John Linsley Hood – MEMORIAL ISSUE

ELECTRONICS WORLD

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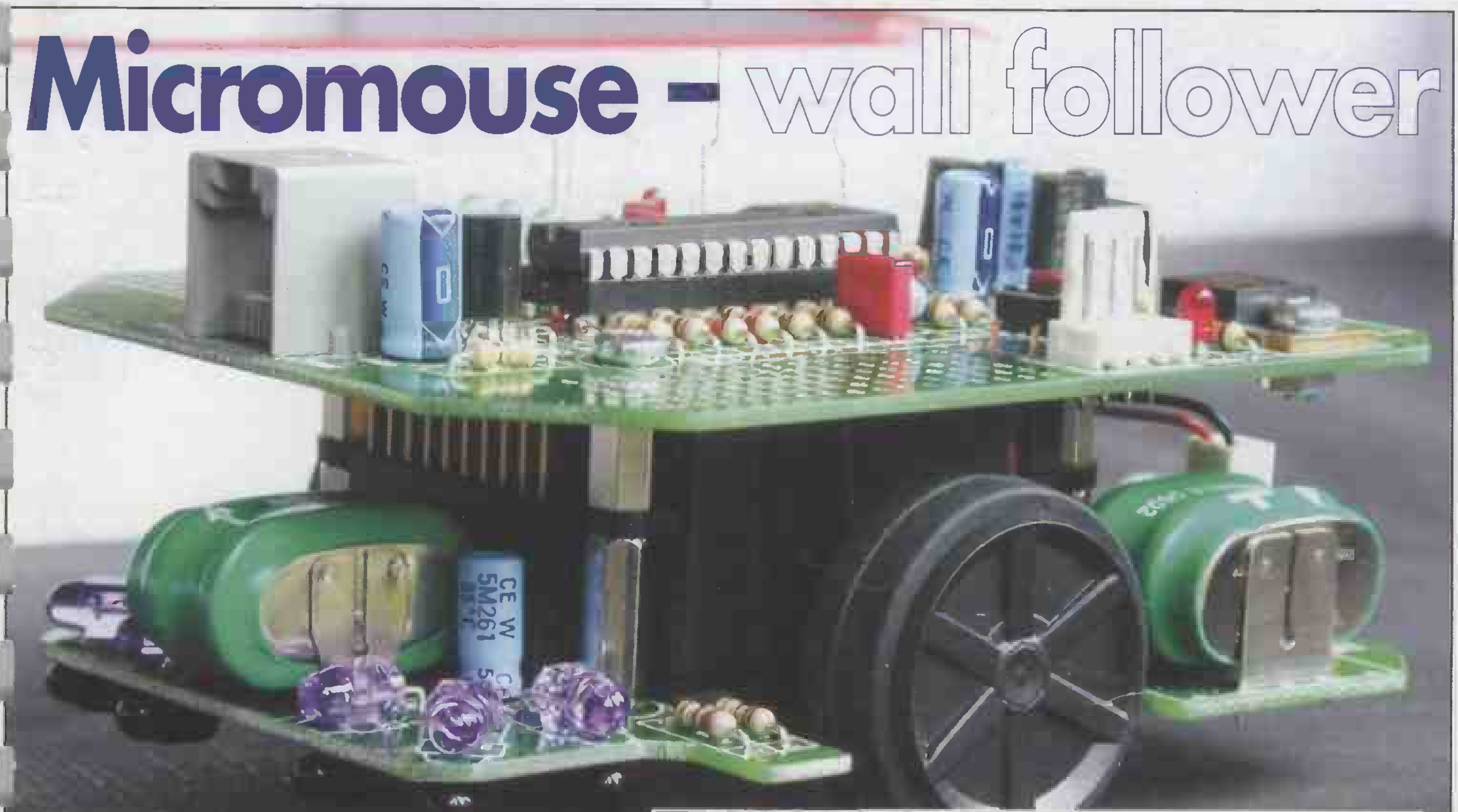

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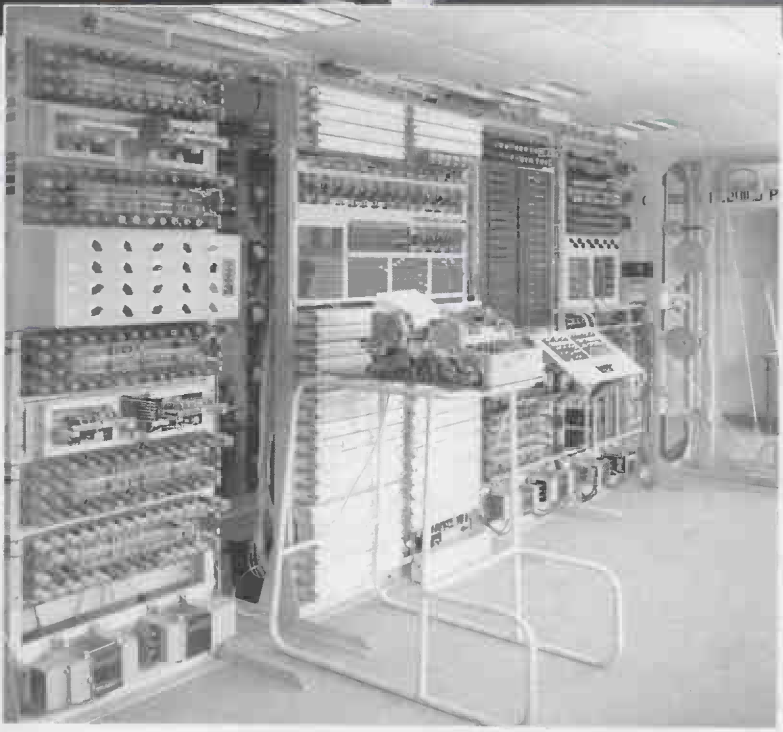

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Audiotastic

If you are into audio – and I know a lot of you are – you will enjoy this issue. Obviously, the death of one our of major audio contributors, John Linsley Hood, means that this issue is dedicated to him. Not only have we got tributes from around the world, but also I've reprinted his classic class A design from *Wireless World* circa 1969. We have faithfully reproduced the layout, courtesy of my optical character reader – the only difference being that a couple of typos have been corrected.

Also in this issue, by pure coincidence as we had planned it ages ago, is the start of a series of articles by Graham Maynard, who has been looking for some answers to the age old questions around the 'sounds' of valves and transistors. His investigations (we think) will finally quantify exactly what those differences are and will culminate in a practical design in his next series, which is currently on the drawing board. I'm hoping this will be a modern classic, like JLH's was in the seventies.

For readers who hate audio, there is much reduced audio content next month and a bumper crop of Circuit Ideas, as I've got a huge number 'in stock' and currently contributors are waiting over a year to see their designs in print, which is unacceptable. So, speed things along a bit, I'm going to increase the number of circuit ideas for a while to clear some of the backlog.

Look out next month for our reader survey. We have not actually done one of these for two years and I reckon (as we're at a bit of crossroads) that we're due for one. Along these lines, we are also looking into the possibility of a 'proper' *EW* website. We are currently evaluating how much it will all cost and manpower requirements etc., but any input as to what you'd like to see on the site would be much appreciated. Some ideas floating around are a forum and a subscription form, along with the old article reprint service and archive CDs that are already there.

I've had a lot of feedback on the subject on an 'electronic version' of *EW*. And plans are afoot to do some test runs in the very near future. So all of you that have written in will be contacted shortly to join our test team. So, if anybody is interested in joining in – drop me a line and I'll put you on the mailing list.

And apologies to our archive volunteers – the JLH tributes and recruiting a new proofreader have taken up most of my time this month. By the time you read this, I'll have a plan that I'll impart to you all. Thanks for your patience.

Phil Reed

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Little inchworm tests friction

A miniature inchworm, moving just 40nanometres with each hump of its body, has been micromachined out of silicon by scientists at Sandia Labs in the US.

But it's not just an engineering curiosity, as the device is giving valuable insights into how friction acts on devices at the microscale.

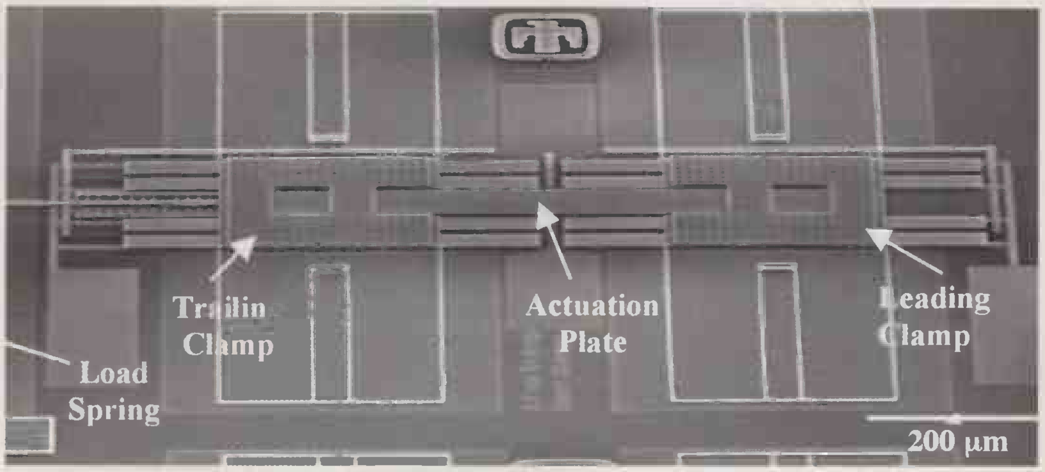
Sandia's project aims to study Amonton's Law - learnt by schoolchildren as frictional force equals the coefficient of friction times the normal force, or F=μN.

While the equation holds true at the macroscale - ladders against walls, for example - it does not neccesarily do so at the microscale, where other forces can increase the friction. This could have bad implications for rotating or sliding microsystems.

The inchworm is built from a suspended plate with a frictional clamp at each end. An electric field switches the clamps on or off. One end of the device is connected to a non-linear spring.

To operate the device one clamp is activated, and a voltage placed on the substrate. This attracts the connecting plate, forcing it to bend, and dragging the other clamp. The second clamp is activated, and the other relaxed, so the worm moves.

At a rate of 80kHz the inchworm can move at 3mm/s.



A photomicrograph of Inchworm, showing the central plate and frictional clamps.

Inchworm creators Maarten de Boer and Alex Corwin measuring friction using Inchworm.

The worm can generate a force of 2.5milliNewtons, about 250 times more than a conventional comb drive.

To measure friction, the worm was walked 20μm away from the spring and held by one clamp. The electric field holding the clamp was gradually reduced until the spring pulled the worm back slightly. This process could be repeated many times, measuring friction against different spring forces.

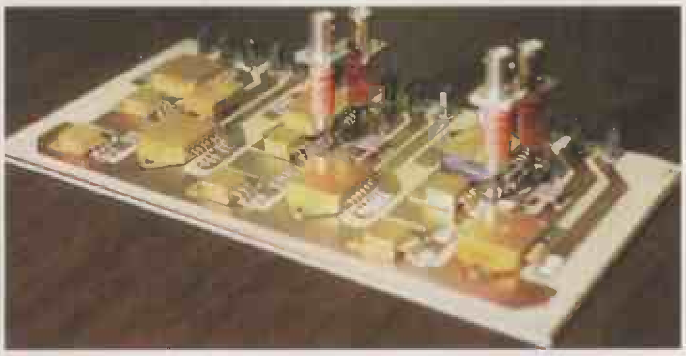
Friction was found to equal μN from loads of 1mN down to 50μN, but below this the static friction increased.

Inverter is all-silicon carbide

Rutgers University in New Jersey has produced an AC to DC inverter entirely in silicon carbide (SiC).

From SiCLAB, the university's silicon carbide lab, the 20kHz, 330V, 5.5kW device has six bipolar transistors and six merged-PIN-Schottky (MPS) diodes. More conventional silicon electronics are used in the driver stage.

MPS diodes are used particularly in SiC. They combine the low forward drop of Schottky SiC diodes with the low reverse leakage of SiC PIN diodes and have the structure of a Schottky diode with many small p-n junctions embedded in its junction.



The small junctions kill leakage. "When reverse-biased," said researcher Leonid Fursin, "the junctions form a depletion region within the Schottky interface." The penalty is only a small loss of Schottky junction area.

Silicon carbide can be used to make semiconducting devices with far higher breakdown voltages than silicon. At 1.7kV, the SiCLAB MPS diode leaks only 9μA.

Keep off the Nanograss

Scientists at Bell Labs have invented ‘nanograss’, silicon surfaces that can trap or release liquids by changin their electrical charge.

This technique for manipulating fluids could help with the cooling of ICs, allowing the system to move coolant where it is needed on a chip.

“The techniques resulting from this research might be applied to fields that range from optical networking and advanced micro batteries to self-cleaning windshields and more streamlined boat hulls,” said David Bishop, vice-president of nanotechnology at Bell Labs.

Individual ‘blades’ in the nanograss are just a few nanometres wide. Liquid droplets cannot form in the sides of the very thin grass and therefore sit on top.

“Physically, this technique reduces the surface area that the droplet feels, and reduces the interaction between the liquid and the substrate by a factor of a hundred to a thousand,” said Tom Krupenkin, who led the research.

The grass is coated with a hydrophobic solution that has reduced water-repellant properties when a voltage is placed across the surface.

“Such behavior may be harnessed to cool computer chips,” Krupenkin said. “A droplet could be sent to a hot spot on the chip, where it would sink in and absorb the heat, and then go on its way.”

Novel optical components, such as filters, could be created by moving the fluid into and out of nanograss areas, he said.

In batteries the nanograss could be used to isolate electrolytes when the battery is not is use, leading to longer lifetimes through reduced self-discharge.

These boots are made for walking

Berkeley Lower Extremity Exoskeleton (BLEEX) has been designed at University of California, Berkeley to make carrying heavy loads easier.

It consists of mechanical metal leg braces connected rigidly to the user with army boots at the feet and, to prevent abrasion, more compliantly elsewhere. The power unit and load go in the attached rucksack.

“We set out to create an exoskeleton that combines a human control system with robotic muscle,” said Homayoon Kazerooni, professor of mechanical engineering and director of UC Berkeley’s Robotics and Human Engineering Laboratory. “We’ve designed it be ergonomic, manoeuvrable and technically robust so the wearer can walk, squat, bend and swing from side to side without noticeable reductions in agility. The human pilot can also step over and under obstructions while carrying equipment and supplies.”

As well as military uses - the project was funded by DARPA, the US Defense Advanced Research Projects Agency - “the fundamental technology developed here can also be developed to help people with limited muscle ability to walk optimally”, said Kazerooni.

In experiments, a human pilot moved about a room wearing 45kg BLEEX and a 32kg rucksack “while feeling as if he were lugging a mere five pounds [2kg]”, said Berkeley.

More than 40 sensors and hydraulic actuators form a local area network (LAN) for the exoskeleton. Power comes from a petrol engine that delivers hydraulic power for locomotion and electricity for the computer.

The current prototype only works on flat terrain and slopes.

The UK’s Highways Agency has started trials of solar panels to reduce motorway noise and feed electricity back into the local grid.

The 50m long system, alongside the M27 in Hampshire, can generate 11kW peak, or some 9,500kWh each year. This is about five times that generated by a standard house system.

"The fences are easy on the eye; they will also help us to test safety issues and see how they affect motorists,” said Les Hawker, Highways Agency project manager for the scheme.

There are two system currently being trailled, neither of which is faced with glass. “One system uses standard modules and the is other based on unique ‘peel and stick’ solar technology which is simply bonded to the aluminium sound barrier, both suited to a wide range of construction applications,” said Dan Davies, director of engineering at Solarcentury, the panel supplier.

Desktop computer is mug-sized

Designed as development tools for the Japanese T-Kernel real-time operating system and associated T-Engines (see box), T-Cubes are 52x52x45mm fully-functional desktop computers.

Crammed inside is a 400MHz MIPS-based NEC VR5701 processor and 128Mbyte of RAM.

Although there is no hard drive, there is 16Mbyte of flash and slots for a PC Card (PCMCIA) card and CompactFlash. Other features include audio, a real-time clock and 1,280x1,024 graphics.

The T-Engine concept has been developed for 'ubiquitous computing environments' where "everything has a computer incorporated in it and is connected to a network", said the firm that developed T-Cube, Tokyo-based Personal Media Company (PMC).

As the ubiquitous environment can extend out through the Internet, a layer of security called eTRON is incorporated in the T-Engine concept "intended to prevent tapping, falsification, and disguise of malicious users so that electronic information can be safely delivered to the other party through insecure network channels", said PMC.

T-Cube due to come out in Japan in the summer, but may be re-named before then, said PMC, but don't get too excited. The user interface is in Japanese or Chinese characters, but not in English.

www.personal-media.co.jp

T-Engines

T-Engines come in several types and run the T-Kernel real-time operating system. Each is a fixed size and certain capabilities.

The Standard T-Engine is 75x120mm with an LCD and intended to be incorporated in portable information devices with comparatively advanced user interface features.

_T-Engine is 60x85mm and for home electronic appliances or instrumentation equipment with comparatively few user interface features.

nT-Engine is coin-size, for small home electronic appliances.

pT-Engine is tiny and designed to fit into the smallest units such as switches, lighting equipment, sensors, locks, and valves in a ubiquitous computing environment.

T-Cube is a modified Standard T-Engine with a video interface, a super set of all T-Engine capabilities, and a non-standard PCB to fit it into the box.

IBM recently demonstrated Power5, claimed to be the world's most advanced microprocessor, running multiple operating systems in virtual micro-partitions.

The chip is IBM's own high-end server and storage system version of the Power Architecture, which also spawned the PowerPC used in Mac computers.

Power5 was revealed at IBM's Power Everywhere event where it also chose to unveil several licensing deals for Power Architecture - notably one with Sony - and to give visitors a peek into the future with a 64-processor 'personal supercomputer' inspired by Blue Gene, the enormous computer IBM is building to solve biological protein-folding problems.

The photo is of a 2.8 billion transistor module including several Power5 chips.

Tags go long range

Radiofrequency ID tags, readable over a 15m range, have been developed by a group of four firms.

A chip capable of working between 1GHz and 2.45GHz was developed by EM Microelectronic and iPico. This was combined with an antenna from Graphic Solutions and a thin battery from Power Paper.

"Using battery-assisted RFID ICs, we achieve a reliability level and reading distances far beyond those attained by conventional, standard passive UHF devices," said Shalom Daskal, the chief executive of Power Paper.

The reader chip can discriminate between thousands of ID tags that might be in range at any one time, while reading up to 200 of the tags per second.

Focus moves to liquid lens

A variable focus lens with no mechanical parts, that mimics the focusing action of the eye, has been developed by Philips Research.

Called FluidFocus, the lens comprises two immiscible fluids, one a conducting aqueous solution, the other a non-conducting oil.

The two liquids are contained in a tube with transparent caps, the inside of the tube, and one end, coated with a hydrophobic material. This forces the aqueous material into a hemispherical blob at one end of the tube.

Placing an electric field across the tube causes the coating to reduce its hydrophobic properties, known as electrowetting, allowing the aqueous lens to spread as the surface tension reduces. The convex lens can actually be made to go concave.

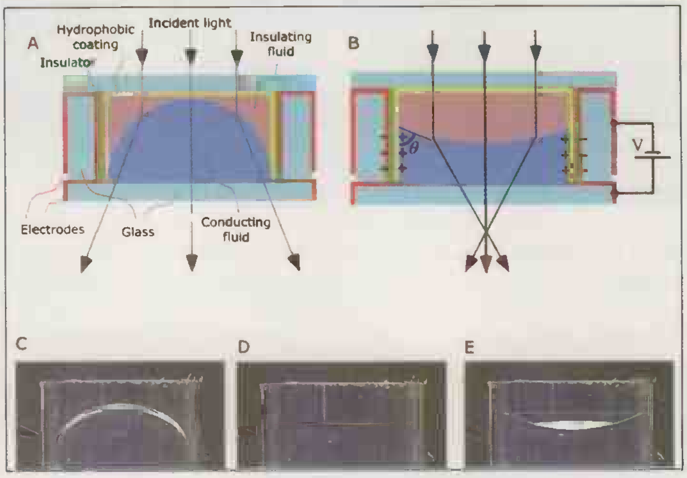
Philips' demonstration lens has a 3mm diameter and is 2.2mm in length. It can focus from 50mm to infinity and can switch over the full range in under 10ms.

The lens uses a DC voltage, and appears in circuit as a capacitor, said the firm. Test devices have been cycled over a million times in the lab.

Such a lens could be ideal for small, low cost devices such as mobile phones. These typically use fixed focus lenses, which to gain a suitable depth of field must use a small aperture. Using a variable focus lens would enable the use of wider apertures, hence more light would enter the system and quality would improve.

Another firm working in the variable lens market is Varioptic, which is currently suing Philips for patent infringement.

Both designs use the electrowetting technique, while Varioptic's DN-1000 lens uses an AC voltage to hold the lens' focus.



Small scope from LeCroy

LeCroy has introduced a range of compact oscilloscopes for benchtop use.

Called WaveSurfer, the scopes have a 34x15cm footprint, slightly larger than Tektronix popular TDS1000 and 2000 instruments, and a huge 26cm (10.4 inch) SVGA screen.

200 MHz, 350 MHz and 500 MHz versions are available, each in both two and four channel variants. One 500MHz probe is supplied per channel.

All six models have a 1Gsample/s ADC and 250kpoint of memory behind every input, and inputs can be paired to produce, depending on the model, one or two 2Gsample/s channels with a 250μs capture time at full sample rate.

Also on the scopes are a 10/100 BaseT network port and three USB 2.0 ports.

Software includes a Windows XP operating system, maths functions and report-generating code. Reports and screenshots can be saved to the internal hard drive or USB flash dongle, or e-mailed across a network with a single button.

Options include a clip-on battery pack for portable use, more memory, an advanced maths package - including additional math functions, chaining of math functions, and parameter math - and a specific package for mask testing of electrical telecom signals.

LeCroy has a reputation for easy-to-use scopes and after trying a prototype, Electronics World can confirm that the WaveSurfer user interface is every bit as good as the firm's other offerings. Nice touches include the ability to draw a box on the display touchscreen for zooming and separate cursor control knobs for measuring. Prices start €4,449.

www.lecroy.com/europe

A Hungarian architect has combined fibre optic cables with concrete to produce wall-making blocks that are translucent to light. The Litracon blocks contain five per cent fibre, and do not lose any structural strength, claimed Áron Losonczi. The blocks can be used in walls metres thick, or as paving with lights embedded underneath.

Electrochromic clock hits the tracks

UK transport sign company Tew Engineering has teamed up with Dublin-based display developer NTera to produce the world's first electrochromic information display - a railway station clock.

NTera's non-emissive technology, which is calls NanoChromic, can produce displays with a contrast of 15:1, similar to ink on paper. Electronics World got to see a prototype several years ago and can confirm this: viewing angle is extremely wide and images are clear in a wide range of lighting conditions.

In electrochromic displays, an ink changes colour under the influence of an electric field - from clear to deep blue in the NTera case.

Although the displays are not strictly bi-stable, the image takes hours to fade leading to the possibility of solar-powered clocks, NTera's business development manager Dan Wood told Electronics World power consumption in the clock pictured, which has 150mm high digits, is 1.5W and no additional illumination is required provided platform illumination is above the statutory minimum.

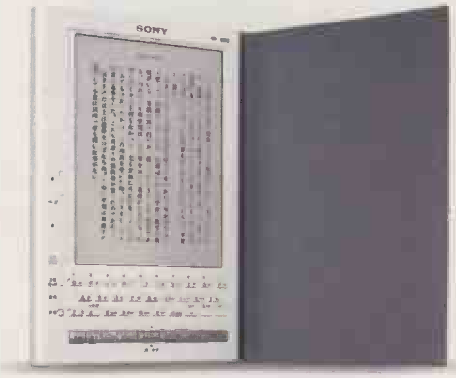
Tew and NTera intend to offer other transport signs in addition to clocks as applications are found.

Drive electronics are currently made from discrete components. NTera is expecting drive Asic silicon this summer which will cut costs enough to make NanoChromic shelf-edge signs in shops viable, said Wood.

Enter the paperless book

Sony has introduced the first commercial electronic book, with help from Philips Electronic and E Ink.

Called Librie, Sony's book has a black and white display with 170pixels/inch and an eight to one contrast ratio, which is only slightly less than newsprint.



E Ink provides the electrophoretic display material, formed from particles each measuring 100μm in diameter. White particles are positively charged and black are negatively charged.

An electric field between a single transparent top electrode and multiple base electrodes pulls the particles in one direction or the other, making the display appear black or white.

Philips provides the driver for the base electrodes in the form of an active matrix. This would usually be considered too power hungry for such an application, but the E Ink material is bistable. Thus once the display has been set, power can be removed.

Sony said four AAA cells can keep a reader engrossed for up to 10,000 turns of the page. There is enough memory in the device to store up to 500 books, said the firm.

Sony said the device is only available in Japan for the time being.

Face matching gets third dimension

NEC has developed a three-dimensional face recognition technology that can match faces even under poor lighting conditions, non-ideal camera angles, or when the subject is changing expression.

The basis for the algorithm is what NEC calls geodesic illumination basis (GIB), which computes geodesics - the shortest 3D distance between points - to produce a 3D map of the face.

Differences in illumination are used as reference points in the technique.

In NEC's own tests of 1,000 subjects, with 72,000 trials, the firm measured a true acceptance rate of 96.5%.

Interest in biometrics is growing, and the Internation Civil Aviation Organisation has mandated that all future passports should contain a biometric. Facial recognition is the ICAO's favourite method.

Disk drives get in a spin

Hard disk drive maker Seagate Technology has published research on heat-assisted magnetic recording (HAMR), which it says could lead to storage at densities of 50 terabit per square inch.

HAMR is designed to overcome the 'superparamagnetic' limit. This limit is due to the extremely low magnetic energy contained in a stored bit, which dissipates over time due to thermal energy. Increasing the recording field can only be taken so far.

A solution is to heat the recording medium as the magnetic field writes the bit of data. A laser is the best source of heat, and this reduces the field needed to write the bit.

Seagate expects to see HAMR in disks by 2010. A 3.5inch internal hard drive could hold perhaps 10Tbyte of data, with a density of 1Tbit/in^2.

The so-called 'areal density' has been increasing in the same vein as transistors on a chip. Commercially available hard drives can now exceed 50Gbit/in^2.

Optical storage, on the other hand, such as DVDs have areal densities under 10Gbit/in^2.

Perhaps the ultimate physical data storage, in a two-dimensional sense, could result from placing individual atoms to indicate a one or zero. One early prediction, using five atoms per bit, placed the density at 250Tbit/in^2. Though no doubt someone will find a way to beat this in the future.

Doping goes small scale

Buckyballs, the football-shaped carbon molecules, have been individually doped using a scanning tunneling microscope (STM) by a team from the Lawrence Berkeley National Laboratory.

Michael Crommie, a staff scientist at LBNL, was able to place a single potassium atom on each buckyball (C_{60}).

"Doping materials is a fundamental component of the entire modern electronics industry," Crommie pointed out, "but we need to take these techniques and scale them all the way down to the single-molecule level."

At the single molecule level, it might one day be neccesary to dope single C_{60} molecules with potassium, phosphorus or boron to create n and p type materials.

"With this work we've shown how to control the electron doping with absolute precision," said Crommie.

His technique is to pass the tip of the STM over the material and use a small current to attract atoms of potassium. They can then be moved and placed on the C_{60}.

A buckyball with four extra potassium atoms was about nine per cent wider and three per cent shorter than an unadorned buckyball.

FPGAs demystified

Following from last month's introduction to Gate Arrays, Eddie Insam will show how to implement a cheap development kit to get started using your own designs

Starting from the hardware point of view, the first thing to do is to decide how much of the application you have in mind is going to be implemented using GA technology. Given a large enough device, it may be theoretically possible to fit in all of your design, but this may be impractical in terms of development time, cost and power requirements. An ideal design would have a neat balance of responsibilities between microprocessors and gate array devices (there can be more than one in a design). A major decision will be whether to use CPLDs or FPGAs. This will be mainly dictated by the size and complexity of the application. As a simple rule of thumb, anything that requires less than 500 registers should be done with CPLDs. For anything that requires between 500 and 1000 registers, consider the use of more than one CPLD rather than go up to a FPGA design.

One of the most flexible parts of GA hardware design is the allocation of I/O pins. Unless you are concerned about speed, you can literally design the PCB first and dedicate any device I/O pins without giving much consideration to their function, as they are all more or less the same and can be allocated later on from the software. As most GAs have so many spare pins it is also common practice to use these as simple interconnect, i.e. connect all the pins of a micro to one side of the GA, and the rest of the circuit to the other side. This will make things like board and system level testing much easier and also reduce the probability of interconnection errors on the PCB design. GAs are in general very, very fast, and have correspondingly sharp rise times of the order of a few nanoseconds. A lot of care needs to be taken when designing PCB layouts. It is common practice to add low value series resistors on any long tracks carrying data or control signals to remote locations to control rise time problems. Do read manufacturer's recommendations on PCB layouts and tracking. Some devices have software programmable rise time control and some of the larger devices also include built in series resistors on their I/O lines.

So much for the hardware. The real effort is in the software, i.e. in the generation of the fuse files that dictate the internal interconnects. It is theoretically possible to generate these files by hand, however as one can imagine, there are software tools that can generate program files from text editors or graphical interfaces. Most manufacturers provide free integrated development environments and tools (IDEs). To somebody who may be used to programming a microprocessor such as PIC or 8051, the development procedures will look familiar; you enter some text using a text editor, you press the 'compile' button, and if everything is OK, you press the 'program' button to transfer the compiled fuse file to the target. There are of course a few more interim steps here, mainly to do with optimisations, but you will not need to know about these in depth until you move into serious development.

A typical GA design will be composed of a number of modules or 'black boxes' interconnected together via wires or bus lines, just like in a real hardware system. Each of these sub-modules can be designed independently, and can be tested or simulated using the various software tools provided. This makes the design approach very modular.

A pleasant surprise to those used to writing standard computer code is that GA design entry can take many different forms: you can for example draw a circuit diagram, using the mouse and a drag and drop CAD like program. You can write code in text form, much resembling traditional software listings. You can enter input in the form of tables, or state transition tables. You can even define your inputs and outputs as waveforms, inputted as timing traces using a graphics waveform editor. They will all produce the same binary compiled output. This allows each sub-module to be written in the most suitable form for its purpose, whether in graphics or text form.

Another major time saving element is that the compiler will do all the optimisation and code reductions. No need to get involved in logic

```
IF      in==H'0'      THEN   out=B'1110111';
ELSIF   in==H'1'      THEN   out=B'0010010';
ELSIF   in==H'2'      THEN   out=B'1011101';
ELSIF   in==H'3'      THEN   out=B'1011011';
ELSIF   in==H'4'      THEN   out=B'0111010';
ELSIF   in==H'5'      THEN   out=B'1101011';
ELSIF   in==H'6'      THEN   out=B'1101111';
ELSIF   in==H'7'      THEN   out=B'1010010';
ELSIF   in==H'8'      THEN   out=B'1111111';
ELSIF   in==H'9'      THEN   out=B'1111010';
END IF
```

reduction, Karnaugh maps or any of those Boolean simplification techniques learnt at college. The compiler will take your statements, no matter how devious and long handed, and produce the correctly reduced arrangement of gates and registers. This is a major benefit, as it allows the designer to enter their definitions in plain language, and not worry about the tedious details of structure and simplification. The pseudo-code shown in the panel shows for example how a designer could define the decoding logic for a seven-segment driver. Note how no attempt has been made in the source to simplify the logic, the compiler will do it all. (*See panel in previoous page*).

The availability of High Level Design tools have given rise to languages that describe the operation wanted rather than the logic functions required to implement them. For example, the high level description FF[].d = FF[].q +1 describes an operation where the D input of a set of flip flops is connected back to their own Q outputs but with the value arithmetically incremented by one, in other words, a simple add by one, or binary counter. The statement does not describe how the gates or flip-flops need to be wired together to perform this function. This is the job for the software, which releases the designer from this responsibility. The compiler will know which is the optimum way of implementing this function for each particular device in a family. It does this by a combination of algorithms and techniques and by referring to internal databases. Some devices for example, may include fast look-ahead carry elements that can be included in the design. Admittedly, some commercial compiler tools will be better than others at this task!

The point here is that designers do not need to concern themselves with optimisations or with the particular use of gates or registers. This allows them to write their inputs in more abstract descriptive ways. The most commonly used high level languages are Verilog and VHDL. Some manufacturers such as Altera have developed convenient short form version of the above (AHDL) mainly to reduce verbosity. I shall not delve too much into details on the use of these languages, as there is plenty of literature and information available.

A development environment (IDE) consists of the various tools such as compilers, libraries, simulators etc, encapsulated by a user-friendly graphics shell. Xilinx's free development software comes under the general name of WEBPACK and is available either as a (pretty massive) download from the internet, or as a CD obtainable from any of their distributors. The CD also contains a full collection of data sheets and application notes, and is a must for anybody involved in Xilinx development. Altera also ships regular CDs containing data sheets, application notes and their main two free IDE suites: Max+Plus Baseline and Quartus II Web. Traditionally, Max is aimed at CPLDs and the lower end FPGA devices, with Quartus covering some of the high end of FPGA devices. The later version of Quartus (from version 2) covers both ranges.

All of the above free development suites are a complete integrated development environment, and are ideal for simple projects of for training purposes. The commercial versions are very similar but also cover the top range devices, access to wider libraries and comprehensive online and telephone customer support.

Unlike development suites for microprocessors, software tools for GAs are closely linked to the devices they are aimed at. Therefore it is important to obtain a tool that includes the full set of specifications (software, electrical and functional) for the device you are working on, this implies getting hold of the latest version available.

Advanced tools

As a designer moves into more advanced projects, requiring more gates, faster timing or better performance, they may begin to find that the design runs too slowly or they cannot be fitted into the device (even though there appears to be plenty of space left). This is because the simple basic tools provided by the free IDEs may not be doing their job at maximum efficiency.

At this point the designer may benefit from a number of third party tools. These replace the relatively simple intrinsic tools provided by the IDE with more sophisticated synthesis, fitting and simulation algorithms. Some of these third party tools can be rather expensive but can be worth the effort and make the difference between a fast design and one that does not work at all.

Intellectual property is the generic name given to sections of software developed by third parties and available for sale, usually on a licence basis. These take the form of modular 'black boxes' that can be dragged and dropped into your project. Examples include FFT modules, MPEG decoders, cryptography and of course CPU cores.

Hard core or soft core?

Most GAs are so large that it is quite feasible to include a full CPU implementation in software, and have plenty of spare space left. These are not software emulations of a CPU, but complete, full speed, bit for bit implementation of the real thing. You can embed a well known architecture such as that of a 8051, a PIC or even an Intel PC. Xilinx's Virtex II Pro has four hard wired Power PC cores, and Altera's Excalibur includes one 32 bit ARM processor. The reason for embedding a CPU is that some applications are better implemented using traditional Turing type computer technology, rather than by using hardwired logic. The embedded CPU, together with embedded RAM and ROM perform the work of an equivalent microcomputer, but usually much faster. Some manufacturers have developed computer architectures more specifically suited to GA implementations. For example, Altera's NIOS, and Xilinx's Microblaze and Picoblaze. As already mentioned, a major advantage of embedding CPUs is the ability to add your own custom instructions to the existing set. The same argument can apply to Digital Signal Processing (DSP) emulation. GAs can easily outperform DSPs for individual designs. Some tools are available to simplify design, such as Altera's DSP builder, which converts Matlab and Simulink output directly into VHDL code.

So you want to get into GA?

So you want to have a go, but don't want to spend a fortune getting a development kit from one of the suppliers. Or maybe you don't mind getting one but don't know which one to choose?

Here are the basics. For a start, avoid spending any money in software as all the tools you require initially are available for free, either as CDs or as internet downloads. Next, decide which manufacturer you are going to go for. This can be a tricky decision but not very important as the general techniques to be learnt will be the same for all manufacturers, so this will be mainly a matter of personal choice.

Next stage is to obtain the IDE tools, don't worry about hardware at the moment; you won't need any for a while. I shall describe the general

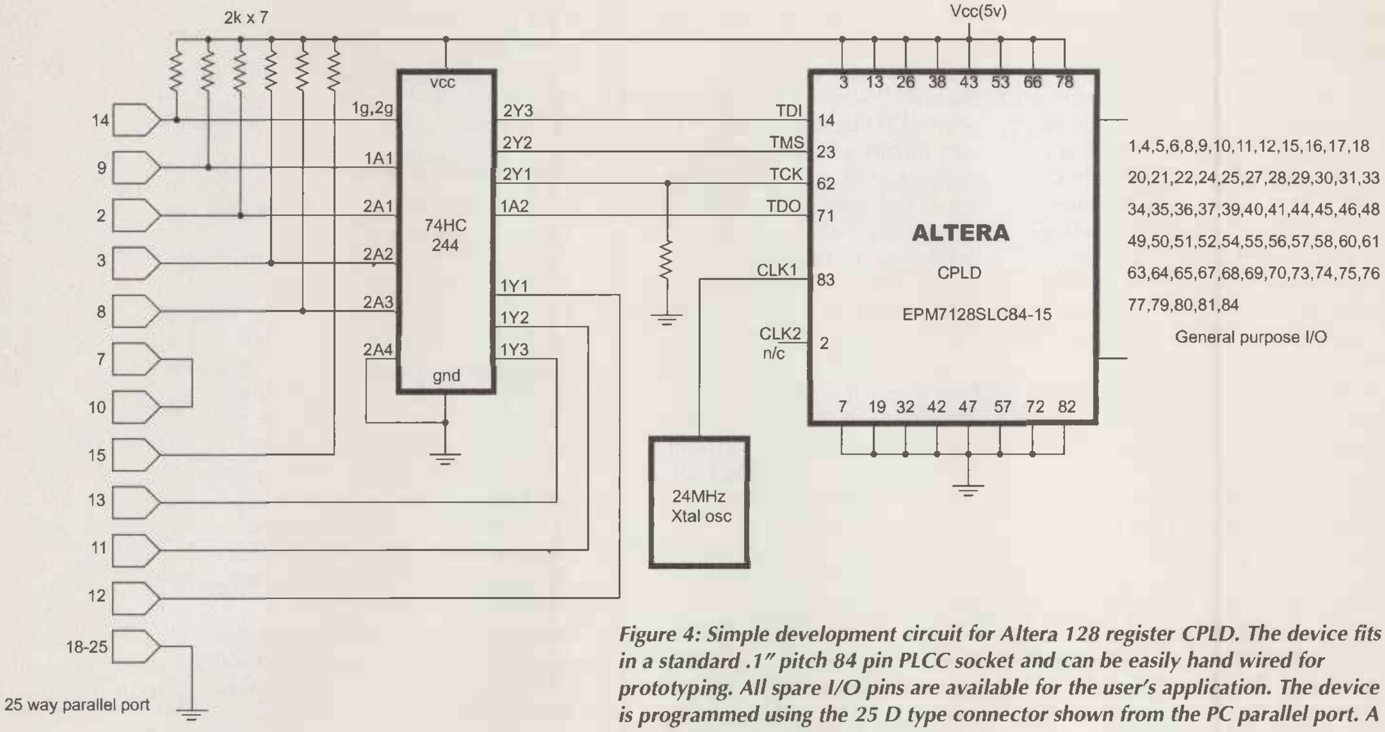


Figure 4: Simple development circuit for Altera 128 register CPLD. The device fits in a standard .1" pitch 84 pin PLCC socket and can be easily hand wired for prototyping. All spare I/O pins are available for the user's application. The device is programmed using the 25 D type connector shown from the PC parallel port. A 5 Volt 100mA supply is also required.

procedure for the Altera IDE, as it is easier to use for the novice and the hardware parts more accessible for initial development.

A similar procedure will be applicable for Xilinx.

You can download the Altera development suite from their website (www.Altera.com.) This will be Quartus II web version 3. Unless you have a very fast internet connection, better send away for the CD, which is always a good idea as it contains a large number of useful data sheets and application notes. You do this by filling the online application form, or by contacting any of their distributors. You will also need a free licence to operate the software. You obtain this online by filling an application form (press the licensing button on the front page). The licence lasts for six months, after which you will be requested to ask for a new one, note that no cost is involved. Why they do this I don't know, but I suspect it provides some form of marketing feedback. Xilinx's WEBPACK software does not require registration as such.

When you receive your CD, proceed with the installation of Quartus II, this will take a few minutes, and may require the installation of a software system driver for the parallel port. This later installation may be the hardest part for some PC configurations. You will also need to ensure the licence file 'licence.dat' as emailed to you by Altera is in the same directory as the program executable.

Now fire up Quartus and proceed straight to the tutorial. You will not need a device programmer or any hardware at this stage. Make sure you have gone through most of the tutorial before you even think of proceeding to the next stage. The learning curve at this point is quite steep, but definitely worth it. You will really need to know all the processes involved, so do not skip any of the sections! The tutorial basically shows you how to use the software, what all the coloured buttons do and what the pretty pictures mean. With the tutorial behind you, you will be able to enter designs, compile and simulate them and see the results on the screen (who needs hardware!)

There is a strange sense of achievement by being able to draw a circuit on a screen, press a few buttons and seeing the waveform they produce. But then again, there is nothing like the real thing. So at this point, you may be itching to do something with real hardware, something that flashes real lights that is. The quick way in is to purchase a development board, which can cost anything from £400. The cheap way in is to obtain your own components and design from scratch.

You will need an actual device. First the bad news, soldering the SMD packages can be a nightmare, so maybe the ready-made development board was not such a bad idea after all! However, there is still a way to get started with a minimum of outlay. Some of the older (mature) devices are still available in convenient .1" pitch PLCC socketed packages, and operate at 5 Volts. You will not miss anything by using semi-obsolete devices for experimenting or for learning purposes as most GAs contain more or less the same elements and work the same way.

A couple of suitable devices are shown below. These are easily available from suppliers such as Farnell and RS, and can be fitted into standard PLCC84 pin sockets.

Altera FLEX EPF10K10LC84-4
576 register FPGA

Altera MAX EPM7128SLC84-15
128 register CPLD

Connection diagrams for both are shown in **Figures 4 and 5**. Note how the CPLD uses the JTAG interface and the FPGA uses the PSS interface for programming. Most devices use one or the other method, and the IDE is capable of generating programming files for either. It so happens that the MAX family can only be programmed via the JTAG interface. Both devices can take two master clock inputs, but only one is shown. Also note how all the series resistors to the 244 are not present, as the programmer will only be used on a 5 Volt device.

Although both devices feature high clock rates, it is recommended that for development a low master clock generator be used (anything below 25MHz). The reason may not be too obvious: the routings generated by the software. If the device is used near its limits, some of these paths may be too long and exceed the clock rate causing

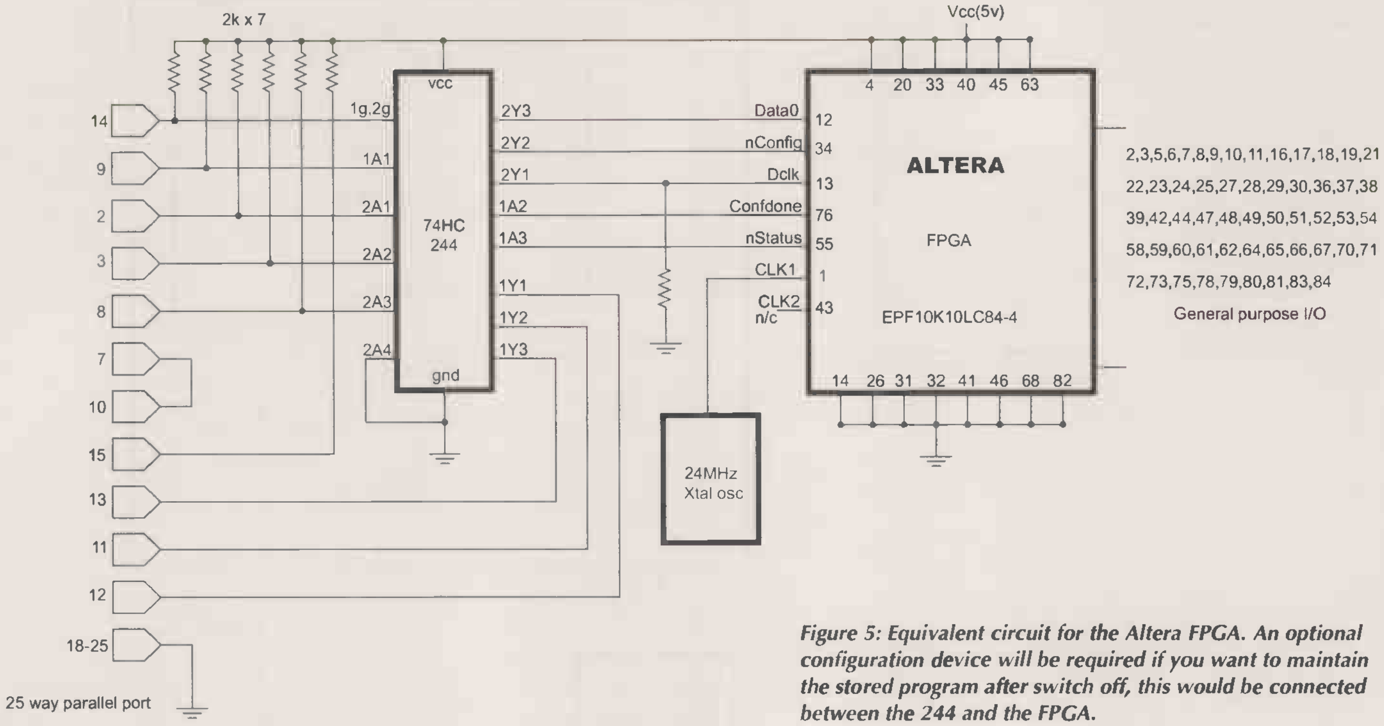


Figure 5: Equivalent circuit for the Altera FPGA. An optional configuration device will be required if you want to maintain the stored program after switch off, this would be connected between the 244 and the FPGA.

strange effects and faults. Seasoned programmers would use the simulator and floor-plan editor to recognise and work around these by hand, but this is an activity we will not want to get involved with at this early stage.

All pins not shown are used for general purpose I/O (i.e. for your application). Leave all unused I/O pins unconnected, as some devices have the strange habit of outputting internal node data to unprogrammed pins.

As mentioned earlier, the FPGA program will only stay as power is applied to the device. To make the program permanent, you need to attach an optional configuration device to the FPGA; this is basically a special purpose EEPROM with some extra logic bits to generate the right programming pulses. Altera's configuration devices are the EPC1, EPC1441 and EPC2. Note that the first two are one-time programmable only, and only the EPC2 can be reprogrammed in-site via its own JTAG interface. It is also possible to use a standard EPROM or flash EEPROM and use a small microcontroller to generate the right timing pulses.

Design tips and techniques

Those of you with a hardware background can quickly get started by using the schematic editor and drawing your circuits directly on the screen. Altera libraries even include old time favourites such as 7400 gates, 7493 counters and 7474 flip-flops. However, it is not a good idea to rely on these legacy components, and it pays in the end to use the more modern building blocks, which are also optimised for the devices being used. Blocks include gates, multiplexers, RAM, counters and various other basic abstract sub-modules.

It is also important to know that the logic circuitry inside GAs is built differently and behaves differently from their discrete logic counterpart. Avoid 'trick' circuits using gates as delays, external RC components, and even things like ripple counters that depend on propagation delays. Although you can still use these techniques, the results may be unpredictable and difficult to debug. The reason is very simple, one compilation may assign two similar gates next to each other on the die. The next compilation may assign gates that are at opposite ends of the chip, with different propagation delays. Gate combinations may even be replaced with a completely different logic arrangement i.e. with a RAM or with a look up table.

Learn to use synchronous logic wherever possible (this is where all registers are clocked from the same master clock). At first hand this may appear to preclude the construction of counters operating at different clock rates, but this is where techniques such as 'clock enable' come into action. Consider the following pseudo-code:

```
ffl[3..0].clk=                                     clk;
ffl[3..0].ena=                                  enable;
IF (ffl[3..0].q == 9)  THEN ffl[3..0].d=H"0";
               ELSE ffl[3..0].d=ffl[3..0].q + 1;
END IF;
```

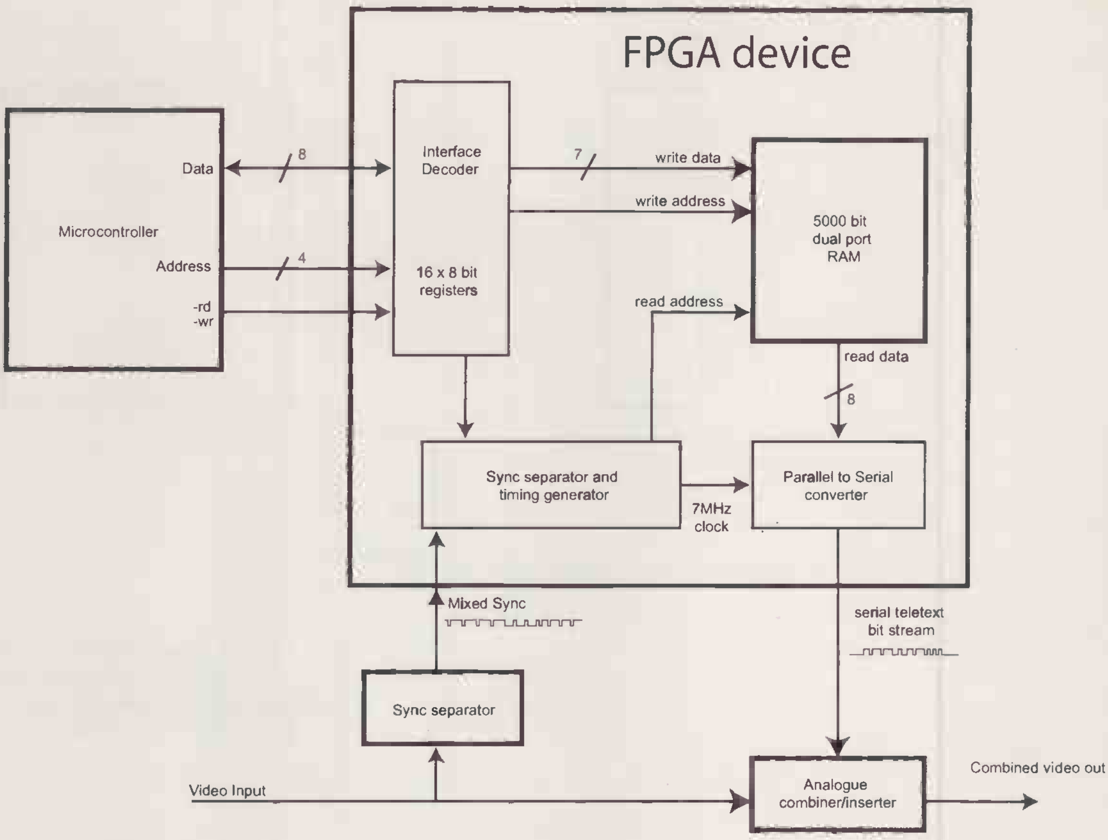
This describes a synchronous divide by ten counter using four flip-flops. The first program line states that the clock of all four D flip flops is connected to the master clock line (the reverse N..0 notation is common in all HDL languages) The third line describes a data multiplexer: when the count has reached nine, the D inputs are connected to ground, which has the effect of resetting the counter on the next clock pulse. Otherwise they are connected back to their Q outputs arithmetically incremented by one.

The counter is toggled from the master clock, and without the second text line, it would operate at this rate. In order to clock this counter at a different rate, we use the clock enable input, which is externally derived from a source that generates one clock wide pulse in every N master clocks.

A pactical example

Figure 6 shows a typical example of what can be done with a medium end FPGA costing less than 10 pounds. The circuit shows a complete teletext generator or inserter as may be used in a hotel video distribution system. The chip, in this case an Altera

Figure 6: Gate Arrays in action: a complete teletext inserter using a single FPGA device costing less than 10 pounds. The external microcontroller is only used to initialise the controller and to download pages in ASCII form at a leisurely rate. All high-speed operations are performed within the FPGA.



1PK50, takes as input mixed video sync at logic levels. Its only output is the teletext serial stream at 7Mbps, which is inserted back into the video signal using a separate analogue mixer. An external microprocessor is used to transfer teletext page content in ASCII form, everything else is done within the chip. A serial RS232 link to a PC could have been designed in instead.

Each of the functional blocks shown in the figure were developed as separate modules in the VHDL language. The device is clocked from a single 64MHz oscillator, an internal Direct Synthesis (DDS) generator is used to synthesise the teletext basic bit rate and provide other timing pulses as needed for sync separation and line counting. The interface to the microprocessor is via a standard data bus arrangement. The FPGA looks to the microprocessor as a collection of registers and these are used to set working variables such as starting and end line number and various other options. Text data for the pages is fed via writes to a single register using an internal auto-increment counter. From this point of view, the FPGA looks no different to the microprocessor from any other parallel driven peripheral. As already mentioned, a serial UART interface could have been used instead for direct interfacing to a PC without the need for a microprocessor. The internal RAM available within the FPGA (about 5kbytes) is used to store about 100 lines of text; a dual port RAM ready-made library module was used here. The other modules perform parallel to serial conversion, parity generation, and generate the timing sequences. Placing all the fast logic in the FPGA releases the microprocessor from any timing dependent duties.

Each module was tested and debugged separately; for example, extra code was added during development to the DDS section to output some of its internal nodes to spare I/O pins, which were connected to a scope to verify timings. After the tests, the extra lines of code were simply removed from the listing.

One of the major aspects of a design like this is that the format of transmission can be changed or redesigned by simply doing a software rewrite. For example a NTSC version, or for a different format of Vertical Interval insertion codes such as time-codes.

Taking it from here

Next time you are working on a project that requires a few logic packages, do seriously contemplate the option of slapping in a GA device instead. Apart from the savings in component costs, you may be saving in testing time, PCB modifications and general hassle. If your project is one of those where a microprocessor is 'not fast enough' think of using a GA as a peripheral handling the fast logic. An ideal application would be one where you need a special fast interface for a standard micro, say a very fast UART or counter, or signal generator, or something that requires fast special purpose processing. Programming a GA to behave like an add-on peripheral is a relatively easy task, with plenty of freely available module library support.

The author

Eddie Insam started his electronics career with his first two transistor radio using 2N35 and CK722 transistors. Things have come a long way since then, and he is now a consultant in innovative applications of telecommunications and signal processing. He can be reached on edinsam@eix.co.uk.

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COLOSSUS

the world's first electronic digital computer

World War II heralded some giant technological leaps. The world's first electronic digital computer, Colossus, was such a beast. Tony Sale (ex Museums Director of Bletchley Park) is running a project to reconstruct Colossus. Charles Coultas looks at the history and some of the electronic features of the machine. For brevity, some of the historical background has been omitted

Colossus Mk2 was commissioned at Bletchley Park 60 years ago on June 1st 1944. It was the world's first electronic digital computer. The machine contained 2,500 valves with a paper tape reader that ran at 5,000 characters per second. It occupied a space 4.5m x 3.2m x 2.5m high and consumed around 6kW.

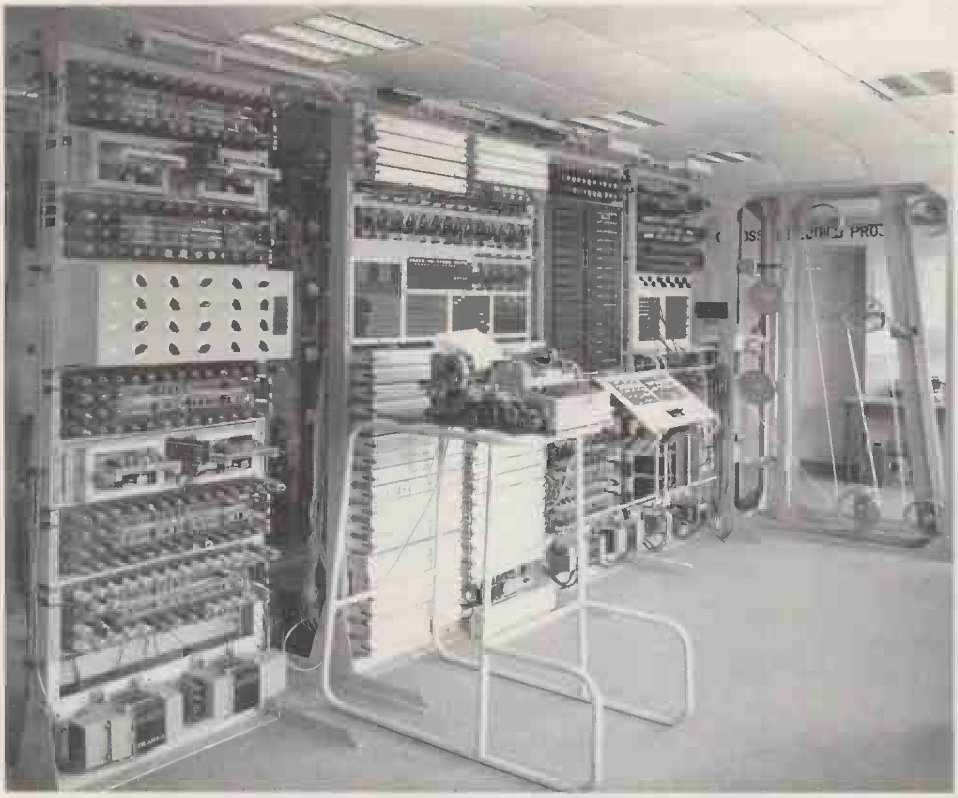
Enigma was considered safe enough for ground based and tactical use but the German Army High Command wanted something that was much more secure. The Lorenz SZ42 was one of the solutions they adopted. ('SZ' stands for Schlusselzusatz or 'key attachment'.) It was interfaced with a teleprinter, taking the characters from the keyboard and converting them to pseudo random form by adding an obscuring character, then transmitting them. The remote Lorenz machine removed the obscuring characters thus revealing the original text. (See box Operation of Lorenz Machine)

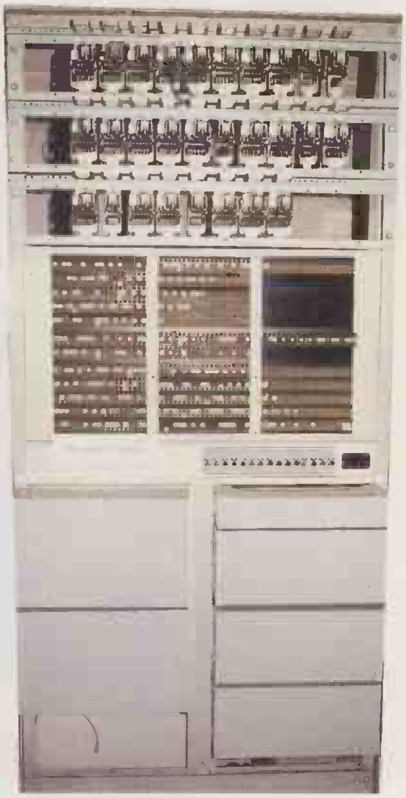
The complexity of the Lorenz machine was such that Bletchley Park stood little chance of breaking into the cipher by trial and error, and they knew it. But in 1941 a German cipher clerk in Vienna made a mistake: he sent a long message of around four thousand characters to a clerk in Athens. The response from the Athens clerk indicated that something had gone wrong and requested "please send the message again". The Vienna clerk reset his Lorenz machine to the same key and the same start position (something that is forbidden as it offers valuable clues to the underlying cipher) and sent the same message again. Being human and probably frustrated that he had to retype the long message, he started abbreviating words. A listening post at Knockholt (in Kent) spotted this and, realising that it might be essentially the same message twice, sent the two encrypted messages to Bletchley Park. Colonel John Tiltman worked out the content of the message but this didn't help to understand the nature of the enciphering machine. Bill Tutte, a brilliant Cambridge mathematician, worked at BP under Tiltman, and within four months had worked out the complete internal structure of the Lorenz machine, just from these two messages.

German teleprinter traffic was code-named Fish at Bletchley and the Lorenz system was known as Tunny. Bletchley Park now had the knowledge to attempt the breaking and decipherment of Lorenz traffic but not the equipment. Hand methods were developed but these could not match the pace at which messages were being received. When keys had been broken they were set up on the Tunny machine **Figure 1** where the decrypted message would be printed. But key breaking by hand was taking far too long. Machine methods were urgently needed.

A machine known as Heath Robinson ran two five-channel paper tapes in parallel (one the encrypted message and the other a possible key) and performed Boolean logic on the data, recording the results on electronic counters, using valves. Keeping the tapes in physical synchronism proved difficult and a faster solution was needed. The answer came from the Post Office Engineering Department. Tommy Flowers and his team had been experimenting with thermionic valves for switching telephone circuits. He claimed that he could design a machine fast enough to work out the wheel settings that had been used in a Lorenz message. Collaboration between Bletchley's Max Newman and Tommy Flowers led to Colossus Mk1. Alan Turing was involved in the statistical and mathematical part of the Fish project. The British government considered this work to be so important that Churchill made any needed resource available.

Colossus was a great success: the first machine was installed at Bletchley in January 1944 and was operational within a few weeks. This led to the immediate ordering of a MK 2 Colossus which arrived 1st June 1944. The Mk 2 was re-engineered from the Mk 1 by Allen Coombs, also from the Post Office. Eventually ten Colossi were installed in F and H blocks at Bletchley Park,





Above left: Colossus rebuild, June 2003.

Above right: Figure 1 the Tunny machine.

each one running 24 hours a day. A small team of Post Office Engineers lived on site to maintain the machines. Despite criticism that reliability would be a problem with so many valves, Flowers was convinced that by never switching the heaters off great reliability could be obtained.

Tony Sale (then working at the Science Museum) started to research Colossus in 1992 and found enough information to attempt a rebuild. However, at the end of the war Churchill had ordered all the machines, their circuit diagrams and photographs to be destroyed as he didn't want the rest of the world to know what Britain knew about automatic computation and code-breaking. Thus the information was patchy, some circuit diagrams were missing but some of the photographs yielded useful details. Additional drawings and photos turned up in the American government archives, sent home by US staff working at Bletchley Park. Proper working drawings were produced for all the metalwork and tape reader mechanisms. Dr Arnold Lynch, the original designer of the paper tape reader helped in the redesign. Sponsors were obtained. (Much of the project was funded by Tony himself.) Colossus is being rebuilt in a room at Bletchley Park, fittingly, where Machine number 9 originally stood. The first phase, basically a Mk 1, was officially switched on by the Duke of Kent accompanied by Dr. Tommy Flowers in June 1996.

Colossus consists of electronic and electromechanical elements. There is no fixed clock as you might expect in a fully digital machine; the sprocket holes from the paper tape are used throughout to control the functions of the computer. Fault finding is helped by running the tape slowly; the machine will actually work with the tape crawling through the reader at a fraction of operating speed. It normally ran at 5000 characters per second, giving a clock period of 200µs. Remember this was 1943/4 and even the rather poor oscilloscopes they had were not DC coupled, you couldn't look at static voltage levels.

The cathode follower was a recent discovery in 1943 and it allowed logic level signals to be extracted from a circuit and subsequently applied to a relay without the need for gas filled valves as had been used previously in Heath Robinson (which was named by the Wrens because of its strange appearance). The wire used would have been silk covered, in the rebuild we use plastic covered wires, and some of us reluctantly use lead-free solder.

The optical paper tape reader moves a length of five track paper tape past a photoelectric reader at high speed, a typical length is 5000 characters, a loop nearly 13 metres long. A variable speed electric motor drives the paper tape. This poses several problems: the tape must run over a pulley system; it must maintain tension to avoid coming off the pulleys and some means must be found to detect the holes in the tape. The tape runs round and round continuously. Tape breaks are spectacular, the tape flies all over the place and caused much delay when it happened in 1944. A low voltage lamp is focussed into a tight beam that illuminates the tape over a short span. A row of glass photo sensors (with octal valve bases) read the holes through a complex optical mask. There were no semiconductor photocells in 1944, cold cathode photocells intended for proximity detection on anti-aircraft shells were pressed into service. We have some of the originals in the rebuild but no spares.

From here the signals are amplified using EF36 pentode valves. Colossus makes extensive use of this valve: it has a heater current of only 0.2 amps (6.3V) which is not much less than the 0.3 amps of other suitable valves available at the time, but when there are over 1700 of them, it makes a difference to both power consumption and heat generated (2kW+). The EF36 was intended as an audio frequency amplifier but Tommy Flowers realised that it could also perform logic functions. By setting suitable voltages on the

Figure 2 left: the programming control panel for the Boolean functions.

Figure 3 right: Surface mount.

control grid, screen grid and suppressor grids, logic could be performed. For example, a bistable pair of valves could be forced into a reset state by pulsing the screen grid of one of the valves low. This would force that valve into the non-conducting state and its anode would go high, forcing its cross coupled partner to switch on.

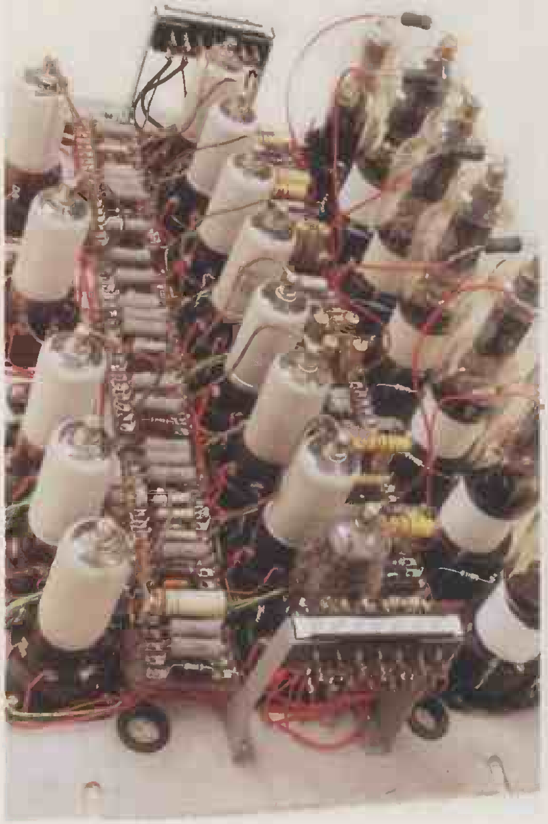
The amplified, and squared-up signals leave the tape reader and enter a central bus. From here the signals can be processed in many ways. A delta (difference from previous) character is also available for processing. This is very important for some algorithms.

Five four-decade counters are provided. These counters are based on an earlier design by Dr. Wynn Williams of the Telecommunications Research Establishment at Malvern. A bistable divides the signals to be counted by two. The result is fed to a five-stage ring counter, thus giving division by ten. Each complete counter has four decades, allowing a maximum count of 9999. The bistables and rings use EF36 valves, 2 for the bistable and 5 for the ring. The outputs are buffered by 6J5 triodes. Each complete counter is driven by a Counter Controller Chassis which provides clock and gating signals depending on what the counter is to count. The results from any counter can be routed to the printer which is based on an electric typewriter. An example of elegant design can be found in these counters: only two valves per decade are ever on at any one time (one in the bistable and one in the 5-stage ring). This means that the electro-mechanical relay logic to drive the printer/display is simplified and power consumption is minimised.

The largest section (the twelve wheel simulators) contains 501 thyratron valves (GT1C's), one for every tab on each Lorenz code wheel. There are twelve cyclic rings, each representing one Lorenz wheel. The heater current for each thyratron is 1.4 amps at 4 volts, totalling 2.8kW. Twelve patch panels have moveable links which can be set by the operator, one link for every tab on each Lorenz wheel. Collectively these provide the 12 selectable key bit streams which can be applied to the bit stream from the paper tape. It is the Boolean processing of these bit streams that gives Colossus its unique position as the first electronic computer. The programming control panel for the Boolean functions can be seen in **Figure 2**, this is how Colossus is programmed. A complex set of uni-selectors shift the start point for each ring in a manner determined by the operator, a new setting is applied to any of the rings for every cycle of the tape. The actual Boolean operations required are programmed in by the operator and can be changed during a run. Colossus doesn't produce a decoded cipher-text, its function is to locate the setting, i.e. start positions and patterns of the Lorenz wheels using sophisticated algorithms. The actual decoding is done offline, using Tunny machines. Tony Sale wrote a Colossus simulator for his laptop PC. The clock frequency of his laptop is 800Mhz but it runs at about half the speed of real Colossus (whose clock speed is 5kHz, a ratio of 160,000:1).

Such is the power of parallel processing but of course this is not exactly comparing like with like.

High tension power comes from seven standard Post Office DC power supplies. Each one produces 50V at up to 5 amps. They are connected in series to give: -150V,-100V, -50V, 0V, +50V, +100V and +200V. Two further supplies give –50V for the relays and uni-selectors. The original machine had a massive bank of capacitors to smooth the outputs from these supplies but the supplies we use don't need them. In fact there are virtually no smoothing capacitors in Colossus except within each power supply. This also reduces the potential danger if a person accidentally touches the DC rails. The mains supply is a single phase



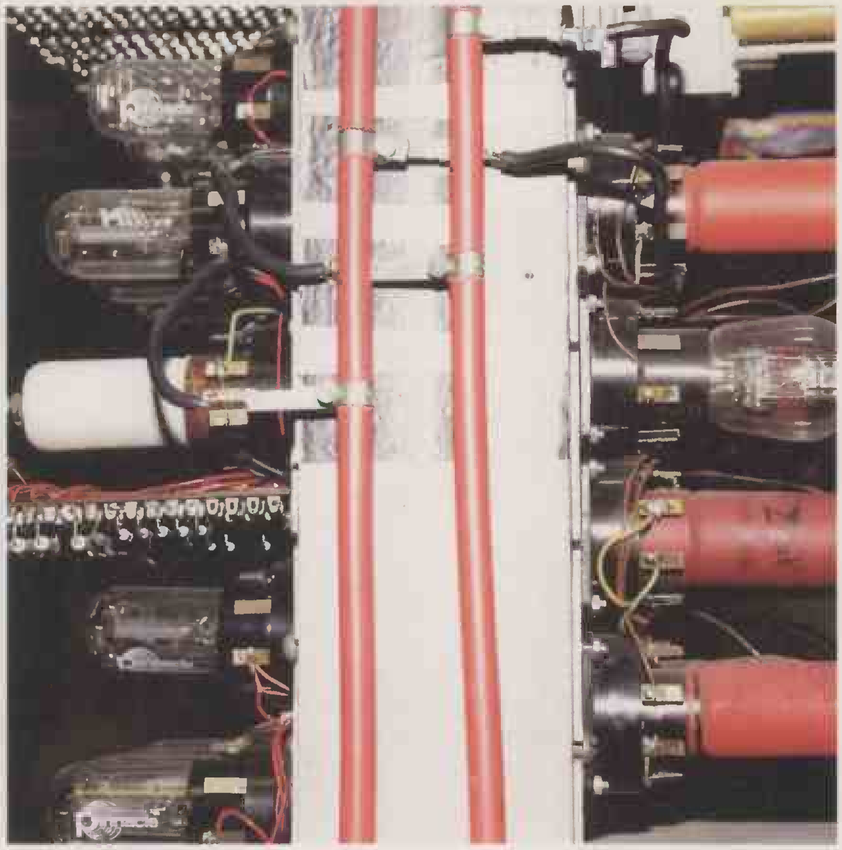


Figure 4 above left: Circuit plate.

Figure 5 above right: Back to back.

60 amp supply distributed by a household consumer unit. Because several people may be working on the machine at any one time, some unseen by the others, we have a safety convention for applying the HT. The person who is about to switch on the HT (the heaters are almost always on) shouts "HT going on....", waits for any objections then throws the switch, shouting "HT on", always being alert to the fact that a loud bang, a wisp of smoke or a strangled cry occasionally follows "HT on".

Colossus uses the following valves in the following numbers: EF36 (logic, pentode) 1731, 6J5 (buffer, triode) 494, 6V6 (logic, driver, beam tetrode) 117, 807(driver, power tetrode) 78, 6K8 (logic) 12, GT1C (latch, thyratron) 513, VR92 (pulse shaper, diode) 36, 5U4 (rectifier) 1, photocells 9. Grand total: 2991. Two large motorised Variacs provide a nice gentle start for the heaters. The thermal shock of having full heater volts applied straight away is a common failure mode in normal valve circuits. It takes about one minute for the heaters to reach full voltage and this care is repaid by very few filament failures.
(We use EF37As in preference to EF36s; they have slightly more favourable characteristics and were easier to come by.)

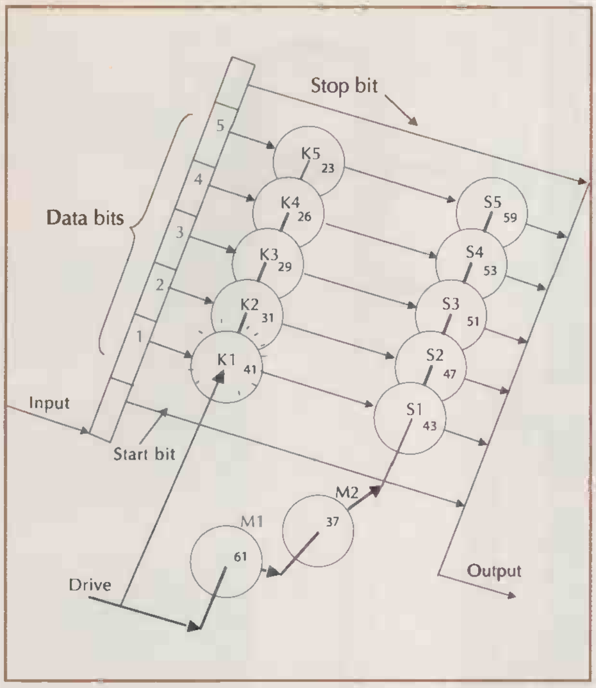
They say there's nothing new in the world, and Colossus is no exception. This 1943 design uses surface mounted components, but not at all the same as we know today. The valve holders have their connecting tags sticking upwards, not through the chassis as was common, even in 1943, see **Figure 3**. These valve holders are mounted on one side of a steel plate, 19 or 29 inches wide. Tag-boards are fitted onto the plate followed by components and all the wiring. Everything is on the same side of the plate, see **Figure 4**. This has several advantages to through-chassis techniques: two plates can be mounted back-to-back on each side of a rack giving higher density, see **Figure 5**. Cooling is by convection, no cooling fans are used (the only area were heat build up can be a problem is above the thyratron racks, because of their 2.8kW heater dissipation). Maintenance is made easier because everything is laid out in front of the engineer; there is no reaching round the back or underneath a chassis.

In June 1944 Colossus was helping to break 300 messages per month. By October 1944 this had risen to 1200. The average time taken to break a message after a change of key was 4 days (compared to the average of 1 hour for Enigma messages). Although the outcome of the war was determined by the fighting troops, it is conservatively reckoned that the code breaking at Bletchley Park shortened the war by two years.

The rebuild has been going on now for ten years and is almost complete. Even today in 2004 with our fancy oscilloscopes and digital multi-meters, we sometimes have trouble sorting out some of the problems that crop up.

Much of the credit to the rebuilt machine's success must go to the expert wiremen who painstakingly installed thousands of wires so very neatly. Credit is due to the team of dedicated volunteer engineers who gave up considerable time to make this project a success. Finally, Tony Sale who had the idea of rebuilding this magnificent British computer in the first place must have the last word: "I feel very privileged to have met Tommy Flowers before he died in 1998 and to have had the opportunity to recreate his wartime masterpiece, the Colossus computer. The rebuild was started in 1994 and phase one was completed in 1996, the 50th anniversary of the American ENIAC computer. It just made the point that Colossus was the first in 1944 and was British. Because Colossus was kept secret until the 1970s, the Americans had got away for far too long with the myth that ENIAC was the first.

Now computer history has rightfully been corrected."



Structure of the Lorenz machine. Numbers below the wheel ident show number of metal tabs on that wheel.

Lorenz wheels.

Operation of Lorenz Machine

The diagram shows how the twelve code-wheels are arranged in the Lorenz machine.

A 7 bit character arrives at the K wheels. The start and stop bits pass through unchanged. Each of the 5 data bits has its own wheel, and each wheel has a different number of metal tabs which are set or not set by the operator. This is the key, 501 bits long. If a tab is not set then the bit passes through unchanged. If the tab is set then '1' is added to the data bit by modulo 2 addition (thus 1 + 1 = 0, 0 + 1 = 1, 1 + 0 = 1 and 0 + 0 = 0, where '+' means 'mod 2'). This means that if a tab is set, the data bit is inverted.

The K wheels all move on one place for each character.

The S wheels receive this encrypted character from the K wheels and the same thing happens, each data bit has 1 added mod 2 if the tab is set, else it is left alone. The S wheels do **not** move on every character however. The M1, motor wheel 1, moves for every input character but M2, motor wheel 2 only moves if the current tab on M1 is set. If the current tab on M2 is **not** set (note inversion here), then all the S wheels move on one place; if it is, they don't move. (Later Lorenz machines had a further quirk but we don't have the space to examine it here.)

The following example shows this in operation (start and stop bits not shown; the code is the International Teleprinter Code):

Input character 'A'	**1 1 0 0 0**	
K tabs set on K1-5 (say)	**1 0 1 0 1**	
Result from K wheels	**0 1 1 0 1**	**Which is 'P'**
S tabs set on S1-5 (say)	**1 1 0 1 0**	
Final result	**1 0 1 1 1**	**Which is 'X'**

All the K wheels and M1 now move on one place. If M1 has a tab set then M2 moves on 1. If M2 doesn't have a tab set, then all S wheels move on one place.

The remote machine would receive this and have the same wheel settings, thus:

Input character	**1 0 1 1 1**	
K tabs set on K1-5	**1 0 1 0 1**	
Result from K's	**0 0 0 1 0**	
Apply S's	**1 1 0 1 0**	
Final result	**1 1 0 0 0**	**Back to our original A**

The actual pattern of the metal tabs was carefully worked out by German mathematicians to yield a near random result in the final output data. A new key had a new pattern of course. Had the famous pair of messages (known as ZMUG from its opening sequence of characters) never been received and decoded it is unlikely that Lorenz would ever have been broken. It is many times more secure than the Enigma system.

Note that unlike Enigma, Lorenz can encrypt a character to the same letter as it was originally. Enigma never output the same letter as was input, a fact exploited by Alan Turing in his design of the Turing Bombe, which consistently broke Enigma.

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www.codesandciphers.org.uk - Tony Sale's web site.

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For details of the mathematics and theory of how Colossus was programmed see: ***Codebreaking with the Colossus Computer,***
Carter, F. Bletchley Park Report #1 1996; #3 1997; #4 1997.

The rebuild team: Bob Alexander, Frank Carter, Ron Clayton, Adrian Cole, Charles Coultas, Rob Dickson, Don Grieg, Phil Hayes, Gil Hayward, Cliff Horrocks (team manager), Mark Hyman, John Lloyd, Peter Merriman, John Pether, Tony Sale (leader), Don Skeggs, David Stanley, Richard Watson, John Whetter.

Colossus is included in the Bletchley Park Tour.
For details see www.bletchleypark.org.uk
If you see engineers wandering about in the Colossus machine room, then that will be us. Ask your tour guide if you can pop in and say hello. Mention EW&WW.

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Kikusui PLZ-303W 300W Electronic Load	1800	84
SIGNAL & SPECTRUM ANALYSERS		
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Advantest R3361C 9kHz-2.6GHz Spectrum Analyser	6350	265
Advantest R3465 9kHz-8GHz Spec Ana With Digital Tx Mode	6950	298
Advantest R9211A 10mHz-100KHz Dual Channel FFT Analyser	2950	89
Advantest TR4133B 100kHz-20GHz Spectrum Analyser	8750	365
AT/HP 339A 110kHz Distortion Analyser	1250	38
AT/HP 3561A 100kHz Dynamic Signal Analyser	2750	99
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AT/HP 3585B 40MHz Spectrum Analyser	5650	229
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AT/HP 85024A 3GHz Active Probe	1500	45
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AT/HP 8562A 22GHz Spectrum Analyser	10950	329

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AT/HP 8594L 2.9GHz Spectrum Analyser	3950	165
AT/HP 8595E/004/041/105/151/163 6.5GHz Spectrum Ana	9350	281
AT/HP 8596E/021 12.8GHz Spectrum Analyser	9500	342
AT/HP 8901A/001 1.3GHz Modulation Analyser	950	48
AT/HP 8903B/001/010/051 20Hz-100kHz Audio Analyser	1950	59
Anritsu MS2661C/8 3GHz Spectrum Analyser	4750	196
Anritsu MS610B 10kHz-2GHz Spectrum Analyser	2650	80
Anritsu MS710C 10kHz-23GHz Spectrum Analyser	7500	225
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AT/HP 8644A/002 1GHz Signal Generator	4250	153
AT/HP 8656B/001 0.01-990MHz Synthesised Sig Generator	1250	38
AT/HP 8657A/022 1GHz GMSK Synthesised Signal Generator	1750	52
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AT/HP E4432B 250kHz-3GHz Synthesised Signal Generator	7250	261
AT/HP E4433A/1E5 250kHz-4GHz Synthesised Sig Generator	7950	239
AT/HP E4433B/1E5/UN3/UN5/UND 4GHz Synth RF Sig Gen	12500	377
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Marconi 2031/002 2.7GHz Synthesised Signal Generator	4500	135
R&S SMH 2GHz Synthesised Signal Generator	4250	193
TELECOMS		
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AT/HP 3788A/001 2MBPS Error Performance Analyser	1350	40
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AT/HP 8920B/1/4/7/13/14/51 1GHz Radio Comms Test Set	3950	119
Anritsu ME4510B Digital Microwave System Analyser	10950	329
Marconi 2945 1GHz Radio Comms Test Set	6500	195
Marconi 2955A/2957A 1GHz Rad Comms Test Set With AMPS	2750	99
Marconi 2955B 1GHz Radio Comms Test Set	3500	126
R&S CMD55/B1/4/6/9/41/42/43/44/51/61/U18/U20 RCTS	5950	179
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Glo Apr 04

Class-A imagineering: Part 1

With over 30 years of audio listening under his belt, Graham Maynard has relentlessly sought answers to questions that are still being asked, like 'do valves sound better?' 'is a valve Watt the same as a transistor Watt?' 'is there such a thing as transistor sound?' Some readers might not like some of his conclusions

The 25W pure class-A amplifier, and the more efficient high power version I detail later in this writing could have been offered as circuit based projects, but that method of publication would not cover the formative and hands-on based observations, design pointers, and fundamentally significant contraindications that inspired their final development. Hopefully my rather lengthy and unapologetically discursive text, with its proposals for two additional *audio* (as opposed to conventional audio frequency amplifier) tests, will stir afresh our pool of knowledge, and provocatively inspire some quite necessary, additional, unassuming, and open minded free thinking, especially amongst a few of the past published mainstream designer-writers.

During the late sixties I did my stint with the student union music service. I also spent more time in the library studying amplifier circuitry than my tutors would have though sensible, before becoming actively involved with mobile disco productions. On the road we had record decks, cassette and microphone sources, mixers, a variety of power amplifiers, and separately boxed Wharfedale 8 inch full range drivers which were used to extend the frequency response of our main Goodmans 18 inch loudspeakers.

Whilst our equipment was not 'hi-fi', we chose each piece carefully, and took pride in providing good quality sound. The output levels at some venues were rather high, yet we did not drive into obvious distortion because additional amplifiers were slaved and 18 inch cabinets stacked as necessary. Thus we quickly learned that different types of power amplifier produced different sounds when playing the same music, above their half power levels, at the same time and equally, into identical loudspeakers. We especially noted that the newly fangled transistor amplifiers did not sound as good as established valve (vacuum tube) chassis, because these were much less easy to listen to when driving loudly. The solid state designs also sounded less clear when the loudspeaker cables were long and they made vinyl record scratches sound overly sharp, these being affectations which, when added to their unreliability both during testing and then one last time during service, meant that we would never choose to use them again.

The most highly acclaimed 'sound stage' performers were KT88 class-AB1 ultralinears. These set the standard, with professional and very expensive transistorised amplifiers eventually coming close, but never quite making it. Apart from sounding different, the solid state cousins had reactive overload characteristics, which meant that they distorted badly at what should have been the tiniest degree of entirely natural and unavoidable amplitude overdriving, and thus they could not do the same job and generate the same 'volume' without sounding harsh, unless they had a much higher, but never used, power rating. Transistor amplifiers might not have had an output transformer limiting their performance, but that necessary extra power capability made them about three times more costly; whereas today it is the valve amplifiers that are so expensive.

Even plain 1% distortion tetrode and pentode chassis were more agreeable to listen to at higher volume than the most up to date of equal power, compound complementary 0.01% solid state designs, especially if the latter incorporated any form of output stage protection circuitry. The plain push-pull valve power output stages had a warm and less clear but quite comfortable sound, while the transistor types had an ice cold and 'frozen-in' response, which, whilst not especially lacking in detail on solo passages, became indistinct with a sound that lacked clarity on full music program. These new bipolar designs also exhibited different degrees of 'tizziness' through our quality *eights* when driving the *eighteens* through louder passages, occasionally being bad enough to sound like a turn of the smaller voice coil becoming loose and rubbing against the magnet, when it wasn't. Also, and this was worst of all for disco, they were devoid of atmosphere in a way that could not be compensated for by tone control adjustment - their sound could be heard in the loudspeakers, and it could be loud, but what came out was increasingly dull and fuzzy at higher volume - an empty pre-dance test was just that, empty. In the same circumstances ultralinear KT88s were clean, un-strained, dynamic and involving; they always made our loudspeakers project openly with a naturally free flowing and recognisably more realistic sound.

Generally a minimum 1.5 to 2 times of continuously rated and equal impedance transistor watts were (are) necessary to competently replace ultralinear KT88 beam tetrodes, and at that time there was not a solid-state substitute for the 200W 4x KT88 ultralinear Marshalls. Thus it does not surprise me that 6x KT88 ultralinear power audio designs are still commanding respect, also that Quad have quite recently re-introduced valve amplifiers to their hi-fi line-up in the form of highly creditable KT88 monoblocks. 'Watt' for 'watt', valves can run loudspeakers so much more loudly than transistor designs before audio distortion becomes noticeable.

Also back then, there were other aspects relating to treble clarity I could not understand. When you aimed an ear in line with a tweeter axis and reflected away the rest of the output from say a three way loudspeaker system, the valve amplifiers sounded quite natural, while the higher components from a 0.01% specified class-B transistor chassis seemed to be carrying lower frequency sounding definition. This was a real puzzle for me because it was as if the transistor designs were impressing lower sounding components upon the treble, than the crossover circuitry was electrically capable of passing. So I connected headphones to the transistor amplifier's output terminals, and listened from another room as I remotely switched the output between a resistor, and the 'hi-fi' loudspeaker. The degradation of headphone fidelity when the loudspeaker became the load was apparent as a masking of clarity on the leading edges of higher amplitude vocal and musical notes which were rich in harmonics and sibilants, yet which did not drive the amplifier into overload.

Clearly, audio waveform amplification gives rise to observable differences in reproduction which are musically more significant than the amplitude non-linearities that induce measurable sine wave THD. These are subtle dynamic changes that affect leading edge fineties and immediacy, and which alter our perception of harmonic relationships and spectral coherence, both of which are simultaneously essential, and must be cleanly reproduced to recreate the ambience and spine tingling emotions we should experience without distraction via the sound playback of a recorded performance. Such are the waveform qualities that many solid-state systems, but not necessarily all, seem to either lose within complex passages, or mask at higher volume, and which no amount of additional closed loop NFB can be guaranteed to recover.

A load of old baloney? Well, we had been lucky enough to have the discos paying for our experience and in spite of hands-on test bench measurements confirming that every amplifier did actually perform exactly as was specified for frequency response, power to clipping, distortion into a resistor, etc., we were all agreed. Those 0.01% specifications were not wrong, yet nor were our ears, and this emphatically demonstrated that an amplifier's measured capabilities for driving sine waves into a dummy load were not of primary relevance. Note though, that I am not making a general statement that all 0.01% measured amplifiers are not going to sound acceptable in isolation, it is just that there was, as there still is today, much more to selecting an amplifier for sound reinforcement, power audio, or for that matter hi-fi use, than can be gleaned by checking out the manufacturers' design specification sheets, because in spite of their super specifications, not all amplifiers are equally competent at driving real-world loudspeaker systems. Thus, whilst we cannot remain forever sceptical, we need to be unassuming and sure about fundamental circuit activity and the simultaneous internal circuit reactions that arise when amplifiers and loudspeaker systems are used together to reinforce or reproduce sound.

Loudspeakers

As for our disco loudspeakers, hi-fi driver units had also been tried on the stage, but most were inefficient and sonically uninspiring, as if no amount of amplifier power could ever put 'life' back into their music. Three-way domestic hi-fi loudspeakers driven by class-B transistor amplifiers were an awful combination, and yet they went on to become a marketing phenomenon. This same set-up also ruined jukebox sound in the 1970s, as they became flashy, digital and unreliable, as well as tizzy. There is little I find subjectively more objectionable than a split human voice, where deeper tones excite a hideously slow bass driver out of phase with the mid, and natural clarity in the upper range is ruined by mid-cone induced break-up which interacts with treble output and causes suckouts which vary with frequency and listening angle. These dissonances arise in a manner that does not always show up via on-axis swept sine wave frequency SPL testing, because phase shifts, resonances and suckouts can fortuitously flatten a publishable one or two metre axial response, in much the same way that sine wave driving plus resistor loading can unfortunately exaggerate a solid state amplifier's capabilities.

Three-ways like my then (soon to be mid-dome-ectomied) Celestion Ditton 66s, might have been capable of generating thunderously impressive bass, with mid-range and high frequency wavefronts that had been optimised for a listening room sweet spot, but they were phasily 'tonal' and 'pass-bandy' on an open stage when compared to less than ideal PA drivers or our eighteen inchers topped by full range eights which had no more than a simple series capacitor to limit voice coil dissipation and cone excursion. I cannot be impressed by the best of transducers within their own designated frequency range, if their sound cannot subsequently be seamlessly integrated with that from other drivers.

The complex crossed-over responses of three-ways were supposed to be flat, but you could and still can hear completely segmented reproduction qualities creating an unnatural sound integration as reactive components, voice coil inductances, cone size and shape dependent driver, radiation, lag characteristics and hard to cure break-up resonances become prominent and not only interfere at different frequencies, but generate back EMFs that cause difficulties within solid state amplifiers. Also, many loudspeakers were once supplied with an internal foam 'damping' which introduced a colouration that reflected its own consistency; this should of course have long ago been replaced with a properly fibrous medium.

And then PA drivers with central metal 'presence' domes appeared. These generated intense upper mid range sound beams that further accentuated transistor amplifier distortion and the peakiness of similarly new electret microphones, the result being ringing ears and a potential for permanent hearing damage 100ft or more from the stage. Ugh! We stuck to hiss-less moving coil microphones and I ended up making manageably sized cabinets housing eight full range 5x9" Elacs with two 'high-fill' Fane soft dome tweeters. These were inexpensive combinations that proved to be very loud, clear, efficient, lightweight, excellent sounding (even with class-B solid state drive!), and not especially deafening when close up because the sound did not emanate from a single cone centre. I always thought that ellipitcals sounded better because unwanted effects due to varying cone angle and radial dimension were much less sharply pronounced than with circular drivers; also when an elliptical is used with its long dimension vertical its radiation pattern is generally more useful.

A lack of competent wavefront integration can still occur today with technically impressive hi-fi or 'time aligned' labelled loudspeakers, in spite of them being supplied with near ruler flat frequency response and impedance specifications. These sounders might well recreate an acceptable stereo image, but it does not matter how flat their on-axis SPL response is because we are still not properly free to experience different positional balances that do not change significantly as we walk through their radiation patterns as we can in front of a stage of real life musicians or sources that generate coherent wavefronts like those radiated by full size electrostatics or columns of smaller high specification full range drivers. Approximately 3dB of array gain arises for every doubling of the number of drivers in a line; i.e. 2x, 4x, 8x, 16x etc. Thus for any given amplifier power, a vertical line not only sounds louder, it reproduces with very much improved clarity and performer presence due to shared cone displacement improving transduction linearity; also the simultaneous outward extension of their combined near field at low voice frequencies is something that needs to be heard to be appreciated. A small transistor radio sized driver that sounds clear but 'thin' when singly mounted in a large cabinet, can delight when many are used to create a tall line source.

Piano, glockenspiel, saxophone, violin and so many other instruments as well as the human voice, all sound so much more like the real thing when their fundamentals, characteristic inflections and harmonics coherently emanate from the same transducing element(s) and are not electrically split between spatially separated drivers. And yet line sources can introduce problems too; for example, if the individual drivers are too large or their centres spaced too far apart, then a sound altering high frequency peak and trough 'comb' effect will develop in the vertical near field, or, when the drivers are small and close together, an inadequate length of flat line will create a beam that sounds quite different in standing and sitting positions because it cannot coherently cover both.

With loudspeakers especially, specifications alone will not guarantee a good sound for every reproducing situation, and unless you've won the lottery, you'll run out of readies before the reviewers run out of enticing superlatives and suggestions that you try ever more exotic systems. Small drivers reproduce more coherently through a wider frequency range and I prefer this ability, but small drivers lack air volume displacement and cannot radiate adequately at lower frequencies, so that even when they are multiple they still need to be augmented by separate sub-bass drivers.

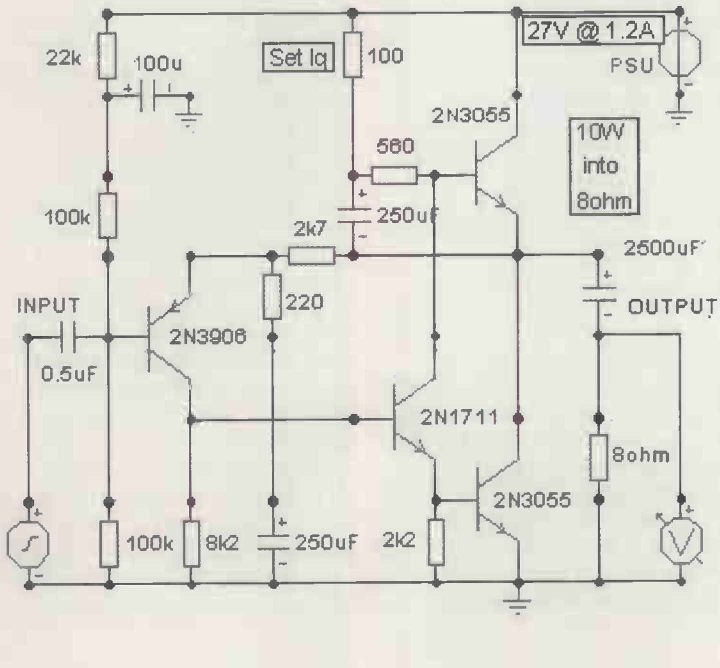

Figure 1: After 35 years, the chokeless 10W JLH-69 class-A still reproduces more cleanly than many class-B designs having better 'specifications'.

Small drivers might also have a high frequency response extending to 20kHz, but that will not necessarily guarantee a capability for generating realistic sounding wavefronts to the limits of audibility because their phase linearity might start to 'roll over' at say 10kHz. Precious few small drivers reproduce high frequencies convincingly, and these are very expensive; the rest need assistance via a 30 to 40kHz specified super-tweeter that will not roll over within the range of CD reproduced playback frequencies when it is crossed over to match the desired application. Wherever you see amplitude peaks in the upper response of a driver or system, whatever its cone, dome or ribbon size, you can be sure that its phase response is changing rapidly at that frequency, and that it started to roll over well before this, as amplifiers do. For example, an amplifier with a ±3dB response from 15Hz to 25kHz, might exhibit a flat phase characteristic between 50Hz and 7.5kHz only, whereas a three-way loudspeaker having the same amplitude response will generate additional transduction phase and side lobe incongruities about and through every crossover frequency.

I guess as individuals we each have to weigh up the increasingly significant costs of improving sound reproduction, against our personal dislikes, objections and tolerances for different kinds of amplifier and loudspeaker induced distortion. We are all different. Also, each of us knows what we like to hear, often without understanding or being able to explain why, and without others being able to comprehend our preferences either. It is this natural variation that makes the opinions of 'non-techies' and especially blind persons so profoundly relevant, and shows us that our everyday systems still have a long way to go.

Formative investigation

Whilst the loudspeakers were the weakest link within our disco chain, it was the solid state power amplifiers that sounded less convincing, so I decided to build for myself a known good transistor chassis in order to double check our witnessed observations. My choice was the 'Simple Class-A Amplifier', by John Linsley-Hood, as published in Wireless World, April 1969, p148; only mine was going to have a triple-parallel output stage with 50W into 8Ω sine wave driving capability. For further reading see 'Class-A power', by John Linsley-Hood, *Electronics World*, Sept 96, p681, also, 'John Linsley-Hood, a lifetime in electronics', *Electronics World*, May 2000, p417.

I had already constructed several of these simple non-complementary 10W amplifiers for friends and myself, see **Figure 1**, and although I never used regulated power supplies, or the extra stabilising components and direct coupling options subsequently suggested, this design proved to be eminently trustworthy. Everyone who hears it is amazed that so few components can exert such competent cone control with a sound that is unaffected and easy to listen to. When good transistors are used the reproduced transients are clear, and neither over-sharp nor dulled by the haze of loudspeaker system back EMF induced sub-currents which can affect class-B reproduction during full music program. Of course, with it being class-A, there was no chance of output stage crossover distortion either, while the simple JLH four transistor topology introduced minimal phase shift and thus there was little risk of invoking closed NFB loop high frequency instability when sensibly constructed, driven and loaded. It is worth noting that I made several five way video distribution amplifiers based upon this very same 'audio' circuit; they used video transistors, and worked extremely well with series resistor outputs feeding MHz signals down several coaxial cables, some being 200 metres long to concealed equipment.

To achieve the 50W output I used six selected high specification 2N3055s, and bolted each directly to its own electrically isolated heat sink; to minimise PSU ripple I fitted 3x 10,000μF of rail smoothers and had a star earth point at the small signal amplifier shielding plate. To extend the low frequency response for pop music reproduction I upped the values of all decoupling electrolytics by a factor of four, because dropping back to the original values had an audible effect, yet increasing the output capacitor to 50mF made no discernible improvement to pop music at that time.

I recall a famous brand miniature full range loudspeaker which had a surprisingly big sound for its size because the enclosure was ported behind the tweeter; it also had a non polarised capacitor in series with the compact mid-bass driver to tune its response and thereby optimise low frequency output by modifying the resonant peak, without leaving it vulnerable to sub-bass overdriving. A 2.5μF capacitor in series with this particular loudspeaker would have compromised the manufacturer's intended bass reproduction characteristics in a way that could have been construed as being a loudspeaker problem, and not due to the amplifier itself! By way of a separate note, I too had configured my magnetic cartridge RIAA equalisation to roll off at 25Hz as JLH had done, instead of at the more usual 50Hz; I used passive plus buffered precision R-C filtering for the upper 2120Hz cut to simultaneously filter noise from the foregoing high headroom gain stage lift below 500Hz. This sounded so much better than conventional circuitry which used only full NFB loop shaping, and the same topology remains relevant today for those wishing to transfer vinyl collections to hard drives via high quality sound processors. When disc rumble or bass feedback became a problem on loud playback (even with wall mounted turntable plinths) I used bass cut and/or switched in the primary of a miniature LT700 equivalent transformer between the pre-amp channel outputs to 'mono' the differential sub-bass without noticeably alterting its overall level, or affecting other audio frequencies. Now with CDs and good spinners we can have the equivalent of kick drums, bass guitar cabinets or many cellos in our lounges without any risk of room shaking feedback.

At that time my favourite power amplifier had been the competent and reliable Leak TL-50 Plus: 2x KT88 (or 6550 for USA), ultralinear, class-AB1, and 50W RMS at 0.1% distortion over 20Hz to 20kHz. This level of distortion is higher than expected today, but don't forget that the quoted figure was for maximum output, and distortion faded down into thermionic hiss at normal listening levels. I also noted that sine wave clipping into a resistor load did not occur until 55W, which probably assisted the bandwidth specification, for there was useful power below 10Hz via its large output transformer which meant that this chassis could be, and was, used for subsonic vibration testing in civil engineering research! I ended up convincing myself that a 50W version of the JLH class-A amplifier should be able to replace the TL-50, especially as high quality plus high power valve output transformers suddenly became no longer available beyond the 1960s. Customer demand has since led to renewed manufacture, but expectant constructors really must bear in mind that only thickly cored transformers embodying the finest of magnetic material, plus split winding techniques are capable of reproducing sound worthy of the expenses incurred in association with hollow-state and electrostatic technology. Falling back to 'calculated' windings on mains transformer toroids really is not the best way of using valves like KT88s, which are approximately £30 each, but up to £320 per pair for unused originals!

Class-A heat

50W at 8 ohms means 57V p-p and 3.6A peak at the load. Adding 6V for transistor operation and emitter resistors, plus 10% for class-A current continuity, gives 63V @ 4.0A. However, when it comes to quiescent biasing, we have to remember that hot power transistor junctions have a higher gain at lower current than is stated in normal 25 degree specification sheets. This means that when they are hot, their gain falls much more sharply with increasing collector current, as well as with reducing Vce. Figures often approximate to an HFE reduction of 40% for every doubling of collector current between low level and maximum, plus anything up to another 40% between zero and peak output voltage conditions. Thus when the output stage base current that is necessary for 4.0A of maximum conduction in one output half is split and shared to provide the standing bias for two output halves that run in hot class-A, the resulting quiescent current ends up far exceeding the 2.0A that might simplistically be expected. Indeed, where low distortion is required from ordinary power transistors running in pure class-A push-pull, the quiescent current often ends up equalling the peak load current that is calculated as being necessary for a maximum output, even though it is rarely used during audio amplification.

Due to the higher currents involved, I replaced the bootstrapped output stage biasing resistors with a constant current generator and used grounded current mirrors to maximise linearity at the first two transistors. The supply was derived directly from a bridge rectifier with the quiescent voltage being set via a resistor in series with the mains transformer primary winding. With its class-A biasing and additional mains transformer losses, the total heat dissipation was 300W – more than twice that from the 'old fashioned' KT88 chassis!

Well; my 50W class-A and the Leak TL-50 were test bench equals. Triple output transistors conferred an ability to drive home hi-fi loudspeakers at enthusiastic listening levels, and both amplifiers performed most satisfyingly. The extended frequency response and clean treble of the class-A design was discernible, though not especially significant during listening comparisons. I also found that it was not easy to identify sound differences between amplifiers when they were running well within their power rating in a home setting and not driving reactive or efficient loudspeakers loudly. By way of a sideshow, the loudspeaker leads from my new amplifier could be tested for output by sparking them together with full signal input; the spark noise always made observers gasp because the transistors never blew. It is likely that the short circuit zero ac voltage currents peaked at just over eight amps, but of course this was via three parallel connected output transistors and they were naturally limited to this level by the current sourced pure class-A base biasing. Also a high value output electrolytic is not quite the same as a direct current short circuit, while constant shorting of the output terminals did no more than trip the 2A thermal breaker I had in series with the mains transformer primary. Continuously sparking the loudspeaker leads at maximum input can destroy many amplifier types, yet it is theoretically and practically possible with a simple class-A amplifier running correctly chosen output transistors because it is already running close to maximum dissipation. In its day this was a party trick!

Listening tests

I was very proud of this new construction and determined that I would show it off driving our highly efficient disco speakers. And when I did, it gave me much more of a surprise than I could have expected, for it was incredibly lifeless. Yes, lifeless! There was a lack of effervescence at levels where the KT88s effortlessly breeze along. Actually, it was a very pedestrian performance. Like an immature and purely voiced choirboy wimpishly lacking the live energy, dynamic drive, raw vigour and 'Easyrider' exuberance that pop music expounds. Yet it was not bad either, because it really was clean at ordinary levels, and it ran into overload without sounding harsh. Once again the ultralinear tetrodes sounded twice as powerful as an amplifier measured as being its equal on the test bench. Disappointed? After all my efforts I was flabbergasted. Words, thoughts and an explanation failed me, though anyone reading this who uses valve power will understand my observations. I tested again after reducing PSU series resistance. With each power transistor convecting 50W of heat, this lifted the output to 75W into 5Ω, but the valves remained superior, and I could not see how bipolar class-A was supposed to be a positive step forwards.

Text books of the day suggested that pure class-A was the very best, and yet here I had this idealised solid state example which I had just proved to myself was not a reference *audio* amplifier at all. It was satisfyingly transparent and tireless for domestic use as part of the home hi-fi system and like so many other transistor amplifiers it was fine for driving audio frequency sine waves into a test bench resistor, but in spite of its heat generation, it sounded indisputably lacking beside the KT88s when being used to drive large and efficient 'pop' loudspeakers in open surroundings. Clearly, an ability to amplify audio frequencies does not automatically show that an amplifier is suitable for universal use as an audio amplifier. I could have thought I had demonstrated that a 'pure class-A' watt is unlike a 'class-AB or class-B' watt; or a 'transistor' watt is unlike a 'valve' watt; or a 'hi-fi' watt is unlike a 'PA' watt; or even that 'loudness' and 'watts' are not related at all. All the clues had been there, but it would be some time before I properly understood why solid state amplifiers performed worse than valves (most still do) relative to their power rating, and it was going to be another twenty years before better gain linear power transistors like the 2SC3281 would become available. I had grown up with, and had had my audio and radio bases founded by valves, thus I remained disappointed with solid-state offerings because they really were incapable of performing as well. Transistors were good for portable radios and low-level audio, but not for power amplifiers. Others raved about compactness, power output and convenience, but because of the way in which they altered reproduction when driving loudly, I was left most unimpressed.

Also, I don't ever remember reading anywhere that normal bipolar transistor output stages running in shared bias pure class-A are not balanced when operating in plain and ordinary push-pull; this includes hot 2SC3281 etc. Take the example of a single pair running a quiescent current of 1.5A, and powering into a low resistance. Load currents of 2A peak might reasonably be expected, but due to the hot current gain non-linearity mentioned above, one half might manage only 2.2A whilst the other drops to 0.2A. The simplistically imagined and often inferred sharing and balanced variation of ±1A about 1.5A, i.e. equal and opposite driving currents of 2.5A and 0.5A, just does not occur. Only at low output levels is push-pull activity naturally equal and opposite and thus of very low distortion; the higher the desired output, then the more disproportionate the driving requirements, the more imbalanced the Vbe changes, the power rail current draws, and the output device storage effects become.

The same applies with bipolar push pull, for the combined gain of driver plus output devices at moments when a dynamic loudspeaker becomes reactive and draws maybe 2.5 times the nominally measured output current, could easily be one tenth of that measured at maximum on the test bench using a nominal resistor load. Negative feedback is used to subsequently reduce audio frequency distortion, but it might be only one tenth as effective through momentary reactive load demands, and be even less capable of improving the fundamental imbalances and internal delays due to transistor action. Valve and mosfet output stages are better than bipolars in this regard, though mosfet gates can cause additional non-linear capacitive loading problems to VAS and driver stages, and thereby alter gain and propagation characteristics within waveform time in a manner that significantly increases with signal input amplitude and frequency, also with dynamic and reactive loudspeaker output loading.

My real-world tested pure class-A biased bipolar amplifier might have sounded better than bipolar class-B, but its powering capabilities turned out to be much less than the ideal I had been expecting; thus it remained no more than a curiosity which was then used for very many subsequent circuit and dynamic biasing modifications and evaluations, including testing with and without a series output choke.

Transistor amplifier designers

I cannot apologise in advance for feeling the need to write this section and I gain no satisfaction from doing so, but it does relate to many amplifiers that are already in existence today, and to the use of circuit elements that are *still* being supported. Thus I trust that by the time you have finished reading these pages, you will properly understand my reasons.

Over the years I have watched amplifier designers using NFB to reduce THD distortion below what were already satisfyingly low 0.1% valve levels at maximum output, as if by meticulously doing so they could assure music listeners that all distortion ills had been cured, and that their circuits really could not be blamed for any of the perceived inadequacies and reproduction changes that arise within the high fidelity playback chain. Yet many of their ever more 'advanced' designs appeared to have been doing no more than moving inexorably sideways, instead of progressing with inspirationally audible real-world improvements. I used to repair top flight hi-fi amplifiers and was amazed at hearing better than 0.01% specified designs which really were so obviously inferior when compared to old 0.1% valve chassis. Also, the more negative feedback that had been used to 'improve' any topology, the greater the sound change and loss of clarity became when the amplifier was running loudspeakers at realistic levels. Most definitely, the reproduced sound we eventually hear is not always commensurate with bench measured amplifier distortion specifications and I heard some relatively expensive products that sounded really awful. At the time I did not express any opinion to those who had bought on the strength of reviews or reputation, for fear of it affecting my income, besides, I did not have any proof to back up my subjective opinion. I knew that it was not the NFB itself that was the problem, for its considered application can genuinely improve sound reproduction, but all the response and open and closed loop analysis theory of the day was not explaining the changes perceived in reproduced sound when NFB loop controlled transistor amplifiers were being used to drive real-world loudspeakers loudly.

It was not the theory that was wrong, but the way in which it was being implemented!

Sadly, I have come across some rather condescending and over confident designers (plural) who unswervingly believe that because their amplifier develops less than 0.01% audio sine wave distortion at full power into a resistor, has >100kHz bandwidth, can run for days at maximum output with 2μF in parallel or into a short circuit, whilst simultaneously passing all the theoretical open and closed NFB loop stability examination tests known, that it cannot possibly distort any audio waveform it is called upon to regenerate at the loudspeaker terminals. There has been no way of penetrating their already established mindset and because they really cannot comprehend that others are genuinely capable of hearing and subjectively describing consequential differences in reproduction which have not (previously) been technically founded, as can blind persons who develop surprisingly keen and additional hearing capabilities plus an ability to describe attributable characteristics or degrees of altered transparency which make a sighted person's hearing seem so inadequate no matter how experienced s/he might have thought their own audio ears had been, these designers then question the technical capabilities of such 'listeners', or label other designers as being not quite up-to-date or 'with it', or suggest that they are attempting to make their mark, or profit from heartfelt irrationality. Even the very best of amplifiers are dulled by 2μF loading and the capacitor will become hot without telling us anything about amplifier reproduction quality.

Not only is this a sad state of affairs, but unfortunate too, for most designers tend to be highly educated people who understand theory, and know how to use it to commercial and executive advantage. They produce highly professional and thesis like presentations of overwhelming theoretical evidence and are occasionally published or granted patents, which means that they are obliged to defend their status or might feel a need to challenge when they believe that 'established' rules have not been followed by lesser educated or other designers who they feel do not have sufficient experience. So often it is their idea of what constitutes a challenge that exacerbates a situation and prevents genuine progress, for a brusque attitude and authoritarian proclamation of prior knowledge, (which they believe to be of primary importance) can so often turn into a personally deriding and clever but undermining word by word argument that misses other intentionally significant points by a mile, instead of being genuinely helpful, informative and explanatory to everyone. Also others will then keep their opinions to themselves for fear of receiving a drenching when side issue clouds become ominous.

The technical pen should be used advisingly, and with carefully considered encouragement to those who wish to contribute; not be wielded like a conqueror's sword that hacks down those who do not speak in the correct tongue or hold similar beliefs. Yet this is what keeps happening in the Letters pages, and rarely do these already 'established' theory based challengers sufficiently inform or provide their free thinking readers with the full unassuming proof that is necessary not only to prove their own case, but to give the supposedly errant writer a basis upon which to address challenge, and thereby either correct or reaffirm the stated foundation.

Thus I have long wondered whether the designers of modern and often more powerful solid-state chassis have properly demonstrated that their circuit improvements were audibly worthwhile within real world audio sound reproducing systems and if they did, where were the comparisons conducted, what loudspeakers were being used, and what was their reference - a good 1% distortion and non-NFB directly heated class-A triode amplifier, or a 0.1% and limited feedback ultralinear class-AB1 tetrode chassis? Don't laugh, I'm actually writing about sound reproduction - not steady state sine wave THD specifications. Thankfully though, some designers do conduct tests against a known good chassis in order to identify and if possible overcome any observable problems before being satisfied that they do indeed have conclusive reasons for presenting a design that does drive loudspeakers more realistically, even if their circuit does not measure as well on the 'established' test bench or via computer simulations.

In part two my writing will shift from past observation into recent circuit analysis and audio waveform simulation.

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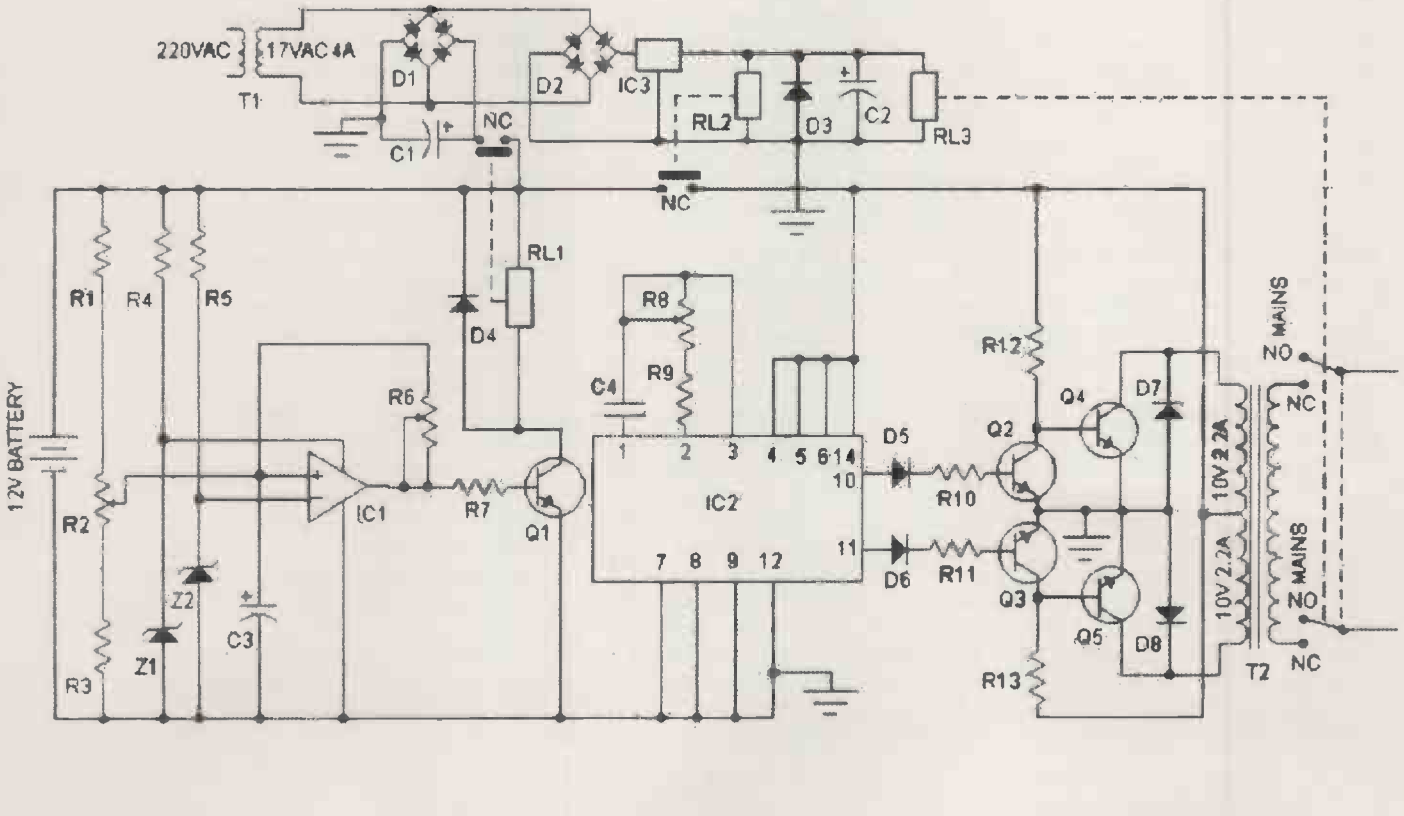
UPS

The circuit diagram presented is that of a fully automatic UPS. It can be used with PCs, TVs or any other domestic appliance (around 500W). The output volts are typically square waves type of about 100Hz. The user can adjust the frequency with the help of R8. The UPS may be divided into three sections.

The first part is that of an automatic battery charger constructed around an op amp (CA3140). It is recommended that the charger is constructed first. A standard variable supply may be connected in place of the battery. The voltage is set to that of a fully charged battery and R2 may be set so that the output of the op amp is high and RL I disconnects the charging system. Again the voltage of the variable supply is set equal to that of a drained battery and R6 may be adjusted for onset of battery charging. As the both the settings are dependent on each other, so a number of tests would be required to set the charging conditions.

The inverter is constructed around a CMOS astable multi-vibrator with Q and $\overline{Q}$ outputs. The frequency of the square wave output can be adjusted with the help of R8. The two outputs drive the two mirror image sets of



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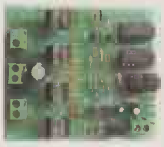

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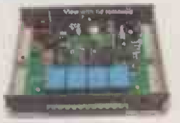

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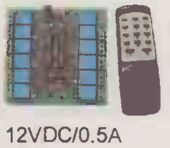

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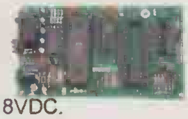

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IC1=CA3140; IC2=4047; IC3=Any 12V regulator
TRANSISTORS:
Q1=C1061 or D313 or any general purpose; Q2,Q3=BD139; Q4, Q5=BD249 (on heat sinks)
DIODES:
D1, D2=Bridge rectifiers (6A) or made from 1N4009; D3-D8=1N4002; Z1=9.1V-1W; Z2=6.2V-0.5W
RESISTORS:
R1-R3=10KΩ; R4=120Ω; R5=2.7KΩ; R6=50KΩ; R7,R10-R11=2.2KΩ; R8=220KΩ; R9=330KΩ; R12-R13=68Ω-5W
CAPACITORS:
C1-C2=47μF-25V; C3=100μF-16V; C4=4.7nF
RELAYS:
RL1-RL2=12V-SPDT; RL3=12V-DPDT
TRANSFORMERS:
T1=220VAC to 17VAC-4A; T2=220VAC to 10+10 VAC-Each Loop 2.2A

two transistors each, switching them in a complementary manner. The two output transistors conduct DC voltage in the two respective loops of the transformer generating 220 volts in the high voltage winding. Two diodes (D7, D8) are used to protect the output transistors from reverse high voltages produced by the inductor.

The third part is that of automatic switching. For this purpose three relays are employed in the circuit. Relay (RL1) is used in the normally closed condition. Reaching the voltage of drained battery to a limit of that of a fully charged one (set by the user) changes the output of the op amp (high). The transistor (Q1) is switched on thereby energizing the RL1 and disconnecting the charging system from the battery. Whenever the battery is drained to a lower level of voltage (set by the user) charging recommences and the cycle repeats.

Relay (RL2), in normally closed (NC) state, is used to keep the inverter circuitry disengaged from the battery whenever the mains 220VAC is not on. As soon as the mains voltage is off (fails), RL2 is de-energised and thus connects the battery to the inverter.

Relay (RL3) being double pole double throw (DPDT) is used in such a manner that when the mains 220VAC is on, RL3 is just conducting the mains to the load (NO). As soon as the mains fails (mains 220VAC is off), RL3 is de-energized, and connects the inverter output to the load (NC). Thus the load is uninterrupted in case of mains failure.

One triple pole double throw (TPDT) relay could be used instead of the two (RL2 and RL3), but I did use two separate relays in order to avoid any chance of high voltage hazard in the low voltage section of the circuit.

Ejaz ur Rehman
Islamabad,
Pakistan

SSB exciter with ladder filter

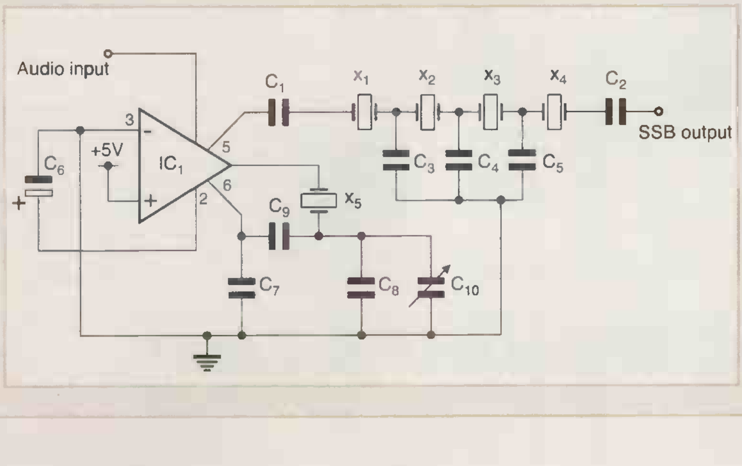
The circuit which is described here has an immense use in the making of SSB transmitters. The heart of this circuit is IC_1 (NE612) which works on Gilbert cell principle. This magnificent IC has a double balanced mixer, oscillator and an internal voltage regulator so there is no need of any external oscillator since this IC contains all the above parts.

For SSB production, any four crystals from the same company are necessary The out put from pin number 5 of IC_1 gives DSB signal only when audio is applied to the IC This is an excellent quality for generating SSB signals. Out put from the pin 5 can be fed to any SSB RF power amplifier another plus point of this circuit is we can use this same circuit to receive the same frequency signals. Thus the size of transceiver becomes very compact.

Buy the crystals of required frequency all the four crystals must be same frequency same company since different company crystals have different internal capacitance which is not good for production of SSB signals Capacitor may be Styroflex or polyester to give high stability Then wire up according to the circuit The out put can be tested by using oscilloscope align the capacitor for proper output

Audio from the mic or amplifier is fed to the input of the IC_1 in pin 6 Double side band is created in the IC The internal transistor oscillator oscillates with the frequency which is same as the frequency of the crystals. The capacitor in series is used to increase the frequency by.001% or a fraction which gives the carrier volt which can be amplified by external RF amplifiers to give the required output.

There is little modification needed to convert this circuit into a receiver circuit a hand full of components are needed for this purpose This SSB exciter can be used or modified from low frequency to 200Mhz. Simply adding the required crystals and tuning. Ladder crystals can be replaced with required quartz filter and switching separate LSB and US13 instead of X5 in the circuit The circuit described here is of general purpose which can be modified according to once needs This circuit is designed and tested for frequency 9MHz/14MHz/28MHz which are ham frequencies. I think that this circuit maybe very useful for hams and electronics enthusiasts This circuit can also used for studying about SSB wave and its characters.



Components list

IC1 - NE602/NE612
XI to X5 Required frequency crystals
Capacitor C1, C2 - 0.01μF
C3,C4,C5 18pF
C6 - 10μF, 16V
C7 - 270pF
C8 - 50Pf
C9 - 10pF
C10- 22pf Trimmer

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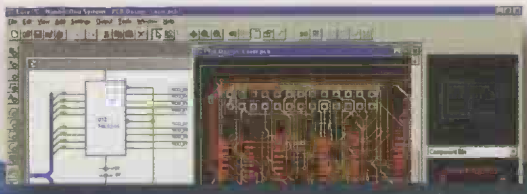

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SPAM? Not today thank you

Most users of e-mail are troubled by SPAM, but precautions are possible, some of them very simple and cost-free. Ian Hickman explains

Spiced ham was a great invention and is very handy if you want a quick meal on your plate. But the modern digital version, 'spam', is something no one wants on their computer. The scourge is large and growing, in every country. In May 2003 the network in the United States was burdened with amount of spam which exceeded non-spam traffic for the first time ever, and where the U.S. leads, the U.K. and the rest of the world follow, sooner or later.

It is, of course, argued by the spammer that spam is simply advertising, which may bring to your attention goods or services that you would like to know about and purchase, but of the availability of which you would otherwise have been unaware. However, the objectionable aspect of spam is its indiscriminate distribution. If you are a gardener, then you will find advertisements for seed, spades, compost, derris dust and the like in your favourite gardening magazine entirely appropriate, even if you don't want to buy any of those items just now. But you would not want, nor expect to see, adverts for spinnakers or depth-sounders. An example of just how annoying inappropriate spam can be was forced on my attention recently - an e-mail arrived in my inbox inviting me to view a pornographic movie which, to judge from the title, was singularly unpleasant and depraved. Had I installed one of the various filters available, it would have been blocked, but under my usual routine, which I possibly neglected on that occasion, and of which more later, it would probably never have reached my inbox.

The popularity of spam as a means of advertising is simply due to the economics of the game, as explained in Reference 1. In the U.S., a spammer can buy a list containing several million addresses for less than $100. Suppose he spends a couple of thousand dollars on e-mailing 20 million messages extolling his sixty-dollar product, then with a mere 34 purchases he breaks even, and thereafter is in profit. This is a response rate of less than 0.0002%, whereas a direct mail advertising campaign needs a response rate in the region of one and a half or two percent to cover its costs.

...a spammer can buy a list containing several million addresses for less than $100...

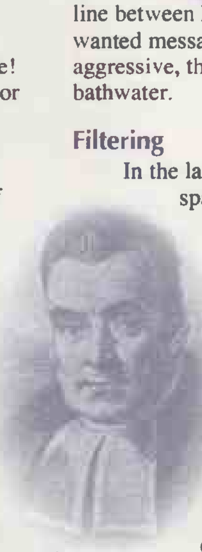
Lists

So just where do spammers get their lists of addresses from? Professional readers of this magazine will probably also receive several 'freebie' electronic magazines, ones with no cover price, being supported entirely by advertising. Like many other magazines, advertisements etc, one is encouraged to supply one's e-mail address when replying to advertisers. I know from experience that these magazines sell their address lists to one another, with the result that one can receive duplicate copies with identical address details – the other day I actually received four identical copies of one such magazine! Whether the e-mail addresses are for sale or not I cannot say, but certainly the sale of circulation lists is widespread, despite the efforts of an audit bureau. However, technology provides an alternative way of discovering email addresses[2].
This is the 'dictionary attack'. A spammer, or someone wishing to generate lists of e-mail addresses for sale, opens a connection to a server, and using software specially designed for the purpose, sends millions of randomly generated e-mail addresses. The vast majority are of course unknown, and - conveniently for the spammer - flagged as such by the server. Those not meeting with such a reply are added to the list. Some modern mail servers are programmed to look for large numbers of messages to unknown e-mail addresses all from the same source, but on a large server, such a 'dictionary attack' may simply be lost in the vast amount of traffic handled. In January, attacks on two well-known servers, emanating from servers in Beijing which were being operated from the United States, were announced. These attacks had been in progress for months, and must have accumulated huge numbers of e-mail addresses. The victims will never know how their e-mail addresses were obtained.

In the past, the small amount of spam I received was easily dealt with, but that blessed state is fast disappearing. What can one do about spam, if, as in many cases, the sheer amount is an intolerable burden? The traditional approaches are to reject any messages from known spammers or the mail servers that they use, and/or to reject any messages containing words typical of spam, such as 'Viagra', 'low interest rates' etc. But these are of limited use. Spammers counter these ploys in various ways, such as changing their addresses or the servers they use. And simple keyword filters tread a fine line between letting spam through with the wanted messages if too gentle, or if more aggressive, throwing out the baby with the bathwater.

Filtering

In the last year, more sophisticated spam filter programmes have become available, based on the probability theory elaborated by the 18th century mathematician Thomas Bayes. A tabular list of open source Bayesian filtering software is given on page 42 of Ref.1, with the URL of each, details of the language in which it is written and a comment - such as 'Originally written by open-source guru Eric



Thomas Bayes

Raymond'. This type of code is being incorporated in products from Microsoft, Netscape and other sources. The URLs are given here as Appendix 1. A Bayesian filter looks at the whole message, rather than simply looking out for keywords. Following training - you go through your inbox and tell it which messages are spam and which not - it forms rules for itself, which it applies when scanning new e-mails. These rules are subsequently refined each time you rescue an e-mail the filter has wrongly assigned as spam, or tell it that something it let through really is spam after all. The great worry about spam filters is the 'false positive' problem: when a message you would like to receive gets discarded. One expert in the field claims that, even when set for zero false positives, the best Bayesian filters can still discard 99.5% of spam.

But filtering at the recipient's level does not help the ISP. Spam is as unpopular with Internet Service Providers as it is with the unwilling recipients, since it uses up a lot of an ISP's bandwidth and disk space. So most ISPs now use server-based software to filter e-mail before moving it around the network to individuals' inboxes. These spam filters, of various sorts, can be quite effective. For example, AOL deletes about 2,400,000,000 items of spam daily, representing about 70 messages aimed at each of its customers' inboxes each day. It is, of course, just possible that an e-mail you sent never arrives at its intended destination, having been erroneously classified by an ISP as spam.

Billions wasted

The financial burden on the I.T. industry is great. The EU's Commissioner for Enterprise and the Information Society says research has shown that spam costs European businesses 2.5 billion euros at present, while the estimated cost in 2003 to US-based ISPs and corporations is $10 billion. Part of the problem is that spammers go to great lengths to disguise their messages as legitimate traffic, and to disguise their identity and location. In the UK, the London-based non-profit anti-spam organisation Spamhaus produces an hourly updated block-list of sources of spam, which is used to protect the accounts of over 140 million e-mail users. The American anti-spam organisation Brightmail runs a network of e-mail addresses as deliberate 'victims'. When a message is caught on a number of such addresses, it is likely to be spam and filters at the server can be updated to block the source. Brightmail protects the broadband customers of BT Openworld amongst others, and updates its filtering rules every five to ten minutes. Spam is not illegal – yet, although Microsoft, amongst others, has taken legal action against specific spammers. In Europe, there is a Privacy and Electronic Communications Directive, under which governments are required to implement anti-spam legislation by 31st October 2003, and similar legislation is in the pipeline in the United States. How effective it will be, remains to be seen. In Europe, the intention is that a spammer will only be able to use e-mails for direct marketing to individuals who have signified their willingness to receive it, the 'opt-in' strategy. In the USA, where the direct marketing lobby is powerful, legislation will probably require individuals to 'opt-out' from each source, effectively still allowing bulk mailing or spam. But whether you live in the US, UK or elsewhere, never accept a spammer's invitation to unsubscribe from his site, by replying 'remove' or in any other way. To do so, alerts the spammer that your e-mail address is not only 'real' (not rejected as unknown by your ISP's server), but also 'active', i.e. visited by its owner. Lists of active e-mail addresses are much more valuable than others, and the spammer can sell such a list, at a huge profit, to other spammers, who will in turn themselves sell it on. A real e-mail address may be inactive for many reasons. The owner may have activated a second e-mail address with the same ISP, or changed to another ISP, e.g. to upgrade to broadband, or just to get away from spammers. If you have a bad spam problem, you can always change to a new e-mail address and only notify your family and friends, legitimate business contacts and firms you want to deal with. Also, if you have your own website, consider very carefully before including your e-mail address on it. You are making a gift to spammers and sellers of lists, who have software that crawls the web, looking for '*@*.*' where * is any string – almost certainly an e-mail addresses. Likewise, when contacting e-mail boards and newsgroups, use a different e-mail address from your main one. If, for business reasons, you wish strangers such as potential customers to be able to contact you, you can hire a PO Box number from the P.O. Business Sales Centre, 08457 7950950. This costs £43.00 or £53.00 for six or twelve months respectively if you collect your own mail from your local Post Office, or twice that amount if you want the mail delivered. Alternatively, for people on the move, there is the free Poste Restante service, but this can only be used for up to three months, in any one town.

Don't download

At present, my own approach is to view what e-mail there is waiting for me at my inbox at the ISP. This is done using their 'webmail' service, accessed over the web with Internet Explorer. ISPs provide webmail as a 'wrapper' around the e-mail they have for you, so you can see what there is and delete any you don't like the sound of, before ever downloading any of it into your computer. If you cannot decide from the title whether it is a message you want or not, my ISP (like others, I guess) can make the content available as a simple text message to view on my screen, which does not entail actually running the code, even at the ISP end of the link. This prevents any undesirable item - virus, worm, trojan or just plain spam - entering my computer. Or at least, it almost always does. Immediately after 'sieving' the ISP-end inbox and deleting any unwanted items, I then download my email, with Outlook Express. There is, however, always the possibility that an unwanted item, spam or worse, arrived in the ISP-end inbox after sieving with webmail, but before downloading with Outlook Express. This could lead to a vulnerability, if the item is opened, should it be not just spam, but an infection of some sort. Outlook Express is often set up so that below the list of the latest e-mails received, there is a 'preview pane'. This displays the latest message received. But beware, in order to do so, it has to open the file. If the file contains a virus or somesuch, you could be in trouble. Even if you downloaded several messages, of which the infective one was not the last, accidentally clicking on its title in the inbox window will display it, and the damage is done.

Zone alarm

This danger can be prevented by going to 'View' in the Outlook Express toolbar, and from the dropdown menu, selecting 'Layout'. This will bring up the 'Windows Layout Properties' box, and you can then unselect the 'Show preview pane' box. Now, just clicking on the title of an item in the inbox window (for example, to transfer it to the Deleted Items box) will not open it. But beware, double clicking the title will still open the file, but in a new window. A useful precaution is to keep your Deleted Items box empty. For further protection, the firewall ZoneAlarm can be downloaded for free from www.zonelabs.com. This will warn you every time someone tries to access your machine, and give you the option to allow or block the request. However, unless you have a very fast processor, it will slow down you machine noticeably if set to the highest level of protection.

There is still a downside to accidentally opening a message, even if it is only spam. Many spammers will include a 'picture' in the message, designed to auto-display, either in the preview pane or a new window. You usually won't see them, as they consist of but a single pixel. These are known as a web bugs, and can be found in web pages, HTML formatted e-mail messages or other web-aware documents. Although there are legitimate uses for them, they are frequently misused by spammers. The display of a web bug triggers a 'phone home' return message to the spammer, confirming that he has reached a real active e-mail address and providing him with statistics on who is looking at the bugged item. Not viewing the message denies him this confirmation, and he may as a result delete your address from his list. This is another reason for disabling the preview pane. Other useful steps include setting Outlook Express to the Resticted Zone and disabling both session- and non-session-cookies. Some firewalls usefully include advertisement-banning features. For example, 'Outpost' from Agnitum can be set to prevent graphics of certain sizes or from known sources being loaded.

Geeks unite

Whilst precautions of this sort suffice, in my case, at least for the moment, a spam filter of some sort will almost certainly become necessary, sooner or later. In addition to the list of filters in Ref. 1, already mentioned, Ref. 2 provoked some interesting correspondence, see Ref. 3. One of the letters recommends the SpamBayes filter, which can be found at spambayes.sourceforge.net, as very suitable for use with MS Outlook Express, stating that it appears to be about 99% accurate. Nobody likes spam, and that goes for geeks, too. They 'fixed' one spammer, who thoughtlessly gave away his postal address in a media interview, so that he received hundreds of pounds weight of junk mail delivered to his door daily, making it almost impossible for him to sort out his wanted post! Details at Slashdot, the world's leading geek website. Details of some other interesting websites are given in Appendix 2

Acknowledgements

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References

1. *Saving Private E-mail*, Steven J. Vaughan-Nichols, Spectrum (*Journal of the IEEE*), August 2003, pp 40 – 44.
2. *Wham, bam – you've got SPAM*, Roger Dettmer, *The IEE Review*, September 2003, pp 38 – 41.
3. *The IEE Review*, October 2003, p4.

Appendix 1

Open-source Bayesian e-mail filtering software may be found at the following sites:-

http://bogofilter.sourceforge.net/
http://crm114.sourceforge.net/
www.mozilla.org/mailnews/spam.html
http://popfile.sourceforge.net/
http://sherpafilters.sourceforge.net/
http://spamassassin.org/
http://spambayes.sourceforge.net/
www.squirrelmail.org/

Appendix 2 – Some other useful websites:-

www.spamabuse.org
organisation against spam

www.mail-abuse.org/
runs special black lists of known spamming addresses and acts as an anti spam co-ordinator

http://spam.abuse.net/
another organisation with a no-spam vision of the world

www.bugnosis.org/
software for detecting web bugs on html pages (however doesn't work in an email client)

www.eff.org/Privacy/Marketing/web_bug.html
web bug info

www.leave-me-alone.com/webbugs.htm
another useful FAQ.

www.agnitum.com/products/outpost/

WATCH SLIDES ON TV
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"Liesgang diatv" automatic slide viewer with built in high quality colour TV camera. It has a composite video output to a phono plug (SCART & BNC adaptors are available). They are in very good condition with few signs of use. For further details see www.diatv.co.uk ....£91.91+ vat = £108.00

Board cameras all with 512x582 pixels 8.5mm 1/3 inch sensor and composite video out. All need to be housed in your own enclosure and have fragile exposed surface mount parts. They all require a power supply of between 10 and 12v DC 150mA.

47MIR size 60x36x27mm with 6 infra red LEDs (gives the same illumination as a small torch but is not visible to the human eye)........£37.00 + vat = £43.48

30MP size 32x32x14mm spy camera with a fixed focus pin hole lens for hiding behind a very small hole........£35.00 + vat = £41.13

40MC size 39x38x27mm camera for 'C' mount lens these give a much sharper image than with the smaller lenses........£32.00 + vat = £37.60

Economy C mount lenses all fixed focus & fixed iris
VSL1220F 12mm F1.6 12x15 degrees viewing angle........£15.97 + vat = £18.76
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VSL6022F 6mm F1.22 42x32 degrees viewing angle........£19.05 + vat = £22.38
VSL8020F 8mm F1.22 32x24 degrees viewing angle........£19.90 + vat = £23.38

Better quality C Mount lenses
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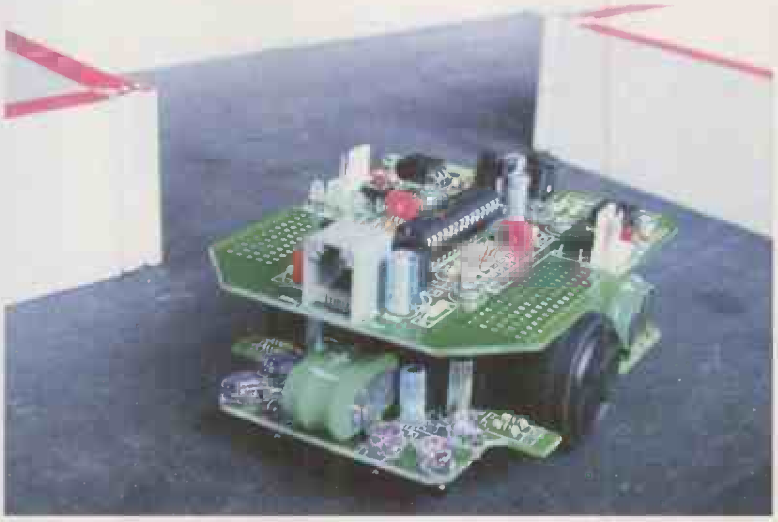
Micromouse wall follower

This article, part one of two, describes the design and construction of a small mobile robot capable of finding the centre of an uncharted maze and is suitable for entry into the annual 'Micromouse' competition. Martin Barratt explains

The Micromouse competition as we know it today originated in about 1980 and is a race from one corner to the centre of a maze constructed as a 16 x 16 matrix of cells each 180mm square. Each cell is bordered by up to four white painted walls each 50mm high and 12mm thick. The maze design is determined by the placement of the walls on a matt black painted baseboard approximately 3m square. The competitors, or 'mice', are generally autonomous robots capable of locomotion, the detection of nearby walls and, for a 'maze-solving' mouse, an awareness of its location within the maze.

When the competition was originally conceived, it was intended that all mice be capable of mapping the maze, and tracking their own progress in such a way that they were aware of their arrival at the central goal. In the early days this process took place at low speeds and the entrant's placing was determined by the duration of the search for the goal. In later years competitive mice have added a further phase to their operation – that of using knowledge of the maze wall locations to determine the shortest route to the centre and running this route at high speed after the search phase is complete.



The wall follower class

The design of a successful maze-solving mouse capable of mapping the maze, determining the optimum route and then travelling it at high speed is a considerable task involving many aspects of electronic and mechanical engineering and so, to broaden the appeal, a separate 'Wall Follower' class was introduced. Because these mice travel to the centre by simply tracking the left-hand wall of a suitably designed maze they are considerably simpler in design, having no need of odometry or maze mapping and solving capability. Indeed, many successful entrants make no use of microprocessors or software and are purely electro-mechanical using, sometimes rather brutal, contact with the walls to guide them.

Design history

The Wall Follower design presented here is based on a mouse designed in early 2003 as a result of running out of time during the development of a full maze solver. Mini-Mouse (it is conventional to give your mouse a name) was entered into the 2003 competition and gave a creditable performance. It did not win its class but was the fastest of the non-contact entrants.

As a fully paid-up member of the 'quart out of a pint pot' club, the author decided that Mini-Mouse should be a single-chip design using the smallest PIC possible, the choice being the 16C71, which offers little in the way of hardware features except a four channel 8-bit ADC. This approach was obviously going to lead to design compromises and place somewhat greater demands on the intricacies of the software (which was to be written in assembler) but that is the author's preferred design strategy.

As a result of discussions with various 'mousers' after the competition, it emerged that the concept of a ready-made design for others to use, either as-is or as a basis for further development, was well liked and thus this project was born.

Design goals

A primary design goal was simplicity of construction and programming 'and to this end' it is also a single chip design. However, it strays from the Mini-Mouse concept by utilising a generously featured and re-programmable micro-controller, the PIC16F876. The software, which is based on that originally written in assembler, is written in a dialect of PIC BASIC and, therefore, should be

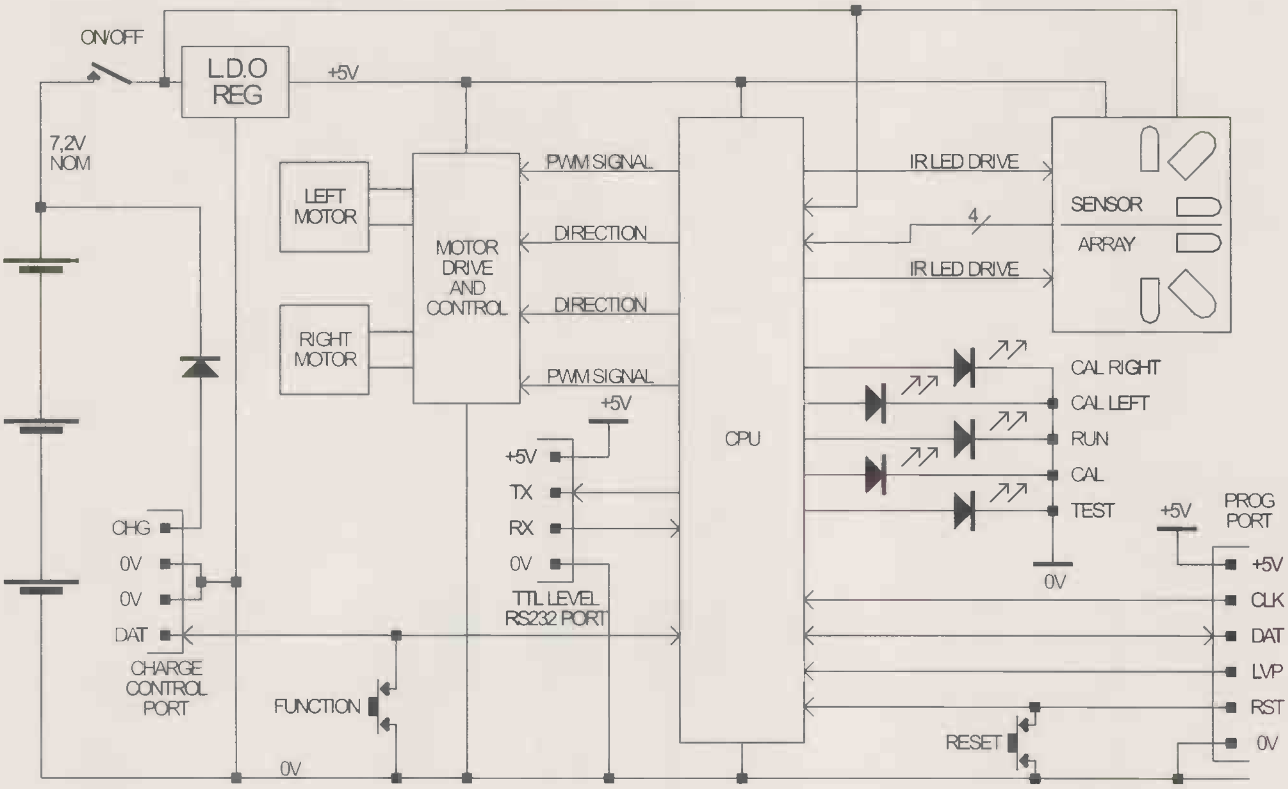


Figure 1:* *Block diagram

relatively easy to modify and adapt. Additionally, to facilitate the use of an alternative micro-controller, an Alternative Processor Interface has been included in the design and the two small prototyping areas provide a convenient way of implementing small design modifications.

Mechanical design

To minimise the mechanical engineering the mouse is designed around a commercially available motor block containing two small DC motors along with their respective gearboxes and wheels and the selected unit was chosen for its size, modest cost and the fact that it possesses a convenient set of mounting holes. The electronic circuitry is constructed on two PCBs of similar size which, when combined, can be manufactured as a single board in the popular, and hence low-cost, 160mm x 100mm Eurocard format. The detailed shape of the motor block required that two rectangular cutouts be made for the wheels and so, rather than waste these areas, a couple of useful auxiliary circuits have also been included.

When in action, one of the main problems mice are frequently seen to suffer is that of taking a less than perfect line when rounding a corner and subsequently getting caught against a wall. It is usually a protruding part that causes the difficulty and although this is not catastrophic, as the handler may nudge the mouse free, it does incur a time penalty. The design presented in this article attempts to overcome this problem by having the upper board extend slightly over the otherwise protruding wheels and thus the smooth board edge allows the mouse to 'scrape' around any corner taken rather too tightly. Additionally, the front corners of the upper board are chamfered to reduce the risk of becoming trapped against the outer wall of a corner should it be taken rather wide.

A further problem relates to the maze floor which because of its inconvenient size, is typically made up of smaller sections joined together and this leads to the possibility (probability) of small steps in the floor surface at the joins. In order to accommodate these imperfections a mouse must be designed to ensure that, under no circumstances, can the driving wheels lose contact with the floor and also that it cannot get caught at a rising step. The design detailed here achieves these goals by having only three points of contact with the maze floor, two of these being the driving wheels and the third a rear-mounted 'stay' formed from an M3 bolt with a domed low friction nylon nut screwed onto the end. As a bonus the nylon nut, because it is a friction fit to the bolt, may also be used to adjust the attitude of the mouse with respect to the floor. The adjusted attitude is maintained by careful placement of the components, particularly the batteries, ensuring that the centre of gravity is aft of the central axle-line and, therefore, that the stay is always under load.

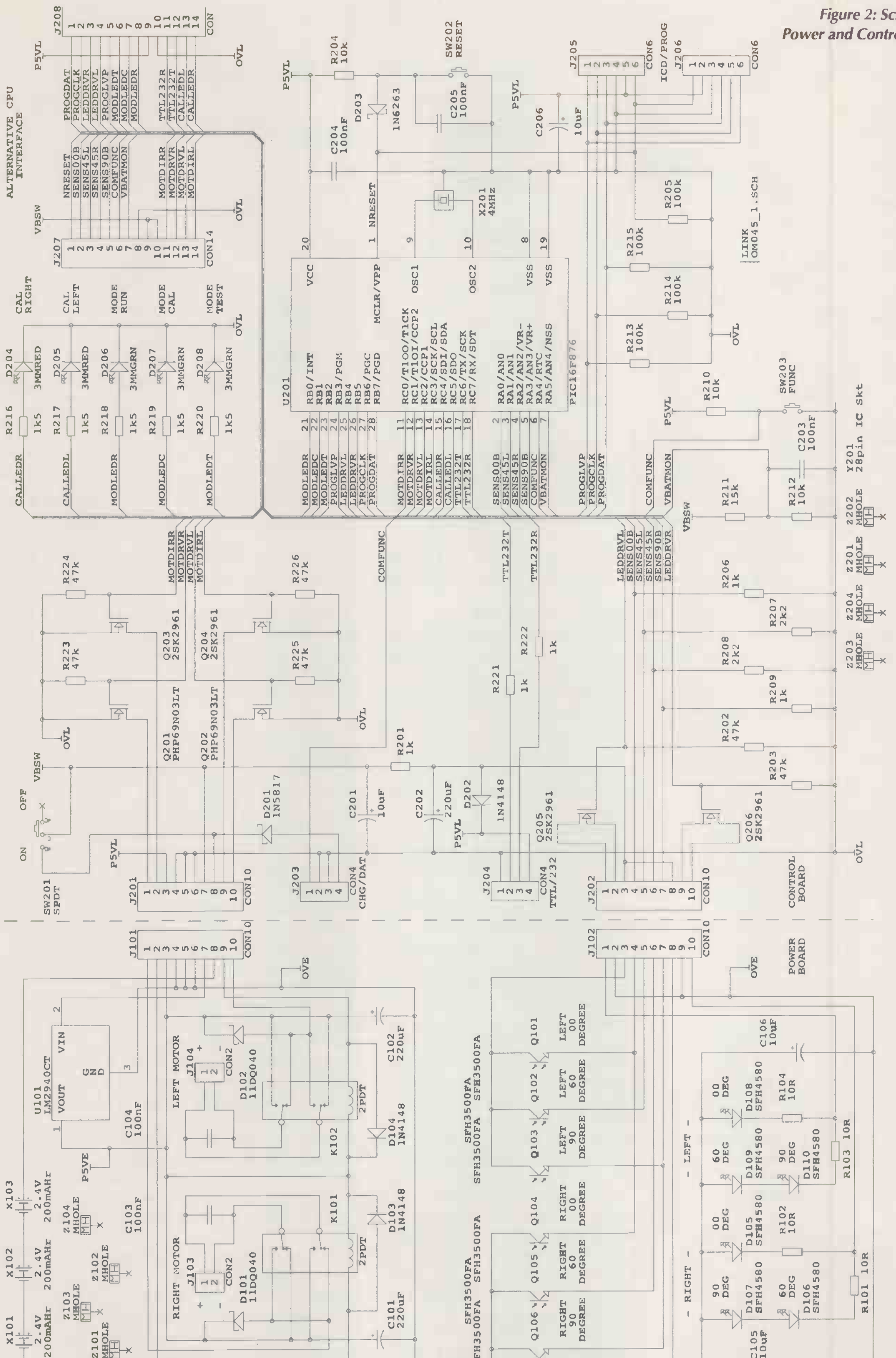
Circuit description

Figure 1 illustrates the block diagram of the mouse showing the major circuit sections and also the I/O connectors while **Figure 2** *(see overleaf)* gives the combined circuit diagram of the Power and Control PCBs and should be referred to for component identification in the following paragraphs.

The power source for the mouse is a crucial design element and the final decision is determined by the conflicting requirements of size and capacity. From one perspective the capacity question is not actually a problem because if the proposed design necessitates large batteries as a result of a long 'run time' then the mouse will not be competitive! However, a lower capacity battery also tends to have a higher internal resistance which, particularly when used in series connected packs, leads to a significant reduction in the terminal voltage at high current drains.

The selected power source for this design comprises three series connected rechargeable NiMH battery packs, designed originally for memory backup, providing a total of 7.2V at 200mAH. This battery type has the advantages of small size and

Figure 2: Schematic Power and Control PCBs.



low weight but does suffer from a highish internal resistance. Therefore, in order to maintain consistent performance over a range of battery voltages, a low-dropout voltage regulator U101 is used to provide a regulated 5V supply for the majority of the electronic circuitry and motors.

A simplified schematic of a single motor drive circuit is given in **Figure 3**. Each of the motors is independently driven by a CPU generated pulse width modulated (PWM) signal, amplified by either MOSFET Q201 or Q202, which effectively controls the applied voltage and hence its speed. The PIC16F876 contains two independent hardware CCP (Capture/Compare/PWM) modules and, in this design, both are used in the PWM configuration. Under software control, each produces a waveform with a variable mark:space ratio at a frequency of about 250Hz for driving the motors. This frequency has been chosen as a compromise between the increased losses of a higher frequency drive and the higher peak motor currents when operating with low M:S ratios at low frequencies. To relieve the batteries of the need to supply the peak motor currents capacitors C101 and C102 provide a local reservoir of energy and their inclusion also helps to reduce interference on the 5V supply.

The direction of motor rotation is determined by a miniature DPCO relay, driven by either Q203 or Q204, under control of the CPU. A logic 1 control voltage from the CPU places the corresponding motor in reverse. Diodes D101 and D102 along with capacitors C103 and C104 provide back-EMF suppression for the right and left motors respectively.

The 6-element infrared sensor array is arranged to have left and right hand sections with each section having sensors positioned at suitable angles to detect walls directly ahead and to the side and also to detect side walls slightly ahead of the current position as shown in **Figure 4**. The individual sensor angles are referred to as '00', '90' and '45' degrees respectively.

Each of the elements consists of an infrared LED emitter D105 to D110 mounted on the upper side of the power board with a corresponding infrared detector Q101 to Q106 on the under side.

Due to the limited number of ADC channels and the relatively low pin count of the PIC16F876, the sensor array is driven in a multiplexed fashion with all emitters in each section being simultaneously driven from a single CPU pin. Should the mouse be positioned such that it sees nearby walls to the side and to the front then all the detectors will produce a response so, in order to obtain the reading from a given sensor, the appropriate ADC channel is selected for the conversion – see **Table 1**.

By examining **Figure 2** it will be seen that the three infrared emitters in each section are actually wired in only two circuits, driven by either MOSFET Q205 or Q206. This configuration is used to reduce the current consumption. The '00' degree sensors are driven separately and are there are two reasons for this. Firstly, each diode has a forward conduction voltage of about 1.9V and so 3 diodes cannot be driven in series from a 5V supply. Secondly, in general the forward-looking sensors need to be able to detect the presence of walls at a greater range and running the emitter at a higher current permits this. Operating the emitters at higher currents also increases the signal to noise ratio, thus improving the reliability of long range wall detection, but simply increasing the emitter operating current also leads to excessive power consumption and the risk of device destruction. The design presented here overcomes these problems by operating the emitters in a pulsed fashion under software control and this method also provides the additional benefit of being able to measure the 'dark' sensor signal – that is with no intended infrared illumination. This quiescent signal, which is dependent on ambient light, may be subtracted from all 'illuminated' readings giving rise to an improvement in accuracy – more on this below.

It was a design goal to be able to monitor the battery voltage so, as the PIC16F876 has a total of five ADC channels, a method of sharing the six sensor detector signals among the remaining four ADC channels was needed. As shown in **Figure 2** the '00' degree and the '90' degree sensors from each section are 'paired' to achieve this. Intuitively it would be reasonable to think that this would cause interference between channels and to some extent it does. However, provided that the left and right hand emitters are only ever activated separately, the two '90' degree sensors operate independently as when one detector is illuminated the other is dark. In the case of the '00' degree sensors, due to their proximity, both of the detectors will be illuminated when either of the '00' degree emitters is activated giving an increase in detected signal and so contributing to the increased wall detection range.

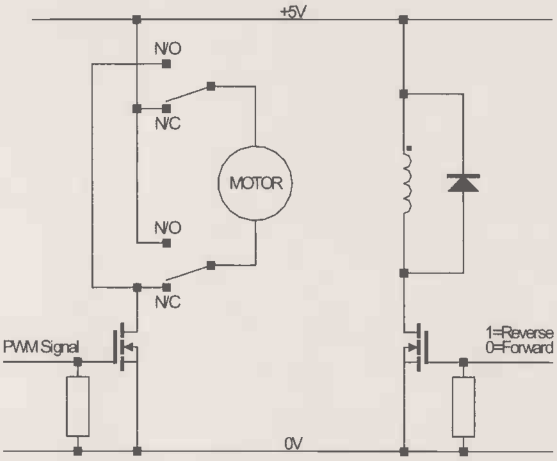


Figure 3: Simplified Motor Drive Circuit

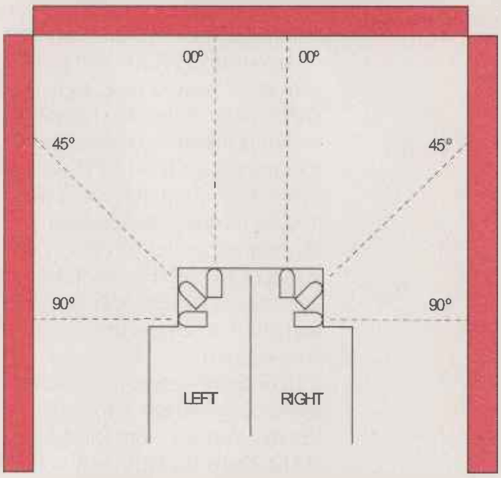


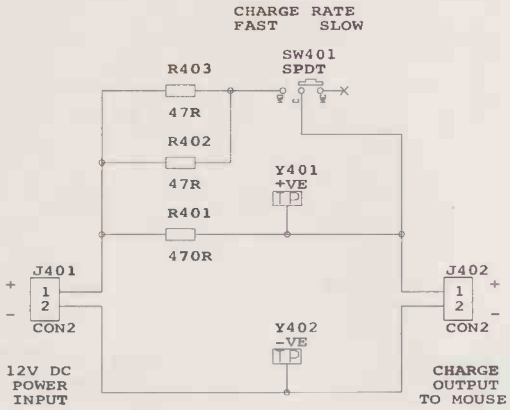
Figure 4: Sensor system arrangement

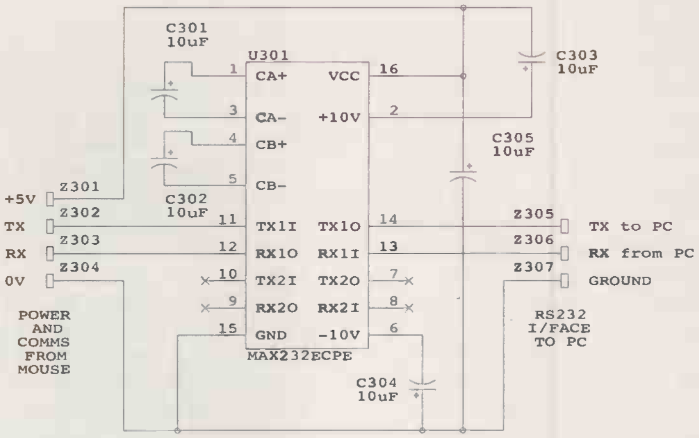
Table 1: Sensor vs ADC channel mapping

Sensor	Emitter drive	ADC channel
LEFT 90	LEFT	3
LEFT 45	LEFT	1
LEFT 00	LEFT	0
RIGHT 00	RIGHT	0
RIGHT 45	RIGHT	2
RIGHT 90	RIGHT	3

Resistors R206 to R209 provide the 0V referenced loads for the infrared detectors with their values chosen as a compromise between the conflicting requirements of fast signal rise-time, achieved with low values, and sensitivity.

Because the detectors are phototransistors the maximum emitter voltage is restricted to a level about 0.7V below its collector. Operating the devices from the 5V supply would, therefore, lead to a reduction





Left – Figure 5: charger board

Right – Figure 6: PC interface board

in dynamic range which is overcome by providing the collectors with a supply of approximately 5.7V derived direct from the battery by the network comprising R201, D202 and C202.

On power-up R204 and C205 provide a delayed reset signal to the CPU via the Schottky diode D203 which is present to isolate the incoming high level VPP voltage, at about 13V, from the rest of the system during programming. Pushbutton switch SW202 is used to issue a CPU reset at any time which cancels the current operating mode and allows the selection of a new one (see below).

In order to permit measurement of the battery voltage a potential divider, formed from R211 and R212, feeds the fifth ADC channel and provides a full-scale voltage of about 12.5V.

User interface

The pushbutton switch, in conjunction with the three mode LEDs, provides a simple user interface. The mouse has three modes of operation, namely RUN, CAL and TEST, selectable in turn by SW203 and indicated by the appropriate LED – more of this later.

Table 2: Programming Connector Pin Allocation

Programming Pin Function	ICD J205	PIC-PG1 J206
+5V	Pin 5	Pin 2
0V	Pin 4	Pin 3
MCLR	Pin 6	Pin 1
PROG CLOCK	Pin 2	Pin 5
PROG DATA	Pin 3	Pin 4
PROG LVP	Pin 1	Pin 6

Table 3: Charge/Data Connector Pin Allocation

J203	Function
Pin 1	Not Committed
Pin 2	0V Reference for Pin1
Pin 3	0V Reference for Charger
Pin 4	Charging Current Input

Ports

Three ports are included to variously provide interfaces for CPU programming and, in conjunction with the auxiliary circuits, battery charging and RS232 communications to a PC.

The first of these ports is the ICD/PROG port and the mouse described in this article has been designed to permit a choice of CPU programming and/or emulation strategies depending on the facilities or budget available to the constructor. The selection made dictates the fitting of either J205 or J206 and **Table 2** lists the pin allocations for these connectors.

J205 is an FCC68-6/6 connector suitable for connection to the Microchip ICD Classic low-cost emulator/programmer permitting a limited, but useful, level of in-circuit debugging to be accomplished along with device programming.

Fitting J206 provides for a very low-cost programming method using a PC serial-port-connected programmer, the PIC-PG1, in conjunction with the free IC-PROG device programming application. This method provides only device programming and does not permit any form of in-circuit debugging.

Figure 5 shows the schematic of the charger board that permits both fast and trickle charging of the NiMH battery pack from a nominal 12V power source. Closing switch SW401 places the charger in 'fast mode' in which the current is set at about 100mA thus fully charging the batteries from flat in about 3 hours – note that NiMH batteries have a charging efficiency of about 66%. The two test points Y401 and Y402 allow the connection of a DVM to monitor the process (see below). When set to trickle charge the current is about 8mA, a level that the batteries are able to sustain indefinitely.

Battery charging is accomplished through J203 – **Table 3** lists the pin allocations – and diode D201 is included to protect the battery pack from the application of a supply with reversed polarity.

The circuit of the second auxiliary function, the PC interface board, is given in **Figure 6** and is simply a TTL to RS232 level converter allowing a direct connection to a PC serial port. The design makes use of the ever-popular MAX232 chip with power being supplied via J204, which also provides the interface to the CPU's on-board UART. **Table 4** gives the connector pin allocations.

Battery charging

NiMH batteries, like most rechargeable types, may be 'fast charged' to save time but the process must be carefully monitored if permanent damage to the battery pack is to be avoided, and any rate over the C/10 rate is commonly considered to be a 'fast' charge. When operated as intended the fast charge rate provided by the charger board is approximately C/2, which is low enough not to present a serious hazard if significant over-charge occurs but it will lead to a reduction in battery capacity.

On attaining full charge the chemical reaction inside the battery changes in order to 'absorb' the extra current and this leads to an increase in the battery temperature. As a NiMH cell has a negative temperature coefficient the fully charged state may be ascertained by noting the slight reduction in battery terminal voltage or by the increase in temperature itself.

Sensor design

Of all the problems to be solved in the design of any mouse this is arguably the greatest. Many possible

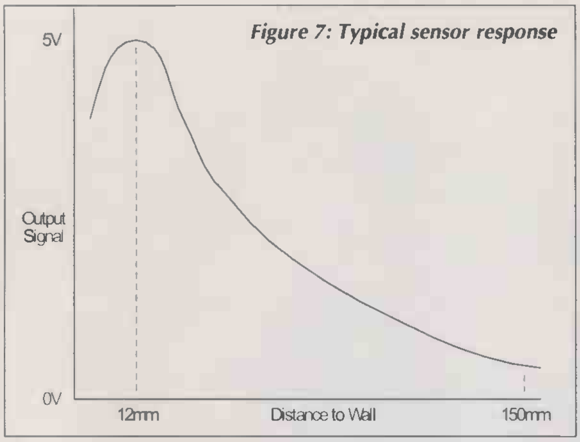


Figure 7: Typical sensor response

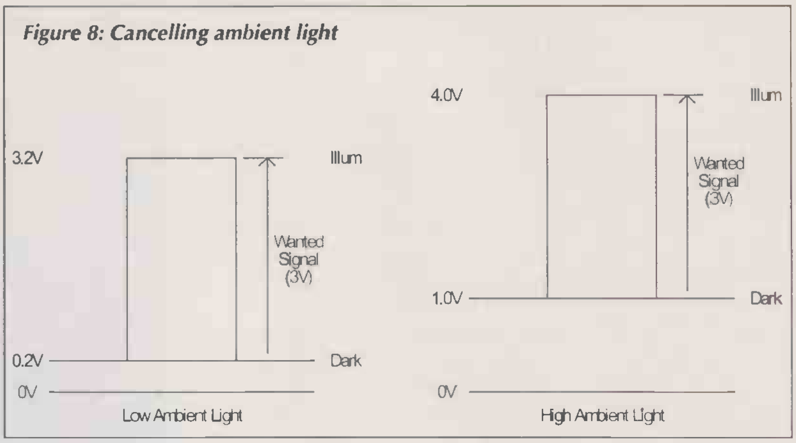


Figure 8: Cancelling ambient light

solutions exist and the final selection was made on the basis of size, cost and simplicity but, of course, these benefits come at a price.

The perfect sensor would provide an output signal directly proportional to the measured distance and do it in very little time while consuming almost no power. The sensor system presented here achieves the last two of these ideals but the output signal from this type of sensor is far from linear, as shown in **Figure 7**. Worse still, due to the narrow beam angle of both the emitter and detector devices, it is actually non-monotonic at short distances. This is a potentially serious problem which, fortunately, may be overcome with suitable sensor arrangement. As it is generally only the '90' degree sensors that need to operate at very close range placing these sensors well within the periphery of the mouse provides the solution. This ensures that, even when the mouse is placed right against a wall, the actual sensing distance is beyond the no-go zone.

At the other end of the scale the sensing system 'noise floor' determines the reliability of long-range measurements and local 'direct illumination' is a major contributor. This problem, which is caused by stray infrared light passing from the emitter through the PCB material directly to the detector, may be largely overcome by placing a solid copper zone on both sides of the PCB between the devices, thus shielding the detectors.

An additional factor affecting long range sensing is ambient lighting – in particular daylight – and needs to be considered when designing a sensing system. Although the chosen detectors incorporate a daylight filter (as indicated by the opacity of their plastic body) and a focusing lens, stray light can still reduce the reliability of measurement. For this reason the detectors are placed on the underside of the board to be as close to the light absorbing matt black maze floor as possible.

Even with these measures, ambient light can still cause an undesirably high photo-current in the detectors, which adds to the desired signal, giving the impression that the wall is closer than it actually is. Taking a 'dark' sensor reading immediately prior to the illuminated one and then subtracting it rectifies this and thus only the signal due to the reflected light from the wall may be determined as shown in **Figure 8**.

Software overview

The software is written for the microEngineeringLabs PIC BASIC Pro compiler. This compiler was chosen from the many available because it can be integrated within the Microchip MPLAB IDE providing easy editing, one touch compilation, and a measure of source level debugging using either the integrated MPLAB simulator or the ICD Classic emulator.

On initial power-up the RUN LED flashes for about three seconds during which time pressing the FUNCT button selects the next 'future mode', as indicated by the appropriate LED flashing, and restarts the three second timeout. Once the desired future mode has been selected letting the three second time out expire enters that mode, which illuminates the appropriate LED steadily and the software then waits for a further press of the FUNCT button before taking any action. Exiting any mode may only be accomplished by pressing the RESET button and re-selecting the desired mode.

The program has a total of three modes of operation as described below:

- **RUN mode:** This is the normal operating mode of the software and provides the functionality to navigate through the maze using the readings obtained from the sensors to determine the necessary corrective action for the motors.
- **CAL mode:** This mode is used to calibrate the infrared sensors to the reflectivity of the particular maze walls in use. With typical mazes this is not strictly required, as the default values defined in the original source code are suitable, but it is sometimes necessary – for best performance – to trim the standard values.
- **TEST mode:** This mode may be used at any time to verify that the mouse travels in an essentially straight line when using the normal motor speeds.

Table 4: PC Interface Board Pin Allocation

	Mouse Side		PC Side	
Wire Colour	PC Interface Board	Socket Housing	PC Interface Board	9-way 'D' socket
Red	+5V	4	N/A	N/A
Black	0V	1	GND	5
Yellow	RX	3	RXIN	3
Blue	TX	2	TXOUT	2

A practice maze

To verify the improvement (or otherwise!) gained by changes made during the development of a mouse it is almost essential to have a practice maze available. A full size maze is a serious undertaking and beyond the needs of most mousers. However, a viable alternative may be constructed that is neither large nor expensive. Pictured right is the author's 3 x 2 maze, measuring just 560mm x 380mm, on which most of the testing of this design was performed. It is constructed using commercially available 'walls' and 'posts' (see photograph) assembled onto an MDF baseboard drilled with holes on a 180mm grid. This method offers the greatest flexibility in wall placement but a perfectly usable 'fixed design' maze may be constructed at very low cost as detailed on the UK Micromouse Web-Site – follow the RH Design Group link.

Useful web addresses

Table 5 lists the web-sites of some organisations involved in either the selling of robotics components or promotion of the Micromouse competition. Please note that the list is far from exhaustive and that inclusion does not imply any form of endorsement by the author.

This year's annual Micromouse competition is being held at the Technology Innovation Centre, Millennium Point, Birmingham on Saturday June 19th starting at 9:00 am. There is no charge for attendance – see the TIC website for further details: http://www.tic.ac.uk and follow the 'News and Events' link.

Next Month

In the concluding part next month a more comprehensive description of the suite of software programs available for the mouse is given. Additionally full construction and assembly notes are provided along with initial testing details and the sensor calibration procedure.

Table 5: Useful website addresses

Organisation	Products	Web-Site
UK Micromouse	N/A	http://micromouse.cs.rhul.ac.uk/
Microchip Technology Inc	PIC Microcontrollers	http://www.microchip.com/1010/index.htm
Osram Opto Semiconductors GmbH	InfraRed Devices	http://www.osram-os.com/
Active Robots Ltd	Motor Block Assembly	http://www.active-robots.com/
Total Robots Ltd	Robots and Parts	http://www.totalrobots.com/
Microrobot North America Inc	Robots and Maze Parts	http://www.microrobotna.com
Taylec Ltd	PIC-PG1 Programmer	http://www.taylec.com/
IC-PROG	IC-PROG Programming S/W	http://www.ic-prog.com/

Software: Please contact Caroline Fisher (preferably by e-mail) with 'Micromouse' as the subject and she'll send the software as a zip file.

Active Loudspeaker Kit

Originally featured in Electronics World, this Jeff Macaulay designed motional feedback active loudspeaker system has generated a great deal of interest from both electronics and loudspeaker hobbyists alike.

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Simple Class A Amplifier

A 10-W design giving subjectively better results than class B transistor amplifiers

by J. L. Linsley Hood, M.I.E.E.

During the past few years a number of excellent designs have been published for domestic audio amplifiers. However, some of these designs are now rendered obsolescent by changes in the availability of components, and others are intended to provide levels of power output which are in excess of the requirements of a normal living room. Also, most designs have tended to be rather complex.

In the circumstances it seemed worth while to consider just how simple a design could be made which would give adequate output power together with a standard of performance which was beyond reproach, and this study has resulted in the present design.

Output power and distortion

In view of the enormous popularity of the Mullard '5-10' valve amplifier, it appeared that a 10-watt output would be adequate for normal use; indeed when two such amplifiers are used as a stereo pair, the total sound output at full power can be quite astonishing using reasonably sensitive speakers.

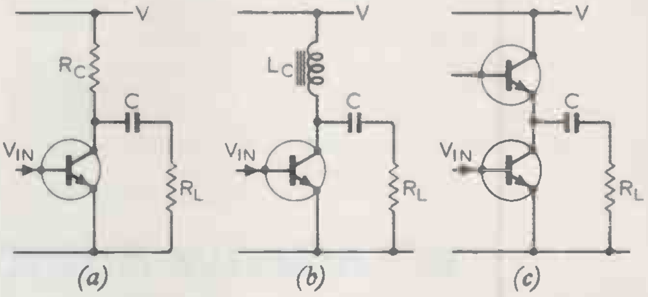
The original harmonic distortion standards for audio amplifiers were laid down by D. T. N. Williamson in a series of articles published in *Wireless World* in 1947 and 1949; and the standard proposed by him, for less than 0.1% total harmonic distortion at full rated power output, has been generally accepted as the target figure for high-quality audio power amplifiers. Since the main problem in the design of valve audio amplifiers lies in the difficulty in obtaining adequate performance from the output transformer, and since modern transistor circuit techniques allow the design of power amplifiers without output transformers, it seemed feasible to aim at a somewhat higher standard, 0.05 % total harmonic distortion at full output power over the range 30Hz-20kHz. This also implies that the output power will be constant over this frequency range.

Circuit design

The first amplifier circuit of which the author is aware, in which a transformerless transistor design was used to give a standard of performance approaching that of the 'Williamson' amplifier, was that published in *Wireless World* in 1961 by Tobey and Dinsdale. This employed a class B output stage, with series connected transistors in quasi-complementary symmetry. Subsequent high quality transistor power amplifiers have largely tended to follow the design principles outlined in this article.

The major advantage of amplifiers of this type is that the normal static power dissipation is very low, and the overall power-conversion efficiency is high. Unfortunately there are also some inherent disadvantages due to the intrinsic dissimilarity in the response of the two halves of the push-pull pair (if complementary transistors are used in unsymmetrical circuit arrangement) together with some cross-over distortion due to the low current non-linearity of the I_c/V_b characteristics. Much has been done, particularly by Bailey[1], to minimize the latter.

An additional characteristic of the class B output stage is that the current demand of the output transistors increases with the output signal, and this may reduce the output voltage and worsen the smoothing of the power supply, unless this is well designed. Also, because of the increase in current with output power, it is possible for a transient overload to drive the output transistors into a condition of thermal runaway, particularly with reactive loads, unless suitable protective circuitry is employed.



(a) (b) (c)

Fig. 1. Basic class A circuits using (a) load resistor R, giving power conversion efficiency of about 12%, (b) l.f. choke giving better efficiency but being bulky and expensive, and (c) a second transistor as collector load.

These requirements have combined to increase the complexity of the circuit arrangement, and a well designed low-distortion class B power amplifier is no longer a simple or inexpensive thing to construct.

An alternative approach to the design of a transistor power amplifier combining good performance with simple construction is to use the output transistors in a class A configuration. This avoids the problems of asymmetry in quasi-complementary circuitry, thermal runaway on transient overload, cross-over distortion and signal-dependent variations in power supply current demand. It is, however, less efficient than a. class B circuit, and the output transistors must be mounted on large heat sinks.

The basic class A construction consists of a single transistor with a suitable collector load. The use of a resistor, as in Fig. 1 (a), would be a practical solution, but the best power-conversion efficiency would only be about 12%. An l.f. choke, as shown in Fig. 1(b), would give much better efficiency, but a properly designed component would be bulky and expensive, and remove many of the advantages of a transformerless design. The use of a second, similar, transistor as a collector load, as shown in Fig. 1(c), would be more convenient in terms of size and cost, and would allow the load to be driven effectively in push-pull if the inputs to the two transistors were of suitable magnitude and opposite in phase. This requirement can be achieved if the driver transistor is connected as shown in Fig. 2.

This method of connection also meets one of the most important requirements of a low distortion amplifier-that the basic linearity of the amplifier should be good, even in the absence of feedback. Several factors contribute to this. There is the tendency of the *Ic/Vb* non-linearity of the characteristics of the output transistors to cancel, because during the part of the cycle in which one transistor is approaching cut-off the other is turned full on. There is a measure of internal feedback around the loop Tr_1, Tr_2, Tr_3 because of the effect which the base impedance characteristics of Tr_1, have on the output current of Tr_3, Also, the driver transistor Tr_3, which has to deliver a large voltage swing, is operated under conditions which favour low harmonic distortion-low output load impedance, high input impedance.

A practical power amplifier circuit using this type of output stage is shown in Fig. 3.

The open loop gain of the circuit is approximately 600 with typical transistors. The closed loop gain is determined, at frequencies high enough for the impedance of C_3 to be small in comparison to R_4, by the ratio $(R_3 + R_4)/R_4$. With the values indicated in Fig. 3, this is 13. This gives a feedback factor of some 34 dB, and an output impedance of about 160 milliohms.

Since the circuit has unity gain at d.c., because of the inclusion of C_3 in the feedback loop, the output voltage, Ve, is held at the same potential as the base of Tr_4 plus the base emitter potential of Tr_4 and the small potential drop along R_3 due to the emitter current of this transistor. Since the output transistor Tr_1, will turn on as much current as is necessary to pull V_e down to this value, the resistor R_2 which together with R_1 controls the collector current of Tr_2, can be used to set the static current of the amplifier output stages. It will also be apparent that V_e can be set to any desired value by small adjustments to R_5 or R_6. The optimum performance will be obtained when this is equal to half the supply voltage. (Half a volt or so either way will make only a small difference to the maximum output power obtainable, and to the other characteristics of the amplifier, so there is no need for great precision in setting this.)

Silicon planar transistors are used throughout, and this gives good thermal stability and a low noise level. Also, since there is no requirement for complementary symmetry, all the power stages can use n-p-n transistors which offer, in silicon, the best performance and lowest cost. The overall performance at an output level of 10 watts, or any lower level, more than meets the standards laid down by Williamson. The power output and gain/frequency graphs are shown in Figs. 4-6, and the relationship between output power and total harmonic distortion is shown in Fig.7. Since the amplifier is a straightforward class A circuit, the distortion decreases linearly with output voltage. (This would not necessarily be the case in a class B system if any significant amount of crossover distortion was present.) The analysis of distortion components at levels of the order of 0.05% is difficult, but it appears that the residual distortion below the level at which clipping begins is predominantly second harmonic.

Stability, power output and load impedance

Silicon planar n-p-n transistors have, in general, excellent high frequency characteristics, and these contribute to the very good stability of the amplifier with reactive loads. The author has not yet found any combination of *L* and *C* which makes the system unstable, although the system will readily become oscillatory with an inductive load if R_3 is shunted by a small condenser to cause roll-off at high frequencies.

The circuit shown in Fig. 3 may be used, with very little modification to the component values, to drive load impedances in the range 3-15 ohms. However, the chosen output power is represented by a different current/voltage relationship in each case, and the current through the output transistors and the output-voltage swing will therefore also be different. The peak-voltage swing and the mean output current can be calculated quite simply from the well-known relationships $W=I^2R$ and $V=IR$, where the symbols have their customary significance. (It should be remembered, however, that the calculation of output power is based on r.m.s. values of current and voltage, that these must be multiplied by 1.414 to obtain the peak values, and that the voltage swing measured is the peak-to-peak voltage, which is twice the peak value.)

When these calculations have been made, the peak-to-peak voltage swing for 10 watts power into a 15-ohm load is found to be 34.8 volts. Since the two output transistors bottom at about 0.6 volt each, the power supply must provide a minimum of 36 volts in order to allow this output. For loads of 8 and 3 ohms, the minimum h.t. line voltage must be 27 V and 17 volts respectively. The necessary minimum currents are 0.9, 1.2 and 2.0 amps. Suggested component values for operation with these load impedances are shown in Table 1. C_3 and C_1 together influence the voltage and power roll-off at low audio frequencies. These can be increased in value if a better low-frequency performance is desired than that shown in Figs. 4-6.

Since the supply voltages and output currents involved lead to dissipations of the order of 17 watts in each output transistor, and since it is undesirable (for component longevity) to permit high operating temperatures, adequate heat sink area must be provided for each transistor. A pair of separately mounted 5in. x 4in. finned heat sinks is suggested.

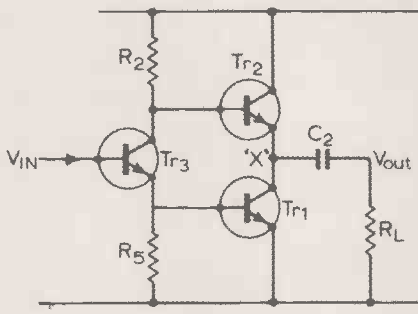


Fig. 2. Arrangement for push-pull drive of class A stage.

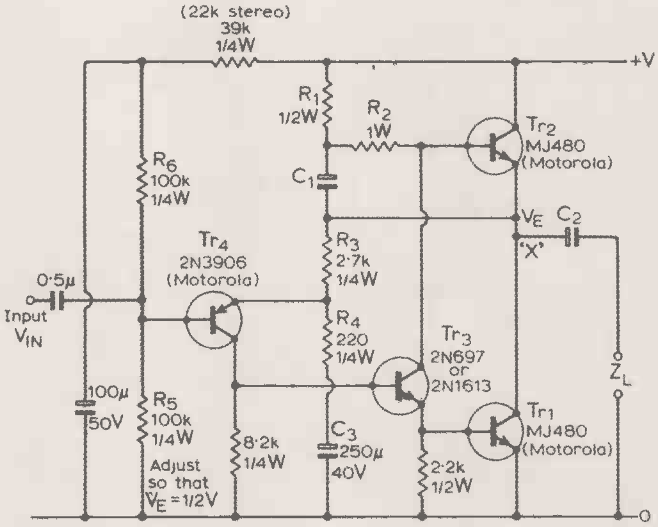


Fig. 3. Practical power amplifier circuit.

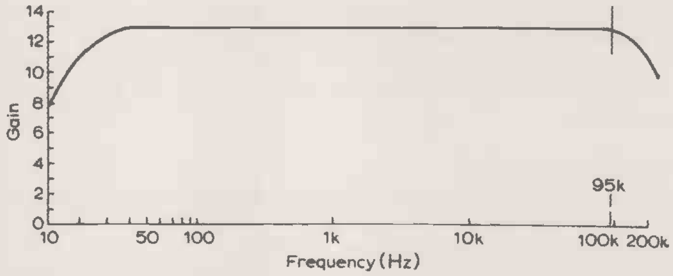


Fig. 4. Gain/frequency response curve of amplifier.

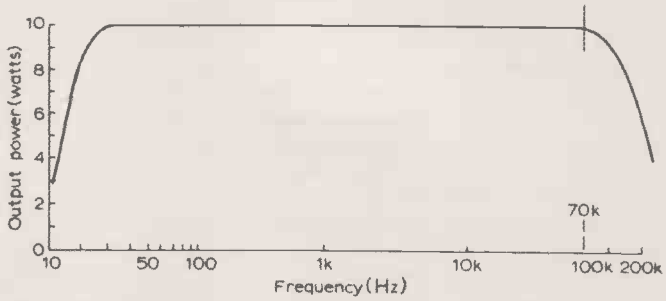


Fig. 5. Output power/frequency response curve of amplifier.

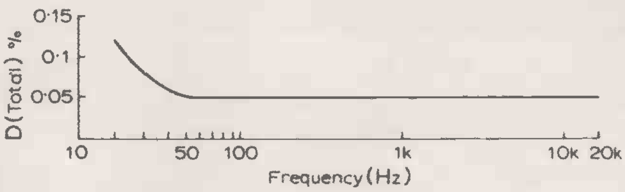


Fig. 6. Distortion/frequency curve at 9W.

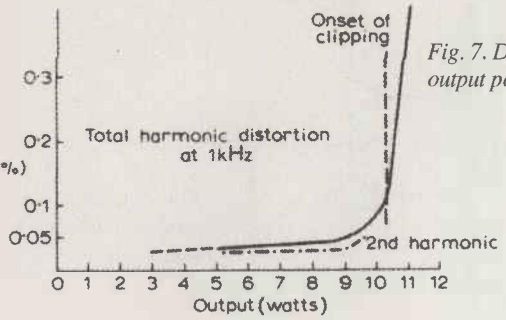


Fig. 7. Distortion/ output power curve

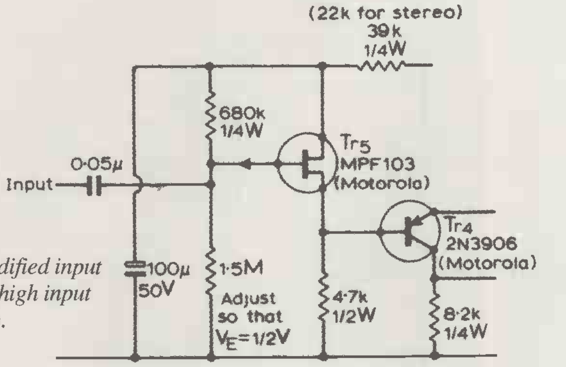


Fig. 8. Modified input circuit for high input impedance.

This is, unfortunately, the penalty which, must be paid for class A operation. For supplies above 30V Tr_1 and Tr_2 should be MJ481s and Tr3 a 2N1613.

If the output impedance of the pre-amplifier is more than a few thousand ohms, the input stage of the amplifier should be modified to include a simple f.e.t. source follower circuit, as shown in Fig. 8. This increases the harmonic distortion to about 0.12%, and is therefore (theoretically) a less attractive solution than a better pre-amplifier.

A high frequency roll-off can then be obtained, if necessary, by connecting a small capacitor between the gate of the f.e.t. and the negative (earthy) line.

Suitable transistors

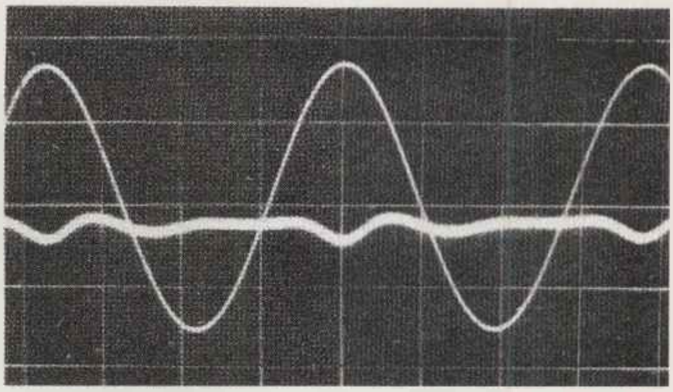
Some experiments were made to determine the extent to which the circuit performance was influenced by the type and current gain of the transistors used. As expected the best performance was obtained when high-gain transistors were used, and when the output stage used a matched pair. No adequate substitute is known for the 2N697/2N1613 type used in the driver stage, but examples of this transistor type from three different manufacturers were used with apparently identical results. Similarly, the use of alternative types of input transistor produced no apparent performance change, and the Texas Instruments 2N4058 is fully interchangeable with the Motorola 2N3906 used in the prototype.

The most noteworthy performance changes were found in the current gain characteristics of the output transistor pair, and for the lowest possible distortion with any pair, the voltage at the point from which the loudspeaker is fed should be adjusted so that it is within 0.25 volt of half the supply line potential. The other results are summarized in Table 2.

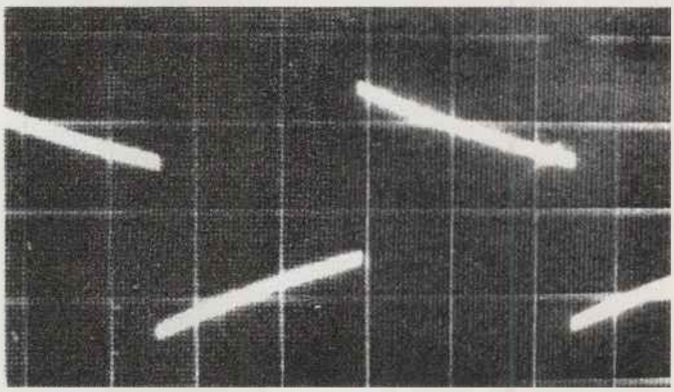
The transistors used in these experiments were Motorola MJ480/481, with the exception of (6), in which Texas 2S034 devices were tried. The main conclusion which can be drawn from this is that the type of transistor used may not be very important, but that if there are differences in the current gains of the output transistors, it is necessary that the device with the higher gain shall be used in the position of Tr1. When distortion components were found prior to the onset of waveform clipping, these were almost wholly due to the presence of second harmonics.

Table 1: Summary of component combinations for different load impedancices

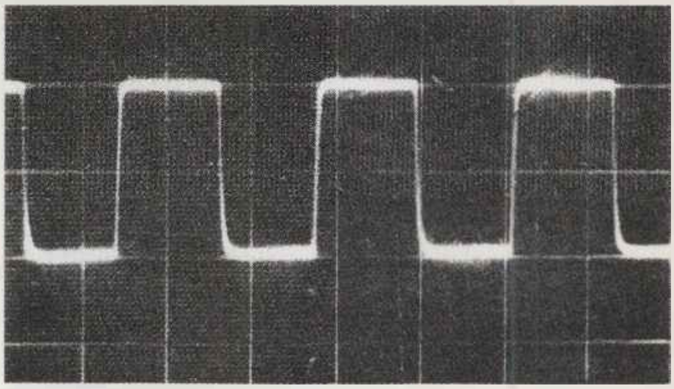
Z_L	V	I	R_1	R_2	C_1	C_2	V_{IN} (r.m.s)
3Ω	17V	2A	47Ω	180Ω	500μ25V	5000μ25V	0.14V
8Ω	27V	1.2A	100Ω	560Ω	250μ40V	2500μ50V	0.66V
15Ω	36V	0.9A	150Ω	1.2kΩ	250μ40V	2500μ50V	0.9V



Sine wave performance at 1kHz. 9 watts, 15 ohm resistive load. Fundamental on scale of 10 V/cm. Distortion components on scale.of 50 m V/cm with r.m.s. value of 0.05%.



Square wave response at 50 Hz.



Square wave response. Scale 10 V/cm. Frequency 50 kHz. 15 ohm resistive load.

Constructional notes

Amplifier. The components necessary for a 10 + 10 watt stereo amplifier pair can conveniently be assembled on a standard 'Lektrokit' 4in. x 4?in. s.r.b.p. pin board, as shown in the photographs, with the four power transistors mounted on external heat sinks. Except where noted the values of components do not appear to be particularly critical, and 10% tolerance resistors can certainly be used without ill effect. The lowest noise levels will however be obtained with good quality components, and with carbon-film, or metal-oxide, resistors.

Power supply. A suggested form of power supply unit is shown in Fig. 9 (a). Since the current demand of the amplifier is substantially constant, a series transistor smoothing circuit can be used in which the power sup-

Table 2: Relation of distortion to gain-matching in the output stage.

	Current gain (TR1)	(TR2)	Distortion (at 9 Watts)
1	135	135	0.06%
2	40	120	0.40%
3	120	40	0.12% (pair 2 reversed in position)
4	120	100	0.09%
5	100	120	0.18% (pair 5 reversed)
6	50	40	0.1%†

Table 3: Power-supply components.

Amp Z_L	I_{OUT}	V_{OUT}	C1	Tr1/2	MR1	T1
15Ω	1A	37V	1000μ 50V	MJ480/2N697	5B05	40V 1A
2x 15Ω	2A	37V	5000μ 50V	MJ480/2N697	5B05	40V 2A
8Ω	1.25A	27V	2000μ40V	MJ480/ 2N697	5B05	30V 1.25A
2x 8Ω	2.5A	27V	5000μ40V	MJ480/ 2N697	5B05	30V 2.5A
3Ω	1.9A	18V	5000μ30V	MJ480/2N697	5B05	20V 2A
2x 3Ω	3.8A	18V	10000μ30V	MJ480/2x 2N697	7B05T	20V 4A

ply output voltage may be adjusted by choice of the base current input provided by the emitter follower Tr_2 and the potentiometer VR_1 With the values of reservoir capacitor shown in Table 3, the ripple level will be less than 10mV at the rated output current, provided that the current gain of the series transistors is greater than 40. For output currents up to 2.5 amps, the series transistors indicated will be adequate, provided that they are mounted on heat sinks appropriate to their loading.

However, at the current levels necessary for operation of the3-ohm version of the amplifier as a stereo pair, a single MJ480 will no longer be adequate, and either a more suitable series transistor must be used, such as the Mullard BDY20, with for example as 2N1711 as Tr_2, or with a parallel connected arrangement as shown in Fig. 9(b).

The total resistance in the rectifier 'primary' circuit, including the transformer secondary winding, must not be less than 0.25Ω. When the power supply, with or without an amplifier, is to be used with an r.f. amplifier-tuner unit, it may be necessary Output to add a 0.25μF (160 V.w.) capacitor across the secondary winding of T_1 to prevent transient radiation. The rectifier diodes specified are International Rectifier potted-bridge types.

Transistor protection circuit

The current which flows in the output transistor chain (Tr_1,Tr_2) is determined by the potential across Tr_2, the values of R_1 and R_2, and the current gain and collector-base leakage current of Tr_2 Since both of these transistor characteristics are temperature dependent the output series current will increase somewhat with the temperature of Tr_2. If the amplifier is to be operated under conditions of high ambient temperature, or if for some reason it is not practicable to provide an adequate area of heatsink for the output transistors, it will be desirable to provide some alternative means for the control of the output transistor circuit current. This can be done by means of the circuit shown in Fig. 10. In this, some proportion of the d.c. bias current to Tr_1 is shunted to the negative line through Tr_7 when the total current flowing causes the potential applied to the base of Tr_6 to exceed the turn-on value (about 0.5 volt). This allows very precise control of the series current without affecting the output power or distortion characteristics. The simpler arrangement whereby the current control potential for Tr_7 is obtained from a series resistor in the emitter circuit of Tr_1 leads, unfortunately, to a worsening of the distortion characteristics to about 0.15 % at 8 watts, rising to about 0.3% at the onset of overload.

Performance under listening conditions

It would be convenient if the performance of an audio amplifier (or loudspeaker or any other similar piece of audio equipment) could be completely specified by frequency response and harmonic distortion characteristics. Unfortunately, it is not possible to simulate under laboratory conditions the complex loads or intricate waveform structures presented to the amplifier when a loudspeaker system is employed to reproduce the everyday sounds of speech and music; so that although the square wave and low-distortion sine wave oscillators, the oscilloscope, and the harmonic distortion analyser are valuable tools in the design of audio circuits, the ultimate test of the final design must be the critical judgment of the listener under the most carefully chosen conditions his facilities and environment allow.

The possession of a good standard of reference is a great help in comparative trials of this nature, and the author has been fortunate in the possession, for many years, of a carefully and expensively built 'Williamson' amplifier, the performance of which has proved, in listening trials, to equal or exceed, by greater or lesser margins, that of any other audio amplifier with which the author has been able to make comparisons.

However, in the past, when these tests were made for personal curiosity, and some few minutes could elapse in the transfer of input and output leads from one amplifier to the other, the comparative performance of some designs has been so close that the conclusion drawn was that there was really very little to choose between them. Some of the recent transistor power amplifier circuits gave a performance which seemed fully equal to that of the 'Williamson', at least so far as one could remember during the interval between one trial and the next. It was, however, appreciated that this did not really offer the best conditions for a proper appraisal of the more subtle differences in the performance of already good designs, so a changeover switch was arranged to transfer inputs and outputs between any chosen pair of amplifiers, and a total of six amplifier units was assembled, including the 'Williamson', and another popular valve unit, three class B transistor designs, including one of commercial origin, and the class A circuit described above. The frequency response, and total harmonic distortion characteristics, of the four

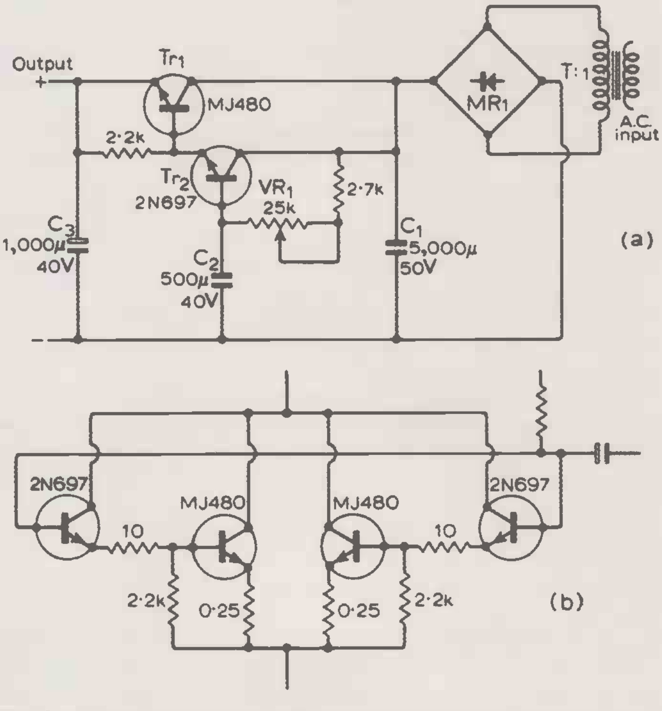


Fig. 9. (a) Power supply unit, and (b) parallel connected transistors for high currents.

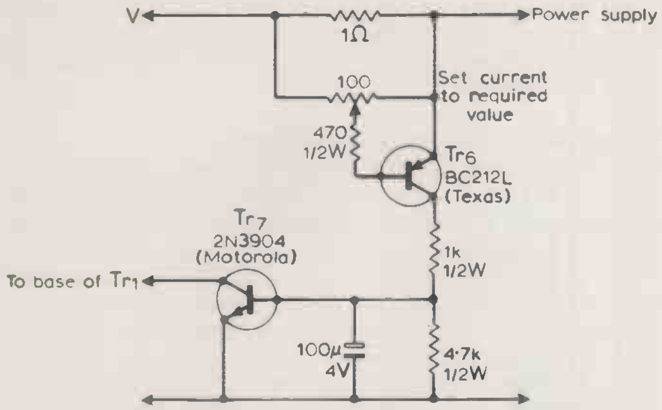


Fig. 10. Amplifier current regulation circuit.

transistor amplifiers was tested in the laboratory prior to this trial, and all were found to have a flat frequency response through the usable audio spectrum, coupled with low harmonic distortion content (the worst-case figure was 0.15%).

In view of these prior tests, it was not expected that there would be any significant difference in the audible performance of any of the transistor designs, or between them and the valve amplifiers. It was therefore surprising to discover, in the event, that there were discernible differences between the valve and the three class B transistor units. In fact, the two valve designs and the class A transistor circuit, and the three class B designs formed two tonally distinct groups, with closely similar characteristics within each group. The 'Williamson' and the present class A design were both better than the other valve amplifier, and so close in performance that it was almost impossible to tell which of the two was in use without looking at the switch position. In the upper reaches of the treble spectrum the transistor amplifier has perhaps a slight advantage.

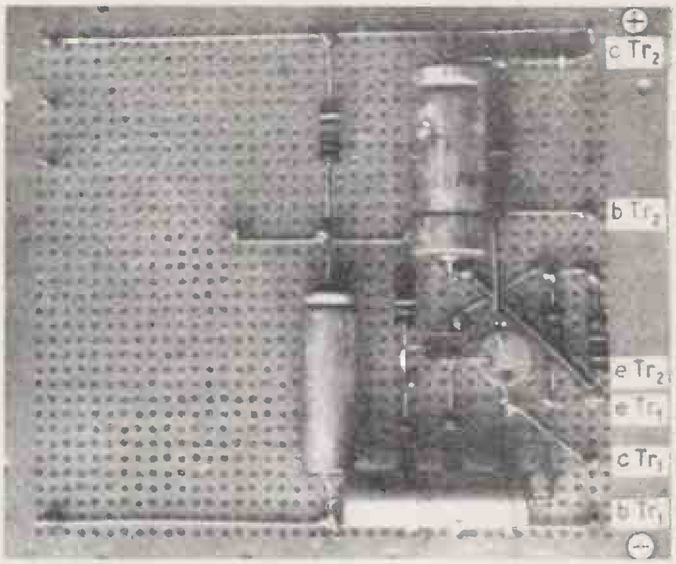
The performance differences between the class A and the class B groups were, however, much more prominent. Not only did the class A systems have a complete freedom from the slight 'edginess' found on some high string notes with all the class B units, but they appeared also to give a fuller, 'rounder', quality, the attractiveness of which to the author much outweighs the incidental inconvenience of the need for more substantial power supply equipment and more massive heat sinks.

Some thought, in discussions with interested friends, has been given to the implications of this unlooked-for discovery, and a tentative theory has been evolved which is offered for what it is worth. It is postulated that these tonal differences arise because the normal moving-coil loudspeaker, in its associated housing, can present a very complex reactive load at frequencies associated with structural resonances, and that this might provoke transient overshoot when used with a class B amplifier, when a point of inflection in the applied waveform chanced to coincide with the point of transistor cross-over, at which point, because of the abrupt change in the input parameters of the output transistors, the loop stability margins and output damping will be less good. In these circumstances, the desired function of the power amplifier output circuit in damping out the cone-response irregularities of the speaker may be performed worse at the very places in the loudspeaker frequency-response curve where the damping is most needed.

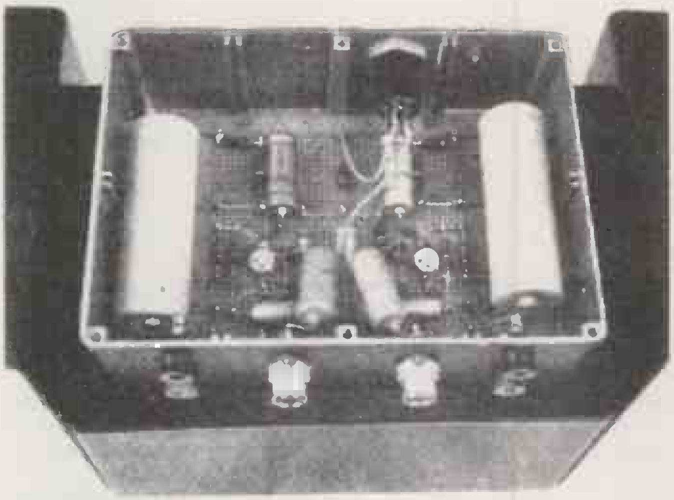
It should be emphasized that the differences observed in these experiments are small, and unlikely to be noticed except in direct side-by-side comparison. The perfectionist may, however, prefer class A to class B in transistor circuitry if he can get adequate output power for his needs that way.

Listener fatigue

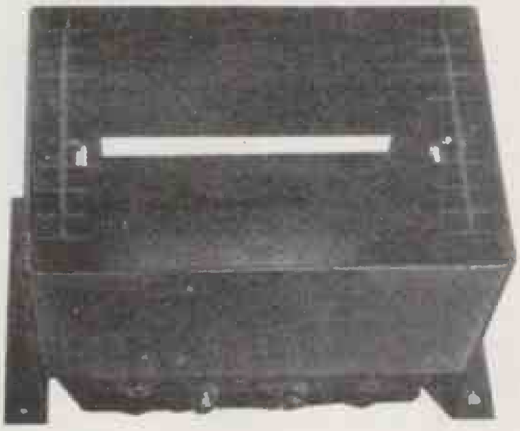
In the experience of the author, the performance of most well designed audio power amplifiers is really very good, and the differences between one design and another are likely to be small in comparison with the differences between alternative loudspeaker systems, for example, and of the transistor designs so far encountered, not one could be considered as unpleasing to the ear. However, with the growing use of solid-state power amplifiers, puzzling tales of 'listener fatigue' have been heard among the *cognoscenti*, as something which all but the most expensive transistor amplifiers will cause the listener, in contradistinction with good valve-operated amplifiers. This seemed to be worth investigation, to discover whether there was any foundation for this allegation.



Layout of single channel of 10 + 10 watt amplifier on standard 4in X 4lin 'Lektrokit' s.r.b.p. pin board.



Underside of completed amplifier, with base cover removed, showing external box-form heat sink.



Looking down on the completed amplifier.

In practice it was found that an amplifier with an impeccable performance on paper could be quite worrying to listen to under certain conditions. This appears to arise and be particularly associated with transistor power amplifiers because most of these are easily able to deliver large amounts of power at supersonic frequencies, which the speakers in a high quality system will endeavour to present to the listener. In this context it should be remembered that in an amplifier which has a flat power response from 30Hz to 180kHz, 90% of this power spectrum will be supersonic.

This unwanted output can arise in two ways. It can be because of wide spectrum 'white noise' from a preamplifier with a significant amount of hiss-this can happen if a valve preamplifier is mismatched into the few thousand ohms input impedance of a transistor power amplifier, and will also cause the system performance to be unnaturally lacking in bass. Trouble of this type can also arise if transient instability or high frequency 'ringing' occurs, for example when a reactive load is used with a class B amplifier having poor cross-over point stability.

Reference

1. Bailey, A. R., 'High-performance Transistor Amplifier', *Wireless World*, November 1966; '30-Watt High Fidelity Amplifier', May 1968; and 'Output Transistor Protection in A.F. Amplifiers', June 1968.

Letters to the Editor

Minimum standing current in class A

I read the article by Mr. J. L. Linsley Hood, in the April issue of *W. W.* with great interest, and the results he has achieved are certainly excellent for so simple a design. However I think he has done the cause of class A amplifiers a slight disservice, by the figures for minimum standing current (Table 1, P. 73) which are considerably above the true minimum figures, a fact which 1 have checked in practice.

The value of standing current required to just enable the output to swing to the points where one or other of the output transistors is bottomed depends on the desired output power and load impedance. These factors also dictate the minimum supply voltage. These values of voltage are $V_{supply} = \; + 2V_{ce.sat}$ (from $P_{out} = V^2/R$ where V is the r.m.s. output). Likewise the peak current may be

determined $I_{ak} = \sqrt{\dfrac{2P_{out}.R_{load}}{R}}$

which equals $\sqrt{\dfrac{2P_{out}}{R}}$

Now the standing current need be only half this value, since the change in load current is due to the upper transistor cutting off and the lower transistor doubling its current (or vice versa), a total change of current which must flow through the load of twice that originally flowing in the transistors, i.e. the standing current. Evaluating these for 10 watts and 8-ohm load we get (ignoring $V_{co.sat}$) figures of 25.3 volts and 790mA giving a total dissipation of exactly 20 watts, which is in agreement with the theory for such a 'perfect' stage (i.e. 50% efficiency). In practice we must add the figure of 2 $V_{co.sat}$ as stated by Mr. Linsley Hood. We thus get figures of 26.5V and 990mA. The corresponding figures for a 10-watt output are 16.7V at 1.29A (3 ohm), and 360V at 580mA (15 ohm). In practice we must also add an allowance to the current to provide for the variation which will take place due to temperature, etc. This excess current is especially necessary in the design described, where the only thing having any appreciable control of the standing current is the current gain of the output pair. I feel that this point was not sufficiently emphasized, or for that matter, the fact that to use any given pair of output transistors, and obtain the correct standing current needs quite a range of the total value of $R_1 + R_2$, from the values quoted of 100 + 560 ohms (for the 8-ohm case) for a high gain pair down to say 68 + 150 ohms for $H_{fe} = 40$. These lower values mean a considerable drop in loop gain, which probably accounts for much of the increased distortion, with lower gain transistors. These lower value resistors would in fact reduce the feedback by about 10dB. If the circuit of Fig. 10 is used it will also be necessary to use lower values for R_1 and R_2 to allow for an excess current which may then be controlled. I therefore question the contention of page 74 that the circuit allows for 'precise control of the series current without affecting . . the distortion characteristics'. Any reduction of loop gain must increase the distortion.

I have just measured a very similar stage to that described and find that for an 8-ohm load and 10-watt output, a supply of around the 27 volts quoted and a standing current of 850 to 900mA is ideal.

L. NELSON-JONES,
Bournemouth,
Hants.

The author replies:
I thank Mr. Nelson-Jones for his comments. Taking his second point first, it is evident that the current gains of the output transistors (particularly Tr_2) influence the standing current through the output chain. However, due to the flattening effect of operation at high junction currents and temperatures, the current variation from transistor to transistor with a given value of $R_1 + R_2$ is much less than the manufacturer's quote range of H_{FE} (30-200) would suggest. The tests which I made last year with limit-value devices gave a spread of ±150mA, when the current gains of the devices were badly matched, and rather less than this with limit-value matched pairs.

It had been in my mind at the time of writing the article that the constructor of the circuit should make adjustments to the value of R_2 (not R_1 which is part of the bootstrap circuit) to obtain the correct standing current, and made the comment (p. 72) that 'the resistor R_2 .... can be used to set the static current of the output stages'. The use of a variable resistor, in series with some suitable fixed value, would have facilitated the setting of this, and I had from time to time wished in retrospect that 1 had suggested this, as an alternative. Where this arrangement is adopted, however, care must be exercised in the layout of the leads to the potentiometer to avoid undesirable output-input feedback capacitances. The potentiometer should also be at the end of R_2 nearest to R_1.

With regard to Mr. Nelson-Jones's first point (about the correct standing current for a class A stage of this type) the calculations he shows are correct, and are substantially identical to those which I made myself in the initial stages of the design of this amplifier. However, in the particular case of a class A design of this type which cannot provide a load current which increases with demand, three further points must be considered.

1. The simple calculation of the ratio of peak-to-mean currents, as in the equations above, gives an answer which is valid only for symmetrical waveforms. Most of the waveforms in speech and music, for which such an amplifier will be used, are unsymmetrical and some allowance must be made for this.

2. The calculations assume that the load is resistive. In practice, loudspeakers present reactive loads, also their impedance may fall to lower than the nominal value.

3. The optimum performance of the output stage is given when the current swing does not take either transistor into current cut-off.

Because of these considerations, which were confirmed experimentally, 1 suggested a value of *quiescent* current which was in excess of the bare minimum 'sine wave into resistive load' value, even though this involves an increase in the thermal dissipation of the system. Safety factors can always be cut down-provided that one knows the circumstances.

J. L. LINSLEY HOOD

Linsley Hood class A amplifier

Recent measurements on this amplifier have indicated that the gain and power bandwidths of this design, using the component layout shown on page 75 of your issue, are wider than indicated by the Figs. 4 and 5 of the article. The apparent fall-off in gain beyond about 100kHz was, in fact, due to shortcomings in the measurement apparatus, and measurements made with better equipment suggest that the -3dB points for voltage gain are above 1.5MHz although power output falls beyond 200kHz.

Since the output is in phase with the input, it is necessary to take care that the output leads and output capacitor are not close to the input. (A 2-inch separation will be adequate for normal lead lengths.) However, an additional point must also be noted. If a capacitative load is connected with *short* leads between the output and the earth line near the input, connection, the potential developed along the earth line, due to its inductance, can inject an in-phase signal, and thereby cause in stability, in the MHz region. To avoid this possibility, it is recommended that the earthy lead to the loudspeaker terminal be returned to the earth line at the same point as the emitter of Tr_1 The inclusion of a small r.f. choke (25 turns of 26-28 s.w.g. wire wound round the outside of a 10-ohm 1-watt resistor is ideal) between the output (point W) and C, will also prevent this possibility of trouble.

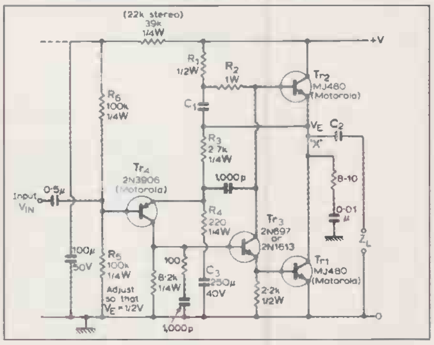
In practice, with the components and layout suggested, the inductance of the normal 12 to 18 inches (or more) of loudspeaker connecting lead prevents instability with capacitative loads, so this should be only of academic interest.

As an alternative, it is possible to reduce the r.f. response of the amplifier to give a smooth, 6dB/octave, roll-off. beyond 50kHz-which removes much of the need for care in the layout of the components, without detriment to the harmonic distortion in the audible range, and without any audible alteration to the performance-by connecting a 1,000pF capacitor between the collector of Tr_3 and the emitter of Tr_4; a 1,000pF in series with 100 ohms between the collector of Tr_4 and earth; and a 0.01μ F in series with a 8 to 10 ohms between the output ('X') and earth. (It should be noted that either all of these components should be added or none at all, they are not alternatives.) If the r.f. response is reduced in this manner, the use of a series r.f. choke would be unnecessary.

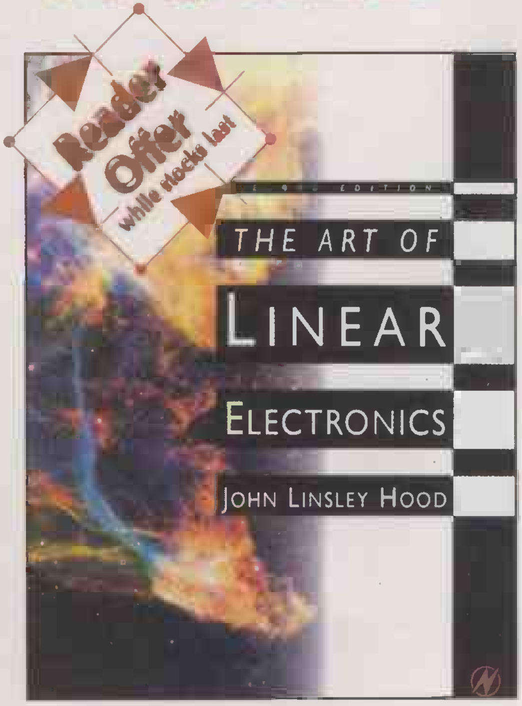
A series of measurements has also been made, using the amplifier design exactly as described in the article (without r.f. chokes or other modifications) to determine the voltage waveform produced, actually across the loudspeaker, with a square wave input to the amplifier. It was found, in practice, with several different loudspeaker systems, that the output waveform was virtually identical to that obtained with an equivalent resistive load-photographs of which were reproduced in the April issue. It was, in fact, the discovery that a good square wave was reproduced up to the 1 MHz limit of the generator in use which prompted a reassessment of the r.f. response of the amplifier. The absence of any overshoot or significant ringing also provides confirmation of the stability of the amplifier under practical conditions.

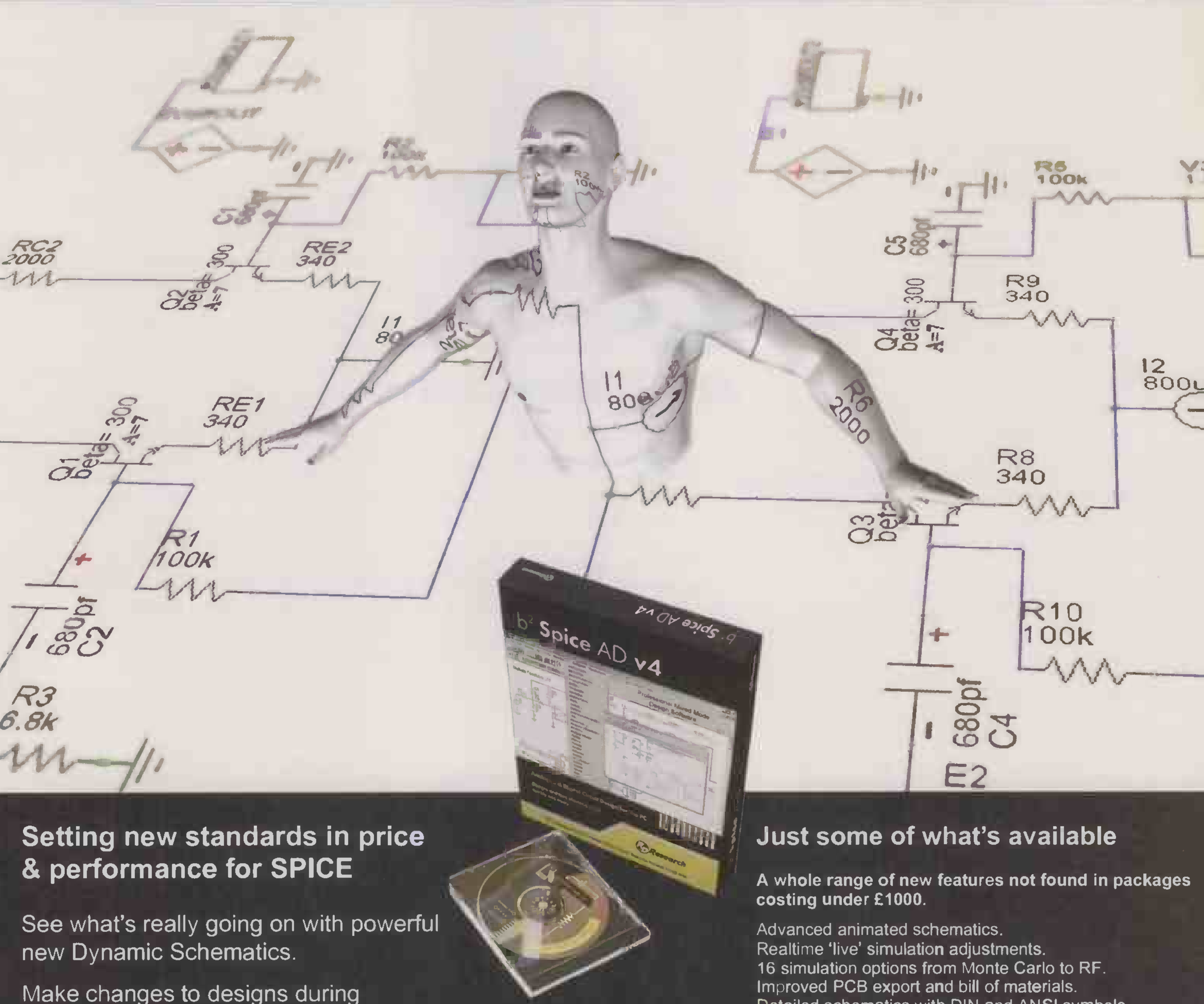
A correspondent has reported that this design has been up-rated successfully to 15 watts into a 15-ohm load, to give a direct power equivalent to the Williamson amplifier, using 2N3055 output transistors with a 43-volt supply (1.1 amp per channel), and rather larger heat sinks. There would seem no good reason why this could not also be done using MJ481s.

J. L. Linsley Hood,



Mr. Linsley Hood's amended circuit of his class A amplifier originally described in the April 1969 issue.





RC2
2000
RE2
340
Q2
beta=300
A=7
I1
80
RE1
340
Q1
beta=300
A=7
R1
100k
680pf
C2
R3
6.8k
R2
100k
C5
680pf
R5
100k
R9
340
Q4
beta=300
A=7
I2
800u
I1
800
R6
2000
R8
340
Q3
beta
R10
100k
680pf
C4
E2
b² Spice AD v4
RD Research

John Linsley Hood

1925 – 2004

I only met John once, about 6 years ago at his home in Taunton, where I spent a pleasant afternoon with John and his wife drinking tea and talking about Hi-Fi and books (two of my favourite subjects). A new edition of Audio Electronics came out of that.

With Valve and Transistor Audio Amplifier Design John bridged the generations, bringing classic audio design techniques, and classic components to the attention of a new generation of designers just as valve amps were coming back in as the 'next big thing'. That was rather nice, sitting on our list between Morgan Jones, the proponent of new generation valve amp designs, and Langford-Smith's Radio Design Handbook (1967).

I recall that JLH said some nice things about Ben Duncan's book with us, resulting in a bit of a mutual admiration society, though I don't think John and Ben ever met.

Sorry this is short, but I wanted to share my appreciation of a real innovator, and true gentleman.

Matthew Deans
Publisher
Engineering & Electronics
Elsevier Science & Technology Books

I wrote an article about the 10 W class A design in a Danish magazine Ny Elektronik back in '78, and I still find, that this solid state amp is one of the best ever.

Jørn
DIYaudio.com member
Jutland
Denmark

I confess to feeling deeply struck and I find it difficult to find the right words to express how big this loss is for the audio and electronics engineering community, and in particular for the old readers (and I am one of those!) of Electronics (Wireless!) World.

Surely we have lost one of the greatest pioneers and masters in the audio field. At the same time, I feel sure he will continue to live among us as a dependable guide with his brilliance and enthusiasm, as well as with all his innovative and time-proof (!!) ideas and solutions. For sure, his many articles and books will be kept with very great care by us all.

Giovanni Stochino
EW contibutor

John pursued the art of audio circuit design as a science, building on and augmenting the work of other giants in the audio design field such as Alan Blumlein and D. T. Williamson.

Many of John Linsley Hood's pioneering designs influenced directly the direction of the modern Hi-Fi industry industry throughout the world. He frequently chose to publish his work in this magazine and its forebear, *Wireless World*, for which all of the magazine's editors over the years have been grateful.

His contributions will be greatly missed.

Frank Ogden
Editor Electronics and Wireless World,
1988 to 1994

Sad to see him passing. Enjoyed very much his JLH1969 design.

Sad indeed. His amp articles are just great. There was one particular tube amp project book he had written which is just out of this world.

Vivek
DIYaudio.com member
Bangalore
India

I was truly saddened to hear of the death of John Linsley Hood. It was not very long after I had joined *Wireless World* that John's article on the class A amplifier landed on my desk for editing. John thought it a trifle, worthy perhaps for consideration for the Circuit Ideas feature I had recently started; but I persuaded the then editor Harold Barnard of it's greater importance, and it soon appeared (April 1969) as a feature item titled 'Simple Class A Amplifier. A 10W design giving subjectively better results than class B transistor amplifiers'.

Commercial transistor amplifiers at that time were, on the whole, harsh-sounding class B designs boasting low measurable THD. Hi-fi buffs felt in their bones that cross-over distortion was a new and horrible phenomenon however small the measured amount.

John managed neatly to bypass the problem with the 'simple' expedient of running the output NPN transistor pair in class A. It was very exciting to compare performance to that of the classic D T N Williamson valve design of the late '40s. John believed that the < 0.1% distortion in a Williamson was very much the same thing as the < 0.1% distortion in his new design - and there were no valves or expensive output transformer. Although John specified matching the gain of the two output devices to minimise the measured distortion, experimenters found to their delight (and perhaps amazement) that mismatching did not lead to any marked subjective change. I suspect that many amplifiers were built, using 'surplus' low power silicon planar devices for gain and phase-splitting, with just a couple of 2N3055s in the output stage.

On reflection now, I do believe that if John hadn't presented *Wireless World* with his design when he did, others would have come forward within a year or so. But his achievement was to be the first, and to change the course of hi-fi at a stroke. He continued to contribute to *Wireless World* - and to other publications - a wide range of audio designs that always aimed to achieve the highest musical fidelity. There can be no doubt either that the vast improvement in performance of class B design has itself been accelerated by the success of his early class A design.

John had a good sense of humour, though I never heard him laugh. For the April 1970 issue I was privileged to edit a spoof high power audio system design that here and there verged on the credible - though it used metal cone loudspeakers, and cast iron water radiator cooling for the amplifier. The 'author' was non-other than George Izzard O'Veering, and the article's title 'Dynamic Range versus Ambient Noise'.

Just a few years ago I wrote to John asking for advice (i.e. a free circuit) to improve the front end of my own class D audio amplifier. He sent back the barest sketch with a recommendation that I buy his latest book - where I would find just what I needed!

John Greenbank
Science Subject Officer Oxford Cambridge and RSA Examinations

Ampman salutes Sir John Laurence Linsley Hood for his contribution to explicit amplification systems, especially the 10W class-A amp.

Ampman prays to god that his soul may rest in peace in heaven.

Ampman
DIYaudio.com member
Punjab
India

To hear of John's passing is very sad news. After working for so many years on his 1969/96 amplifier circuit I went to bed feeling hollowed by a sense of personal loss.

I was very much hoping that JLH would be able to see my upcoming article, and read of my findings as to why his designs were repeatedly being chosen by listeners in place of other circuitry that came with better 'specifications'. I believe he knew already.

John clearly had much more knowledge and experience than most of us can ever hope to learn, and I am grateful he took the trouble to put pen to paper, providing us with solid foundations for our own future work.

I did not have any direct contact with JLH, and I was not linked to his work, but he was inspirational. Even as we remember him, his circuits are still being constructed around the world - as they will be for years to come. He passed on a legacy that will long be appreciated throughout the audio world he so loved.

Graham Maynard
EW contributor

I'm sad to hear one of my greatest inspirators has past away

I enjoyed his writing so much and often read back his articles (well a few of them at least, since it seems he has written quite a bit) that I now almost know them word for word ... his books and articles and especially the 10W class A amplifier design have become part of the fundament of my hobby.

I would like to thank him for that.

Greetings to JLH…

Thijs
DIYaudio.com member
The Netherlands

I too will miss him and the articles that he wrote; I read his amplifier articles thoroughly. He was one of the few that explained his choices as he described his design, with the result that I learned a lot from him. His designs had a "signature" about them; you could tell it was his design by his use of transistors. The VCO of his FM tuner circuit springs to mind, but there are many more that show his understanding of transistor operation.

Shame that there will be no more.

JohhnyX
DIYaudio.com member

I am saddened to hear about his departure. I own two of his textbooks, numerous articles from E.W.W., and a letter from him.

He has been a real influence on all my designs. I will miss him greatly.

Dan Banquer
Swampscott
Massachusetts
USA

It's sad to hear of John's demise. His articles helped me along quite a bit during my early learning days.

Lots of our present knowledge is propped up by his numerous contributions to the subject.

He belongs to an age that is responsible for what we are doing today.

GBHS.

AM
DIYaudio.com member

This too has come as a surprise to me. I had found a number of articles written by JLH very informative. He is one of the first, no the first, that I began reading, therefore this news is tinged with regret.

Thanks JLH.

Brownlow
DIYaudio.com member
UK

Very sad indeed!!!

Thoughts and prayers to all of JLH's family and friends

Jay Meredith
Costa Mesa
CA
USA

Sad news indeed.

One of the greats of this industry, never to be forgotten.

Hugh R. Dean
Aspen Amplifiers P/L
Melbourne
Australia

In the early 70s we grew up learning about amplifiers from the articles of JLH in the *Wireless World*. Over the years we have enjoyed his vast knowledge on almost all topics in electronics, especially audio.

I have never found his photograph anywhere, nor was there much written about him. We only knew him from his designs.

By far he has been one designer who has inspired our generation the most. His contribution cannot be paralleled.

He will be dearly missed.

Anqshudus
DIYaudio.com member
New Delhi
India

I also learnt my electronics from reading John Linsley Hood's articles and pouring over his circuit diagrams.

His subjective and open minded approach to design has I believe, stood me in good stead. I also notice that others posting here are still employing some of these ideas in their circuits and producing great sounding amplifiers.

It is also worth remembering that John Linsley Hood has left us a legacy of some great sounding amplifiers all of which were designed in his spare time.

He gave us his designs for free and wrote a some excellent books.

A true DIY giant who will be sadly missed but remembered very well.

Mike
DIYaudio.com member
UK

Very sad news…

I hope there will be more like him.

Promitheus
DIYaudio.com member
Oberursel
Germany

John was and will remain a legend amongst audio engineers for two main reasons. His ability to design products that match or out-perform some very expensive commercial products and his belief that these should be available to the public at sensible prices. At the time I learned of his death, some of my customers were in the middle of compiling a letter that I was going to pass on to him. This letter was essentially to thank him for the enjoyable and outstanding quality of sound reproduction that was made available by him. When I first heard one of his amps, I was instantly impressed by the 'correctness' of sound and realised that my search for the audio holy grail was nearing a close.

He will be sorely missed and I can only hope that someone else will pick up the mantle and follow his ethics and skill.

Shaun Williams
Williams-Hart Electronics
Gwynedd
Wales

Sad news indeed.

A gifted individual without peer.

Ian Mackenzie
DIYaudio.com member
Australia

Apart from 'The Bible', John's words in print are the only other written words of importance which have, in 60 years, taken hold of me. I felt that I was there with John and could sense the truth in his words.

He is a great loss to electronics and we will never see his like again – though I know his spirit lives on.

D Lucas
Anstruther
Scotland

LETTERS to the editor

Letters to "Electronics World" Highbury Business, Media House, Azalea Drive, Swanley, Kent, BR8 8HU
e-mail EWletters@highburybiz.com using subject heading 'Letters'.

EMC

I was interested to read Ian Darney's letter (Reflections on filters) in March's issue of *EW*. However, I can only agree with it in part.

He is quite correct in saying that it is not essential that a filter reflects back the rejected frequencies, it may absorb them. However, the cost of making an EMC filter that is correctly matched over the wide range of frequencies to be rejected would be prohibitive.

Moreover I can't accept his statement that any unwanted energy is either:

- absorbed by the filter.
- reflected up and down the line until it is radiated away.

There is a third possibility – it may be reflected back to the source and absorbed there.

It may seem odd that source can also be a sink, but any source has measurable output impedance, and if this has a resistance component it can in fact absorb energy

J.S. Linfoot
Oxford, UK

Attracting non-readers

Regarding the important question of *Electronics World* non-readership (February 2004 Editorial), the answer is 'They think they don't need to read *Electronics World*'. In the UK, at least, electronics is a consumer technology rather than supplier. Yes, there are some specialised, but minority, component and systems builders but we import most of what we consume, and you don't need to understand how things work, in order to use them.

It is not all gloom and doom. I'm sure that, if it were left to the UK industry, I wouldn't be able to go and buy components for the low prices currently being charged. I can buy op amps, doubled balanced mixers etc, for less than a cup of tea and that has to be good, hasn't it? Someone can make these things and ship them from the other side of the world and, presumably, still make money at it.

As a fairly recent retiree, I spent the last twenty years of my career as a manager encouraging engineers to stay connected to the roots of electronics as companies tried to sever them. I used to try to find 'sandwich' students to work as electronics engineers for a year, prior to returning to university to complete their degrees. This was quite difficult; since many students opted for the 'systems' option, which concentrated on computer based systems design and programming, rather than electrons, transfer functions and reliability. I used to think I had struck gold, if I found someone who could work out which way the diodes pointed, in a bridge rectifier circuit! Who would blame them, when the disparate financial rewards, for the two types of qualification were considered?

In truth, the competent professional electronics engineer needs to master all disciplines, not just hardware and software, but business, management and politics, all at the same time. Over my long career, I lost count of the number of engineers who 'escaped' to management and took pride in claiming that they didn't understand some basic electronic concept, often related to, oddly enough, EMC, before making decisions based upon that lack of understanding.

Electronics World does play a vital part in encouraging that professionalism by giving a balanced airing to all those areas, but how many managers with an electronics qualification read it? My guess is, not many. At the other end of the educational scale, how many schoolteachers read it? My guess is, not many.

Electronic engineering is a key profession, to the continued development of civilisation. There is no branch of modern society that does not depend upon electronics for its survival. It is as vital as water, energy, law and order but where is the drive, in the UK, to encourage young people to take an interest? There isn't one.

Engineers, not just the electronic kind, are depicted, in the media, as 'oily rags', 'techies' and general eccentrics and it's largely our own fault. We've thrown our industry to the wolves and now we should make every effort to rebuild it.

We know what has to be done to achieve that. We have to make products that people will buy. That means they have to work reliably, look right and are competitively priced. When we can do that, we will have a viable industry so why is it that, when we know the theory of success, we can't put it into practice? This is a serious matter and one that must be faced up to. *Electronics World* can help to mobilise those managers with vestiges of electronics competence to bring themselves up to date and face up to their responsibilities. Bring electronics out of the closet and make it a serious contender for attention in the media. Get a debate going on how to do that. *Electronics World* has some tremendous contributors; get Mr. Catt on TV. I'm sure he could light someone's fire and then everyone will want to buy this respected journal. Keep up the good work.

Bryce Kearey
Crowthorne, Berkshire, UK

Mr. Catt on TV, now there's a thing! – Ed

Infinity?

While thinking on the subject of infinity I made the following postulate:-

There exists a number so large that it is one more than that number which can be formed by adding two smaller numbers using the fastest computer within the run-time-span of that computer or computers.

This number will of course change with time as computer(s) become faster or more powerful. It might be said to be infinity, but I am calling it the Harcourt Number.

R. Harcourt B.Sc. C.Eng
Honiton, Devon, UK

April fool?

Are you sure your calendar is not off by a month? *The Hybrid Audio Amplifier* article in your March issue seems to have been printed a month early; it would have been ideal for April Fool's day.

The design simply uses a valve as a bootstrapped current source as a load for the voltage gain stage and makes claims for the results which are to say the least, wild. I'm sure the given specs are ok, but the current source could be far more easily implemented using an FET.

Bootstrapping the driver transistor's load resistor has been common practice since the days when Philips first published a complementary audio output stage using the AC127 & AC128 as a pair (if you're old enough to remember those!) Replacing the bootstrapped load resistor with a bootstrapped current source, makes sense as it not only increases the open-loop gain, but also avoids a loss of drive current on positive output peaks and also avoids early effect problems in the current source. What doesn't make sense is using a valve to implement one, with all the increase in cost and complexity.

I have seen many people who make all sort of wild claims for valve amplifiers, special speaker cables and the like. However, having been designing and building high quality amplifiers for over 30 years, I feel I am qualified to put in a word on the subject. I have also been working for more than 15 years with a firm selling some of the best professional and domestic audio equipment on the market, and have had the chance to carry out (informal) A/B tests on various units both with myself, and with various other listeners, including professional musicians.

Yes, I have found that some people did actually prefer the sound of valve amps, usually not because they sounded better; but because their deficiencies masked the deficiencies in the recordings used. You have to remember that even the best recordings use an analogue transducer (a microphone) that introduces various artefacts. In some cases (specially with older subjects) it was simply a preference for the kind of (distorted) sound they grew up listening to as kids.

In my experience a well designed and built solid-state amp, with good source recordings sounds infinitely better than any valve amp I've ever run into.

As regards TIM and other artefacts, they are occasionally audible in a poorly designed unit, but not in any modern amplifier built to a reasonably good design. The distortion and artefacts you get from even the best speakers are far, far worse than anything an amp can do. And the 'golden ear' which can detect a 0.001% artefact, through more than 5% distortion from a well made speaker, is in my humble opinion, a figment of the imagination. My 'back of the envelope' calculations tell me that to get a speaker to reproduce the kind of transient that would induce TIM in a good amp would need a diaphragm & coil mass in the milligram range, or use superconducting magnets from a MRI machine.

I have also performed a number of A/B tests on speaker cables. True, there are marginal frequency response differences due to cable capacitance differences, which are sometimes audible. There are also differences in 'tightness' due to differences in speaker damping, but these are usually significant only in the worst cases.

I have run across one set-up where several people could consistently discern a difference caused by a cable. It turned out however, that the amplifier was distorting due to RF pick up on the speaker cable, and that the cable geometries were sufficiently different to make the level of pick-up significantly different. This was what was causing the problem. On changing the amp to one without this problem, the audible difference between cables disappeared.

I have also run across speaker protection relays which made a difference to the sound, but on investigation these turned out to have silver contacts, which had oxidised. I have never found the problem with platinum or gold contacts.

Yes, it is a good marketing ploy (though dishonest) to convince people to shell out several times the amount to buy audio equipment that makes claims to possess superior performance (which however does not show up on measurements). But lending them credence in this journal is rather insulting to the readership of this magazine, since most of are professionals with a solid scepticism about these immeasurable intangibles, based on our scientific education, as well as our experience of many years. I can understand magazines meant for the lay Hi-Fi customer, or the electronic hobbyist condone such claims, but *Electronics World*?

Joseph Carri
By email

Stand by for a very serious look into amplifiers, distortion, 'valve sound' and all those other intangibles as this month we start a series of articles that might just challenge well known theories. – Ed

April fool II

I presume that the feature *Hybrid Audio Amplifier* was a wind-up, so why did it not appear in the April issue? I have serviced guitar amplifiers which claimed to have a 'valve sound' channel in them, but at least the solitary 12AX7 was actually in the signal path!

Michael Hawkins
Farnborough, Hants

Loop gain

It would seem from Mr. Ellis's letter, *EW*, March 2004 in response to my previous letters, indicates that he still misunderstood the point made, or misunderstands the complexities of feedback analysis. My reference to calculating the forward open loop gain and the closed loop gain was to address the fact the gain measured at one input, i.e. the signal input, is not the same gain measured at the other input, i.e. the feedback input. This is very apparent when the signal input is at the base of a transistor stage, and the feedback is directly at its emitter. As for on an independent determination of A and B, as noted by Mr. Ellis's, this is not irrelevant to the issue at all.

I apologise for not highlighting in more detail the exact paper of Dr. Middlebrook that shows a method of accurately determining the loop gain, as it would seem from Mr. Ellis's reply, that it is precisely this knowledge that Mr. Ellis's indicates that he lacks by the equations and figures he refers to in his letter. By reference to his figure 1, he states an equation that relates the two voltages at each side of a voltage source placed in series with the loop. This equation is one of the fundamental issues. It is incorrect, and does not give the loop gain directly as Mr. Ellis's states. The loop gain requires that the output and input resistances at each node be included. An example of Dr. Middlebrook's technique is shown here http://www.spectrum-soft.com/news/spring97/loopgain.shtm, essentially, two measurements are required, one using a series voltage source and another with a current source. I will leave it to Mr. Ellis to actually do the calculations of the simple series voltage method to show that the output and input impedances at the series source terminals are indeed required, which are of course, not known.

Mr. Ellis's next relevant comment concerns the notion that the amplifier does not know whether or not to behave any differently on closed loop or not. This is most decidedly incorrect. Again, the fundamental issue is the unknown, interacting impedances at each node. Node impedances are affected by the gain at that stage. For simplicity, consider a three-ring cmos inverter oscillator. To calculate the gain at one stage requires knowing its load impedance, i.e. Av=gm.ZL. However, ZL is given by the internal feedback capacitance of the next stage its driving divided by its gain. But this gain is of course, given by what it in turn drives. This results in a complicated set of interacting equations. It is simply not easy to separate out the bits and bobs of the circuit. Mr. Ellis does note that one can attempt to include some loading impedances, however, as illustrated here, this is not as simple as it might appear in many cases.

It may be stated, that the only way to calculate the loop gain correctly and accurately in a real amplifier, is to do a calculation when the loop is closed, not open. So, Mr. Ellis is most certainly incorrect in claiming that an open loop measurement is satisfactory. It does not include loading effects. Indeed, Mr. Ellis states that he broke his loop in figure 2 at X, which has exactly this problem. The node drives a capacitor connected to a gain node, where the gain node is inside the loop, and dependant on the reflected loading at that point, hence its (Miller) effect is indeterminate. Its somewhat ironic, that Mr. Ellis chose to break the loop at X, after the 10k resistor, rather than at Y, the main amplifier output, as this is one of the worst places to break the loop. At Y, the impedance would be low, minimising this error. If Mr. Ellis had actually bothered to use the series technique at X and Y, and compared the results, he might well be illuminated.

Mr. Ellis might also well investigate this aspect of loop design more easily using Super Spice, http://www.anasoft.co.uk. This software implements the single series voltage source method to calculate loop gain directly and automatically. Indeed, there is an example schematic (AutomaticLoopGain.sss) where the source can be simply moved from before and after the series feedback resistor to see the effect on the loop gain. The difference is substantial.

I won't comment on the other points raised in Mr. Ellis letter, as I am just about to pop to the bathroom to wash my hair.

Kevin Aylward
By email

John Ellis replies:

With regard to Mr. Aylward's response to my letter in the March edition of *Electronics World*, I agree with his point that the closed loop method should be used for loop analysis. However, Mr. Aylward has, in places, misrepresented, or misinterpreted, what I said.

Mr. Aylward has said that the concept of obtaining the loop gain by comparing the open loop gain with the closed loop gain "contains a well known error". Actually there are several candidates for error, ranging from the loop gain being negative (-AB rather than AB), the gains between inverting and non-inverting inputs of an amplifier can be different, the open loop gain not being calculated correctly, and lastly using only the voltage gain rather than voltage and current. They hardly amount to a single error!

The old-fashioned method of comparing open loop gain with closed loop gain may not be quite as bad as has been suggested. This is because the method involved approximations that are not unreasonable. In respect of the possible errors mentioned:

(1) The loop gain should be -AB instead of AB. But, in the simple feedback diagram I gave in my previous letter, the minus sign is wrapped up in the implicit inverting feedback node and the equation for closed loop gain (A/(1+AB)) is correct for that network.

(2) Even for different gains, the comparison works. If we assign an open loop gain Ap to the non-inverting (positive) input, and another gain An for the inverting (negative) input, then the closed loop gain is Ap/(1+BAn) where B is the feedback attenuation. Mr. Aylward cites the case of a single-ended input stage where the input is fed to the base and the feedback to the

emitter. Clearly these have different gains and input impedances. The loop gain in this case is (-)B.An, but the "B" would have to take account of the input impedance of the emitter and isn't given by the feedback resistor ratio alone. Due to the effective isolation afforded by the transistor from the collector to the emitter, the input impedance can be reasonably well represented by the standard SPICE equivalent circuit. An independent assessment of B from An may not be required because the phase of the loop gain is obtained from the product. So far, the method holds.

(3) The biggest difficulty is, indeed, in breaking the loop and yet representing closed loop conditions. The open loop calculation should apply to the same circuit as the closed loop calculation. Catch 22: if you open the loop the circuit is no longer the same. What the classical method required was that the missing feedback network is duplicated, one network taken to the feedback node and one to the output. The next step was to ground the free ends. For a relatively high value of feedback resistor, noting that the input and output impedances are low, particularly on closed loop, which we are trying to emulate, an approximation is made, going from "relatively low" to "zero". For an emitter input, the "low" can indeed be low. For a differential amplifier, the feedback input acts as a virtual earth and can also be low. On open loop, the output impedance may be low also because of the load which should remain attached. Hence for amplifier circuits with a relatively large feedback resistor and low value of load impedance, this method could give reasonably accurate results.

(4) The final point concerns the use of a single voltage calculation. In my diagram there was an error in my haste. Apologies for that: the load had been moved inadvertently. The implicit assumption that the classical model makes here is that because the current gain is very high, the voltage gain is dominant. In Mr. Aylward's letter, he refers to a paper explaining the closed loop method. In that paper, it is confirmed that the current gain and voltage gain are combined in parallel, so that the lower dominates. In a typical amplifier, the current gain is usually much greater than the voltage gain, and so the "voltage gain only" approximation is reasonable..I would therefore accept that the classical method is "approximate" but consider that a blanket "incorrect" is an overly harsh judgment.

Most of Mr. Aylward's other criticisms can be put into perspective from the above. Briefly, his comment that the "notion of an amplifier does not know whether or not to behave any differently on closed loop ... is incorrect" misrepresents what I said. I stated "transistor", not amplifier, and the distinction is crucial. What I meant in case this is not clear is that the internal sub-circuits representing the transistors do not change between open and closed loop This is precisely the point of the matching criterion mentioned above, but maybe "should not change" is a better way of putting it to include the feedback node impedances.

Mr. Aylward says that my method "does not include loading effects". This has been addressed. Regarding the particular instance of the feedback resistor, I stated in my letter that I had not specifically rebalanced the loading, but that the result would have had a trivial effect on the stability calculations. If the feedback resistor Rf were 10k ohms, and the attenuator 330 ohms, the error in not balancing the attenuator is less than 3%. It does assume a differential circuit rather than a single-ended though. Nevertheless, in light of the previous comments, this should have been adjusted. At the output, there was an 8 ohm load attached to the amplifier. I should have mentioned this since the effect of opening the feedback loop is reduced from what might have been an enormous error to one which is less than 0.1%. The effects of internal components are of course taken into account by the simulations. So all internal loading effects such as those Mr. Aylward described are included.

Mr. Aylward continues with a discussion on the nature of breaking the feedback loop for a closed loop calculation. It seems, though, that Mr. Aylward did not read my letter sufficiently carefully. Which end of the feedback resistor was disconnected in the loop was immaterial because I did not use the closed loop method. In summary, the classical method took steps to address some of the key points Mr. Aylward raised. These steps are essentially "reasonable approximations", but approximations nevertheless. They may not be applicable in all cases, and it is necessary to use great care. As the closed loop method avoids the uncertainties, I agree it should be used instead. The degree of care needed to ensure that the open loop conditions are applicable means that it may even be simpler to use the closed loop method in the first place.

John Ellis

Boolean Castles in the Sand

"Come, AND, OR and NOT, our souls inspire, and lighten us with celestial fire. Enable with perpetual light the dullness of our blinded sight." - with apologies to God's double.

A typical example of the hero-worship of Boole which inhibits scepticism is at http://www.maxmon.com/1847ad.htm; "1847 AD to 1854 AD George Boole Invents Boolean Algebra"

The article by Sallows, *EW* May 04, p32, beautifully illustrates the fact that there remain serious, debilitating structural defects in the way we digital designers go about our business.

There is a missing basic function in the Boolean set, quite as important as any one of the acknowledged three, AND, OR, NOT, each taken on its own. This can be proved from first principles, as I have done. Will readers write in to say what they think it is?

I have done more logic design with discrete AND, OR and Invert gates than anyone else. I never got promoted up into paper, but continued at the logic and circuit coalface for decades. Between firings, I worked for Data Products Corp., a company which, uniquely, had this usually missing function among its available set of logic boards, along with AND, OR and Invert. In 1965, the circuit cost of the gate had just dropped to little more than that of the other three. I found that I ended up using equal amounts of AND, OR and ??? gates in my extensive designs, for reasons which became obvious. At the same time, on my course on logic design at UCLA up the road under Montgomery Pfister, who wrote the standard textbook, I noticed that this function, missed by Boole, remained missing. (Actually, I went on the Pfister course to chase after another item missing from the discipline of logic design, the Glitch, which I published on later, and which is still suppressed. See IEEE Trans. Com. EC-15 No. 1, Feb. 1966).

I became very frustrated over the years, and prevailed on Ron Treadway to add this function to the Motorola TTL logic chips. He had just been stolen from Texas Instruments to help Motorola to catch up in TTL. We had fallen behind in the most popular (7400) family of logic gates because Narud, our head of R&D, had for years refused to allow his R&D team to design any TTL, the market leader. He preferred ECL, and said he would resign if forced to develop TTL. So he resigned (or rather was fired) in the course of time after Treadway appeared. I also published an article "The ??? Element", dated February 1968, which I have in front of me. All to no avail. Lewin, who later tried to hitch a ride on my WSI bandwagon, wrote the next standard text book. He devoted a quarter of his book to the Quine-McCluskey minterm/maxterm algorithm for "minimisation" (which is not minimal because it ignores the missing logic gate), and further entrenched the myopia. I taught the latter junk while Principal Lecturer at West Herts College. Now Sallows puts a further nail in the coffin of rationality.

In next month's *EW* I hope the editor will let me tell you more. I will give references at www.ivorcatt.com/47.htm

Ivor Catt
St. Albans, UK

Falling standards

I am sure that Paul Bartlett (Letters *EW* March) does not need to 'get out more' in order to be aware that educational standards in English have fallen in recent years. As a reader of *WW/EW* for over sixty years I am disappointed that the Editor appears to be satisfied with this state of affairs. It is a pity that 'Free Grid' is no longer around.

Bertrand Russell defined a pedant as one who prefers his statements to be true. I would hope that so far as scientific statements are concerned, the Editor himself is a pedant.

Alan Granger
Warwick, UK

I certainly try to be, but being human, I don't get it right all the time – Ed

NEW PRODUCTS

Please quote *Electronics World* when seeking further information

Cable car-jumpers

Tyco Electronics have won a contract providing 15/25kV cable assemblies and inter-car jumpers for the new Swiss ICN2 tilting trains. Specifically designed to account for bigger movements between cars due to the vehicle geometry and tight track curves, Raychem inter-car jumpers offer low vertical profile, are fully insulated to 25kV that requires no maintenance or cleaning.

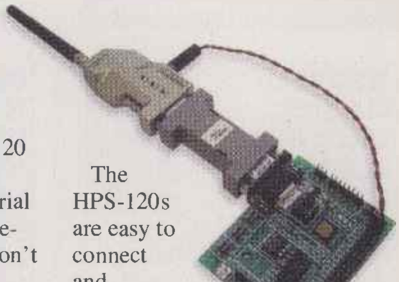
Tyco Electronics
www.tycoelectronics.com

New modules for wireless programming of robots

Programme, control and collect data from your mobile robot, without wires, using a pair of HandyPort wireless modules.

The new HandyPort HPS-120 acts as a transparent wireless replacement for an RS232 serial cable. So when you need to re-programme your robot you don't have to stop it, pick it up and connect it to your PC, you can simply download a new programme 'on-the-fly'.

Not only can you programme wirelessly, you can also send data to, and receive data from your robot. So if you want to take control yourself you can, or if you want to read on-board sensors you can do this as well.



The HPS-120s are easy to connect and configure. With the standard antennae their range is up to 100 metres, but if you fit the optionally available dipole antennae, the range can be up to 300 metres.

Total Robots
www.totalrobots.com

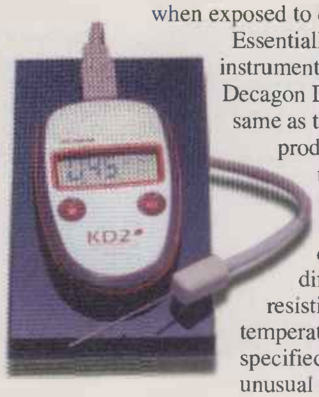
COTS tantalum capacitor for critical apps

A new range of surface mount tantalum capacitors for military and space applications has been launched from Kemet Corp. The T493 series comes in five standard EIA case sizes with a variety of options. Where surge robustness is critical the most stringent testing protocol can be selected, where ESR and response times are important, the low ESR version can be selected.

TTI Europe
www.ttieurope.com

Out of this world: probing regolith

A modified thermal analyser is to go to Mars in 2007 aboard NASA's Phoenix Scout Mars lander. A robotic arm will push the probe into the planet's surface to measure the thermal conductivity of the regolith, the Martian soil material, giving scientists valuable information on how much the normally cold regolith warms up when exposed to direct sunlight.



Essentially the instrument, from Decagon Devices, is the same as the KD2 production units used for measuring thermal conductivity, diffusity, resistivity and temperature, but re-specified to suit this unusual application.

Labcell Ltd
www.labcell.com

North and south – independent switching

A sensor suited to operation in battery operated, hand-held equipment requiring a contactless switch such as flip-phones, pagers, personal organisers, laptops and palmtops has been introduced by Allegro Microsystems Europe. It is a micropower omnipolar Hall-effect switch which combines ultra-sensitive, pole-independent switching with a latched digital output. With improved magnetic sensitivity, small size and low power requirement it is a cost-effective contactless replacement for mechanical or reed switches in all types of portable applications. It offers true onmipolar operation so that either south or north pole of sufficient strength with turn the output on, in the absence of a magnetic field the output is off.

Allegro Microsystems Europe Ltd
www.allegroeurope.com

Touchscreen technology saves time and money

Using Zytronic's Zytouch touchscreen technology, Westland Helicopters Ltd can quickly configure an entire helicopter instrument panel layout during customer trials. The aircraft's human machine interface can now be refined during a single meeting with customer air crews and specifiers, shrinking the time taken to make adjustments from weeks to as little as an hour.

Zytronic
www.zytronic.co.uk

High temperature resistant connection blocks

A new range of connection blocks suitable for use in applications where high temperatures are expected have been launched by Camden Electronics. The CHTB series high temperature resistant connection blocks feature a DIN 40685 porcelain insulation body capable of withstanding temperatures up to 1000°C. The nickel-plated brass inserts feature a working temperture of 350°C, maximum working voltage is 450V AC with maximum current of 24A for 3.2mm inserts and 57A for 6mm insert types (test voltage 2500V).

Camden Electronics
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NEWNES GUIDE TO RADIO AND COMMUNICATIONS TECHNOLOGY

Ian Poole

This is a guide to the technology and applications of modern radio and communications equipment. The author's approach provides a useful foundation for college students and technicians seeking an update on the latest technology.

Jul 2003 ▲ 352 pages ▲ Index ▲ PB
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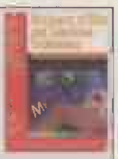
Code 0-7506-5612-3 **£16.99**

DICTIONARY OF VIDEO AND TELEVISION TECHNOLOGY

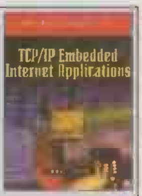


Jack Tsatsoulin

This work provides comprehensive and contemporary information on the essential concepts and terms in video and television, including coverage of test and measurement procedures. The CD accompanying the text includes an electronic version of the book.

Sept 2002 ▲ 365 pages & CD-Rom
Published in UK
Code 1-878707-99-X **£29.99**

TCP/IP EMBEDDED INTERNET APPLICATIONS

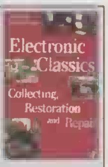


Edward Insam

This text highlights an engineer's approach to Internet protocols and applications, reducing R&D time for engineers. The book aims to be the main design guide for the cutting edge of Internet-enabled electronic products and systems.

Aug 2003 ▲ 384 pages ▲ Index ▲ Appendix
PB ▲ Published in UK
Code 0-7506-5735-9 **£32.50**

ELECTRONIC CLASSICS: COLLECTING, RESTORATION AND REPAIR



Andrew Emmerson

This text encompasses all aspects of buying, collecting, restoring, repairing, sourcing parts, professional services, clubs and societies. The first part covers technical aspects of restoration and details where components can be found. The second part presents useful information for collectors.

Aug 1998 ▲ 256 pages ▲ Index
10 halftones ▲ 50 line illustrations ▲ PB
Published in UK
Code 0-7506-3788-9 **£21.99**

INTRODUCTION TO DIGITAL SYSTEMS

John Crisp

This self-study text introduces digital electronics from first principles, before going on to cover all the main areas of knowledge and expertise. It covers the practicalities of designing and building circuits, including fault-finding and the use of test equipment.

Feb 2000 ▲ 302 pages ▲ Glossary ▲ Index
PB ▲ Published in UK
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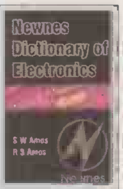
NEWNES DICTIONARY OF ELECTRONICS



S W Amos; R S Amos

Aimed at engineers, technicians and students working in the field of electronics, this dictionary provides clear and concise definitions, including TV, radio and computing terms, with illustrations and circuit diagrams.

4th edition ▲ Mar 2002 ▲ 394 pages
100 illustrations ▲ PB ▲ Published in UK
Code 0-7506-5642-5 **£12.99**

NEWNES GUIDE TO TELEVISION & VIDEO TECHNOLOGY

Eugene Trundle

An exploration of television and video technology. It covers the fundamentals of digital television (satellite, cable and terrestrial) and digital video, as well as providing a grounding in analogue systems.

3rd edition ▲ Feb 2001 ▲ 432 pages ▲ Index
PB ▲ Published in UK
Code 0-7506-4810-4 **£17.99**

NEWNES GUIDE TO DIGITAL TV

Richard Brice

Covering all aspects of digital television, this text encompasses the electronics of the equipment, data compression, television production, servicing and the different transition methods - terrestrial, satellite and cable. The text has been updated with developments since the 2000 edition.

2nd edition ▲ Oct 2002 ▲ 304 pages ▲ Index
45 illustrations ▲ 15 photographs ▲ HB
Published in UK
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Robin Pain (Design Engineer, Cotag International Ltd)

A text using simple circuit examples to illustrate principles and concepts fundamental to the process of analog and digital fault finding. It aims to help the reader tackle any job, from fixing a TV to improving the sound of a hi-fi. A digital multimeter and oscilloscope are needed for these jobs.

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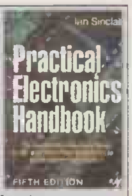

Ian Sinclair

A collection of all the key data, facts, practical guidance and circuit design basics needed by a spectrum of students, electronics enthusiasts, technicians and circuit designers. It provides explanations and practical guidance, and includes new sections on SHF techniques and intruder alarms.

5th edition ▲ Feb 2000 ▲ 571 pages
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RSGB RADIO & ELECTRONICS COOKBOOK

Radio Society of Great Britain

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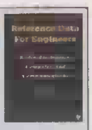

Mac E Van Valkenburg; Edited by Wendy Middleton

Written by professionals for professionals, this is a complete reference for engineers, covering a broad range of topics. As well as addressing radio technology data, it covers digital electronics, computers and communications.

9th edition ▲ Aug 2001
1568 pages & CD-Rom ▲ 1385 line illustrations
HB ▲ Published in UK
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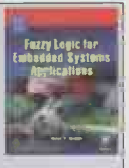

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Oct 2003 ▲ 312 pages ▲ PB
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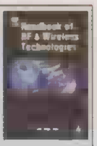

Farid Dowla (Lawrence Livermore National Laboratory, University of California-Davis, USA)

Subjects covered include third-generation wireless, wireless sensor networks, RF power amplifiers, spread spectrum modulation, signal propagation and antennaes. This is far more than just a tutorial or reference guide—it is a "guided tour" through the world of cutting-edge RF and wireless design, combining theory, applications and philosophies behind the RF/wireless design process.

November 2003 ▲ 720 pages ▲ HB

Code 0-7506-7695-7 **£59.99**

DIGITAL INTERFACE HANDBOOK

John Watkinson, Francis Rumsey

A detailed manual for those who need to get to grips with digital audio and video systems. It sheds light on the differences between audio interfaces and shows how to make devices "talk to each other" in the digital domain. Also includes detailed coverage of all the regularly used digital video interfaces. New information included in this third edition: dedicated audio interfaces, audio over computer network interfaces and revised material on practical audio interfacing and synchronisation.

3rd edition ▲ September 2003 ▲ 392 pages
231 line illustrations ▲ PB

Code 0-2405-1909-4 **£29.99**

TV FAULT-FINDING GUIDE

Edited by Peter Marlow

A distillation of the most-used fault reports from 11 years of *Television* magazine. Arranged by make and model, it features over 200 reports on over 300 models of television, including diagnosis and repair advice.

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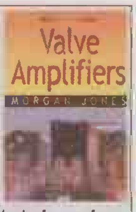

Morgan Jones

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3rd edition ▲ Aug 2003 ▲ 624 pages ▲ Index
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Edited by Peter Marlow

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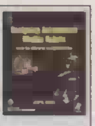

John Holland

Covering topics such as advanced sensor fusion, control systems for a wide array of application sensors and instrumentation, and fuzzy logic applications, this volume is essential reading for engineers undertaking robotics projects as well as for undergraduate and graduate students studying robotic engineering, artificial intelligence and cognitive science. Its state-of-the-art treatment of core concepts in mobile robotics helps and challenges readers in exploring new avenues in an exciting field.

January 2004 ▲ PB & CD-Rom ▲ 352 pages

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Steve Beeching

A comprehensive guide to domestic VCR technology and repair techniques. This edition brings the information fully-up-to-date, with expanded coverage of camcorders, sections on DVD equipment and the latest VCR technology.

5th edition ▲ Apr 2001 ▲ 323 pages
Illustrations ▲ PB ▲ Published in UK

Code 0-7506-5039-7 **£20.99**

VIDEO DEMYSTIFIED

Keith Jack

This edition has been updated to include information on digital television, datacasting, interactive video, digital camcorders and VCRs, and video interfacing. Coverage is international, including European, Asian and North/South American video standards, methods and techniques.

3rd edition ▲ Jul 2001 ▲ 784 pages & CD-Rom
References ▲ Glossary ▲ Index ▲ PB
Published in UK

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ANALOG ELECTRONICS: CIRCUITS, SYSTEMS AND SIGNAL PROCESSING

D Crecraft (formerly Open University); S Gergely (formerly University of Coventry)

Designed to complement the digital systems modules and develop the essential skills needed for RF circuit design, this book demystifies the art of analogue circuit design and analysis. The content meets the requirements of first and second year electronics engineering courses.

May 2002 ▲ 435 pages ▲ 150 line illustrations
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Douglas Self

This text on the design of audio amplifiers is based on Douglas Self's work in *Electronics World* magazine and a career at the cutting edge of audio design. This handbook aims to provide a practical guide to the state of the art, and includes detailed design and construction information.

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AVR: AN INTRODUCTORY COURSE

John Morton (University of Cambridge)

AVRs have certain strengths compared to other microcontrollers but are less well-known or understood. The author wrote this guide to introduce AVRs to those who have little or no microcontroller background and to encourage them to start using these useful devices with easy projects to try.

Sep 2002 ▲ 256 pages ▲ 150 illustrations
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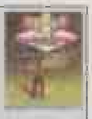

Clive Maxfield

The second edition of this comprehensive introduction to contemporary electronics now has added material. It is written for the engineer, hobbyist or student who needs a thorough electronics reference, as well as for non-technical people, and is accompanied by a CD-ROM.

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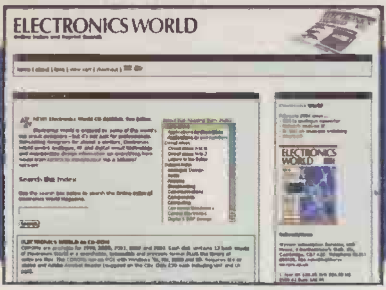
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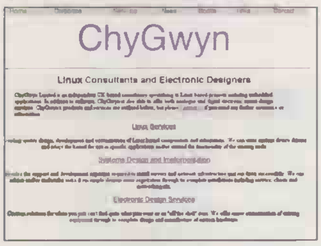
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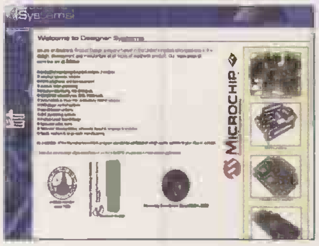
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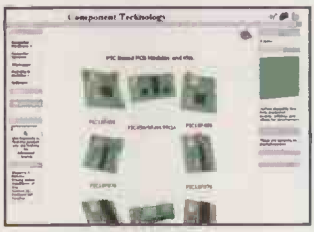
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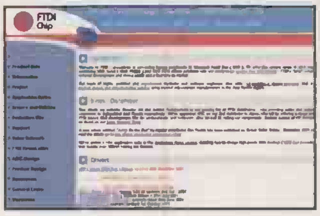

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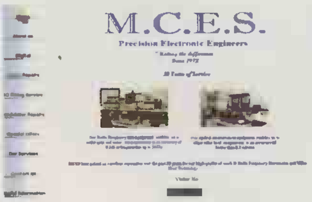

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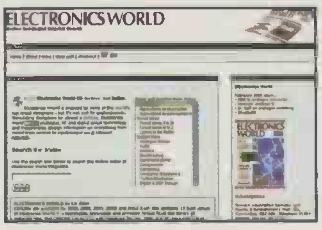

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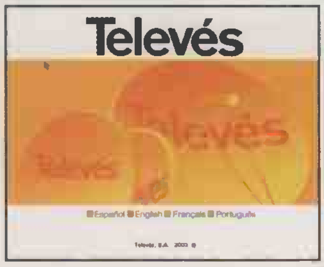

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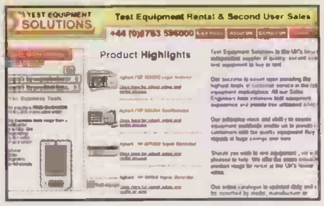

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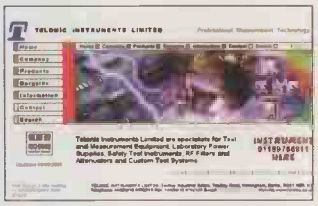

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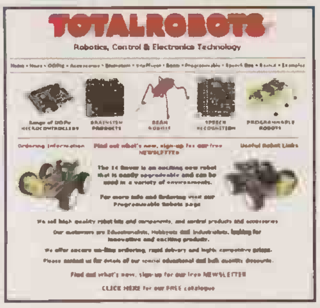

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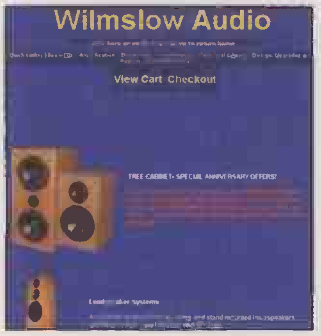

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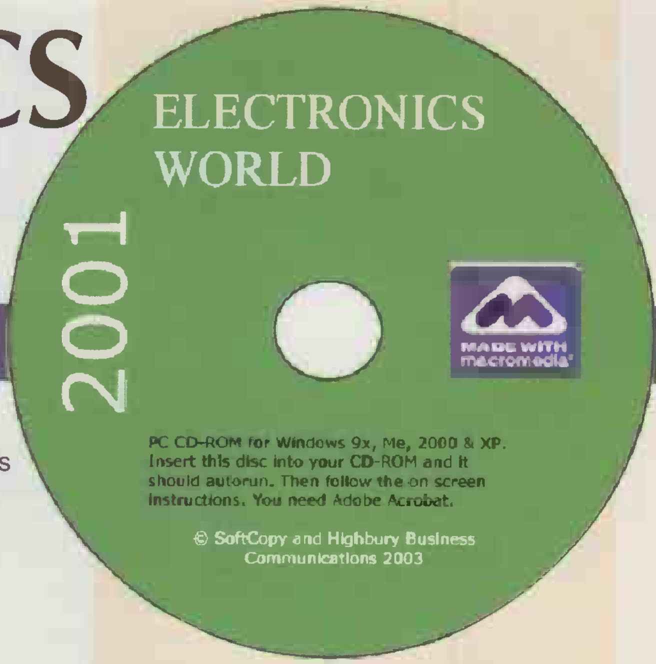

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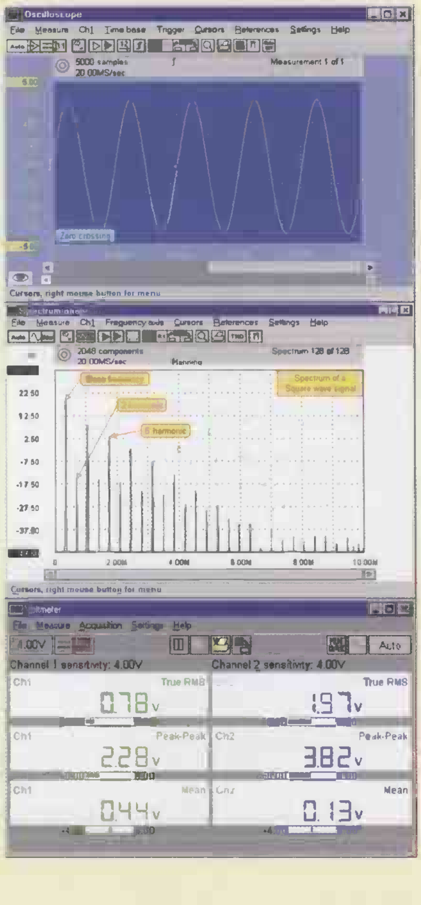

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