in the most economical way. The Airbus A320, for example, is, fully fly-by wire aircraft and several modern fighters use such systems to enable them to perform manoeuvres that would have been quite out of the question in manually flown aircraft.

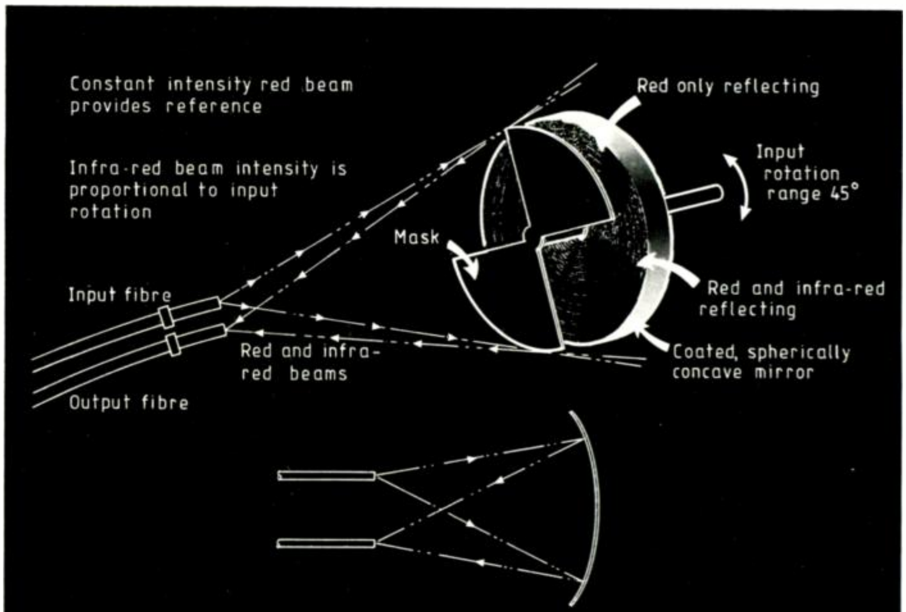
Together with these obvious advantages, there is one disadvantage: electrical interference. Interference generated by equipment on board such as motors, engines and avionics and that picked up from external sources such as lightning and deliberate em countermeasures dictate elaborate screening, some of which is provided by the metallic structure of many aircraft. If the aircraft is built of non-metallic material – a non-rigid airship, for example – then extensive local screening becomes necessary, with its cost and weight penalties.

For this reason, communication between the pilot's controls, computer and controlled elements can benefit from the use of optical fibres, and GEC Avionics has recently provided such a system for the Airship Industries Skyship 600-04, which made its maiden flight on October 23 in Weeksville, Carolina. In this insallation, the optical fibres simply function as links between the units; future developments will certainly bring about the use of fibre bundles as data buses.

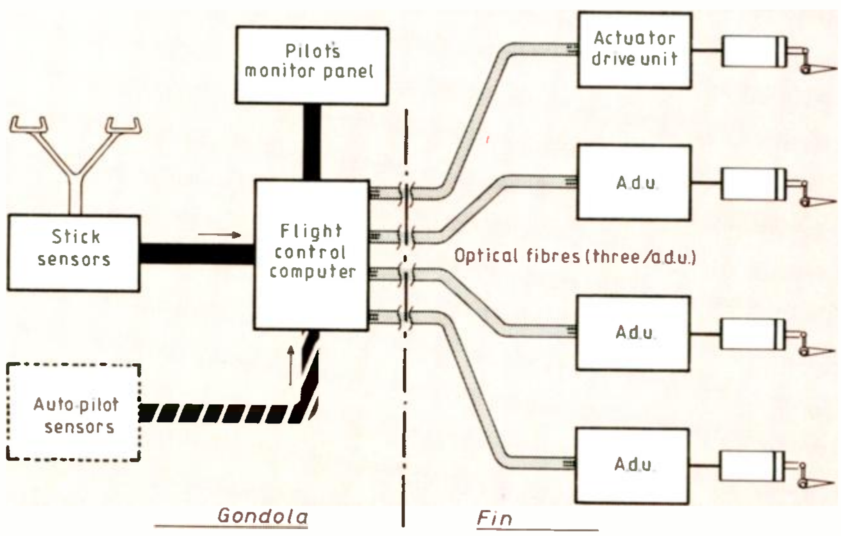
Mechanical control runs present their own problems in this type of airship; since the ship is non-rigid, rods and linkages can distort the structure; and since the distance from pilot to control surfaces could be around 30 metres, the control runs must be long and could suffer from lost motion.

Compared with a heavier-than-air aircraft, an airship is a fairly relaxed environment, which allows failure detection and the ensuring remedial action to take place quite slowly. The pilot is included in the loop and makes the decision to change from the active control lane to a stand-by-one.

In the elemental system shown below the flight control computer (fcc) in the gondola accepts duplicated command data from the pilot's stick sensors, together with simple autopilot information, converts the analogue electrical signals to digital optical form and transmits the data, with additional protection bits, to an actuator drive unit (adu) and servo amplifier for each of the four control surfaces. A microprocessor in the fcc takes inputs from the adus, pilot's controls and autopilot to monitor the system and to provide the pilot with an indication of control positions and controller status, including failure, on a pilot monitor panel (pmp).



Optical-fibre rotation position transducer.



Elements of the optical control system.

Shown above is an alternative, optical type of rotation position pickoff, which avoids the use of electrical connection between the pilot's controls and the computer. The input shaft carries a segmented mask in front of a spherically concave mirror, some parts of which reflect red light and others infrared and red light, the coatings being shaped in a similar manner to that on the mask. The mirror reflects light from the input optical fibre to the output fibre, the ratio of red to infrared light (red always being present) allowing the position of the shaft to be computed.

Future development is aimed at the evolution of a system to provide automatic stability over the whole flight envelope and automatic cruise, hover, speed and mooring control, together with the vectored thrust control for the pivoted engines.

Based on information provided by J. W. Hill of GEC Avionics.

SMART TEMPERATURE SENSORS

Intelligent microprocessor-based sensors expand process control, medical, and industrial manufacturing applications

The most notable trend in the temperature-sensor industry is the increasing use of microprocessor-based temperature devices. The smart temperature sensor and transmitter market is expected to find application in the automotive, medical and household field in the next five years. Computerized monitoring of a greater number of control loops for distributed process control, greater utilization of data acquisition systems capable of internal data conversion, and transmitting a signal from a remote site to a computer are all expected to cause microprocessor-based smart temperature-sensing systems to proliferate.

It is expected that it will soon be possible to integrate the sensing element and related instruments on a single chip, but only for temperature sensors in low-temperature sensing and control applications. For applications where high-temperature sensing and controls are called for, the manufacturers would still have to solve the problems associated with harsh environments.

Developments

A temperature sensor is chosen on the basis of price, accuracy, size, the temperature range it can measure and the environment in which it must function. The most difficult application involves high-temperature measurements in a hostile environment. There are at least 15 different types of temperature sensors and no single sensor is capable of measuring temperature in all circumstances.

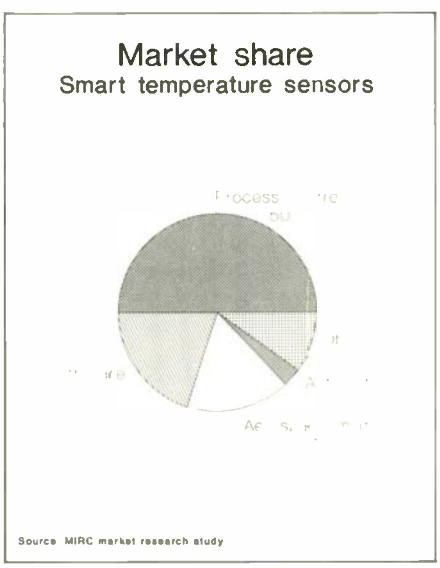
Among the major types of temperature sensors, thermocouples are largely used in process control, while resistance temperature detectors (RTDs) are suitable for distillation tower and pulp/paper stock temperature control, since they are accurate, linear and immune to environmental conditions. Thermistors are used in plastics manufacturing, oven control, and gas steam monitoring in petrochemical processing.

At the present time, thermocouples are expected to remain dominant in industrial process applications, owing to their compatibility with advanced transmitters. However, enhanced computer control should reduce the need for sensors with lighter accuracy and linearity. Since RTDs can satisfy the needs of microprocessor-based systems, they are expected to dominate industrial process applications. By the year 1994, RTDs could very well become the chief sensors used for the coming generation of digital factory controls.

Advancements in signal-processing instrumentation are expected to foster multipoint, distributed temperature measurement and the use of high-capacity computer input multiplexers or data loggers. Multiloop temperature control is expected to supersede the discrete, open-loop type.

Non-electrical temperature sensors would still be used for certain industrial process applications due to their low cost and availability. However, as electronic signal transmission becomes more prevalent, the use of mechanical temperature sensors is expected to slow down in the years ahead.

During the years 1988-1994, a technological trend toward implementation of smart temperature sensors, capable of a-to-d conversion at the sensing element and of transmitting the signal, is envisaged. Computerized monitoring of additional control loops for process control temperature monitoring would provide further impetus to the development of microprocessor-based smart temperature sensors and transmitters.



In the field of smart devices, developments have made possible intelligent digital signal transmitters which can convert thermocouple, RTD, millivolt, and milliampere inputs into a linearized 4-20 mA signal. An internal temperature sensor automatically compensates for changes in ambient temperature. The smart temperature transmitter can be field-programmed to accept any number of sensor inputs. The smart temperature sensors and signal transmitters reduce the time needed for manual checking (transmitters can be remotely checked), have on-board diagnostics, and reduce the troubleshooting time in case of failure. The microprocessor-based system improves sensor performance and permits remote communication in a hazardous location without the need for physical access by an operator.

At the present time, these devices carry a high price. Our industry survey indicates that, at this point, they are not adaptable and, as a result, most of them are custom-designed rather than general purpose. Presently, the devices are designed on multiple chips. Right now, it is not feasible to integrate the whole temperature sensor and related instruments into a single chip, since it would require a good deal of miniaturization and very large-scale integrated circuitry.

Other advancements have occurred in microprocessor-based thermostats. These programmable, memory-capable thermostats can be monitored and reset by a central computer via telephone wires. They include continuously rechargeable backup batteries and room-temperature sensors and they can function by themselves without a host computer by being manually programmed to maintain room temperature correlated to the time of the day.

World market forecasts

Between 1985 and 1987 the world market for smart temperature sensors and transmitters grew at a compound average rate of 7.5% per year and reached a level of $164.4 million. Following the initial developments which spurred market growth for smart tempeature sensors and transmitters in the mid 1980s the growth rate has slowed down slightly to 8%. This decline in growth rate is due to a sluggish world economy, a decline in the process industry and a recession in the semiconductor manufacturing sector. Of the 1987 world market of $164.4 million, the US accounted for $74 million, Europe for $49.3 million and the rest of the world for $41.1 million.

During the next seven years, we expect the world smart temperature sensors and transmitter market to grow at average annual rates of 10% and 13.3% respectively and, in 1994, to reach $356.7 million. The trend toward computerized temperature monitoring among the process, chemical/petrochemical, and general industrial manufacturing industries will provide an impetus to market growth.

Other contributing factors to market growth will be an increased acceptance of microprocessor-based temperature monitoring and control devices among users, a need for improved sensor performance, easy access to remote communications and digital communication network capabilities and the diagnostic abilities offered by the smart temperature sensors and transmitters.

At the present time these microprocessor-based devices to high-priced customized items and are limited to specific applications where a user can justify the cost. As technology advances, unit price reductions will open up new markets. New market applications may include expanding usage in energy management/hvac, industrial clean room applications, home appliances, automotive industry, and biomedical/healthcare (patient monitoring) applications. Also, if the semiconductor and telecomms industries rebound as is occurring at the present time, increased use of these devises is expected in electronic process instrumentation.

As shown in the chart, the process-control industry was the biggest user of smart temperature control and monitoring devices last year. This sector included hvac manufacturers/end users, petrochemical/chemical processors, food processing manufacturers, and energy/environmental companies.

Last year the aerospace/military sector accounted for 15-18% of the market. The medical/health care sector including medical instrumentation manufacturers encompassed 20% of the market. The medical/health care sector is expected to increase its consumption of smart temperature sensors in the years ahead. The automotive sector has 3% and other industries, including household appliances and electronic process control, accounted for 7-12% of the market.

Adapted from Intelligent Sensor Markets, by Chris Nugent, director of research at Market Intelligence Research Co, Mountain View, California (tel 415-961 9000)

Salmonella sensing

Recent concern about salmonella infection in eggs has made the rapid and reliable detection of food poisoning bacteria a hot topic. The testing of feed, hens and sample eggs only give information about the *likelihood* of salmonella being present in the egg on the breakfast table; there is no known way of testing the individual egg without breaking it. Of course sample testing eggs or testing hens may well be adequate, if the result could be obtained rapidly enough. The trouble is, conventional test methods take about five days to confirm salmonella presence in a sample. The key to rapid testing lies in the sensitivity of the test.

A detector known as surface plasmon resonance (SPR) detector is in development at PA Technology's laboratory in Royston which is claimed to detect the presence of salmonella at concentrations of 10 to 100 organisms per millilitre within eight hours. This works by detecting the changes to the angle at which light falling on a surface produces a wave which travels along the surface; surfaces are prepared which selectively attract the bacteria of interest and which cause changes to the SPR angle. In practice, the presence of other, harmless, organisms in high concentrations may limit the sensitivity of the technique to 1000 or more organisms per millilitre, which implies that 24 hours preparation and growth may be needed before the bacteria can be detected.

One of the more promising techniques, according to PA's Alec MacAndrew, is conductance sensing in association with a highly selective growth medium. Media such as these support the growth of single or closely related species of bacteria. In the presence of the bacteria, the conductivity of the sample changes as the culture grows; in its absence, no conductivity changes are detected. The technique is potentially rapid and easy to use. Cadbury's have announced a possible medium.

FIBRE OPTIC GYROSCOPE

Latest advance in angular rate measurement provides instant readiness, wide dynamic range, digital readout and has no moving parts

Though the fibre optic gyroscope was invented over a decade ago, it relies on an effect first described in the 1920's. The Sagnac effect is the differential phase shift induced by rotating an optical system in which light travels clockwise and anti-clockwise round the system.

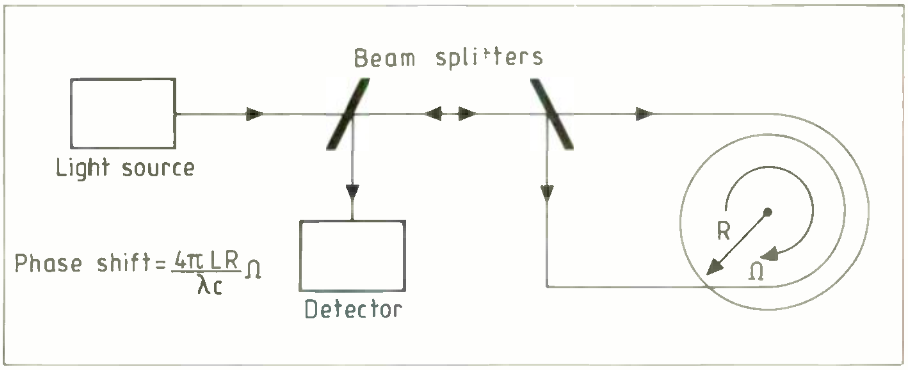
In a practical arrangement, light from a source is passed through a first beam splitter, and a single optical mode selected. The light then passes through a second beam splitter and propagates in both clockwise and anti-clockwise directions around a fibre optic coil. In the absence of rotation, the propagation times are identical so that when the light arrives back at the second beam splitter perfect constructive interference occurs. The gyro signal is obtained by directing the returning light to a photodetector via the beam splitter. Rotation results in a difference in propagation time between clockwise and anti-clockwise beams, which is manifested as a relative phase shift between the beams, and hence reduced intensity at the detector. This change in intensity is very small for useful rotation rates, and techniques have to be introduced to enhance the resolution.

According to British Aerospace nulling systems offer the greatest potential for production gyroscopes. The BAe fibre optic gyro architecture shown below uses a tracking phase modulator to cancel the rotation-induced optical phase shift. The signal required to achieve a null is a direct measure of the optical phase shift, which is proportional to the applied angular rate around the axis of the fibre coil.

Light from a 1.3μm edge-emitting light emitting diode is passed to the coil via a fused optical coupler, a fibre polarizer and the integrated optics chip which comprises a Y-junction and phase modulator. The fibre coupler and Y-junction are guided-wave equivalents of the beam splitters shown in the basic concept. Light returning from the coil passes back through the phase modulator, interferes at the Y-junction and is directed to the detector via the polarizer and coupler.

Light propagating around the coil has its phase modulated by a signal which is synchronous with the delay time around the coil. The modulation biases the gyro to a point of maximum sensitivity. Rotation induces a rate-dependent signal which is demodulated, filtered and integrated, and used as the input to the serrodyne voltage controlled oscillator, which outputs a sawtooth waveform. Applied to the phase modulator in the integrated optic chip, this is used to null the Sagnac phase shift induced by the applied angular rate.

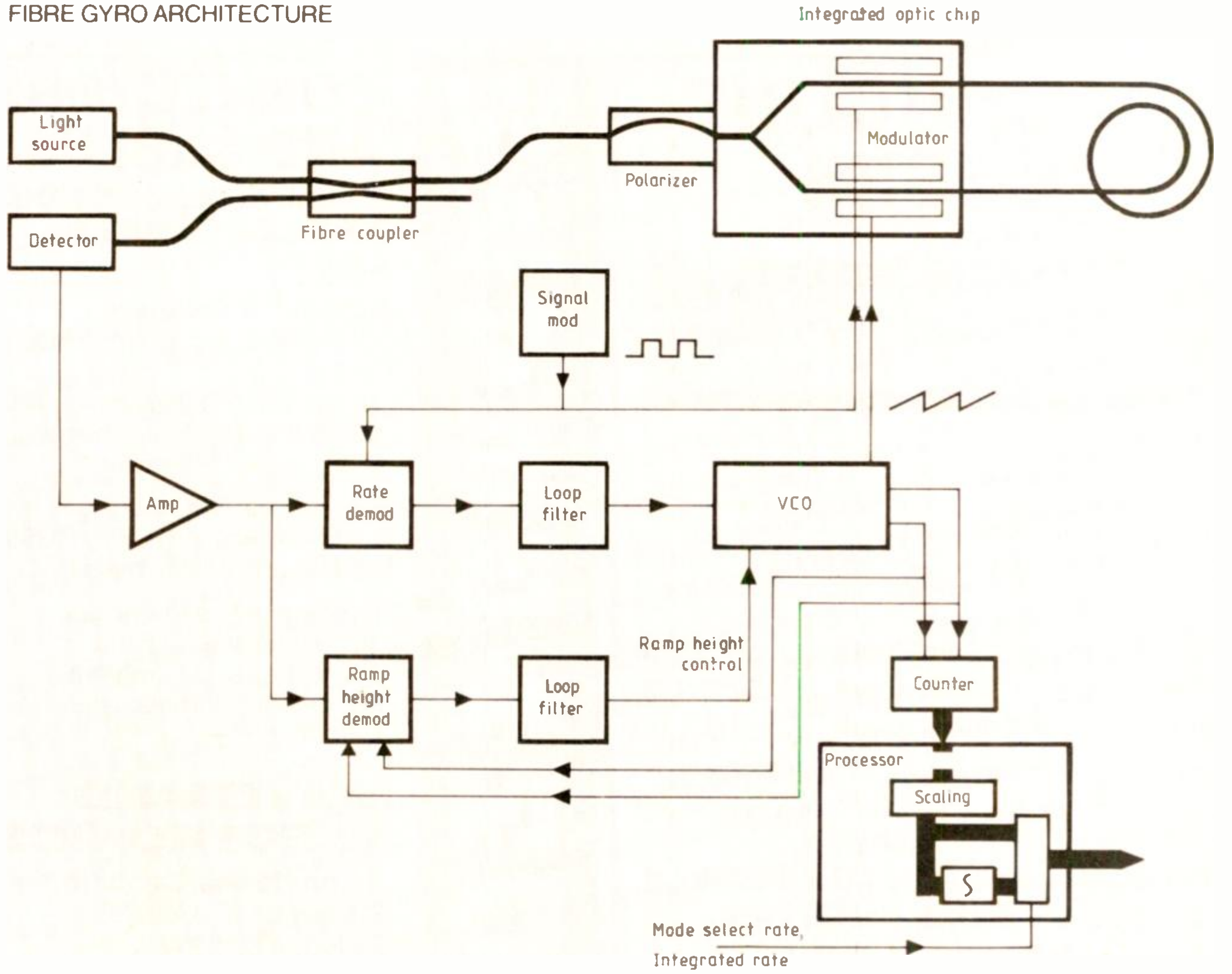
The output from the gyro is obtained by counting the reset pulses from the serrodyne oscillator, each of which corresponds to fixed positive or negative angular increments depending on the polarity of the ramp. A microprocessor performs scale factor corrections on these signals and outputs either rate or integrated rate information.



The basic concept of the fibre optic gyro relies on an effect first described by Sagnac in the 1920's in which a differential phase shift is induced in light that travels clockwise and anti-clockwise around a rotating optical system.

In a practical arrangement, light from a source is passed through a first beam splitter and a single optical mode selected. The light then passes through a second beam splitter and propagates in both clockwise and anti-clockwise directions around the fibre coil. In the absence of rotation, the propagation times are identical so that when the light arrives back at the second beam splitter perfect constructive interference occurs. Rotation results in a difference in propagation time between clockwise and anti-clockwise beams, manifested as a relative phase shift between them and therefore reduced intensity at the detector. The phase shift is very small and the key problem is how to apply to electronics to enhance the resolution and provide a measurable input.

FIBRE GYRO ARCHITECTURE



PIONEERS

26. Harold S. Black: inspiration on the ferry

W.A. ATHERTON

It has been called one of the most fundamental developments in the history of communications, yet patent offices in American and Britain nearly dismissed it as unworkable. It is now one of the most widely used electronic circuits, yet it had "all the initial impact of a blow with a wet noodle", according to one who was there at the time. "It" is the negative-feedback amplifier, invented by Harold S. Black of Bell Telephone Laboratories in 1927.

For years Black had wanted to increase the number of telephone channels which could be passed through an amplifier. Whilst others at the recently-formed Bell Labs aimed at solving the problems of using three channels, to their bewilderment Black dreamed of 3000. For any significant increase, however, the problem of distortion within amplifiers needed to be beaten. To Black, as to many others, that was the goal. At last the answer came to him 'in a flash' whilst travelling to work in New York: if some of the output were fed back to the input in antiphase, the distortion could be cancelled. He sketched the idea on to the first piece of paper that came to hand, his newspaper.

IRONING SHIRTS

Harold Black was born in 1898 in the small factory town of Leominster, about 35 miles west of Boston, Massachusetts. His first job was ironing shirts for $12 a week, his father having been made redundant. Even then, in his teens, he owned a set of cheap books on electricity and magnetism, had conducted his own experiments and wanted to become an electrical engineer – "because I didn't have much money".

In the summer of 1921 Black graduated with a degree from the nearby Worcester Polytechnic Institute. His education, he recalled in 1977, included "surveying, hydraulics, engineering, pattern making, drop-forge, and machine shop, in addition to physics, chemistry, and mathematics".[1] On 5 July he moved south to join Western Electric at its laboratories near Manhattan's West Side docks in New York City. His $32 a week salary was $5 more than other graduates who started with him. However, in September, when the others received a $3 rise and he did not, he decided to resign. By next morning his alternative plan, to go to business school at Harvard, had lost its attraction and so he stayed put. When finally he did leave, because he had reached the enforced retirement age of 65, it was a reluctant parting. "They fired me", he said.

The Western Electric laboratories became the backbone of the new Bell Telephone Laboratories, founded on 27 December, 1924. When they became operational on 1 January, 1925, there were about 3600 employees, including around 2000 technical staff – and, of course, Harold Black was one of them.

After his decision not to resign Black started to go into work on Sundays to read memoranda files dating back to 1898 – the year he was born. By the time he was up to date he had learned what was happening on all 12 floors of the laboratories. He knew the names of the engineers and their supervisors and he had acquired a strategic view of the problems they faced.

INTOLERABLE DISTORTION

One of those problems lay with the electronic amplifiers which were used as repeaters. "No one knew how to make amplifiers linear or stable enough in those days", wrote Black in 1977. "They were subject to an intolerable amount of distortion".[1] The main problem was the generation of unwanted frequencies, particularly second harmonics, within the thermionic valves.

As Black pondered he began to realise the size of the problem to which he had turned his mind. It was not long since the first coast-to-coast voice communication had taken place across America, using an open wire with a single channel. The largest repeater amplifier so far built was for only four channels. Yet he foresaw a need for a nationwide network providing "many, many channels".

At home in his rented accommodation in New Jersey he plotted graphs to show how linearity would be affected by increasing the number of channels and the number of amplifiers. Third-order harmonics, he assumed, would be reduced as he knew second-order ones were. He showed his work to Ralph Hartley (who invented the Hartley oscillator in 1915). Hartley disillusioned him. Third harmonic distortion, he said, would increase cumulatively with the number of amplifiers. In a string of 1000 amplifiers, the cumulative voltage distortion would be about 60dB. Black reconsidered. He thought of the problems of a single amplifier catering for up to 3000 channels. He realised that for a string of x amplifiers the distortion from each amplifier must be reduced by a factor of x. But how? His supervisor complimented his work as "beautiful"; but why bother with 3000 channels?

Immediately after Christmas 1921, Black asked to be assigned the task of producing amplifiers capable of multichannel work

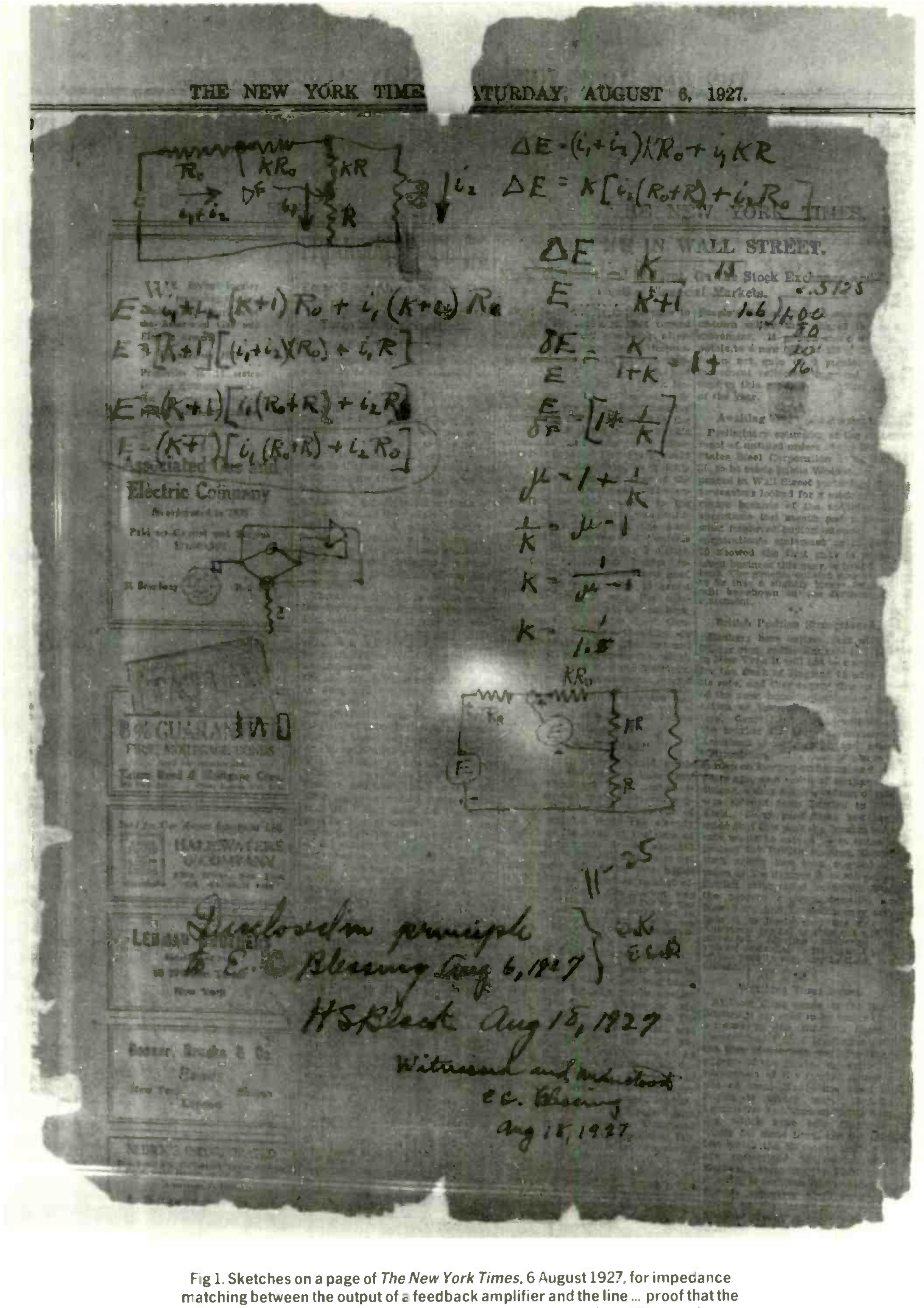


Fig 1. Sketches on a page of *The New York Times*, 6 August 1927, for impedance matching between the output of a feedback amplifier and the line ... proof that the ability to perform long division is not an essential attribute of a brilliant engineer.

over several thousand miles. In effect he was told to go ahead – provided it did not interfere with his other work!

Over the next couple of years he studied the problem at weekends and in the evenings. Like others he defined the problem as the need to improve the performance of the thermionic valves, by a factor of hundreds or thousands. As one other worker put it: if a factor of ten had been needed it might have been possible, with hard work.

Black attributed what might be called the breakthrough to inspiration received from Charles Steinmetz, the famous electrical engineering genius from General Electric at Schenectady, New York. Steinmetz gave a lecture at the American Institute of Electrical Engineers (now the IEEE) in New York in March 1923. It was not the subject that inspired Black but the clarity and logic of Steinmetz's thoughts. Perhaps it was Steinmetz's last, and most indirect, contribution to electrical progress: seven months later, to the day, he died.

When Black got home at two o'clock in the morning he redefined his problem as Steinmetz might have done. He now saw the problem as not one of improving the valves but of removing the distortion from the output of the amplifier. He was now willing to accept an imperfect amplifier and view its output as a combination of the wanted signal and an unwanted signal. By reducing the output to the same amplitude as the input, and subtracting one from the other, he would be left with only the unwanted signal which, whatever its cause, he now regarded as distortion. This distortion could then be amplified in another amplifier and subtracted from the original amplifier's output. The next day, 17 March 1923, he sketched out how to achieve his goal in practice and gave his invention a name – the feedforward amplifier.

"HOORAY!"

The same day he built two versions of the new amplifier and found that he had reduced the unwanted distortion by over 40dB. It was a phenomenal advance. He had proved that entirely new solutions were possible which were far better than squeezing the last drop out of valve improvements.

However, the feedforward amplifier was not then a practical circuit. It could be made to work, and for four years Black struggled to crack problems which were not fully beaten until decades later. It was not until 1972 that Bell engineers felt they had successfully demonstrated the feedforward amplifier. Black was invited to see a demonstration. "Hooray", he shouted.

It took those four years for the moment to arrive when "in a flash" Harry Black saw that the answer to his problem was to feed the output of the amplifier back to the input in reverse phase: the negative-feedback amplifier.

Black was on a ferry crossing the Hudson River on his way to work, looking at the Statute of Liberty, when inspiration struck. Quickly, before the idea was lost, he sketched a diagram and wrote equations on the nearest piece of paper to hand, that day's

...the answer... was to feed the output of the amplifier back to the input in reverse phase: the negative feedback amplifier

New York Times, for Tuesday, 2 August, 1927. He signed the sketch and as soon as he arrived at work "paper in one hand and his pipe in the other" he had it witnessed, understood and signed by a colleague. Four days later he sketched out the arrangement for matching the output impedance of a negative-feedback amplifier to that of the line. Again he was on the ferry and again *The New York Times* was used as a notepad (**Fig. 1**). Note the day of the week: Saturday!

By the end of the year Black had a working model in which the reduction of distortion was 50dB, the target he had set himself six years earlier. Boldly he asked for permission to develop the new amplifier for a new transcontinental telephone cable. The director of research, Black recalled, objected on the grounds that a negative-feedback amplifier would not work. Instead Black was told to build a very powerful "Colpitts amplifier", the push-pull amplifier invented by E.H. Colpitts* of the Bell System in 1912 – one of the earliest electronic circuits.

A few years of hard work passed for Black and his colleagues before the new design could be said to be successfully completed. They were driven on by the now-appreciatd economic necessity of such a device. "It was this pressing need, plus Black's stubbornness, that carried us through those early years", one of his colleagues has said. "The advantages he pointed to were so compelling as to drive us through years of failure."

FIELD TRIAL

A field trial of the negative feedback amplifier was completed with great success in 1931 at Morristown in New Jersey. Sixty-eight repeater amplifiers were crammed into a 25-mile length of cable. Each amplifier measured 19 × 9 × 10 inches and the loop through the amplifier and the feedback path was over a yard long.

Experts the world over, so it has been said, asserted that the negative-feedback amplifier would never work. Certainly the patent offices, according to Black himself, initially did not believe in it. The British Patent Office demanded a working model and the Americans took nine years to issue the patent, partly because of its very broad claims. By the time he died in 1983, aged 85, Harry Black had taken revenge on the patent offices of the world by keeping them busy. He held over 300 patents.

Black's published papers in 1933 and 1934 silenced most doubters with the results of the Morristown field trial. In later years Harry Nyquist and then Hendrik Bode put the design of negative-feedback amplifiers on to a systematic mathematical footing. Negative feedback became an indispensable tool of amplifier design.

As if one claim to fame of such magnitude is not enough, Black could claim another. Alec Reeves, of the ITT laboratories in Paris, had conceived a digital method of speech transmission in 1937 and named it pulse-code modulation (see Pioneers 21, *E&WW*, September 1988, p.873). The Second World War compelled Reeves to flee back to his home in England and devote his time to other matters. "Having had it patented, for understandable reasons I then let the invention slip from my mind until the end of the war. It was in the United States during World War II that the next step in PCM's progress was made, by the Bell Telephone Laboratories". That work was carried out by Black and his co-workers. Their publications of 1947 are claimed as the first technical publications on pulse-code modulation (PCM). Black himself, when in his eighties, claimed to have been the first in America to use PCM.

When Bell Laboratories "fired" him at the age of 65, after 42 years with the laboratories and its predecessor, Black joined a company called General Precision Corporation as Principal Research Scientist. At the age of 68 he became a communications consultant and in 1980, at the age of 82, he was still doing some consultancy from his home in New Jersey "not too far from Bell Labs." He still liked to call in there because, as he put it, "I can't get over the things they're doing now".[2]

That is all a far cry from Harry Black's first attempt at a telecommunications system. When he was 16 years old he built a microphone "out of pieces of wood, two pieces of carbon I had sawed from a battery, a tin can, and a spring for contact". It was sensitive enough to hear a watch tick "or a conversation anywhere in the house". He then passed a thin wire across the street and into a neighbour's house and, using an old telephone, he found he could listen, in his own attic, to their conversation. This triumph was driven by the same desire as his later effort to beat distortion: better communications. Not so much with his neighbour, perhaps, as with his neighbour's five daughters. However the system did not survive the return of the girls' father from work. "So my first telecommunications system did not last very long", Black observed.[1]

References

1. H.S. Black, *IEEE Spectrum*, December 1977, pp54-60

2. *Electronics*, Vol. 53, No 9, 17 April, 1980, p429.

* E.H. Colpitts also invented the Colpitts Oscillator in March 1915, a month after R.V.L. Hartley, also of the Bell System, had invented the oscillator named after him.

Next in this series of pioneers of electrical communication: Harry Nyquist and Hendrik Bode.

Tony Atherton is a principal Lecturer at the IBA Harman Engineering Training College, Seaton, Devon.

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BBC digits to Oz

BBC World Service has established a dedicated digital link via satellite to Sydney, Australia, providing a good quality (speech) programme feed to Australian broadcasters. Ten Australian stations, including ABC and all four major commercial radio networks, are taking the service. In Sydney, the potential reach is already 70% of radio listeners.

While BBC World Service can be received in Australia on HF from the Far Eastern relay at Kranji, Singapore (four 100kW and five 250kW transmitters) and intermittently from the Caribbean relay or UK transmitters, this is subject to the variability of HF propagation, the heavy congestion of the HF broadcast spectrum, and the minority interest of listeners in HF reception.

The digital programme feed from Bush House is transmitted over a Mercury digital satellite link to the Australian Telecom Ceduna earth station near Adelaide and thence to Sydney where it is decoded back into analogue form and made available by terrestrial or satellite links to the newsrooms of the 100 or more Australian radio stations capable of accessing such a service.

Digital transmission is based on the use of the French AETA 7kHz SCOOP codec (Speech COdec OPtimizing quality/ Système de COdage OPtimisant la Parole) conforming to CCITT recommendation G722. This codec is designed to provide a good quality analogue speech bandwidth of 50Hz to 7kHz (instead of the standard 300Hz to 3.4kHz telecommunications speech bandwidth) with a signal-to-noise ratio of 50dB (12dB better than the 38dB for digital speech encoding) while not requiring more than the 64Kbit/s capacity of a standard digital telephone channel.

SCOOP codecs for the Bush House and Sydney terminals have been supplied to the BBC by L-TEQ Data Systems Ltd of Weybridge, Surrey. For the past two years, a BBC news and current-affairs feed has been used by up to 60 American Public Radio stations by means of an analogue satellite link to Washington DC and this is being converted to digital transmission using 7kHz SCOOP codecs.

Coding is based on sub-band adaptive pulse code modulation (ADPCM) and the codec was originally developed for the French broadcasting authorities who are using this type of codec on satellite links. A 15kHz (128Kbit/s) version for high-quality music links will become available later this year and may be used for the ILR satellite links. With either version, two SCOOP channels can be used for stereo distribution over satellites, a bit-rate of 256Kbit/s providing 15kHz, full FM-quality, stereo.

It would thus appear that the French system is basically similar to, but pre-empts, the four-bit ADPCM encoding proposed by S.M.F. Smyth and J.V. McCanny of Queen's University, Belfast ("Television Broadcast" September 1988) which also achieves a 15kHz audio bandwidth with a bit rate of 128Kbit/s.

Growth of world broadcasting

In recent years, with the decline of listener interest in h.f. radio reception, the BBC has been keen to secure international or local medium-wave or FM outlets on a dedicated 24-hour basis. Currently, BBC programmes are carried on a 5kW FM transmitter at Tanglin, Singapore; on two 500kW and one 200kW MF transmitters at Zyyi, Cyprus; on two 750kW transmitters on Masirah island, off Oman; and on a 10kW FM transmitter in Berlin. In Hong Kong, BBC World Service is to be carried to the colony on a dedicated "Channel Six" of Radio Television Hong Kong, using the satellite feed to the BBC Hong Kong HF relay station opened in 1987.

At the beginning of December, the USSR ceased jamming the transmissions of the American-funded Radio Free Europe, Radio Liberty and Radio Free Afghanistan and also some Deutsche Welle (West German) programmes. It would appear that the large and complex networks of Russian skywave and ground-wave jammers are now virtually dormant. Jamming of BBC and Voice of America programmes ceased about two years ago.

Since the effects of blanket jamming on HF broadcasting can never be confined solely to the specific transmissions being attacked, this latest move should bring considerable improvement to world broadcasting generally. It should also reduce the need for simultaneous, megawatt transmissions on several different frequencies that has added greatly to the congestion of the HF broadcast spectrum.

Russian efforts to establish its first overseas MF relay base on Cuba have not been without problems. Cuba agreed to the base and gave Moscow World Radio a frequency. Unfortunately for the Russians, this frequency is not an IFRB assignment to Cuba and, I believe, is the one used by the Americans for their Radio Marti programmes directed at Cuba. In 1982, Cuba "walked out" of a Region 2 planning conference after filing a plan for 187 omnidirectional MF stations, including two 500kW installations. Cuba apparently considers it has the right to work to this plan although it has never been accepted by ITU/IFRB.

Need to improve pacemaker EMC

For many years it has been recognized that there is a potential hazard when patients with implanted cardiac pacemakers are subject to the very high field-strengths that may exist near high-power broadcast, communications and radar transmitters. A draft standard was issued by CENELAC in 1986: "Safety of implantable cardiac pacemakers" (pr EN50 061) which defines an acceptable reaction threshold to disturbance voltages (measured from peak-to-peak) from low audio frequencies to above 50MHz.

However, a paper by T. Bossert and M. Dahme of the Institut fuer Rundfunktechnik (IRT), Munich, at last September's "International Conference on EMC" showed that for practical application in radio engineering, the specification of disturbance field-strength instead of disturbance voltages is necessasry since only field-strength can be measured (often with great difficulty in the near-field).

In practice, as IRT work has underlined, there is still as much as 40dB variation in the sensitivity of pacemaker designs to RFI voltages between the least and most susceptible models. The IRT experiments, backed up by theoretical studies at the West German Institut fuer Medizinische Technik at Giessen, show that quite simple, low-cost circuit modifications of the best design can provide a further 32dB voltage improvement. IRT believes that the work has shown that, if their suggestions were adopted, pacemakers would function satisfactorily at all field strengths within the ANSI limits of non-ionized radiation, as applied to healthy persons not having implanted pacemakers. Clearly this is not the situation at present.

Pacemakers show most sensisitivity to pulsed AM signals. External RF signals may cause an inhibited pacemaker to start stimulation when it is not needed, although this is unlikely to have any serious effect on the patient. But external signals can also inhibit the action of a stimulating pacemaker. Since this effect usually occurs at much lower levels of RFI and is much more dangerous to the patient, it represents the critical design threshold.

The IRT experiments were based on laboratory measurements on 34 models when placed within a NaCl solution corresponding to the specific conductivity of the human trunk at 5MHz. This showed that an implanted electrode is well screened from the purely electric field of the plate capacitor, although susceptible to RFI.

Suggested improvements to pacemaker circuitry put forward by IRT are: (1) Shunting the input/output leads to cases with an RF-type capacitor of at least 1nF; (2) Inserting a passive low-pass filter between the input/ output leads and the high sensitivity input amplifier; and (3) Avoiding non-linearities by choosing adequate symmetrical clipping levels of about 10 to 20V. With such modified pacemakers, patients could be assured that the working of their life-saving aids would not be affected by radio signals at field strengths within ANSI limits.

Radio Broadcast is written by Pat Hawker.

RADIO COMMUNICATIONS

Spectrum management

All the signs are that another "general" World Administrative Radio Conference of the ITU will be held in the early 1990s at which the entire International Table of Frequency Allocations, forming a vital part of the ITU RADIO Regulations which have the status of an international treaty, will be revised. The first post-war conference at Atlanta City, USA in 1947 introduced the important concept of dividing the world into three regions, permitting the spectrum to be divided up rather differently for some services in different parts of the world, but generally all three post-war conferences have maintained the traditional concept of allotting "bands" of frequencies to specific "services" (some on a "shared basis with "primary" and "secondary" status and with an increasing number of "footnote" exceptions relating to specific countries). Individual frequency assignments are confirmed and co-ordinated and protected by registration by the International Frequency Registration Board at Geneva. International rather than purely national regulation of the radio spectrum arises basically from the need to limit or control radio interference across national frontiers as well as from the international nature of many telecommunications services, including the aeronautical and maritime mobile services. Radio waves capable of propagation over long distances, such as HF and satellite, high-power LF and MF, tend to pose the greatest problems although with, for example, new pan-European systems there is increasing need for common frequencies and standards on VHF and UHF.

With the ever-growing congestion of the spectrum there has been increasing dissatisfaction with the traditional concepts of international regulation. The ITU Plenipotentiary Conference this year will be urged by some delegates to explore possible alternatives for consideration at the next WARC.

As Les Barclay (DTI) has noted: "With the availability of frequency-agile transmitters and receivers and micro-computer control, there is now a body of opinion which advocates a new method of managing the HF spectrum, whereby frequencies are not specifically assigned but a system is permitted to select its own optimum frequency from time-to-time, using real-time channel evaluation (RTCE) techniques. This fundamental new aproach needs a full evaluation. This could be done using a comprehensive HF propagation model, and adequate models for this purpose do not yet exist."

Another far-reaching proposal, affecting all parts of the spectrum, has come from Wayne Longman (Canadian Department of Communications). This would add an important element of flexibility based on the concept of protecting allotments in other countries primarily by not exceeding pre-agreed interference levels. Provided this could be achieved, any country would be permitted to obtain IFRB recognition and protection regardless of whether the transmissions concerned are for the service(s) allocated to that band. In other words so long as any station *in any service* does not affect the spectrum in another country by more than a pre-agreed interference limit, such a station would be acceptable, since other countries would still be able to implement stations in that band with no greater technical constraints than before. This concept would not eliminate the need for ITU band boundaries and services but would increase each country's sovereignty over the use of the spectrum within its territory, while maintaining an international regulatory system striving to avoid interference between countries. It would to some extent help overcome the present difficulty that, in general, once an allocation has been made to a "service", any system belonging to that service, no matter how different from the foreseen model, can claim protection consistent with its status in the frequency allocation table.

An element of this concept has already been incorporated in the planning for Region 2 of their new 1605 to 1705kHz broadcast band. The concept would allow services having greater interference characteristics to be assigned deeper within a country's own territory. Longman suggests that "the adoption of this technique might yield the ultimate flexibility in the use of the radio spectrum".

HF propagation study

CCIR Study Group 6 (IWP6/14) in an effort to obtain improved modelling of HF propagation is currently setting up an ambitious measurement programme based on automatic monitoring of "beacon" transmissions from nine dedicated transmitters. These are being located in northern and southern mid-lattitudes and near the Equator in each of the three ITU Regions (Europe/Africa, the Americas and Far East/Australasia).

Each transmitter will radiate on five frequencies sequentially, remaining on a specific frequency for four minutes. During this time a 12-second coded sequence will be transmitted: a brief burst of FSK for synchronizing purposes, morse callsign, two bursts of 1.2Kbit/s complementary sequences to permit automatic measurement of the multipath characteristics existing over the path, four seconds of FSK reversals to permit measurement of both signal and background field-strengths; then three seconds of steady tone to permit manual measurements to be made. Transmitting antennas will be omnidirectional broadband vertical monopoles.

A large number of receiving terminals are planned at locations spread throughout the globe. These will comprise an active monopole antenna; a computer-controlled synthesized receiver of the type available at the top-end of the amateur-radio market; a special-purpose computer interface; and a controlling personal-computer and data processor with floppy-disc storage.

The receivers will be programmed to monitor a 12-second transmission on one frequency and then switch to another transmission. During each hour 25 frequency/transmitter combinations will be monitored at each location with the data on floppy disc forwarded to CCIR, Geneva.

In brief

American radio amateurs in Texas and Arizona have made the first Earth-Moon-Earth ("moonbounce") contact on the 10GHz amateur band. In Texas a modified SSB transverter fed a TWT amplifier delivering 55 watts to a 12-ft dish. Receiver noise figure was 2.1dB. In Arizona a 14.5-ft dish was fed with 90 watts RF and the receiver had a 1.5dB noise figure.

Based on a study of sediments laid down in Australia, Ron Bracewell claims that the Sun's cycle of activity has maintained a steady rhythm, averaging 11.2 years, for over 600-million years.

Archivists have expressed concern that the "electronic office" will leave few permanent records for future historians to study. A more immediate problem appears to be the fading within months of the contents of facsimiled documents.

Robert Morris, a graduate student at Cornell University and son of the chief scientist at the National Computer Security Center — a division of the US National Security Agency — has been revealed as the person who introduced a "virus" (worm) into thousands of terminals of the UNIX computer networks of ARPANET, MILNET and NSFNET. Although the virus did not destroy any data or compromise programs, the cost of eliminating the flaws in UNIX networks that permit virus infection is likely to prove substantial. According to *Nature*, Prof. James D. Bruce (MIT) claims that: "Many people are hailing this as the end of the user-friendly era of computing, but if we've gone that far we have literally put our heads in the sand, or locked ourselves into a fortress we can't get out of." The situation with network security is analogous to people putting locks on doors as a deterrent, then adding alarm systems until eventually it gets to the point where it is difficult to get into your own home.

Radio Communications is written by Pat Hawker

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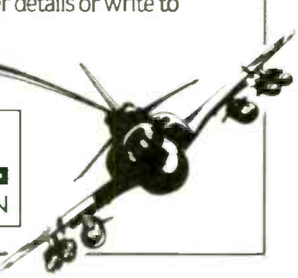

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Vision to Sound Power Ratio	— 10 to 1
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Spurious Harmonic Output	— −40dB (80dB if fitted with TCFL1 filter or combined via TCFL4 Combiner/Leveller

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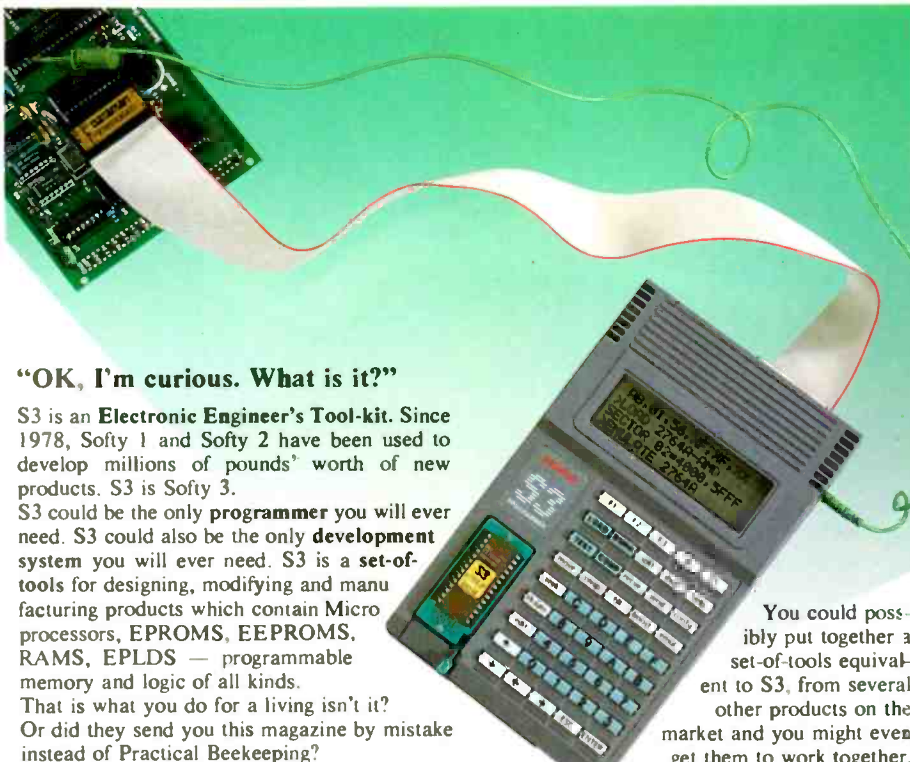

"OK, I'm curious. What is it?"

S3 is an **Electronic Engineer's Tool-kit.** Since 1978, Softy 1 and Softy 2 have been used to develop millions of pounds' worth of new products. S3 is Softy 3.
S3 could be the only **programmer** you will ever need. S3 could also be the only **development system** you will ever need. S3 is a **set-of-tools** for designing, modifying and manufacturing products which contain Micro processors, EPROMS, EEPROMS, RAMS, EPLDS — programmable memory and logic of all kinds.
That is what you do for a living isn't it?
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"I think I have all the tools I need"

Engineers have discovered lately that they are more productive in a windowing, multitasking computer environment. The PC workstation is now fashionable. Coffee-stained notebooks, boxes of tangled wire and two-legged-transistors are going out-of-style. Today you can sit down at a computer keyboard and tackle everything from design to documentation. At a keystroke you can re-assemble your source-file, download to your memory-emulator and run your program. The

"Unbelievably good, obviously designed by working engineers for working engineers"

prototype of your new product will work exactly like the real thing, except that you can set break-points, examine variables and stack, debug the code and so forth. Logic Analysers, Storage Scopes, lots of instruments these days have RS232 or IEEE interfaces, and can be controlled in another task-window, to provide insight into what's going on. S3 fits in well, needing only a single RS232 port for complete remote control. In short, if you value your time, isn't it time you bought yourself some proper equipment?

"I wonder — would I use it much?"

S3 is a small computer which uses PROMS for storage like other computers use disks. A PROM in the front panel socket can be loaded as a working program or as data. S3 can make this data-memory externally available, taking the place of any 25 or 27 series PROM in your prototype. If the Flying Write Lead is connected to the microprocessor's write-line, it can emulate RAM too, by providing the WRITE input missing from PROMS. This is a real advantage over simple ROM-emulators, because variables and stack can be inspected and the target system can feedback data. Memory is permanent, in effect,

"I wouldn't dream of parting with it"

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"Why should I spend hard-earned cash?"

Presumably to help you make some more cash, a little easier.

"What's it like as a programmer?"

S3, as it comes, will program any 24/28 pin EPROM/EEPROM that goes in the socket. Of course, the manufacturers, bless their little hearts, are always bringing out PROMS which use new programming methods. But not-to-

"I'll bet you sell thousands of these"

worry, upgrading is usually a simple matter of installing the latest software which takes only a few seconds. We supply up grades at nominal cost in a PROM — or you can get 'em FREE by calling our Bulletin Board.

"It's a bit of a risk. Does it work?"

Yes! Do be careful; other makers go on about performance, yield, dire-consequences and peace-of-mind to frighten you into buying their big, expensive Prommers. Why not buy one of these on approval and compare it with S3? The

*"It beats the socks off the two ****s we've got"*

PROM makers supply free data-sheets which set-out the way to program their devices. You can check voltages and signals with an oscilloscope. Speed comparisons — theirs, not ours — prove S3 to be faster. 14 secs to Program an Intel 27C256, 3 secs to Load or Verify. Compare features, price, performance, decide which Prommer you like best and send the other one back.

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SIZE: 7.3 x 4.4 x 1.8 ins. WEIGHT: 18oz. approx.
BATTERY: 8.4 volt 500ma/hr rechargeable nicad.
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EMULATE for 6 hours.
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